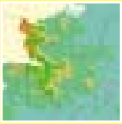
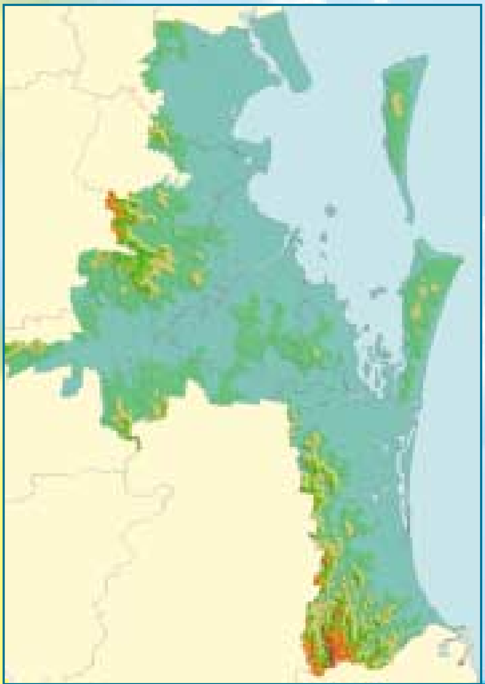
Natural Hazards & the risks they pose to *South-East* QUEENSLAND





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Produced by **AGSO – Geoscience Australia**
in conjunction with the **Bureau of Meteorology**

Department of Industry, Science and Resources

Minister for Industry, Science and Resources

Senator the Hon.Nick Minchin

Parliamentary Secretary: The Hon.Warren Entsch MP

Secretary: Russell Higgins

AGSO – Geoscience Australia

Chief Executive Officer: Neil Williams

ISBN: 0 642 46708 0

AGSO GEOSCIENCE AUSTRALIA

Produced in conjunction with

Bureau of Meteorology — Department of the Environment and Heritage

and in cooperation with

Queensland Government Natural Resources and Mines

Queensland Government Department of Emergency Services

Redland Shire Council

Caboolture Shire Council · Gold Coast City Council · Brisbane City · Redcliffe City Council · Logan City Council · Pine Rivers · Ipswich City Council

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EXECUTIVE SUMMARY

Natural hazards and the risks they pose to South-East Queensland is the third in a series of multi-hazard case studies by the AGSO *Cities Project*. The Project undertakes research towards the mitigation of risks posed by a range of natural hazards to Australian urban communities. The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous.

This report considers risks posed by tropical cyclone (including severe wind and storm tide), east coast lows, thunderstorm, landslide, earthquake, flood, heat wave and bushfire hazards. The vulnerability of South-East Queensland to the effects of natural hazards is increasing as a result of population and development growth. Risk modeling brings together natural hazard research and the vulnerability of the community (the people, buildings and infrastructure) in order to define threat in an objective and relative manner.

We have adopted a systematic approach to the description of the elements at risk in the community and their vulnerability, grouping the various elements into the five themes of setting, shelter, sustenance, security and society. We have developed an overall vulnerability profile of South-East Queensland by which to identify those CCDs and suburbs that provide a disproportionate contribution to community risk because of the number and nature of the elements at risk they contain.

Our analysis enables us to make estimates of the risk in South-East Queensland posed by a number of hazards. Estimates are based on the average recurrence interval (ARI) of a hazard. ARI is the average period in years between the occurrence of a hazard of a given size or larger. It must be appreciated that **an ARI gives no indication** of when a hazard will occur next.

- When compared to other hazards, flooding represents the greatest risk across the region. Flooding, given a 100 year ARI, affects at least 47 400 developed properties, of which, more than half have overfloor flooding. Damage (as a percent of insured loss) across the entire study area is about 1.1% per dwelling (including contents) during a 100 year ARI event. More than half the damage occurs within the Brisbane-Bremer catchment, about 27% occurs within the Pimpama-Coomera-Nerang-Tallabudgera-Currumbin catchment, about 13% in the Logan-Albert and 2% in the Caboolture-Burpengary catchment. This estimate, however, is based on an aggregate and it is unlikely that any one event will impact the entire region to the same extent.

- There is a moderate to high level of risk from storm tide inundation in the region. The number of properties affected by overfloor inundation increase dramatically from 7000 to 44 000 buildings as the ARIs increase from 50 to 10 000 years respectively. At the 100 year ARI level the equivalent of 2100 dwellings (including contents) could be destroyed, or about 0.37% of the value across the region. This estimate, however, is based on an aggregate and it is unlikely that any one event will impact the entire region to this extent.

- The risk posed by tropical cyclone (TC) severe wind is low to moderate across the region. There are, undoubtedly, localised areas in which the combination of building age, construction and site conditions could produce high damage levels. The area at most risk is the coastal strip in which shielding from wind and storm tide is likely to be minimal. Percent damage losses across the entire range of ARIs from 100 to 5000 years show a steady increase in the number of affected dwellings with an increase in the recurrence interval. At the 100 year ARI level, the equivalent of 150 dwellings (including contents) could be destroyed, or about 0.024% of the value across the entire region.

- The overall level of earthquake risk in South-East Queensland is low, however, the risk is greater in the many areas that are built on unconsolidated sediments or on Tertiary geological units. There have been few reports of earthquakes causing significant damage in South-East Queensland, however, the historical record is short, and the consequences of a rare earthquake, such as the magnitude 6.3 that occurred offshore of Bundaberg in 1918 can be significant. South-East Queensland faces a moderately low risk to its residential buildings from earthquakes. The vulnerability of South-East Queensland residential buildings to earthquake is low as the majority (an estimated 95%) are of light timber frame construction performing well in earthquake.

- Landslide risk is a very localised phenomenon. Within the Gold Coast hinterland region, in particular in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas, risk posed from landsliding is significant. During a 100 year ARI event, a maximum of four fatalities and up to two dwellings could be destroyed on slopes >25°. Individuals living in the Beachmont basalt geological unit are particularly at risk. On slopes <25° the number of fatalities is significantly less at about 0.3, with about 2.7 dwellings destroyed. Some sections of roads on slopes <25°, are expected on average to be blocked or partially blocked every 1 to 2 km and have a section destroyed by landslide about once every 5 km. In other areas such as Caboolture, Pine Rivers, Brisbane, Ipswich, Redland, and Redcliffe, landslide risk is very low and it is unlikely that existing buildings would be destroyed or people killed.

- There is a significant overall risk from hail, lightning and wind from severe thunderstorms, though the impact from any one storm will be very localised. We have not, however, been able to quantify the level of that risk.

- There is a significant and widespread risk of fatalities from heatwaves, the level of which, however, can not be quantified at this stage.

- There is a low overall risk of bushfire damage in urban areas, however, the risk in rural areas and rural fringe areas is moderate to significant.

A comparison of hazards indicates that by far the greatest hazard risk posed to the South-East Queensland community is from flooding. The January 1974 floods remain the most severe example of urban flooding in Australia and affected the entire South-East Queensland region. The earlier floods of 1841 and 1893, though much larger in magnitude, resulted in significantly less damage because of a smaller population, fewer buildings and less infrastructure.

Storm tide poses slightly less risk to the region, the last major events to cause damage resulted from TC *Dinah* (1967) and TC *Dora* (1971). Earthquake and severe wind pose much less of a risk to the region, though their impact will still be significant, especially for the longer return periods.

It has been more than 25 years since the last significant hazard impacted the South-East Queensland region. During this period the potential for impact has increased significantly as a result of increased urban development, and awareness and perhaps preparedness for hazards has decreased with the passing of time. It is hoped that this report will provide a level of awareness appropriate to the true risk in the region.

ACKNOWLEDGEMENTS

This multi-hazard risk study of South-East Queensland is the outcome of the research and experience of many people over many years. Where appropriate, the work of others is acknowledged in the conventional manner through the citation of literature. There are many others, however, whose work, comment and involvement should be acknowledged. We do that here with great appreciation and thanks.

Of greatest significance has been the encouragement and support given by the local communities across the region and the eight local governments involved. The following local government officers provided us with access to information and the benefit of their local knowledge and experience: John Hall, Col Morehead and Adrian Sturk (Caboolture Shire Council); Alan Sheridan and Linda Adams (Pine Rivers Shire Council); Ces Greenwood, Prakash Shandil and Peter Marsh (Redcliffe City Council); John Butler and Ken Morris (Brisbane City Council); Andrew Underwood, David Kay, Arie van den Ende, Geoff McMahon and Ashley Dobbie (Ipswich City); Lou Caminos, Bob Ballantyne, Karen Mawby and Trevor Williams (Logan City Council); Wayne Dawson and Mark Grenfell (Redland Shire); and Lawrie Yakimoff, Lionel Perry, Mehran Vaziri, Hayden Betts, Bernie Winter and Tony Hannigan (Gold Coast City Council). The cooperation of these officers and their respective councils made this study possible. The South-East Queensland Regional Organisation of Councils (SEQROC) also endorsed the project at the political level and our thanks go to its Chair, Councillor Jim Soorley, Lord Mayor of Brisbane City, and to Gold Coast Councillors Peter Anderson and Ted Shepherd for that support.

At the State Government level, the *Cities Project* has been strongly supported by the Department of Emergency Services (DES), especially the Division of Counter Disaster and Rescue Services headed by Jack Noye and the Rural Fire Service led by Dave Luxton. We also received excellent support from the Queensland Geological Survey within the Department of Mines and Energy, especially from Warrick Willmot, Len Cranfield and Frederick von Gnielinski. The Department of Natural Resources, in particular Russell Cuerel, also provided support. Input was also received from Ross Barker and the staff of the Planning Information and Forecasting Unit of the Department of Communications, Information, Local Government and Planning.

State Government enterprises, particularly Powerlink and Energex, contributed useful data.

The former Director of the Queensland Region of the Bureau of Meteorology, Rex Falls, his successor Gary Foley and the staff of the Regional Office have given outstanding support as well as direct input to this study. We are especially grateful for their direct and generous contribution to the study in the form of their contracting Bruce Harper, a consultant engineer of Systems Engineering Australia Pty Ltd, to coordinate their input. The Regional Office of the Bureau also provided invaluable support over four years through the provision of office space and facilities for the *Cities Project* in Brisbane.

Members of the academic community have also provided great support throughout the evolution of this study. In particular, the *Cities Project* has received ongoing support and assistance from David King and Linda Berry of the Centre for Disaster Studies at James Cook University; Russell Blong, Director of the Natural Hazards Research Centre at Macquarie University; as well as 'Dingle' Smith of the Centre for Resource and Environmental Studies at the ANU.

Our work was also generously supported by ERSIS Australia (now part of MapInfo Australia) and its General Manager, Wal Mayr, through their provision of essential base datasets.

In the Australian Geological Survey Organisation (AGSO), the *Cities Project* would not have been established without the vision and inspiration of Wally Johnson, Chief of the Geohazards and Geomagnetism Division. Once established, it has been sustained by the ongoing commitment of AGSO's Executive Director, Neil Williams, his deputy, Trevor Powell, and Wally's predecessors as Division Chief, David Denham and Colin Chartres. The Geohazards Group Leader, John Schneider, under whose leadership the *Cities Project* now comes, has also made a very valuable contribution, especially based on his experience in hazard and risk modelling in the United States.

Chapters 1 to 3, including the approach to the vulnerability analysis and the risk assessment process, have evolved with the *Cities Project* over the past five years. They draw heavily on the experience of their principal author (Ken Granger) during his time as a scientific adviser to DES and his involvement in the Tropical Cyclone Coastal Impacts Program. It also draws heavily on the input of participants in three workshops held at Australian Emergency Management Institute at Mount Macedon. The approach to community vulnerability draws heavily on the two 'Vulnerability Index' workshops held in 1995 under the leadership of Mike Tarrant, in particular the 'five esses' approach, the core of which was suggested by George Silberbauer of Monash University. The overall risk management approach has drawn on the 1996 'Risk Management' workshop led by John Salter and the ongoing evolution of an approach to emergency risk management that commenced with that workshop. The *Risk-GIS* methodology for assessing community vulnerability in Cairns was subsequently reviewed and subjected to a sensitivity analysis by David King, James Maloney and Colin MacGregor of James Cook University. Their suggestions and advice, based on that review, have been taken up in this study. Sarah Hall accumulated and analysed a wealth of invaluable information on the logistic and public health resources of the region.

The processing and editing of council-supplied property data that is central to the risk assessment was undertaken by, Lisa Cullen, Leigh Bexley and John Lawson, temporary staff working out of the *Cities Project's* Brisbane office; and by Rob Lacey of AGSO who carried out the analysis of satellite imagery to map urban growth in 1980 and 1990.

The hazard-related contents of Chapters 4, 5, 6, and 10, which deal with the major meteorological hazards experienced in the region, were coordinated by Bruce Harper for the Bureau of Meteorology. He received great assistance and support from Bureau officers, especially Jeff Callaghan, Geoff Crane and Jim Davidson. Trevor Jones, John Stehle, Rob Lacey and Bruce Harper prepared the risk assessment for tropical cyclone winds. George Walker, of Aon Reinsurance Aon Group Australia Ltd, provided a thorough and valuable review of the risk assessment for tropical cyclone severe wind in AGSO's earlier reports to South-East Queensland local governments. Greg Reardon, John Ginger and David Henderson of the Cyclone Structural Testing Station, James Cook University, provided valuable comment on building vulnerability.

Chapter 7 was compiled by Matt Hayne, Marion Michael-Leiba, Donald Gordon, Robert Lacey and Ken Granger. We are grateful to Warwick Willmott of the Queensland Department of Mines and Energy for helpful comments during the progress of this work.

Chapter 8 was prepared by Trevor Jones, John Stehle, Rob Lacey and Denis Hackney. Ingo Hartig provided valuable GIS input. Thanks go to the QUAKES group from the University of Queensland, who conducted a microtremor survey of Brisbane City in 1997 and analysed those data. Col Lynam also provided information on two recent earthquakes in South-East Queensland. Leigh Bexley of AGSO prepared a comprehensive database of geotechnical information. Our thanks go to Queensland Rail, Queensland Main Roads, Queensland Department of Natural Resources and Mines, and Gold Coast City Council for providing borehole data. Transfield Corporation generously provided geotechnical data for the Brisbane airport area. The geological coverages of Queensland Department of Natural Resources and Mines were also used for the earthquake susceptibility maps.

Chapter 9 was prepared by Miriam Middelmann and Bruce Harper on behalf of the Bureau of Meteorology, with GIS support provided by Rob Lacey. Valuable input was received in particular from Russell Blong (Natural Hazards Research Centre), Ken Durham (Queensland Department of Emergency Services), Russell Curnell (Queensland Department of Natural Resources), Col Moorehead (Caboolture Shire Council), Peter Stonadge (Pine Rivers Shire Council), Ken Morris and Bob Peters (Brisbane City Council), Ashley Dobey (Ipswich City Council), Lou Caminos (Logan City Council), and Haydn Betts, Anne D'Arcy and Sayedur Khan (Gold Coast City Council).

Valuable historical material was provided by the Ipswich Historical Society. In particular, thanks go to Ian Wilson and Elaine Hughes for allowing AGSO access to their superb historical photography collection, and for their assistance in tracking down photographers, who are too numerous to name here individually. Permission to publish photos held by the Caboolture Local Studies Collection, Pine Rivers Local Studies Library, John Oxley Library and the Gold Coast Local Studies Library is also gratefully acknowledged. The permission to publish slides/photos held Wayne Muller (Griffith University), John Ebbelinghaus and Bob Anthony Jnr is also appreciated.

Chapter 11 (compiled largely by Ken Granger) received significant input from Dave Luxton, Queensland Rural Fire Commissioner and Tania Philips of the QFRA Rural Fire Service. Additional information was also provided by Peter Berg of Gold Coast City Council.

The production of this graphics contained in this report was supervised by Greg Scott of AGSO, assisted by Ingo Hartig, Don Gordon, Neil Corby and Rob Lacey.

To all of these people we extend our appreciation and thanks.

We also gratefully acknowledge the support of our respective spouses, partners and children for their understanding during our times in the field and our distracted nature during the writing of this report. The completion of this work would not have been possible without your support.

CHAPTER 1: HAZARDS AND RISK CONCEPTS

Ken Granger

This Report

This study provides details of the outcomes of research into the risks faced by the communities of South-East Queensland that are posed by a range of natural hazard phenomena. In this study, the acute (i.e. potentially fatal) hazards considered include tropical cyclones, east coast lows ('winter cyclones'), floods, earthquakes, landslides, severe thunderstorms, heatwaves and bushfires. The risks from some of these hazards have been assessed in more detail than others, although the extent of our attention to detail does not in all cases reflect the severity of the risk of a particular hazard. In addition, the potential impacts of climate change are also addressed. It has been developed as a primary resource for those people who have a professional or personal interest in community risk within the region and is based on more detailed reports developed specifically for use by officials of the eight local government councils included in the study area.

This regional project is the fourth in a series of case studies being undertaken under the Australian Geological Survey Organisation's (AGSO)[1] *National Geohazards Vulnerability of Urban Communities Project*, more commonly referred to as the *Cities Project*. AGSO and its research partners see this regional study as providing the foundation on which the communities of South-East Queensland can develop strategies to mitigate those risks and to cope with the impact of hazards when they occur. It builds on *Cities Project* multi-hazard risk assessment work already published on the individual Queensland centres of Cairns, Mackay and Gladstone and the Australian Capital Territory. It also draws on work being undertaken in the New South Wales centres of Newcastle and Wollongong.

Cities Project case studies clearly represent pioneering research. As such the results they present will undoubtedly change as better information, techniques and tools develop. We encourage readers to view this report as a starting point, rather than an end in itself and we welcome feedback on any aspect covered in our reports.

It must be emphasised at the outset that this report represents a broad 'reconnaissance' of the hazards and the risks that they pose. It is not intended to be used, nor should it be used, to assign measures of risk to individual properties – the scale, resolution and accuracy of the data available to us does not support such precision. **Should you wish to obtain such detailed, site-specific information regarding risk you should contact the relevant local government council.** The report should, therefore, be seen as the first step in the process of comprehensive community risk management. The next steps are essentially up to the eight councils involved and their respective communities.[2]

The Cities Project

The *Cities Project* was established in 1996 to undertake research directed towards the mitigation of the risks faced by Australian urban communities that are posed by a range of geohazards. **The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous.** It formed a significant part of Australia's contribution to the International Decade for Natural Disaster Reduction (IDNDR) which ran through the 1990's and continues to be a focus for Commonwealth community risk research. It can also be seen as a response to the findings of the 1993 Senate Inquiry into Major Disasters and Emergencies (Senate, 1994). In its

[1] A list of acronyms and abbreviations used in this report is included as Appendix A.

findings the Senate Committee encouraged the emergency management community to modify its doctrine from one that had been traditionally dominated by attention to disaster response, to one which gives greater attention and emphasis to risk mitigation and the reduction of community vulnerability.

Such a broadly-based program of research obviously requires a multi-disciplinary approach. To enable AGSO, a research agency traditionally focused on earth science, to achieve the objectives set for the *Cities Project*, a network of operational, research and supporting partners has been developed. We have been most fortunate in attracting the commitment of partners of great quality and enthusiasm. They span a very broad range of scientific disciplines, administrative responsibilities and industry sectors. Of particular value has been the close collaboration with:

- the Bureau of Meteorology;
- the Queensland Departments of Emergency Services, Mines and Energy and Natural Resources;
- the South-East Queensland Regional Organisation of Councils (SEQROC) and the eight councils covered by this study[3];
- researchers in various CSIRO Divisions, academic centres and a number of private sector agencies.

Risk Management

The concept of risk, and the practice of risk management, received a significant boost in Australia with the publication of the Australia and New Zealand Risk Management Standard in 1995 and its subsequent revision as *AS/NZS 4360:1999 Risk Management* (Standards Australia, 1999a). This generic guide provides the philosophical framework within which the *Cities Project* studies have been developed. That process is outlined in **Figure 1. 1.**

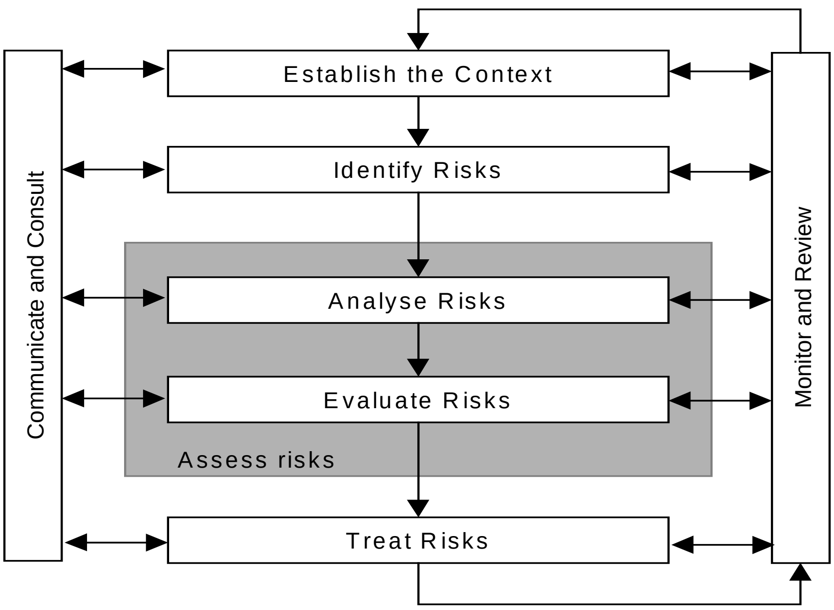


Figure 1. 1 : Risk management overview (Standards Australia, 1999a, after Fig 3.1)

[3] From north to south they are Caboolture Shire, Pine Rivers Shire, Redcliffe City, Brisbane City, Ipswich City, Redland Shire, Logan City and Gold Coast City.

This study deals largely with the risk identification and risk assessment (i.e. the analyse and evaluate) stages of the process. Whilst we provide some opinion on matters relating to risk treatment, these are the responsibility of those, such as the local governments and the Queensland Government agencies, that have that statutory role.

What is Risk?

The risk management Standard defines 'risk' as:

> *the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood.*

This definition is really too general for our purposes, consequently we have chosen to follow the conceptual basis and definitions developed under the Office of the United Nations Disaster Relief Coordinator (UNDRO) in 1979 and cited by Fournier d'Albe (1986) as follows:

- ***Natural hazard*** *means the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon.*

- ***Vulnerability*** *means the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude…*

- ***Elements at risk*** *means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area.*

- ***Specific risk*** *means the expected degree of loss due to a particular natural phenomenon: it is a function of both natural hazard and vulnerability.*

- ***Risk*** (i.e. 'total risk') *means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.*

Total risk can be expressed simply in the following pseudo-mathematical form:

$$\textbf{Risk}_{\textbf{(Total)}} = \textbf{Hazard x Elements at Risk x Vulnerability}$$

This approach is not only elegant, it is also very practical. Given the complexity of urban communities and the degree to which the various elements at risk are interdependent, the 'total risk' approach is considered mandatory. Further, it also lends itself to quantitative, qualitative and composite analytical approaches.

Our experience, however, has clearly shown that there is quite a gap between the ideal of total risk articulated in the definition and the practical reality of risk assessment. Put simply, the data does not exist by which to measure total risk across all elements at risk in complex urban communities for all hazards and for all probabilities. To overcome this problem we have resorted to the use of a series of indexes that reflect the relative level of hazard exposure and the relative level of community vulnerability. By drawing these together we have produced a 'risk index' which is then used to create 'risk surface' maps to illustrate the spatial relationship between levels of exposure and vulnerability. These are described in some detail in each of the hazard-specific chapters.

Risk mitigation (i.e. moderating the severity of a hazard impact) is the principal objective of risk management. In this context, risk mitigation might be seen as:

> *the process by which the uncertainties that exist in potentially hazardous situations can be minimised and public (and environmental) safety maximised. The objective is to limit the human, material, economic and environmental costs of an emergency or disaster, and is achieved through a range of strategies ranging from hazard monitoring to the speedy restoration of the affected community after a disaster event*
>
> (after Granger, 1988 and 1993).

It is clear that uncertainty is a key factor, indeed it can be argued that, in many instances, the effectiveness of risk mitigation strategies is inversely proportional to the level of uncertainty that exists. The risk management process, particularly the risk analysis and risk evaluation stages, is clearly aimed at developing the best and most appropriate information with which to reduce that uncertainty.

The amount of total risk may be diminished by reducing the size of any one or more of the three contributing variables – the hazard, the elements exposed and their vulnerability. This can be illustrated by assuming the 'dimension' of each of the three variables represents the side of a triangle, with risk represented by the area of the triangle. In **Figure 1. 2** the larger (yellow) triangle portrays each of the variables as being equal, whilst in the smaller (green hachure) triangle the total risk has been mitigated by the halving of both exposure and vulnerability. The reduction of any one of the three factors to zero would consequently eliminate the risk.

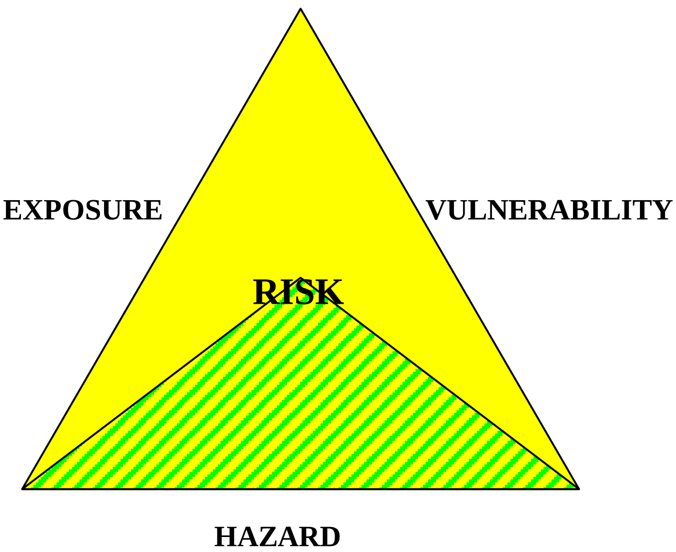


Figure 1. 2 : The risk – hazard – exposure – vulnerability relationship

Risk Identification

A detailed understanding of what events have occurred in the past (including prehistoric events) and their effects provides the basis for understanding what could or will happen in the future, i.e. it is the key step in the risk identification process. To this end, AGSO has developed catalogues on historic earthquakes, landslides and tsunami events; the Bureau of Meteorology (BoM) maintains comprehensive collections on severe weather events such as cyclones, east coast lows and floods; and the insurance industry maintains some data on the losses associated with such events. Throughout this report we provide details of the known history of hazard impacts in South-East Queensland. This history is not only important in establishing levels of probability for future events but also to illustrate that such threats are very real.

The hazards included in this study were selected on the basis of their known history of impact in South-East Queensland both in terms of the fatalities caused and the resulting economic losses. It is worth reflecting that, between 1967 and 1999 major disasters (excluding drought) cost Australia, as a nation, on average $1.14 billion annually (Bureau of Transport Economics, 2001) and that disaster impacts in Queensland contribute significantly to that total.

The known fatalities attributed to natural hazards, as given in Table 1.1, helps to put them into perspective.

Table 1. 1 Fatalities in Australia caused by natural hazards (based on Coates, 1996 and AGSO data)

Natural Hazard	Period Covered	Fatalities
Heatwaves	1803 - 1992	4287
Tropical cyclones	1827 - 1989	1863 – 2312*
Floods	1803 - 1994	2125
Bushfires	1827 - 1991	678
Lightning strikes	1803 - 1992	650
Landslides	1803 - 1999	84
Earthquakes	1803 - 1999	15

* minimum and maximum estimates which also include approximately 170 flood fatalities

The real number of fatalities is almost certainly greater than listed, given that the statistics in the table were derived largely from reports contained in the *Sydney Morning Herald* and its predecessor, the *Sydney Gazette*. Nevertheless, they confirm that we do not live in an especially benign environment.

Monitoring and surveillance**:** One of the principal sources of historical hazard event information and hazard phenomenon knowledge is the extensive network of monitoring stations and remote sensing resources that have been established across Australia. For example, AGSO has access to more than 150 seismographs across Australia, whilst the Bureau of Meteorology maintains some 45 weather radar sites (including one at Brisbane Airport), around 250 automatic weather stations and more than 3,000 stream gauging stations. The Bureau also takes data from the Japanese Geostationary Meteorological Satellite (GMS) 48 times a day, in addition to data taken from the polar orbiting satellites operated by United States National Oceanographic and Atmospheric Administration (NOAA).

Risk Analysis

AS/NZS 4360:1999 (p. 3) defines ‘risk analysis’ as:

> *a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences.*

We have identified three distinct aspects of this process.

Phenomenon process knowledge**:** The focus of hazard science research is on the mechanisms that cause, create, generate or drive the hazard phenomena, e.g. what causes earthquakes and what influences the transmission of their energy through various geological strata. This is underpinned by information relating to the background climatic, environmental, terrain, ecological and geological aspects of the site that are relevant to hazard studies, e.g. the depth and nature of the sediments and their likely behaviour under earthquake shaking. Whilst there is little that can be done to eliminate or reduce the severity or frequency of these phenomena, a good understanding of what drives them enhances our ability to forecast or predict their behaviour. It is also fundamental to establishing an understanding of event probabilities.

***Elements at risk and their vulnerability*:** This is a relatively new area of study and is focused on developing an understanding of the vulnerability of the wide range of elements that are at risk within the community, i.e. the people and their physical and social infrastructures. It involves disciplines as diverse as geography, demography, psychology, economics and engineering.

A significant effort has been made to develop very detailed data on the principal elements at risk in the built environment of South-East Queensland, whilst comprehensive statistics of good resolution are available from the quinquennial national censuses to provide at least basic measures of human vulnerability. For convenience we have grouped these elements at risk into the five broad groups we refer to as the "five esses". The data which have been collected over South-East Queensland include:

The Setting. Basic regional data were accumulated from a very wide range of custodians for themes including:

- the physical environment (climate, vegetation, geology, soils, land use, topography, elevation);
- access (external links by major road, rail, air, marine and telecommunications infrastructures);
- administrative arrangements (local government, suburb and other administrative boundaries); and,
- population and its distribution.

Shelter. The buildings that provide shelter to the community at home, work and play vary considerably in their vulnerability to different hazards. The degree to which different building characteristics contribute to the relative degree of vulnerability associated with exposure to a range of hazards is shown in **Table 1. 2**

Table 1. 2 Relative contribution of building characteristics to vulnerability

CHARACTERISTIC	FLOOD	WIND	HAIL	FIRE	QUAKE
Building age	***	*****	***	*****	*****
Floor height or vertical regularity	*****	*		****	*****
Wall material	***	***	*****	****	****
Roof material		****	*****	****	***
Roof pitch		****	***	*	
Large unprotected windows	**	*****	****	*****	**
Unlined eaves		***		*****	
Number of stories	****	**		*	*****
Plan regularity	**	***		***	*****
Topography	*****	****		****	***

In Table 1. 2 the number of stars reflect the significance of each attribute's contribution to building vulnerability, where the greater the number of stars, the greater the relative contribution of an attribute to building vulnerability.

In the first three *Cities Project* case studies, comprehensive structural data were developed on virtually every building. In the South-East Queensland study, however, such an effort was clearly impractical given that there are more than 1 million individual buildings. None-the-less, descriptions of the 'typical' residential and commercial structures in each council area have been developed. Information on the location, function and the approximate vintage of some 685 090 individual developed properties in the study area was developed, based largely on material provided by the respective local government councils augmented by field work and other documentary sources such as the UBD Refidex.

Access to shelter is also significant, so information on mobility within the community is needed. Details of the road network, for example, were accumulated.

Sustenance. Modern urban communities are highly reliant on their utility and service infrastructures such as water supply, sewerage, power supply and telecommunications. These so-called *lifelines* are significantly dependent on each other and on other logistic resources such as fuel supply.

The community is also dependent on the supply of food, clothing, medicine and other personal items. Information was accumulated on all of these, as well as on the industries that wholesale, distribute and service these sectors (such as transport, material handling equipment and storage). Most (if not all) of the key logistic facilities in South-East Queensland were identified in the property database. Basic data on the key elements of the power and water supply, telecommunications and sewerage infrastructures were also obtained.

Security. The security of the community can be measured in terms of its health and wealth and by the forms of protection that are provided. Physically, these may be assessed by the availability of hospitals, medical centres, nursing homes, industries, commercial premises, ambulance stations, fire stations, police stations and works such as flood detention basins and levees. Also important are socio-demographic and economic statistics related to the elderly, the very young, the disabled, household income, unemployment, home ownership and the resources available at the fire and police stations. Emergency plans are also a key component of community security.

Society. Here we find some of the more intangible measures such as language, ethnicity, religion, nationality, community and welfare groups, education, awareness, meeting places, cultural activities and so on that contribute significantly to the community's social cohesion. Some of these may be measured in terms of the facilities that they use, such as churches, schools and sporting clubs, however, the more meaningful measures relate specifically to the individuals, families and households that make up the community.

Extensive use has been made of the detailed data from the 1996 National Census published in the *CData96* product (ABS, 1998a) to flesh out our understanding of the social, demographic and economic dimensions of vulnerability under both the 'security' and 'society' components.

***Synthesis and modelling*:** Clearly, the range and variety of information needed to fuel a comprehensive risk analysis is enormous. Whilst there are many sources now available from which such information can be captured or derived, much of it with the essential spatial and temporal attributes needed, there remain important gaps. Our knowledge of hazard phenomena and the processes that drive them, for example, are far from perfect. The behaviour of some hazards, such as floods, have an established body of modelling research behind them, whilst models of the behaviour of other phenomena, such as cyclones and earthquakes are, as yet, still evolving. It is necessary, therefore, to develop appropriate models to fill the knowledge gaps.

A key aspect of these models is an understanding of the probability of recurrence of events of particular severity and the levels of uncertainty that exist in both the data employed and the models themselves. **Given these uncertainties, we remain cautious about presenting our findings as anything more than *indications* of what the future may hold.**

Risk Evaluation

AS/NZS 4360:1999 (p. 3) defines 'risk evaluation' as:

> *the process used to determine risk management priorities by evaluating and comparing the level of risk against predetermined standards, target risk levels or other criteria.*

We see two key components of this.

Scenario analysis**:** This is an emerging technique that contributes to 'future memory', an understanding of *what will happen when….* The output embraces forecasts or estimates of community risk including economic loss and potential casualties, or assessments of the impact of secondary or consequential hazards, such as the spread of fire or the release of hazardous materials following an earthquake. It also provides essential input to both the development of risk treatment strategies and to framing long-term forecasts or estimates.

In an effort to address the diverse range of applications to which the output from risk scenarios may be put, we have adopted the practice of running a range of scenarios. These typically extend from the relatively small and more frequently occurring events, to those in the so-called 'maximum probable' or 'maximum credible' range.

Acceptability**:** In the approach to risk assessment set out in *AS/NZS 4360:1999*, it is the practice to compare the level of risk found during the assessment process with previously established risk criteria, so that it can be judged whether the risk is 'acceptable' (or at least tolerable) or not. At first glance this may seem to be something of a chicken-and-egg process - if you do not know what the level of risk posed by earthquake is in South-East Queensland, for example, how can you realistically determine what level of risk is acceptable?

Levels of acceptability are, however, built into such things as urban planning design constraints and the Australian Building Code, where criteria are based on 'design levels' of hazard impact. For example, under the earthquake loading code, *AS1170.4-1993 Minimum design loads on structures Part 4: Earthquake loads* (Standards Australia, 1993), the 'design level of earthquake shaking' is one in which there is an estimated 10% probability of the ground motions being exceeded in a 50 year period, i.e. the acceptability criterion is set at a 10% chance of exceedence over the nominal lifetime of a typical building.

The acceptability factor is central to the process of risk prioritisation. This is the first step in the allocation of resources to risk mitigation, especially if considered in a multi-hazard context. We are beginning to address the complex issue of comparing the risks posed by hazards with greatly different impact potential. In South-East Queensland, for example, there is a strong spatial correlation between the areas that are most at risk from flooding and those in which sediments are most likely to maximise earthquake impact. Additionally, the impact on the South-East Queensland community of a cyclone hazard with an average recurrence interval (ARI) of once in 150 years is likely to be more severe than the impact of the shaking associated with an earthquake with an ARI of 150 years. The maximum credible earthquake event could, however, have a greater potential for catastrophe, than the maximum credible cyclone.

The ultimate responsibility for determining what levels of risk are acceptable or tolerable rests with the each community and those State and local government agencies responsible for risk management.

Risk Mitigation Strategies

Whilst the role of AGSO and the *Cities Project* is concerned primarily with risk identification and assessment, the following processes provide some insight into the risk mitigation process.

***Warnings and forecasts*:** An effective warning and forecasting system, combined with a high level of community awareness and risk appreciation, is clearly one of the most potent mechanisms by which to achieve risk reduction. These are typically taken to mean short-term warnings, such as those issued by the Bureau of Meteorology for the hazards that can literally be seen coming, such as cyclones, floods and severe thunderstorms. They may, however, also embrace the longer-term estimates of the 'hazardousness' of areas such as those contained in the earthquake hazard (acceleration coefficient) maps that accompany *AS1170.4-1993* (Standards Australia, 1993), or by hazard maps specifically prepared for a community. They can both be significantly enhanced through the scenario analysis process.

***Mitigation strategies and response options*:** Risk assessments are made so that strategies may be developed that will ultimately lead to the elimination, reduction, transfer or acceptance of the risks, and to ensure that the community is prepared to cope with a hazard impact. Whilst the development and implementation of these strategies lie essentially outside the competence of the *Cities Project*, our experience in working with emergency managers and others to date suggests that some of the most effective strategies are:

- a strong risk management culture;
- well maintained and appropriate information about risk, linked to comprehensive monitoring and warning systems;
- wide-spread and ongoing community awareness programs based on risk history, scenario analysis and an effective risk communication capability;
- emergency management plans, resources, training and decision support tools based on risk assessments;
- risk-based planning of settlement, development and the siting of key facilities (such as hospitals);
- protection plans for key facilities and lifelines;
- appropriate and enforced building and planning codes; and,
- cost-effective engineered defences such as levees and retrofit programs.

Guidelines have been developed by the Queensland Department of Emergency Services (Zamecka and Buchanan, 1999) for use by local government councils in developing and implementing risk mitigation activities. These should be consulted in conjunction with the risk assessments contained in this study.

Community Risk Thresholds

A key component in each of these stages of risk management is the various frames of reference that exist in the community. These are the standards to which the community, or significant elements of it, subscribe in determining and sanctioning behaviour or attitudes. These standards vary according to the extent of past experience, especially of major disasters, and the specific interests of the particular community element involved. A developer, for example, has a significantly different frame of reference, and consequently risk acceptance thresholds, to those of an emergency manager or an environmentalist. An understanding of these frames of reference, and the thresholds they produce, is particularly relevant in establishing community levels of risk acceptance.

Not all acceptability criteria can be expressed as categorically as those outlined in the Building Code because they deal with human nature and the political *outrage* dimension of risk management. There is a considerably higher level of acceptance of risks that are 'voluntary', i.e. those willingly undertaken by individuals, such as air travel or smoking, than there is to those that are seen as being 'involuntary', many of which carry a significantly lower risk. For example, in NSW, the chances of a fatality occurring from smoking 20 cigarettes a day has been calculated as being 5000 per million people per year and for travel by motor vehicle as 145 chances per million people per year. By contrast, the chances of fatality from 'cataclysmic storms and storm floods' is calculated as 0.2 chances per million per year and lightning strike as 0.1 per million people per year (Higson, 1989).

The levels of risk acceptance can also vary considerably over time. The threshold of acceptance is typically much lower immediately after a hazard impact, for example, than it was immediately before the impact.

The existence of these conflicting frames of reference reinforces the need for a strong feedback mechanism between establishing acceptability and formulating risk mitigation and response strategies. In developing risk management options and strategies, the competing value systems and expectations of these various frames of reference need to be taken into account.

The key components of the *Cities Project's* understanding of the risk management process are illustrated in **Figure 1. 3.**

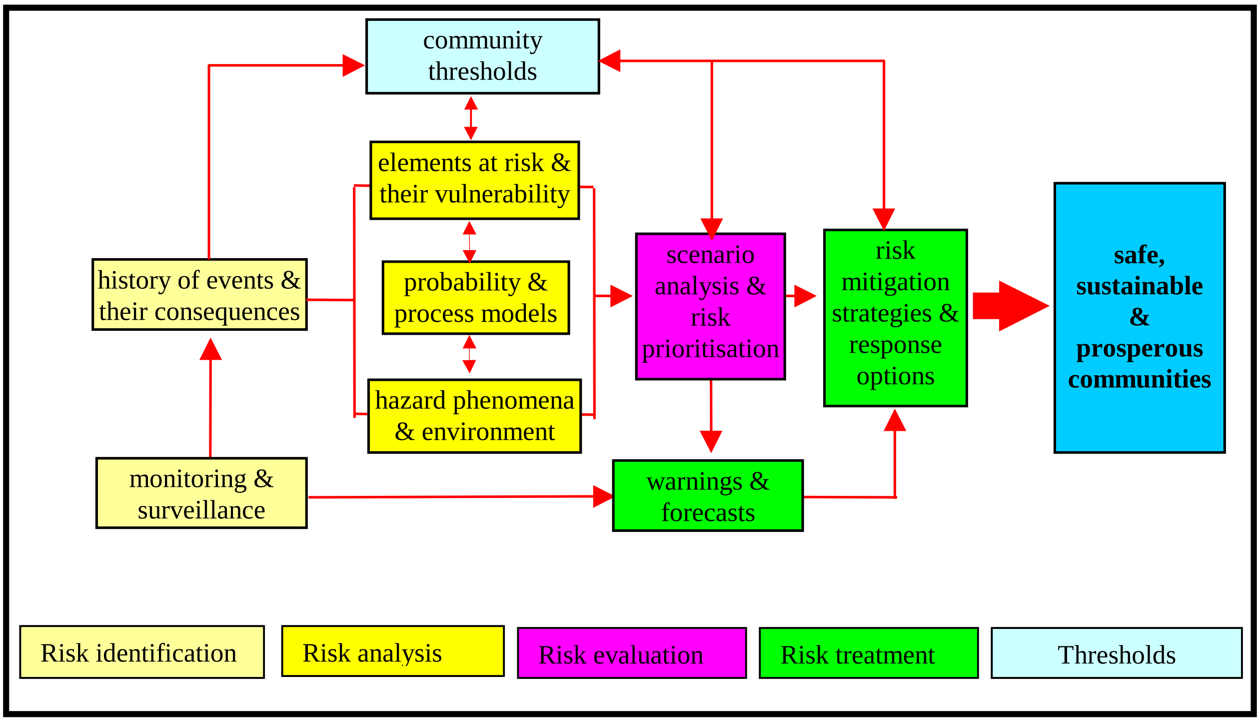


Figure 1. 3 : Cities Project interpretation of the risk management process

The bottom line is that if we get all of this right, the outcome will be safer, more sustainable and more prosperous communities.

Confidence, Uncertainty and Probability

The analysis of issues as complex as community risk is highly dependent on the accuracy, currency and appropriateness of the data that it employs. Every effort has been made to ensure that the best available data have been used in the various analyses included in this study. For the most part, the results of modelling and other forms of analysis have been subjectively examined for 'reality' against the experience of the authors, officials in each of the eight local government councils and a good number of external reviewers with appropriate local knowledge and experience.

The allocation of event probabilities is an area of particular uncertainty. For example, a common description of event probability is the so-called 'return period' of a particular phenomenon, typically given in a form such as 'a one-in-one hundred year flood'. Not only are such figures typically based on less than 100 years of record, but also it has been widely reported that such an expression of probability is prone to be misinterpreted and misused. Description of an event as a '1:100 year event' is frequently taken (wrongly) to indicate that there will not be another such event for another 100 years.

We prefer the terms 'average recurrence interval' (ARI) and 'annual exceedence probability' (AEP) which we consider less ambiguous. A typical ARI statement would be:

> *on the basis of the existing record, a flood measuring 11 m or more on the reference gauge occurs, on average, once every 25 years.*

A comparable AEP statement (for the same event) would be:

> *there is a 4% probability of a flood of 11 m or more occurring in any given year.*

To put the issue of probability in a more familiar context we have produced **Table 1. 3** to illustrate probabilities related to the chance of one or more events of a given magnitude occurring in a given time frame. In this table, an event with a given ARI occurring in a specific time frame is compared with the betting odds (given in parenthesis) that most punters are familiar with.

Table 1. 3 Probability of one or more events in a specific period (Leiba, pers. com., 2000)

Period in which event might occur (years)	50 year ARI (2.0% AEP)	100 year ARI (1.0% AEP)	200 year ARI (0.5% AEP)	500 year ARI (0.2% AEP)	1000 year ARI (0.01% AEP)
5	10% (10 to 1)	5% (20 to 1)	2% (50 to 1)	1% (100 to 1)	0.5% (200 to 1)
10	18% (5 to 1)	10% (10 to 1)	5% (20 to 1)	2% (50 to 1)	1% (100 to 1)
25	39% (2 to 1)	22% (5 to 1)	12% (10 to 1)	5% (20 to 1)	2% (50 to 1)
50	63% (2 to 1 on)	39% (2 to 1)	22% (5 to 1)	10% (10 to 1)	5% (20 to 1)
100	86% (7 to 1 on)	63% (2 to 1 on)	39% (2 to 1)	18% (5 to 1)	10% (10 to 1)
200	98% (near certain)	86% (7 to 1 on)	63% (2 to 1 on)	33% (3 to 1)	18% (5 to 1)
500	99.999% (certain)	99% (near certain)	92% (near certain)	63% (2 to 1 on)	39% (2 to 1)

Similar information is shown graphically in Figure 1. 4.

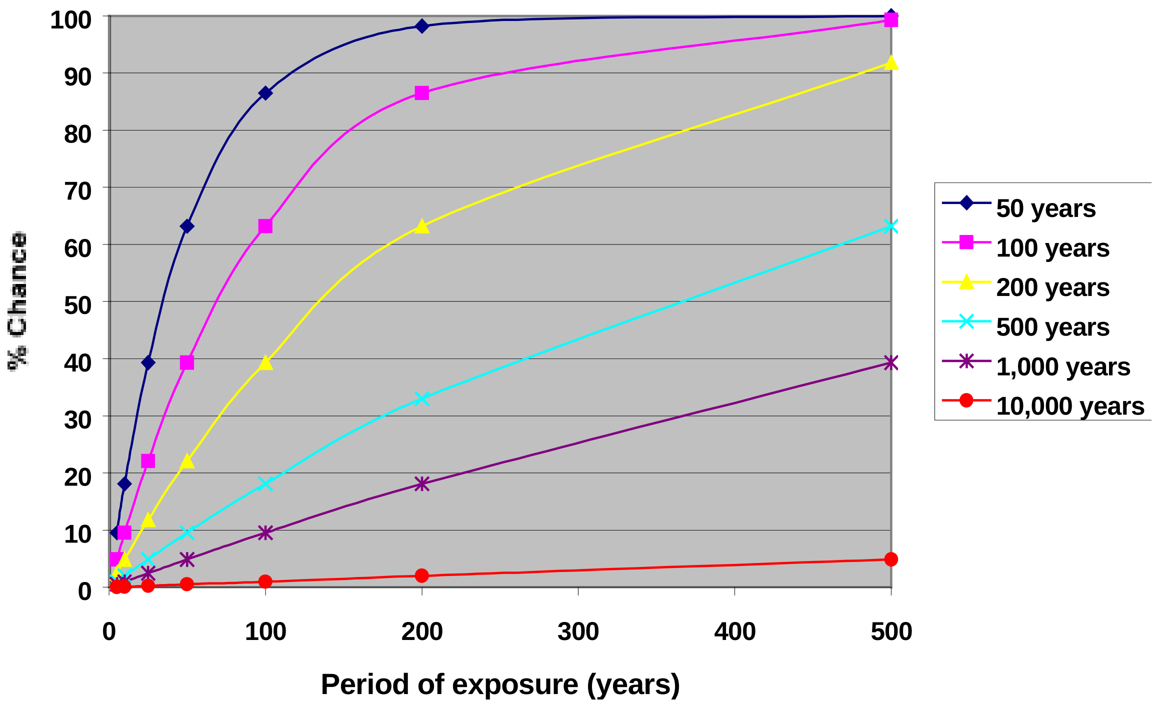


Figure 1. 4 Chance of one or more events with a given ARI occurring in a given time frame

With this approach, it is much easier to see that the short term risk of a developer or elected official, whose exposure is typically from three to five years, is considerably less than that of a householder or company (say 25 to 50 year exposure) or individual (perhaps a 100 year exposure).

Whilst such statements may be made about the probabilities of events occurring, they are frequently based on an incomplete and, often, statistically inadequate record. This is certainly the case in South-East Queensland. The record of earthquakes, floods and cyclones extends over, at best, 150 years. For the first 100 years or so of that time there was minimal instrumental measurement except for floods. Many of the smaller or more distant earthquake events before about 1970, for example, have undoubtedly gone undetected and unreported.

We realise that uncertainty can create difficulties for public officials in their dealings with developers and others. Childes and others (1996), for example, document the difficulties experienced by Redcliffe City Council, between 1987 and 1996, in relation to establishing new planning constraints to take account of scientific estimates of sea level rise associated with climate change. Council adopted the 'mid-point' of the range of sea level rise nominated over a given time-scale adopted by the Queensland State Government. A developer, however, challenged them, using a more conservative estimate published by different scientists. They conclude their study in the following terms:

> *The uncertainty inherent in a range of scenarios set at the international or national levels by researchers or other authorities is critical to those dealing with developers and consultants directly at the local government level. Professional engineers and planners rely on the range quoted (and therefore the uncertainty) to argue the case for caution against pressures from developers and architects to relax regulations to lower floor heights and kerb and channel levels for new building projects. In the absence of clear legislative guidelines for planning at the national/state level, the Council has only been able to stand firm on its raised*

development heights in recent years because of available published scenarios in the scientific literature, set at international conferences, that support their pro-active stance.

The absence of what might be termed 'absolute knowledge' in this report should not be seen as invalidating the assessments made. Rather, it should be seen as a challenge for the next iteration of the risk management process.

CHAPTER 2: THE SOUTH-EAST QUEENSLAND SETTING

Ken Granger and Marion Leiba

Introduction

The South-East Queensland region covered in this study is one of Australia's fastest growing urban regions and is already home to almost 2 million people. The study area covers around 5230 sq km, extending about 150 km from north to south and 110 km, at its widest point, from east to west, and takes in the following areas:

- the eastern urbanised portions of Caboolture and Pine Rivers Shires;
- the north-eastern urbanised portion of Ipswich City; and
- the complete areas of Redcliffe, Brisbane, Logan and Gold Coast Cities and Redland Shire.

The boundary of the study area and local government boundaries are shown in Figure 2.1.

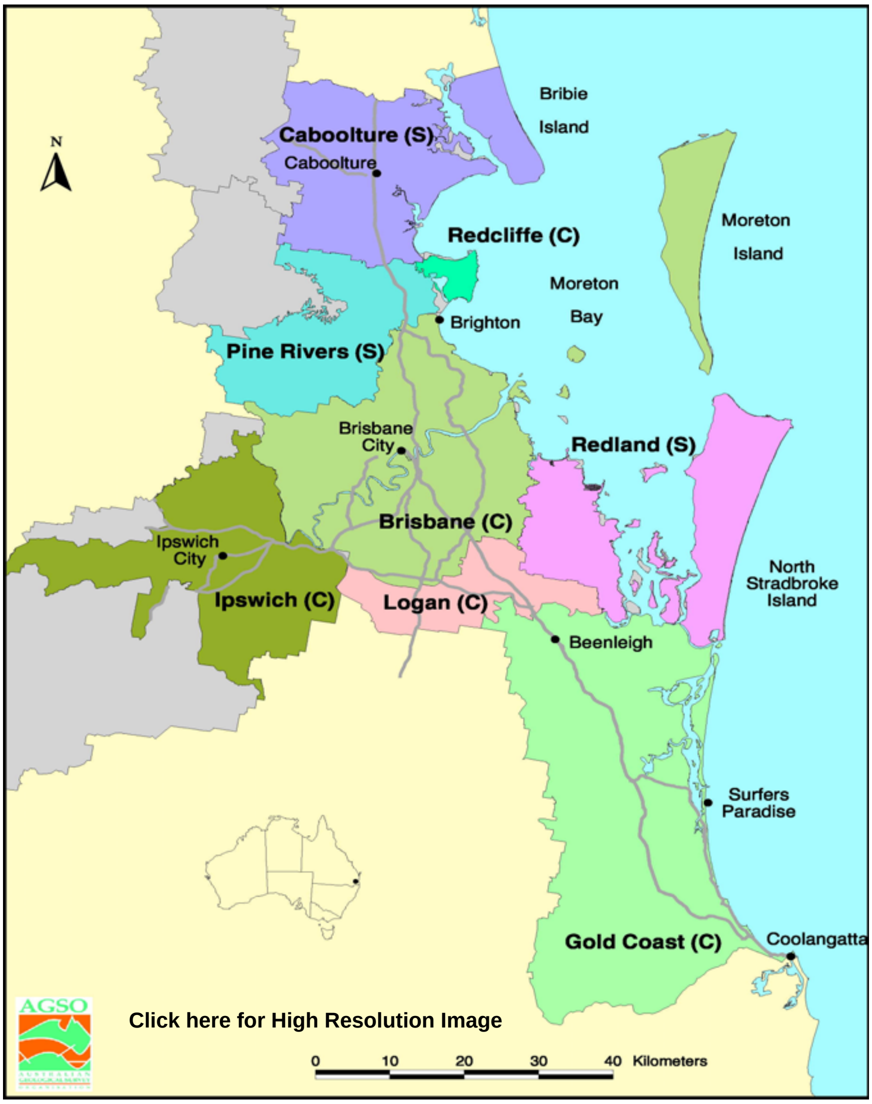


Figure 2. 1 South-East Queensland study area extent and location

The Physical Setting

Topography: The area covered by this study can be divided into three main topographic regions, namely: the coastal zone, dominated by Moreton Bay, its sand islands and coastal plains; the major river floodplains and estuaries; and the hinterland foothills and mountains. The major features are shown in Figure 2.2.

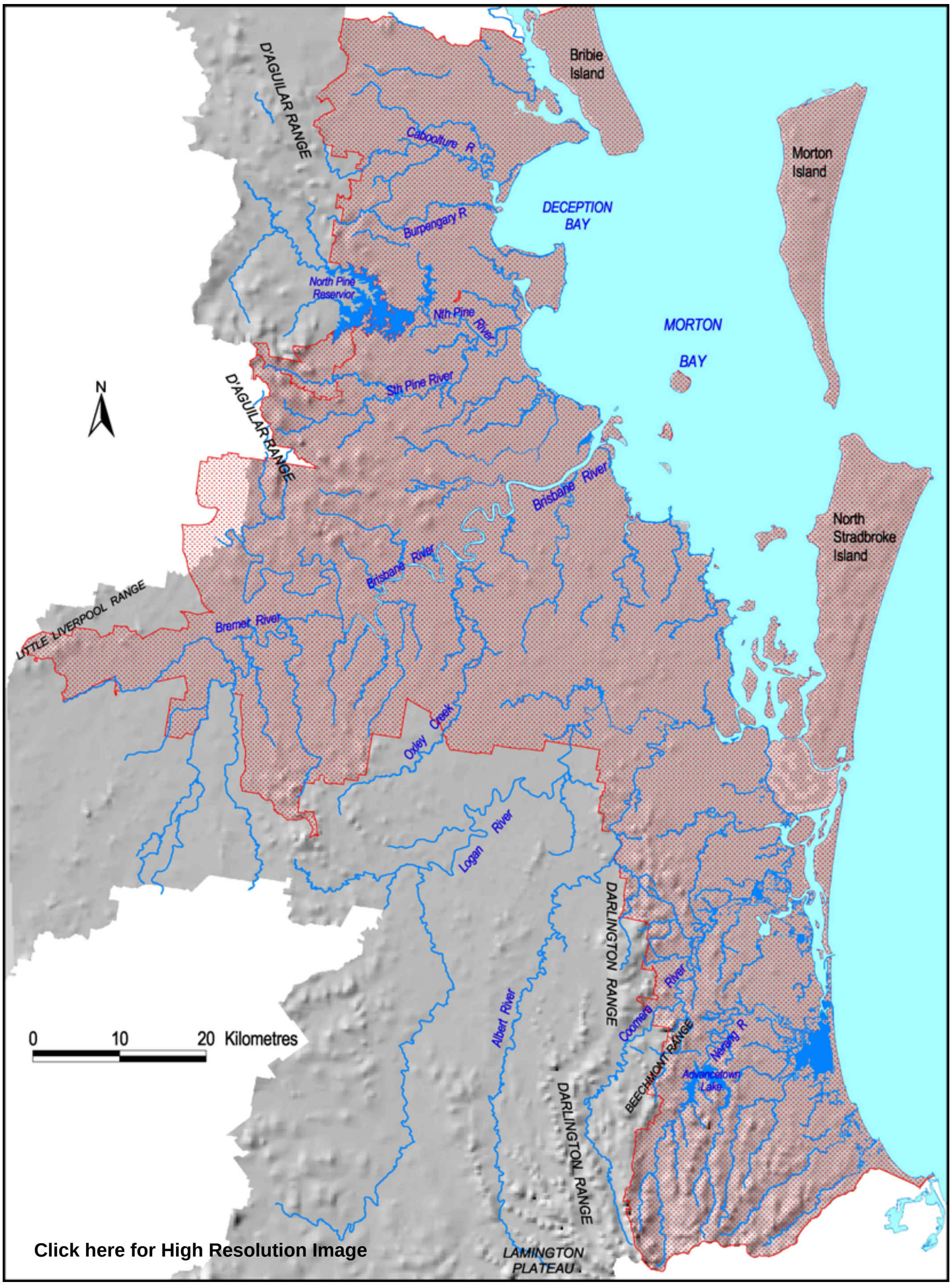


Figure 2. 2 Terrain features of the South-East Queensland area

Coastal zone: The region's coastline is dominated by Moreton Bay which is formed by a series of barrier islands, most notably Bribie, Moreton (the largest), North Stradbroke, and South Stradbroke. Numerous smaller islands, such as Coochiemudlo, Macleay, St Helena and Russell, together with many shoals, banks and reefs, occur mainly in the southern portion of the Bay. South of Moreton Bay, the coastline is that of the Coral Sea, and the lagoon of The Broadwater.

Moreton Bay is a shallow body of water, with an average depth of only 6.8 m (Dennison and Abal, 2000). The absolute tidal range varies from 2.6 to 2.9 m inside the Bay and 1.9 m along the open coast of the Coral Sea. The tidal planes, relative to the Australian Height Datum (AHD), for three selected sites are shown in Table 2. 1.

Table 2. 1 Tidal planes at Beachmere and Toorbul relative to AHD (from Queensland Transport, 1997)

Tidal Plane	Beachmere (metres)	Brisbane Bar (metres)	Gold Coast Sea Way (metres)
Highest astronomical tide	1.34	1.47	1.13
Mean high water springs	0.81	0.92	0.65
Mean high water neaps	0.43	0.52	0.39
Mean sea level	0.0	0.0	0.0
Mean low water neaps	-0.54	-0.49	-0.27
Mean low water springs	-0.92	-0.89	-0.53
Lowest astronomical tide	-1.26	-1.24	-0.76

On the mainland, the shoreline is backed by a generally narrow, but low lying, coastal plain, broken in places such as the Redcliffe Peninsula, Shorncliffe and Wellington Point, by rocky promontories or by the estuaries of the major rivers. In some areas, most notably on Bribie Island, around the Brisbane International Airport and the sea port at Fisherman Island, the Manly Boat Harbour, and at Birkdale, Cleveland and The Broadwater, the coastline has been modified by development, including residential canal estates. The coastal plain is generally narrow, rarely exceeding more than 15 km. Elevations on the coastal plain are generally less than 20 metres above AHD.

The Coral Sea coastline is particularly prone to sand mobility and features such as the Southport Spit were created as a consequence of sea intrusion at Jumpinpin to the north. Dune build-up in the area now occupied by Sea World did not occur until the 1920's. Rivers and creeks have also altered their shallow courses, e.g. the mouth of the Nerang River has moved approximately five kilometres north over the past 100 years. Consistent coastal erosion redistributes the sand and isolated events, such as cyclones, exacerbates the condition. Artificial structures such as groynes have been replaced by a new attempt at stabilisation with an artificial reef at Narrow Neck to retard the marine action of re-deposition.

River floodplains: The South-East Queensland region is crossed by six major river systems and numerous creeks. Typically the headwaters rise in the Great Dividing Range to the west with the rivers traversing the coastal plain in a generally eastward direction, emptying into Moreton Bay, The Broadwater or the Coral Sea. In the past 100 years urban development has impinged onto many areas of the floodplains and several river courses have been altered through the creation of water storages in their upper reaches and dredging or reclamation works in their lower reaches.

Figure 2.3 delineates the catchments of the major rivers. The northern coastal region is drained by the Caboolture River/Burpengary Creek, the North and South Pine Rivers and the northern creeks of Brisbane which flow to Moreton Bay. The Brisbane/Bremer River system is the major catchment in the region and includes a number of urban creeks including Moggill and Enoggera Creeks in the north and Oxley and Bulimba Creeks on the southern side. The southern coastal region is traversed by the Logan River and its major tributary, the Albert River, which empties into the southern extent of Moreton Bay, whilst the Pimpama, Coomera and Nerang River systems empty into The Broadwater. The southern boundary of the region is marked by another major river, the Tweed, however, its catchment is almost entirely within NSW.

Apart from the complex and inter-connected estuary of the Pimpama, Coomera and Nerang systems, the estuaries of the South-East Queensland rivers are generally quite small. For the most part, floodplains are generally narrow, with the main stream generally entrenched. In their lower reaches they all tend to meander significantly. More detailed descriptions of the major catchments are given in Chapter 8 which examines flood risk.

There are 16 major dams and reservoirs throughout the South-East Queensland region which act primarily to provide urban water supply storage, though some have a role in irrigation and flood mitigation. The characteristics of these dams and the role they play in flood mitigation is dealt with in Chapter 8.

The hinterland*:* The narrow coastal plain is backed by the foothills and escarpments of the hinterland high country. The main ranges trend in a north to south direction and include (from the north) the D'Aguilar, Annand, Taylor (Mount Coot-tha), Little Liverpool, Dugandan, McPherson and Darlington Ranges and the Lamington Plateau. The highest country is in the southern sector where Mount Wanungara (at the junction of the McPherson and Darlington Ranges) reaches 1180 m above AHD. The southern area is also the most rugged, with deeply incised streams forming spectacular gorges and water falls. By contrast, the greatest elevations attained in the D'Aguilar Range at the northern end of the region are 756 m at The Summit, 742 m at Mount D'Aguilar and 690 m at Mount Samson. These hills are significantly less rugged that the Lamington Plateau.

A number of outlier hills, all with summits at less than 300 m above AHD, also provide relief closer to the coast. These include Mount Cotton, Mount Gravatt, Mount Petrie, Pine Mountain and Toohey Mountain to the south and Round Mountain, The Saddleback and Miketeebumulgai in the north. The northern examples are the three most southerly of the features known collectively as the Glass House Mountains.

Geology: Based on the work of Hutton and Willmott (1992), Willmott (1992), and Willmott and Stevens (1988), the following geological history of the region is evident. From 370 to 290 million years ago, thick layers of sediment accumulated in a deep ocean off the geologically unstable eastern edge of Australia. These were subsequently crumpled and uplifted, and now form the Neranleigh-Fernvale beds, Bunya Phyllite, Rocksberg Greenstone, and the Kurwongbah beds. They consist of varying proportions of hardened and slightly recrystallised sedimentary rocks, chert, jasper, greenstone (recrystallised basaltic volcanic rocks), pillow lava and conglomerate. They crop out throughout the study area, predominantly in the western, central and southern parts.

From 240 to 220 million years ago, the continental edge was beginning to stabilise, but volcanoes erupted and molten granitic rock squeezed up into the rocks deep beneath the surface. In the northern part of the study area, these granitic rocks crop out as the Dayboro and Neurum Tonalites, and in the central part as the Mount Samson Granodiorite, Samford Granodiorite, Enoggera Granite, and Karana Quartz Diorite. They do not crop out in the southern part of the study area. The volcanic rocks are represented by the Brisbane Tuff, the Brookfield Volcanics and the Jollys Lookout Andesite in the central part of the study area, and by the Chillingham Volcanics in the southern part. In the far western part of Pine Rivers, volcanism started slightly earlier than 240 million years ago, with the eruption of the Fahey Range Volcanics.

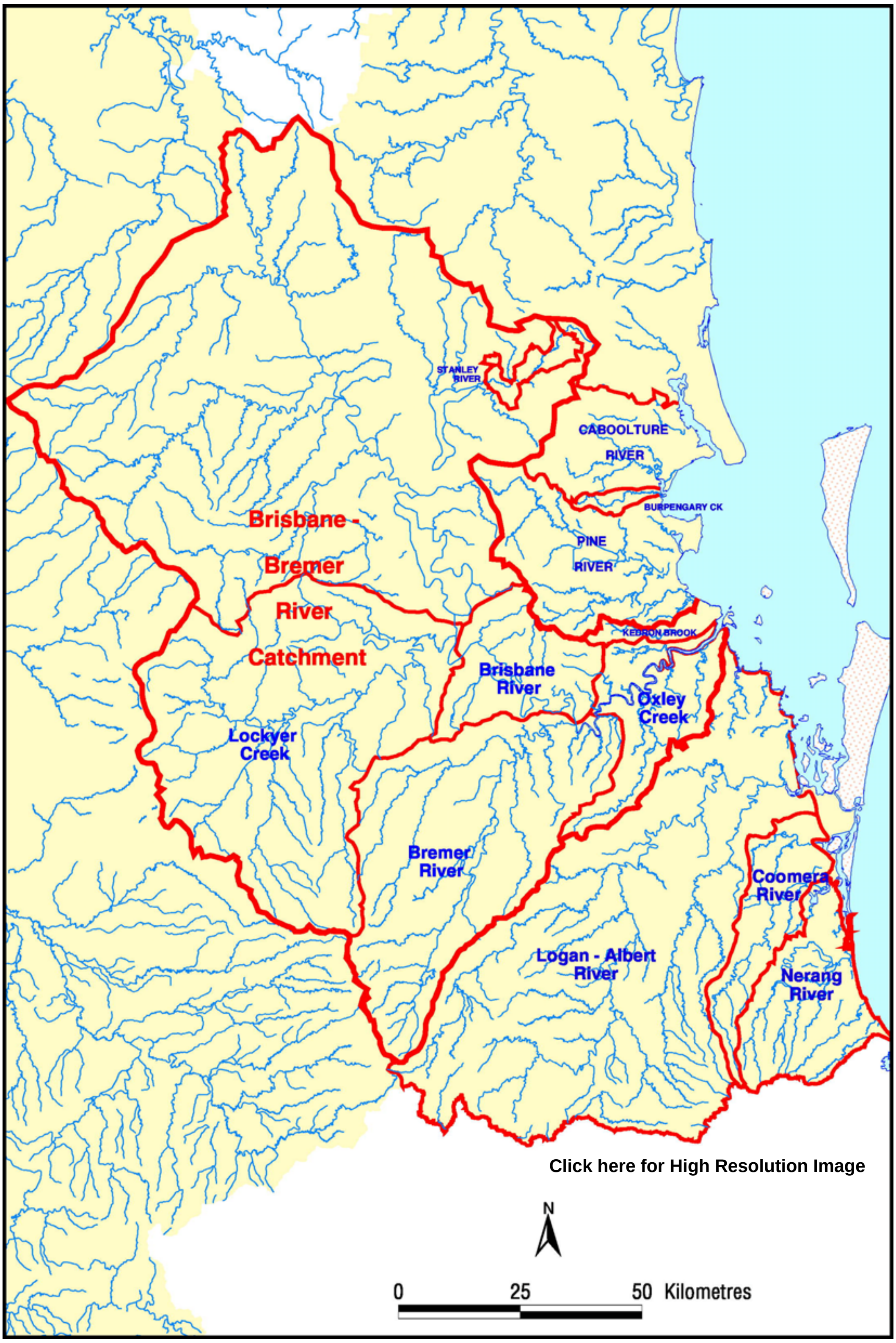


Figure 2. 3 Major river catchments in South-East Queensland

Between 220 and 180 million years ago, the continent was almost stabilised. Sediments, including coal, were deposited in river plains, lakes and swamps. These subsequently formed a variety of rock types including sandstone, shale, coal, siltstone, mudstone, and conglomerate. There was still a small amount of volcanic activity in the central part of the study area, erupting basalt lava and rhyolitic volcanic ash. The Kholo and Brassal Subgroups of the Ipswich Coal Measures, the Aspley and

Tingalpa Formations, then later the Woogaroo Subgroup, Landsborough Sandstone, Marburg Formation, and Walloon Coal Measures were formed at this time. The Landsborough Sandstone crops out in the north and north east. The Aspley and Tingalpa Formations occur in the Brisbane area. The remainder crop out in the central and southern parts of the study area.

The rocks were folded into broad open folds about 120 million years ago. A long period of erosion then followed.

Several small basins formed across South-East Queensland 65 to 45 million years ago. They may have been related to the opening of the Tasman Sea. Soft sediments were deposited in these small lakes and there were some basaltic volcanic eruptions. The Petrie Formation, Oxley Group and the Booval Group were deposited at this time. They consist chiefly of mudstone, siltstone, claystone and sandstone, with varying amounts of basalt, oil shale, brown coal, limestone, conglomerate and dolomite, and occur mainly in the central part of the study area..

Between 28 and 20 million years ago, there were extensive eruptions of basalt and some rhyolite lavas, and molten rock also squeezed into the sediments beneath the surface. The volcanic activity may have been connected with the opening of the Tasman Sea.

The largest basaltic volcano affecting the study area was the Tweed volcano, which was like the shield volcanoes on the Island of Hawaii. It was centred on Mt Warning and its lavas extend as far north as Mt Tamborine. It erupted a pile of basalt lava flows with two intervals of rhyolite (silica-rich lava) and fragmental volcanic rock. The first basalts in the southern part of the study area, and some subsequent rhyolitic fragmental volcanics and lavas, are thought to have been erupted from a shield volcano centred over Focal Peak, just west of Mt Barney. Basalts from other volcanoes are found in the Little Liverpool Range, and at Mt Glorious. They also crop out at the tail end of the Maleny Plateau and at Mt Mee (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001), but these are outside the study area.

Trachyte and rhyolite molten rock squeezed into pre-existing rocks to form the Glasshouse Mountains in the north, and Flinders Peak and Mt Juillerat near Ipswich. Some intrusions of molten rock filled the conduits of volcanoes.

Following the volcanic activity, erosion continued, carving out the present landscape, depositing material on floodplains, and carrying sediment out to sea.

A simplified geology of the region is shown in Figure 2.4.

Climate: The region lies on the Queensland coast between 27.0^{o} and 28.2^{o} south latitude and consequently has a moist sub-tropical climate. Rainfall is seasonal, with the heaviest rain occurring during the summer months. Rainfall and temperatures, however, are modified by altitude on the western extents of the study area. The more extreme rainfall events are generally associated with tropical cyclones. In the past 92 years of detailed records, only 15 of these storms' centres have passed within 100 km of Brisbane at the region's centre..

Temperatures rarely exceed 35.0^{o}C or go below 10.0^{o}C for extended periods.

The main climatic statistics are summarised in Tables 2.2a to 2.2d which compare the statistics for recording stations on or close to the coast and Tables 2.3a to 2.3e (inland stations) which illustrate the modifying influence of distance from the coast. Caloundra (Table 2.2a) and Crohamhurst (Table 2.3a) are outside the northern boundary of the study area, however, their statistics are the best available to illustrate the northern sections. All statistics are derived from BoM (2000).

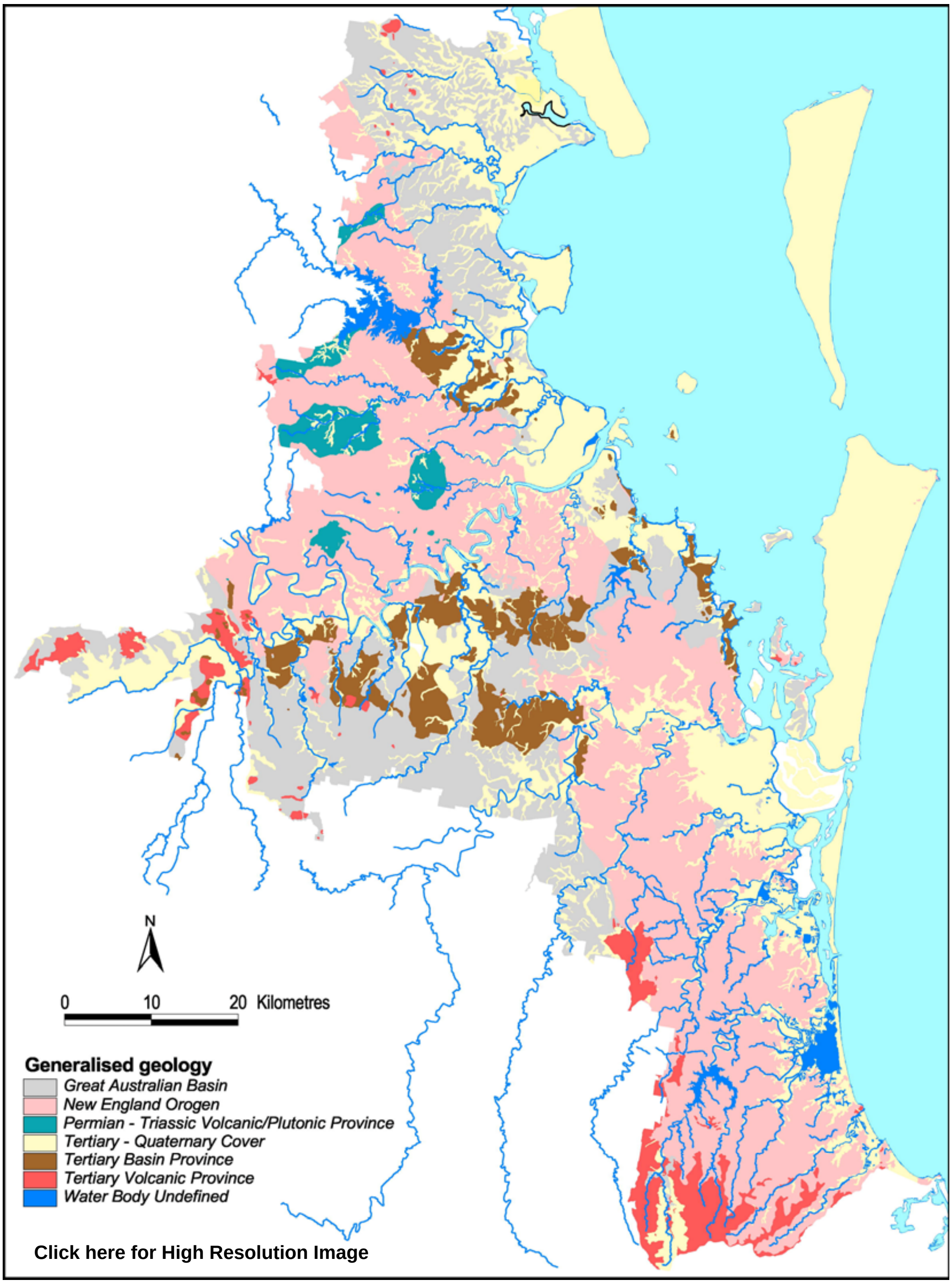


Figure 2. 4: South-East Queensland generalised geology.

Coastal sites:

Table 2. 2a Caloundra for the period 1886 to 1992

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (°C)	27.6	27.2	26.4	24.6	22.2	19.8	19.3	20.3	22.3	24.1	25.4	27.0	23.8
Mean min temp (°C)	21.5	21.2	19.9	17.4	14.9	11.7	10.8	11.6	14.0	16.5	18.5	20.5	16.5
Highest daily temp (°C)	37.6	35.2	33.8	32.5	29.6	26.5	27.0	28.4	33.3	32.2	34.6	35.5	37.6
Lowest daily temp (°C)	15.0	11.6	13.4	9.3	6.4	4.3	3.3	5.0	6.8	9.2	11.7	9.0	3.3
Av. rainfall (mm)	177	202	208	173	170	102	90	61	54	81	113	144	1575
Highest 24hr rain (mm)	178	345	185	160	164	234	239	89	99	155	281	241	345

Table 2. 2b Redcliffe for the period 1981 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (°C)	28.8	28.5	27.6	25.6	23.3	21.0	20.5	21.3	23.8	25.2	26.7	27.9	25.0
Mean min temp (°C)	21.9	21.5	20.0	17.6	15.0	11.2	10.7	11.0	14.0	16.4	18.9	20.6	16.6
Highest daily temp (°C)	38.2	35.0	35.0	32.0	28.7	27.0	27.1	29.0	33.5	34.0	40.0	40.1	40.1
Lowest daily temp (°C)	16.8	15.9	13.2	6.1	4.9	0.2	0.0	0.0	5.0	6.9	11.3	12.5	0.0
Av. rainfall (mm)	119	151	133	123	117	66	59	40	34	72	98	126	1137
Highest 24hr rain (mm)	132	136	93	136	155	106	95	59	36	62	110	102	155

Table 2. 2c Brisbane Regional Office for the period 1840 to 1994

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (°C)	29.4	29.0	28.0	26.1	23.2	20.9	20.4	21.8	24.0	26.1	27.8	29.1	25.5
Mean min temp (°C)	20.7	20.6	19.4	16.6	13.3	10.9	9.5	10.3	12.9	15.8	18.1	19.8	15.7
Highest daily temp (°C)	43.2	40.9	38.8	36.1	32.4	31.6	29.1	32.8	38.3	40.7	41.2	41.2	43.2
Lowest daily temp (°C)	14.9	14.7	11.3	6.9	4.8	2.4	2.3	2.7	4.8	6.3	9.2	13.5	2.3
Av. rainfall (mm)	160	158	141	93	74	68	57	46	46	75	97	133	1146
Highest 24hr rain (mm)	465	270	284	190	149	282	193	124	80	136	169	168	465

Table 2. 2d Southport for the period 1881 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (°C)	28.5	28.3	27.6	25.9	23.3	21.2	20.6	21.4	23.3	25.2	26.7	28.1	25.0
Mean min temp (°C)	20.3	20.5	19.2	16.5	13.4	10.6	9.2	9.8	12.1	15.0	17.4	19.2	15.3
Highest daily temp (°C)	39.0	26.7	36.1	35.0	31.7	27.6	28.9	28.3	33.2	39.4	42.2	38.3	42.2
Lowest daily temp (°C)	14.4	15.0	8.3	8.9	3.3	0.6	-3.9	0.6	2.8	5.5	8.0	5.6	-3.9
Av. rainfall (mm)	179	190	202	139	132	97	76	57	59	86	104	134	1454
Highest 24hr rain (mm)	776	880	712	639	592	691	406	229	198	515	476	440	880

Inland sites:

Table 2. 3a Crohamhurst for the period 1892 to 1999

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	28.8	28.0	26.9	24.9	22.0	19.7	19.5	21.1	23.8	26.1	28.1	29.0	24.8
Mean min temp (^{o}C)	18.7	18.9	17.6	14.3	11.1	8.2	7.1	7.6	10.5	13.7	16.0	17.8	13.5
Highest daily temp (^{o}C)	39.5	37.7	37.2	33.5	30.0	27.5	30.8	30.5	34.5	39.0	40.3	40.0	40.3
Lowest daily temp (^{o}C)	11.4	12.0	10.0	5.7	1.7	-1.1	-1.4	-1.5	1.0	2.5	5.5	8.0	-1.5
Av. rainfall (mm)	268	311	282	171	131	103	86	56	60	99	118	175	1858
Highest 24hr rain (mm)	493	907	412	252	193	338	186	91	111	194	121	342	907

Table 2. 3b Samford for the period 1912 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	29.3	28.7	28.1	26.2	23.4	20.9	20.6	22.0	24.5	26.3	28.0	29.3	25.6
Mean min temp (^{o}C)	22.5	20.4	20.5	16.0	16.0	13.3	12.4	13.8	13.8	18.5	19.4	21.9	12.4
Highest daily temp (^{o}C)	39.5	36.3	35.6	36.0	31.8	27.8	29.1	30.7	35.4	39.0	39.3	40.0	40.0
Lowest daily temp (^{o}C)	10.5	11.5	8.5	3.9	1.7	-1.7	-2.7	-3.5	-0.5	2.0	3.8	5.5	-3.5
Av. rainfall (mm)	158	161	131	96	81	60	56	34	45	83	95	125	1122
Highest 24hr rain (mm)	316	244	126	255	179	145	207	155	108	148	155	174	316

Table 2. 3c Archerfield Airport for the period 1929 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	30.1	29.3	28.3	26.1	23.5	21.1	20.7	22.1	24.6	26.6	28.2	29.4	25.8
Mean min temp (^{o}C)	19.9	19.7	18.1	14.8	11.8	9.0	7.2	7.7	10.4	13.9	16.8	18.8	14.0
Highest daily temp (^{o}C)	43.3	40.3	36.2	32.8	29.6	27.6	28.3	32.2	37.8	37.2	40.5	39.8	43.3
Lowest daily temp (^{o}C)	13.7	14.2	10.7	5.3	0.6	-0.8	-2.5	-1.8	-0.4	4.2	7.9	9.8	-2.5
Av. rainfall (mm)	139	158	131	84	78	68	55	38	37	80	98	127	1092
Highest 24hr rain (mm)	186	344	192	163	183	175	159	67	58	118	140	114	344

Table 2. 3d Amberley for the period 1941 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	31.0	30.3	29.3	27.1	23.9	21.5	21.0	22.5	25.2	27.5	29.5	30.8	26.6
Mean min temp (^{o}C)	19.6	19.6	17.8	14.1	10.3	7.1	5.5	6.4	9.5	13.4	16.3	18.4	13.2
Highest daily temp (^{o}C)	44.3	42.6	38.9	36.8	32.8	29.1	29.6	33.3	39.2	41.1	42.1	43.8	44.3
Lowest daily temp (^{o}C)	11.6	11.1	7.9	2.1	-0.3	-4.3	-4.3	-4.9	-0.2	2.1	7.0	6.8	-4.9
Av. rainfall (mm)	116	125	85	57	55	47	43	30	34	75	77	123	876
Highest 24hr rain (mm)	240	109	106	112	121	110	170	46	69	115	72	185	240

Table 2. 3e Mt Tamborine for the period 1888 to 2000

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	25.7	25.3	24.4	22.6	19.8	17.7	17.1	18.3	20.3	22.6	24.6	25.9	22.0
Mean min temp (^{o}C)	17.1	17.3	16.4	14.0	11.2	9.1	8.0	8.6	10.4	12.8	14.8	16.3	13.0
Highest daily temp (^{o}C)	35.7	35.3	34.9	31.4	27.4	26.6	25.4	24.9	29.6	35.8	37.8	37.8	37.8
Lowest daily temp (^{o}C)	11.7	10.3	6.9	7.6	3.8	-0.6	1.4	-1.1	-0.3	4.7	8.3	9.6	-1.1
Av. rainfall (mm)	220	216	193	134	126	98	89	56	59	93	117	163	1563
Highest 24hr rain (mm)	179	793	698	893	118	830	557	255	253	532	439	639	893

Vegetation: The South-East Queensland area includes a very diverse range of natural vegetation types, both marine and terrestrial. There are significant examples of most habitats that still remain undisturbed by development. These range from the extensive seagrass beds in Moreton Bay, through the dune and mangrove communities along the coast and Moreton Bay islands, the wetlands and paperbark forests of the estuaries, the tall eucalypt forests of the lowland areas, to the rainforests of the higher parts of the hinterland. Excellent descriptions of these habitats can be found in Poole and others (1996).

Extensive areas have, however, been cleared of natural vegetation. This was originally done to make way for cropping and grazing, but more recently urban development has provided the impetus for clearing activities.

Settlement

South-East Queensland was home to several aboriginal tribal groups. From early European reports such as those of settler and explorer Tom Petrie in the north and the botanist Charles Fraser in the south, it is clear that these groups flourished because of the diverse habitats and food sources the region offered, ranging from fish, turtles and dugong in Moreton Bay to bunya nuts in the mountains.

The first Europeans to sight the area were with James Cook on the *Endeavour* in 1770. Cook named Glass House Bay (Moreton Bay) and the Glass House Mountains as he sailed north along the coast. The first detailed surveys of the area were undertaken by Matthew Flinders in the *Norfolk* in 1799. He charted and named Moreton Bay, the ‘Pumice Stone River’, Skirmish Point (on Bribie Island) and ‘Red Cliff Point’. The first penetration inland was by John Oxley along the Brisbane and Pine Rivers during his 1823 exploration of Moreton Bay in the *Mermaid*. Oxley’s party went inland as far as College’s Crossing (in the area now occupied by the present-day Brisbane suburb of Karana Downs). The first record of Europeans living in the area, however, involved the castaways Pamphlett, Finnigan and Parsons who were found on Bribie Island by Oxley in 1823.

Following Oxley’s exploration, the Moreton Bay area was chosen for the site of a penal settlement in 1824. The first settlement was established on the Redcliffe Peninsula by Lt Henry Miller and an advance party of 14 soldiers and 30 convicts on 24 September 1824. Three weeks after landing, the party experienced considerable resistance from local aborigines. Two convicts and one soldier were speared to death close to the encampment and Miller decided to abandon the site, though he gave ‘the prevalence of fever’ as the reason. The abandoned buildings were referred to as ‘oompie bong’ (house of the dead) by the local aboriginals – the name Humpybong still persists on the Peninsula (CSC, 1979). The transfer of the settlement to the banks of the Brisbane River began in early December 1824.

Early exploration around the Morton Bay Colony was by water, both along the coast and along the Brisbane River. The Brisbane and Ipswich areas were, therefore, the first areas to be explored and became the jumping-off point for expeditions by the early explorers, including Major Edmund Lockyer (1825), Captain Patrick Logan (1826-1830) and Allan Cunningham (1827). The discovery of coal near Ipswich in 1825 and the ease of access along the Brisbane River were the key determinants in the early growth of the Moreton Bay colony.

Brisbane became the capital of the Queensland colony when it was separated from New South Wales in 1859. Brisbane’s role and character as administrative, transport, service and economic centre for the colony, and subsequently the State, remains paramount.

The coastal area to the north of the Brisbane settlement and the bunya pines of the mountains were reserved by Governor Gipps for the use of the Aboriginal people. In 1840, Gipps also imposed a restriction on the establishment of ‘stations’ within 50 miles of the penal settlement. This directive was effectively revoked with the opening of Brisbane to free settlers in 1842, though an attempt was made to restrict the size of holdings within the 50 mile limit.

Settlement away from the Brisbane River corridor began in 1841 with the selection of Durundur (near present day Woodford, to the west of Caboolture) by the Archer brothers and by 1842 settlers had taken up land at Samsonvale and Captain Griffin had established ‘Whiteside’ which occupied much of present day Redcliffe City and Pine Rivers Shire. The coastal area to the north of Brisbane was not settled until 1850 when Henry Jeffreys selected some 6500 hectares on the north bank of the Caboolture River. It was not until after the creation of the Queensland colony in 1859, however, that settlement became more established and road links to Brisbane developed. The main activities in the area north of Brisbane were the growing of cotton (stimulated by the loss of supply because of the American Civil War), logging and the milling of timber, the produce being mainly transported down the Caboolture River by steamers. The importance of the Caboolture River as a transport route, however, began to decline after the railway reached Caboolture in 1888 and had largely disappeared by turn of the Century.

The first Europeans to enter the area to the south of Brisbane were with Captain Patrick Logan, commandant of the Moreton Bay Penal Colony, in 1826. His group 'discovered' the river that Logan named after himself. With the early focus on development within the Brisbane-Ipswich corridor, and the Gipps' restrictions on free settlement, it was about twenty years after its discovery before European settlement began to intrude into the Logan Valley and beyond. The first leases along the Gold Coast area were taken up in the 1860s.

The first agricultural development to the south of Brisbane was based on the growing of cotton and sugar on the fertile alluvial soils of the major rivers, though much of the area was considered to be of little use because of the extensive estuarine swamps and wetlands. Tourism was, however, an early developer with Burleigh Heads being surveyed as a 'watering place' in 1871, followed by the more suitable Southport in 1873. Road and ferry services developed to meet the increasing demand for travel to the 'Coast' and by 1889 the railway had reached Southport. The name 'Gold Coast' was officially adopted in 1958 and around the same time the first high rise and canal estates began to be developed.

The focus of urban development in the region remains centred on the original Brisbane site, given the city's role as the centre of State Government and regional Commonwealth administration. Urban development of the region since 1960 is dealt with in more detail in Chapter 3.

Population

According to the National Census taken in September 1996, the population of those parts of the eight Local Government Areas (LGA) covered by this report was 1 803 902 (883 025 males and 920 879 females). Of this total, 89 589 were recorded as 'visitors', of whom 24 065 (or about 26.9% of all visitors) were from overseas. The greatest concentrations of visitors were in Brisbane City (40.8%) and Gold Coast City (38.5%), however, the majority of the overseas visitors were in Gold Coast City (52.0%), whilst Brisbane City had 36.6%.

Population density varies across the study area. The five most densely populated neighbourhoods (as represented by the census collectors districts - CCD - used in the 1996 census), are in Surfers Paradise and range from 16 760 persons per square kilometre to a remarkable 40 933 persons per square kilometre. Of the 29 CCD with densities in excess of 10 000 persons per square kilometre all but four are along the Gold Coast strip. There are 14 CCD with densities of less than 1 person per square kilometre. These include large sections of the Bay islands, rural fringe areas and industrial zones such as the Brisbane International Airport. There are 3180 CCDs in area covered by this study. Figure 2.5 shows the concentric zonation of density declining away from the centres of Brisbane and Surfers Paradise.

This distribution is based on the national census which counted people where they slept on census night (a *de facto* census) rather than where they normally reside (a *de jure* census). Population distribution, however, varies considerably during the day when people are at work, or school, or shopping and so on. It will also be different during periods of peak traffic flow in the morning and evening. This is highly significant for understanding the risks posed by hazards, such as earthquake, for which there is no warning, as the impact will depend significantly on where people were at the time of the event.

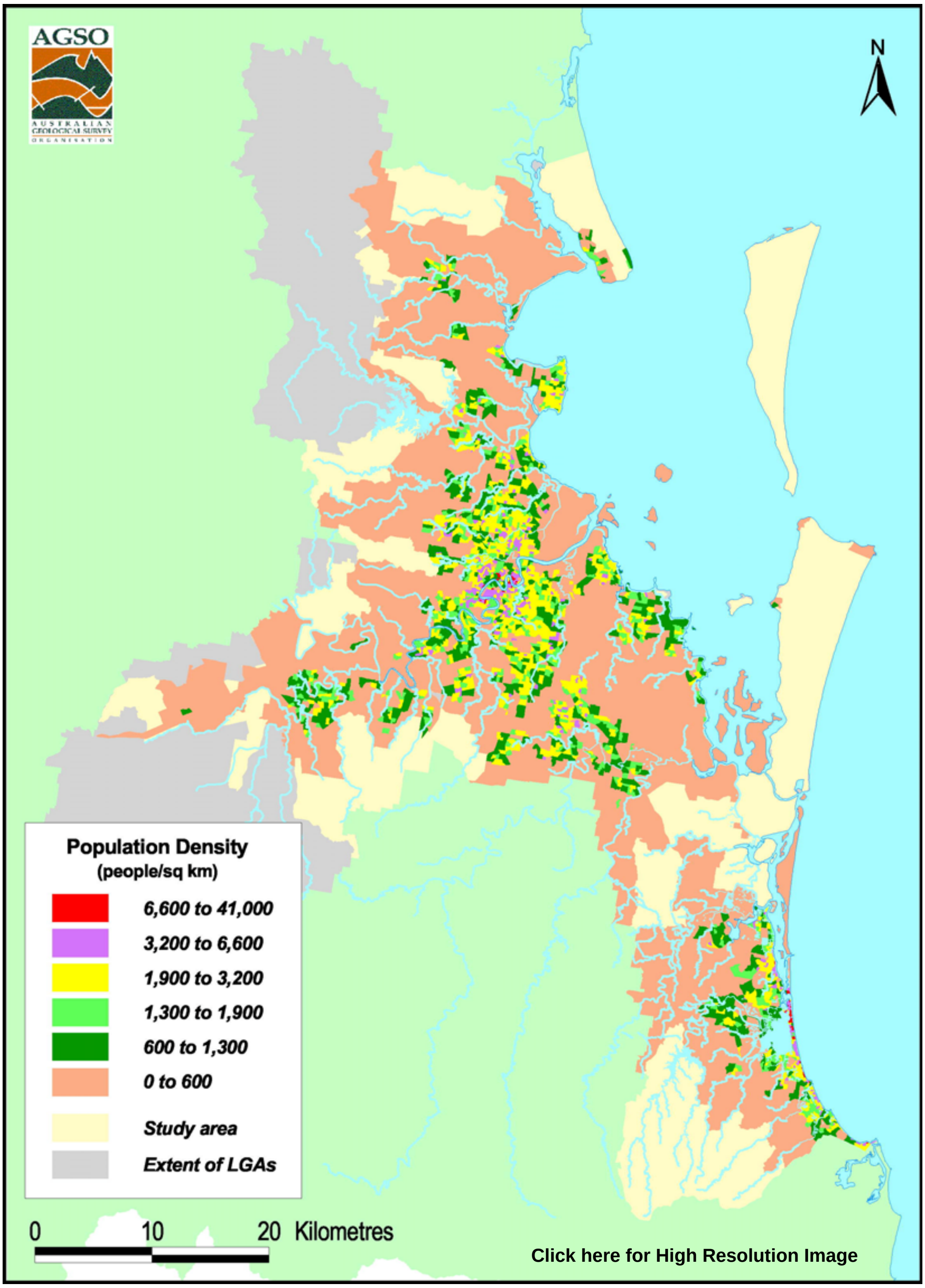


Figure 2. 5 South-East Queensland population density distribution (based on ABS, 1998)

Unfortunately there are no statistics available that detail population distributions during the day or the weekend or during school holidays and so on. It can be assumed, however, that during business hours, neighbourhoods with high numbers of industrial, commercial and educational establishments, for example, will have higher concentrations of population and residential neighbourhoods lower concentrations than that measured by the census. Extreme population concentrations, like those experienced around Southbank in Brisbane or around the Cavill Mall on the Gold Coast during festivals such as New Year and Australia Day, can be well in excess of 100,000 people per sq km.

Similar densities may prevail at times in the larger shopping, sporting and entertainment venues such as the Myer Centre, Pacific Fair, Suncorp Stadium and the Boondall Entertainment Centre.

The gender ratio also varies considerably across the study area. They range from less than one female to every 100 males in Wacol Corrective Institution area to 2400 females to every 100 males in the CCD that contains the Villa Maria Nursing Home and Hostel in Fortitude Valley. The mean value across South-East Queensland, however, is 105.8 females per 100 males.

The age/sex structure of the resident population each of the eight local government areas and the total South-East Queensland population is shown in Figure 2.6.

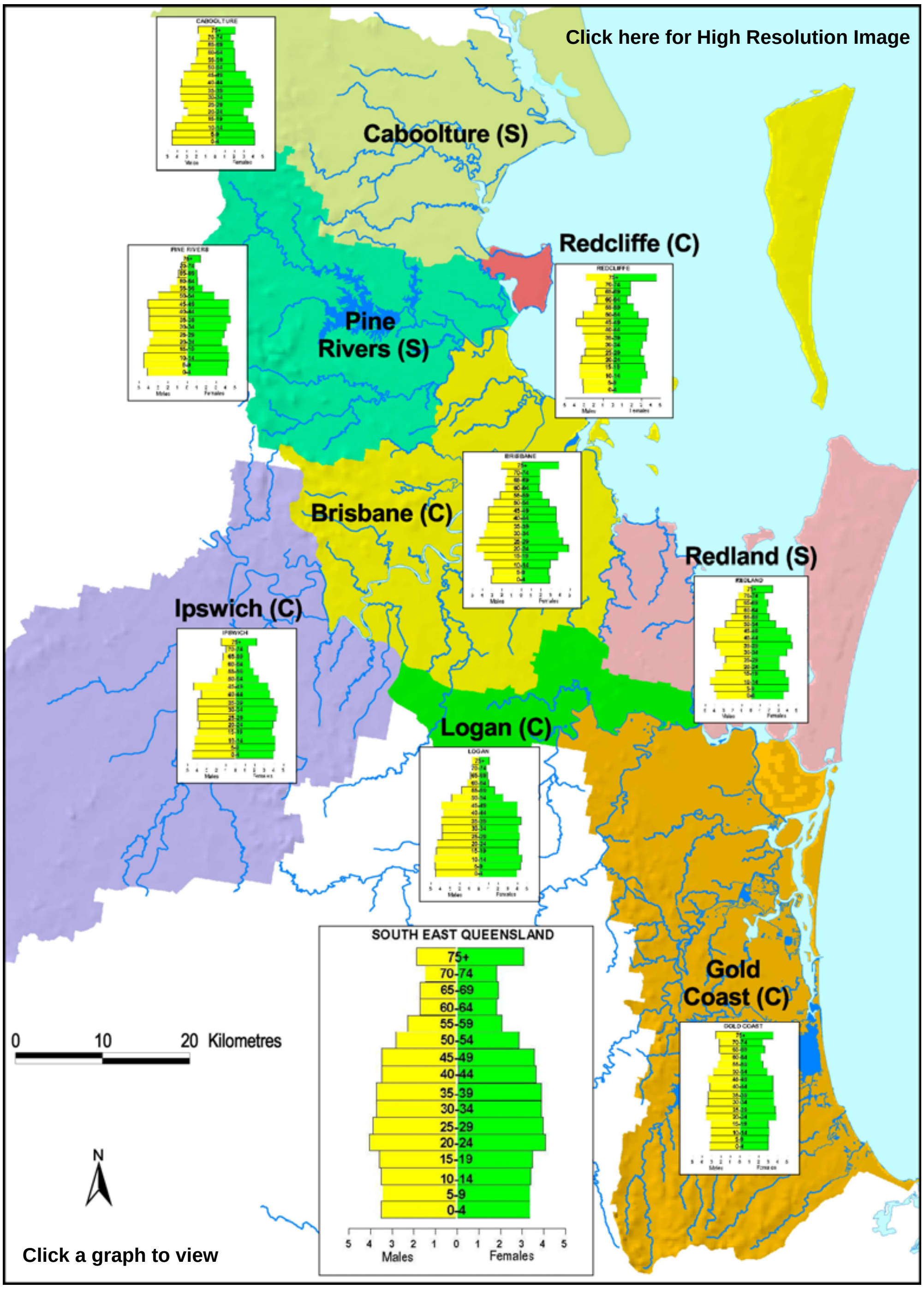


Figure 2. 6 Age/sex structure of South-East Queensland populations

A comparison of the figures reveals a significant variation in the age/sex makeup of each local government area. The areas in the current centres of growth, for example, such as Caboolture, Pine Rivers, Redland and Logan, display a middle aged (30 to 49 year cohorts) 'bulge', a relatively broad youth base and a relatively small proportion of young adults. This contrasts significantly with Brisbane, for example with its greater emphasis on younger adults (the 15 to 29 year cohorts) and elderly (over 65). Redcliffe and Gold Coast are rather more 'elderly', reflecting their attractiveness to retirees. Logan and Ipswich are more 'stable' or 'settled' populations with a more evenly balanced age structure across the youth, young adult and middle aged cohorts. The region overall, however, has a strong bias towards the young adult/middle age cohorts and the elderly cohort.

The Planning Information and Forecasting Unit of the Queensland Department of Communication and Information, Local Government and Planning (DCILGP) produced a median population growth forecast in January 1999 which indicated that the population of region will increase over the next 11 years as shown in Table 2.4. The numbers in the table are for the total area of each LGA.

Table 2.4 Estimated population growth to 2011 by LGA (based on DCILGP median forecasts)

Local Government	1996 Population	2001 Estimate	2006 Estimate	2011 Estimate
Caboolture Shire	98 859	121 000	144 950	169 900
Pine Rivers Shire	106 266	119 944	135 157	150 614
Redcliffe City	48 790	50 100	50 550	51 000
Brisbane City	806 844	867 843	915 435	956 236
Ipswich City	130 244	141 447	155 162	168 288
Redland Shire	100 099	118 642	134 391	148 718
Logan City	158 731	176 600	188 600	201 100
Gold Coast City	356 441	408 095	461 621	513 975
Region	1 806 274	2 003 671	2 185 371	2 359 831

South-East Queensland is not self-sufficient in terms of food production, though Brisbane is the hub of transport, processing and distribution of foodstuffs throughout Queensland, northern NSW and much of the South-West Pacific region. Such dependence clearly imposes limits to the community's resilience.

The region is heavily reliant on its transportation links to the rest of the world. The major links are:

- the main highway links are provided by the Bruce Highway to northern centres; the Pacific Highway to southern destinations; the Warrego Highway to Toowoomba and points west and the Cunningham Highway to Warwick and the south-west. Road transport accounts for much of the general freight carried both to, from and within the area, with road freight terminals generally concentrated in the Rocklea area of Brisbane. Brisbane (Roma Street Transit Centre) and Surfers Paradise are also major terminals for interstate and intra-state bus routes;

- Brisbane is the terminus for both rail freight and passenger services throughout much of Queensland and for links to New South Wales. A major rail freight link also services the Port of Brisbane and rail links to the Ipswich coal fields also carry significant bulk freight. The main rail freight terminus is in Acacia Ridge, with the transhipping and marshalling yards in Moorooka. Roma Street Station is the terminus for both interstate and intra-state passenger services as well as the *Citytrain* commuter rail services that cover the South-East Queensland region. There are about 130 stations serviced by the *Citytrain* service within the region, most of which interface with local bus services.

- The Port of Brisbane provides major sea port facilities at Fisherman Island and at berths along the Brisbane River as far upstream as Hamilton/Bulimba. The Port of Brisbane is Australia's third largest port. It provides 28 berths and 6510 m of quayage as follows:

- 7 container terminals
- 6 crude or refined oil berths
- 1 grain or woodchip berth
- 1 grain/dry bulk/general cargo berth
- 7 general cargo berths
- 1 clinker berth
- 2 chemical/fertiliser berths
- 1 sugar berth
- 1 wet bulk berth.

In 1998-99 the port had 2191 ship movements amounting to a total movement of 20 745 590 tonnes, valued at $12.8 billion. The port handles 50% of Australia's beef and cotton exports and 30% of east coast car imports. The Port of Brisbane Authority, a public entity, operates the port. Details can be found on their web site at http://www.portbris.com.au.

There are numerous marinas throughout the region servicing fishing and other commercial vessels as well as private craft. The largest of these are at Ningi (Spinnaker Sound), Scarborough, along the Brisbane River, Manly Boat Harbour, Redland Bay and in The Broadwater.

Water taxi and/or vehicle ferry services operate from Scarborough and Pinkenba to Tangalooma on Moreton Island; Cleveland and Redland Bay to Dunwich on North Stradbroke Island; from Victoria Point to Coochiemudlo Island; from Redland Bay to Macleay, Lamb and Russell Islands; and from Runaway Bay to points on South Stradbroke Island.

- Brisbane International Airport, at the mouth of the Brisbane River, is the third busiest airport in Australia, handling 10.7 million passengers, including 2.53 million international passengers, in 1998-99. It has a 3520 m main runway oriented roughly north/south and a 1700 m secondary runway orientated north-west/south-east. Twenty international carriers operate scheduled services through Brisbane's international terminal to destinations in Asia, Europe, New Zealand and the Pacific Islands. Ten domestic carriers also operate scheduled services from Brisbane's domestic terminal to interstate and intra-state destinations. Brisbane International Airport also provides a base for the Royal Flying Doctor Service, Hawker Pacific maintenance services and several air freight operations. The airport was privatised in 1997 and is now operated by the Brisbane Airport Corporation of which Brisbane City Council and the Port of Brisbane Authority are significant stakeholders. Details can be found on their web site at http://www.bne.com.au.

  The Brisbane Air Traffic Service Centre, located on the airport, manages all en route air traffic control in the northern half of Australia and the oceans to north and east, approximately 5% of the global airspace. It is also capable of serving as an emergency backup for the Melbourne ATSC which controls traffic in the southern half of Australia and the Southern and Indian Oceans. These two centres are the key elements of The Australian Advanced Air Traffic System (TAATS). Details can be found on their web site at http://www.airservices.gov.au.

  Brisbane's original airport at Archerfield is base for the general aviation, flight training and recreational aviation sectors. It has two pairs of parallel runways, one pair with a maximum length of 1481 m and a minimum length of 1100 m are oriented more-or-less east/west, and the second pair of 1245 and 1100 m respectively are oriented north-east/south-west. At least 29 enterprises are based at Archerfield including the Royal Queensland Aero Club and the Department of Emergency Services Air Rescue Unit. Archerfield Airport Corporation operates the airfield.

Coolangatta Airport, operated by Gold Coast Airport Ltd, has a 2042 m runway capable of taking most domestic aircraft. Regular scheduled services operate directly from Sydney and Melbourne by both Ansett and Qantas, as well as regional operations by Impulse and other operators. The Coolangatta runway is actually in NSW but the terminal is in Queensland. There are plans to upgrade the airport and to operate international flights directly to it. Small landing grounds are also available at;

The RAAF Base at Amberley is the only other airfield in the study area capable of taking the larger commercial aircraft, however, it currently does not support civilian services.

There are natural-surface airfields or landing grounds at Caboolture, Redcliffe, Carrara, Upper Coomera, Coombabah and Yatala. With the exception of Caboolture, these are only used by recreational aviation, including gliding, ultra-light flying and/or sports parachuting, and have few facilities. Caboolture airfield has several maintenance facilities and an aircraft museum. The Broadwater is also a designated alighting area for float planes;

Power supply for South-East Queensland is drawn from the State grid. The base-load power stations at Swanbank (7 km south-east of Ipswich) with a total capacity of 973 megawatts (908 MW from two coal fired generators and 65 MW from two gas turbine units) are the only generation facilities located within the South-East Queensland study area. The pumped storage hydro-power station at Wivenhoe Dam (500 MW capacity), just outside the area, is also available to boost input at times of peak demand. These generating facilities do not produce sufficient output to meet the demand of the South-East Queensland region. The shortfall is drawn from the more distant power stations at Tarong (near Nanango), Callide (west of Gladstone), Gladstone and Stanwell (near Rockhampton). All of these power stations, with the exception of Gladstone, are operated by state-owned enterprises. Gladstone power station is operated by the private company, NRG. There is also reported to be a new “green” power station producing electricity from burning cane waste in the Gold Coast area. The first interconnection of the Queensland power grid to that of NSW (the so-called ‘Westlink’) became operational in early 2001.

Powerlink Queensland operates the major transmission lines of the State grid. The key facilities in this network are: Powerlink’s major 275 kilovolt (kV) substations at Brendale (supplying the northern area), Belmont and Rocklea (supplying much of the central and southern suburbs) and Mudgeeraba in the south; the 110 kV substations at Brendale, Ashgrove West, Runcorn, Richlands, Tennyson, Swanbank and Loganlea; and the 110 kV switching stations at West Darra and Blackwall. Power reticulation within the region is provided by Energex. Both Powerlink and Energex are state-owned enterprises.

Water supply for the region is drawn from a variety of sources, though the largest is that from the Brisbane River at the Mount Crosby weir and treated at three major facilities nearby (the Westbank Treatment Plant, the Eastbank Treatment Plant and the Mount Crosby Filtration Plant). These are operated by Brisbane Water, a Brisbane City Council business entity. The major storages for this supply are provided by the Wivenhoe and Somerset Dams on the upper Brisbane River. They are operated by the South-East Queensland Water Corporation, a statutory authority responsible to the Minister for Natural Resources.

Water is also drawn from Lake Samsonvale and Lake Kurwongbah in the Pine River catchment. These relatively shallow lakes can periodically become unusable because of blooms of toxic blue-green algae. Water from the Pine River sources is treated at the major treatment plant off Woonara Drive, Petrie.

Supply in the Redland area is drawn from the Tingalpa Reservoir (Leslie Harrison Dam) and the Capalaba treatment plant, whilst the Gold Coast area is served by water drawn from the Advancetown

Lake (Hinze Dam) and Little Nerang Dam. It receives its main treatment at the Mudgeeraba and Molendinar treatment plants.

Ground water is not used extensively, except on Bribie Island where a trench system at Woorim provides the supply.

Telephone links are facilitated by at least 139 telephone exchanges operated by Telstra, the most important of which is the Wooloongabba facility.

The Australian east coast remote control centre for Telstra's national *Radphone* and national VHF *Seaphone* services, the 24 hour Global Marine Distress and Safety System (GMDSS) and (under contract to the Australian Maritime Safety Authority) the safety of life at sea (SOLAS) services are located at Ningi. In the even of disruption at the Ningi site, its services can be picked up by other stations in the Telstra's national and international network.

Other telecommunications providers, such as Optus, operate discrete networks, however, details were not available.

Brisbane is a significant fuel refining and distribution centre. Its two refineries produce fuel and other petroleum products that are distributed throughout Queensland, northern New South Wales and some Pacific Island nations. These refineries and their associated fuel depots are located on either side of the mouth of the Brisbane River. The BP Refinery is on Gibson Island on the north side and the Caltex refinery is on Whyte Island on the south side.

Jurisdictions

Brisbane was incorporated as Queensland's first local government in February 1859, three months before creation of the colony. As the town grew, further local governments were incorporated, however, in 1924, seven councils were amalgamated to form the present Brisbane City. Its boundaries have remained more-or-less the same since then, though small adjustments continue, such as the addition of three suburbs (Carol Park, Karana Downs and Mount Crosby) from Ipswich City in April 2000. Given that Brisbane is also the seat of the State Government, there are significant areas in which the State Government exercises control. The relationship between the State Government and the City Council is governed by the *City of Brisbane Act 1924*, whilst all other local governments in Queensland come under the *Local Government Act*.

Caboolture became the centre for one of the first local government bodies established in Queensland outside of Brisbane. The Caboolture Divisional Board was Gazetted in November 1879. Its boundaries extended from Kedron Brook in the south to the Maroochy River in the north (taking in land that is now covered in whole or part by the councils of Brisbane City, Redcliffe City, Pine Rivers Shire, Caboolture Shire, Kilcoy Shire, Landsborough Shire (now Caloundra City) and Maroochy Shire).

The growth of the region saw the creation of new local councils from the original area administered by the Caboolture Divisional Board as follows:

Pine (Rivers) Shire	January 1888
Redcliffe City	April 1888
Maroochy Shire	July 1890
Landsborough Shire	February 1912
Kilcoy Shire	February 1912

The area now covered by Ipswich City was, until 1993, under the jurisdiction of two local authorities – Ipswich City Council and Moreton Shire Council. The 1993 boundaries remained in force until April 2000 when three suburbs (Carol Park, Karana Downs and Mount Crosby) were transferred to Brisbane City. Redland Shire was created in 1949 by the amalgamation of the former Cleveland and Tingalpa Shires. It was subsequently expanded by the addition of North Stradbroke Island and some of the other Bay Islands. The area now covered by Logan City was, until 1978, under the jurisdiction of Beaudesert Shire and the former Albert Shire. Logan Shire was proclaimed on 8 June 1978 and three years later it was dedicated as a city. Gold Coast City was incorporated in its present boundaries in 1995 after the amalgamation of the former Albert Shire and Gold Coast City Councils.

Suburb and locality boundaries throughout South-East Queensland have been formalised and boundaries gazetted. Whilst suburbs have no administrative or legal standing, they are extremely important as a community reference – they are the most broadly understood spatial reference used by everyone on a daily basis. It is important, therefore, that their boundaries are meaningful and (ideally) designed to take account of the community interest.

Conclusions

The South-East Queensland study area is the most heavily urbanised area of Queensland and is the third most populous metropolitan area in Australia. It has been forecast that the region will overtake Melbourne as the nation’s second urban centre within a few decades. Because of the level of services it can provide, the region is also seen as the main centre for neighbouring regions in northern NSW and the South-West Pacific region.

CHAPTER 3: THE ELEMENTS AT RISK AND THEIR VULNERABILITY

Ken Granger and Sarah Hall

In the first chapter we introduced the 'five esses' (shelter, sustenance, security, society and setting) into which we have organised our consideration of the elements at risk in the community and their vulnerability. The broader 'setting' elements were outlined in the previous chapter. In this chapter we describe the key aspects of the remaining four groups. At the outset, however, it is important to understand the limitations and uncertainties imposed on this study by a range of issues.

Given the broad regional nature of the South-East Queensland study, it has not been possible, with the resources and time available, to undertake the extensive and detailed field work that would provide data at a resolution similar to that compiled for earlier *Cities Project* studies (Cairns, Mackay and Gladstone). We have, therefore, been heavily reliant on data made available to us by the eight local government councils involved. This council data has been developed for a range of local government purposes such as rates administration, urban planning and assets management; it has not been developed to support community risk assessment studies. As a result, many of the descriptive attributes available, such as the classification of land use, has been far from ideal for our purposes. We have had to interpret and otherwise massage that source data, as best we could, with the use of documentary sources such as the *Yellow Pages* and the UBD Street Directory, personal knowledge of the region and limited field verification. Any error or uncertainty introduced by the land use data will be consistent across the study area so the relative levels of vulnerability reflected by the various indexes used will also be consistent across the study area.

Geocoding of property data has been based on the digital cadastral database (DCDB) maintained by the Department of Natural Resources, with the point location of properties ('buildings') established as the land parcel centroid. Whilst this may not be absolutely accurate for many of the non-residential properties, parcel centroid is felt to be quite adequate for residential properties, which make up the bulk of the developed land in the study area. Whilst this practice will undoubtedly introduce some spatial inaccuracies at the individual property level, at the broader 'neighbourhood-level' of assessment employed here, we feel that it is more than adequate, i.e. whilst the absolute accuracy may be questioned, the relative accuracy is more than adequate.

The second major source of data used to develop an understanding of the elements at risk and their vulnerability has been the statistical summaries of the results of the 1996 national census. Those data are now five years old and in areas of rapid urban growth, as found in parts of South-East Queensland, they will now be quite inaccurate. The 1996 data, however, is the most comprehensive and best available at a reasonably high level of spatial resolution. We believe that overall, the values used (mostly ratios rather than absolute values) will still be valid for the vast majority of the area.

Shelter

Buildings: The buildings that provide shelter to the community at home, at work and at play vary considerably in their vulnerability to different hazards, and hence the degree of protection they provide the community. A series of eight databases containing details of the use and other characteristics of a total of approximately 685 090 developed properties in the study area was developed. For convenience, this mass of detail has been summarised down to the local government area (LGA) level in Table 3.1.

Table 3. 1 South-East Queensland developed property use by local government area

Locality	Properties	Houses	Flats	Motels, etc	Business	Logistic	Safety	Community	Utility	Telecoms
Caboolture	37 473	34 269	1862	32	727	77	37	223	18	12
Pine Rivers	38 384	34 935	1780	12	1267	46	21	232	91	12
Redcliffe	20 013	16 935	1949	17	721	62	33	133	6	3
Brisbane	321 700	278 153	24 910	427	10 026	4745	404	1827	799	56
Ipswich	45 654	41 430	1383	47	1857	86	35	349	67	14
Redland	42 919	40 390	375	40	853	62	48	435	46	8
Logan	59 001	49 772	6148	21	2208	241	27	234	20	8
Gold Coast	119 946	86 950	25 982	672	4750	375	155	664	118	34
Region	**685 090**	**582 834**	**64 389**	**1268**	**22 409**	**5694**	**760**	**4097**	**1165**	**147**

Notes:
1. The numbers will not necessarily tally across the table because some minor usages, such as open land, have not been included.
2. Flats include all domestic multi-resident properties regardless of the number of dwelling units involved.
3. Motels etc. includes all commercial accommodation such as caravan parks, hostels, etc.
4. Businesses include all shops, offices and industries other than those which have a logistic function.
5. Logistic includes all facilities that process, wholesale or retail food and fuel as well as associated properties involved in transport and storage.
6. Safety includes all police, fire, ambulance, SES, marine rescue, life saving, hospitals and other medical facilities.
7. Community includes schools, recreational and sporting clubs, churches, theatres, libraries and properties with a government function.
8. Utility includes power and water supply and sewerage facilities.
9. Telecoms includes telephone exchanges and other telecommunications facilities such as broadcast radio and TV transmitters.

This table provides the council-by-council tally of the uses to which the developed land in the study area is put. It should be noted that the numbers relate to individual properties rather than buildings. For example, in the 1996 census there were 132 931 individual flats and units recorded in the region, compared with the 64 389 properties used for multi-occupant dwellings identified in Table 3.1. Around 94% of all developed properties in South-East Queensland, however, are residential (houses, or blocks of flats) and have a single building. We did not attempted to tally buildings in institutional properties (e.g. schools) or industrial and commercial properties that typically have more than one building.

Distribution of residential development is uneven across the study area. There are 15 neighbourhoods (i.e. CCD) in which less than 10% of all properties are used for residential purposes. These are in unpopulated areas such as Moreton Island; in the industrial and commercial precincts that follow along the Brisbane River from Carole Park to Eagle Farm and Lytton; or in the commercial hub of Surfers Paradise. The vast majority of CCD are more than 90% residential, with 458 of them (14% of the total) having a 100% residential function. This distribution is shown in Figure 3.1.

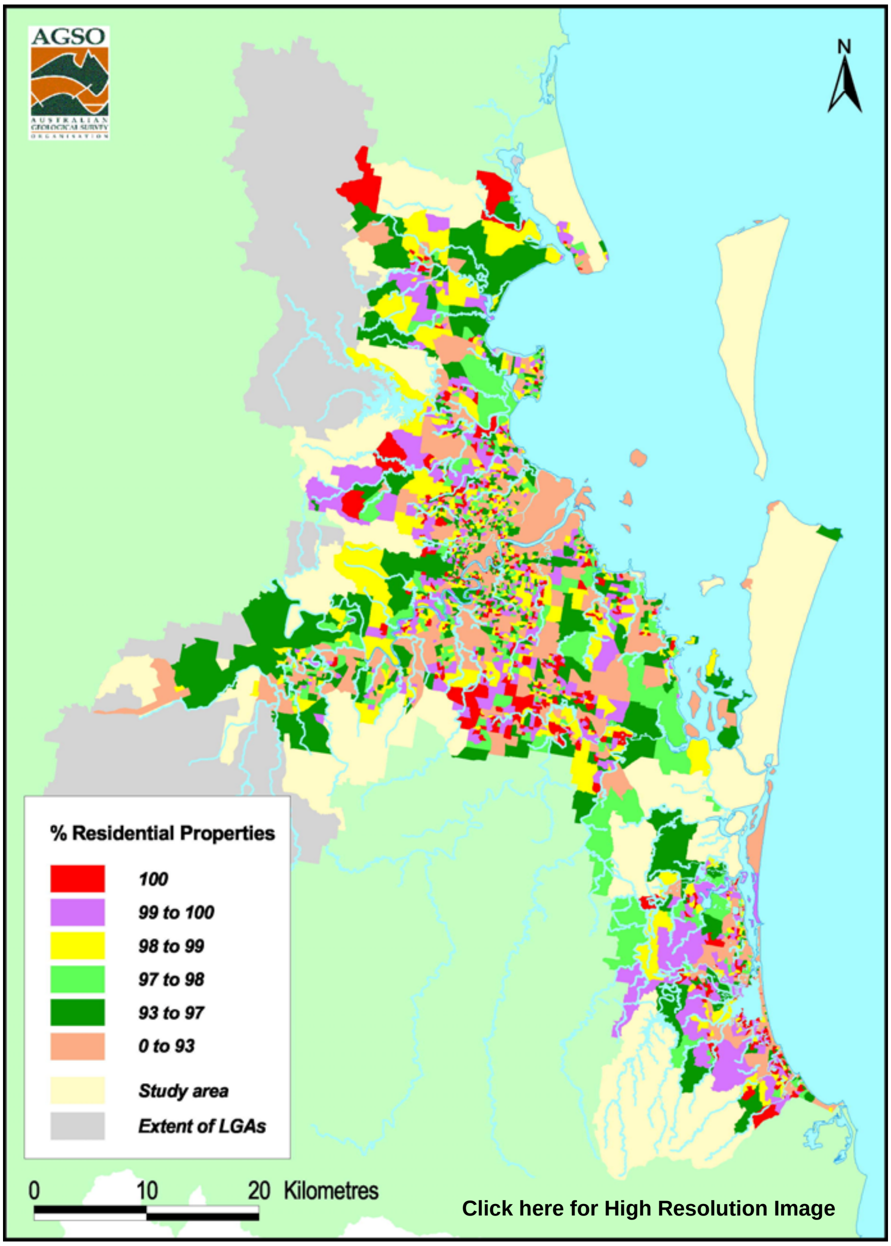


Figure 3.1 Distribution of residential property.

The period of development of each suburb is strongly reflected by the general style of housing each contains. In the older suburbs throughout the region, the most common houses are elevated on stumps and have timber or fibro-clad walls. They also (typically) have high pitched, hip ended roof shapes and small windows. In these older suburbs, however, there has been some degree of re-development with some of the original houses giving way to blocks of flats and other higher density developments.

This is in strong contrast to houses in the more recent suburbs which are almost universally built on a slab, have walls of brick, tiled roofs and large areas of glass. Roof forms are predominantly gable ended, but typically have a much lower pitch than those in the older suburbs. Brick walls are most common in suburbs that developed since the 1960's. Given their general vintage, the majority are likely to be of brick veneer construction, rather than 'solid' or cavity construction, given that brick veneer became an accepted construction method in Queensland in the late 1950s and has been the predominant 'brick' form since then.

Many of the multi-level blocks of flats, town houses and units, especially the common 'six pack' types, have a reinforced concrete frame and are brick veneer clad.

A similar age-dependency is also found with non-residential buildings. Older buildings, including schools and commercial properties are typically of solid brick, timber or fibro construction with metal roofs, whilst industrial buildings have predominantly steel frames and are metal-clad. Larger buildings constructed since the mid-1970s are typically of concrete frame construction, whilst in the period since about 1990 pre-cast tilt-up construction has become common.

The pattern of urban growth in the region over the past 40 years, can be seen in Figures 3.2 to 3.6. These maps have been compiled from a range of sources including historic aerial photography, satellite imagery and council records.

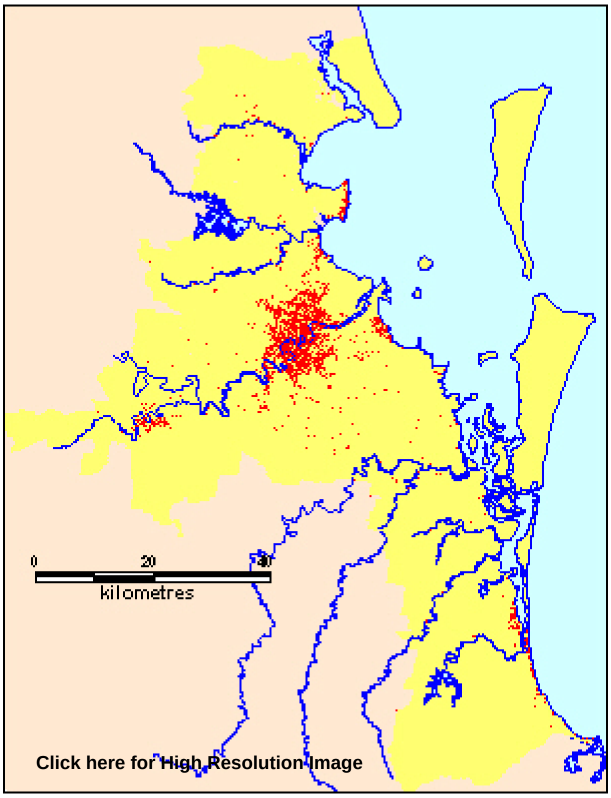


Figure 3. 2 Urban development in 1960

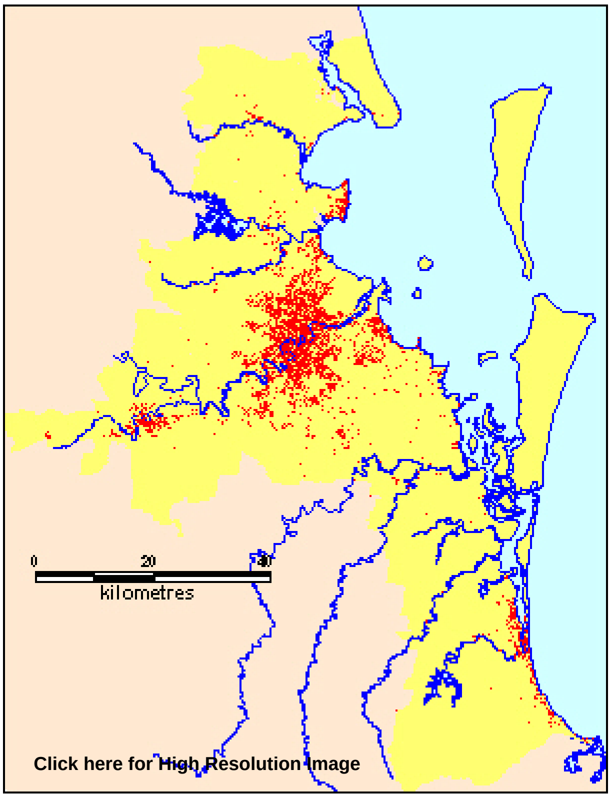


Figure 3. 3 Urban development in 1970

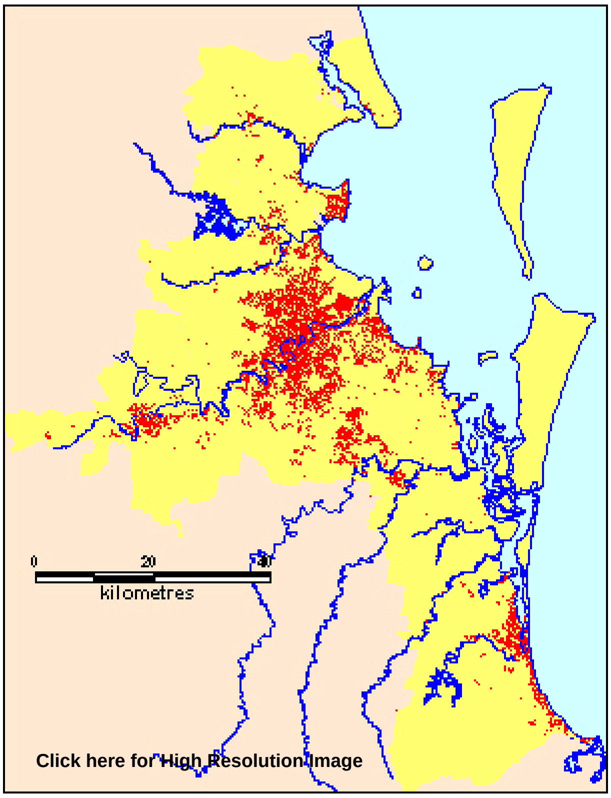


Figure 3. 4 Urban development in 1980

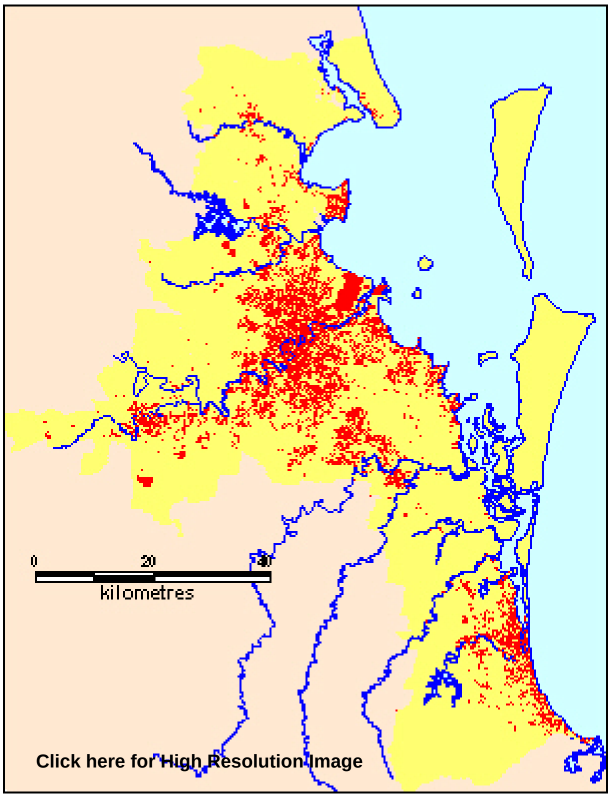


Figure 3. 5 Urban development in 1990

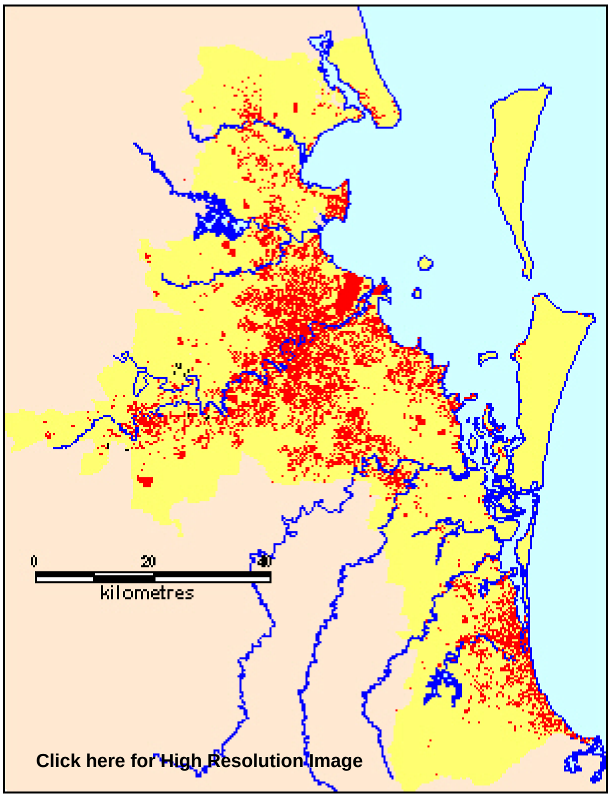


Figure 3. 6 Urban development in 2000

Engineered buildings constructed since 1975 have been subject to the Wind Loading provisions of the Australian Building Code, whilst domestic buildings have been covered since 1983. Earthquake Loading provisions were introduced in 1979 and upgraded (and extended to domestic construction) in

1993. The approximate numbers and percentages of properties in each LGA, by age class, are shown below. No allowance is made for re-development of properties – if a property had a house on it in 1960, but was subsequently redeveloped with units in 1999, it will still be shown as pre-1960.

LGA	Pre1960	1961-1970	1971-1980	1981-1990	1991-2000
Caboolture	934 (2.4%)	2410 (6.4%)	8752 (23.4%)	10 939 (29.2%)	14 438 (38.5%)
Pine Rivers	437 (1.1%)	6823 (17.8%)	11 401 (29.7%)	9695 (25.3%)	10 202 (26.6%)
Redcliffe	8271 (41.3%	4803 (24.0%)	5308 (26.5%)	904 (4.5%)	727 (3.6%)
Brisbane	162 669 (50.6%)	57 235 (17.8%)	49 803 (15.5%)	26 520 (8.2%)	25 464 (7.9%)
Ipswich	8942 (19.6%)	8861 (19.4%)	7226 (15.8%)	7410 (16.2%)	13 215 (28.9%)
Redland	1424 (3.3%)	2808 (6.5%)	12 131 (28.3%)	15 815 (36.8%)	10 720 (25.0%)
Logan	337 (0.6%)	3382 (5.7%)	30 381 (51.5%)	15 554 (26.4%)	9347 (15.8%)
Gold Coast	10 678 (8.9%)	14 704 (12.3%)	20 218 (16.7%)	47 751 (39.8%)	26 591 (22.2%)
Region	193 052 (28.2%)	101 683 (14.8%)	146 686 (21.4%)	134 588 (19.6%)	110 704 (16.2%)

Mobility: The ability of people to get to and from shelter is almost as significant as the shelter itself. The region has a well developed urban road network. The 15 400 km of roads that make up the network is almost entirely bitumen sealed and, apart from the occasional flooding of low-lying bridges and culverts, is an all-weather network. In the study area there are 629 km of freeways and highway (Beaudesert Road, Bradfield Highway, Bruce Highway, Centenary Highway, Cunningham Highway, D'Aguilar Highway, Gateway Motorway, Gold Coast Highway, Ipswich Motorway, Logan Motorway, Mount Lindsay Highway, Pacific Highway and Motorway, Southeast Freeway, Warrego Highway, Western Freeway); 1411 km of urban main roads; 964 km of suburban access roads, and 11 586 km of suburban roads. Maintenance of these roads is largely the responsibility of the individual LGA in which the are located. Only the designated highways and urban main roads are maintained by the Department of Main Roads.

Passenger transport in the region is based ver heavily on use of the family car. Mobility is, consequentially, very heavily dependant on household access to private cars, of which there are an estimated 926 200 in the region. Households without access to a car are consequently considered to be more vulnerable than those with access. Figure 3.7 shows the distribution of households with no access to a car.

The highest proportion of car-less households is 21 out of the 24 households (87.5%) in an inner Spring Hill neighbourhood, whilst thirteen other neighbourhoods have more than 50% of households without access to cars. These are either inner city neighbourhoods in suburbs such as Brisbane City, Broadbeach, Fortitude Valley, Redcliffe, South Brisbane, Surfers Paradise, or West End; Bay Island communities such as Eden Island; or areas where the inhabitants are not permitted to travel, such as the CCD containing the Wacol prisons. By contrast, there are 204 rural and rural fringe CCDs where no households are without access to a car. The mean value across the region is 12.2%.

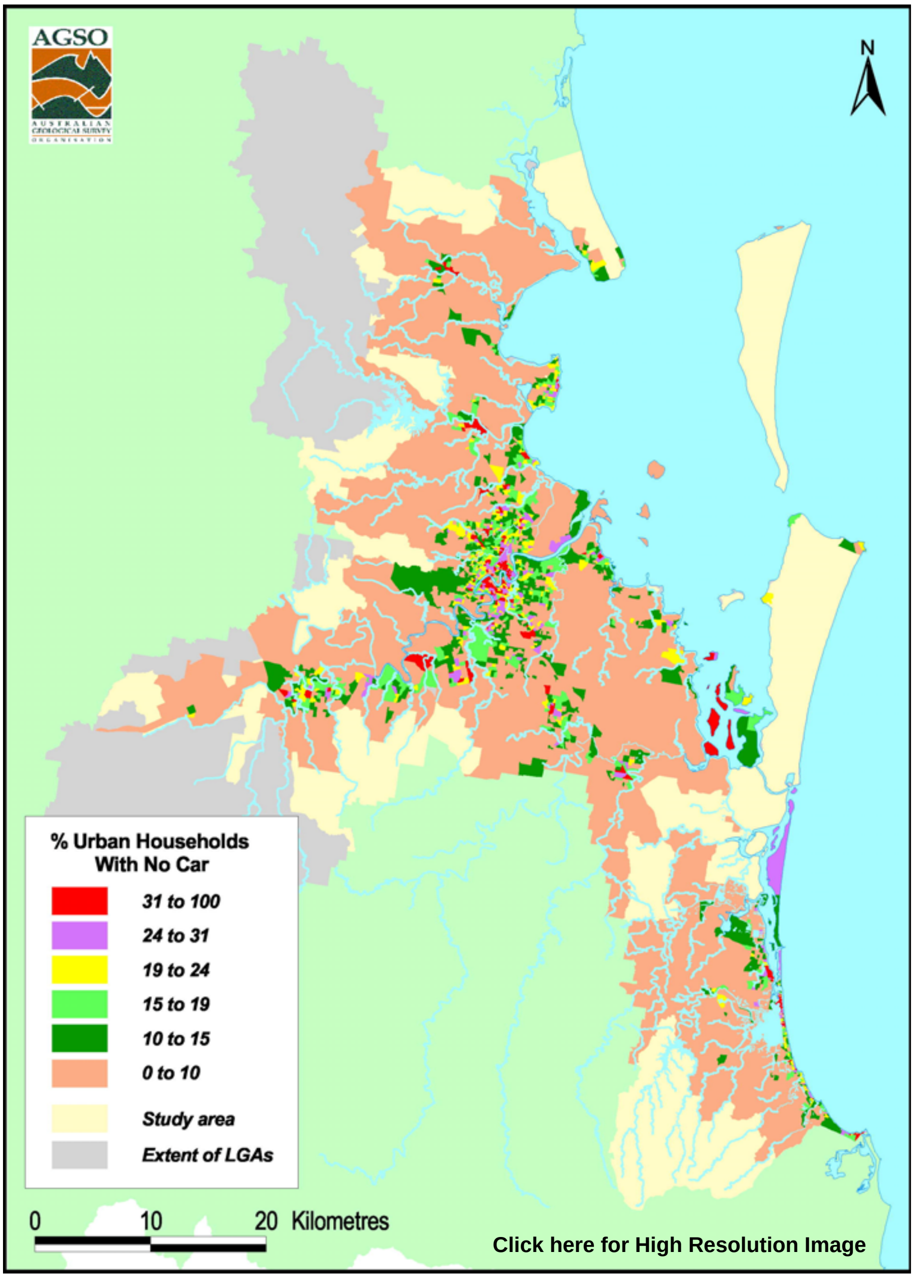


Figure 3. 7 Percentage of urban households with no car (ABS, 1998a data)

This dependence on the private car is quantified in Table 3. 2 which shows the proportions of travel mode used to get to work in South-East Queensland on the day of the 1996 census. It clearly shows the dominance of the car, especially the use of the car by a single occupant. Most of the 'multiple mode' travellers are likely to have either driven or caught a bus to the nearest railway station before completing their journey by train.

Table 3. 2 Mode of travel to work in South-East Queensland (Source: ABS, 1998a)

MODE	NUMBER	PERCENT
Train	26 657	3.5
Bus	27 701	3.6
Ferry	864	0.1
Taxi	3205	0.4

Car driver	463 005	60.7
Car passenger	57 301	7.5
Motor bike	6884	0.9
Bicycle	7660	1.0
Walk	21 157	2.8
Worked at home	34 478	4.5
Did not go to work	92 015	12.1
Multiple modes	21 858	2.8

The region has good numbers of coaches, taxis, hire cars and other passenger vehicles available, especially in Brisbane and Gold Coast Cities where the tourist industry is strongest. Brisbane City Council operates by far the largest and most comprehensive bus service throughout its area (and to some areas in neighbouring LGA). Throughout the rest of the region, bus services are operated by private providers. These include:

- in Caboolture - Caboolture Bus Line, Kangaroo Bus Lines and Bribie Island Coaches;
- in Pine Rivers - Thompsons – Strathpine and Hornibrook Bus Lines;
- in Redcliffe - Hornibrook Bus Lines;
- in Brisbane – Brisbane Bus Lines, Griffith University Shuttle, Mt Gravatt Bus Service, Rochedale Bus Service, St Andrews Hospital and Westside Bus Service;
- in Ipswich – Heritage City Sunbus;
- in Redland - National Bus Company and North Stradbroke Island Bus Service;
- in Logan - Clarks Logan City buses and Park Ridge Transit; and
- in Gold Coast - Surfside Buslines and Time Out Coaches.

The routes and schedules for all of these services are provided on the *Transinfo* web site (*www.transinfo.qld.gov.au*).

Sustenance

South-East Queensland communities are sustained by a well developed infrastructure of utility lifelines (power, water, sewerage, telecommunications, etc) and logistic resources for the supply and distribution of food, clothing, fuel and other personal requisites. Each of these is important in its own right. There is, however, a very significant degree of interdependence as illustrated in Table 3. 3. In this table, the loss of the lifeline in the left-hand column will have an impact on the lifelines across the row to a significant (**S**) or moderate (**M**) degree.

Table 3. 3 Interdependence of lifeline assets

	POWER	WATER	SEWER	COMMS	ROAD	RAIL	BRIDGE	AFLD	PORT
POWER		**S**	**S**	**S**	**M**	**S**		**S**	**S**
WATER	**M**		**S**					**M**	**M**
SEWER		**S**						**M**	**M**
COMMS	**S**	**S**	**S**		**M**	**S**		**S**	**S**
ROAD	**M**	**M**	**M**	**M**		**M**	**M**	**M**	**M**
RAIL					**M**		**M**		**M**
BRIDGE	**S**	**S**	**S**	**S**	**S**	**S**			
AFLD									
PORT									

(developed from Granger, 1997, Table 2)

It is clear from this analysis that power supply and telecommunications ('comms') are overwhelmingly the most important of all lifeline assets in terms of what is dependant on them, followed closely by bridges, roads and water supply. Their significance to community sustainability, however, may be somewhat different - e.g. people can not survive for long without a safe water supply, but they can survive (albeit with some inconvenience) without the telephone, light and even power for some time.

Power supply: As described in Chapter 2, the main source of the region's power supply is from the base-load power stations on the Queensland grid, notably Swanbank, Tarong, Callide, Stanwell and Gladstone. Transmission lines operated by Powerlink bring that supply to the Blackwall switching station (Ipswich) and the South Pine (Pine Rivers) and Belmont substations from whence it is reticulated by Energex.

Energex manages reticulation throughout the region. There are 163 high voltage sub-stations operated by Energex throughout the area. Energex also operates 638 km of 110 kV line and 1410 km of 33 kV line in the area as well as an unknown length of 240 V reticulation. Whilst some high voltage mains have recently been established underground and the reticulation in newer residential subdivisions is now largely established underground, observation indicates that this infrastructure is overwhelmingly above ground. This makes it particularly susceptible to damage by tree fall or airborne debris carried by the high winds associated with severe thunder storms or cyclones.

Water supply and sewer: The major water supply infrastructure for the region was described in Chapter 2. The entire developed urban area of South-East Queensland and some rural residential areas have access to a reticulated and treated water supply. This is achieved through an extensive network of reservoirs, pumping stations, supply mains and smaller distribution pipelines. Throughout much of the older parts of the area the pipe network consists of quite brittle material such as asbestos cement (AC) and cast iron. These pipes are quite susceptible to failure under pressure surges, soil subsidence or the ground shaking experienced in earthquakes. Most newer urban areas, however, are serviced by more resilient pipelines of PVC or concrete-lined steel.

There is some degree of interconnection between the supply system operated by Brisbane Water and those operated by the other LGA so that failure of supply from storages in areas such as Caboolture, Pine Rivers, Redland and Gold Coast Rural can in part be supplemented from Brisbane. A major failure in the Brisbane Water system, however, could not be made up from external supply.

Rural properties depend on roof catchment and tank storage. Some LGA, such as Caboolture Shire, are also encouraging urban dwellers to install roof catchment tanks to supplement the mains supply. Other councils, including Brisbane City, prohibit domestic roof catchment and storage.

Most of the residential parts of the region are connected to a reticulated sewerage network. Like the water reticulation network, the much of the sewer network consists largely of jointed and brittle pipes using material such as earthenware and concrete. Each LGA operates its own network and treatment systems and all depend on numerous electric pumps to keep things moving.

There are at least 28 sewerage treatment plants in the region operated by the respective LGA. These range from small-scale secondary treatment plants which discharge effluent directly back into the drainage system, to modern tertiary treatment plants. Amongst the more significant are the Luggage Point plant at the mouth of the Brisbane River and the Elanora Water Quality Control Centre on the Gold Coast.

In the rural or rural residential areas not serviced by reticulated sewer systems, sewage treatment is by on-site septic or domestic treatment plants.

Telecommunications: Much of the telecommunications network infrastructure operated by Telstra in the study area (both copper wire and optical fibre) is underground, though network details were not available for this study. The key to telecommunications - regardless of whether it is by conventional telephone, mobile phone, fax or Internet - and regardless of the service provider - is the network of telephone exchanges. There are approximately 140 telephone exchanges throughout the region which service both urban and rural communities. These range from simple metal cabins, such as the Highvale exchange near Samford to the major South-East Queensland zone exchange at Woolloongabba.

Details of the infrastructure operated by Optus and other providers were unavailable.

Both ABC and commercial broadcast radio and TV services covering the region area are broadcast from transmitters within the study area, the main concentration being on Mount Coot-tha. There are also local studios for the ABC, Channel Nine, Channel Ten as well as Prime (Channel 7) bureau, on the Gold Coast. The ABC radio studios are located in Toowong, whilst the transmitters are at Bald Hills. Several commercial radio stations also cover the region, ranging from nationally syndicated stations to local community stations. All of these broadcast facilities have a role to play in keeping the community aware of any impending threat from hazards such as severe storms, floods or cyclones.

Dedicated telecommunications networks serving both public (e.g. police, emergency services, councils, etc) and private users (e.g. taxis, couriers, fishing fleet, etc) also cover the study area. Details of their transmitter locations were not available to this study.

Logistic support: The supply and distribution of goods such as fuel, food, and clothing are essential to the sustenance of the community. Of particular significance are those facilities that provide bulk or large scale storage and distribution services.

Fuel supply: The fuel distribution regime in South-East Queensland is characterised by the concentration of physical infrastructure within a 7 km-wide area at the mouth of the Brisbane River, and the high degree of integration of the operations of the individual fuel companies. The risks posed by the spatial and economic centralisation of this critical logistic industry have local, regional, national and international significance.

There are four major international conglomerates – Mobil, Shell, Caltex and British Petroleum (BP) and two 'independent' suppliers, Fletcher Challenge and South-East Queensland Fuels. All six of these companies operate in an environment of limited, if not restricted, competition as a result of fuel pricing policies, government excises and economies of scale, especially in terms of production. On a national level it is not economical for each of the major companies to refine their own product at each major urban location. In most cases, fuel is exchanged, on shared infrastructure, rather than being sold between companies. The fuel exchanged between companies in Perth for instance is balanced somewhere else in the country. This system determines the product levels to be exchanged in Brisbane. This leads to a very dynamic situation which makes it difficult to be definitive about the is amount of fuel traded, or available, at any one time.

At the very centre of the distribution network is the BP refinery on Bulwer Island, Pinkenba, on the north side of the river, and the Caltex refinery on Whyte Island, Lytton, on the south side of the river. They are connected by an underwater pipe and a shared 'network' pipe that runs both over and underground to the major terminals where product is stored and distributed. There are four major product terminals, three (Shell, Fletcher Challenge and the jointly operated BP-Mobil site) are in the Whinstanes area of Eagle Farm and one (Caltex) in Lytton. Mobil also operates a smaller lubricants terminal in Morningside. These terminals receive stocks from:

- either or both of the local refineries, and/or
- by sea or road from other Australian refineries, and/or
- by sea directly from overseas (notably Asian) refineries.

These terminals typically hold between 5 and 10 days of supply.

Apart from the supply of aviation fuels to the Brisbane International Airport, which is by underground pipelines, distribution of products to down-stream suppliers and users within South-East Queensland from these bulk terminals is exclusively by road tanker. Distribution to more distant consumers to the west (say beyond Miles) is by rail, and to northern ports is by sea. The major companies no longer operate their own dedicated ‘company’ trucks; distribution is contracted out to transport companies such as Lynfox and Finemores. This is effectively a round-the-clock operation, given that most service stations and other retail outlets rarely carry more than two or three days of stock, with some smaller outlets even requiring daily resupply because of limited on-site storage.

Disruption of fuel supplies for more that a few days would have a profound impact on the South-East Queensland community, given their heavy dependence on road transport. Such disruption could be caused by any one or more of:

- the isolation of these major facilities due to flood or storm damage to the access routes;
- production problems brought about by plant failures or industrial action (as witnessed by the Longford gas plant accident in Victoria in 1999);
- excessive demand situations (such as those caused by a major military exercise held in Queensland in mid-2001);
- product contamination (such as that experienced in 2000 with some Mobil avgas supplies); or
- disruption to shipping services bringing both crude and refined product to Brisbane.

The general spatial layout of the key fuel facilities is shown in Figure 3.8. The locations of the pipelines are only indicative.

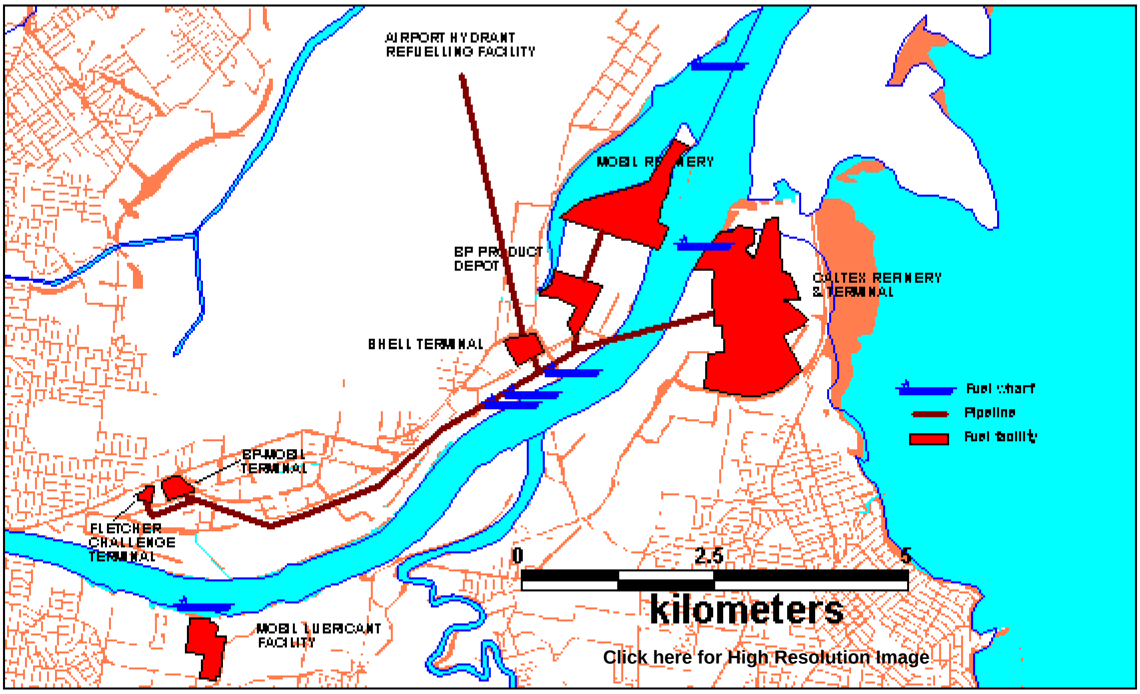


Figure 3. 8 Queensland’s major fuel supply infrastructure

Food supplies: Brisbane is the centre for the distribution of most foods throughout the South-East Queensland region and beyond. As with fuel supply and distribution, there are very few truly independent distributors. Many of the supposedly 'independent' retailers are, in fact, either subsidiaries of the larger players, such as Woolworths, or are supplied by them. Economies of scale dictate that large holdings of supplies are stored in one location and that there is a significant degree of integration of the supply infrastructure. The food distribution system, however, is significantly more widely disbursed spatially, though most of the major facilities are located within the Brisbane City suburbs of Acacia Ridge, Archerfield and Rocklea.

Food supplies seem to come from two sources. Dry goods are trucked in from the major depots in Sydney and Melbourne to the State distribution centres in the Rocklea/Archerfield area. Fresh fruit and vegetables are distributed from a centre close by in Richlands. Woolworth's Richlands centre itself is supplied by local growers, either through the Lockyer Valley and Toowoomba, or further north for trans-seasonal produce. The Brisbane Markets at Rocklea are not so much a distribution point for growers but a market distribution point for known customers. Coles-Myer, for example, operate from Rocklea, as well as distributing produce from their own farms. Franklins, by contrast, buy from the Rocklea markets and operate a warehouse for distribution at that locality.

South-East Queensland has a reliable and varied supply of fresh meat. The government Q Meat abattoirs in Townsville, Bundaberg, Ipswich and Brisbane ensure that the sources of supply are widely dispersed. Australian Country Choice, which operates in partnership with Q Meats at the Cannon Hill abattoirs, supplies boneless product and carcasses to both Coles and Woolworths. Most of the supply for Cannon Hill is trucked in from feedlots in the west or north. Seasonal interstate supply is common, for instance, chilled lamb carcass is trucked in directly from Victoria in one day. Local butchers predominantly buy cartons of processed (i.e. boneless) meats. It is unlikely that there would be a shortage of supply of fresh meat. According to industry sources, in the event of no refrigeration due to power cuts, sufficient supply could be maintained as long as the roads were open for chiller trucks.

Dairy produce is increasingly being trucked in as processed milk product from interstate. National Foods Ltd, (Pura-brand milk products) for instance, operates chiller trucks directly from factories at Morwell in Victoria to the shelves of the major retailers such as Woolworths and Coles. Milk is tankered in to the Pauls facility at Crestmead for processing before distribution. Dairy Farmers process and package the bulk of their milk at their factory at Booval. Their factories in Caboolture and Toowoomba now serve mainly as points of accumulation for producers in the Caboolture-Sunshine Coast and Darling Downs areas respectively.

Bread supply throughout South-East Queensland is dominated by two major players, Goodman Fielder (Buttercup breads, Allied Flour and Alliance Flour) and George Weston Foods (Tip Top breads). Buttercup have three bakeries within the South-East Queensland study area - at Carina, Darra and Andrews. There are two Tip Top two bakeries – at Nundah and Slacks Creek. These major bakeries truck directly to the larger distributors such as Woolworths, Franklins and Coles. Flour and pre-mix baking products are produced by both Allied and Alliance mills. The Allied mill is in Tennyson, whilst Alliance operates mills at Archerfield and Albion. Apart from these major bakeries there is a growing range of small-scale franchised suburban bakeries such as Bakers Delight and Brumby's. These bakers utilise pre-prepared bread mixes to bake a range of 'specialty' breads on-site.

Brisbane is also home to several national food manufacturing or processing facilities. Most notable of these are the Arnott's Biscuit factory at Virginia; the Golden Circle cannery at Northgate and the Sanitarium Health Foods factory at Moorooka.

The centralized nature of the food supply and distribution process can best be illustrated by looking at the Woolworths (the largest retailer in the region) distribution arrangements.

> Woolworths receives most of their dry goods by rail and road from Sydney and Melbourne, however, transport is the responsibility of the suppliers and details of routes and volumes were unavailable. Woolworths maintain three distribution locations, which are, in the order of importance:
>
> - their Acacia Ridge depot holds dry goods and groceries and supplies approximately 90% to Woolworths stores throughout Queensland and Northern NSW as far south as Grafton. On average, stocks held at this location should last around 2.5 weeks of normal consumption. This centre is supplemented by the smaller grocery distribution centre at Oxley. Supplies are delivered 6 days per week.
> - their Eagle Farm cold store holds chilled and frozen goods and has the same distribution area as that of the Acacia Ridge depot. Supplies are brought in each day apart from Sunday.
> - their Richlands fresh fruit and vegetable facility holds, on average, 1 to 2 days of stock at normal levels of consumption.
>
> Woolworths retail stores not only receive goods from these depots but also from the suppliers directly. Dairy product, usually from southern states, comes in by truck to the individual stores. Meat is delivered from the Brismeat processing factory at Churchill and Woolmeat, at Underwood. Their smallgoods processing centre (Chisholm Manufacturing) at Wacol produces predominantly pork smallgoods.
>
> There are 41 Woolworths stores throughout South-East Queensland providing dry, dairy and fresh foods. These stores tend to hold the same level of stocks as the distribution centres, however, fast moving stocks would run out at 1-2 days, without resupply, at the store level.

The other major distributors, including Coles, Bi-Lo (a Coles subsidiary), Australian Independent Wholesalers, Davids and Franklins each operate comparable, if smaller, networks of supply and distribution, mainly from facilities in Acacia Ridge, Loganlea, Morningside, Richlands and Rocklea. Their sources of supply and the levels of stock held are also similar to that described for Woolworths.

Perhaps the most notable feature about the food distribution system in South-East Queensland is the very heavy reliance on frequent and regular re-supply by road and rail from distant suppliers. It is evident that all distributors, both large and small, carry the minimum amount of stock on hand to satisfy normal levels of consumption because of the economies involved and the efficiency of the system under normal conditions. This economic regime is also evident in the vast majority of households where only basic stocks of food are typically held. This is quite reasonable under normal conditions, however, it would represent a significant contribution to vulnerability when disaster strikes. What could be termed ‘convenience store complacency’ represents a significant, if hidden threat.

The region is serviced by a very large number of outlets for key commodities such as food, clothing and other personal requisites. The largest complexes include:

- in Caboolture – Morayfield Plaza, the Caboolture Park Shopping Centre, Bribie Shopping Village (Bongaree), Burpengary Plaza and Deception Bay Plaza;
- in Pine Rivers – Westfield Plaza at Strathpine, however, smaller suburban centres are established in Arana Hills, Everton Hills, Kallangur, Lawnton, Petrie and Samford Village;
- in Redcliffe – Peninsula Fair (Kippa-Ring) and the Margate Shopping Centre

- in Brisbane - Carindale Shopping Centre, Garden City (Upper Mount Gravatt), Pick N Pay Hypermarket (Carseldine), the Queen Street Mall precinct (Brisbane City), Sunnybank Hills Shoppingtown, Toowong Village and the Westfield Shoppingtowns at Chermside, Indooroopilly and Toombul
- in Ipswich – Booval Fair, Brassall Shopping Village, Centrepoint Boulevard (Ipswich), Ipswich City Heart, St Ives Shopping Centre and Redbank Plaza;
- in Redland – Capalaba Central, Cleveland Town Centre, Capalaba Park, Koala Park (Victoria Point) and Birkdale;
- in Logan - Logan Hyperdome (Shailer Park), Marsden Park, Springwood Mall, Waterford Plaza, Woodridge Park and Woodridge Plaza;
- in Gold Coast - Eagleby Shopping Plaza, Harbourtown Shopping Centre (Biggera Waters), Helensvale Plaza, Runaway Bay Shopping Village, Australia Fair (Southport), Southport Park, Nerang River Plaza, Robina Town Centre, Pacific Fair (Broadbeach Waters), Burleigh Shopping Town (Burleigh Heads), The Pines Shopping Centre (Elanora) and Showcase on the Beach (Coolangatta).

A hierarchy of stores, ranging from extremely large regional complexes down to the traditional ‘corner store’ is evident. Virtually every suburb has its own retail outlets, be they in smaller integrated drive-in complexes, in strip developments, or as free standing establishments.

Security

In the context of our risk assessment methodology, ‘security’ relates to aspects of community health, wealth and the services and structures that provide for public safety. In addition to identifying the physical elements at risk that relate to these aspects, we have identified a range of factors (health, wealth, socio-economic disadvantage and protection) that will provide relative measures of community vulnerability and their distribution across Brisbane.

Health: South-East Queensland is very well served by its hospitals and other medical services. There are 14 major public hospitals in the region, four of which have multiple facilities. They are, from north to south:

- Caboolture Hospital
- Redcliffe Hospital
- The Prince Charles (Prince Charles and Bald Hills Acute) Hospital (Chermside)
- Royal Brisbane (Keperra, Queensland Radium Institute and Royal Brisbane) Hospital (Herston)
- Royal Children’s (Royal Children’s and Riverton Centre) Hospital (Herston)
- Royal Women’s Hospital (Herston)
- Mater Misericordiae (Adult Public, Children’s Public and Mother’s Public) Hospital (South Brisbane)
- Princess Alexandra (Woolloongabba)
- The QE II Jubilee Hospital (Coopers Plains)
- Ipswich Hospital
- Redland Hospital (Cleveland)
- Logan Hospital (Meadowbrook)
- Gold Coast Hospital (Southport)
- St Vincents Hospital (Robina)

In addition to these public hospital facilities, there are 19 major licensed private hospitals. They are:

- Caboolture Private Hospital
- Riverview Private Hospital (Strathpine)
- Peninsula Private Hospital (Redcliffe)
- North West Private Hospital (Everton Park)
- Holy Spirit Hospital (Brisbane)
- St Andrew's War Memorial Hospital (Brisbane)
- Mater Misericordiae Children's Private Hospital (South Brisbane)
- Mater Misericordiae Mother's Private Hospital (South Brisbane)
- Mater Misericordiae Private Hospital (South Brisbane)
- Greenslopes Private Hospital (Greenslopes)
- The Sunnybank Private Hospital (Sunnybank)
- The Wesley Turrawan Hospital (Clayfield)
- The Wesley Hospital (Auchenflower)
- Saint Andrews Private Hospital (Ipswich)
- Mater Private Hospital (Cleveland)
- Logan Private Hospital (Meadowbrook)
- Allamanda Private Hospital (Southport)
- John Flynn Hospital (Tugun)
- Pindara Private (Benowa)

There is also a military hospital located within the Gallipoli Barracks at Enoggera. The distribution of hospitals across the region is shown in Figure 3.9.

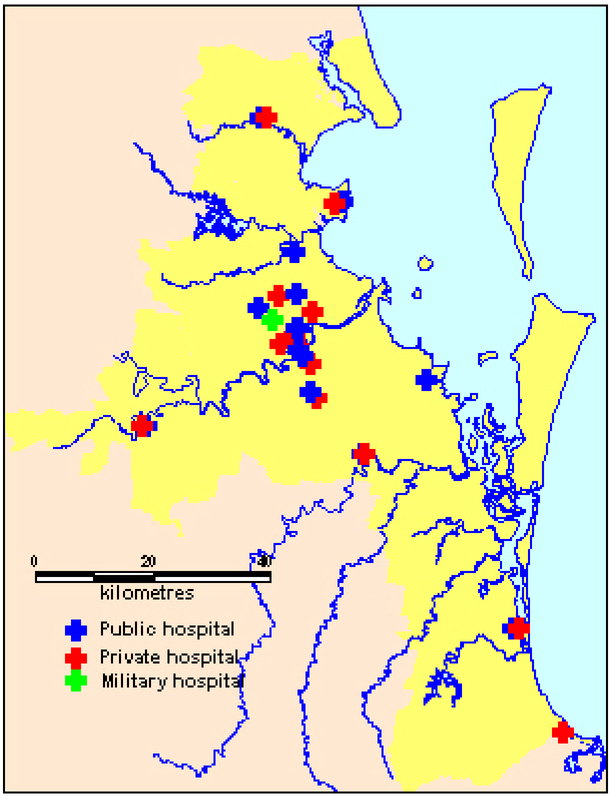


Figure 3.9 South-East Queensland hospitals

There are several hundred smaller private hospitals, day surgeries, medical centres, clinics, aged care hostels, nursing homes and hospices are established throughout region. In addition, there is a comprehensive range of specialist medical services, such as medical imaging and pathology, as well as physiotherapy, dental, podiatry, chiropractic, optometry and pharmacist services available. Many of these specialist services are concentrated at or close to the major hospitals, or in enclaves such as Wickham Terrace in Brisbane. A wide range of community health or support services, such as Blue Nurses and Meals on Wheels, are also available in most areas.

The age make-up of the population is a reasonable indicator of the health vulnerability of the community, with the very young (under 5 years) and the elderly (over 65) considered to be the most vulnerable groups. The relative distribution of these age groups is shown in Figure 3.10 and Figure 3.11 respectively.

The average percentage of the population per CCD that is under 5 years across the region is 6.4%. The highest percentages are in neighbourhoods of Oppossum Creek (50.0%), Banyo (23.1%) and Lytton (22.0%) each of which have populations of less than 50, so their under 5 years statistics are somewhat exaggerated. The higher values for 'normal' sized neighbourhoods (more than 15% of the total population under 5 years) are located in the outer suburbs – the so-called 'nappy valleys', especially in Logan City, Caboolture Shire, Pine Rivers Shire and Ipswich City.

The average percentage of people per CCD who are over 65 across the region is 13.0%. The spatial distribution is like a mirror image of the under 5 years distribution, i.e. 'God's waiting rooms' rather than 'nappy valleys'. The highest values coincide with CCD that contain the larger retirement villages and aged care institutions such as nursing homes. There are 20 CCDs in which more than 50% of the population is over 65, with the greatest percentage being 93.8% in an Ashmore neighbourhood. They are very much concentrated in Gold Coast (9 of the 20), Brisbane (8/20) and Caboolture (2/20).

We have no specific information on the numbers or distribution of the particularly vulnerable segments of the population with specific physical or mental disabilities, or of their carers.

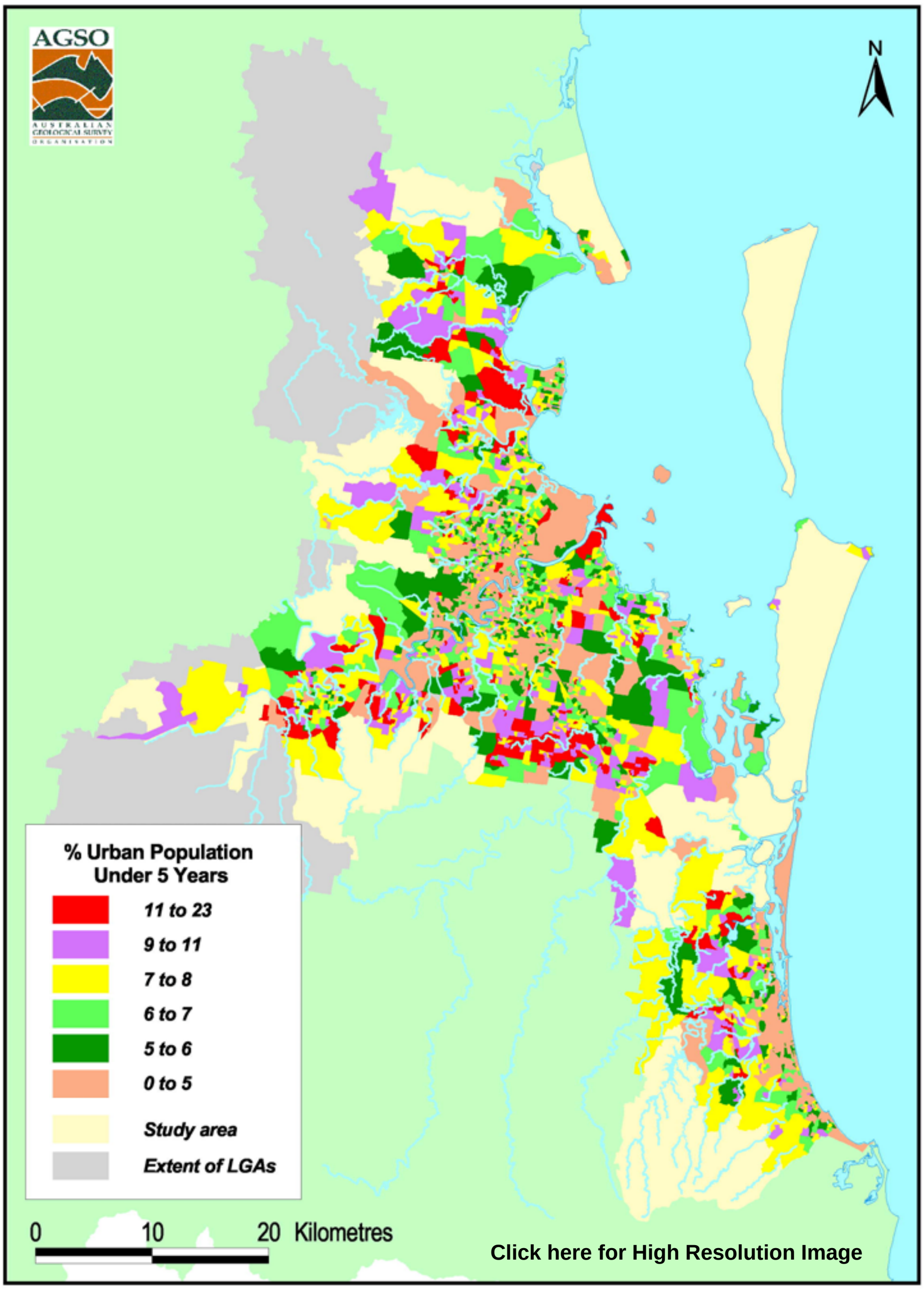


Figure 3. 10 South-East Queensland urban population under 5 years of age (ABS, 1998a data)

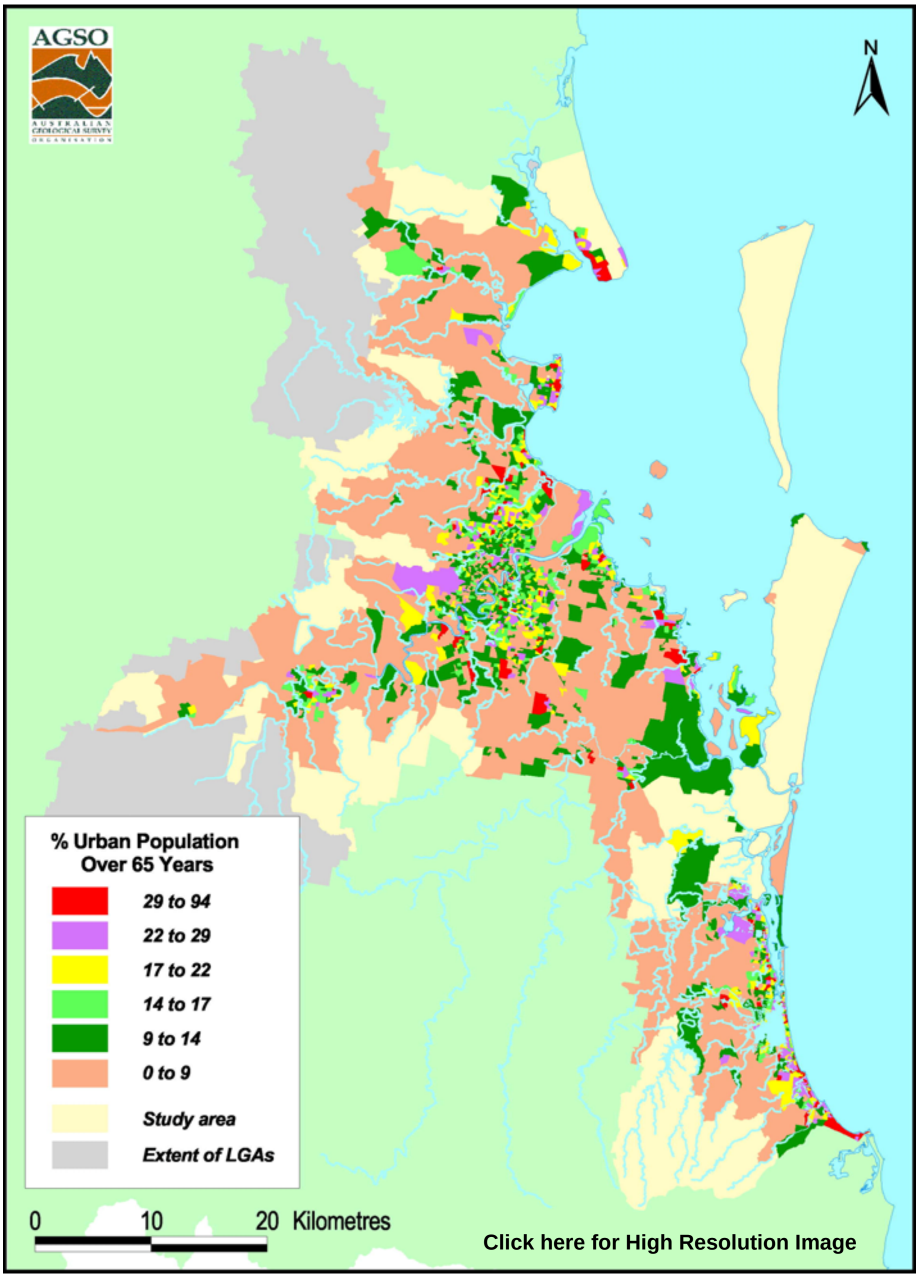


Figure 3. 11 South-East Queensland urban population over 65 years of age (ABS, 1998a data)

Wealth: The economy of South-East Queensland is extremely diverse, with strong input from retail, industry, services, manufacturing, property and the public sectors. The 1996 makeup for the study area are provided in Table 3.4.

Table 3. 4 South-East Queensland employment by industry (Source: ABS, 1998a)

INDUSTRY GROUP	PERSONS EMPLOYED	INDUSTRY PERCENT
Agriculture, forestry and fishing	7445	0.9
Mining	3418	0.4
Manufacturing	90 477	11.5
Electricity, gas and water supply	4212	0.5
Construction	56 096	7.1

INDUSTRY GROUP	PERSONS EMPLOYED	INDUSTRY PERCENT
Wholesale trade	49 203	6.3
Retail trade	113 836	14.4
Accommodation, cafes and restaurants	40 081	5.1
Transport and storage	37 622	4.8
Communication services	15 780	2.0
Finance and insurance	29 338	3.7
Property and business services	89 904	11.4
Government administration and defence	38 559	4.9
Education	56 246	7.2
Health and community services	76 810	9.8
Cultural and recreational services	21 608	2.7
Personal and other services	31 049	3.9
Non-classifiable economic units	11 361	1.4
Not stated	13 417	1.7
Total persons employed	786 462	

The distribution of the commercial activity in South-East Queensland is concentrated strongly in a band that more-or-less straddles the Brisbane River, and in the commercial/industrial enclaves of Caboolture, Brendale, Surfers Paradise, Broadbeach, Andrews and Coolangatta. There are 24 CCD across the region in which all of the properties have a commercial purpose, all of them in the Surfers Paradise-Broadbeach area. The distribution is shown in Figure 3.12.

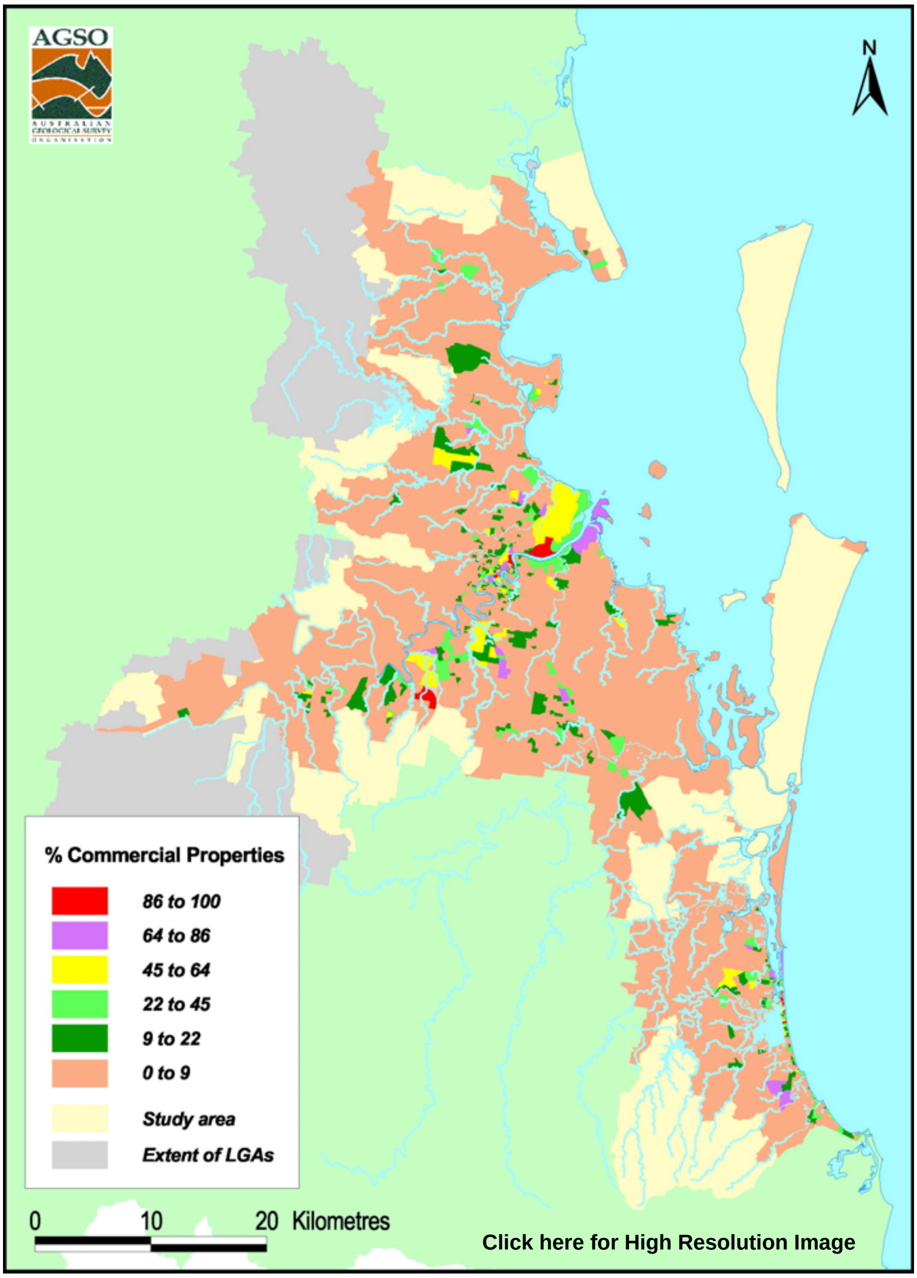


Figure 3. 12 South-East Queensland commercial and industrial facility concentrations

The Brisbane CBD is a particularly significant commercial enclave given that it has a substantial concentration of key commercial operations including the Brisbane Stock Exchange, the headquarters of the major insurance companies and banks and the registered offices of many thousands of companies (with the accounting firms that inhabit the many high rise towers in the city). It also houses major administrative functions including the State Parliament, the headquarters of many State Government departments and agencies and the regional offices of several Commonwealth Government departments. These enterprises exercise a level of control that extends well beyond the boundaries of Brisbane City.

The spatial distribution of 'wealth' within the region can also be gauged from indicators such as unemployment and rental accommodation. Such indicators are relevant to risk calculations because the less wealthy will have greater difficulty recovering from a disaster impact and are more likely to have no, or inadequate, insurance protection, thus exacerbating their losses.

At the 1996 census the unemployment rate across the study area averaged 10.14%, however, there are some 16 CCD in which the 1996 unemployment levels was in excess of 33%. The highest levels of unemployment in 1996 were in South Brisbane, Leichhardt and Goodna where the rates were over 40%. By contrast, the areas generally north of the Brisbane River and the rural areas to the west, had relatively low levels of unemployment. There were 24 CCD in which there was zero unemployment. Amongst the more significant of these were the Gallipoli Barracks at Enoggera and the Amberley RAAF Base, though neighbourhoods in inner Brisbane suburbs such as Fortitude Valley also feature. The distribution is shown in Figure 3.13.

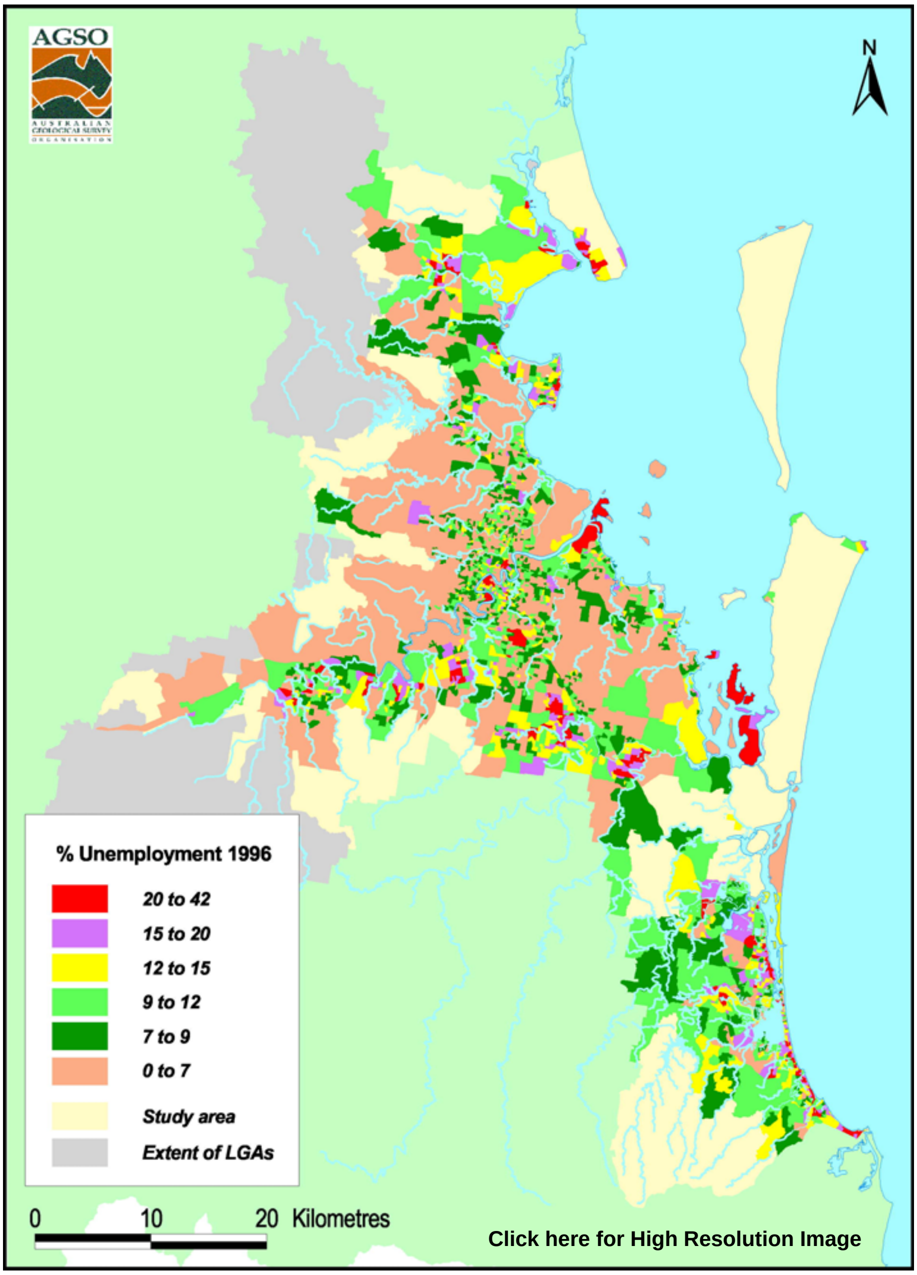


Figure 3. 13 South-East Queensland 1996 urban unemployment rate (ABS, 1998a data)

Across the region, the spatial distribution of the unemployment rate only correlates closely with the proportion of households that are in rented accommodation in the east-west Ipswich-Brisbane-Logan corridor. In other areas, most notably in the Toorbul-Donnybrook-Bribie Island area flanking Pumicestone Passage, where low-cost accommodation such as long-stay caravan parks are available, and on the Bay Islands such as Russell Island, the correlation is somewhat negative. There are 24 neighbourhoods where more than 70% of households are in rental accommodation, three of which register a 100% figure. These tend to be dominated by institutions such as Enoggera Barracks, the Villa Maria Nursing Home neighbourhood in Fortitude Valley, the Banyo seminary and the Amberley RAAF base. By contrast there are 22 neighbourhoods in which there were no households in rental accommodation. Most of these were in the Eagle Farm-Brisbane City corridor, around Surfers Paradise and the Wacol prisons. The mean ratio across all CCDs in the region is 28.5% and the spatial distribution is shown in Figure 3.14.

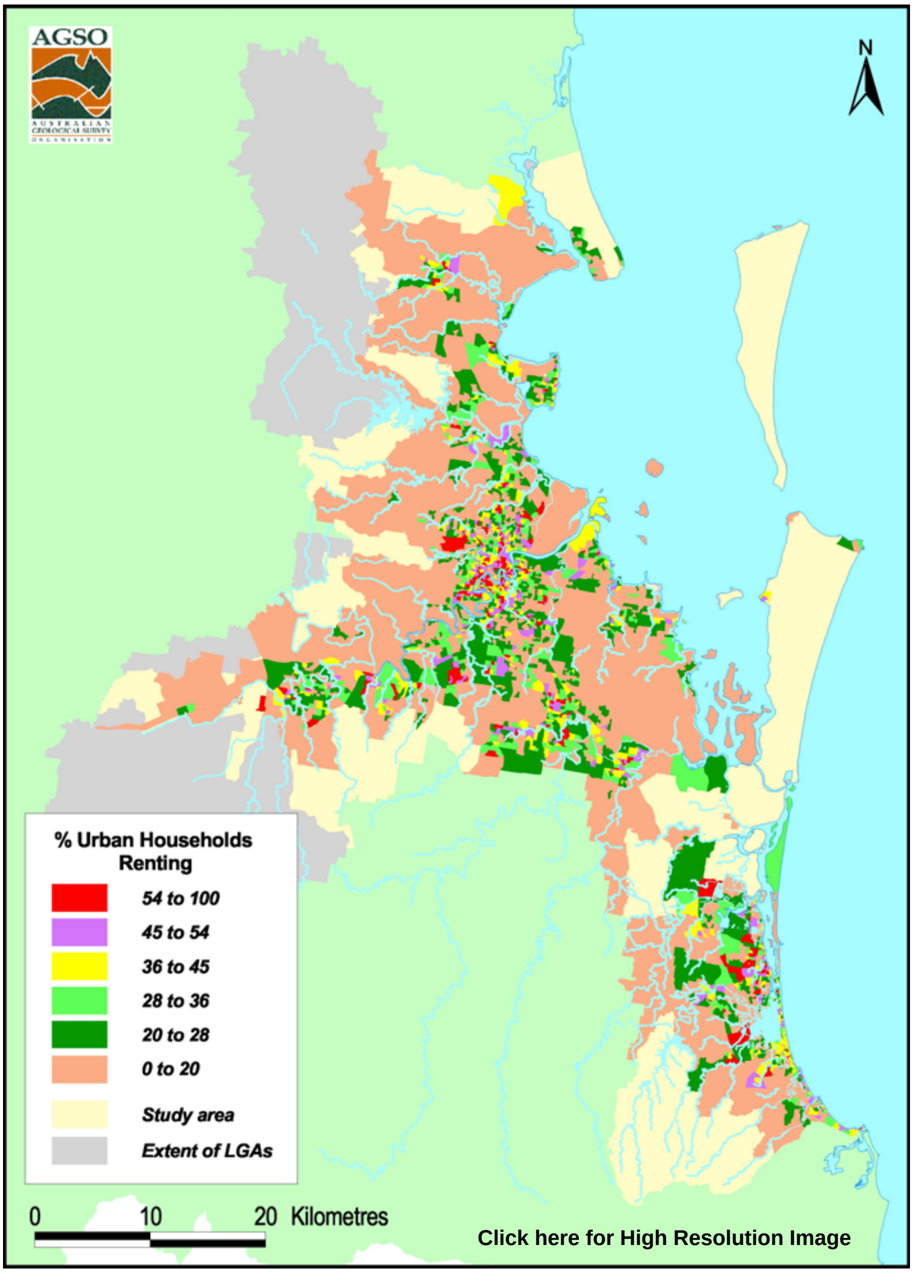


Figure 3. 14 South-East Queensland percentage of urban households in rental accommodation (ABS, 1998a data)

An *Index of Socio-Economic Disadvantage* has been compiled by the ABS by undertaking a principal components analysis on 20 weighted variables from the 1996 census. The attributes, such as low income, low educational attainment, high unemployment and jobs in relatively unskilled occupations, were selected to highlight disadvantage (see Table B1 in Appendix B for a list of variables used). The resulting index has been standardised to have a mean of 1000 and a standard deviation of 100 across all CCD in Australia (ABS, 1998b). The mean index value for the South-East Queensland study areas is 1001.0, essentially the same as the national mean. There were two CCD with index values under 600 (i.e. more than four standard deviations below the national mean). These were neighbourhoods in Inala and Leichhardt. At the other end of the scale, three CCD had indexes of 1200 or more (two standard deviations above the national mean). These were in Stephens, Chapel Hill and Spring Hill. The spatial distribution is shown in Figure 3.15.

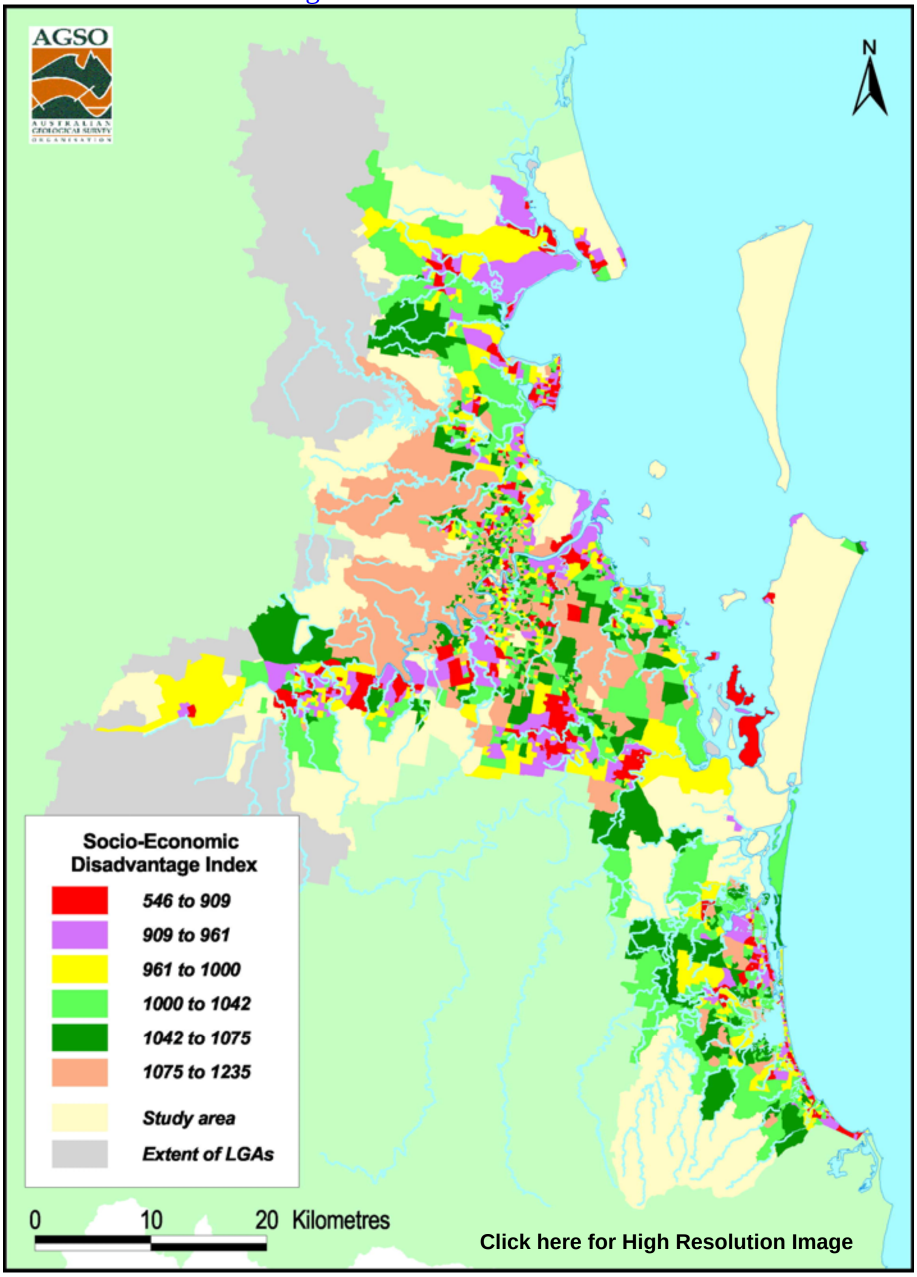


Figure 3. 15 South-East Queensland Index of Socio-Economic Disadvantage (based on data from ABS, 1998b)

A similar *Index of Economic Resources* is also available. This index is based on a profile of the economic resources of families. It is compiled from 22 weighted variables that reflect the income and expenditure of families, including measures of income, rent and home ownership (see Table B2 for a list of variables used). This index is also standardised with a national mean of 1000 and a standard deviation of 100. The region's mean index value is 1007.9, again very close to the national mean. The lowest index value is 696.6 (more than 3 standard deviations below the national mean) in an Inala CCD, whilst the highest value of 1325.22 is in Southbank (three standard deviations above the national mean). The spatial distribution is shown in Figure 3.16.

Protection: The full range of public safety services is provided in the region. Police services come under the Queensland Police Service (QPS). There are some 80 QPS establishments distributed across South-East Queensland. These range from the State Headquarters in Brisbane, the Police College at Oxley, to a number of specialist units such as the Dog Squad, Mounted Police and Water Police, to shop-front 'Police Beats' located in some of the larger shopping malls. For administrative purposes the area is divided between four Regions: North Coast Region which includes Redcliffe and Caboolture, headquartered at Maroochydore; Metropolitan North Region, headquartered in Brisbane Metropolitan South Region, headquartered in Mount Gravatt; and South East Region, headquartered in Surfers Paradise. More details can be obtained from the QPS web site at www.police.qld.gov.au.

The Australian Federal Police have offices in Spring Hill and the Gold Coast suburb of Robina.

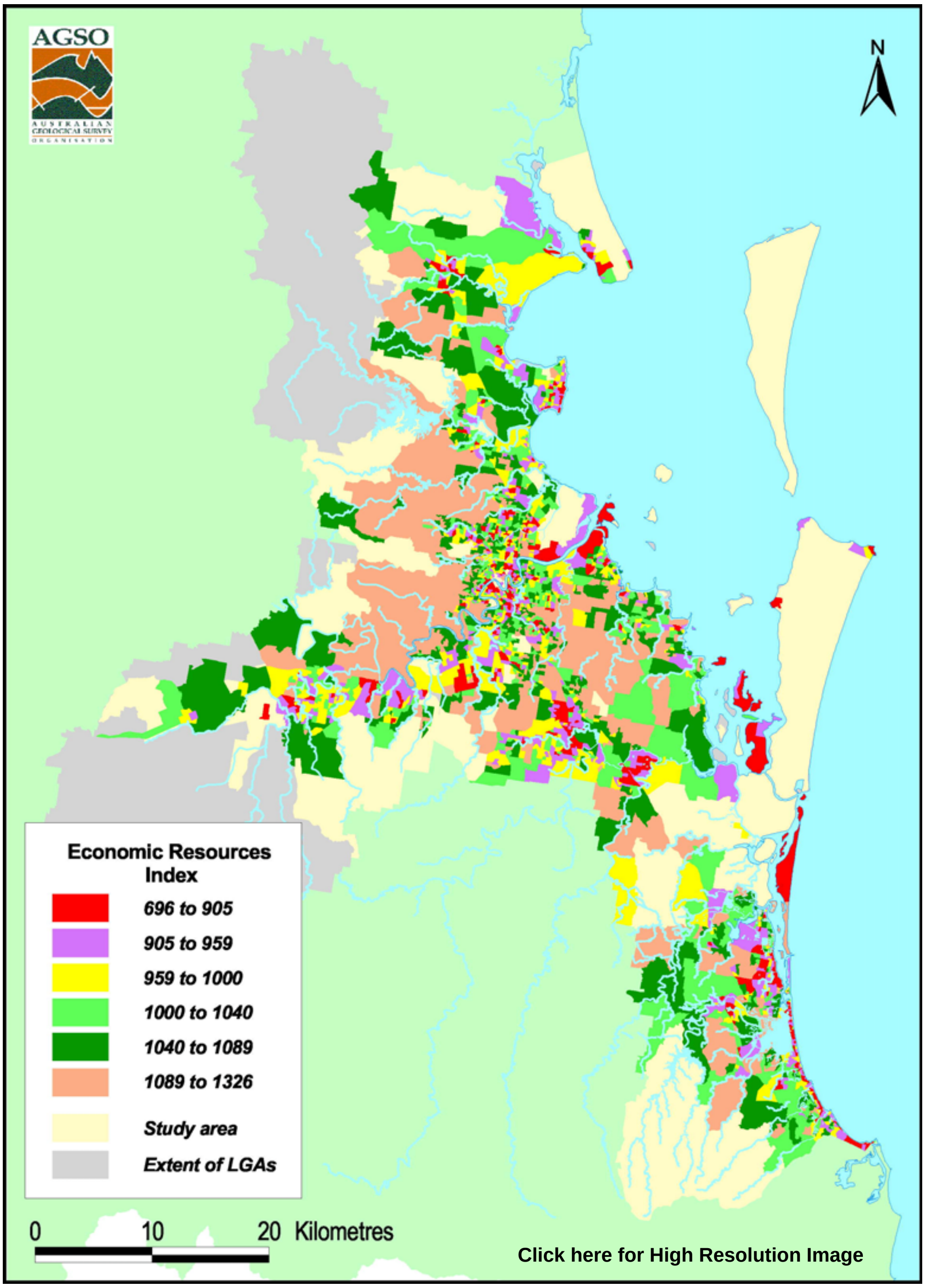


Figure 3. 16 South-East Queensland Index of Economic Resources (ABS, 1998b data)

The other emergency services come under the Department of Emergency Services which is headquartered at the Emergency Services Complex at Kedron Park. The headquarters of the Queensland Ambulance Service (QAS), the Queensland Fire and Rescue Authority (QFRA) and the Counter Disaster and Rescue Services Division (which oversights the SES and other volunteer groups as well as maintaining the operational Chemical Hazards and Emergency Management Unit and Queensland Rescue Aviation Services). The State Disaster Coordination Centre, which is activated in times of major emergency or disaster, is also located within the Kedron Park complex.

Ambulance services throughout the State are provided by the QAS. Within South-East Queensland there are 46 ambulance stations spread throughout three Ambulance Regions: Greater Brisbane Region, headquartered at Kedron Park; and South East, headquartered in Beenleigh. For details see their web site at www.ambulance.qld.gov.au. QAS resources are supplemented at major events, such as the RNA Exhibition and New Year festivities, or in times of emergency, by volunteers from the Saint Johns Ambulance Brigade who are trained in first aid.

The QFRA units within South-East Queensland include 50 urban brigades staffed by full time officers and 38 rural brigades staffed by volunteers. Several rural brigades provide fire services in rural villages such as Samford and Springbrook. The area is divided between three QFRA Regions: Brisbane North, extending from the Brisbane River north as far as Caboolture, with headquarters at Kedron Park; Brisbane South, covers the southern suburbs of Brisbane and the Redland area, with headquarters also at Kedron Park; and, South Eastern, which covers Ipswich and the southern parts of the area to the NSW border, with headquarters in Beenleigh. In addition to fire fighting and fire prevention activities, QFRA units are also responsible for road rescue activities such as extracting people trapped in motor vehicle accidents. For details see their web site at www.fire.qld.gov.au.

Fire services are provided at Brisbane International Airport by the Airport Fire Service which has two stations on the airport; at the Amberley air base by the RAAF Fire Service; and in the Gallipoli Barracks at Enoggera by Army fire fighters. Other major facilities such as the port and the fuel refineries also have their own staff trained in fire fighting duties. There is a mutual aid agreement in place between the QFRA and the NSW Fire Brigades that enables units from either state to assist each other if required. This is especially significant along the border between Coolangatta and Tweed Heads.

Both Ambulance and QFRA response management for the region is controlled from two joint Ambulance and Fire Communication Centres (AFCom), one located in the Spring Hill Ambulance Station and the other at Emergency Services Communications Centre in Southport.

Training and administration of State Emergency Service (SES) volunteer units is coordinated by the Department of Emergency Services (DES) Disaster and Rescue Services Division’s District Managers throughout the State. There are two such districts covering South-East Queensland; Metropolitan, which covers SES units in Caboolture, Pine Rivers, Redcliffe, Brisbane and Redland from its headquaters in Brisbane; and South East District, headquartered in Beenleigh which covers SES units in Ipswich, Logan and Gold Coast. Details can be found on the web site at www.emergency.qld.gov.au/ses.

Local SES units are the responsibility of each individual LGA, with planning and coordination the responsibility the Local Counter Disaster Committee (LCDC). LCDCs are typically chaired by the LGA’s mayor or another senior elected official, and supported by an executive officer. In the larger councils, such as Brisbane and Gold Coast, the executive officer is a full-time professional disaster coordinator, whilst in smaller councils this role is added to the duties of a senior official, typically the senior engineer or works manager. The LCDC is also responsible for the development and implementation of the local disaster plan.

Marine rescue services are provided by the Australian Volunteer Coast Guard, Volunteer Marine Rescue Association of Queensland and Surf Life Saving Queensland. Each of these is a volunteer organisation, however, they each receive funding support and administrative coordination through DES. Volunteer marine rescue bases operate from Bribie Island, Scarborough, Shorncliffe, Manly, Victoria Point, Cleveland, Currumbin, Main Beach, Jacobs Well, South Stradbroke Island, Southport. There are 22 surf lifesaving clubs on the Gold Coast and one on Bribie Island.

DES also operates its air wing (both rotary and fixed wing) rescue services from their base at Archerfield Airport, whilst the Royal Flying Doctor Service operates from Brisbane International Airport.

The Queensland Corrective Services Commission oversights correctional centres in the region. The major prison complex is at Wacol and includes the Moreton Correctional Centre, Sir David Longland Correctional Centre and the Wacol Remand and Reception Centre. The Numinbah Valley Correctional Centre is located on Nerang-Murwillumbah Road, in the Gold Coast hinterland. The Woodford Correctional Centre, located in Caboolture Shire, is outside the area covered by this study.

South-East Queensland hosts a number of Defence Force establishments that are potentially significant to public safety. The largest of these is the Army base at the Gallipoli Barracks, Enoggera which is headquarters to armoured (2/14 Light Horse), artillery (1 Field Regiment) and infantry (6 Royal Australian Regiment and 9 Royal Queensland Regiment) combat units of the 7th Task Force, together with supporting elements including electrical and mechanical engineers (104 Field Workshop), intelligence, medical (including 2 Field Hospital), military police, transport, and signals (1 JSU, 136 Signal Squadron and 7 CSU) units. Logistic support resources are headquartered at the Bulimba Barracks with a detachment at the Banyo Barracks. Training units are at Wacol (1st Training Group) and St Lucia (Queensland University Regiment). Other establishments include the Greenbank range complex and camp, the Defence Centre at Victoria Barracks, Milton and the Army's Land Warfare Centre which is partially located within the Gold Coast. The Kokoda Barracks at Canungra, are, however, within Beaudesert Shire. There are Reserve establishments in Caboolture, Ipswich, Logan and Gold Coast.

RAAF Base Amberley is home to No 1 and No 3 Squadrons (F-111), which make up the RAAF Strike and Reconnaissance Group, No 38 Squadron (Caribou), of the Air Lift Group, and numerous support, maintenance and training elements. The base is essentially self supporting though significant numbers of personnel and their families live in the general Ipswich community.

The Royal Australian Navy maintains a naval support office in the Bulimba Barracks.

The Commonwealth's Bureau of Meteorology Regional Office at 295 Ann Street, Brisbane City houses the regional forecasting centre and the Cyclone Warning Centre (when activated). This agency provides warnings of severe weather events and floods throughout Queensland.

Society

The capacity of individuals, families, households and neighbourhoods to withstand the impact of disaster has much to do with the cohesiveness and resilience of those communities. Social cohesion is a very complex thing and difficult to measure, especially in a population as mobile as that found in Brisbane. The development of indices of social vulnerability has still a long way to go, however, the measures discussed below, including family structure, language and ethnicity, religion, length of residence, education and community services, appear to be amongst the most relevant.

Family structure: The literature on community vulnerability has identified the structure of families as having a significant bearing on susceptibility or resilience to disaster impact. Single parent families, especially 'women-led' families with younger children, and large families, for example, have been shown to be particularly susceptible. Morrow (1999), for example, identifies those types of family as having been amongst the most adversely affected by the 1992 impact of Hurricane *Andrew* in Florida.

Table 3.5 summarises the number of families in the South-East Queensland according to their size and structure. There are 216 305 households made up of a couple plus their children, of which 27.1% contain 5 or more people (i.e. notionally 3 or more children). There are 66 561 households made up of a single parent and their children, of which 19.0% contain 4 or more people (likewise three or more children).

Table 3. 5 Number of households with children by type and size (Source: ABS, 1998a).

	Number of people usually resident					
	2	**3**	**4**	**5**	**6+**	**Total**
Couple with children		69 899	87 734	41 835	16 837	216 305
One parent family	30 986	22 904	8922	2670	1079	66 561
Totals	30 986	92 803	96 656	44 505	17 916	282 866

The spatial distribution of large families and single parent families expressed as a percentage of all families, is shown in Figure 3.17 and Figure 3.18 respectively, based on ABS (1998a) data. As a broad generalisation, the larger families tend to be located in the rural fringe and areas of recent urban growth, whilst the single parent families tend to be concentrated in the inner and older suburban areas.

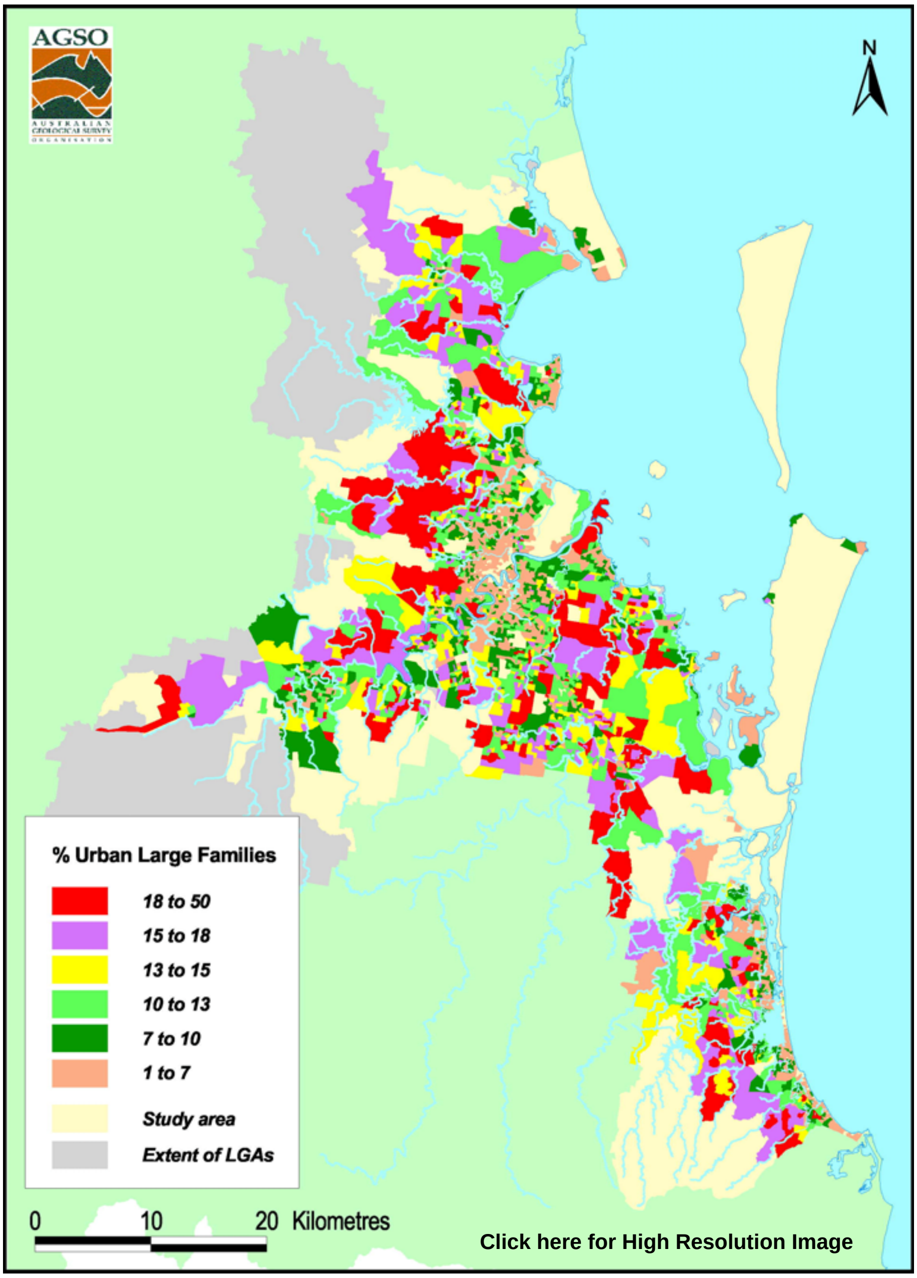


Figure 3. 17 South-East Queensland urban proportion of large families (ABS, 1998a data)

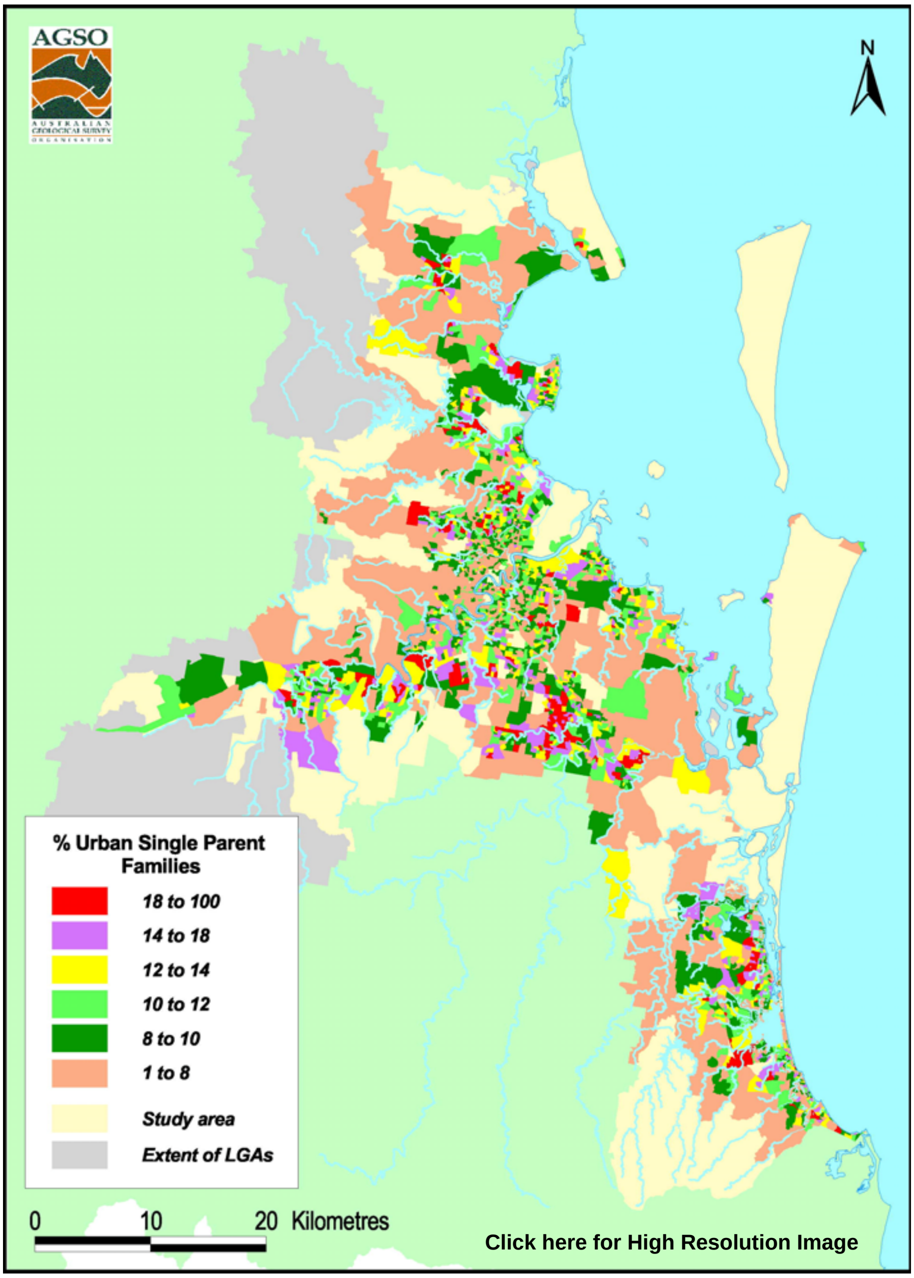


Figure 3. 18 South-East Queensland proportion of urban single parent families (ABS, 1998a data)

Across the study area the overall percentage of large families is 7.9%. There are 19 neighbourhoods across the region with percentages of 25% or greater. These are mostly in Brisbane City (10/19), with Gold Coast (4/19), Logan, Ipswich (both2/19) and Pine Rivers also represented.

Around 23.5% of all families, across the study area, have children with only one parent present. There are 63 neighbourhoods where the percentage exceeds 25%, one of which has 100% (the CCD which contains the women's prison in Wacol). The majority of these neighbourhoods are in Brisbane City (32/63), with Gold Coast, Ipswich (each with 9/63), Caboolture, Logan (each with 4/63), Pine Zrivers (3/63) and Redcliffe (1/63).

Language and ethnicity: One of the strongest social links in a community is derived from language and ethnicity. For the resident population, English is overwhelmingly the most common language spoken, with 86.6% of the population over five years of age speaking only English at home. The next largest groups are 'other' (2.3%), Chinese (1.6%), Italian (0.8%), Vietnamese (0.7%), German (0.6%)

and Greek(0.5%). The ‘other’ group appears to include mainly Pacific Island and Asian languages such as Polynesian, Japanese and possibly Korean.

These figures relate specifically to the resident population. In 1999, however, Brisbane received 704 428 international visitors, of whom at least 53% were from non-English speaking countries, especially Japan (108 056), Taiwan (66 837), Germany (26 623) and other European countries (93 151).

Some 74.4% of the population living in the region in 1996 was born in Australia. Of the overseas born community, the United Kingdom (6.4%), New Zealand (3.8%), Germany (0.6%) and Vietnam (0.6%) were the major sources. About 1.2% of the population was of Aboriginal or Islander descent. The most significant concentration of any single ethic group is in Darra where 30% of the population in one CCD were born in Vietnam, and in several Inala neighbourhoods where up to 12.4% are of Aboriginal or Islander descent.

Religion: One of the more significant linkages that tend to span social cleavages such as ethnicity, is religion. In South-East Queensland, the majority (80.0%) of residents who provided answers to the questions on religion in the 1996 census were Christian. Of the remainder, 1.0% were Buddhist, 0.6% Islamic, 0.5% Hindu and 0.2% Jewish, whilst 17.4% said they had no religion. Of the Christian faiths, Catholic (35.5% of all Christians), Anglican (31.4%), Uniting (12.0%), Presbyterian (6.1%) and Baptist (2.9%) have the largest congregations. Distribution across the city is quite even, though localised concentrations are obviously found where there are institutions such as convents, boarding schools and church-run nursing homes.

Length of residence: Awareness of the local hazard history, environment and how to cope with disaster, as well as the level of integration into the local community, can be measured by the length of time people have lived in the area. The population of the region is clearly a mobile one, with only 53.0% of the population at the 1996 census living at the same address that they were living at five years previously. Around 3.7% (or 117 CCD) had more than 75% of their population living at different addresses five years previously. The main concentrations of new residents are clearly apparent in Figure 3.19.

Some of the higher figures were recorded in ‘institutional’ areas such as Enoggera (the army barracks), Amberley (the RAAF base), Saint Lucia (the University) and Wacol (the prisons). Also obvious are the suburbs in which urban development is in progress in all LGA. Perhaps less obvious, but also quite important is the inner Brisbane area where re-development, ‘gentrification’ and densification of settlement is strongest. This change is overwhelmingly based on in-migration.

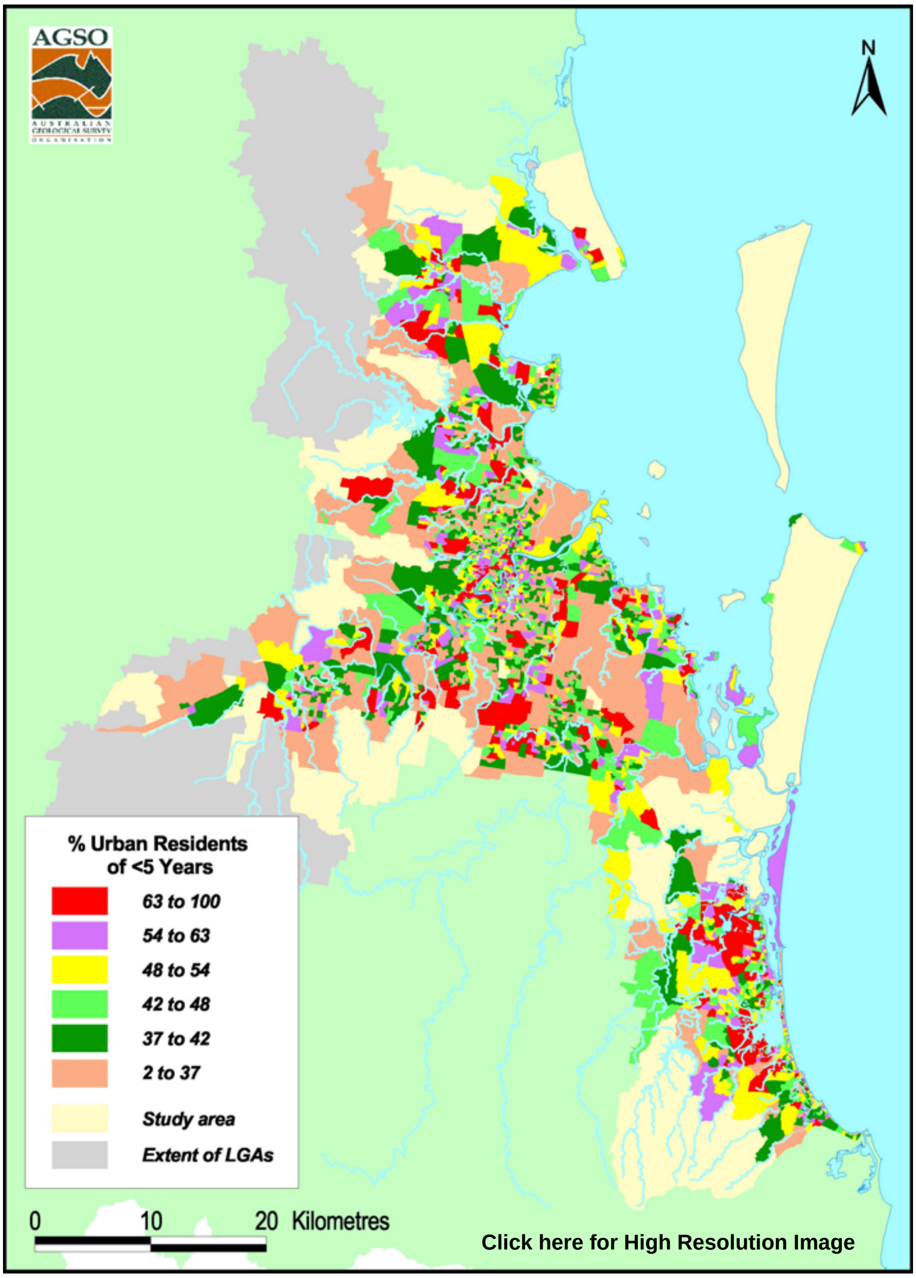


Figure 3. 19 Proportion of urban population at census address for less than 5 years (ABS, 1998a data)

Elderly living alone: Another category of community member that has a particularly elevated level of susceptibility consists of the elderly folk who are living on their own. Whilst many of these may be living in 'managed' communities such as retirement villages, a substantial number are living in their own homes, In many instances these people can become isolated from their neighbours and the community as their mobility declines. The distribution of people who are over 65 and living alone is shown in Figure 3.20. Over the whole region the CCD mean is only 2.9% of the total population, however, this is clearly uneven. Twenty-seven CCDs have more than 15% of their population as elderly living alone. These neighbourhoods are in Brisbane (14/27), Gold Coast (6/27) Redcliffe (4/27) and Caboolture, Ipswich and Redland (each with 1/27). The distribution shows a clear preference for localities closer to the coast and the major rivers.

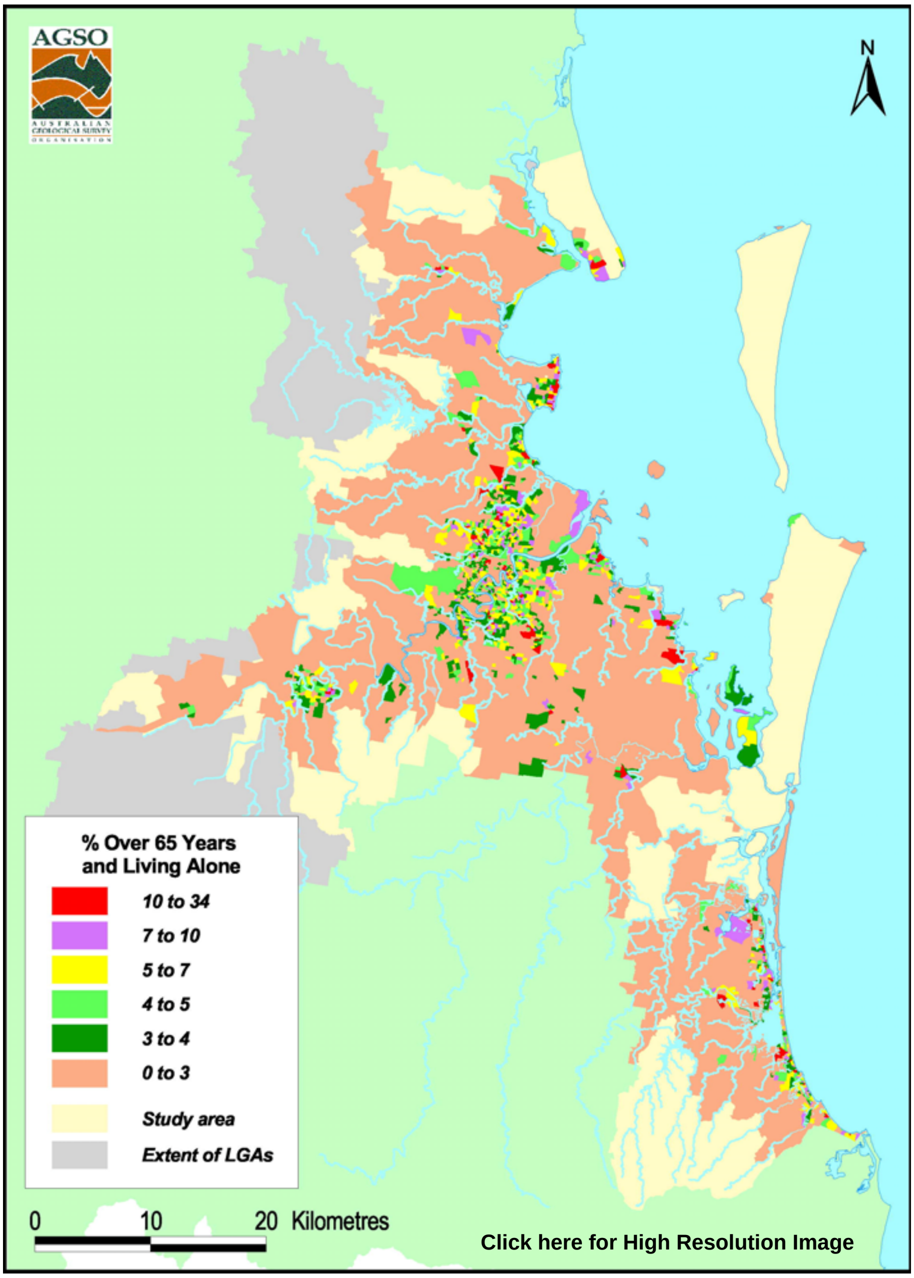


Figure 3. 20 Proportion of population who are over 65 and living alone (ABS, 1998a data)

Education: The disaster management literature suggests that the capacity of the community to understand and respond to information on risk or hazard potential is, to some degree, dependant on education and literacy. Much of the research reported in this literature, however, relates to developing countries where levels of literacy and access to information are typically poor. In a developed country such as Australia, basic levels of education and literacy are comparatively high across the community. In South-East Queensland some 28.9% of people over 15 had gained some form of post-secondary qualification and the vast majority of the remainder being at least literate. In this community, therefore, education levels are unlikely to make a particularly significant contribution to community vulnerability.

Educational facilities are typically identified in disaster plans as shelters or evacuation centres following disaster because they have ample space and facilities such as toilets and canteens. There are approximately 700 pre, primary, secondary and special schools in South-East Queensland. There are, in addition, five universities – Australian Catholic University (Enoggera campus), Bond

(Robina), Griffith (Gold Coast, Logan, Morningside, Mount Gravatt, Nathan and South Brisbane campuses), Queensland University of Technology (Carseldine, Gardens Point and Kelvin Grove campuses) and University of Queensland (St Lucia, Dental School, Medical School and Veterinary Farm campuses). There are 17 TAFE campuses spread across the region. There are also several vocational institutions, such as theological colleges, tourism and hospitality colleges, secretarial colleges, art schools and so on.

At the other end of the educational process are at least 650 child care centres and kindergartens that serve areas of employment and all residential suburbs. Given the very young age and vulnerability of children at these centres, they deserve particular attention.

The SEIFA *Index of Education and Occupation* also provides an overview of the distribution of population with an educational 'advantage'. As with the two SEIFA indexes already discussed, this index is also standardised with a national mean of 1000 and a standard deviation of 100. The South-East Queensland study area mean value is 1003.9 (very close to the national mean) and ranges from a high (high educational levels and high occupation status) of 1312.8 (more than three standard deviations above the national mean) in St Lucia, to a low (low education levels and job status) of 724.6 (more than two standard deviations below the national average) in a Woodridge neighbourhood. The spatial distribution is shown in Figure 3.21. Tables B1, B2 and B3 lists the variables used to build this index.

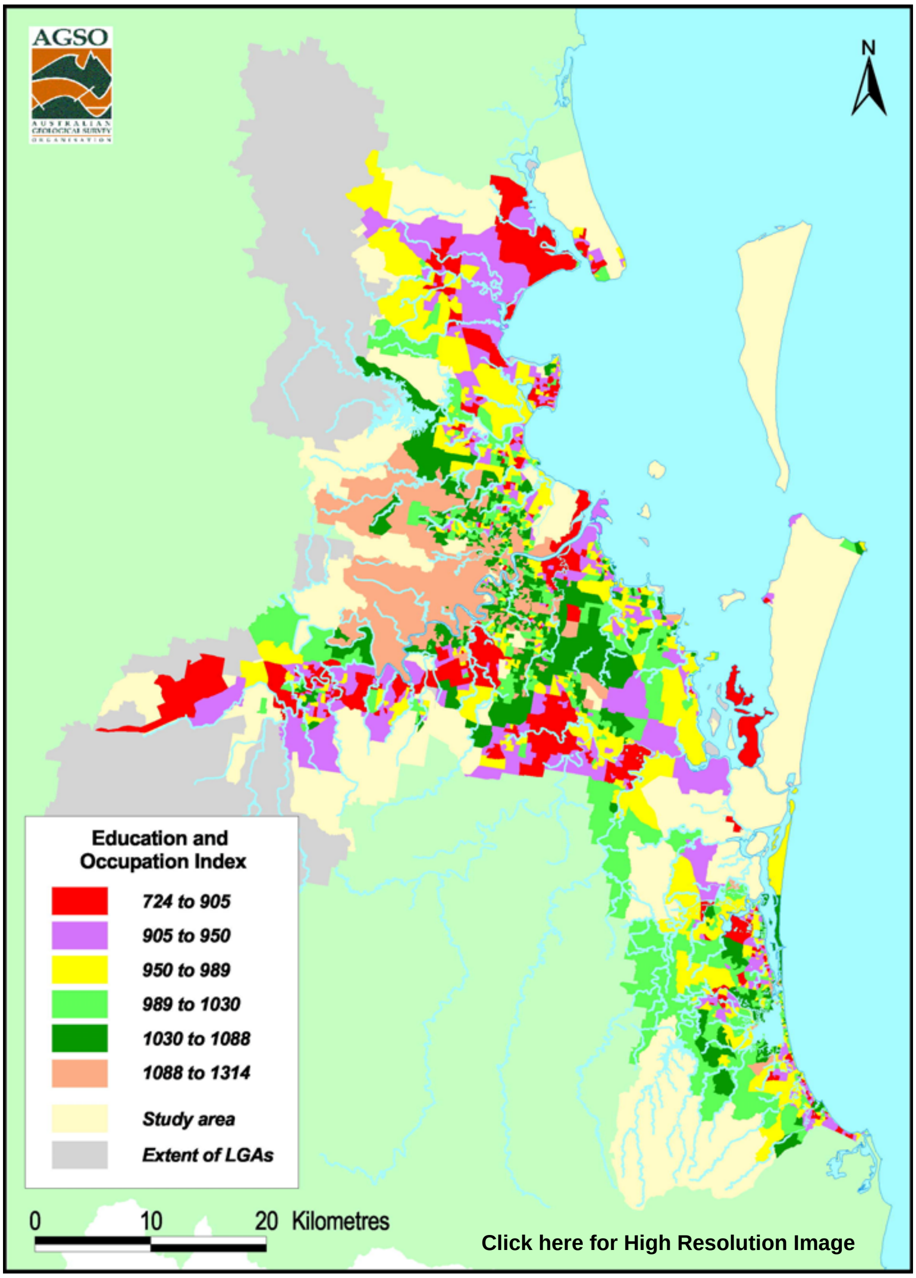


Figure 3. 21 Index of Education and Occupation (ABS, 1998b data)

Community services: Community based groups provide a significant level of social resilience and effective networks for the dissemination of information. The region is extremely well served by these groups, which include those based on schools (e.g. Parents and Citizens Associations), churches (e.g. youth groups, fellowships, etc), sporting activities and community service clubs (e.g. Apex, Rotary, Boy Scouts, etc). It is likely that there is a degree of cross membership between these various groups, a situation that has been observed in other communities and which greatly enhances community resilience and cohesion.

Cultural and Natural Heritage: One of the more intangible and frequently overlooked, group of elements at risk are those features that make up the community's cultural and natural heritage. These range from Aboriginal such as the many Bora Ring sites and prehistoric occupation sites such as the South Stradbroke Island middens, to modern attractions such as the Gold Coast theme parks.

Given that Brisbane is the oldest urban centre and the State capital, it is not surprising that there is a concentration of cultural heritage features present. These include historic and otherwise significant structures, libraries, art galleries, museums, document archives and so on. Most of the more significant cultural heritage features, such as the State Library, Queensland Art Gallery and Queensland Museum, Old Government House, Newstead House and Parliament House, are concentrated around or close to the city centre. The National Trust of Australia (Queensland) maintains a register of places that have been identified as being significant to the local and national heritage estate. The David Fleay Wildlife Park and the Currumbin Sanctuary on the Gold Coast, for example, are listed on this register. The Queensland State Archives are housed in Runcorn whilst each LGA has its own archival repository.

The region also contains several areas of significant natural heritage value. Perhaps the most important of these are the wetland areas of Moreton Bay that have been classified under the 1971 Ramsar Convention on Wetlands as a primary site of international importance, especially given their significance as a feeding ground for migratory water birds and the various national parks that occupy much of the western borders of the area.

Critical, High Risk and Hazardous Facilities

The distribution of facilities that are critical to the safety and sustenance of the community provides a strong indicator of community vulnerability, particularly in the aftermath of a disaster impact. At least 550 such facilities have been identified in region that would meet this criteria. They include facilities such as port, airport and rail infrastructure, telephone exchanges, power substations, water treatment plants, major fuel and food storage facilities, and so on.

Some of these facilities could, under certain circumstances, exacerbate the impact of a hazard event by adding to the danger. The loss of containment of hazardous materials such as chemicals or flammable substances as the result of a hazard impact, for example, would magnify the danger because of toxic contamination, fire or explosion. The hazards contained at some of these facilities are not always obvious. For example, large commercial cold storage facilities typically use large quantities of ammonia as their refrigerant (as much as three tonnes in some facilities). Apart from its noxious properties, as a gas, ammonia is highly flammable.

A wide range of essentially incompatible chemicals may be stored on the same premises. Supermarkets, garden supply nurseries, pool supply shops, hardware stores, school chemistry laboratories, pharmacies and so on, store a wide range of chemicals (generally in small quantities) that can become very dangerous if not properly contained and stored. Some chemicals, such as the various forms of cyanide, can be extremely dangerous, even in very small quantities. Some of these are used in a wide range of processes and can be found in the most obscure businesses such as fibreglass manufacture, electro-plating, jewellery manufacture and the manufacture of dental prostheses. Most facilities that store quantities of hazardous substances over certain thresholds, however, must display safety placards that identify the chemicals and the nature of the hazard they represent.

Facilities in which people concentrate at various times can also be considered to be high risk facilities (in terms of people exposed), especially for hazards such as earthquakes which can strike without warning at any time of day. Such facilities are too numerous to list individually, but would include the following groups of facility:

- schools, preschools and other educational facilities;
- entertainment, recreational and sporting facilities;
- transport terminals;
- tourist accommodation such as hotels, resorts and hostels;
- shopping, commercial and professional centres; and,
- hospitals and nursing homes.

The significance of a facility may extend beyond the community in which it is located if a wider community of interest depends on it for services or supply. For example, the disabling of the Mount Crosby water treatment plants would, at least temporarily, disrupt the supply of safe water to much of South-East Queensland population. In general, however, alternative facilities are available within a fairly short distance in neighbouring local government areas.

A Composite Community Vulnerability Profile

In this chapter so far we have described a broad range of the elements at risk within the Brisbane community and identified some of the key aspects that contribute to their vulnerability. These have been drawn from the large amount of high resolution data accumulated on the people, buildings and infrastructure of Brisbane. Whilst these data provide a detailed quantitative description of specific aspects of the area's risk environment, they do not, of themselves, provide an adequate measure of overall community vulnerability. Nor do they individually reflect the relative levels of vulnerability across the area.

We consider that it is highly desirable, however, to be able to identify those parts of the study area that would provide a potentially disproportionate contribution to community risk because of the number and nature of the elements at risk they contained.

There is little in the risk or disaster management literature to provide a guide for this task so we created our own methodology for the Cairns study (Granger and others, 1999), based on the 'five esses' described in this and the previous chapter, and a composite, or combined community vulnerability assessment. We modified that methodology slightly for the Mackay study (Middelmann and Granger, 2000) to take account of a review of the Cairns work by the Centre for Disaster Studies, James Cook University (King, Moloney and MacGregor, 2000) and that approach has been maintained, with some further minor additions, here. Appendix D provides a detailed explanation of the methodology and the logic behind the selection of the variables included in this study. The key difference in the method used here, as opposed to Cairns, is that vulnerability profiles have not been aggregated to the suburban level but have been calculated at the CCD level only. Suburb boundaries are overlain on the 'vulnerability surfaces' for ease of reference.

It is emphasised that the values indicated on the following maps do **not** equate to a risk rating. They are simply index values that provide an indication of the **relative contribution** made to overall community risk across the study area, assuming that an even and equal exposure to the impact of all hazards existed. (The lower the index number, the greater the relative degree of susceptibility.) This is clearly not the case, as will be explored in the following chapters. The following six figures show the 'vulnerability surfaces' for each of the five 'esses' (setting, shelter, sustenance, security and society) and a composite 'community vulnerability' surface.

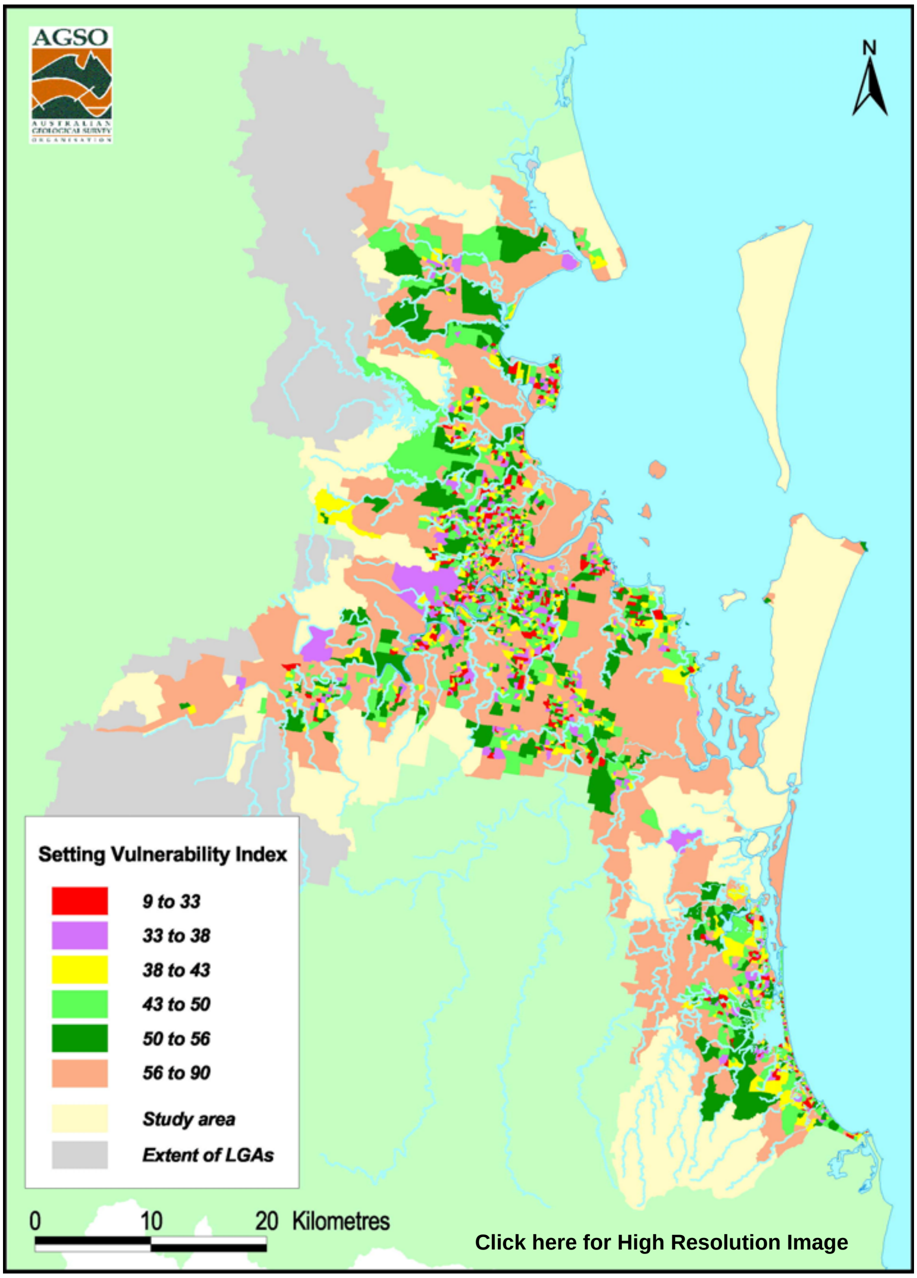


Figure 3. 22 Setting Vulnerability Index

The suburbs which contain the top 1% of setting vulnerability indexed neighbourhoods (i.e. those that contribute most) are (in alphabetic order):

> Auchenflower, Balmoral, Benowa, Bethania, Birkdale, Broadbeach Waters, Camp Hill, Carina Heights, Carseldine, Chermside, Coolangatta, Coombabah, Herston, Indooroopilly, Ipswich, Kangaroo Point, Labrador, Lutwyche, Mermaid Beach, Nerang, Norman Park, Redcliffe, Sandgate, Southport, South Brisbane, Sunnybank, Surfers Paradise, The Gap, Woodridge, Wynnum West and Zillmere.

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

> Albion, Banyo, Boondall, Camira, Cannon Hill, Carole Park, Daisy Hill, Donnybrook, Eden Island, Eight Mile Plains, Elimbah, Goolman, Greenbank, Heathwood, Karawatha, Karragarra Island, Kippa Ring, Labrador, Moreton Island, North Booval, North Stradbroke

Island, Oxley, Pannikin Island, Priestdale, Richlands, Russell Island, Saint Helena Island, Virginia, Wacol

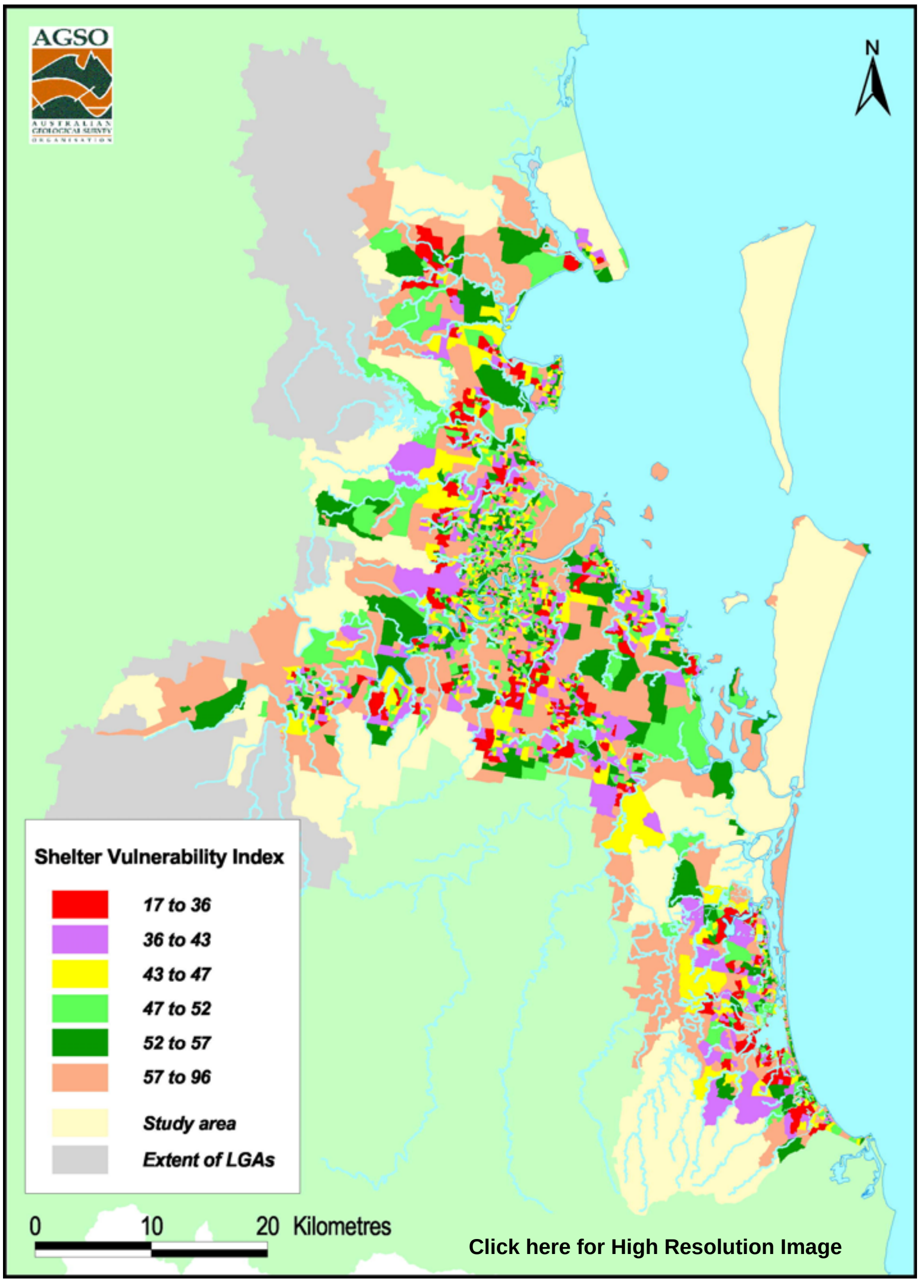


Figure 3. 23 Shelter Vulnerability Index

The suburbs which contain the top 1% of shelter vulnerability indexed neighbourhoods (i.e. those that contribute most) are (in alphabetic order):

Aspley, Calamvale, Carrara, Carseldine, Collingwood Park, Deception Bay, Eight Mile Plains, Elanora, Gailes, Kallangur, Kingston, Labrador, Lawnton, Manly West, Mansfield, Mudgeeraba, Nerang, Oxenford, Robertson, Rochdale South, Runcorn, Stevens, Sunnybank Hills, Tanah Merah, The Gap and Tingalpa.

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

Acacia Ridge, Amberley, Banyo, Belmont, Boondall, Brisbane City, Camira, Carole Park, Coolangatta, Daisy Hill, Eagle Farm, Elimbah, Fortitude Valley, Karawatha, Kippa Ring, Nathan, Oxley, North Stradbroke Island, Pannikin Island, Richlands, Saint Helena Island, South Brisbane, Stephens, Surfers Paradise and Wacol.

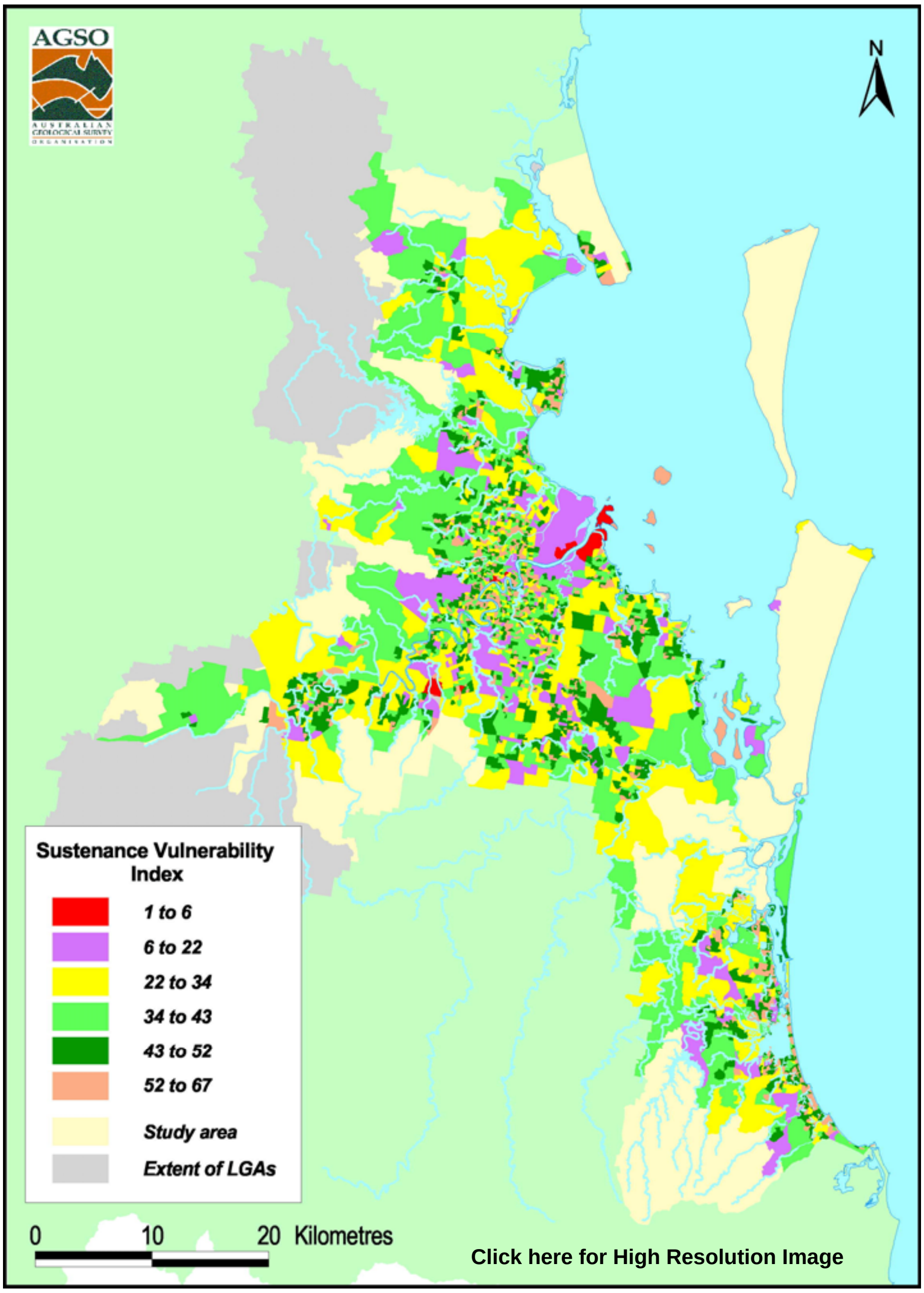


Figure 3. 24 Sustenance Vulnerability Index

The suburbs which contain the top 1% of sustenance vulnerability indexed neighbourhoods (i.e. those that contribute most) are (in alphabetic order):

Andrews, Aspley, Bald Hills, Banyo, Brendale, Brisbane City, Calamvale, Camp Hill, Darra, Eagle Farm, Fortitude Valley, Hemmant, Inala, Loganholme, Lytton, Murarrie, Nerang, Newstead, Norman Park, Norwell, Pinkenba, Redcliffe, Rocklea, Rothwell, Salisbury, Sandgate, Sherwood, Underwood, Wacol, Willowbank and Wynnum.

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

> Biggera Waters, Broadbeach, Burleigh Heads, Main Beach, New Farm, North Stradbroke Island, Pannikin Island, Richlands, Runaway Bay and Surfers Paradise.

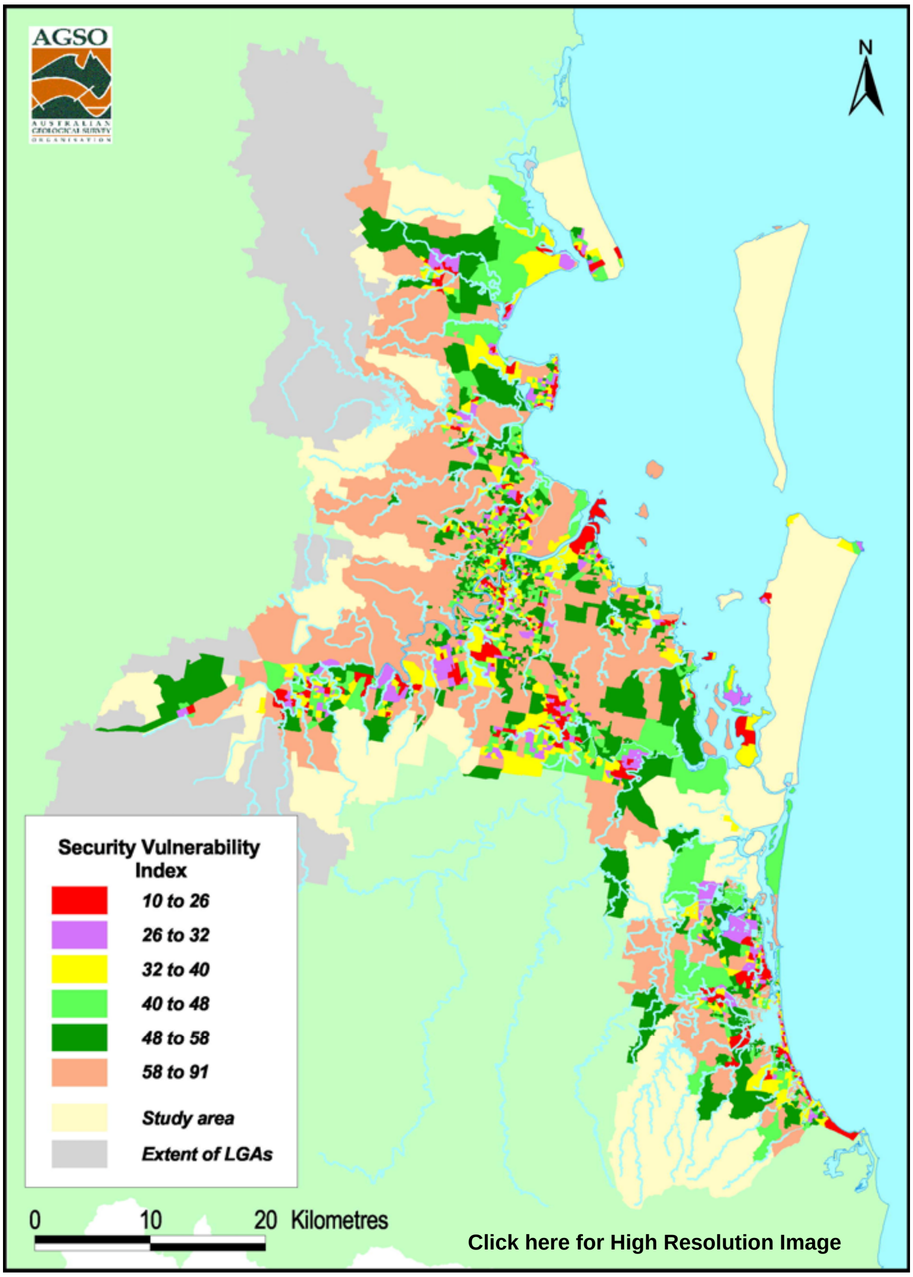


Figure 3. 25 Security Vulnerability Index

The suburbs which contain the top 1% of security vulnerability indexed neighbourhoods (i.e. those that contribute most) are (in alphabetic order):

> Beenleigh, Booval, Caboolture, Cleveland, Coolangatta, Fortitude Valley, Holland Park, Inala, Ipswich, Kelvin Grove, Lytton, Marsden, Morayfield, Riverview, Scarborough, Southport, Stafford, Tugun, West End, Windsor, Woodridge and Zillmere.

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

Amberley, Camira, Camp Mountain, Carindale, Chappell Hill, Boondall, Daisy Hill, Eight Mile Plains, Ferny Grove, Figtree Pocket, Forestdale, Heathwood, Jindalee, Kenmore, Kippa Ring, Lawnton, Mount Ommaney, Pannikin Island, Richlands, Robertson, Saint Helena Island, Samford Valley, The Gap, Westlake, Whiteside and Wacol.

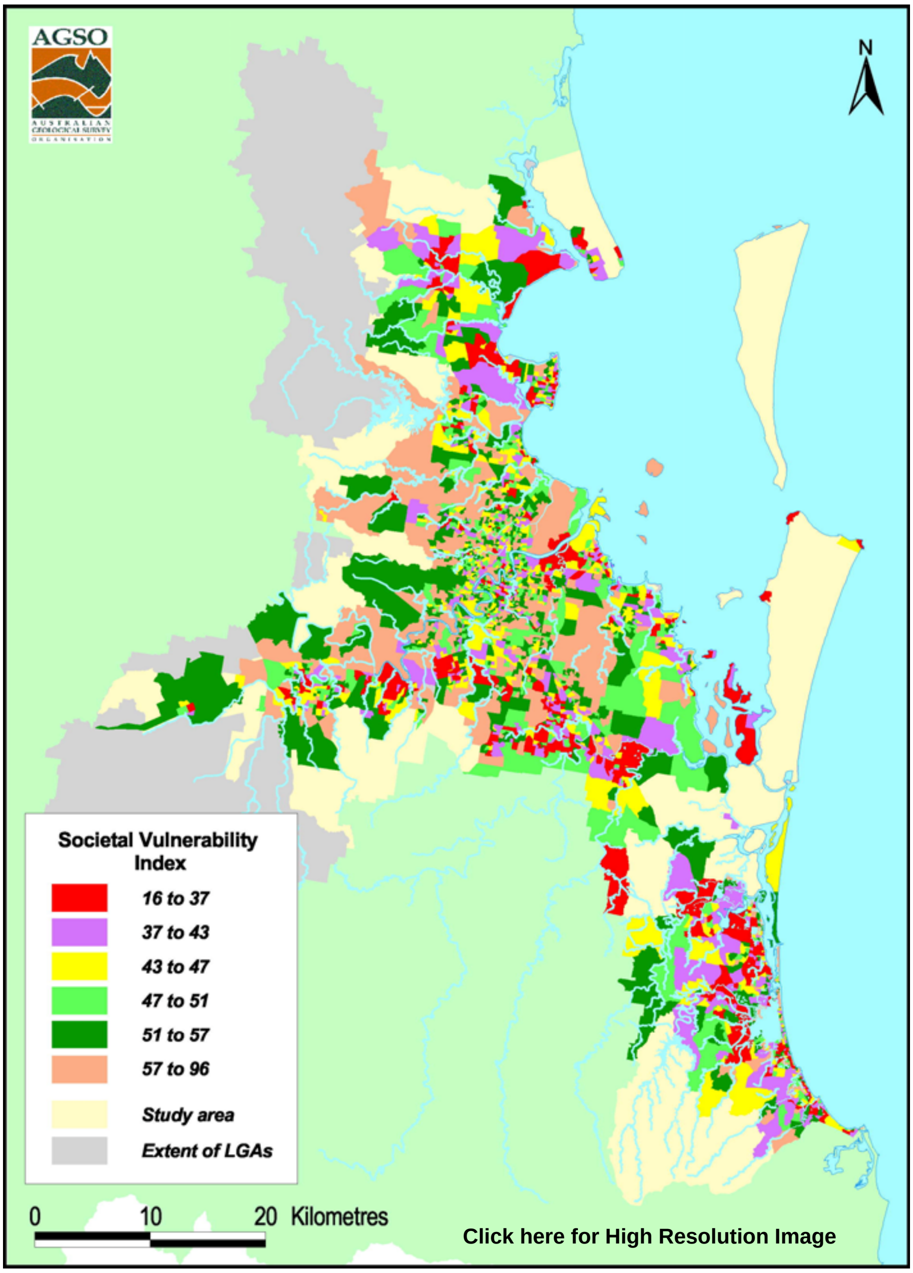


Figure 3. 26 Societal Vulnerability Index

The suburbs which contain the top 1% of societal vulnerability indexed neighbourhoods (i.e. those that contribute most) are (in alphabetic order):

Ashmore, Beenleigh, Biggera Waters, Caboolture, Cleveland, Clontarf, Coomera, Deception Bay, Eagleby, Goodna, Heritage Park, Inala, Kallangur, Labrador, Morayfield, Macleay Island, Marsden, Mudgeeraba, Nerang, Palm Beach, Southport, Tugun

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

Acacia Ridge, Bellbowrie, Boondall, Brisbane City, Broadbeach, Camira, Carindale, Carole Park, Coolangatta, Forestdale, Fortitude Valley, Heathwood, Karawatha, Kippa Ring, Lawnton, Oppossum Creek, Pannikin Island, Richlands, Saint Helena Island, Stephens, Surfers Paradise, Underwood and Wacol.

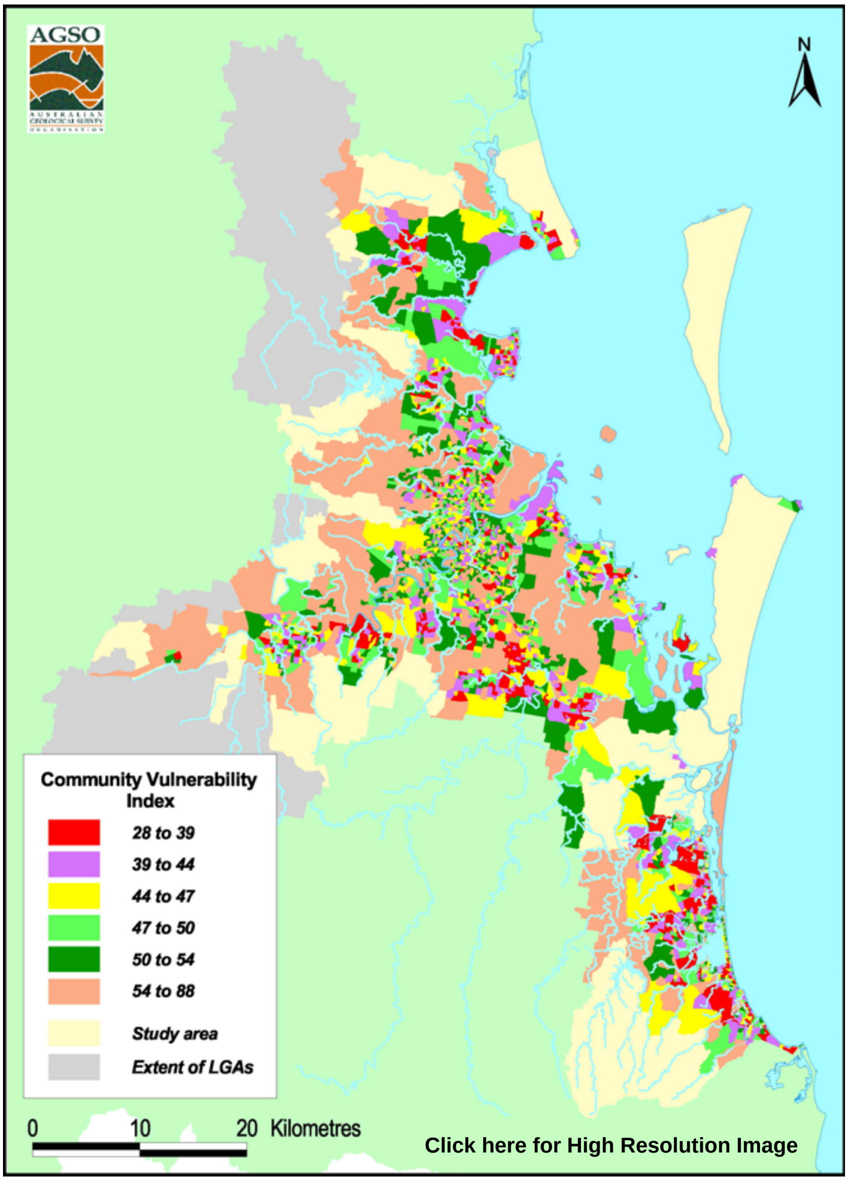


Figure 3. 27 Community Vulnerability Index

The suburbs which contain the top 1% of overall community vulnerability indexed neighbourhoods (i.e. those that contribute most to overall community vulnerability) are (in alphabetic order):

Ashmore, Boronia Heights, Caboolture, Capalaba, Carina Heights, Coombabah, Deception Bay, Dinmore, Goodna, Inala, Kallangur, Kingston, Lawnton, Nerang, Oxenford, Redbank, Redcliffe, Riverview, Rothwell, Stephens, Waterford West, Woodridge, Woody Point and Wynnum West.

The bottom 1% of neighbourhoods (those that contribute least) are contained in the suburbs of:

Amberley, Bellbowrie, Boondall, Brisbane City, Camira, Carole Park, Coolangatta, Daisy Hill, Eagle Farm, Ferny Grove, Fortitude Valley, Greenbank, Heathwood, Karawatha, Kippa Ring, Lawnton, North Booval, North Stradbroke Island, Oppossum Creek, Pannikin Island, Priestdale, Richlands, Saint Helena Island, South Brisbane, Stephens, Surfers Paradise, Wacol and Wulkuraka

Conclusion

The understanding of the South-East Queensland community that has been developed here provides the essential 'elements-at-risk' and 'vulnerability' input to the risk formula. It provides the essential description and definition of the urban landscape of South-East Queensland, across which a range of hazard events have, and will, impacted. We now turn out attention to the hazard phenomena and the way in which they will affect this community.

CHAPTER 4: TROPICAL CYCLONE RISKS

Bruce Harper, Ken Granger, Trevor Jones, John Stehle, and Rob Lacey

The Cyclone Threat

There is little doubt that tropical cyclones (TC) pose a significant threat to the urban communities of South-East Queensland. These spectacular meteorological phenomena are very large in scale, and have the potential to bring severe loss to the whole region. On long-term average, 1.2 cyclones pass within 500 km of Brisbane each year. The most active cyclone season on record (1962/1963) saw 7 cyclones passing into the region. In the past 92 years of detailed record, the centres of 15 of these storms have passed within 100 km of downtown Brisbane. An historical inventory of cyclones effecting the region is included in Appendix D, based largely on a listing of historical events compiled from many sources by the Bureau of Meteorology's Queensland Regional Office in Brisbane.

Perhaps the most significant regional impact by a tropical cyclone in recent history was the severe and widespread flooding caused by TC *Wanda* in January 1974 – the so-called 'Australia Day' floods that caused such devastation in Brisbane and elsewhere in the region.

There are three components of a tropical cyclone that combine to make up the total cyclone hazard - strong winds, intense rainfall and oceanographic effects including high energy waves, strong currents, storm surge and resulting storm tide. The destructive force of cyclones, however, is usually expressed in terms of the strongest wind gusts experienced. Maximum wind gust is related to the central pressure and structure of the system, whereas the storm surge is linked closely to the combination of the surface winds, central pressure and regional bathymetry. Rainfall intensity varies considerably, with the heaviest rain typically associated with the system after it decays into a tropical low, or rain depression, as it loses intensity over land.

The Bureau of Meteorology (BoM, 1999) uses the five-category system shown in Table 4.1 for classifying tropical cyclone intensity in Australia. Severe cyclones are those of Category 3 and above.

Table 4.1: Australian tropical cyclone category scale

Category	Maximum Wind Gust (km/h)	Potential Damage
1	<125	minor
2	125-170	moderate
3	170-225	major
4	225-280	devastating
5	>280	extreme

In this chapter we concentrate on the destructive wind and (where appropriate) storm tide inundation hazards and the risks that they pose. The closely related phenomenon of east coast lows is discussed in Chapter 5 (East Coast Low Risks) and the consequences of the intense rainfall associated with tropical cyclones are largely addressed in Chapter 9 (Flood Risks).

The Cyclone Phenomenon

The classic definition of a tropical cyclone (WMO, 1997) is:

> *A non-frontal cyclone of synoptic scale developing over tropical waters and having a definite organized wind circulation with average wind of 34 knots (63 km/h) or more surrounding the centre.*

Basically, a tropical cyclone is an intense tropical low pressure weather system where, in the southern hemisphere, winds circulate clockwise around the centre. In Australia, such systems are upgraded to *severe* tropical cyclone status (Category 3 and above - referred to as hurricanes or typhoons in some countries) when average, or sustained, surface wind speeds exceed 120 km/h. The accompanying shorter-period destructive wind *gusts* are often 50 per cent or more higher than the *sustained* winds.

Genesis: Tropical cyclone development is complex, but various authors (including Gray, 1975; Riehl, 1979; and WMO, 1995) have identified six general parameters necessary for their formation and intensification. Dynamic parameters include:

- low-level relative vorticity;
- exceedence of a threshold value of the Coriolis effect of the earth's rotation; and,
- minimal vertical shear of the horizontal wind between the upper and the lower troposphere.

Thermodynamic parameters include:

- sea surface temperature (SST) above 26°C through the mixed layer to a depth of 60 m;
- moist instability between the surface and the 500 hPa level (approximately 5600 m above sea level);
- high values of middle tropospheric relative humidity; and,
- warm upper troposphere air.

Globally, tropical cyclones form more frequently in the northern hemisphere (with 75% of the global total) than in the southern hemisphere (Gray, 1968 and 1979). In the southern hemisphere, cyclones occur in three principal regions:

- the Indian Ocean near Madagascar, where over 10% of the global total cyclones occur;
- the oceanic area to the north-east and north-west of Australia; and,
- the Gulf of Carpentaria.

Cyclones in the Australian region have their maximum occurrence between 15°S and 20°S latitude, commencing in November/December and continuing to March/April. The greatest incidence is in January to March, transferring from east to west as the season advances (Lourensz, 1981). In terms of both cyclone intensity and the likelihood of crossing the coast, the most cyclone-prone area along the Queensland coast is around Mackay (Harper, 1999). The period of recorded observations of cyclone occurrences, however, is only a little more than 100 years, and in sparsely settled regions, or out at sea, detection has been accurate only since the early 1960s with the advent of satellite observation.

After their formation in low latitudes, cyclones then tend to move westwards and pole-wards under the combined effects of easterly steering currents and dynamic effects, although individual tracks can be quite erratic. South of latitude 15°S on the Queensland coast (i.e. roughly south from Cooktown), the major direction of movement is south-eastward. This is caused by interaction with the north-westerly winds east of deep mid-latitude troughs which tend to steer tropical cyclones south-eastward parallel to the coast. The continental east coast itself participates in this process by influencing the evolution and structure of these trough systems.

The main structural features of a severe tropical cyclone at the earth's surface are the eye, the eye wall and the spiral rain bands. These features are clearly seen in the satellite image of TC *Fran* shown in Figure 4.1. The eye is the area at the centre of the cyclone at which the surface atmospheric pressure is lowest. It is typically 20 to 50 km in diameter, skies are often clear and winds are light. The eye wall is an area of cumulonimbus clouds which swirls around the eye. Recent studies (Black and Marks 1991; Wakimoto and Black, 1994) suggest that unusually high winds can occur in the vicinity of the eye wall due to instabilities as the cyclone makes landfall. Tornado-like vortices of even more extreme winds may also occur associated with the eye wall and the outer rain bands. The rain bands spiral inwards towards the eye and can extend over 1000 km or more in diameter. The heaviest rainfall and the strongest winds, however, are usually associated with the eye wall itself.

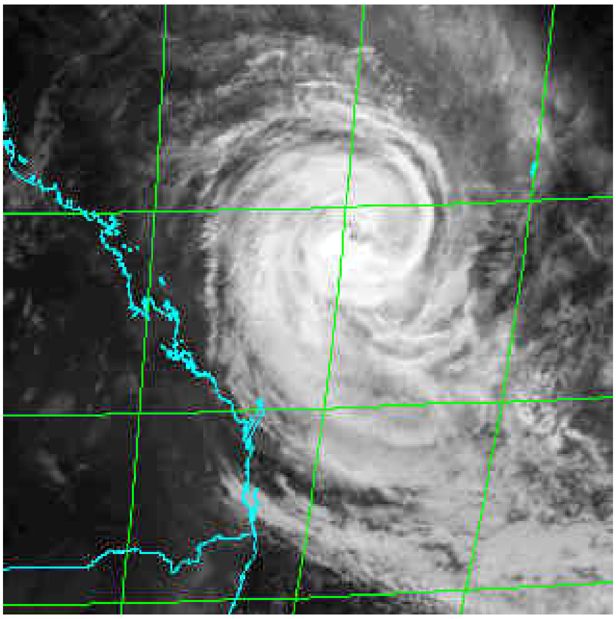
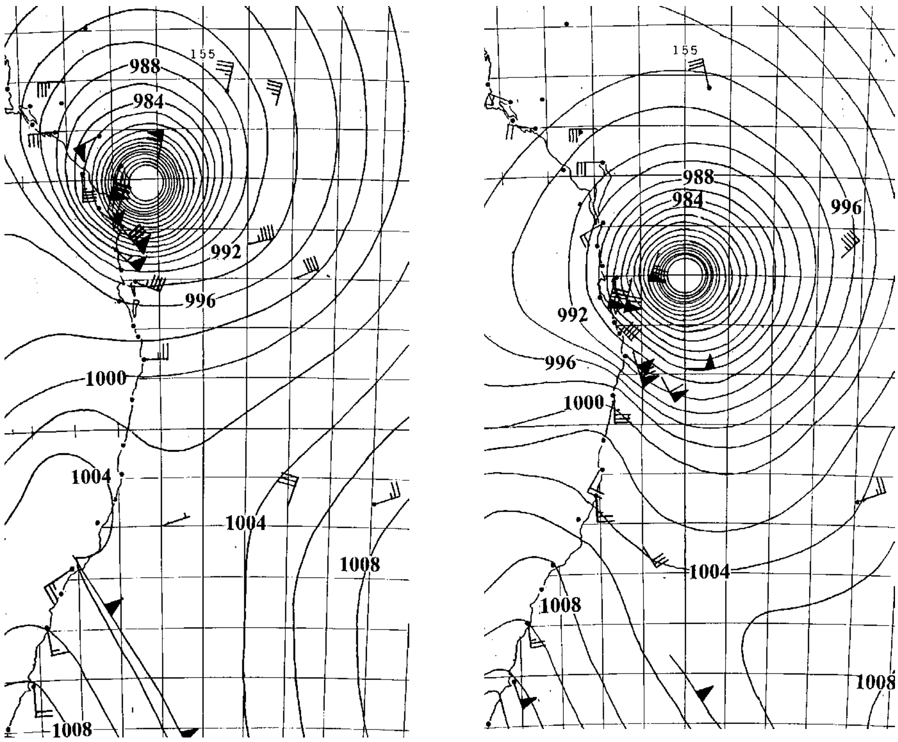


Figure 4.1: TC *Fran* approaching the Queensland coast in March 1992

Given specifically favourable conditions, tropical cyclones can continue to intensify until they are efficiently utilising all of the available energy from the immediate atmospheric and oceanic sources. This maximum potential intensity (MPI) is a function of the climatology of regional SST, atmospheric temperature and humidity profiles. Applying a thermodynamic model for the South-East Queensland region, the MPI is thought to represent a central pressure of about 940 hPa (Holland, 1997). This is of similar intensity to severe Category 4 TC *Dinah* which passed close to the region's coast in January 1967. Thankfully, it is rare for any cyclone to reach its MPI because environmental conditions often act to limit intensities in the Queensland region, for example, the extensive cloud cover of the rain bands shades the sea over a large area, thus reducing the sea surface temperature from which the cyclone derives much of its energy.

Cyclonic winds circulate clockwise in the southern hemisphere. The windfield within a moving cyclone, however, is generally asymmetric so that, in the southern hemisphere, winds are stronger to the left of the direction of motion of the system (the 'track'). This is because on the left-hand side, the direction of cyclone movement and its circulation act together; on the right-hand side they are opposed. During a coast crossing in the southern hemisphere, the cyclonic wind direction is onshore to the left of the eye (seen from the cyclone) and offshore to the right. The large-scale surface pressure (isobar) fields of the mature TC *Dinah*, as it tracked south-south-east 150 km off the coast, are given in Figure 4.2. The strongest winds in this situation would be generally expected just to the left of the track (i.e. on the eastern side). The development of the intense pressure gradient (and gale to storm-force southerly winds) south-west of TC *Dinah*, as it interacted with the ridge pushing up the NSW coast, should be noted. At the time of closest approach, therefore, Brisbane was subjected to southerly winds. However, Brisbane experiences only light winds under the strong synoptic south-east-to-southerly flow, possibly created by shielding from the McPherson Ranges along the border with New South Wales.

For any given central pressure, the size of individual tropical cyclones can vary enormously. However, because it is difficult for a cyclone to form south of 25ºS (i.e. south of Bundaberg), the vast majority of cyclones affecting the South-East Queensland region have traveled from further north and are likely to be either mature, undergoing decay, or tending extra-tropical (similar to east coast lows). In those circumstances, small cyclones are relatively rare.



1100 UTC 29-Jan-1967 2300 UTC 29-Jan-1967

Figure 4.2: Synoptic features of severe TC *Dinah*.

Large cyclones can have impacts far from their track, especially with the generation of large waves and storm tide. For example, TC *David* crossed the coast near Yeppoon in 1976, and TC *Pam* passed 450 km offshore from Brisbane in 1974, but both caused significant coastal impacts in South-East Queensland.

Climatology: Historical searches for tropical cyclones affecting the South-East Queensland region have uncovered significant community impacts as early as the mid-1800s (see Appendix D) but the detailed record maintained by the Bureau of Meteorology's National Climate Centre begins in the 1907/08 season. An overview of this 92 year official record is given below, summarising cyclone activity within a radius of 500 km from Brisbane, which includes all cyclones which may have been capable of having an influence on the region within a nominal 24 hour period.

Figure 4.3 summarises the frequency of occurrence on an annual (or seasonal) basis. It includes 111 storms since 1902. This produces an average of 1.2 storms per year, but varies between 0 and 7 occurrences in any one season. While this is an extensive period of record, Holland (1981) advises caution in utilising records prior to 1959/60 in any detailed statistical analysis of the frequency of occurrence or intensity because of the major changes in observing technology, standards of reporting and increasing scientific understanding over that time. Experimental satellite imagery first became available in 1960, leading to the adoption of objective intensity estimating methods from 1968 onwards, with the later Dvorak technique (Dvorak, 1975) still in regular usage. While evidence of incomplete detection is suggested in the record prior to the 1930s, restricting the data set to post-1959/60 results gives a total of 44 storms in the 40 year period, producing a slightly decreased average occurrence rate of 1.1 per season.

Figure 4.3 also shows the 5 year moving average of occurrences, which can be compared with the annual and 5 year averaged Southern Oscillation Index (SOI). Recent sustained negative SOI (*El Niño*) influences can be seen to be associated with a significant reduction in cyclone numbers across the region from 1975 onwards. Further discussion on these points is provided later in regard to climatic variability.

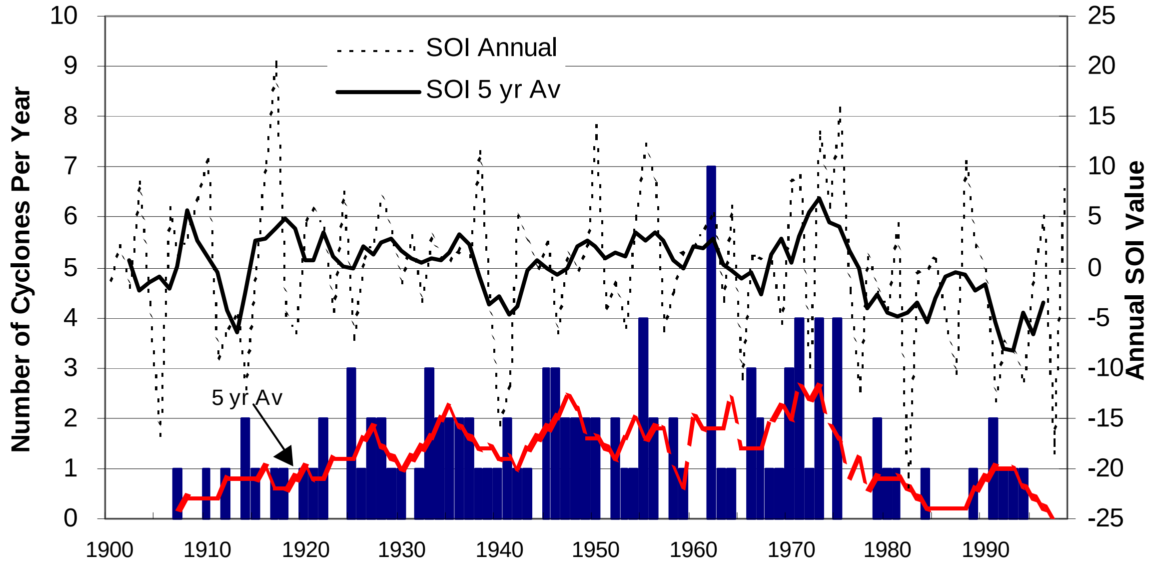


Figure 4.3: Frequency of occurrence of tropical cyclones within 500 km of Brisbane.

Severe Wind: Tropical cyclones are accompanied by strong winds, with potentially destructive gusts (more than 130 km/h) within 100 km of the centre of Category 3 or greater storms. These strong winds can persist for many hours, or even days, depending on the track of the storm, and can cause widespread building and infrastructure damage or even loss of life (Systems Engineering Australia, 1999). Most of the structural damage caused by tropical cyclones is inflicted by the strong winds. This damage can be caused directly by the wind and/or by the debris that it propels, frequently with great force.

Some measure of the destructive power of cyclonic winds can be gauged from the following account of damage caused by the 1893 cyclone, reproduced in Caboolture Historical Society (1973) and taken from the account published in the *Telegraph* of 25th February 1893:

> *A recent visitor to Woody Point* (Redcliffe) *supplies the following account of the total destruction of Mrs. Bell's well known residence 'Klanger'. This place was caught in a tornado on February 17th* (1893) *at 7 a.m.*
>
> *The first intimation the occupants had of the strength of the wind was the front door bursting open. Mrs. Bell, who was in bed at the time, went to shut the door, when she was lifted bodily up and her head knocked against the ceiling of the hall. Mrs. Bell was found amongst the debris, apparently without a broken bone but severely bruised.*
>
> *Her daughter, Mrs. Hobbs, and the latter's two children, who were also in the house, had a miraculous escape from death, as the building fell in on them. In fact one child was under a wardrobe that took four persons to lift and the other had a hairpin knocked into her head. All of them were very much bruised, especially Mrs. Bell and her daughter.*

The man servant was carried from the kitchen steps into a mulberry tree and hurt about the legs by falling timber.

The house and the 8 ft. 6 in. verandah appear to have been lifted bodily up, carried about five to ten yards and then crashed to pieces.

Nearly all the furniture is smashed to atoms and bedsteads are broken and twisted like so many twigs. At one time it was thought that a valuable piano, which had somehow escaped the weight of the falling building, was uninjured – but unfortunately that is not the case.

Perhaps the most remarkable incident is that a large box with a glass top containing birds eggs was not damaged in any way.

Parts of the galvanized iron roof were carried a long distance and wrapped around a big tree.

A light buggy belonging to Mr. Parry Okeden which was in a shed at the stable was lifted and carried into a fig tree. When taken down it appeared none the worse for its aerial flight, except that part of the ironwork was bent.

A poor horse, which had been feeding some distance away, must have been lifted up and dashed against a tree as the unfortunate animal was found almost cut in two.

Mrs. Boden, a daughter, says that when Mrs. Bell was found she was holding a silver tea pot which had been presented to her in appreciation of her hospitality.

Heavy Rainfall: Before proceeding to discuss the risks associated with severe wind and the oceanic effects of storm tide and extreme waves in South-East Queensland, it is worth touching briefly on the climatology associated with the severe rainfall that frequently accompanies tropical cyclones. The consequences of this rainfall are dealt with more fully in Chapter 9 (Flood Risks).

WMO (1995) lists three typical conditions associated with heavy rainfall generated by tropical cyclones:

- a sustained vortex wind structure after landfall, fed by favourable convergence at low levels;
- stagnation or a slowly moving centre near the coast; and,
- a sustained supply of water vapour from a favourable cloud belt.

Three heavy rainfall bands are normally found in a tropical cyclone after landfall. The first is associated with the eye wall core, which extends between 15 to 50 km from the centre. Next, spiral rain bands may extend for several hundred kilometres and can produce torrential rains. An 'inverted trough' may also form towards the south causing heavy rains around the periphery of the storm. The outer circulation may also interact with other synoptic-scale systems to create heavy rains in areas very remote from the storm centre. For example, southern Queensland is often affected by a tropical cyclone making landfall some distance to the north causing heavy rainfall further down the coast.

Topography also affects the rainfall generation process due to coastal convergence and uplift effects. The presence of the mountainous areas of the Great Dividing and Border Ranges to the west are, therefore, important factors in delivering heavy rainfall events in South-East Queensland.

Severe Waves: The Queensland Beach Protection Authority (BPA - now within the Environment Protection Authority) has maintained a near-continuous record of wave heights dating, back to 1976, using moored buoy systems offshore from Point Lookout on North Stradbroke Island. A recent analysis of some 21 years of data (Allen and Callaghan, 2000) revealed the maximum recorded significant wave height of 7.4 m occurred during TC *Roger* in 1993. Based on their statistical analyses, Table 4.2 indicates that the average recurrence interval (ARI) for significant wave heights at this location caused by tropical cyclones. The significant wave height (Hs) is an estimate of the average height of the highest one-third of waves in a 20 minute period, and is found to be similar to the visually estimated wave height made by an experienced observer. The single highest wave (Hmax) during the same period is typically around 1.8 times higher than Hs.

While Table 4.2 is based on the best data set available, it is acknowledged that the observation period coincides with a relatively benign phase of tropical cyclone activity, as discussed previously. For example, many of the intense cyclones during the 1950s and 1960s would have generated severe wave conditions which, if included in the analysis, are likely to increase the probability of higher waves. Accordingly, Table 4.2 is regarded as a likely under-prediction at this time and further 'hindcast' studies utilising numerical models will be required to improve upon the available measured data.

Table 4.2: Predicted extreme wave heights due to tropical cyclones in South-East Queensland (after Allen and Callaghan, 2000).

Average Recurrence Interval (ARI) yrs	Predicted Significant Wave Height (Hs) m
2	3.9
5	4.6
10	5.2
20	5.8
50	6.7
100	7.5

One of the principal impacts of severe waves is significant beach erosion, especially when combined with storm tide effects. Between late January and early April in 1967, a sequence of cyclones – TCs *Dinah, Barbara*, *Elaine* and *Glenda* – attacked the beaches of southern Queensland causing extensive erosion and economic loss to the tourist industry. This was followed in June by three east coast low events which, together with the earlier cyclones, were estimated to have removed more than 8 million cubic metres of sand from beaches between Point Danger and the Nerang River mouth (DHL, 1970). Extensive property damage occurred along the Gold Coast strip - houses fell into the sea at Mermaid Beach, Nobby's and Palm Beach (see Figure 4.4). Large sections of the esplanade collapsed at Surfers Paradise, Main Beach and Palm Beach. A volunteer army of 5000 people placed around 100 000 sandbags along the foreshore helping to prevent many other houses being lost to the sea. It then took two years for natural accretion to rebuild much of the region's beaches.

In some areas, unrestricted development within the active beach zones had robbed the beach of its natural buffer against storm attack and those areas remained chronically affected for many years. This and other significant coastal erosion events prompted State legislation to ensure the sustainable development of coastal areas and lead to the creation of the BPA in 1968. The BPA was instrumental in undertaking essential research and investigation into coastal management problems. Extensive artificial beach nourishment programs have also been conducted by Gold Coast City Council over a number of years to restore beach amenity and provide property protection. In 1994, the Queensland and New South Wales Governments agreed to jointly finance and build an artificial sand by-passing system to restore the natural northward progression of sand past the Tweed River entrance, which had been contributing to erosion of the southern Gold Coast beaches for many years. This system is expected to become operational in 2001 and will greatly enhance the ability of Gold Coast beaches to withstand future cyclone attack.

Figure 4.4: Severe beach erosion at Palm Beach during 1967 (EPA photograph).

Storm Tides: All tropical cyclones on or near the coast are capable of producing a storm surge, which can increase coastal water levels for periods of several hours and simultaneously affect over 100 km of coastline (Jelesnianski, 1965; Sobey and others, 1977; Harper, 1999b). When the storm surge is combined with the daily tidal variation, the absolute combined water level reached is called the *storm tide*. An individual storm surge is measured relative to the mean sea level (MSL) at the time, while storm tide is given as an *absolute* level such as its height above the Australian Height Datum (AHD). Only the storm tide level can thus be referenced to a specific ground contour value. Evacuation of low lying areas prior to storm landfall will be required in some circumstances to help prevent loss of life through drowning. The storm tide will also be capable of causing significant destruction of near-shore buildings and facilities if large ocean swells penetrate the foreshore regions.

Figure 4.5 summarises the various components which work together to produce an extreme storm tide. Firstly, the storm surge is generated by the combined action of the severe surface winds circulating around the storm centre generating ocean currents, and the decreased atmospheric pressure causing a local rise in sea level (the so-called *inverted barometer* effect). The strong currents impinging against the coast are normally responsible for the greater proportion of the surge. As shown in Figure 4.5, the surge adds to the expected tide level at the time the storm makes landfall.

Also accompanying the surge are the extreme wind-generated ocean waves - a combination of ‘swell’ and local ‘sea’ driven before the strong winds. These waves increase in height (shoal) as they approach the shore and as part of the process of wave breaking, a portion of their energy can be transferred to a localised increase in the still-water level. This effect is termed *wave setup* and, although generally much smaller than the surge, can add 0.5 m or more to the surge level at exposed locations. Additionally, waves will run up sloping beaches to finally expend their forward energy and, when combined with elevated sea levels, this allows them to attack foredunes or near-shore structures to cause considerable erosion and/or destruction of property.

The potential magnitude of the surge is affected by many factors; principally the intensity of the tropical cyclone, its size and its forward speed. As the cyclone approaches the coast, the local shape of the coastline and the slope of the undersea bathymetry are particularly significant contributors to the resulting surge height. When the resulting storm tide exceeds the normal range of the daily tide the local beach topography will dictate whether significant coastal inundation will occur.

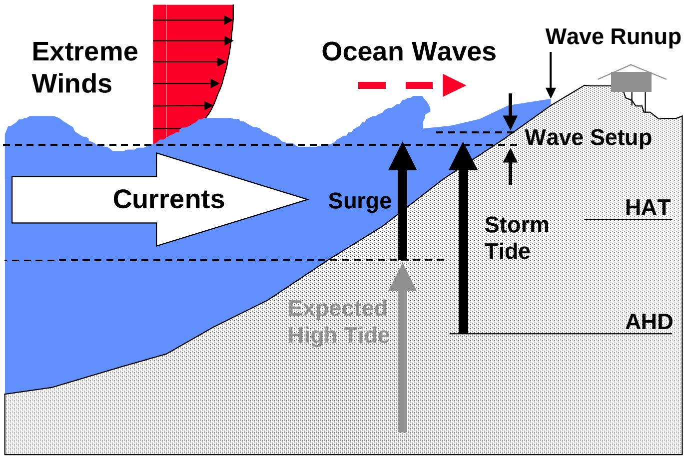


Figure 4.5: Components of a storm tide (from Harper, 1998)

Table 4.3, mainly extracted from Harper (1998), provides a summary of some recorded storm tide events in the study region. This list should be regarded as indicative only but shows that at least 29 separate surge events have occurred over the past 100 years. Of these, about half resulted in storm tide levels reaching above the HAT (Highest Astronomical Tide) level. Mostly the affected areas were within Moreton Bay, especially Beachmere, but parts of the Gold Coast such as South Stradbroke Island, McIntosh Island and Mermaid Beach have also been partly inundated at various times. The *Courier Mail* of Monday 22nd February 1954, for example, reported:

> *… 42 families were evacuated from areas swollen by the Nerang River. Twenty-two residents of McIntosh Island spent a nightmare eight hours before being rescued by police and lifesavers. At the first attempt … three men made the island (by) boat and took the residents into the biggest of the houses. But soon after the stumps supporting the house gave way, and the party rushed outside seconds before the building collapsed. Drenched to the skin the party, which included six small children, then moved into another house on the highest point of the island. There, waist high in water, they waited for rescue. 'Then the wind dropped and we were able to make it. Five minutes after we had completed the rescue, the wind started howling again.'.*

The open coasts of the South-East Queensland region are afforded some protection against extreme storm surge by the relatively narrow continental shelf (Harper,1998) but are open to severe wave attack and subject to high levels of wave setup. Conversely, the shallow waters of Moreton Bay are protected against serious wave attack but subject to wind stress effects which impact many low lying residential areas from Beachmere in the north to Bay Islands in the south. The extensive tidal estuaries of Moreton Bay and The Broadwater are also susceptible to storm tide, which can exacerbate the effect of river flooding.

The highest known water levels occurred during TC *Dinah* in 1967, eclipsing the previous 1954 event on the Gold Coast. TC *David* in 1976 also created significant impact, even though its centre was over 600 km to the north, near Yeppoon.

Table 4.3: Historical storm tide record for South-East Queensland

Date	Place	Event	Storm Surge (m)	Storm Tide Level (m on AHD	Inundation Above HAT (m)
08-Jun-1891	Brisbane		?	1.8	0.3
19-Feb-1894	Brisbane		0.6	1.6	0.2
11-Feb-1915	Brisbane		0.6		
16-Jun-1928	Brisbane		?	1.7	0.2
05-Feb-1931	Brisbane		1.1	2.0	
01-Feb-1934	Brisbane		1.2	?	
20-Jan-1938	Brisbane		0.5	1.4	
"	Gold Coast		>0.5	1.8	>0.5?
25-Mar-1946	Brisbane		0.6		
23-Jan-1947	Brisbane		>0.5	?	
28-Jan-1948	Brisbane		0.5	1.8	0.3
18-Jan-1950	Brisbane		0.6	1.8	0.3
25-Jan-1951	Brisbane		?		
21-Feb-1954	Brisbane		0.7	2?	?
"	Coolangatta		>1?	2?	>0.5?
17-Feb-1957	Brisbane	TC *Clara?*	>0.5	?	
01-Jan-1963	Brisbane	TC *Annie*	0.8	?	
29-Jan-1967	Moreton Bay	TC *Dinah*	2?	2.8?	1.5?
"	Broadwater	"	1.5?	1.8?	0.8?
11-Feb-1972	Fraser Island	TC *Daisy*	3?	?	?
"	Bribie Island	"	0.8?		
"	Tweed Heads	"	0.6?		
24-Jan-1974	Brisbane	TC *Wanda*	0.6		
"	Broadwater	"	0.3		
07-Feb-1974	Brisbane	TC *Pam*	0.7	1.9	0.4
"	Broadwater	"	0.6		
"	Kirra	"	0.4		
12-Mar-1974	Brisbane	TC *Zoe*	0.7		
"	Broadwater	"	0.5		
19-Jan-1976	Moreton Bay	TC *David*	0.8	1.9	1?
14-Feb-1981	Gold Coast	TC *Cliff*	0.7		
01-Feb-1988	Beachmere		0.2	1.5	0.2
26-Apr-1989	Beachmere		0.6	1.5	0.2
17-Mar-1993	Gold Coast Seaway	TC *Roger*	0.7	1.3	
04-Dec-1994	Beachmere		0.1	1.5	0.2
02-May-1996	Beachmere		0.7	1.8	0.4
26-Mar-1998	Brisbane	ex TC *Yali*	0.3	1.5	
13-Jul-1999	Beachmere		0.2	1.5	0.2
		Total Events:	29		16

The Bureau of Meteorology has been concerned with forecasting storm tide effects in and around Moreton Bay for many years and Gourlay (1981) proposed a simplified method for estimating peak surges from individual storms based on the cyclone central pressure and its distance from Cape Moreton. At about the same time, a numerical modelling study was undertaken for setting the tarmac elevations for the new Brisbane Airport (BBW, 1979) which provided estimates of the combined surge plus tide. Shortly afterwards, the BPA funded further numerical modelling which was part of a comprehensive assessment of storm tide risks along the Queensland coastline (BPA, 1985a & b). The BPA analyses used a combination of numerical hydrodynamic modelling of individual model cyclones having a variety of intensities and tracks, and statistical modelling of the tidal variation. The selection of intensities and frequency of occurrence were based on the historical record of the time (circa 1980). The BPA study did not update estimates of storm tide within Moreton Bay but only provided estimates on the open coast between Cape Moreton and Point Danger.

Recently, a further update of storm tide levels was independently commissioned by Gold Coast City Council to assist in flood planning studies (H. Betts, Gold Coast City Council, personal communication, 2000). The predictions from these various studies are summarised in Table 4.4, where the indicated storm tide level considers the **combined effects of tide, storm surge and wave setup** as recommended by the various studies listed. Levels are given relative to AHD and the highest expected tidal level (HAT) is also indicated (from Queensland Transport, 1999).

Table 4.4: Predicted total storm tide levels for the South-East Queensland region

Site	Highest Astronomical Tide	Average Recurrence Interval (ARI) years				
		50	100	500	1000	Reference
	m above AHD	m on AHD	m on AHD	m on AHD	m on AHD	
Moreton Bay	1.47	2.3	2.5	3.2	3.5	BBW (1979)
Cape Moreton	1.20	2.0	2.0	2.2	2.2	BPA (1985b)
Point Lookout	1.18	2.0	2.0	2.2	2.2	"
Jumpinpin	1.13	2.0	2.1	2.2	2.3	"
Surfers Paradise	1.13	2.0	2.0	2.2	2.2	"
Point Danger	1.11	2.0	2.0	2.1	2.2	"
Gold Coast Seaway	1.13	1.9	2.1			GCCC(2000)
Coomera River Mouth	1.03	1.8	2.0			"

Harper (1998, Appendix D) uses the same data and extends the scenario range to the 10 000 year ARI event for all areas other than the Gold Coast Seaway and Coomera River mouth.

It can be seen that only very slight variation in total storm tide levels is expected along the open exposed coastline. Within The Broadwater (e.g. Coomera River) slightly lower levels are predicted for the more frequently occurring scenarios, whereas in Moreton Bay (including Deception Bay) significantly higher levels are indicated.

Climatic Variability: Figure 4.3 shows that the incidence of tropical cyclones can be quite variable from one year to the next. This is because of the complex set of factors which influence their genesis. For many years, one of the most frequently used indicators of seasonal cyclonic activity has been the so-called *El Niño*-Southern Oscillation (ENSO) phenomenon (Nicholls, 1992). This is the name given to a near-periodic (between one and three year) cycle of alternating cold and warm ocean temperatures between one side of the Pacific Ocean and the other. The *El Niño* phase sees abnormally warm ocean temperatures off the coast of South America and along the central and eastern Pacific equatorial zone, and simultaneously cooler ocean temperatures in the western Pacific and the Coral Sea. During the reverse cycle, or *La Niña*, ocean temperatures near the Queensland coast are typically above average. Ocean temperature is not the only factor causing cyclone variability but it is a prime contributor. When combined with associated shifts in large-scale zones of atmospheric convergence (Basher and Zheng, 1995), the regions of tropical cyclone genesis in the South Pacific tend, as a result, to move further towards the east (*El Niño*) or the west (*La Niña*).

There are several techniques used for determining the state or strength of the ENSO condition. One of the most widely used methods is the Southern Oscillation Index (SOI), which compares differences in the mean monthly sea level atmospheric pressure between Darwin and Tahiti. The SOI has been shown to be a strong indicator of rainfall and tropical cyclone activity in northern Australia and Queensland (e.g. Nicholls, 1992).

Another common method is to use sea surface temperature readings (SSTs) from various zones in the Pacific. These data have become routinely available from satellites as well as from ships, drifting buoys and from moored buoy networks positioned along the equator. Using an accepted SST-based sequence from 1959 to 1997 (e.g. from Pielke and Landsea, 1999), Figure 4.6 shows that when the historical record is separated into *El Niño* and *La Niña* periods, there is a quite noticeable effect on the tracks of tropical cyclones in the Coral Sea. During *La Niña* (the positive SOI phase), cyclone activity tends to be located closer to the east coast of Queensland and further south than during the *El Niño* (negative SOI) phase. While the ENSO phenomenon appears to be somewhat random, *El Niño* years have outnumbered *La Niña* years by about a factor of 3 since the mid-1970s. This has been reflected along much of the east coast of Queensland by a corresponding reduction in the frequency of cyclone occurrence and Figure 4.3 indicates this effect from about 1975 onwards within 500 km of Brisbane. Exactly why this preference for *El Niño* episodes has persisted during this period is not entirely clear but it may be related to longer period climatic variability as discussed below, or even global climate change. From 1998 to early 2000 there was a return to mild *La Niña* and near-neutral conditions.

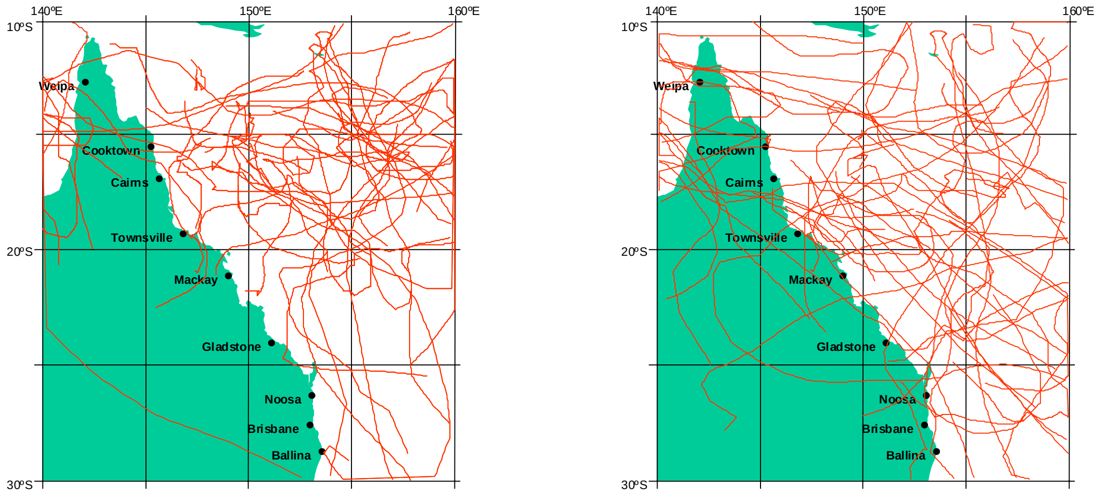


Figure 4.6: Differences in tropical cyclone tracks between *El Niño* (left) and *La Niña* (right) years.

Power and others (1999) recently highlighted the potential importance for Australian climate of an apparent 10 to 30 year longer-term cycle of ocean temperatures in the Pacific Ocean. This oscillation is also measured in terms of relative SST heating or cooling but relates more to the whole of the tropical Pacific Ocean region, rather than just differences between the eastern and western limits. Termed the Inter-decadal Pacific Oscillation (IPO), this long-term variation in mean SST appears to modulate the effect of ENSO on rainfall in Australia. When the IPO is ‘positive’, the tropical ocean is slightly warmer than average, while to the north and south, the temperatures are slightly less than average. During this period, the effect of ENSO on rainfall appears to be less significant. When the IPO is ‘negative’, the tropical ocean is slightly cooler and ENSO seems to be much more strongly correlated with Australian rainfall.

The IPO effect may also be related to the large-scale thermo-haline circulation between the Atlantic and the Pacific Ocean that has been identified as a potential indicator of hurricane incidence in the Atlantic (Landsea and others, 1994). Callaghan and Power (submitted *AMM*, 1999) describe a possible modulating effect of the IPO on Australian tropical cyclone activity which suggests that damaging impacts in Queensland are more likely during negative (cooler) phases of the IPO, which is associated with warmer ocean temperatures near Queensland. Since the mid-1970s, there has been a prolonged positive phase of the IPO that is only now (1999-2000) showing some possible signs of reversal. If this is correct, recent trends may suggest that cyclone incidences along the Queensland coast could increase, especially in the South-East. However, these outcomes remain speculative at this time since it will require several further years of observations to confirm whether the IPO phase is changing.

The South-East Queensland cyclone experience

Most tropical cyclones in the region occur during the period between December and March, although prior to the 1960s, some east coast lows (so-called 'winter cyclones') were also classified as tropical cyclones and appear in the archive during other months (see Chapter 5). Figure 4.7 shows the recorded monthly occurrences, combined with a closest approach analysis. February can be seen to have the highest incidence, with 34 cyclones, followed by March with 31, and January with 13. December and April are equal with 10 cyclones each. In terms of closest distance to Brisbane, February and March have similar proportions of about 15% being within 100 km. Half the storms have been at least 300 km distant.

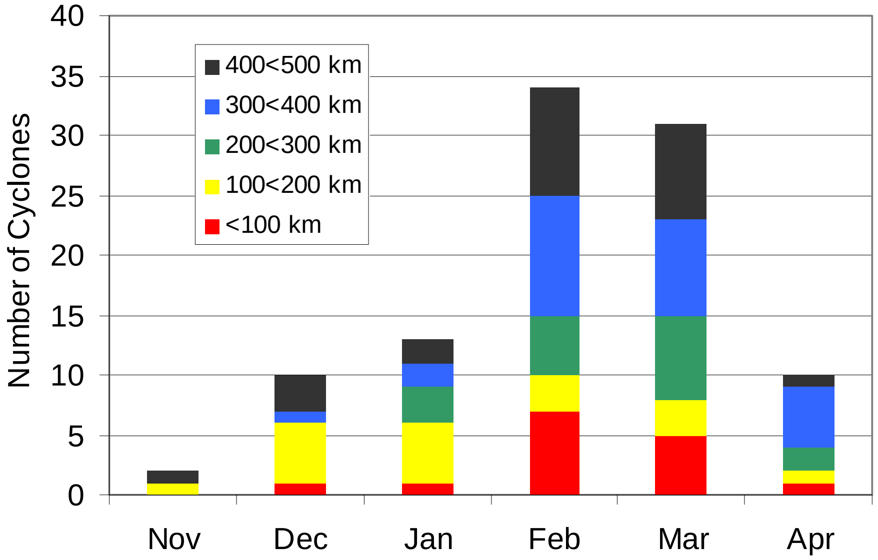
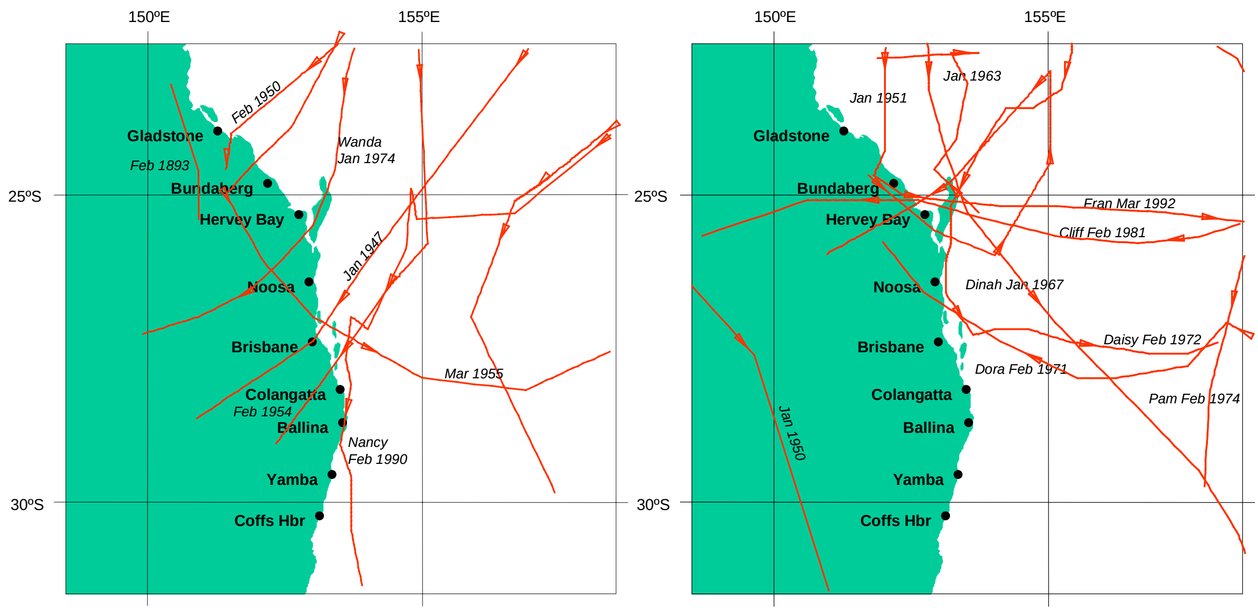


Figure 4.7: Seasonal distribution of tropical cyclones and closest approach analysis.

Individual tropical cyclone tracks can be quite variable and, when combined with their overall size and intensity, their impacts can also vary enormously. Figure 4.8 provides a selection of tracks of cyclones which have resulted in significant impacts in the South-East Queensland region. Figure 4.8a presents the tracks of 7 cyclones which caused severe flooding impacts. These include the infamous Brisbane River floods of February 1893 (907 mm rainfall at Crohamhurst north of Caboolture in 24 hours) and January 1974 (TC *Wanda)*, as well as a number of smaller but still significant events. Typically, these cyclones either crossed the coast and decayed inland or spent considerable time near the coast creating strong, moist, onshore flows. Figure 4.8b presents a selection of 9 cyclones whose impacts were more concentrated on the coast or caused significant wind damage. These include the January 1950 cyclone which originated in the Gulf of Carpentaria and actually passed 300 km inland but was accompanied by a strong and extensive circulation which created a 0.58 m storm surge in Moreton Bay.



(a) Flood impacts (b) Wind, wave and surge impacts

Figure 4.8: Selected tracks of tropical cyclones impacting South-East Queensland.

As tropical cyclones move into temperate latitudes they begin to interact with troughs in the middle to upper westerlies. There are three possible outcomes in South-East Queensland as a result of this interaction:

- the cyclone may remain far enough removed from these westerlies to retain tropical cyclone characteristics (e.g. TC *Dinah*);
- the westerlies may interfere destructively with the cyclone circulation and weaken it (e.g. TC *Nancy*); or,
- the cyclone may interact favourably with an upper trough to form an intense temperate latitude cyclone – collectively termed ‘extra-tropical cyclones’ in the literature.

This latter interaction is called *extra-tropical transition* and globally has been associated with some extreme tropical cyclone impacts in high latitudes. The 1938 ‘New England’ Hurricane in the United States is listed 4th on the list of all-time greatest US hurricane disasters (Pielke and Landsea 1998) and in 1968, TC *Gisselle* caused widespread destruction in New Zealand, sinking the *Wahine* in Wellington Harbour.

A recent Queensland example of a tropical system undergoing this type of potentially destructive transition at higher latitudes is TC *Lance* in April 1984. History now also records *Lance* as an east coast low in terms of its impact on South-East Queensland. Figure 4.9 illustrates the sequence of development of this system whereby *Lance* had decayed into a low pressure system east of Proserpine late on April 6th, losing its ‘tropical cyclone’ status. However, as it drifted south, its remnant circulation underwent rapid extra-tropical transition to the north and offshore of Brisbane, buffeting parts of the southern coast with 110 km/h winds over the next three days. Fortunately it maintained its distance from the coast, thus avoiding more major impact.

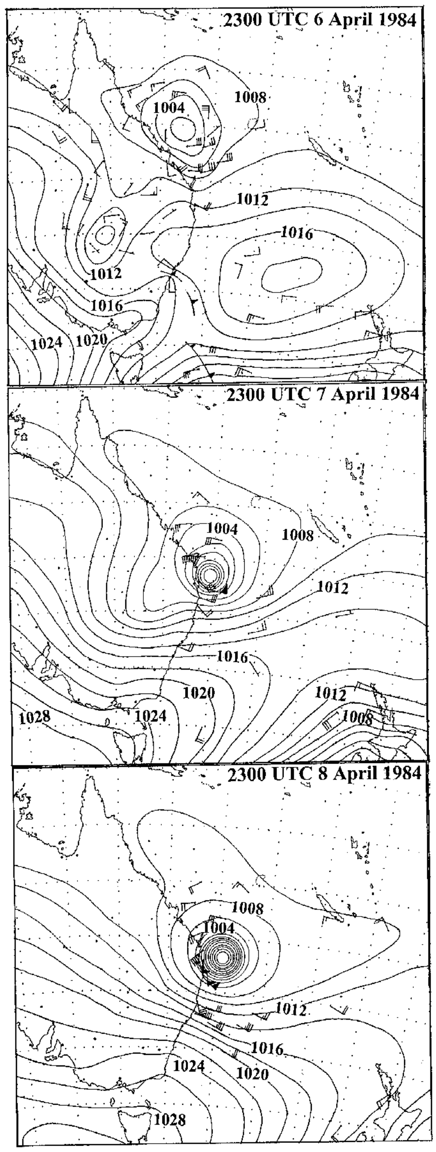


Figure 4.9: Extra-tropical transition of TC *Lance* in April 1984.

The severe wind threat

Tropical cyclones bring with them winds with potentially destructive gusts to more than 130 km/h within 100 km of the centre of Category 3 or greater events. These strong winds can persist for many hours, or even days, depending on the track of the storm, and can cause widespread building and infrastructure damage or even loss of life.

While it is the peak gust wind speed which generally causes building damage, the somewhat lower mean or sustained wind is responsible for the generation of allied coastal threats such as storm surge and its accompanying extreme waves and it is important in terms of the fatigue performance of roofing and in the performance of other structures such as transmission towers. It is very important that peak gust wind speed and mean wind speed are not confused. Due to the upper wind's interaction with the surface (including the ocean), frictional effects retard the upper mean airflow closer to the ground and this results in mechanical mixing. Together with convective influences, these processes lead to a variability which we know as 'gustiness' on top of the mean wind. In Australia, the mean wind standard is the 10 minute average, while the gust wind standard is the 3 second peak gust. The ratio between these two values during severe tropical cyclones is typically about 1.4 to 1.5 over-water and can be higher over-land, depending on the surface roughness. In and around Brisbane, the gust wind speed is the important factor.

Wind force is proportional to the square of the wind speed and as a result of consequential structural failure, damage tends to increase disproportionately to the wind speed. According to Meyer (1997), winds of 250 km/h cause, on average, 70 times the damage of winds of 125 km/h. Damage tends to start when peak gust wind speeds begin to exceed 110 km/h. In addition to the high wind speeds, the turbulence of the winds caused by terrain features and large buildings is also an important factor.

Buildings: The construction, design, age and location of buildings each have an influence on the risk of building damage. Generally, however, the more brittle the exposed building material and the weaker the connection between building elements, the greater the susceptibility to wind and debris damage. Advances made in cyclone resistant construction since the 1970s have resulted in improved building performance under wind loads. For houses built since 1980, or ones which have had their roofing systems upgraded to the new standards, *there shouldn't be any serious problems unless very extreme winds occur, they have been poorly constructed, or … a door or window* (has been left) *open* (George Walker, Aon Group Australia Ltd, written communication, 2001).

Roof shape and pitch are influential. In simple terms, gable ended roofs take the full force of the wind, whereas the wind flows more smoothly over hip ended roofs. Depending on wind direction, flat or low pitched roofs can experience greater levels of suction than do high pitched roofs. Hip ended roofs with a pitch of around 30^o tend to perform the best in buildings not designed for wind. In modern construction there is unlikely to be any significant difference in performance as the differences in wind pressures are taken into account in the design. The fastening of roofing material to trusses and the fastening of roof members to walls and foundations are also important.

Building age is highly significant because it reflects both the degree of conformance to the *Building Act*, and the degree to which factors such as metal fatigue and the corrosion of metal fixings may have progressed. Mahendran (1995), for example, reported that exposure of metal roofs to strong winds sets up fatigue around the fastening screws. Roofs in which fatigue has been established, and is exacerbated by further events, may subsequently fail in winds significantly lighter than those that they were designed to withstand. Corrosion of metal fixings such as nails, screws, straps and bolts, especially in the salt laden atmosphere of coastal areas, may also reduce structural integrity over time.

Temporary forms of construction such as caravans and tents are particularly vulnerable to high wind speeds. These types of construction generally lack a secure fixing to the ground and hence are easily toppled or blown away. These types of residences are not considered in this analysis.

Some of the key forces on buildings are illustrated in Figure 4.10 and Figure 4.11. The first figure shows the way in which the suction forces generated on low pitched roofs may be countered by a reduced pressure inside the building where the integrity of the windward walls and windows are maintained and there is a predominance of openings on the leeward side. The second figure shows how an overpressure inside the building is created when that integrity is compromised by a window being broken on the windward side. The additional force can destroy the roof, if not the whole structure.

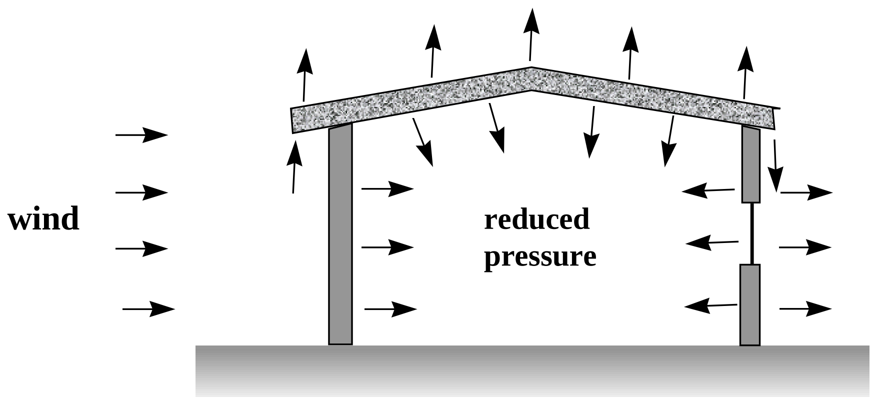


Figure 4.10 Wind forces working on a building with external integrity

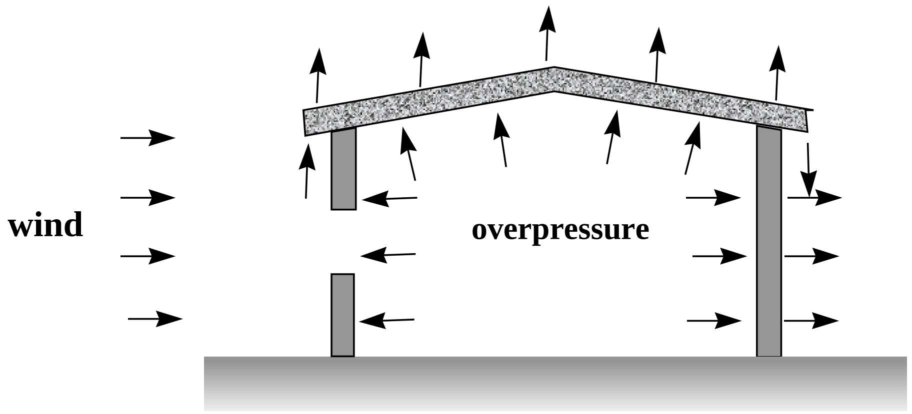


Figure 4.11 Wind forces working on a building where its external integrity is lost

Wind loading standards in Australia were first implemented by structural engineers in 1952 and have been variously updated over time. After the experience of the severe destruction wrought by TC *Althea* (Townsville) in 1971 and TC *Tracy* (Darwin) in 1974, special efforts were made to strengthen building standards in Queensland and elsewhere in Australia, especially for domestic structures. Standard *AS1170.2 Minimum design loads on structures: Part 2 – Wind loads* was first published in 1973 and was subsequently revised in 1975, 1981 and 1983. The current (5th) edition was published in 1989 (Standards Australia, 1989). This Standard was first adopted under the Queensland *Building Act* in 1975. Before this, each local authority had its own building regulations, and many authorities would have referred to the wind code. However, housing was not explicitly addressed in the *Act* until 1981. Implementation of the 1981 publication did not occur until 1 July 1982 (George Walker, Aon Group Australia Ltd, written communication, 2001). *AS1170.2* is now encompassed by the Building Code of Australia. The wind loading code is based on a design event for which there is a 5% probability of exceedence in any 50 year period (i.e. a notional 1000 year ARI or 0.1% AEP).

Severe Wind Risk Assessment

Methodology:

The impact of severe winds in tropical cyclones will vary considerably from site to site because of the influences of local terrain and topographic factors. These relate primarily to:

- terrain 'roughness' (e.g. open sea, fields, trees, houses, etc);
- shielding or interference from adjacent objects (e.g. other buildings); and,
- topographic effects on slopes and the near the tops of hills.

The wind loading code makes significant allowance for these site factors. These site factors have been determined on a property-by-property basis. Terrain and shielding effects have been accounted for by categorisation of properties into five groups; "Foreshore", "Inland", "Town", "Town Centre" and "Foreshore Town", as illustrated in Figure 4.12. The site classes and site nomenclature were derived in part from the approach of Harper (1999a).The relevant terrain and shielding factors, which allow a reduction of the basic wind speed under *AS1170.2-1989* rules, are given in Table 4.5. Although the categories are few and broad in nature, they are considered to be sufficient for risk assessment on a broad scale. Local variations in terrain roughness due to the existence of open spaces within urban areas, variations in vegetation types, or local shielding effects from nearby buildings, for example, are not considered, although a more detailed analysis would require this.

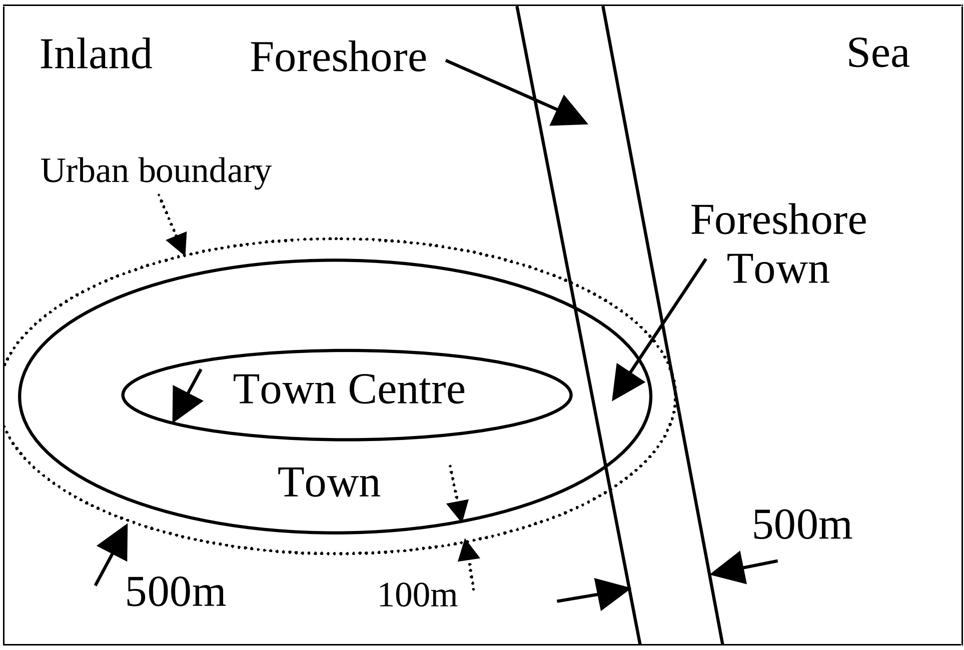


Figure 4.12 Classification scheme for the five terrain/shielding categories

Table 4.5 Terrain and shielding multipliers

Category	AS1170.2 Terrain Category	Building Height, z (m)	Terrain multiplier, $M_{z,cat}$	Shielding multiplier, M_s
Foreshore	2.0	7	0.946	1.0
Town	2.5	7	0.864	0.85
Inland	2.5	7	0.864	1.0
Foreshore Town	2.0	7	0.946	0.85
Town Centre	3.0	7	0.782	0.85

Topographic effects were calculated for north, south, east and west wind directions, on a 200 m grid, with elevation derived from a 10 m grid Digital Elevation Model (DEM). In some parts of the region, the DEM was coarser because detailed topographic information was not available. The effect of using a coarser DEM grid is that wind risk will be slightly underestimated because topographic 'highs' and 'lows' are smoothed out. The affected areas are in minor parts of Caboolture Shire and all of Pine

Rivers, where AUSLIG's Three Second DEM was used (grid cell approximately 100 m), and Brisbane City, where a 20 m grid cell was used.

The method used is in accordance with *AS1170.2*. An example of how the topographic factor varies along a surface profile is shown in Figure 4.13. The topographic factor increases the basic wind speed, which is referenced to flat, open terrain.

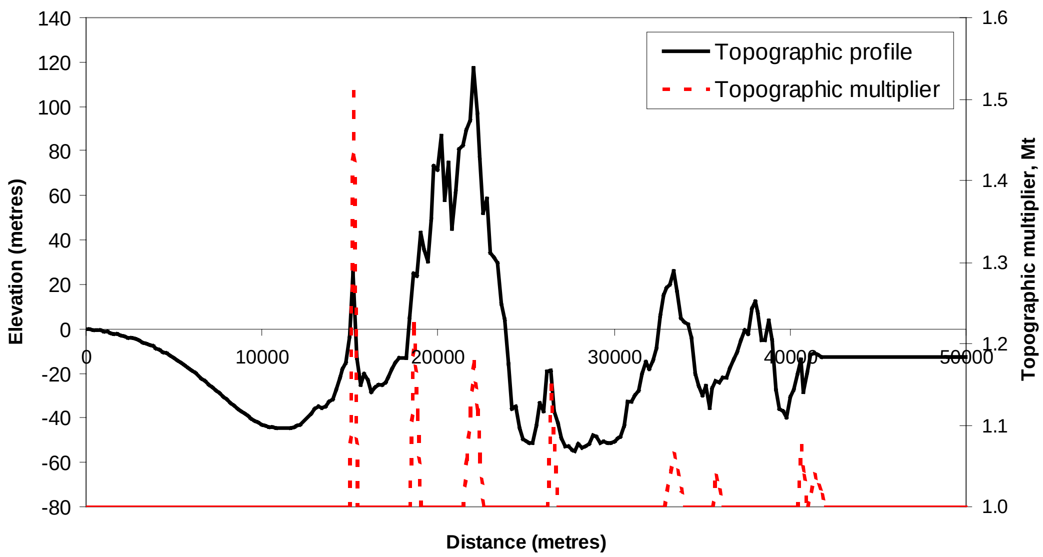


Figure 4.13 An example of variation in the topographic multiplier for a single surface profile

Although South-East Queensland has some hilly terrain, topographic effects are generally not important because most of the urban development is located on flat areas. High values for the topographic factor, which can reach a maximum of 1.54, apply to only a very small percentage of properties.

For the modelling of building vulnerability to wind, two age classes have been established, that is, nominally pre- and post-1980. Damage loss curves for these two age classes were previously developed by Walker (1994), based on insurance industry experience in Australia, and are shown in Figure 4.14. The high level of uncertainty associated with these curves should be recognised.

Harper (1999a, p. 20) made the following points:

> *The problem in estimating domestic quality building behaviour in strong winds stems from a number of issues:*
>
> - *relatively few instances of severe damage being available;*
> - *a lack of accurate wind measurements at, or near building exposure conditions;*
> - *structural redundancy, variable load paths and variety of fixings;*
> - *wide variations in building style and quality of construction; and,*
> - *second-order effects such as debris damage.*
>
> *Based on damage assessments undertaken primarily for the insurance industry* (since 1971) *it has been possible to develop indicative 'damage curves' for Australian domestic construction (Walker 1994, Harper and Holland 1998) which are also deemed consistent with US experience in Hurricane* 'Andrew' *(Sparkes 1993).*

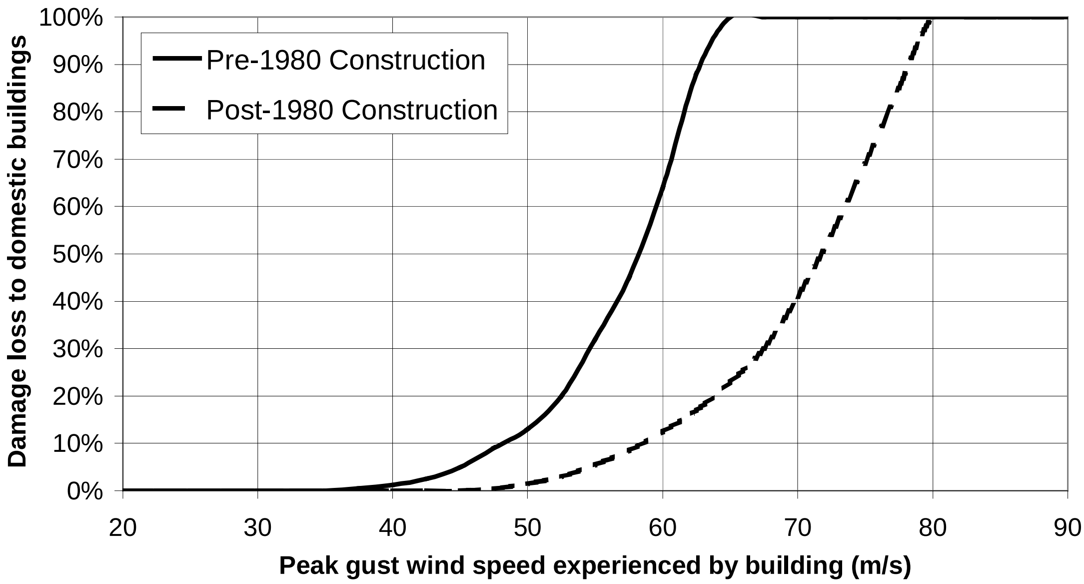


Figure 4.14 'Damage loss curves' (adapted from Harper, 1999a; originally developed by Walker, 1994)

The damage loss curves presented by Harper (1999a), and reproduced here in Figure 4.14, clearly illustrate the significance of the introduction of mandatory building standards in the 1980s. This point was evident in the experience of the impact of TC *Winifred* near Innisfail in 1986 and most recently with TC *Vance* at Onslow in Western Australia in 1999 (Reardon, Henderson and Ginger, 1999). The percent damage loss values shown are relative to the nominal insured value of a single, 'typical' dwelling and associated assets, or, when aggregated, the total residential building stock. Industrial and commercial buildings, where individual engineering design and inspection have been applied, may be expected to suffer significantly less damage than dwellings in similar conditions. This is not always the case, however, as was observed in the damage to Dubbo caused by a severe thunderstorm on 6 January, 2001 (Stehle and Henderson, in prep.). Nonetheless, the percentage losses assessed here, for residential properties only, are considered to be indicative of the total urban losses.

Although *AS1170.2-1989* presents guidance on the estimated peak gust wind speed for Brisbane as a function of ARI, application of point wind speed estimates across an entire urban community is not appropriate because it will overestimate the potential damage to the community. This is due to the complex spatial variation in tropical cyclones (especially near the eye, etc.) and the likelihood of decay of the wind strength with increasing radius from the centre of a cyclone, and decay of wind strength as a cyclone moves inland. It has also been suggested that the tropical cyclone wind hazard, as represented by *AS1170.2*, is more conservative than recorded tropical cyclone wind data and advanced numerical modelling suggests (Harper, 1999b).

Hence, to explore the community-wide wind hazard potential in Southeast Queensland, a series of synthetically generated tropical cyclone wind fields have been supplied by Dr Harper at Systems Engineering Australia Pty Ltd (SEA), expressly for use in this study. These modelled maximum envelope wind gust data have wind speeds that approximate the return period wind speed for ARIs 100, 200, 500, 1000, 2000 and 5000 years at one of three reference sites according to the model of Harper (1999b). The three reference sites are Brisbane GPO, Caboolture GPO and Bundall in Gold Coast. For each ARI being considered, the potentially high spatial variability of the cyclonic winds (due to track, speed, size, etc.) has been approximated by taking 30 sample scenarios, each of which produces a similar peak wind speed at a reference point but not necessarily at any other point. For each ARI, ten scenario events have return period wind speeds referred to the Caboolture site, 10 events have return period wind speeds referred to the Brisbane site, and 10 have return period wind speeds referred to the Gold Coast site. A single scenario representing a maximum credible (simulated 50 000 year return period) wind speed at each of the three reference sites was also supplied. A total of 180 synthetic storms were generated, excluding the 50 000 year ARI events. These events are intended to be a representative sample of the broad range of possible scenario cyclonic events that could impact on the region in all time frames.

The wind swath for each scenario event consists of values of peak wind gust speed and direction on a uniform grid. These values were then interpolated to values at the centroid of each CCD for damage calculations. The damage level to houses and flats was calculated for each CCD, for each scenario event. Damage to the flats and houses in the entire South-East Queensland region was also calculated for each scenario event.

Each loss scenario was associated with a probability of occurrence equal to one-thirtieth of the probability of an individual scenario storm for a given ARI. For example, a particular storm that has a 100-year ARI wind speed at Brisbane GPO is assigned a probability of occurrence of 1 ÷ 100 ÷ 30 = 0.033%. The losses associated with this storm have the same probability of occurrence as the storm.

Cumulative loss curves for each CCD, and for the entire South-East Queensland region, were prepared by aggregating the probabilities of exceedence of various loss levels for all 180 scenario storms. A relationship describing the ARIs at which various levels of damage were exceeded was developed from the loss curve.

Results:

Before the results of the wind and storm tide loss assessments are presented, it must be pointed out that very significant uncertainties are associated with the estimates of damage losses presented here for severe wind and storm tide. Therefore, the reader should treat the estimates of damage losses as indicative only. Refer to the comments on limits and uncertainties in this chapter.

Limits and uncertainties in the wind risk assessment include, but are not confined to:

- uncertainty in the hazard model. Uncertainties originate from the inherent variability of cyclonic wind fields, from uncertainties due to assumptions made in the parametric hazard model, from the incomplete sampling of the total probability space of synthetic cyclone events, from assumptions made about the probabilities of events selected from the synthetic catalogue, and from the short and incomplete historical record of cyclonic winds in Southeast Queensland that is used as a reference for the hazard model;
- uncertainty in the terrain model. AGSO's GIS-based approach of developing the terrain model is innovative. However, the terrain model was developed for a broad-scale study and it will contain inaccuracies at the individual parcel level. Uncertainties in the terrain factors will arise from assumptions made in *AS1170.2*. The time-dependent interaction of the cyclones with the terrain and built environment is not modelled;
- uncertainty in the building damage loss model. Some of these uncertainties have been mentioned earlier in this chapter. Additionally, although the building damage loss model is based on Australian data, the data refer to dwellings constructed in cyclonic areas. Dwellings constructed in Region B of *AS1170.2* will have different performance characteristics from modern dwellings constructed to wind codes in cyclonic areas;
- uncertainties and incompleteness of the property inventory for information such as building age, condition, and compliance with wind loading standards; and

- limitation on the scope of the risk assessment. The analysis does not consider non-residential structures such as commercial, industrial and infrastructure facilities. Nor does it consider direct or indirect economic or social losses, or casualties, that are a consequence of building damage. Hence, significant further analysis is required to develop a more comprehensive understanding of how the community could be affected.

A more rigorous analysis would account for all of these uncertainties and limitations, although it would entail considerable additional effort.

A summary of the tropical cyclone severe wind damage losses in the South-East Queensland region is given in Table 4.6 and plotted in Figure 4.15. Damage losses are expressed as a percentage of the total insured value of a 'typical' residential building and its contents. Alternatively, the damage losses can be considered as a percentage of the total insured value of all of the residential buildings and their contents. The losses are the minimum losses expected for the probability associated with that loss. For example, there is an annual probability of 0.2% that damage losses will be 0.23% of the total insured value, or higher than 0.23% (Table 4.6).

For an annual probability of 0.1%, damage losses are calculated to be equivalent to the repair or replacement cost of at least 1500 dwellings, or approximately 0.23% of the total residential building stock. This AEP corresponds approximately to the likelihood of the design event in *AS1170.2-1989*.

Table 4.6 Residential damage losses for cyclonic winds in South-East Queensland

ARI (years)	AEP	Damage (insured value of building and contents – equivalent number of houses and flats)	Damage (% of total insured value of building and contents for houses and flats)
100	1.0%	150	0.024%
200	0.5%	500	0.078%
500	0.2%	1050	0.16%
1000	0.1%	1500	0.23%
2000	0.050%	1800	0.28%
5000	0.020%	2500	0.38%

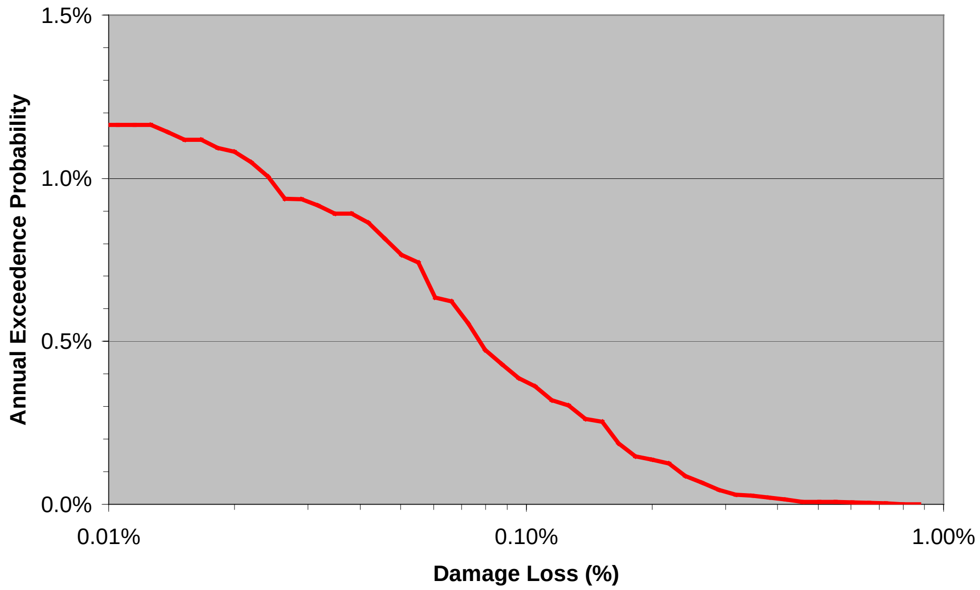


Figure 4.15 Cumulative tropical cyclone wind damage losses for residential buildings in South-East Queensland

The reader should note that, typically, the South-East Queensland region is larger than the spatial extent of damaging winds from the synthetic windfields of the scenario cyclones. For example, a scenario cyclone selected for its damaging windspeeds in the Gold Coast may have windspeeds at Caboolture that would cause little or no damage. Similarly, a scenario cyclone selected for its potentially damaging winds in Caboolture may have lesser windspeeds in Logan and Gold Coast. The estimates of damage losses to the South-East Queensland region, in its entirety, are therefore reduced compared to estimates of damage to individual LGAs with scenario cyclones that pass close to those individual LGAs.

A probabilistic distribution of potential tropical cyclone wind damage risk across the South-East Queensland region is shown in Figure 4.16. The annual risk to each CCD is shown. The risk is defined in terms of the percentage loss of the insured value of a 'typical' residence including contents or, alternatively, the percentage loss of the insured value of the residential building stock and contents (multiplied by an annual probability of one). The percentages in the legend of Figure 4.16 must be multiplied by 10^{-6}. All of the scenario storms were used to prepare the map.

The damage patterns, and the severity of damage, will be different for each individual scenario event (and each real event), and each of these will be different from the probabilistic map shown in Figure 4.16. The level of damage in each CCD from individual scenarios ranges from negligible upwards, depending on the spatial patterns of wind gust velocities, and their interaction with the terrain and topography model.

The spatial pattern of damage losses strongly indicates areas of older construction, exposed terrain (especially adjacent to the coast and major waterways) and steep topography, according to the assumptions of the analytical model. Settlements having more than one of these attributes are particularly at risk of above-average wind damage levels.

Areas of relatively old (pre-1980) settlement are expected to suffer stronger damage than newer areas. These affected areas of older settlements include parts of Redcliffe, older suburbs in Ipswich such as Ipswich and Leichhardt, older suburbs in Logan such as Loganholme and Slacks Creek, and older suburbs of Brisbane including Hendra, Pinkenba, and parts of Hamilton, Bowen Hills, Mansfield and Nundah.

The expected damage to older settlements near the coast is estimated to be almost 100 times greater than the average residential damage across the entire region. Brighton, Sandgate, Shorncliffe, Wynnum, Manly, and Lota are examples of those suburbs most at risk of damage. Coolangatta, Surfers Paradise and Burleigh Heads are also expected to suffer significantly higher wind damage than the regional average.

On the other hand, large areas of urbanisation offer significant shielding from severe winds and, in these areas, modelled damage is reduced compared to damage in areas where urbanisation is less dense. This is the case in a very large area of Brisbane, extending South from Zillmere and Apsley to the Brisbane River, and South from Brisbane City to suburbs such as Coorparoo, Greenslopes and Camp Hill.

Residences that are not shielded by other buildings, such as those in semi rural areas, are also expected to suffer higher damage rates than residences of similar age in more densely urbanised settlements. However, the numbers of dwellings in such areas are relatively small compared to those in the main urban areas, although this may be little satisfaction to those potentially affected. Such areas include Gumdale and Chandler in South-East Brisbane, and the northern parts of Caboolture Shire such as Elimbah.

Areas of predominantly new dwellings (post-1980) are expected to fare relatively well in future strong winds. Redland is a good example, where about 62% of all buildings were constructed after 1980. Cyclonic wind risk is relatively low, despite Redland's coastal location.

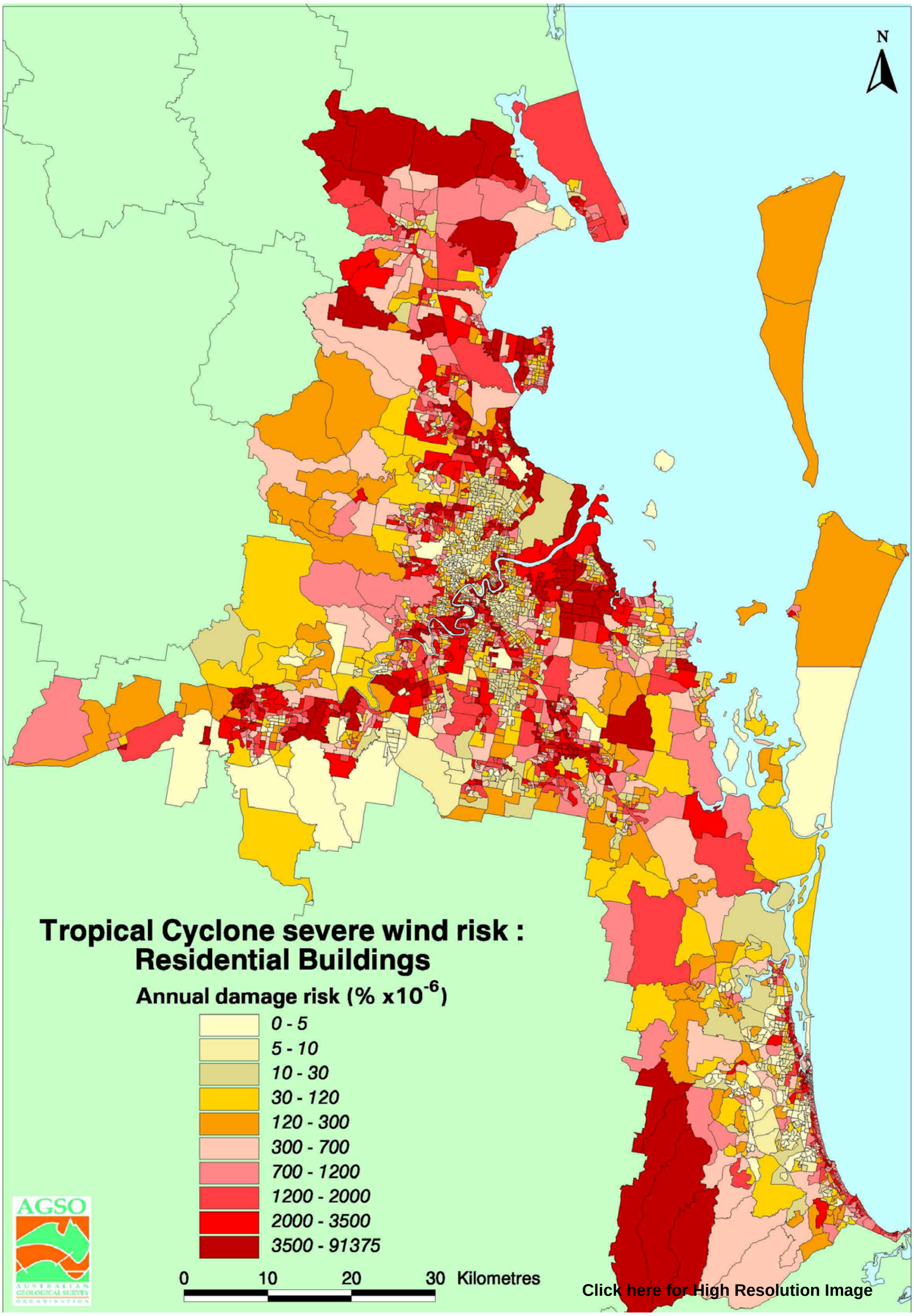


Figure 4.16 Annual tropical cyclone severe wind risk to residential buildings. Units are the percentage of the insured value of a 'typical' residence including contents, multiplied by 10^{-6} (see text)

Comments on risk to lifelines and other assets: With most cyclones that approach to within the radius of maximum winds, the greatest amount of inconvenience has been caused by damage to the power reticulation infrastructure. Power lines are often brought down by tree branches, palm fronds and other wind-blown debris. Electricity authorities in coastal areas of Queensland tend to maintain good clearance of trees from power lines and the more critical areas tend to be serviced by underground mains. Power poles and pylons may be brought down by high winds. In the Brisbane Valley, near Esk, in 1999, for example, several transmission line pylons were brought down in extreme wind gusts associated with a local storm . Also, in TC *Steve* in Cairns (late February 2000), several poles were pushed out of the vertical because their foundations had been saturated by up to four weeks of repeated heavy rainfall.

Tree and branch-fall also represents a significant threat to buildings and other assets such as cars. Trees and branches will also block roads and may even dislocate underground utilities, such as water mains, if their root systems are extensive. Again, saturation of the soil prior to severe wind will increase the likelihood of trees being brought down. The disposal of debris produced by wind damage to trees in cyclones can present Council waste managers with a major challenge.

Strong winds also pose a threat to telecommunications, especially those which utilise above ground infrastructure such as microwave dishes, aerials, radio transponders and satellite dishes. This infrastructure is particularly susceptible because most of it relies on line-of-sight operation. The misalignment of antennae by the wind will disrupt the networks that they support. In stronger winds, large transmission or relay towers may even be brought down.

Strong winds approaching from over the sea, as in tropical cyclones and east coast lows, also carry salt spray from the surf for many kilometres inland. This has a short-term impact on vegetation through scalding, but will also have a longer-term impact on ferrous metal in buildings, cars, and so on, unless it is washed away by fresh water fairly quickly.

Storm Tide Risk

Whilst severe wind is likely to cause the most widespread damage, storm tide has the potential to cause significant property and infrastructure damage, and potentially serious loss of life, though this would be confined to developed areas on low lying coastal and riverside terrain. Storm tide risk is very much confined by topography.

Most models and hazard maps of storm tide adopt a ‘still water’ inundation approach that simply delimits the area affected by the horizontal contour equivalent to the storm tide elevation. The ‘still water’ models typically do not take account of any wave setup, wave runup or waves on top of the storm tide produced by wind as it moves inland. The model we use here, however, does take those components into account.

Sea wave height and power decay rapidly as the surge moves inland. Smith and Greenaway (1994, Figure 3.7), for example, provide a curve representing ‘velocity decay’, relative to distance from the shoreline, for Mackay. This curve was based on the North American experience of storm tide and shows that the velocity of sea waves, based on a wind speed of 130 km/h, declines from 1.54 m/sec to 0.5 m/sec within 500 m of the shore.

Whilst the destructive potential of sea waves declines rapidly inland, shallow water, wind-driven waves may be present in some areas inundated by the storm tide. With the inshore propagation of the storm surge, wind waves can propagate substantially further inland than would normally occur, producing unusual erosion or deposition. Jelenianski (1989, cited in Chowdhury, 1994), calculated that the height of wind waves in shallow waters (crest to trough) could be as much as 50% to 75% of the depth of over-land inundation. For convenience of model computation we adopted an overall average of 60%. The addition to total water level by these waves would, therefore, be half of that value, i.e. 30%.

Inundation depth is important, not only because of the damage caused by immersion, but also because of the stress placed on structures by moving water and waves. Smith and Greenaway (op. cit, p. 38) make the assumption that 'if the combination of still-water and wave height exceeded floor level by 1 m building failure will occur.' In the USA, the Federal Emergency Management Agency (FEMA) have adopted 1 m above floor level as their 'base flood elevation' for calculations of planning constraints and flood insurance exposure. The significance of this elevation was demonstrated in coastal areas that experienced the impact of Hurricane *Hugo* in 1989. FEMA (1992), quoted by Smith and Greenaway (ibid), state that:

> *Practically all residential structures not elevated above the base flood level sustained major damage or complete destruction, from either collapse under wave force, floating off foundations, or water washing through and demolishing the structures… as long as adequate openings were left under the living space, Hugo's surge and waves passed beneath* [properly elevated] *structures.*

It is important to note that no concession is made regarding the form of construction. It is likely, however, that structures engineered to withstand the high levels of lateral loads typical of those established in the wind or earthquake components of the Australian Design Loading Standards, would perform better than those built to lesser levels of strength. One would expect light timber-framed buildings with fibro cladding to be less resilient than reinforced concrete block buildings, for example. The experience in the USA indicates that substantial engineered buildings are not immune to total destruction from storm tide, especially if they are located along the foreshore 'front row' where sea wave power and height are at their greatest. The literature is not clear, however, as to the degree of risk associated with inundation of water of more than 1 m over floor level at distance from the shoreline where water velocity is relatively minimal, i.e. more than say 1.5 km from the shore, as could be the case in some parts of South-East Queensland.

The scouring associated with the retreating water at the next low tide may further attack structures weakened by the initial impact of the storm tide. Scouring may also damage roads, bridge approaches and underground utilities, such as water mains, in some areas.

People who remain in areas subject to storm tide inundation are at substantial risk of drowning, especially if they are out of doors. Even where people are inside their houses or other shelter, the risk of drowning increases with the height of water over floor level. Clearly, those people sheltering in buildings that are likely to have more than 1 m over floor level should be evacuated well before the cyclone crosses the coast.

In addition to the loss caused by the severe damage to, or demolition of buildings, the damage done to building contents would be substantial. Smith and Greenaway (ibid) assume a total loss of contents, such as floor coverings, built-in cupboards, white goods and commercial stock, where inundation is simply over floor level. They do not, however, take account of damage to assets, such as vehicles or mechanical equipment exposed at ground level. The life of electrical or electronic facilities, such as electric motors or underground telecommunications infrastructure, will be significantly reduced, if not terminated, should they be exposed to inundation. Given that seawater is involved, corrosion is probably a greater problem than with fresh (muddy) water associated river flooding.

Salt scalding is also likely to cause the loss of plants. There is little evidence in the literature, however, of storm tide inundation causing long-term harm to agricultural production as a result of soil salination, probably because the salt is typically flushed away by heavy rain or river flooding following cyclone impact.

Storm Tide Scenarios

The total storm tide height (i.e. the combined total of storm surge, atmospheric tide and wave setup above AHD) annual exceedence probabilities cited in Table 4.4 and Appendix 2 in Harper (1998), have been used to model the impact of storm tide inundation for 2%, 1%, 0.2%, 0.1% and 0.01% AEP scenarios (i.e. ARI of 50, 100, 500, 1000 and 10 000 years respectively) on developed properties in South-East Queensland. The modelling was aimed at identifying:

- developed properties that would be inundated to more than 1 m over floor;
- developed properties that would have water over the floor but less than 1 m in depth;
- developed properties that would have water on the property but not over floor level;
- developed properties that would be free of inundation.

To take account of the wind-driven wave component, an allowance of 30% of the mean depth of over-ground level inundation of the total storm tide is made for shallow water wind waves in the calculation of over-floor inundation. This is based on half the wave height value which is calculated at 60% of average over-land water depth.

Properties that are within 150 m of the shoreline which have over-floor inundation are considered to be at heightened risk posed by sea wave velocity and a degree of additional inundation from the broken (foam) component of waves that break close to the shore line. Although this distance is arbitrary, the authors consider it to be a reasonable estimate and a pertinent issue.

At present, published model results do not indicate the movement of surge onshore or the lateral translation of that surge. In light of the uncertainties surrounding these aspects of surge it has not been possible to apply any spatial constraints, other than ground elevation, in this study. As such, the analysis produces a generic ‘worst case’ assessment of storm tide exposure across the area of study. This potential over-estimation of the spatial extent must be taken into account when interpreting cyclonic storm tide risk. It is hoped it may be more clearly defined with the application of more advanced modelling capabilities.

This conservative approach is consistent with the stated needs of emergency managers who must plan to cope with such events. The resulting figures should be seen as reflecting the upper level of impact estimates.

Data uncertainty: In this model, the key values of floor height and ground height were taken from the detailed property database described in Chapter 3. Floor heights have been estimated on the basis of building age rather than field survey, as was done by the *Cities Project* in Cairns, Mackay and Gladstone. A broad generalisation has been adopted where houses built before 1980 will have a suspended floor at least 0.8 m above ground level and houses built after 1980 will be on a slab (0.3 m above ground level). No allowance has been made for the high-set ‘Queenslander’ style house so common in northern Queensland. Observation of high set houses in coastal areas of South-East Queensland indicates that where such houses exist, the under-house areas have almost all been enclosed, thus making them two story houses with floor heights at 0.3 m. Again these are perhaps conservative assumptions. Non-residential buildings are all assumed to have a floor height of 0.3 m above ground level.

The ground height for each property was interpolated in the GIS from the Digital Elevation Model (DEM) developed by AGSO from a range of sources. In the low lying coastal areas at risk from storm tide inundation, the accuracy of the DEM is, at best, in the plus-or-minus 0.3 to 0.5 m range. The use of such ‘imprecise’ data may seem to introduce potentially significant error or uncertainty in the outcome. It should be recognised, however, that the error estimates for the AGSO DEM are substantially less than those published for the original topographic data and are the very best available. Unfortunately, DEM data covering the coastal areas of Caboolture Shire (e.g. Bribie Island, Beachmere and Deception Bay) were not available at an appropriate resolution for this study. In these areas we have resorted to making 'best guess' estimates based on the network of permanent survey marks (PSM) maintained by the Department of Natural Resources, local knowledge and reports of historic events. The DEM data for Brisbane pre-dates the development of the current international airport and much of the Fisherman Island port area, both of which have been subject to significant filling since that time. Where possible, allowance for that work has been taken into account.

There are also uncertainties associated with the inundation models used. For example, the uniform wave setup value recommended by the BPA, is sensitive to wave energy which is influenced by cyclone characteristics such as track, velocity and so on.

These uncertainties relate to **absolute** accuracy. In our application of these data, however, we are more interested in **relative** accuracy, which appears to be quite consistent across regions with similar topography. Given all of the other uncertainties in the model (e.g. with surge height estimates), and the degree of generalisation involved in the analytical process, the uncertainties in elevation (and other input items), probably make little overall difference to the final assessment. Certainly the results reported here are conservative but appear to be both realistic and logical.

The storm tide risk model: The properties subject to inundation at various depths under the five scenarios were identified using the following models for:

- inundation over ground level only: *Gd_ht <std + sww*
- inundation over floor level: *Fl_ht + Gd_ht <std + sww*
- inundation > 1.0 m over floor level: *Fl_ht* + 1 + *Gd_ht <std + sww*

where:

Gd_ht is the height of the ground above AHD;
Std is total storm tide height;
Fl_ht is the height of the building floor above ground level;
Sww is the height allowance for shallow water wind waves calculated as 30% of the mean depth of over-ground inundation.

Modelling results are presented separately for the area inside Moreton Bay and for the Gold Coast area facing the Coral Sea. This is to take account of the different estimated storm tide heights likely to be experienced in each area, as outlined in Table 4.4. Whilst the damage estimates for the Gold Coast area could be generated by a single tropical cyclone, it is unlikely, given its much greater spatial extent, that a single cyclone would have an equal impact throughout Moreton Bay. The estimates for the area inside Moreton Bay, therefore, represent the aggregate damage for the range of cyclones that would be experienced for the given AEP. Given the significant unpredictability of cyclone behaviour, however, it would be prudent, from both personal and public safety perspectives, to assume that the effects modelled **could** be produced by a single cyclone event.

Assumptions: In the following scenarios two key assumptions have been made. First, that there will be no significant land-based flooding prior to the storm tide impact. We feel that this is a reasonable assumption given that significant storm surges are more likely to be associated with cyclones that move rapidly over the ocean and approach the coast at close to right angles. Such cyclones are less likely than slow moving cyclones to be preceded by substantial rainfall. This assumption appears to be reasonable based on historic experience elsewhere in Queensland.

The second assumption is that the population will be concentrated at their place of residence at the time of impact. We feel that this is also a reasonable assumption, given that there would be 24 and 48 hours warning of the impending cyclone impact and that families would seek shelter together at home wherever possible. This is in contrast to the situation with earthquakes (see Chapter 8), where a range of population distribution scenarios (e.g. day, night, weekend, holiday period, etc.) needs to be considered.

It should be noted that the numbers of properties identified as 'not affected' in each of the following scenario include those in Ipswich and Logan Cities and Pine Rivers Shire where there is no exposure to storm tide.

The 2.0% AEP scenario: Under this scenario a total storm tide elevation above AHD of 2.3 m would be experienced inside Moreton Bay (i.e. roughly 1.5 m above mean high water spring tides (MHWS) or 0.9 m above HAT); a 2.0 m elevation would be experienced along the open Coral Sea coast (1.35 m above MHWS and 0.9 m above HAT); and 1.8 m inside The Broadwater. The modelled impact (with all the caveats outlined above), in terms of the inundation of developed properties is summarised in Table 4.7.

Table 4.7 Developed properties affected by a 2.0% AEP storm tide

Level of Inundation	Moreton Bay	Coral Sea	Region
>1m over floor	350	50	400
<1m over floor	5350	1200	6750
on property but below floor level	10 250	4050	14 300
not affected	548 850	114 300	663 150

Overall, the impact of a 2.0% AEP (ARI of 50 years) storm tide event would have minimal impact on a regional basis with only 1.0% of all developed properties likely to be affected by over-floor inundation. Such an event would, however, certainly cause damage to buildings and short-term dislocation in a few localised areas. Inside Moreton Bay, the main areas of concern would be those facing Pumicestone Passage (notably Donnybrook, Toorbul, Bellara and Bongaree), Deception Bay (Godwin Beach, Beachmere, Deception Bay and Scarborough) and Bramble Bay (Woody Point, Clontarf, Brighton, Sandgate, Shorncliffe and Nudgee Beach) in the northern section; along the Brisbane River and its major tributaries (especially along Bulimba Creek, Breakfast Creek and Norman Creek) and the north-facing coastal areas such as Birkdale, Cleveland and Victoria Point as well as the low lying areas of the Bay Islands (such as Coochiemudlo, Macleay and Russell), in the south of the Bay. In all, 15 950 properties would suffer some degree of impact within Moreton Bay, of which 35.7% would have over-floor flooding.

In the areas along the Coral Sea coast, the greatest impact would be felt in the low lying areas facing The Broadwater and the tidal estuaries that enter it, and along Currumbin and Tallebudgera Creeks. Levels of inundation in this area, however, would be significantly less than experienced inside Moreton Bay for a scenario of the same ARI. Around 5300 properties would be affected, of which 23.5% would have over-floor flooding.

Most of the properties identified as having more than a metre of water over floor level would be facilities such as boat ramps, wharves and similar features that are, by their very function, on the water. None-the-less, around 15 700 people would be directly affected in dwelling which would have water over floor level. Some precautionary evacuations may need to be considered. These would need to have been completed before the winds of the cyclone reach 75 km/h, the speed above which it is considered to be unsafe to be outside shelter. This wind speed is typically reached about 6 hours before the eye of the cyclone actually reaches the area.

Very few key facilities would be affected by storm tide inundation under this scenario, though there are likely to be some roads closed by sea water flooding.

The modelled impact of the study area is shown in Figure 4.17 (northern Moreton Bay) Figure 4.18 (southern Moreton Bay) and 4.19 (Coral Sea coast).

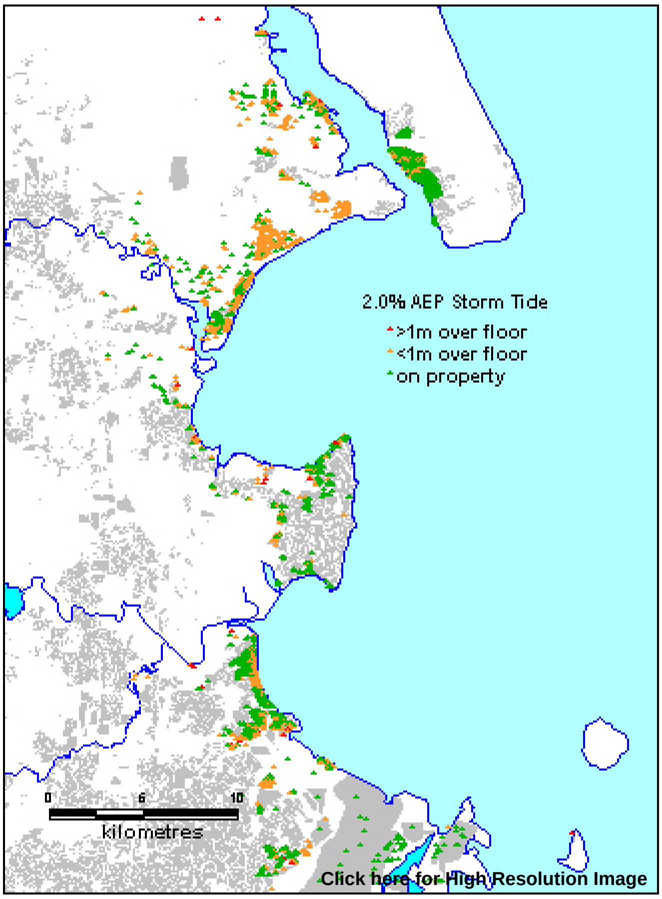


Figure 4.17 Modelled impact of a 2.0% AEP Storm tide in northern Moreton Bay

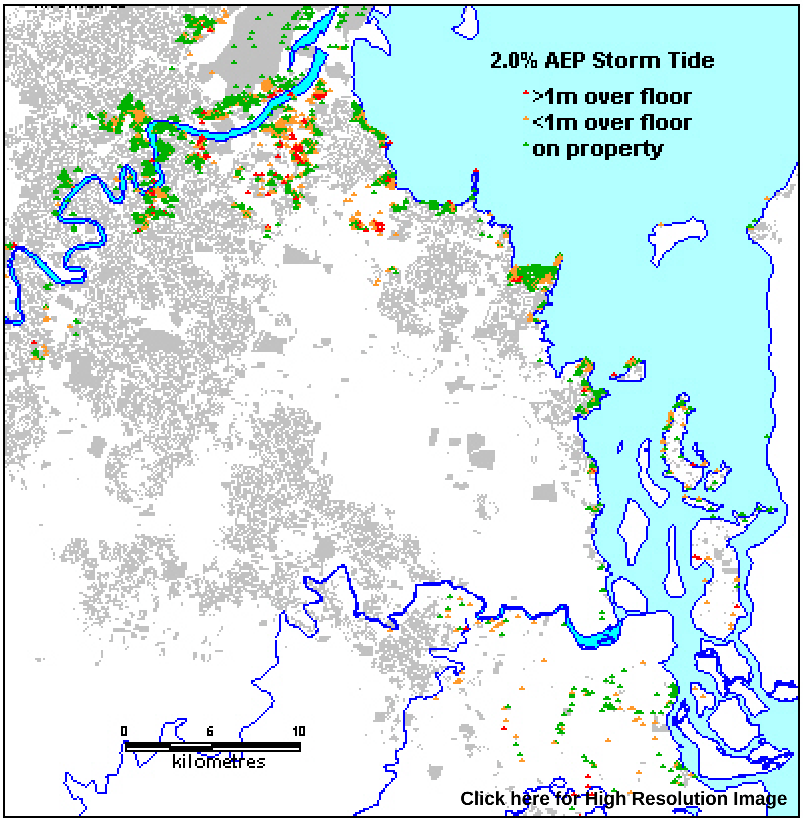


Figure 4.18 Modelled impact of a 2.0% AEP storm tide in southern Moreton Bay

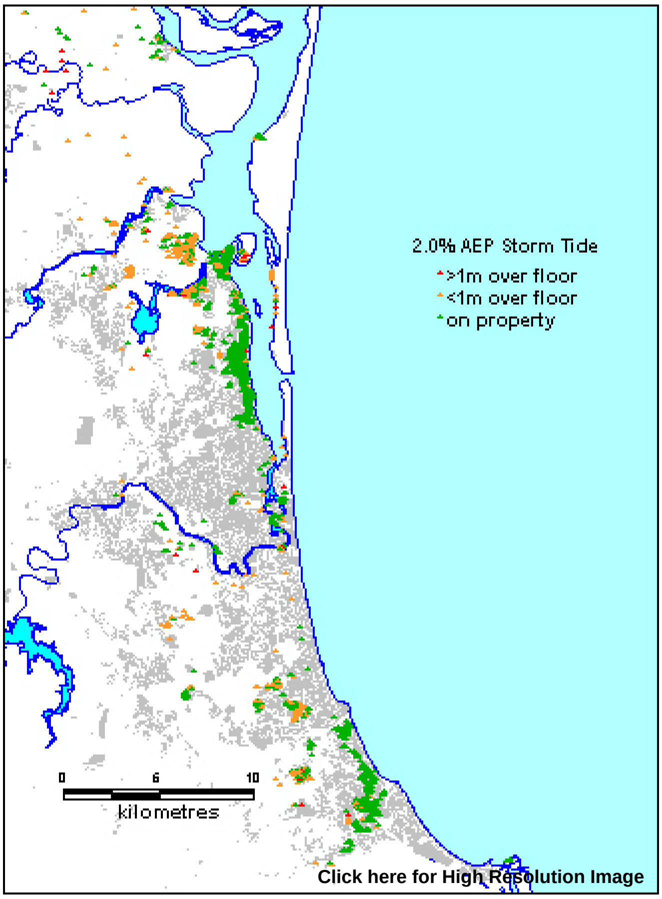


Figure 4.19 Modelled impact of a 2.0% storm tide along the Coral Sea coast

The 1% AEP scenario: Under this scenario a total storm tide elevation above AHD of 2.5 m would be experienced inside Moreton Bay (about 1.7 m above MHWS or 1.1 m above HAT) and 2.0 m would be experienced along the open Coral Sea coast and inside The Broadwater (about 1.35 m above MHWS or 0.85 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.8.

Table 4.8 Developed properties affected by a 1.0% AEP storm tide

Level of Inundation	Moreton Bay	Coral Sea	Region
>1m over floor	850	100	950
<1m over floor	6750	1850	8600
on property but below floor level	11 950	5200	25 750
not affected	545 300	112 500	657 800

Overall, the impact of a 1.0% AEP (ARI of 100 years) storm tide event would affect only 1.5% of the region's developed properties having water over floor level. It would, however, certainly cause significant damage to buildings and their contents and cause short-term dislocation in localised areas. The horizontal extent and depth of inundation experienced in a 2.0% AEP event would increase slightly under a 1.0% AEP scenario. For example, the suburb of Banksia Beach on Bribie Island, which is built around a large canal estate, would be affected for the first time. Within Moreton Bay a total of 19 550 properties would be affected to some degree, of which 38.8% would have water over the floor; along the Coral Sea coast, 7150 properties would be affected, with 27.2% having over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 22 000 and the need to consider precautionary evacuations would also increase. Up to 1500 people could be at significant risk in dwellings that would have more than 1 m of sea water over floor level. Certainly seaside caravan parks at risk of inundation would need to be evacuated ahead of cyclone impact. As many as 520 commercial properties and 230 logistic and transport facilities would be subject to over-floor flooding, together with a small number of key facilities, including telephone exchanges and power substations.

The modelled impact of the study area is shown in Figure 4.20 (northern Moreton Bay) Figure 4.21 (southern Moreton Bay) and 4.22 (Coral Sea coast).

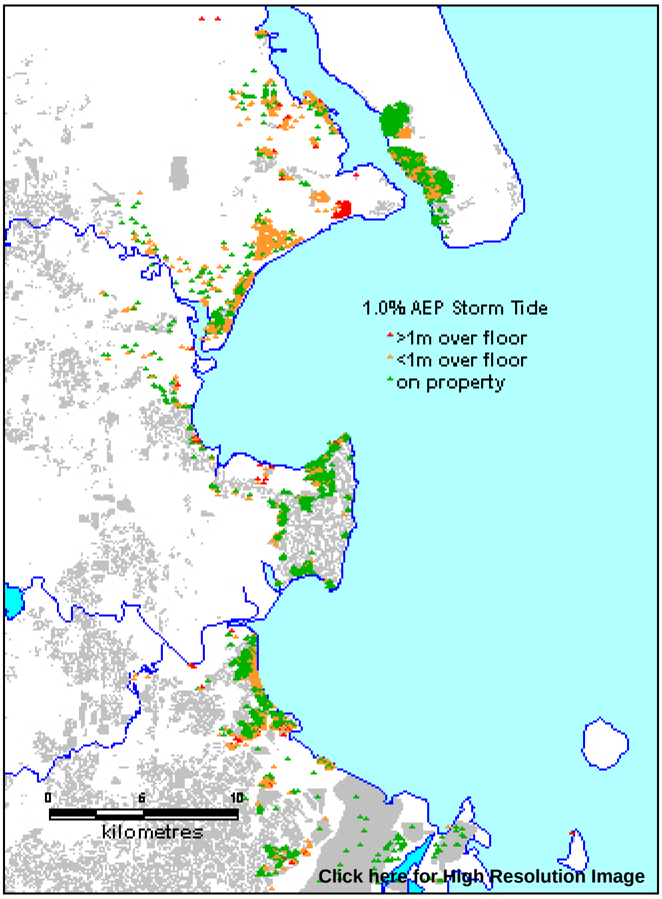


Figure 4.20 Modelled impact of a 1.0% storm tide in northern Moreton Bay

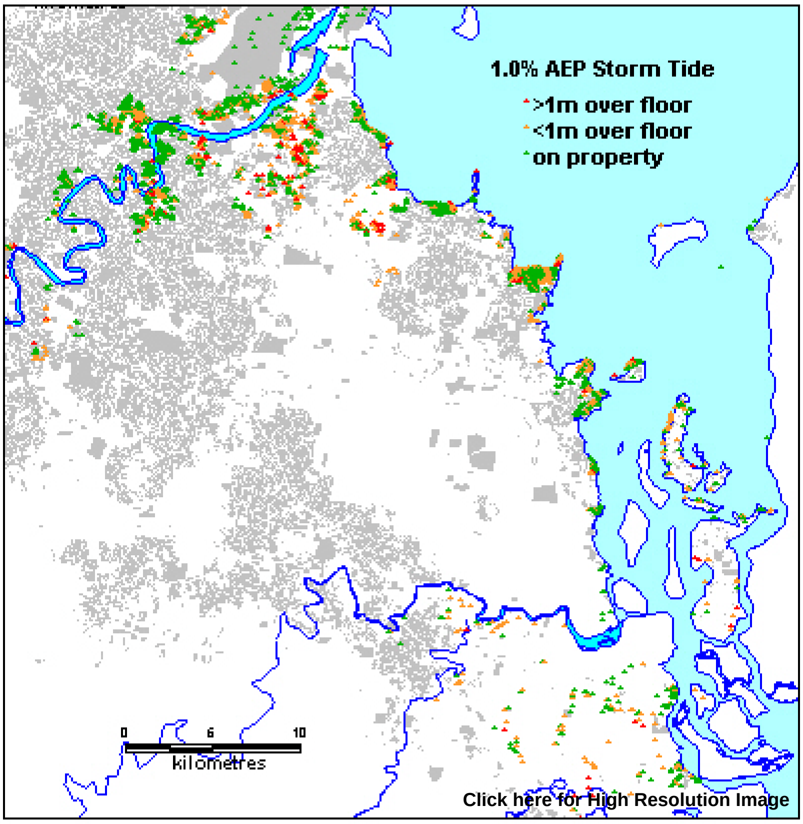


Figure 4.21 Modelled impact of a 1.0% storm tide in southern Moreton Bay

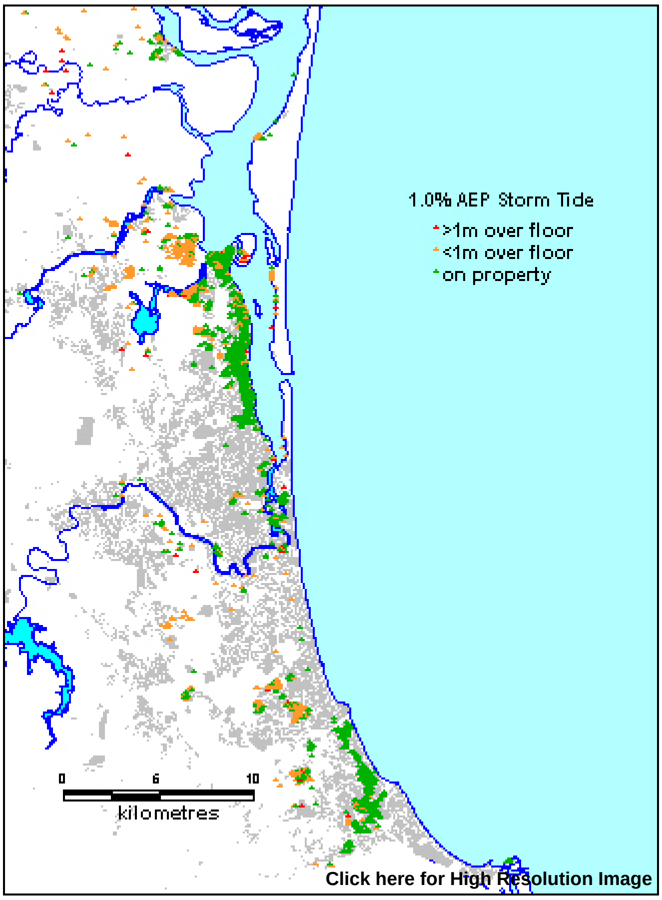


Figure 4.22 Modelled impact of a 1.0% storm tide along the Coral Sea coast

The 0.2% AEP scenario: Under this scenario a total storm tide elevation above AHD of 3.2 m would be experienced inside Moreton Bay (about 2.4 m above MHWS or 1.8 m above HAT) and 2.2 m along the open Coral Sea coast and in The Broadwater (1.55 above MHWS or 1.05 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.9.

Table 4.9 Developed properties affected by a 0.2% AEP storm tide

Level of Inundation	Moreton Bay	Coral Sea	Region
>1m over floor	6550	200	6750
<1m over floor	15 100	3000	18 100
on property but below floor level	7350	6550	13 900
not affected	535 800	109 900	645 700

Overall, the impact of a 0.2% AEP (ARI of 500 years) storm tide event would affect only 2.2% of the region's developed properties with over floor inundation. It would, however, certainly cause very significant damage to a large number of buildings and their contents and cause short-term dislocation in localised areas. The horizontal extent and depth of inundation experienced in a 0.2% AEP event would be greater than that for the 1.0% AEP scenario and the depth of inundation would be significantly increased leading to a much greater proportion of properties with over-floor flooding. Within Moreton Bay a total of 29 000 properties would be affected to some degree, of which 74.6% would have water over the floor, whilst along the Coral Sea coast, 9750 properties would be affected, with 32.8% having over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 57 500 of whom at least 20 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. Consideration may need to be given to the total evacuation of some Bay Island communities given the ease with which they would be isolated and because their ability to handle internal evacuations would probably be inadequate. As many as 1300 commercial properties and 630 logistic and transport facilities would be subject to over-floor flooding, together with 34 public safety facilities and 66 lifeline facilities, including water supply, power supply, sewerage and telecommunications facilities.

The modelled impact of the study area is shown in Figure 4.23 (northern Moreton Bay) Figure 4.24 (southern Moreton Bay) and 4.25 (Coral Sea coast).

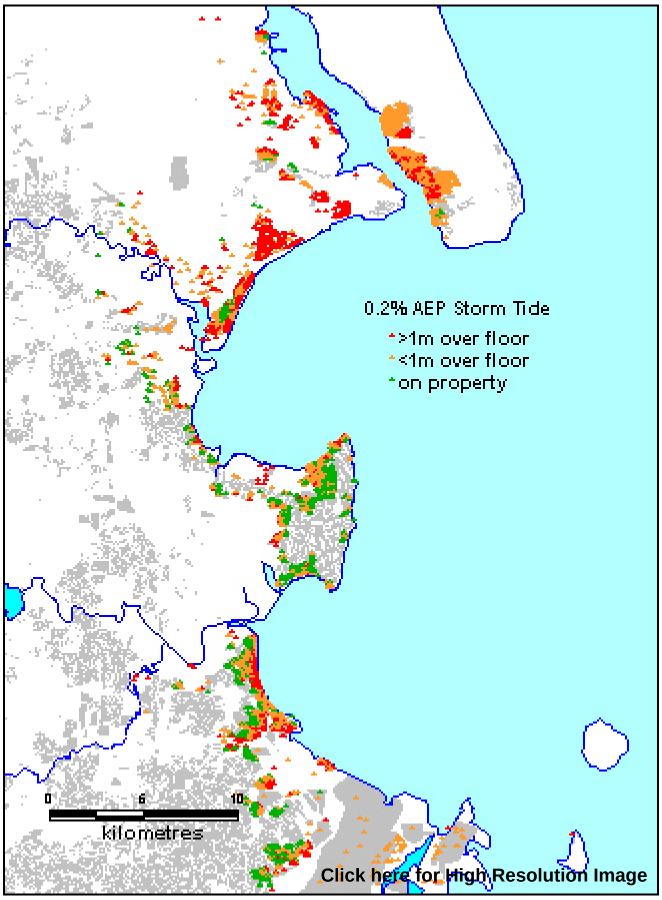


Figure 4.23 Modelled impact of a 0.2% storm tide in northern Moreton Bay

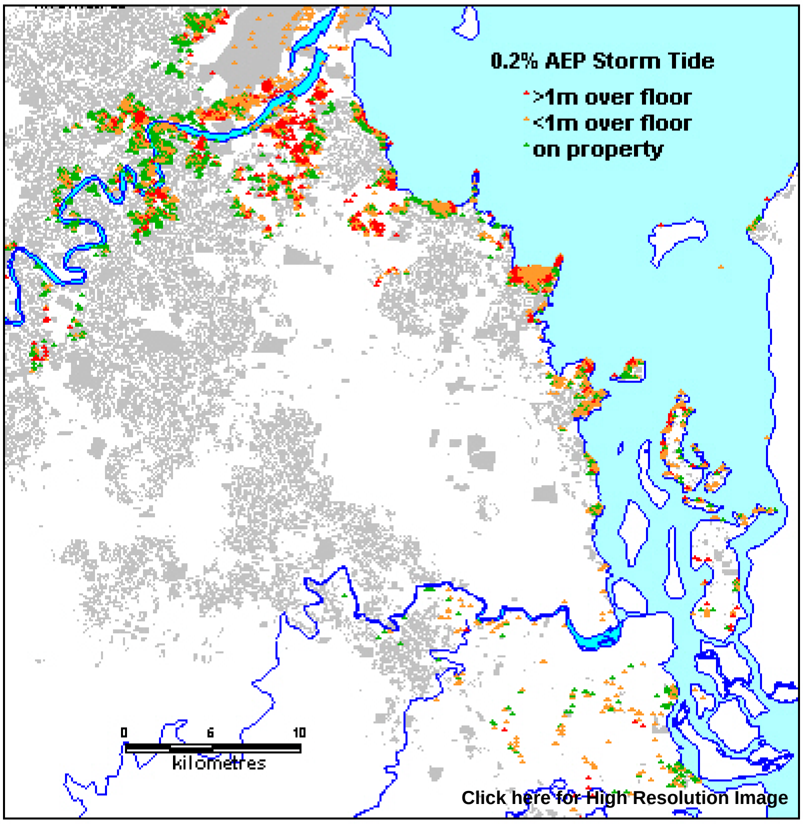


Figure 4.24 Modelled impact of a 0.2% storm tide in southern Moreton Bay

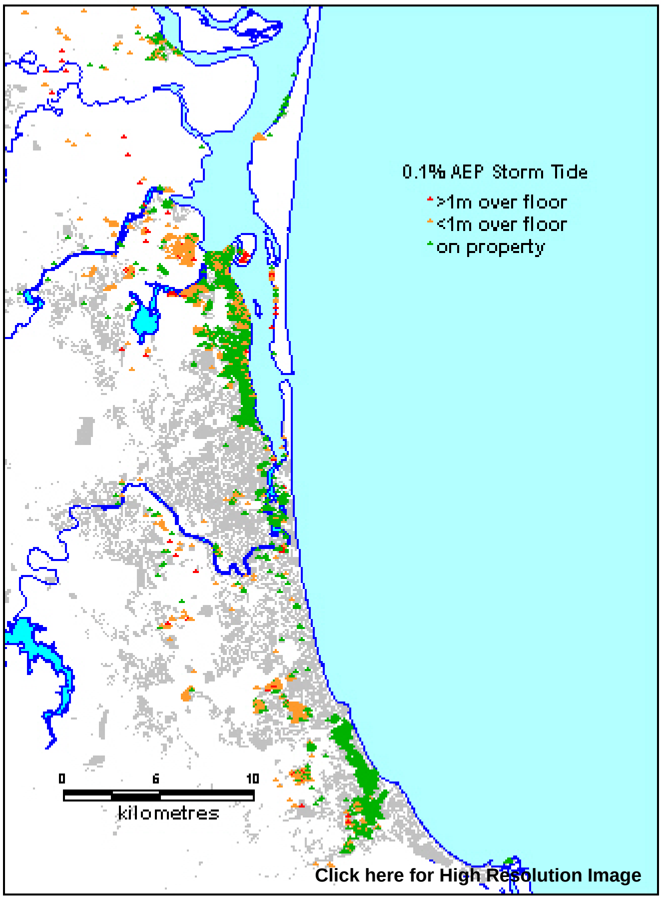


Figure 4.25 Modelled impact of a 0.2% storm tide along the Coral Sea coast

The 0.1% AEP scenario: Under this scenario a total storm tide elevation above AHD of 3.5 m would be experienced inside Moreton Bay (2.65 m above MHWS or 2.1 m above HAT) and 2.2 m along the open Coral Sea coast and in The Broadwater (1.55 above MHWS or 1.05 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.10.

Table 4.10 Developed properties affected by a 0.1% AEP storm tide

Level of Inundation	Moreton Bay	Coral Sea	Region
>1m over floor	15 550	200	15 750
<1m over floor	11 000	3000	14 000
on property but below floor level	5450	6550	12 000
not affected	532 750	109 900	642 650

Overall, the impact of a 0.1% AEP (ARI of 1000 years) storm tide event would affect 4.3% of the region’s developed properties with over-floor flooding. It would certainly cause very serious damage, including total destruction, to a large number of buildings and their contents and cause significant short-term dislocation in all coastal areas. In Moreton Bay the horizontal extent and depth of inundation experienced in a 0.1% AEP event would not be much greater than that for the 0.2% AEP scenario, whilst along the Coral Sea coast there would be virtually no difference in the level of impact. Within Moreton Bay a total of 32 000 properties would be affected, of which 83.0% would have water over the floor.

The number of people directly affected in their dwellings with water over floor level would increase to around 68 000 of whom at least 40 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. It would be very prudent to evacuate all of

Bay Island communities well ahead of the cyclone's arrival. As many as 1780 commercial properties and 870 logistic and transport facilities would be subject to over-floor flooding, thus producing significant long-term economic consequences. At least 39 public safety facilities (including medical facilities) and 77 lifeline facilities (water supply, power supply, sewerage and telecommunications facilities) would also be flooded.

The modelled impact of the study area is shown in Figure 4.26 (northern Moreton Bay) Figure 4.27 (southern Moreton Bay) and 4.28 (Coral Sea coast).

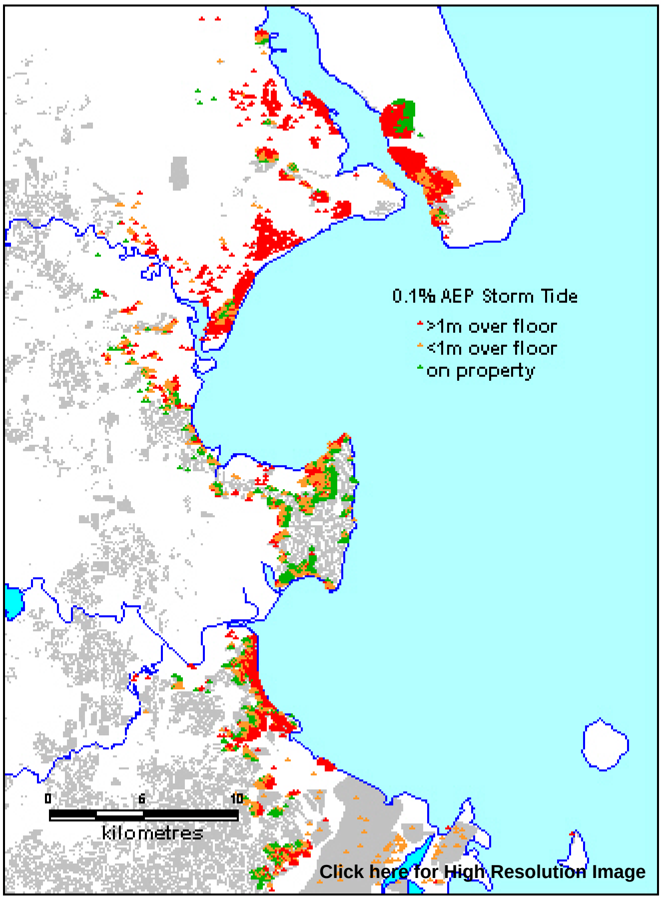


Figure 4.26 Modelled impact of a 0.1% storm tide in northern Moreton Bay

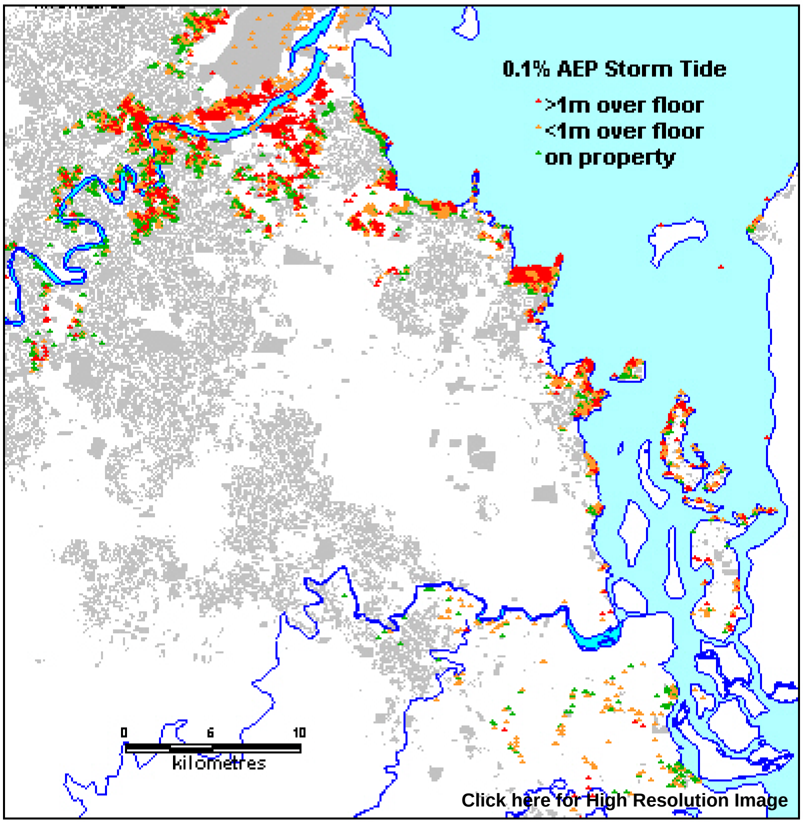


Figure 4.27 Modelled impact of a 0.1% storm tide in southern Moreton Bay

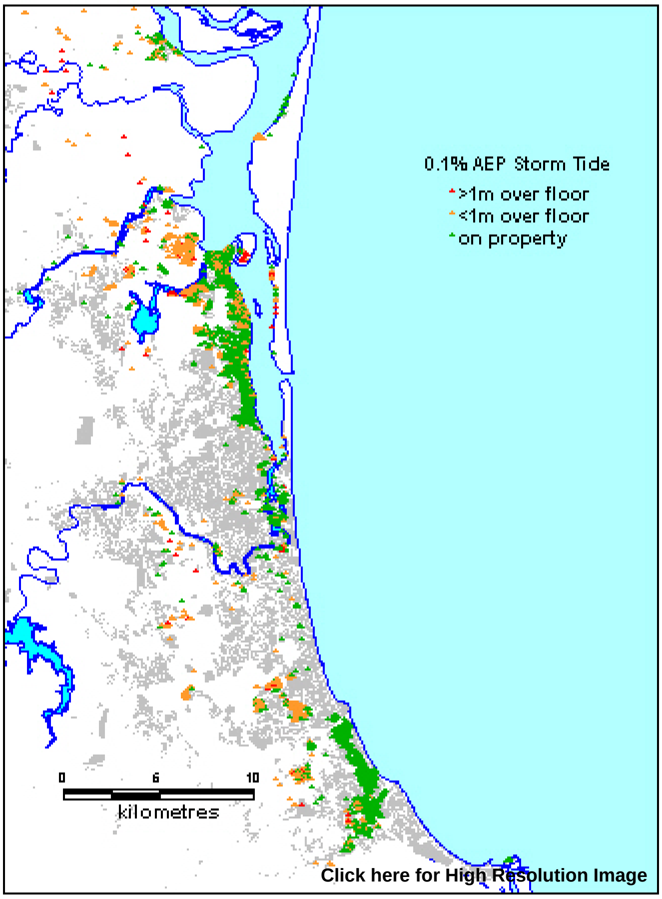


Figure 4.28 Modelled impact of a 0.1% storm tide along the Coral Sea coast

The 0.01% AEP scenario: Under this most extreme scenario a total storm tide elevation above AHD of 4.4 m would be experienced inside Moreton Bay (3.55 m above MHWS or 3.0 m above HAT) and 2.4 m along the open Coral Sea coast and Broadwater (1.75 m above MHWS or 1.25 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.11.

Table 4.11 Developed properties affected by a 0.01% AEP storm tide

Level of Inundation	Moreton Bay	Coral Sea	Region
>1m over floor	27 650	500	28 150
<1m over floor	10 150	4950	15 100
on property but below floor level	5250	7400	12 650
not affected	520 750	106 800	627 550

Overall, the impact of a 0.01% AEP (ARI of 10 000 years) storm tide event would affect 6.3% of the region's developed properties with over-floor flooding by sea water. It would, none-the-less, be devastating in all low lying coastal areas. The likelihood of significant loss of life would also be great unless an effective evacuation were conducted from the areas of likely impact well ahead of the impact of the cyclone. Both the horizontal extent and depth of inundation experienced in a 0.01% AEP event would significantly greater than that for the 0.1% AEP scenario. For example, the seaside suburb of Woorim, on Bribie Island, that would probably be immune to lesser levels of inundation, would be seriously affected and the Redcliffe Peninsula would be effectively isolated from the mainland for a short period. Within Moreton Bay a total of 43 050 properties would be affected, of which 87.8% would have water over the floor. Along the Coral Sea coast, 12 850 properties would be affected, of which 42.4% would have over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 101 800 of whom at least 80 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. Bribie Island and all of Bay Island communities would have to be evacuated well ahead of the cyclone's arrival to minimise the risk of major community trauma and serious loss of life and. The economy of the region would also suffer serious impact with as many as 2500 commercial properties and 1180 logistic and transport facilities subject to over-floor flooding. At least 66 public safety facilities (including medical facilities) and 100 lifeline facilities (water supply, power supply, sewerage and telecommunications facilities) would also be flooded.

The modelled impact of the study area is shown in Figure 4.29 (northern Moreton Bay) Figure 4.30 (southern Moreton Bay) and 4.31 (Coral Sea coast).

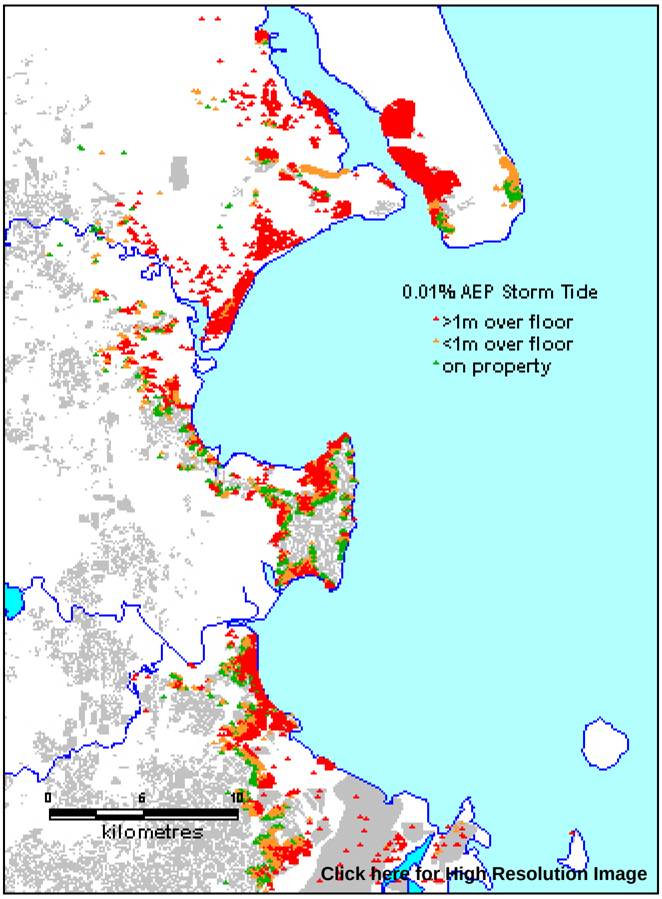


Figure 4.29 Modelled impact of a 0.01% storm tide in northern Moreton Bay

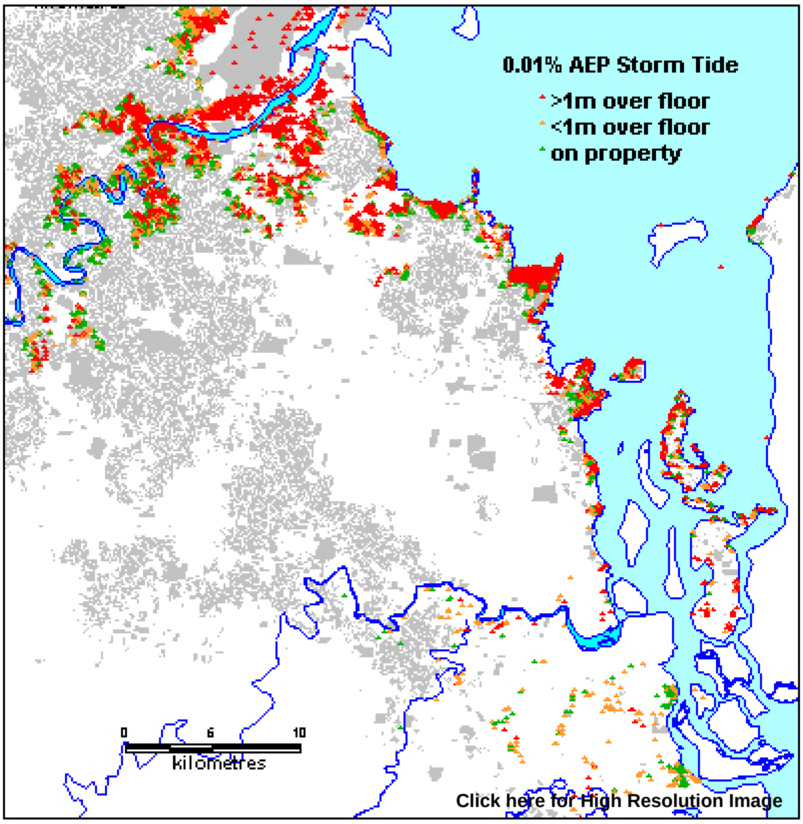


Figure 4.30 Modelled impact of a 0.01% storm tide in southern Moreton Bay

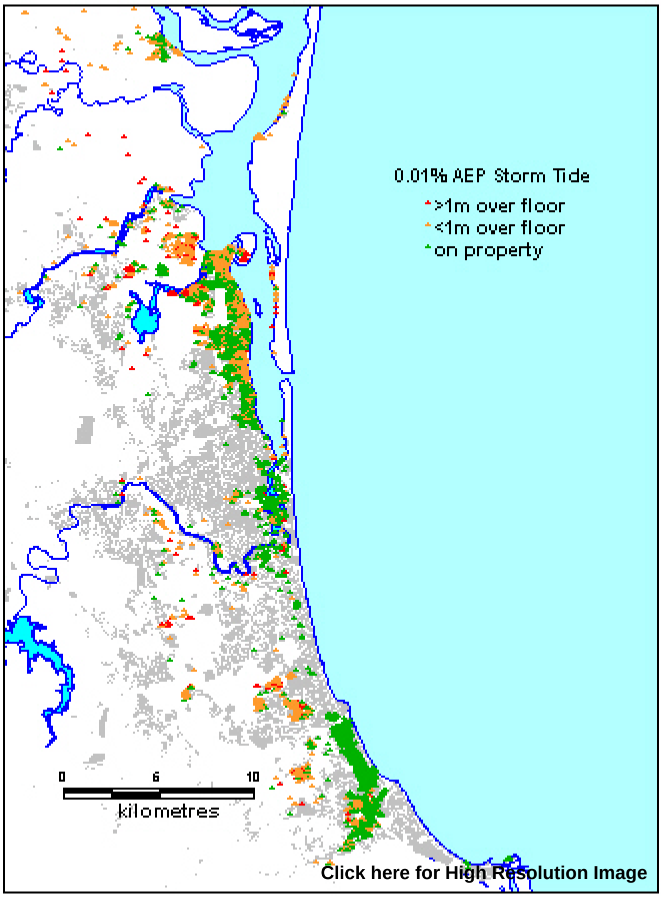


Figure 4.31 Modelled impact of a 0.01% storm tide along the Coral Sea coast

Comparative storm tide risk: It is clear that the impact of storm tide on South-East Queensland is potentially very serious, as has been demonstrated by the impacts of cyclones such as TC *Dinah* (1967) and TC *Dora* (1971) when developments close to the coast, such as the major canal estates, were significantly less extensive than they are today.

An analysis of the function of properties affected under each scenario reveals that the transport and storage facilities have the greatest per capita exposure at the more likely event levels. This can, to some extent, be accounted for by the number of facilities such as marinas and port facilities that are at the water's edge. Community facilities also carry a relatively high exposure. This is largely accounted for by the numbers of recreational facilities, such as golf and other sporting clubs, being located on the more inundation-prone land. The figures provided in Table 4.12 for each class of function are the percentages of all developed properties in South-East Queensland, within each functional class, that would have water of any depth over floor level.

Table 4.12: Percent of properties, by function, affected by over-floor inundation in each scenario

Function	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
Houses	0.9	1.3	3.4	4.1	6.0
Flats	1.0	1.5	3.7	4.3	6.7
Commercial accommodation	0.9	1.3	3.5	4.6	7.0
Business & industry	1.9	2.3	5.9	8.0	11.2
Logistic, transport & storage	3.5	4.0	11.0	15.3	20.8
Public safety & health	1.4	1.6	4.4	5.1	8.7
Community, education & sport	2.4	3.0	5.4	6.3	8.8
Utilities	1.6	2.0	5.0	5.9	7.9

The low per capita proportions of houses and flats masks the fact that domestic properties would be, by far and away, the largest numbers of properties, in absolute numbers, that would be inundated above floor level. The percentage of all properties inundated over floor level that are either houses or flats for the 50, 100 and 500 year ARI scenarios are 85.9%, 89.4% and 90.0% respectively.

Climate change and sea level rise: All of the statistics contained in the above scenarios are based on current sea levels and climate. As indicated earlier in this chapter, the climate change models developed since the mid 1980s indicate that global warming and consequent sea level rise will occur as the result of the so-called ‘Greenhouse’ effect. The most recent estimates published by the IPCC indicate that, under ‘business as usual’ Greenhouse gas regimes, by 2100, sea level globally will have risen by between 20 cm and 86 cm, with a best estimate of 50 cm. There is some suggestion in the international literature, however, that the Australian region will be at the lower end of this scale. The impact of an increase in sea level on storm tide inundation in South-East Queensland, based on the current extent of development and assuming that there is no change to cyclone recurrence and intensity, is shown in Table 4.13.

Table 4.13: South-East Queensland properties affected by over-floor inundation under different sea level estimates

Sea Level	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
Current sea level	7150	9550	14 850	29 750	43 250
Low estimate (+0.2 cm)	10 800	19 150	28 550	34 500	48 400
Best estimate (+0.5 cm)	23 650	25 350	38 350	41 350	55 850
High estimate (+0.86 cm)	32 300	34 400	45 550	50 300	65 150

Clearly the greatest proportional change is with the more likely (higher probability) events. This is all the more reason for sea level rise to be factored into mitigation strategies, as is already evident in Redcliffe (Childs and others, 1989 and 1996).

Storm Tide Risk Assessment

It is clear that tropical cyclones, both in terms of their strong winds and storm tides, pose a significant threat to the South-East Queensland community, especially when events of longer average recurrence intervals (lower AEP) are considered. It is significant that the main area of concern, even for the more likely events, lies along the coastal strip in which storm tide is likely and shielding from the wind is minimal.

By relating the relative level of exposure to the respective hazards across the region to the level of relative vulnerability (the vulnerability index detailed in Chapter 3) across the region it is possible to derive a rating of overall risk posed by the hazard. This is done by a process of spatial correlation that draws together, at the individual CCD-level, the spatial relationship between the three components of ‘total risk’ (hazard, elements at risk and vulnerability described in Chapter 1). The resulting index can be used to produce a ‘risk surface’ map.

Inundation hazards are, by their very nature, limited by topography. This is particularly evident with storm tide which is, in effect, inundation caused by a temporary increase in sea level. The level of storm tide exposure is shown in Figure 4.32 which indicates the degree to which exposure increases as the probability of a storm tide impact decreases. The indicator used to quantify exposure is the number of properties that would have water over floor level under each AEP scenario.

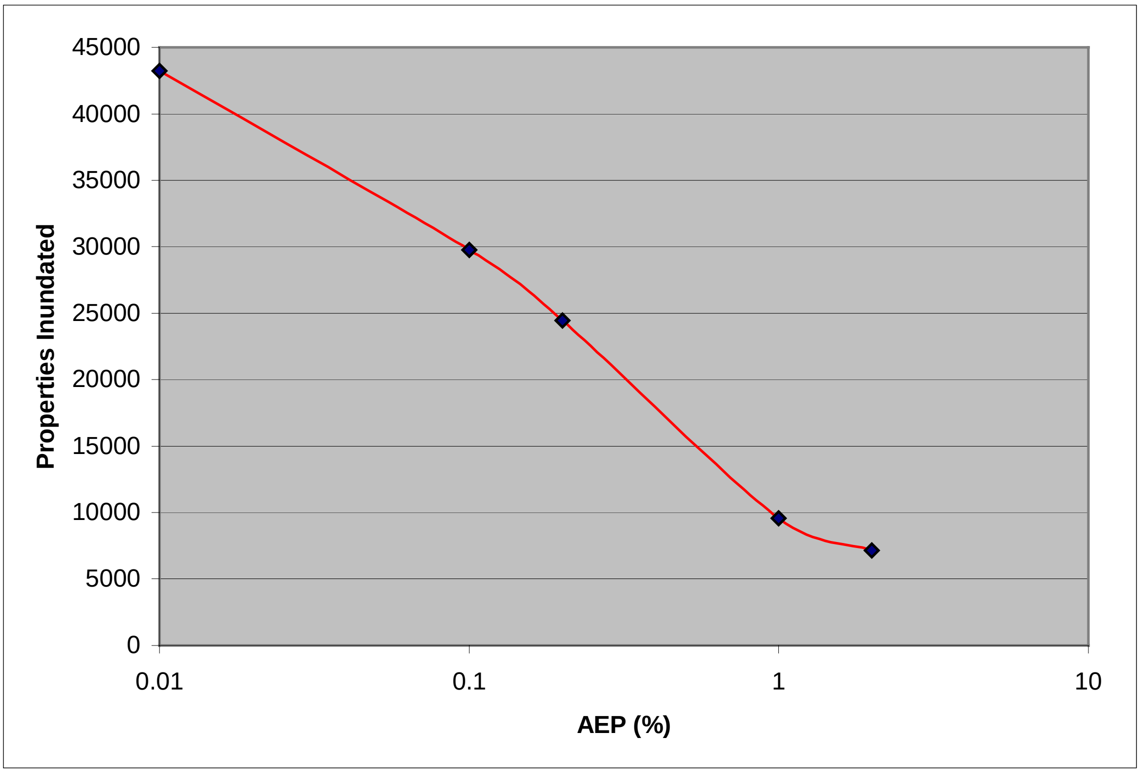


Figure 4.32 Cumulative storm tide impact across all scenarios

It is apparent that most of the LGA that have a recognised storm tide risk in the region have established, or are moving to establish, the 100 year ARI storm tide level for their planning threshold. This, then can be used as the 'design' level against which community risk can be measured. There are 9550 developed properties across the region that would be exposed to over-floor inundation in a 1.0% AEP storm tide event. Whilst this represents only 1.5% of all developed properties, it is still a relatively high number exposed at the 'design' level. This can be explained, at least in part, by two factors:

- the extent of residential development in areas potentially exposed to storm tide inundation that had occurred prior to the introduction of that threshold, especially over the past 25 years; and,
- the number of non-residential developments that, because of their function (e.g. marinas, port facilities, slipways, etc), have to be located by the water.

The 1.0% AEP urban storm tide risk index is shown in Figure 4.33. The risk index represents the product of the number of properties exposed and the vulnerability index, therefore, the higher the index number, the greater the degree of overall risk at the 'design' level of exposure. The risk in rural areas, such as on Bribie and Moreton Islands have been excluded.

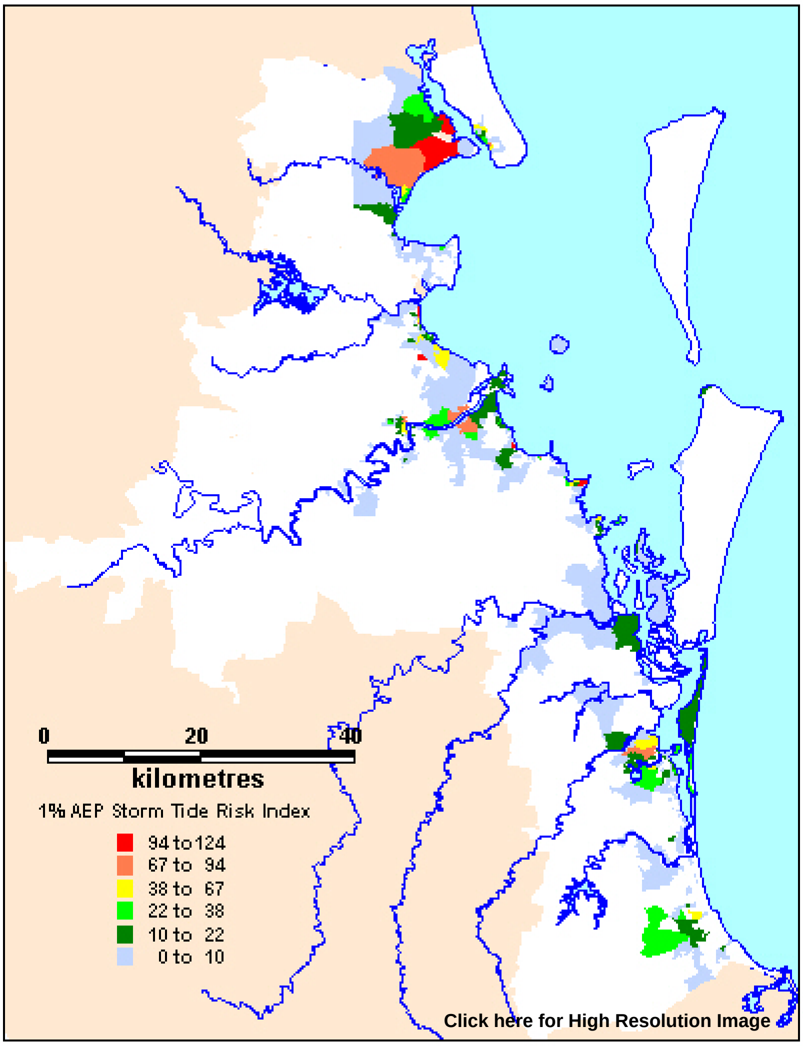


Figure 4.33 1.0% AEP storm tide risk index

The areas that carry the greatest level of exposure tend to be those that are perceived to be the most desirable residential locations, that is, close to the coast, in canal estates or along the lower reaches of the Brisbane River. They are the properties that carry a significant value premium because of this high level of desirability. As a broad generalization, therefore, whilst these communities are significantly exposed to the threat of storm tide inundation, they also tend to be the most economically resilient. Indeed, 82.4% of the 375 CCD with a storm tide exposure fall within the bottom half of the vulnerability index range.

The neighborhoods that do have a high storm tide risk index tend to be in the areas of older residential coastal development (particularly Bongaree, Brighton, Lota and Sandgate); rural or rural village-type communities (e.g. Beachmere, Boondall, Ningi, Nudgee Beach and Toorbul); some of the more modern canal estates (most notably Birkdale, Cleveland and Hope Island); and some of the more commercial/industrial areas on the lower reaches of the Brisbane River (e.g. Albion, Hemmant and Pinkenba). These are neighborhoods in which there tend to be more elderly people and/or people in the lower socio-economic ranges.

The main cautionary note that should be made here, however, is that **sea water inundation is not** (as a general rule) **an insurable risk** and even the residents of the more expensive neighborhoods at risk of storm tide inundation could suffer a significant economic loss.

Community Awareness

Whilst we have not conducted any specific research to test community awareness of the risks posed by cyclones in South-East Queensland, the anecdotal evidence we encountered clearly indicates that there is a widespread and significant degree of ignorance and/or complacency of the cyclone threat throughout region. This tends to be supported by the work done by researchers at the James Cook University Centre for Disaster Studies on community awareness in Cairns and other North Queensland communities with have a much more frequent experience of cyclone impact than does South-East Queensland. Amongst the observations made by Berry and King (1999), for example, is the following:

> *Residents consistently express surprise at suffering the direct effects of cyclones or floods. Many hold the belief that, for various reasons, their particular communities are protected or immune from hazards.*

The poor level of awareness of cyclone risk in South-East Queensland is not surprising given:

- that it has been more than 25 years since the last significant cyclone impact (see Figure 4.3);
- that a significant proportion of the population has migrated from southern states where cyclones do not occur;
- the tendency by some representatives of disaster-sensitive industries, such as real estate and tourism, and some local government councillors in the region, to decry public information relating to natural hazards risks as being 'bad for business'; and,
- the tendency for the media to sensationalise research reports, such as the recent IPCC climate change report, to the extent that the information they contain loses relevance and/or credibility.

A poor level of awareness invariable give rise to low levels of preparedness and consequently a increased level of vulnerability.

Cyclone Forecasting and Warnings

The Bureau of Meteorology Tropical Cyclone Warning Centre (TCWC) in Queensland, based in Brisbane, has responsibility derived from *The Meteorology Act* (1955) for issuing warnings of tropical cyclones which might affect the Queensland coast (BoM, 1999). This encompasses an area lying between 138ºE (Gulf of Carpentaria) and 160ºE (west of New Caledonia). A continuous watch is maintained over this area for the possibility of a tropical cyclone entering or developing. Once developed, the TCWC is responsible for naming the system using an internationally approved sequence of names. The TCWC then monitors and predicts the intensity, structure and movement of any tropical cyclone within its jurisdiction.

The TCWC has an extensive array of information and computational resources available to its staff. A variety of satellite derived products are available (e.g. visible and infra-red imagery, radar, water vapour) which enable tropical cyclones to be detected and monitored throughout their life cycle. Additionally, weather radars provide coverage within about 300 km of the entire east coast south of 15ºS. There is also an extensive network of automatic weather stations (AWS), 15 of which are located along or offshore of the Great Barrier Reef between 15ºS and 25ºS and provide a very effective observational system. Further guidance is available from a number of numerical weather models, both global and local area.

A range of warning products are produced depending on the situation. *Tropical Cyclone Outlooks* are disseminated daily to advise the potential for cyclonic activity within the next 72 hours. A *Tropical Cyclone Information Bulletin* is issued whenever a tropical cyclone exists but is not posing a threat to the coast. A *Cyclone Watch* is issued if coastal or island communities are expected to be affected by gales within the next 48 hours and this is upgraded to a *Cyclone Warning* if gales are expected within the next 24 hours. *Tropical Cyclone Threat Maps* are also issued at this time to indicate the extent of watch and/or warning zones in relation to particular localities, as well as showing the extent of gale force, storm force and hurricane force winds. Warnings are updated hourly during periods of significant community threat and the Standard Emergency Warning Signal (SEWS) is used to provide additional media impact to the warnings.

Storm tide warnings are issued by the Bureau of Meteorology in conjunction with the State Counter Disaster Organization (SCDO, 1999) which interfaces with a number of key State Government organizations. The Department of Emergency Services provides the executive role for the SCDO and the Beach Protection Authority provides specialist advice and data in respect of wave and storm surge readings from its real-time network of wave rider buoys and storm surge gauges. The issuing of storm tide warnings is also staged depending on the threat and the expected onset of high winds at the affected locations, which might impede potential evacuation to higher ground.

The final role of the Bureau of Meteorology is to undertake assessment of its own performance and to document the outcomes from the severe weather event. It does this by compiling annual verification statistics and maintaining a database of events.

Further Information

More detailed information on the levels of exposure of individual neighborhoods or properties to the various tropical cyclone risks outlined here should be referred to the respective local government council.

CHAPTER 5: EAST COAST LOW RISKS

Bruce Harper and Ken Granger

The East Coast Low Threat

East coast lows, also known as *east coast cyclones, winter cyclones* or *easterly trough lows*, are one of a family of low pressure systems which most often develop during the winter months along the east coast of Australia between 25ºS and 40ºS latitudes (Holland and others, 1987; Hopkins and Holland, 1997). These large scale storm systems often develop rapidly and can become quite intense, with storm force winds extending over wide areas. These events contribute significantly to flooding and wind damage along the coastal margins as well as marine accidents, storm surge and beach erosion in South-East Queensland.

Prior to the introduction of satellite imagery in the early 1960s, many east coast lows were classified as tropical cyclones. While their impacts may be similar or even possibly greater in some cases, the east coast low has a different physical mechanism and a highly asymmetrical poleward cloud pattern where the heaviest rainfall frequently occurs. Another feature of east coast low development is the tendency for clustering of events when conditions remain favourable. For example, near Brisbane, almost one third of events occur within 20 days of a preceding event (Allen and Callaghan, 2000).

The effect of these storms on nearby coastal areas can be severe, frequently with loss of life and property from flooding and maritime incidents. The first documented east coast low in Queensland occurred in August 1846 when the vessel *Coolangatta* was driven ashore in the area now bearing its name (Allen and Callaghan, 2000). Bureau of Meteorology estimates indicate approximately 35 deaths in the region can be attributable to east coast lows over the period 1973 to 1999, the majority being due to flooding.

Unfortunately, east coast lows have not been systematically recorded in the manner that tropical cyclones have been since the turn of the century. They are typically more complex systems which are often difficult to categorise. Accordingly, many of the studies have concentrated on detailed investigations of historical weather charts and station observations to reconstruct a time history of occurrences. The longest assembled record available (1880 to 1980) is from PWD (1985), which considered the region from Tweed Heads south to Gabo Island, near Bass Strait. This study classified the various storm systems into six categories, depending on their synoptic situation, as summarised in Kemp and Douglas (1981). Holland and others (1987) considered the period 1970-1985 and used three broad classifications. Hopkins and Holland (1997) broadened this to 1958-1992 and Allen and Callaghan (2000) focussed on 1976-1997 when wave data was available.

The East Coast Low Phenomenon

East coast lows typically form after a low or deep trough intensifies in the upper atmosphere over eastern Australia. A low pressure system then develops at sea level near the coast to the east of the upper level system, often intensifying rapidly. These cells of low pressure are typically quite small relative to the broad synoptic features, but can interact with developing high pressure systems to the south to produce severe gale conditions over periods of up to several days (Allen and Callaghan, 2000; Callaghan, 1986). These storm systems draw their energy from a combination of strong ocean temperature gradients, coastal convergence, uplift and a supply of moist sub-tropical air at the surface. The East Australian Current and the Great Dividing Range are principal players in the development of these storms, the circulation centres of which often track very close to the coast over considerable distances. An example of the tracks of several prominent systems is shown in Figure 5. 1.

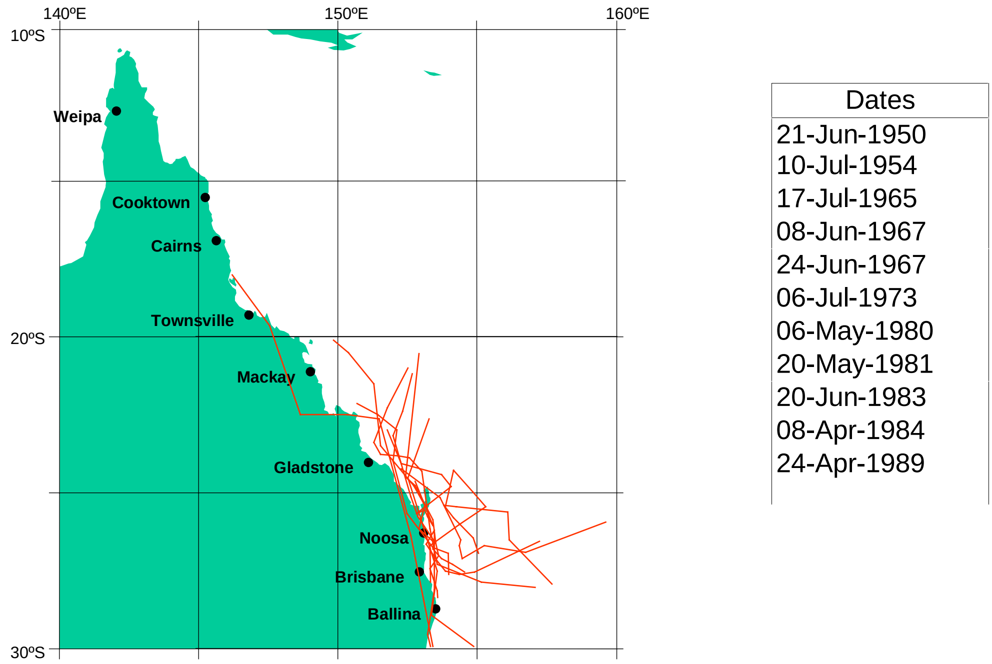


Figure 5. 1 Selected tracks of east coast lows affecting SE Queensland

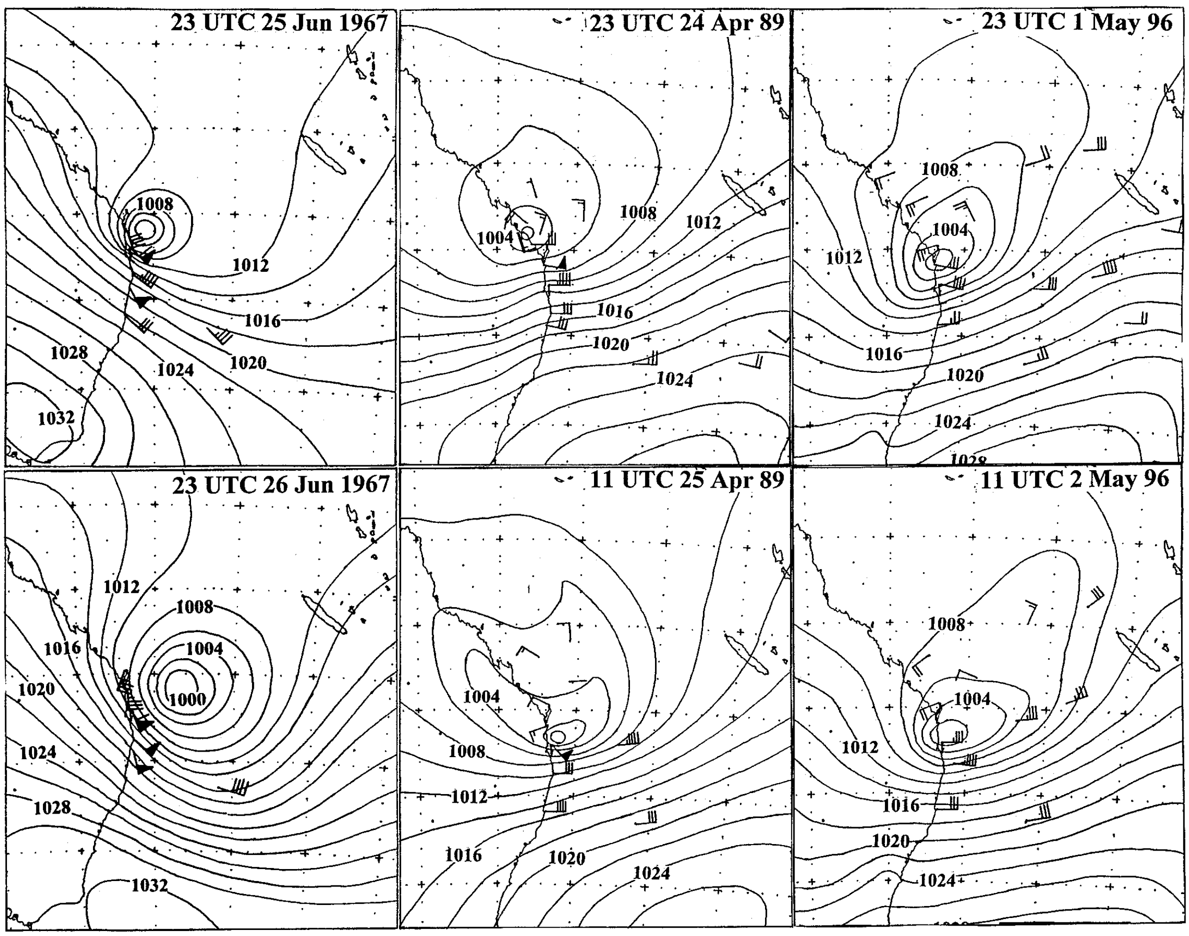


Figure 5. 2 Examples of three east coast low synoptic developments.

Although their centres may be close to the coast, their impacts extend over considerable distances, as can be seen in the three examples in Figure 5. 2 where the steep gradients in the surface pressure fields and regions of strong onshore winds are indicated. The onshore flow is responsible for the heavy rains and, combined with the extended fetch regions over the ocean, the generation of high waves. Storm surge is also possible, whereby the strong clockwise winds create a net onshore flow at the surface causing a rise in water levels along the coast. The 'inverted barometer' pressure effect can also be significant, with some east coast lows having central pressures below 990 hPa. Wave setup caused by breaking wave processes at the coast also contributes to the total storm tide impact.

While Chapter 4 presents the case for enhanced tropical cyclone activity during periods of highly positive SOI, the east coast low phenomena appears sometimes to be negatively correlated with the SOI, or sensitive to rapid changes in the SOI (Hopkins and Holland 1997). Figure 5.3, for example, shows the relationship between the SOI and the annual anomaly (deviation from the mean occurrence) of east coast lows for the period of more reliable data from 1950 – 1997. In this case, both data sets have been smoothed to indicate the 5 year running mean. The interaction over this period is compelling enough to suggest that east coast low occurrences affecting South-East Queensland are higher during periods of negative SOI (*El Niño* periods) and lower during positive SOI periods (*La Niña* periods). However, the intensity appears to be higher during *La Niña* periods, probably because of the enhanced trade winds and the higher SST anomaly, which both affect the rate of intensification.

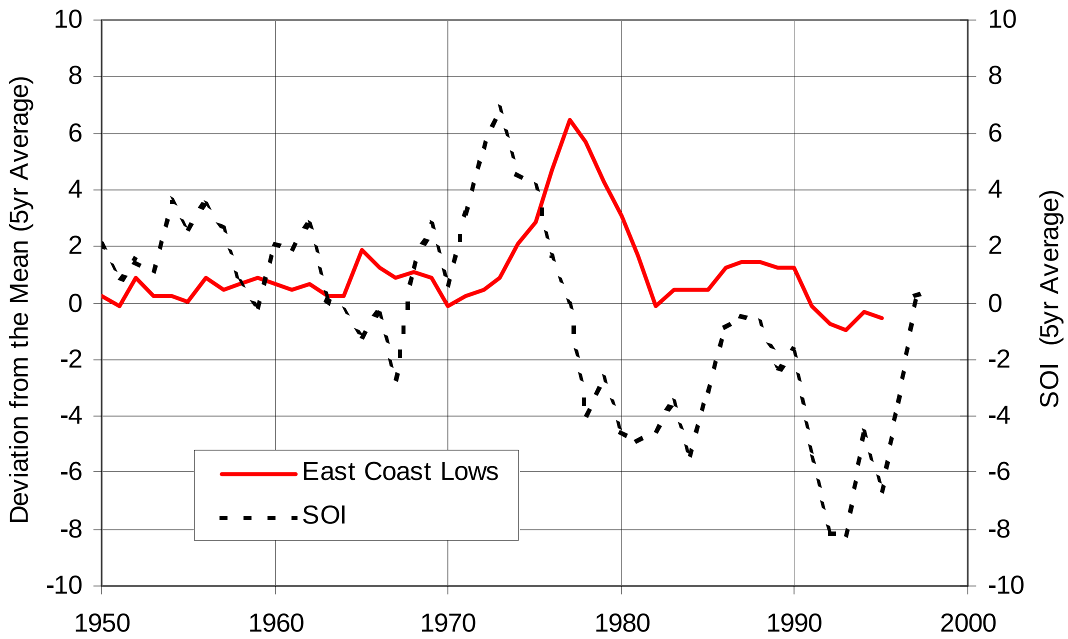


Figure 5. 3 East coast low and SOI relationships for South-East Queensland.

Rainfall: Almost all east coast low events cause widespread heavy rains, concentrated around the poleward side of the low pressure core where warm equatorial air ascends into the cooler airmass. Hopkins and Holland (1997) found that, considering the east coast between 20ºS and 40ºS latitudes, over 16% of heavy-rain days were directly related to east coast low systems. A heavy-rain day was defined as one in which the daily rainfall exceeded 10 times the long-term monthly mean daily rainfall at selected coastal recording stations. Their study shows that peak daily rainfall from such systems can exceed 250 mm in South-East Queensland while rain-associated damage attributable to all east coast lows is estimated in millions to tens of millions of dollars per year and may contribute up to 7% of all major Australian disasters since 1967.

Severe wind: Mean wind speeds recorded in the South-East Queensland region during the passage of east coast lows are typically around 50 to 60 knots (26 to 31 m/sec) with peak gusts reaching as high as 85 knots (44 m/sec). These speeds are generally within the range established under the Wind Loading Code and applied by local governments throughout the region. There should be only limited damage to buildings constructed since the introduction of that code in 1983. Older buildings may be at risk, especially those in more exposed locations such as along the waterfront or on exposed ridges. The severe wind risk associated with tropical cyclones, which is also relevant to east coast low winds, is analyzed in detail in Chapter 4.

Extreme Waves: Allen and Callaghan (2000) presents an analysis of wave conditions measured offshore of Point Lookout on North Stradbroke Island for the 21 year period October 1976 to December 1997, which was largely free of major tropical cyclone influences. This spaned the available wave recording period at that time, with allowances for outages and changed recording techniques. Their data set included waves from tropical cyclones as well as east coast lows and these were separately subjected to statistical extreme value analyses. Slightly higher waves for a given return period were predicted for east coast lows, probably because of their higher frequency of occurrence, wide area of influence and often extended south-east fetch. Table 5.1 summarises the estimated significant wave height (Hs) as a function of ARI. Note that individual maximum wave heights can approach twice the height of the significant wave, which is a statistical measure of wave height.

As these waves propagate towards shore they are modified by the near-shore bathymetry and will progressively break as the water shallows. Near the beach face, the breaking process can produce a quasi-steady increase in the local water level which is termed wave setup. This is typically between 10% and 15% of the incident breaking wave height and adds to the storm surge impact as described below. When combined, wave height, setup and surge provides the opportunity for severe beach erosion, such as that experienced during the period of extended storm activity (east coast lows and tropical cyclones) during 1967 along the Gold Coast (see Chapter 4 for more details).

Table 5. 1 Predicted extreme wave heights due to east coast lows in SE Queensland (after Allen and Callaghan, 2000)

Average Recurrence Interval (ARI) yrs	Predicted Significant Wave Height Hs m
2	4.9
5	5.7
10	6.1
20	6.5
50	6.9
100	7.2

Storm Surge: The detailed basis of storm surge generation is covered in Chapter 4 in regard to tropical cyclones, but the same mechanisms apply also for east coast lows. The main differences between the storm surge generating potential of these two types of storm systems relate to the gradient of wind speed and pressure over the horizontal extent of the storm. Also, east coast lows tend to only move parallel to the coast. Typically, this means that a landfalling tropical cyclone is capable of producing a higher storm surge on the coast than a parallel-to-the-coast moving east coast low because its energy is often more focussed. However, an intense east coast low may exceed the total storm surge from a weak tropical cyclone, particularly when wave setup is an important component of the total water level. These differences were accounted for in the BPA (1985a and b) studies into storm tide in the region, discussed in Chapter 4. One of the assumptions of that study was that the peak surge height caused by an east coast low on the open coast might be approximated as about 6% of the peak significant wave height Hs. Using Table 5.1 as a guide, the 100 year ARI storm surge could then be of the order of 0.4 m. Wave setup would be, say, about 0.7 m on the coast, thus exceeding the surge component. Astronomical tide levels must then be included to arrive at the total water level for any particular situation.

Table 4.3 in Chapter 4 presents some historical storm surge and storm tide levels for the South-East Queensland region and Table 4.4 summarises predicted storm tide levels for a number of sites where studies have been carried out. East coast low impacts are especially noticeable in the many low lying coastal regions in and around Moreton Bay. When ocean water levels become elevated during periods of relatively high tides, the strong south-east winds acting on the shallow Bay waters can further exacerbate the problem. For example, at Beachmere near the mouth of the Caboolture River, flooding from the sea is a relatively common event, with water levels exceeding the Highest Astronomical Tide (HAT) level on an annual basis, rather than the expected 1 in 19 year average without storm surge effects (data collected by resident P. Whitehouse).

The South-East Queensland East Coast Low Experience

In this brief overview, a composite data set has been created based essentially on PWD (1985), using their categories E, S, I and C for the northern sector, and Allen and Callaghan (2000) using their type 1 and 2 events. Two additional heavy rain events from Hopkins and Holland (1997) were also included. This composite set covers the 118 year period 1880 – 1997 and considers only those east coast low events which had some impact on South-East Queensland. On this basis the areal extent of the data set is within about a 500 km radius of Brisbane. Figure 5. 4 presents this data set as an annual frequency of occurrence histogram, overlaid by a 5 year running mean and an exponential trend line.

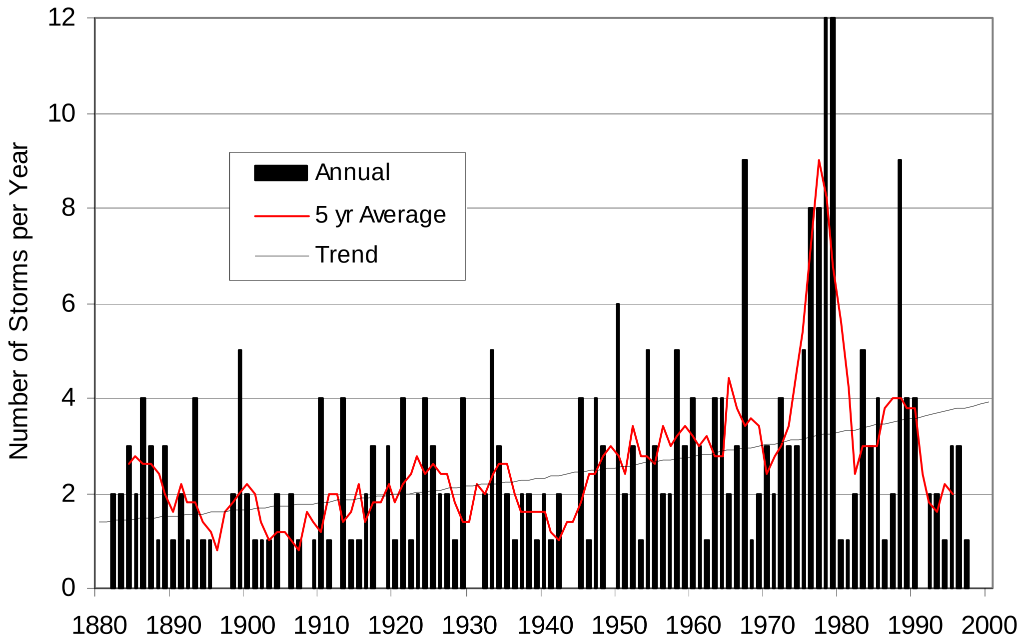


Figure 5. 4 Historical record of east coast lows affecting South-East Queensland

The incidence of these types of storms can be seen to fluctuate quite widely from one year to the next, with none in some years and the highest incidence being twelve in 1978/79. The long term average annual occurrence is about 2.5 storms per year but since 1960 the average has increased to 3.7. While the frequency of occurrence prior to 1960 will be affected to some extent by the lack of routine satellite coverage, the approximate doubling of frequency of storms over the past 30 years appears highly significant (Hopkins and Holland, 1997) and to some extent appears linked to broader climatic indices such as the SOI. It is noted that the incidence of east coast lows is significantly greater than that of tropical cyclones in the South-East Queensland region (see Chapter 4).

East coast lows, because of their frequency of occurrence and ability to rapidly intensify, are the major cause of marine incidents in the South-East Queensland region. Small craft are often extensively damaged at their moorings and even larger ships have met disaster. The 1600 tonne *Cherry Venture,* one of the more notable shipwrecks in recent history, was driven ashore south of Double Island Point - a victim of the severe July 1973 east coast low.

Appendix E is derived from Bureau of Meteorology records and presents historical accounts of significant east coast low events which are known to have affected South-East Queensland.

Interpretation

The major impact of east coast lows on South-East Queensland will be in terms of potential storm tide and severe waves, wind damage and flooding. The levels of total risk for both severe wind, storm tide and flood will be similar to that detailed in Chapters 4 (Cyclones) and 7 (Flood).

Forecasting and Warnings

Typically, warnings for severe east coast lows would be issued by the Bureau of Meteorology in Queensland under the title of a *Severe Weather Warning*. Warnings of potential flooding impacts from east coast lows are prepared by the Bureau of Meteorology Flood Warning Centre in Brisbane, as described in Chapter 7.

The Bureau of Meteorology issues marine weather warnings for sea and swell conditions associated with east coast lows. The BPA provides access to real time wave buoy data to assist in the warning preparation.

Storm surge warning procedures for east coast lows follow similar procedures to those described for tropical cyclones in Chapter 4.

The final role of the Bureau of Meteorology is to undertake assessment of its own performance and to document the outcomes from the severe weather event. It does this by compiling annual verification statistics and maintaining a database of events

CHAPTER 6: SEVERE THUNDERSTORM RISKS

Bruce Harper, Ken Granger and Sarah Hall

The Thunderstorm Threat

The term ‘thunderstorm’ is a generic description of a relatively small scale convective process which can occur when the atmosphere is moist and unstable. Cumulo-nimbus clouds then rapidly develop, potentially reaching heights of up to 20 km, with associated lightning, thunder, severe wind gusts from downdrafts, heavy rain and large hail. Many thunderstorms are typically short-lived (up to an hour) and limited in size (up to 10 km in diameter) but can traverse large distances during that time and are capable of inflicting significant damage (Kessler, 1983). Individual storm impacts can vary significantly both in space and time. In Australia, a s*evere thunderstorm* is defined as a thunderstorm which causes one or more of the following phenomena (BoM, 1995a):

- a tornado;
- wind gusts of 90 km/h or more at 10 m above the ground;
- hail with diameter of 20 mm or more at the ground;
- an hourly rainfall intensity in excess of the 10 year ARI for a region (about 70 mm/h or greater, dependent on the location and previous rainfall).

Ironically, lightning is not used as a discriminator of thunderstorm intensity. Almost all convective storms will exhibit some lightning and hence some thunder and there is no established link between lightning display and overall storm intensity.

South-East Queensland is a region that is particularly susceptible to severe thunderstorms, especially during the summer months. For example, the highest recorded wind gust from 48 years of data at Brisbane airport occurred during a severe ‘supercell’ thunderstorm in January 1985. The peak wind gust was 184 km/h but only affected a limited area - it was the accompanying 60 mm diameter hail which devastated several northern suburbs with a damage swath up to 10 km wide (Jhamb and others, 1985). This represented a record insurance payout of about $300 million in present values (based on ICA, 1998). The April 1999 hailstorm, which affected 22 000 properties in Sydney and caused an Australian record $1.7 billion in insurance losses, is an indication of the enormous damage potential of such storm systems in densely built-up metropolitan regions.

While tropical cyclones are potentially capable of greater destruction on a wide geographic scale, severe thunderstorms dominate the annual wind speed records in South East Queensland and, together with flooding and lightning, are responsible for most of the annual damage to property.

The Thunderstorm Phenomenon

Genesis: Thunderstorms typically occur when dense cold air overlies warm moist air and uplift is initiated by one of several possible factors such as solar heating, orographic (topographic) effects or fronts and troughs (BoM, 1995a). Strong localised upward currents of air can develop as the heat energy stored in the moist warm air is converted to kinetic energy high in the clouds. During this process, condensation of the moist air occurs at altitude, together with separation of positive and negative electrical charges, leading to the generation of lightning. Hail is formed by the freezing of raindrops at very high levels. These are then thought to grow steadily in size while being recirculated throughout the storm by powerful updrafts and downdrafts. When the weight of the circulating water and ice can no longer be supported by the updrafts, they fall to earth in concentrated shafts, dragging the surrounding air downwards and causing strong ‘downburst’ winds at the surface. When conditions are favourable, mature thunderstorms can form in very short periods of time and have highly organised motion comprising complementary up- and down-drafts. Sometimes, practical warnings for such events are not possible.

The most common type of thunderstorm is termed the *ordinary* cell, which is limited in size and lifespan, but can produce short bursts of severe weather. *Multi-cellular* storms are more persistent and larger in impact, formed by successive cell generation on the forward left flank, allowing them to move transverse to the prevailing wind and to present a broader impact front. Several other variants also exist, but the most dangerous form is termed the *supercell* thunderstorm, which is schematically illustrated in Figure 6. 1 (BoM, 1995b).

The *supercell* is typically an isolated form and always has the potential to be severe because of its strong and persistent rotating updraft, which dissipates at the upper levels forming the characteristic anvil and overshoot of clouds. Vertical wind shear (i.e. wind speed increasing with height) is important in the development of severe storms such as *supercells*. The shearing effect serves to separate the updrafts from the downdrafts, thus creating a circulation. In a normal thunderstorm the downdraft tends to fall back into the updraft, effectively dissipating the storm's energy. Hail and heavy rail is associated with the downdraft zones and under some specific conditions may also form a tornado towards the left rear flank of the storm cell. This small but rapidly rotating column of air descends below the cloud base, reaching the surface with devastating consequences. Thankfully, the strength of severe winds from thunderstorms is inversely related to the area they impact. For example, very severe downdrafts (or microbursts) can attain speeds of more than 200 km/h and affect areas up to 1 km wide, while severe tornadoes might have winds in excess of 400 km/h but are typically restricted to widths of less than 100 m (Fujita, 1981).

As the storms translate at speeds typically in the range of 40 to 50 km/h, these relatively narrow impact widths become long swaths of potentially very high damage. *Supercells* may have a lifespan of several hours and present an impact front as wide as 40 km. Records of damage generally indicate 'pulsing' whereby the ground level impacts tend to fluctuate, probably depending on the supply of material held aloft by the updrafts (Harper and Callaghan, 1998). Very severe *supercells* can exhibit almost continuous damage fronts for several hours as combinations of wind, rain and hail.

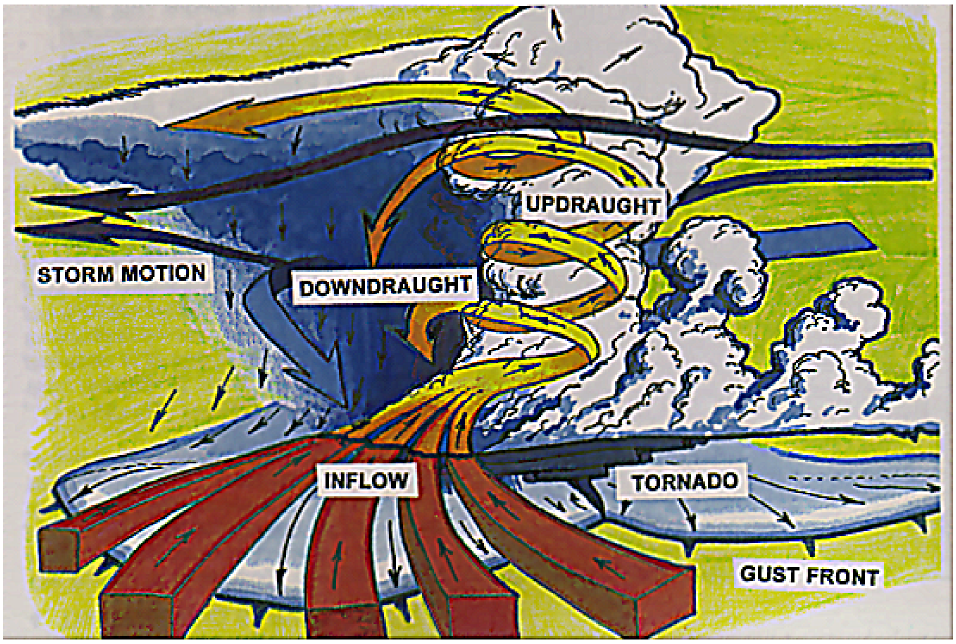


Figure 6. 1 Schematic illustration of a supercell severe thunderstorm [BoM diagram].

The increasing sophistication of radar systems is allowing greater insight into the structure of such storms. For example, Doppler radars now routinely used in the USA can measure wind speeds based on the movement of airborne particles within a severe thunderstorm and help to detect the presence of tornadoes. Doppler radar coverage is not yet available for South-East Queensland, however, forecasters have access to 3D enhanced radar such as shown in Figure 6. 2. This depicts the horizontal and vertical extent of several severe thunderstorms which wreaked havoc across Brisbane suburbs on 16th December 1998. Thousands of motor vehicles were heavily damaged by hail, the largest reported hailstone being 100 mm in size at Bracken Ridge. The total damage bill was estimated as $76 million with the most affected suburbs being Clayfield, Windsor, Wilston, Albion, Northgate and Wavell Heights.

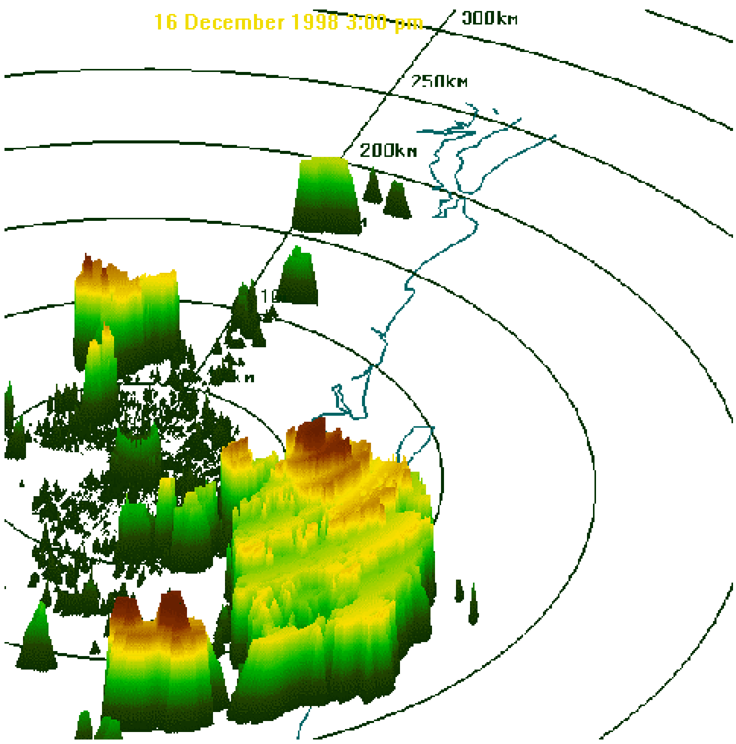


Figure 6. 2 Example of a 3D radar view of severe thunderstorms over Brisbane

Climatology: The most recent review of severe thunderstorm climatology in South-East Queensland was undertaken to assist in estimating likely long-term risks to insurers (SEA, 1997). This study combined various datasets from the Bureau of Meteorology and undertook a number of analyses to determine the frequency and intensity of severe thunderstorms within 150 km of Brisbane. The review relied on a number of earlier studies which considered the synoptic conditions for the occurrence of severe storms. Principal amongst these was Callaghan (1988), which used a 10 year data set containing only storms with high radar reflectivity regions (>60 dBZ) thus ensuing only potentially severe storms with very heavy rain and/or hail were considered. After some simplification, Callaghan’s analysis leads to essentially four classes of severe thunderstorms in the region, based on broad synoptic pre-cursor types as follows (Harper and Callaghan, 1998):

Type A: SE Change	(23%)
Type B: Strong NW Flow	(17%)
Type C: Weak NW Flow	(43%)
Type D: Other	(17%)

Callaghan also proposed a strong association between both storm intensity and track as a function of the regional topography; these being related to:

- the highland regions to the south and west providing elevated convective heat sources and hence buoyant air;
- for storms to reach the coast, a generally westerly steering current at middle levels and providing vertical wind shear is needed to sustain severe storms;
- low level convergence on the coastal plain which compensates for the loss of buoyancy in moving off the ranges;
- the interaction between the sea breeze and frontal/trough systems generates and intensifies severe thunderstorms in the populated coastal plains region.

Destructive Winds: The structure of severe winds in thunderstorms is significantly different from those in tropical cyclones. Instead of the wind being essentially horizontal, driven by the large scale pressure gradient, it originates as a vertical 'downburst' from high within the thunderstorm cloud structure, as schematised in Figure 6.3. The descent time may be several minutes, depending on the height of the storm. The downburst consists of a mass of colder air which, when it impacts the ground, spreads radially and horizontally, creating very sharp increases in wind speed. The forward speed of the storm then adds to the downburst speed, creating an elongated 'footprint' of damage which may be a few kilometres wide and about three times its width in length. The increase in wind speed and change in direction is often particularly rapid, typically reaching a maximum within a minute or less of initially calm starting conditions.

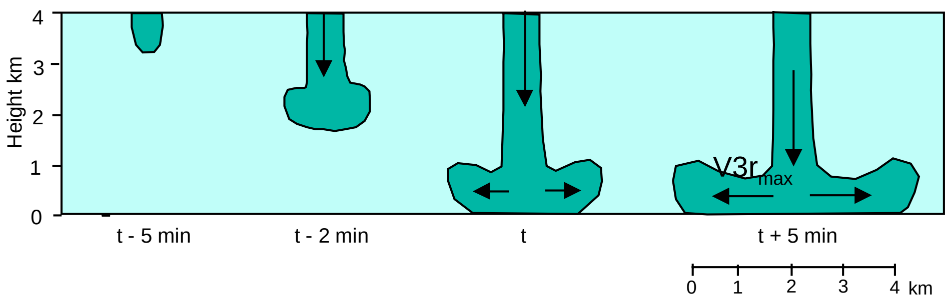


Figure 6. 3 Schematic example of a thunderstorm 'downburst' (after Hjelmfelt, 1988).

Tornadoes are features which may accompany severe supercell thunderstorms and are normally found at the left rear sector of the storm. Their exact origin is still largely unexplained but they clearly represent an extension of the strong rotational updrafts which exist within supercell storms. Peak wind speeds are estimated to approach 450 km/h in the largest tornadoes, although actual measurements are sparse. Their spatial size is small, ranging from just a few tens of metres up to a few kilometres. Track lengths typically vary from 1 km upwards and can extend for over 100 km if conditions are favourable. Contrary to popular belief, Australian tornadoes can be just as destructive as their US counterparts.

Because downburst winds increase so rapidly and tornado winds are so concentrated, the concept of mean and gust winds is less relevant than for tropical cyclones. Essentially the mean wind in a downburst is also the gust and the actual surface turbulence levels can be much lower than in tropical cyclones. This has ramifications for 'long' or 'large' structures such as transmission lines, where the wind pressure may be much more constant over a wide area than is typically the case in more turbulent wind conditions. Also, 'long' structures act as 'tornado traps'; their lateral width being more likely to intersect the relatively narrow swath which a tornado might create. A number of overhead power transmission line failures have occurred in South-East Queensland linked with severe thunderstorms.

Hail: Bureau of Meteorology records suggest that approximately 30% of all severe thunderstorms produce damaging hail, with actual sizes varying depending on the strength of the recirculating updrafts in the storm system. Hail is thought to grow by the accumulation of super-cooled water droplets as the hail nucleus is supported by the strong updrafts. Eventually, the mass of ice particles cannot be maintained and the hailstones typically fall in intermittent ‘shafts’ which form damage swaths at ground level due to the forward movement of the storm. These swaths vary from a few kilometres in width and up to 10 kilometres in length. However, the formation of hail (and lightning) is not completely understood. For example, the extremely rapid development of the hailstorm depicted in Figure 6.2 tends to question the simple recirculating theory and suggests a shorter and more direct mechanism for hail generation is possible.

Heavy Rainfall: A thunderstorm, with its strong moist updrafts, is a storehouse of precipitation. Whether this manifests as rain or hail depends on the particular storm features and atmospheric conditions on the day. Supercells and single cell thunderstorms are normally not responsible for levels of precipitation that cause flash flooding (BoM, 1995a) but rather it is the multicellular, or so-called mesoscale convective, systems which are responsible for the greatest sustained rainfall rates.

The speed at which a raindrop approaches the ground depends not only on its size but also the strength of the downdraft in which it is imbedded. Hence a 9 m/s falling drop may be subject to a further 10 m/s downdraft velocity, providing a very high rainfall rate. The most intense rain generally occurs under the core of the storm cell just after the first rainfall reaches the ground. It then spreads gradually and typically lasts for up to about 15 minutes. Flash floods typically occur when a storm moves relatively slowly across an area with limited drainage paths and high runoff capacity so that a large amount of rain falls in a small area and causes a high impact.

Lightning: Almost all storms produce some lightning and associated thunder, although there are no reliable methods for predicting overall storm intensity on that basis (BoM, 1995a). An average thunderstorm produces a few lightning flashes each minute and generates several hundred megawatts of electrical power during its lifetime. The source of this electrical energy is not completely understood but the more widely accepted theories involve charge generation and separation due to the production of solid precipitation (graupel or hail). It is postulated that the negatively charged larger particles settle relative to smaller positively charged particles, thus creating the charge separation distance over the height of the cloud convection layer.

Cloud-to-cloud discharges often occur between the positive and negative centres, resulting in extensive luminosity, but are of little concern at the ground. Cloud-to-ground lightning develops as the potential gradient between the base of the cloud and the ground increases, and eventually exceeds the insulating capacity of the air (Kessler, 1983). Cloud-to-ground lightning originates from the cloud as invisible (to the eye) discharges termed *stepped leaders*, because of their discrete method of advance. Positive charges are then induced in the underlying ground and when the discharge is about 10 to 100 m above ground, a travelling spark moves up from the ground to meet it. After contact, a large current is established with the cloud base, and the highly luminous lightning stroke propagates upwards. This return stroke is actually the visible portion of the stroke and is normally followed in quick succession by a number of secondary strokes before the charge is sufficiently dissipated to break the connection. In the case of isolated tall structures such as buildings or towers, the stepped ladder begins from the ground upwards. Most lightning strokes are negative, transferring negative charge from cloud to ground, but positive strokes can also occur. Thunder is generated during the stroke due to the rapid increase in air temperature surrounding the stroke. This creates a shock wave that initially travels faster than the speed of sound and generates a ‘sonic boom’ effect. Audible detection is limited to about 25 km from the stroke.

Traditionally, the collection of ‘thunder day’ statistics at observing stations has been used to estimate the occurrence and distribution of lightning across the state. However, this leads to fairly inaccurate sampling of the true occurrence. Following a period of development of remote sensing techniques for lightning detection in the late 1970s, magnetic direction-finding systems were established and have been operating in South-East Queensland for more than 15 years. The first system was jointly operated by (now) Telstra and Energex. Recently, more accurate time-of-arrival lightning tracking systems have been commercially developed and their information is able to be purchased by lightning sensitive industry sectors, including sporting bodies. Based on the analysis of about six years of lightning flash data by Quelch and Byrne (1992), the ground flash density (flashes/sq km/yr) for estimated discharges in the range of 30 to 100 kA is more than 2 along the coastal ranges and nearby hinterland. In the metropolitan region of Brisbane, levels as high as 0.5 are common, making lightning a relatively common impact from severe thunderstorms. Each year in Australia, lightning claims up to 10 lives and causes over 100 injuries.

The South-East Queensland Thunderstorm Experience

SEA (1997) assembled all the available data for the region over the period 1967 to 1996 and identified various deficiencies in terms of completeness of information and consistency in recording which need to be taken into account when drawing statistical conclusions from the data. Nevertheless, the study led to the following summary conclusions for the area within a 150 km radius of Brisbane:

- there are, on average, about 20 days each year when severe thunderstorms occur in the region;
- on each of these days there are often up to 5 individual storm systems involved,
- the thunderstorm 'season' is mainly October through April;
- predominant approach direction is from SW;
- the typical forward speed of storms is 40 km/h;
- approximately 30% of severe storm days involve severe hail;
- tornadoes occur on average about 1 day per year in the region; and,
- the most damaging storms appear to be of Type A (south-east change).

Appendix F provides a summary record of the more damaging severe storms which have occurred across the South-East Queensland region, dating back to 1956. These are certainly not all of the potentially severe thunderstorms that have occurred, but only those where significant damage was actually reported. Based on the Appendix F data, Figure 6. 4 shows the variation in annual occurrence over the 45 years of record. The largest number of damaging storms (eight) in any one year occurred in 1995 and 1999, with 1998 a close second. The average frequency of damaging storms is two per year over this period. The 5 year running mean of annual occurrences is also shown for comparison, highlighting some apparent cyclical activity over this time, and with an increasing trend being apparent in later years. As outlined by SEA (1997) though, these apparent trends in increased damaging storm occurrences over the past 15 to 20 years need to be considered within the context of the significantly expanding metropolitan regions and increased media access. The more densely populated the region becomes, the greater the frequency of damage resulting from severe storms will increase. This effect is especially important as the region begins to develop more in an east-west fashion, thus providing more elements at risk beneath the potentially damaging storm swaths from the south-west quadrant.

Figure 6. 5 shows the distribution of storm occurrences on a monthly basis over this period of time. The storm season typically begins in October and ends in April. December ranks as the most affected month with over 30% of occurrences, closely followed by November with 27%. January is next with about 17% and the other months, with the exception of May to August, make up the remaining 26%.

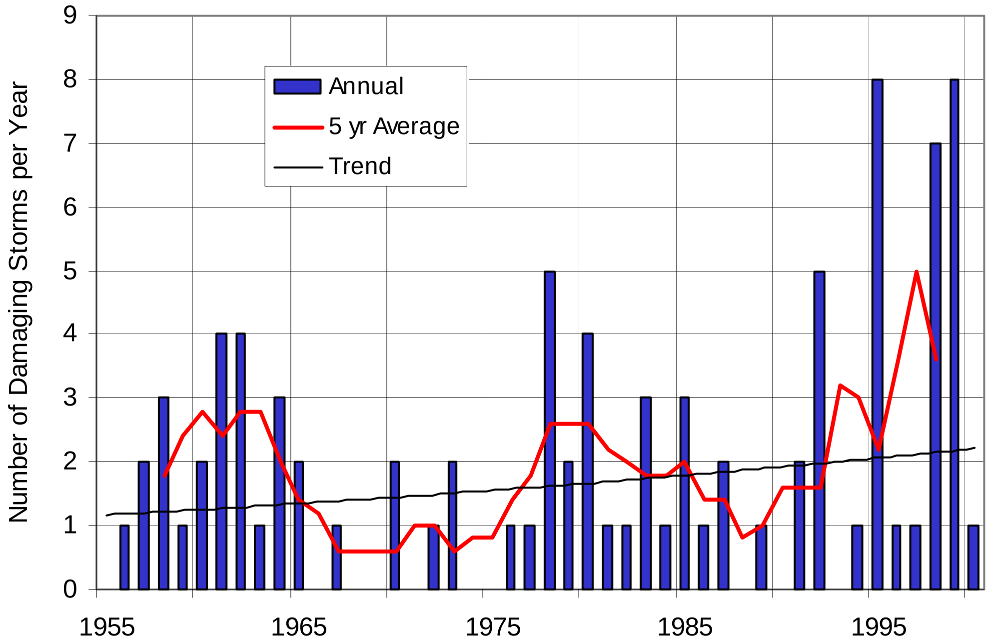


Figure 6. 4 Historical record of damaging thunderstorms affecting South-East Queensland

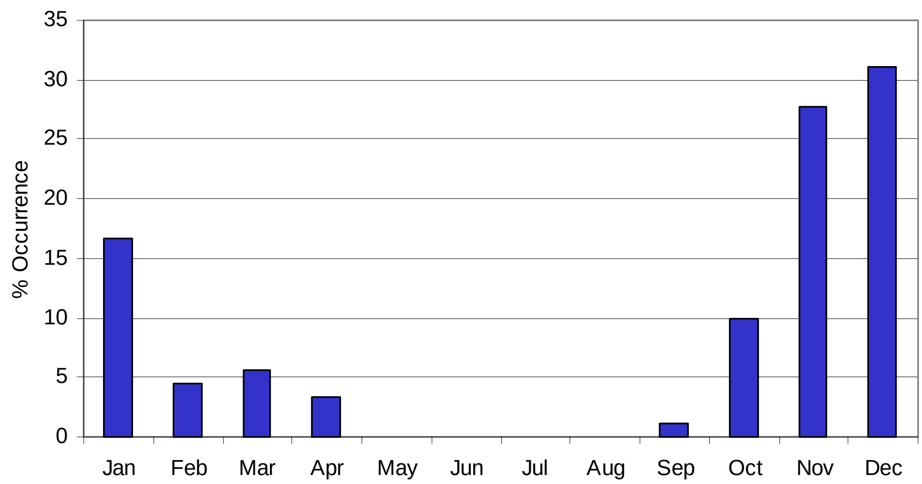


Figure 6. 5 Monthly distribution of damaging thunderstorms affecting South-East Queensland

In spite of the identified deficiencies in the database of severe storms (see Appendix F), the cyclical record in Figure 6.6 suggests possible influences with the Southern Oscillation Index (SOI) of the type already identified for tropical cyclones and east coast lows. To assist in this comparison, Figure 6.6 also presents a 5 year running mean of the deviation from the annual average occurrence, or mean anomaly, compared with the 5 year smoothed SOI over the same period. Certainly, during the 1970s, the enhanced SOI or *La Niña* cycle appears to have been associated with a decrease in occurrences of damaging storms while in the reverse or *El Niño* period, occurrences appear near-normal or generally enhanced. The recovery of the SOI to *La Niña* status over 1999/2000 appears also to be associated with a relatively reduced incidence of damaging storms in 2000. These trends are of course indicative only and further research may indicate other more relevant reasons for the cyclical behaviour.

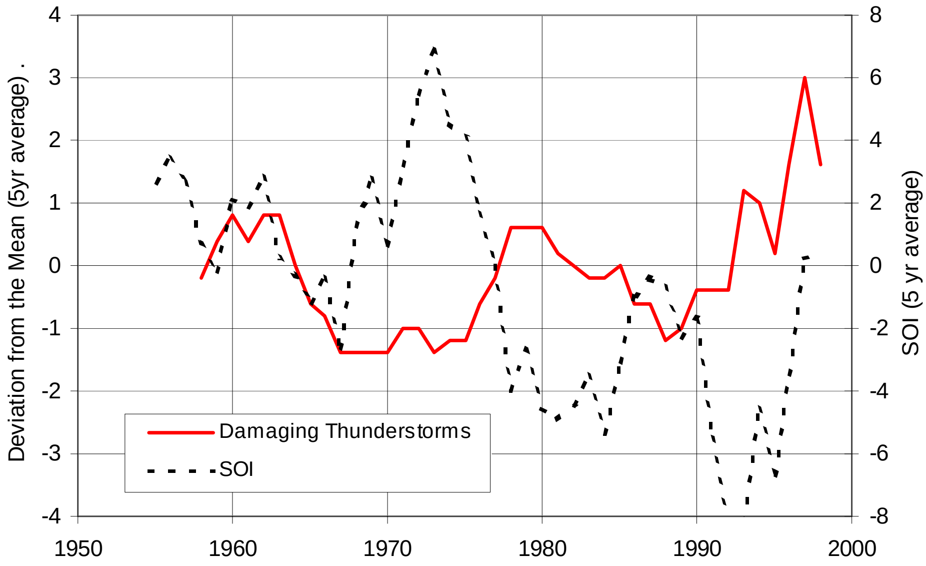


Figure 6. 6 Damaging thunderstorms and SOI relationships for Sout-East Queensland

Destructive winds from thunderstorms occur much more frequently in the South-East Queensland region than do the severe winds brought by tropical cyclones. They also act over much smaller areas. As a result, thunderstorms tend to cause localised but sometimes severe damage in a few suburbs, rather than affecting the whole community. Figure 6.7 summarises the occurrence of severe wind gusts (> 90 km/h) recorded at a number of airport sites over the past 60 years (from SEA, 1997). Each airport is separately shown, together with the only two instances when tropical cyclone winds exceeded 90 km/h (1954 and 1974), although there were a number of occasions on which cyclonic winds came close to this value.

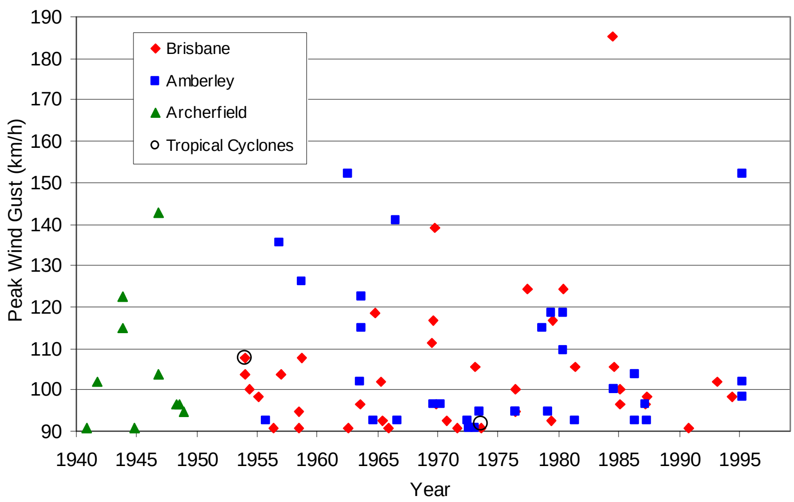


Figure 6. 7 Severe wind gusts recorded at South-East Queensland airport sites 1940 to 1995

The likelihood of experiencing severe thunderstorm winds at any point in South-East Queensland on a long-term basis can then be estimated from statistical analyses, as shown in Figure 6.8 (after SEA, 1997). This shows the datasets recorded at Brisbane and Amberley together with a statistical best fit line which is the average of separate analyses for each airport. This analysis estimates the 100 year ARI to be about 170 km/h and the 1000 year ARI winds at about 220 km/h. It also suggests that the highest recorded wind gust of 184 km/h in 1985 has an ARI of about once in every 200 years. It should be noted that these statistics apply for a single point location such as a house, whereas the chance of experiencing these wind gusts anywhere in the region is significantly greater. That is why emergency services regularly need to respond to damage caused by severe thunderstorms every season.

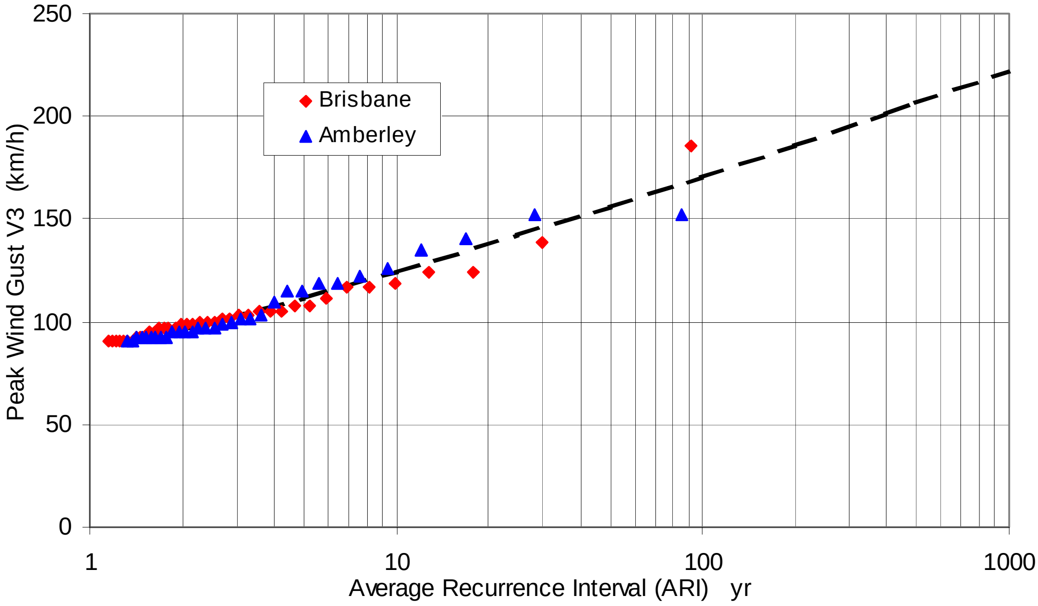


Figure 6. 8 Estimated point probabilities of severe thunderstorm wind gusts in South-East Queensland (after SEA 1997).

In South-East Queensland coastal regions the topographic variability may tend to limit the longevity of tornados but not necessarily their strength. Figure 6.9 shows one of two severe tornadoes which damaged farms and forest plantations on 29 November 1992, near Gin Gin.

There have been at least 15 confirmed or suspected tornadoes in the region over the past 45 years. In November 1973 a tornado, between 100 m to 230 m wide, cut a 51 km swath of damage from Brookfield through Nathan to Eight Mile Plains and across Redland Bay. It unroofed 500 houses, damaged around 1400, with 500 being declared structurally unsafe. The impact of a re-occurrence of such a storm with the present extent of suburban development would be increased many times over. Figure 6.10 shows some of the housing damage at Macgregor which illustrates the destructive capacity of such systems.

Figure 6. 9 A tornado during the Bucca storm in November 1992

Figure 6. 10 Tornado damage from the November 1973 event in Brisbane

In the South-East Queensland region, reliable reports have been made of hail up to 120 mm in size (rockmelon size). In the Toowoomba hailstorm of 1976 there was one report of a 200 mm 'chunk'. During the descent from high in the cloud, several pieces of hail can coalesce, forming ragged non-spherical shapes that break apart after impact. The most significant hailstorm in Brisbane was in January 1985, where a supercell caused extensive damage in two separate parts of the city over about a half hour period. The largest hail was approximately 63 mm in diameter (tennis ball size). The recent Sydney hailstorm in April 1999 had common hail sizes up to 63 mm but there were several reports of hail of between 80 and 120 mm. Figure 6.11 shows some examples of hail from the November 1995 storm which damaged the roofs of more than 300 homes in the western Brisbane suburb of Bellbowrie.

Figure 6. 11 : Examples of large hail capable of breaking tile roofs.

Statistical data on the occurrence of hail is extremely limited and rarely verifiable. While the Bureau of Meteorology observation network records the number of 'hail days' at official recording stations, this gives no discrimination of size. Hail size is typically reported by members of the public or gleaned from newspaper reports.

Thunderstorm Risks

The risks posed by destructive winds to buildings and infrastructure elements have been dealt with in Chapter 4, whilst the risks associated with the flash flooding and landslides that can be triggered by intense rainfall episodes are covered in Chapters 6 and 8 respectively. Whilst the areas affected by any given single thunderstorm will be much smaller than that affected by a tropical cyclone or east coast low, for those caught in the path of severe thunderstorms the impact is no less serious. Buildings can be destroyed, infrastructure brought down or dislocated and people killed. They are serious hazards indeed.

Thunderstorms have six main adverse impacts:

- disruption of power supply (and the subsequent knock-on affect on water supply, etc) from lightning strike or downed power lines;
- road and rail access cut because of flash flooding, traffic accidents or fallen vegetation and/or power lines;
- damage to houses due directly to severe winds, hail or storm water, or indirectly by wind-blown debris;
- personal fear, injury or death from both direct and indirect causes;
- significant insurance losses to both buildings and possessions such as cars;
- fires and/or fatalities caused by lightning strikes.

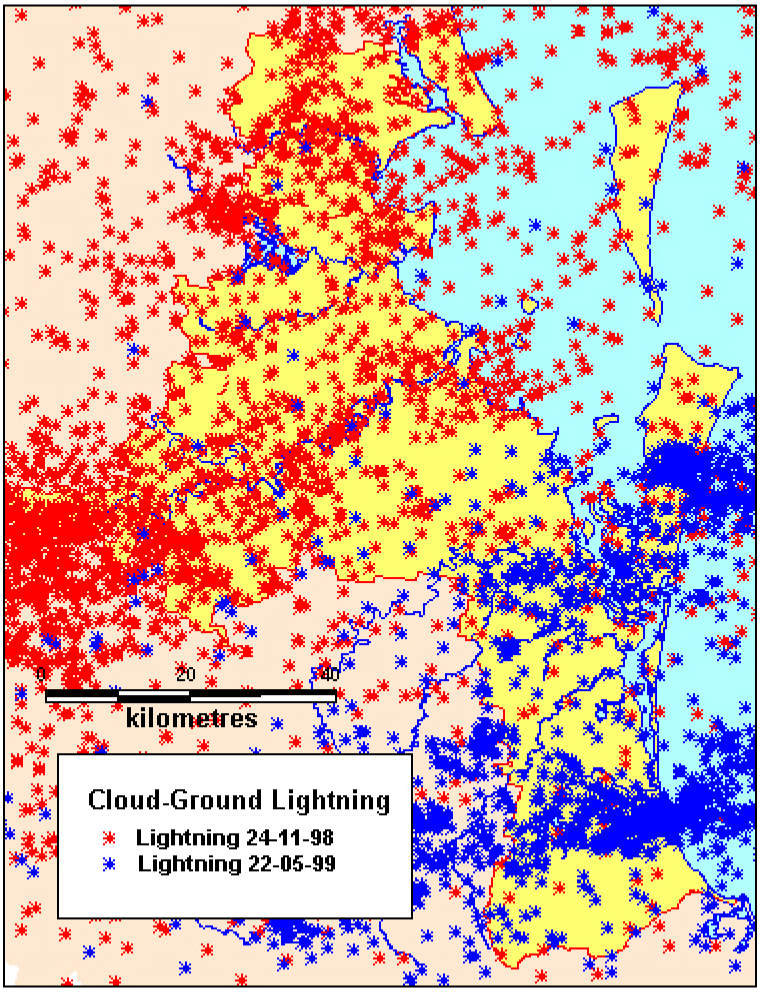
Damage to housing and infrastructure due to hail is a progressive failure, dependent upon the hail size and to some extent on the angle of attack. Windows are normally the first affected and will break at around the 30 to 40 mm hail size (SEA, 1999). Aluminum awnings, external shades and vinyl sidings are also susceptible to hail damage at about this size. Roofs and guttering are normally next to fail, especially aged AC sheeting, brittle tiles and aged corrugated iron. There were several reports from the 1995 Bellbowrie storm of hail penetrating both roof tiles and the plaster board of the ceiling before damaging furniture inside the building.

When roof integrity is lost, significant rainwater entry occurs and contents damage rapidly rises. As has been witnessed with the 1999 Sydney event, delays in roofing repair can severely exacerbate the consequential losses. In past events involving hail sizes in the order of 80 mm, some insurance losses in South-East Queensland have reached 25% of the insured value of the property (SEA, 1999). Motor vehicle damage can also be very extensive when hail sizes exceed 40 mm. Because many severe thunderstorms cross the metropolitan area around 6 pm, they coincide with daily peak traffic periods and can cause significant road chaos. It should also be remembered that large hail is a significant personal hazard and serious injuries can be sustained by people (or animals) unable to gain shelter.

Specific lightning protection is required for commercial and industrial buildings and structures to provide isolation for electrical, telecommunications and computer equipment and personnel who operate such systems. As well as the immediate impact of the peak current from a lightning strike, earth potential rise (EPR) is a common cause of extensive damage to underground cables and is the most common form of injury through the use of telephones during an electrical storm (Quelch and Byrne, 1992). Telephone subscribers are warned against the possibility of lightning-induced electrical or acoustic shock if the handset is used during thunderstorms.

Fatalities from lightning strike are quite rare, however during the period 1803 – 1991 some 650 people were killed by lightning strike in Australia. These fatalities are especially seasonal and gender/age-based. Over 85% of all outdoor lightning strike victims have been males between the ages of 15 and 19 struck between midday and 6pm in the summer months of November to February. Historically, most outdoor fatalities involved those working on the land, however, urbanization and the rise in outdoor recreation, especially water related sports, golf and cricket, is changing this statistic (Coates and others, 1993).

In the period from February 1998 to September 2000 there were 12 042 cloud-to-ground lightning discharges registered by the GPATS Lightning Position and Tracking System (LPATS) over land in the South-East Queensland study area. Even with this short period of records it is clear that they were distributed more-or-less evenly across the region – there were certainly no areas in which lightning was not a potential problem, nor were there areas that appeared to receive an abnormally high incidence of lightning strokes. Figure 6.12 illustrates the cloud-to-ground strokes recorded on two separate days, 24 November 1998 (in red) and 22 March 1999 (in blue) are also shown highlighted in the figure to illustrate the extent of lightning possible during a 24 hour period. GPATS (Global Position and Tracking Systems P/L) is a commercial operation that manages an Australia-wide lightning detection system.



Click here for High Resolution Image

Figure 6. 12 Cloud-to-ground lightning strokes for 24 November 1998 and 22 March 1999

Interpretation

Whilst it can be anticipated that at least one damaging thunderstorm could have an impact somewhere in South-East Queensland 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. They are such common events that most of the population now take the warnings of severe storms issued by the Bureau of Meteorology quite seriously and attempt to get themselves and/or their cars at least under cover.

There are no appropriate statistics by which to measure the severe thunderstorm total risk.

Community Awareness

There is perhaps a greater awareness of the risks posed by severe storms in South-East Queensland than there is for any other hazard. This is no doubt due to the frequency with which severe thunderstorms occur across the region and the media attention that they attract. Most people in the region have experienced, or know of someone who has experienced, hail damage to their house or car in recent years, for example. The impact of the 1999 Sydney hail storm, which was heavily reported by the electronic media, may also have reinforced the storm risk message.

It is perhaps ironic, however, that people tend to be more concerned about the welfare of their cars in response to a warning about the possible threat of hail than they are about their own personal safety in the face of more significant threats from tropical cyclones or floods, for example.

Forecasting and Warnings

The Bureau of Meteorology (BoM, 2000) is responsible for issuing warnings for all severe weather events. South-East Queensland lies within the Southeast Coast Warning Region, which extends from the Sunshine Coast south to the New South Wales border and west to Toowoomba. Operational procedures for the issuing of severe thunderstorm warnings from the Brisbane office of the Bureau detail three distinct phases: (a) Monitoring Phase, (b) Advice Phase and (c) Warning Phase.

As is evident from the foregoing physical description of these phenomena, their rapid and unpredictable development poses many challenges for weather forecasters. The public also need to appreciate the practical difficulties of not only detection but also in disseminating timely warnings to the community through media outlets, which are not always fully staffed at critical times. Input from the public at large remains an important element in providing timely warnings to the whole community for these small-scale short-duration severe weather events.

In the monitoring phase, a continuous watch is kept for the precursors of strong convection and for the occurrence of potentially severe thunderstorms. Sources of information used by the forecasters include synoptic, upper wind and temperature data, radar and satellite imagery, analytic fields derived from the above information, and prognostic fields from computer models. In addition, special observations are received from a network of over 60 volunteer *Storm Spotters* in South-East Queensland. These individuals receive basic observer training from the Bureau and report the occurrence of severe thunderstorms and the conditions associated with them via a dedicated FREECALL telephone link to Bureau forecasters. This ensures the Bureau is made aware of any potentially severe storm activity as soon as possible. *Storm Spotters* also record and report their observations through the return of special 'Severe Thunderstorm Reporting Cards' which add valuable information to the historical archive of storm occurrence and damage.

A *Severe Thunderstorm Advice* is an early alerting message for the community and is prepared when severe thunderstorms are expected within the next four to six hours. A number of specific atmospheric indices are used to determine when such a situation is likely, even without the actual formation of storms. Typically, these 'top priority' advices are made available for noon radio news services and outline the degree of thunderstorm threat for that afternoon. The *Advice* is updated at least two-hourly until a cancellation advice is issued.

In the event that thunderstorms, which are approaching, or are already within, the warning area are expected to be severe, or a report of a severe event has been received, then a *Severe Thunderstorm Warning* is issued. These are necessarily short term forecasts, usually valid for a maximum of two hours. Such warnings may mention the possibility of flash flooding when this is considered likely, large hail if applicable and tornadoes if a confirmed ground report has been received. It is not possible to reliably detect tornadoes from presently installed radar technology, although some classical vertical structures are indicative of strong and possibly rotating updrafts. More reliable tornado and downburst detection will become possible when 3D Doppler radar coverage can be made available for the Brisbane region. In particularly hazardous situations, the Bureau authorises the use of the *Standard Emergency Warning Signal (SEWS)* to provide additional media impact to the warnings.

In many instances thunderstorms develop to the severe stage within the warning zone and sometimes within the coastal plain where the majority of the population is located. Therefore, to provide practical lead-time it is sometimes necessary to issue warnings before there is any clear evidence of severity from radar echoes or observations. Accordingly, *Severe Thunderstorm Warnings* are issued hourly as top priority and increased to half-hourly when there is specific evidence of severity. Specific warning cancellations are also issued as appropriate and media outlets are carefully instructed on the period of validity of specific warnings so as to not cause confusion for the public.

The final role of the Bureau of Meteorology is to undertake assessment of its own performance and to document the outcomes from the severe weather event. It does this by compiling annual verification statistics and maintaining a database of events. The aim of the Severe Thunderstorm Warning Service is to provide a probability of detection of 70% or greater of severe events, a false alarm ratio of 40% or less, and at least thirty minutes lead time (i.e. time between the issue of a warning and the occurrence of the severe phenomena) on 70% of occasions.

Further Information

More detailed information on the levels of exposure of individual neighborhoods or properties to the severe thunderstorm risks outlined here should be referred to the respective local government council.

CHAPTER 7: LANDSLIDE RISKS

Matthew Hayne, Marion Michael-Leiba, Don Gordon, Rob Lacey and Ken Granger

The landslide threat

A landslide is the movement of a mass of rock, debris or earth down slope. Whilst the causes of slope movement can be quite complex, all slides have two things in common, they are the result of failure of part of the soil and rock materials that make up the hill slope and they are driven by gravity. Landslides can vary in size from a single boulder in a rock fall to tens of millions of cubic metres of material in a debris avalanche. While not as well recognised as many other hazards such as cyclones, storm surge, floods and earthquakes, in Australia landslides cause more economic loss as well as injury and loss of life than is generally recognised.

Whilst the Thredbo, New South Wales, landslide which killed 18 people in July 1997, or the Gracetown, Western Australia, cliff collapse which caused nine fatalities in September 1996, made the world news, many smaller events kill one or two people at a time, and do not receive such extensive media coverage. In Australia, a total of 88 people are known to have been killed by 38 landslides since 1842. An additional 115 people are known to have been injured. It is almost certain that these statistics are incomplete and that the number of fatal events is much higher than presently reported. Globally landslides are one of the most common geohazards accounting for about 25% of the annual death toll from natural hazards (Hansen, 1984).

Data are too incomplete to give accurate costs incurred from landslides but are estimated to total about 500 million dollars since 1900. This may equate to hundreds of millions, or perhaps billions, of present-day dollars. Landslides have caused many instances of damage and disruption to buildings, roads, railways, and pipelines. An example is the Wollongong-Sydney-Brisbane railway, where costs associated with landslide damage are estimated to average $25 million per year during the period 1989-1996. The costs prior to 1989 are not available. More than 200 buildings throughout Australia have been damaged by landslide. Many of these were destroyed, the total cost is estimated to be of the order of $30 million in present-day dollars.

By developing and applying reliable and accurate methods for assessing landslide hazard and risk it is possible to enhance forward planning strategies leading to disaster mitigation, reduce economic losses and build safer communities and environments.

The landslide phenomenon

Landslide causes can be divided into internal and external. External causes include the steepening or heightening of a slope by river erosion or excavation, the deposition of material along the upper edge of slopes and earthquake shocks. If an external cause leads to a landslide the shearing stresses along the potential surface of sliding must have increased to the point of failure. Internal causes are those which lead to a slide without any change in surface conditions. These include increased pore-water pressure and decrease in sediment cohesion. If a slope fails in spite of the absence of external causes, then it must be assumed that the shearing resistance of the material has decreased (Terzaghi, 1950).

Certainly the most common trigger for landslides is an episode of intense rainfall. The rainfall threshold values for slope failure in various parts of the world are in the range 8 - 20 mm over one hour, or 50 - 120 mm over a day depending on geology and slope conditions (John Braybrooke, Douglas Partners Pty. Ltd., written communication, 1998). In much of the south east Queensland study area, rainfall intensities of such magnitude have an average recurrence interval (ARI) of about one year.

It is important to note that many slope movements/landslides occur after much longer periods of rainfall. Thus, the antecedent rainfall magnitude over a period (before the day of landslide occurrence) of one week or a month, or even more, may be of critical importance (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001). In particular, Flentje (1998) has developed an interesting approach for rainfall analysis which includes the concept of Antecedent Rainfall Percentage Exceedance time (ARPET). Regarding the rainfall thresholds in the Wollongong area of New South Wales, Chowdhury and Flentje have concluded that threshold magnitudes for relatively long antecedent periods of rainfall (1 to 3 months) are relevant to most of the deep-seated, slow moving landslides (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001).

On the other hand relatively short antecedent periods (1 day to one week) are relevant to most shallow slips and shallow debris flows. However, one must emphasise that these periods are specific to one region. Periods of antecedent rainfall for which threshold magnitudes are relevant would differ markedly from one region to another, depending on geology, climate, geomorphology, etc (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001).

Landslides common to the study area include:

Rotational slides: In the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas develop on moderate to steep slopes (15°-25°), where colluvial material has accumulated around concave slopes adjacent to gullies and below the base of the basalt. These slides move quickly. They exhibit a semi-circular, back tilted upper section and a disrupted toe section. This type of failure is very difficult to predict and areas where they may occur must be treated cautiously (the geology of the South-East Queensland area is described in Chapter 2. Landsliding in areas underlain by the older Neranleigh Fernvale Beds (essentially to the east of the basalts) occur as translational and rotational slides on the flanking slopes of the quartzite ridges. In the Brisbane and Ipswich areas, rotational slides have also been noted on shallower slopes in soil or colluvium, and on slopes as low as 7° on unlaterised Tertiary sediments. Many alluvial river bank failures in South-East Queensland are probably rotational slides.

Complex multiple rotational slides: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera, and Currumbin valley areas are characterised by broad, relatively deep, slow moving slides that occur on the outer edges of benches and on colluvial fans where gentle slopes occur above a drop-off. Virtually all benches and colluvial aprons show examples of these failures, which in places are very numerous. The slopes of their upper sections are low but steepen over the lip of the drop-off to between 13° and 25°. They almost always occur around gully mouths where the gully drops over the scarp of a bench. Some of the largest slides cover almost the entire width of a bench or apron being up to several hundred metres across. They are of great significance for planning of future settlement, as they occur on relatively flat land seemingly suitable for building.

Debris flows: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera, Currumbin valley, the western part of Pine Rivers and Caboolture areas are triggered by the action of torrential rain on loose material (rocks and finer material) on mountainsides or escarpments, adjacent to gullies or concave slopes where colluvial debris is thicker. The boulders and finer material, mixed with water, flow down the slope as a torrent. The coarser material is deposited near the base of the slope, while the finer material travels further as a flash flood. Debris flows can be highly destructive. Within the study area debris flows occur mainly on the steeper slopes (>25°). Due to the difficulty of building in these areas they therefore impact settlement only rarely. Roads in these areas are however subject to the effects of debris flows and undercutting adds to instability.

Debris flows are common on slopes that formally supported rainforest. The flows are possibly aided by a greater thickness of colluvial material as well as on the basalt scarps. Small flows also occur on cleared steep slopes adjacent to gullies underlain by the Marburg Formation and to a lesser extent the Neranleigh-Fernvale beds and the Woogaroo Sub-Group.

Rock falls: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas occur sporadically from exposed rock faces on the scarp line. Due to the steep nature of the terrain towards the scarp line there is little potential for settlement impact.

Rock falls have also been recorded along the South-East Queensland coastline, especially the sea cliffs in the Point danger area of Coolangatta and Redcliffe. These rock falls are largely the result of the under-cutting of the cliff by wave action over time. At Burleigh Heads, rocks fall from a columnar outcrop at the top of the headland. They can roll down to sea level crossing two footpaths that round the headland. Rock falls can also occur on steep river banks such as the Tertiary sediments along the Brisbane River.

Landslide hazard and risk methodology

Hazard: Quantitative estimates of landslide hazard have been made based on a 100 year ARI rainfall event. The hazard probability estimate is calculated in the following manner:

PROBABILITY OF BEING IMPACTED AT A POINT WTHIN A GEOLOGICAL / SLOPE UNIT GIVEN A 1 IN 100 YEAR LANDSLIDE EVENT	=	TOTAL AREA OF MAPPED LANDSLIDES PER GEOLOGICAL/ SLOPE UNIT	/	AREA OF GEOLOGICAL /

Equation 7.1. Calculation for a 100 year ARI landslide hazard probability.

Vulnerability: Risk estimates have only been determined for three principal elements, namely, people (p), buildings (s) and roads (r).

Vulnerability (V) is the potential degree of loss of elements within the area affected by the landslide. In this report, we have considered only vulnerability to destruction. For example, if a particular instance of landsliding has a 50% chance of destroying a property impacted by it, then V=0.5. If it is judged that landsliding will have a one in ten chance of causing a fatality in a building impacted by it, then V=0.1. If a building is destroyed, V=1 it is taken to mean that the building is damaged to a degree that it is regarded as unfit for habitation.

The Australian Geomechanics Institute (2000) and the International Union of Geological Sciences (1997) provide summaries of vulnerability. The latter make the apt observation:

> *"Although the state of the art for identifying the elements at risk and their characteristics is relatively well developed, the state of the art for assessment of vulnerability is in general relatively primitive".*

Very few quantitative assessments of vulnerability have been made and those that do are usually semi-quantitative in nature. Application of vulnerability values derived from other studies is difficult as vulnerability is affected by many factors, the more obvious of these include:

- nature of the element at risk
- position of the element at risk
- velocity of landslide movement
- magnitude of landslide displacement
- volume of landslide and
- prior warning

A number of general observations concerning the nature of the landslide and the vulnerability have been made, these include:

- higher velocities usually result in greater vulnerability; this is qualified however, by the fact that rate of movement is less important for structures than it is for loss of life (Fell and Hartford, 1997)
- landslides with greater displacement such as debris slides, flows and rock falls will produce greater vulnerabilities
- the greater the depth of slide material the greater the vulnerability for structures and persons (International Union of Geological Sciences, 1997) and,
- landslides that provide little warning result in greater vulnerability; this will especially be true of debris slides, flows and rock falls.

The velocity, magnitude of displacement, volume and prior warning are closely associated with landslide type. With the above factors and observations in mind, it becomes necessary to assess vulnerability as a function of landslide type.

Previous Estimates of Vulnerability: Vulnerability estimates for rotational slides and slumps derived from the Cairns area, and used in the South-East Queensland study region, were made by Michael-Leiba *et al*. (1999). By using the Australian Landslide Database the vulnerability of persons (Vp) was estimated at Vp=0.1. This was revised to Vp=0.05 to reflect a more realistic value based on the probability that landslides causing death are more likely to be reported in the media (and therefore included in the database statistics) than those that do not. This estimate is in good agreement with Wong *et al*. (1997), for the vulnerability of a person in a building if debris strikes the building. Building vulnerability (Vs) in Cairns was estimated at Vs=0.5. This assessment was altered to Vs=0.25 in order to reflect the conservative nature of the estimate given that many slightly damaged buildings would go unreported. Vulnerability of roads (Vr) in the Cairns region were estimated from council records and a mean value of Vr=0.3 was adopted.

Michael-Leiba *et al*. (2000) also derived qualitative vulnerability estimates for elements subject to debris flows in the Cairns region. These areas are analogous to slopes >25° in the South-East Queensland study region. Leiba *et al*. analyse debris flow by dividing it into proximal (bouldery, >19°) and distal (flash flood, 14°-19°) portions and estimate the associated vulnerability. Providing that the occupants are within a structure then Vp=0.9. Buildings have been estimated at Vs=1 and roads at Vr=1.

Vulnerability estimates for people, buildings and roads in the South-East Queensland field area are presented in Table 7.1. Vulnerability estimates for elements on slopes <25° are derived from subjective approximation and the work of various authors. Vulnerability estimates for debris flows occurring on slopes >25° are more sound, with agreement between Michael-Leiba *et al*., Fell and Hartford and others. This agreement may simply be a result of the extreme values, however they do seem logical and are adopted here. The vulnerability for roads was estimated following discussion with the Cairns City Council about the incidence of road blockage and repairs due to landslides in Cairns. We do not know the magnitude of the uncertainty in these figures.

Table 7.1. Vulnerability of elements.

	Vulnerability (V)		
	Persons (p)	Structures (s)	Roads (r)
Debris slides, flows and rock falls, >25° slope in Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas	0.9	1	1
Rotational slides and slumps, <25° slope in Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas	0.05	0.25	0.3
Small debris slides, flows, slumps and rock falls in Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas	0.05	0.25	0.3

Specific risk: In this report, we have taken specific risk as being the probability that an individual will be killed, property lost or road destroyed or blocked by landslide given a 100 year ARI rainfall event.

The specific risk (R_s) for both buildings and roads is the product of the hazard (H) and vulnerability (V) (Equation 7.2).

Equation 7.2. Specific risk.

$$R_s = H \times V$$

The specific risk of an individual being killed by a landslide is taken to be the probability of the *occupant of a building* being killed by a landslide given a 100 year ARI event. This is the probability of the building being impacted by a landslide (H) multiplied by the vulnerability (V_p) of an individual.

Equation 7.3. Specific risk for people.

$$R_p = H \times V_p$$

Total risk: Total risk is a measure of the expected number of lives lost, or buildings or km of roads destroyed from a 100 year ARI rainfall event scenario given the present level of development.

Total risk (R_t) is calculated by multiplying the specific risk (R_s) by the number of each of the elements at risk (E). It must be remembered however, that estimates are only based on the present state of development, future changes such as vegetation clearing will alter the exposure to risk (the total risk for undeveloped areas is considered zero).

Equation 7.4. Total risk.

$$R_t = H \times V \times E$$

Landslide in the Gold Coast Hinterland Region

The region of South-East Queensland covered in this landslide hazard and risk assessment (Figure 7.1) is approximately 654 km^2. This region has been chosen firstly, as it is recognised as having significant landslide potential and secondly, because it has been the focus of detailed studies in the past (Willmott 1981 and 1983; and Willmott and Hayne, 2001) on which this analysis will build.

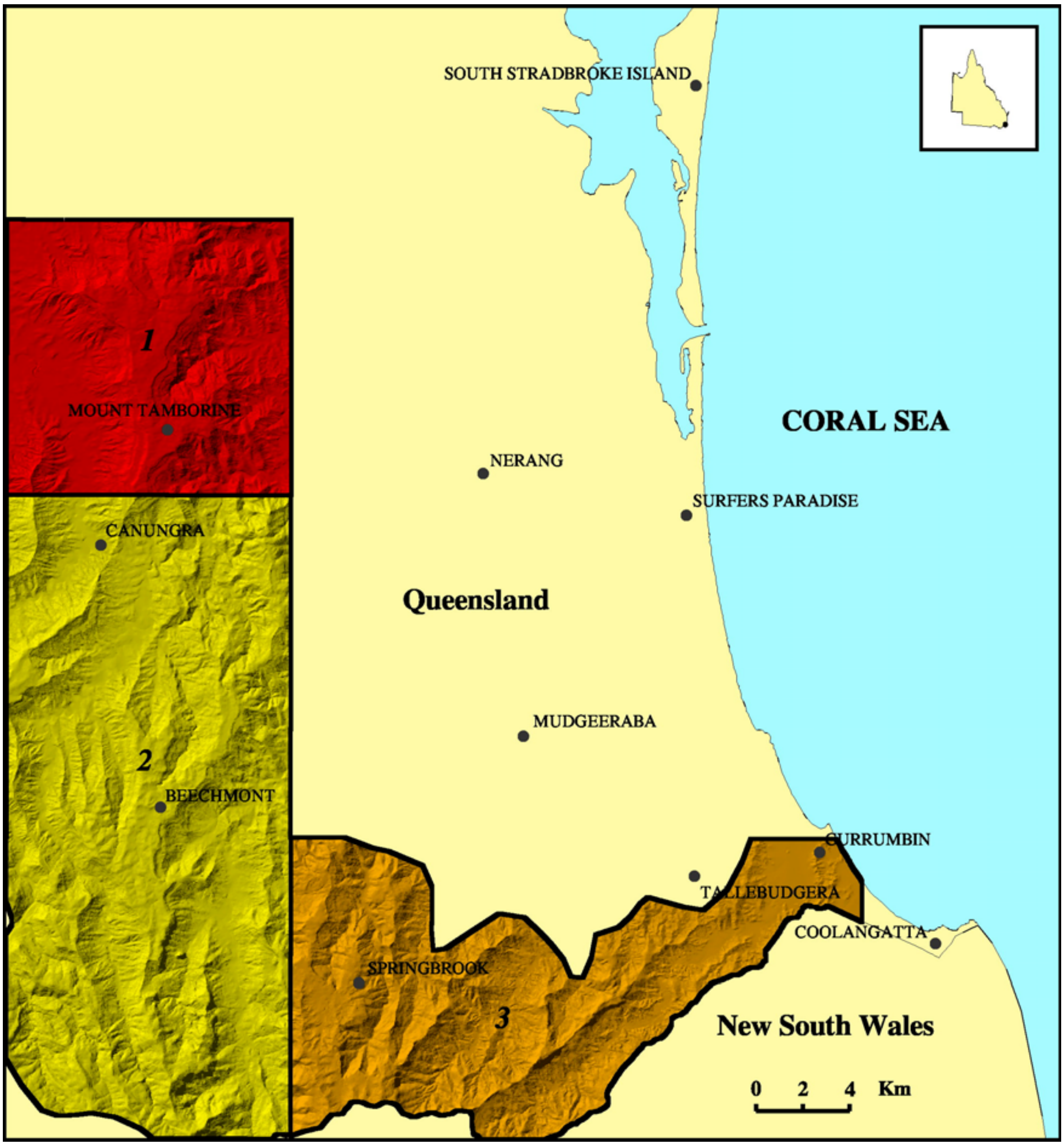


Figure 7.1. Gold Coast regional landslide investigation area.

The region is characterised by deep valleys that have been eroded back forming ranges capped by a plateau. The valleys cutting into the plateaux have steep sides with intermittent benches that have developed large deposits of colluvial material that are prone to landsliding. The valleys act as catchments for a number of rivers and creeks that trend in a northeasterly direction. These streams continue to erode the valley heads and future problematic development of urban, rural and semi-rural areas intensifies already burgeoning slope stability problems.

Willmott (1981 and 1983) and Willmott and Hayne (2001) documented a detailed and comprehensive mapping survey of the landslides and geology of the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas. Landslides resulting from the 25-28th January 1974 rainfall event were mapped from aerial photos and ground surveying. On the basis of combinations of topographic, geological and groundwater conditions the region was divided into stability zones.

The Snowy Mountains Engineering Corporation (SMEC) (1999) carried out a broad landslide risk assessment of the administrative area of the Gold Coast City. This included the basalt areas, for which risk was extrapolated from the earlier 1983 study of areas to the west. Using a Digital Terrain Model (DTM), a lattice grid based on 50 metre squares was developed. Based on slope angle and geology overlaid on this grid, stability classifications were developed. Stability assessments have also been made by consultants for various building blocks but no attempt has been made to collate this material.

Areas of potential landslide have also been investigated using a machine-learning approach (Hayne and Gordon, 2001). The high resolution achieved in this study is generated from a 5m DEM. Environmental variables of aspect, slope, geology, morphology, curvature and vegetation were measured from landslides resulting from the 1974 rainfall event and used to identify further areas of landslide potential.

Willmott (1984) has documented observations of the causes of landsliding on the basalt plateaux of South-East Queensland. A comparison of forests cleared and uncleared on slopes surrounding Mt. Tambourine has highlighted the development of permanent springs after clearing. Close inspection of the uncleared slopes revealed little evidence of sliding whereas, on cleared slopes large areas of land have failed dramatically. Vegetation plays a crucial role in landslide occurrence. The geological nature of the area enables groundwater to be fed laterally outward onto the hillsides. Following the loss of tree canopy on the steeper scarps and slopes rapid saturation of the soil occurs and there is a reduction in soil strength caused by the loss of tree root systems.

Identification of individual aquifers is not generally possible due to colluvial cover, although some particularly active layers can be inferred by lines of springs on some benches. The Chinghee Conglomerate (Th), consisting of interbedded coarse sandstone and conglomerate, has been identified by Willmott as a unit which can act as an aquifer giving rise to hill side springs. The junction between the basalt and the underlying rocks can also act as an aquifer, possibly due to a weathered, impermeable clayey zone at the junction, or simply because the underlying rocks are less permeable. Apart from the major aquifers, however, the close stratification of the lavas suggests that many local permeable zones would be present, and it must be assumed that virtually all the basalt flanks of the plateau and ranges are influenced to some extent by seepage.

In summary, a number of unique geological features within the volcanic terrain of the Gold Coast hinterland combine to produce an area prone to landslip. These include:

- horizontal strata that directs ground water movement between porous and nonporous layers;

- accumulations of colluvial debris;
- the presence of clays; and
- the presence of beds of soft sediments.

As previously alluded to, the role of vegetation in landslide occurrence is complex due to the fact that vegetation influences the majority of factors involved in landslide development. These include climatic, hydrological, erosion and weathering factors. Most importantly deforestation of areas can produce elevations in the water table and increased pore-water pressures due mainly to the reduction in evapotranspiration. Clearing of vegetation may also reduce the overall internal strength due to the loss of tree root support. The effects upon a geologically sensitive location have been exacerbated by forest clearing through:

- a rise in groundwater levels and pressures caused by reduced transpiration, resulting in a reduction in strength of soil and colluvial debris, especially on benched slopes;
- increased rate of absorption of rainfall by the soil, reducing the time taken to reach high groundwater pressures;
- decreased release of groundwater pressures on lower slopes because of changes in soil texture and compaction; and
- a direct reduction in strength of surface material through the loss of the binding support of roots, especially on scarps and steep slopes.

Hazard and risk: The spatial distribution of potential sliding may alter in relation to rainfall intensity. Willmott (1981, 1983) and Willmott and Hayne (2001) undertook detailed mapping of the landslides associated with the major rainfall event of 25-28 January 1974 associated with TC *Wanda*. Mapping from both field observations and stereoscopic aerial photographs was used. Rainfall distribution across the study area from this event ranged from 1000 mm in the north to 1100 mm in the south, however by far the majority of the area received about 1000 mm of rain over a three day period. Intensity-Frequency Duration curves for a number of stations throughout the study area indicate that the 1974 rainfall event was in fact a 100 year ARI event.

As this is the only detailed recording of landsliding associated with a rainfall event a full suite of return period scenarios has not been developed. A landslide hazard map and hazard and risk estimates for this particular event will be presented.

In order to quantify hazard and risk for large regions such as the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas it is necessary to subdivide the region into similar physical characteristics, in this instance geology and slope have been chosen. The importance of geology as a controlling influence on landslide distribution and frequency in the study area has been noted by Hayne and Gordon (2001); Willmott (1981 and 1983) and SMEC (1999). Field observations and research by Hayne and Gordon (2001), Michael-Leiba et al. (1999), Fell and Hartford (1997) and Willmott (1981 and 1983) indicate different hazard and risk values between debris slides, flows and rock falls, and rotational slides and slumps and complex multiple rotational slides. In the study region debris slides, flows and rock falls occur predominantly on very steep slopes and scarps >25°, while rotational slides and slumps and complex multiple rotational slides occur predominantly on slopes <25° (Willmott, 1981, 1983 and Willmott and Hayne, 2001).

The geological history of the South-East Queensland region is outlined in Chapter 2, however, in order that the geological boundaries and hazard and risk estimates can be compared the geology of the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas is presented below (Figure 7.2). Calculations of hazard and risk are presented in Table 7.2.

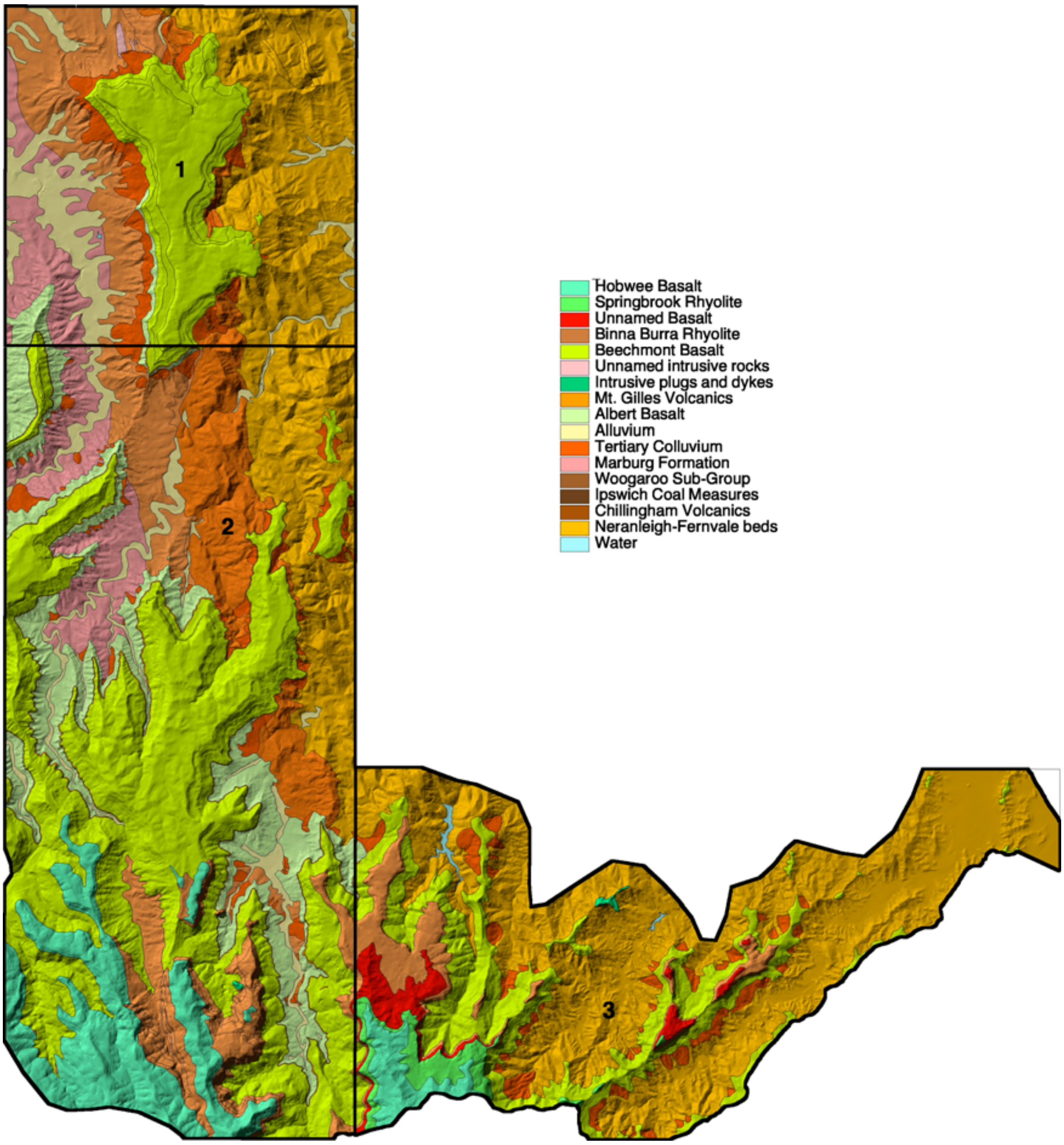


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Figure 7.2. Geology of the Gold Coast hinterland region

	Geological Unit/Symbol		Geological Unit Area (m^2)	Area of Mapped Landslides (m^2)	Probability of Impact	Specific risk (Rs)			Number of dwellings	Persons in Dwellings	Dwellings destroyed given a 1 in 100 year event	Fatalities given a 1 in 100 year event	Road length (km)	No. of slides blocking roads	Expected road closures/km	Expected road destruction/km
						Persons (p)	Buildings (b)	Roads (r)								
Debris slides, flows and rock falls, >25° slope	Hobwee basalt	/Tlh	11,833,605	0	0.00000	0.00000	0.00000	0.00000	5	14	N/L	N/L	0.6	0	0.0	0.0
	Springbrook Rhyolite	/Tls	1,511,044	0	0.00000	0.00000	0.00000	0.00000	6	17	N/L	N/L	0.4	0	0.0	0.0
	Unnamed Basalt	/Tl	1,495,873	0	0.00000	0.00000	0.00000	0.00000	7	20	N/L	N/L	0.1	0	0.0	0.0
	Binna Burra Rhyolite	/Tlr	12,085,786	0	0.00000	0.00000	0.00000	0.00000	8	22	N/L	N/L	0.7	0	0.0	0.0
	Beechmont Basalt	/Tlb	54,766,891	881,101	0.01609	0.01448	0.01609	0.01609	80	224	1.28705644	3.24338224	13.3	3	0.2	0.2
	Unnamed intrusive rocks	/Ti	10,902	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Intrusive plugs and dykes	/Tir	238,260	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Mt. Gilles Volcanics	/Th	1,275,702	61,316	0.04806	0.04326	0.04806	0.04806	1	3	0.04806452	0.12112258	0.3	0	0.0	0.0
	Albert Basalt	/Ta	6,261,465	195,002	0.03114	0.02803	0.03114	0.03114	3	8	0.09342957	0.23544252	0.9	0	0.0	0.0
	Alluvium	/Qa	146,547	0	0.00000	0.00000	0.00000	0.00000	2	6	N/L	N/L	0.1	0	0.0	0.0
	Tertiary Colluvium	/TQc	4,221,210	35,977	0.00852	0.00767	0.00852	0.00852	18	50	0.15341241	0.38659927	0.1	0	0.0	0.0
	Marburg Formation	/Jbm	2,262,885	31,730	0.01402	0.01262	0.01402	0.01402			N/D	N/D	0.4	0	0.0	0.0
	Woogaroo Sub-Group	/RJbw	2,937,798	10,700	0.00364	0.00328	0.00364	0.00364			N/D	N/D	0.5	0	0.0	0.0
	Ipswitch Coal Measures	/Ri	80,369	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Chillingham Volcanics	/Rc	6,371,640	12,663	0.00199	0.00179	0.00199	0.00199	2	6	0.00397480	0.01001650	0.9	0	0.0	0.0
	Neranleigh-Fernvale beds	/DCf	47,959,386	40,940	0.00085	0.00077	0.00085	0.00085	299	837	0.25523805	0.64319988	19.0	0	0.0	0.0
Rotational slides and slumps, <25° slope	Hobwee basalt	/Tlh	26,754,288	0	0.00000	0.00000	0.00000	0.00000	78	218	N/L	N/L	14.5	0	0.0	0.0
	Springbrook Rhyolite	/Tls	3,891,199	0	0.00000	0.00000	0.00000	0.00000	157	440	N/L	N/L	7.5	0	0.0	0.0
	Unnamed Basalt	/Tl	4,249,677	0	0.00000	0.00000	0.00000	0.00000	44	123	N/L	N/L	5.9	0	0.0	0.0
	Binna Burra Rhyolite	/Tlr	14,025,717	0	0.00000	0.00000	0.00000	0.00000	383	1072	N/L	N/L	19.8	0	0.0	0.0
	Beechmont Basalt	/Tlb	133,779,457	2,629,538	0.01966	0.00025	0.00491	0.00590	545	1526	2.67809842	0.37493378	187.6	13	0.1	0.0
	Unnamed intrusive rocks	/Ti	328,081	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	1.6	0	0.0	0.0
	Intrusive plugs and dykes	/Tir	86,786	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Mt. Gilles Volcanics	/Th	2,748,577	178,234	0.06485	0.00081	0.01621	0.01945	3	8	0.01621148	0.00081057	1.5	1	0.7	0.2
	Albert Basalt	/Ta	34,617,841	1,074,525	0.03104	0.00039	0.00776	0.00931	56	157	0.00775991	0.00038800	24.3	14	0.6	0.2
	Alluvium	/Qa	26,632,325	11,022	0.00041	0.00001	0.00010	0.00012	73	204	0.00010346	0.00000517	45.6	4	0.1	0.0
	Tertiary Colluvium	/TQc	20,885,697	304,024	0.01456	0.00018	0.00364	0.00437	59	165	0.00363914	0.00018196	6.4	4	0.6	0.2
	Marburg Formation	/Jbm	27,477,271	94,661	0.00345	0.00004	0.00086	0.00103			N/D	N/D	32.0	0	0.0	0.0
	Woogaroo Sub-Group	/RJbw	35,430,000	94,081	0.00266	0.00003	0.00066	0.00080	3	8	0.00066385	0.00003319	52.4	0	0.0	0.0
	Ipswitch Coal Measures	/Ri	1,828,942	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	3.0	0	0.0	0.0
	Chillingham Volcanics	/Rc	24,803,509	62,383	0.00252	0.00003	0.00063	0.00075	33	92	0.00062877	0.00003144	15.5	0	0.0	0.0
	Neranleigh-Fernvale beds	/DCf	141,743,377	77,834	0.00055	0.00001	0.00014	0.00016	9520	26656	0.00013728	0.00000686	277.7	0	0.0	0.0

Table 7.2. Specific risk and total risk for people, buildings and roads.

Hazard based on geology and landslide type (slope angle <25° or >25°) in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas is presented below (Figure 7.3). This estimate is based on a 100 year ARI rainfall event.

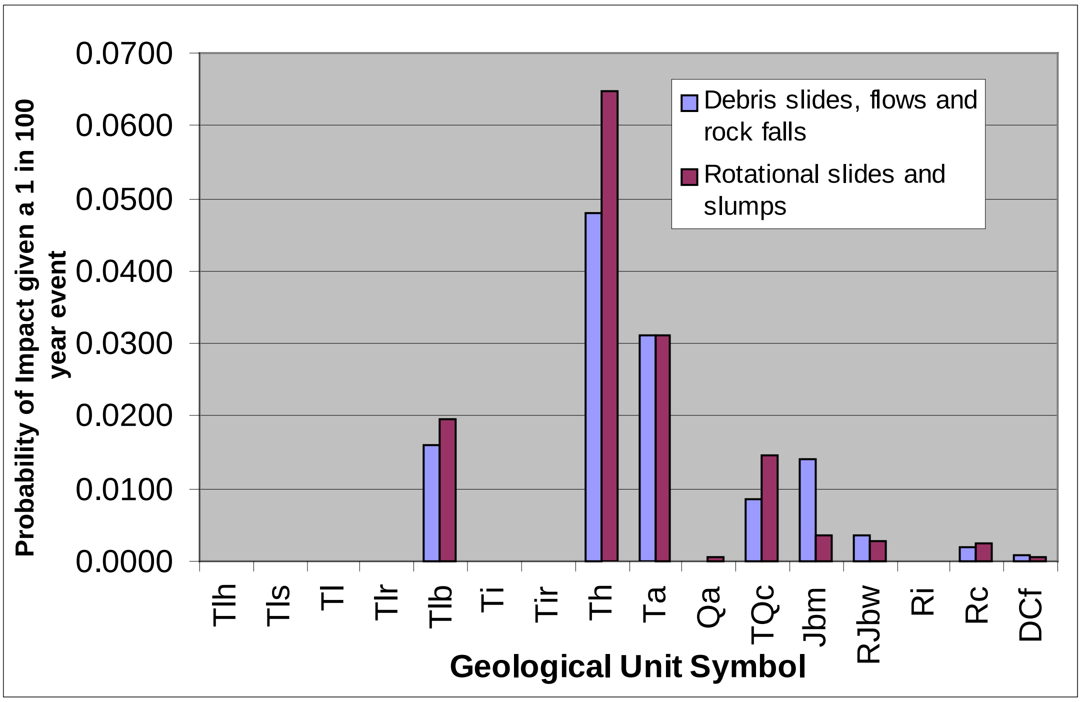

Figure 7.3. Landslide hazard probability for geology and slope units given a 100 year ARI rainfall event.

The specific risk: *people, buildings and roads* – the assessment of specific risk from both debris slides, flows and rock falls; and rotational slides and slumps given a 100 year ARI rainfall event is presented in Figure 7.4 and Figure 7.5, respectively. Calculations for these figures are given in Table 7.2.

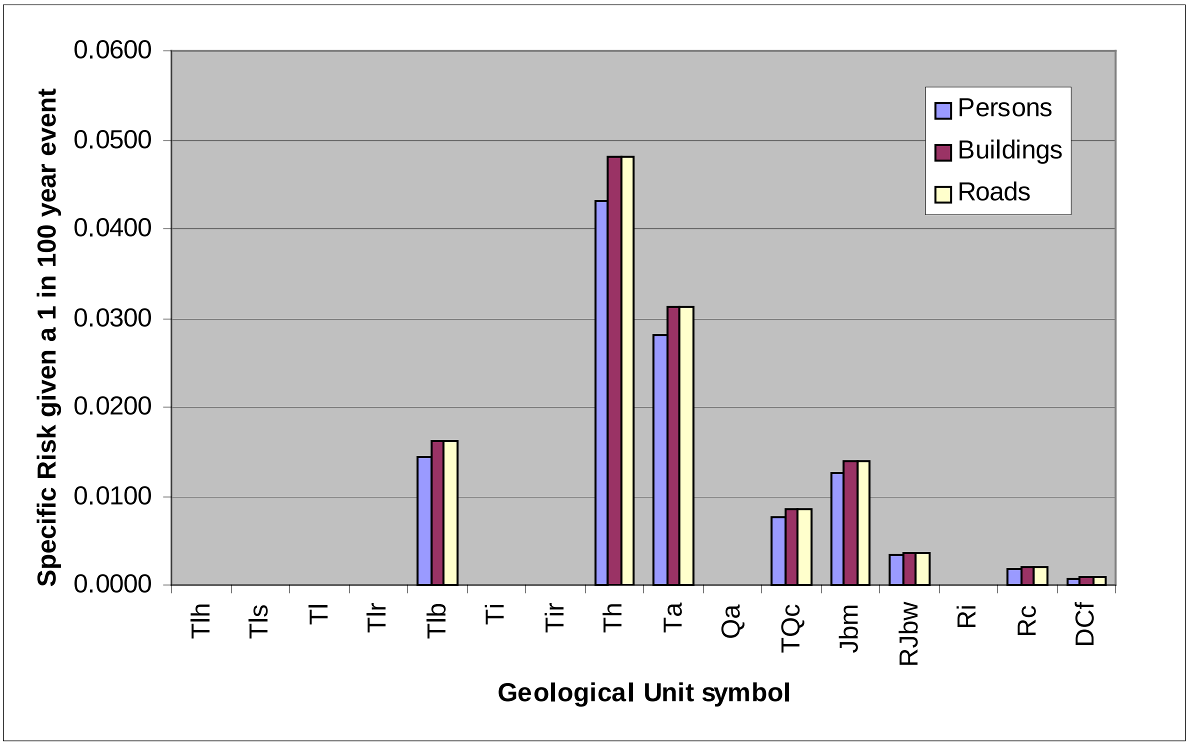

Figure 7.4. Specific risk from debris slides, flows and rock falls given a 100 year ARI rainfall event.

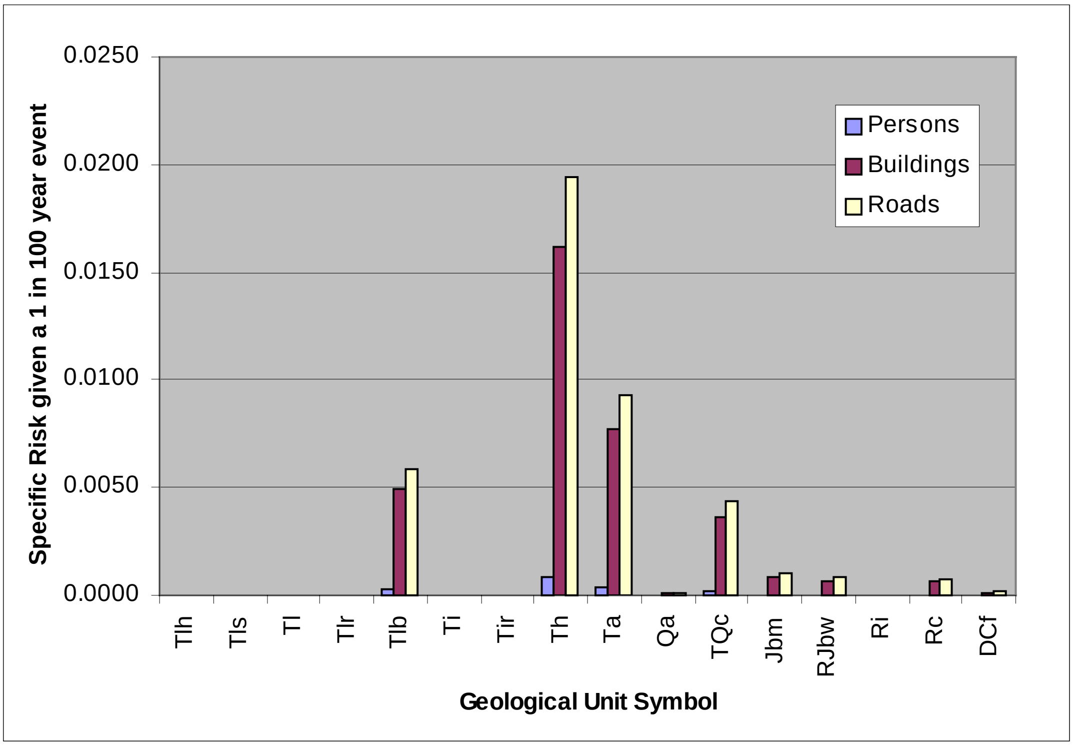

Figure 7.5. Specific risk from rotational slides and slumps given a 100 year ARI rainfall event.

The following specific risk maps (Figure 7.6 and Figure 7.7) include each of the elements at risk: persons, buildings and roads. These figures have been developed from the specific risk estimates (Table 7.2). Probability has been divided into five increments from lowest to highest.

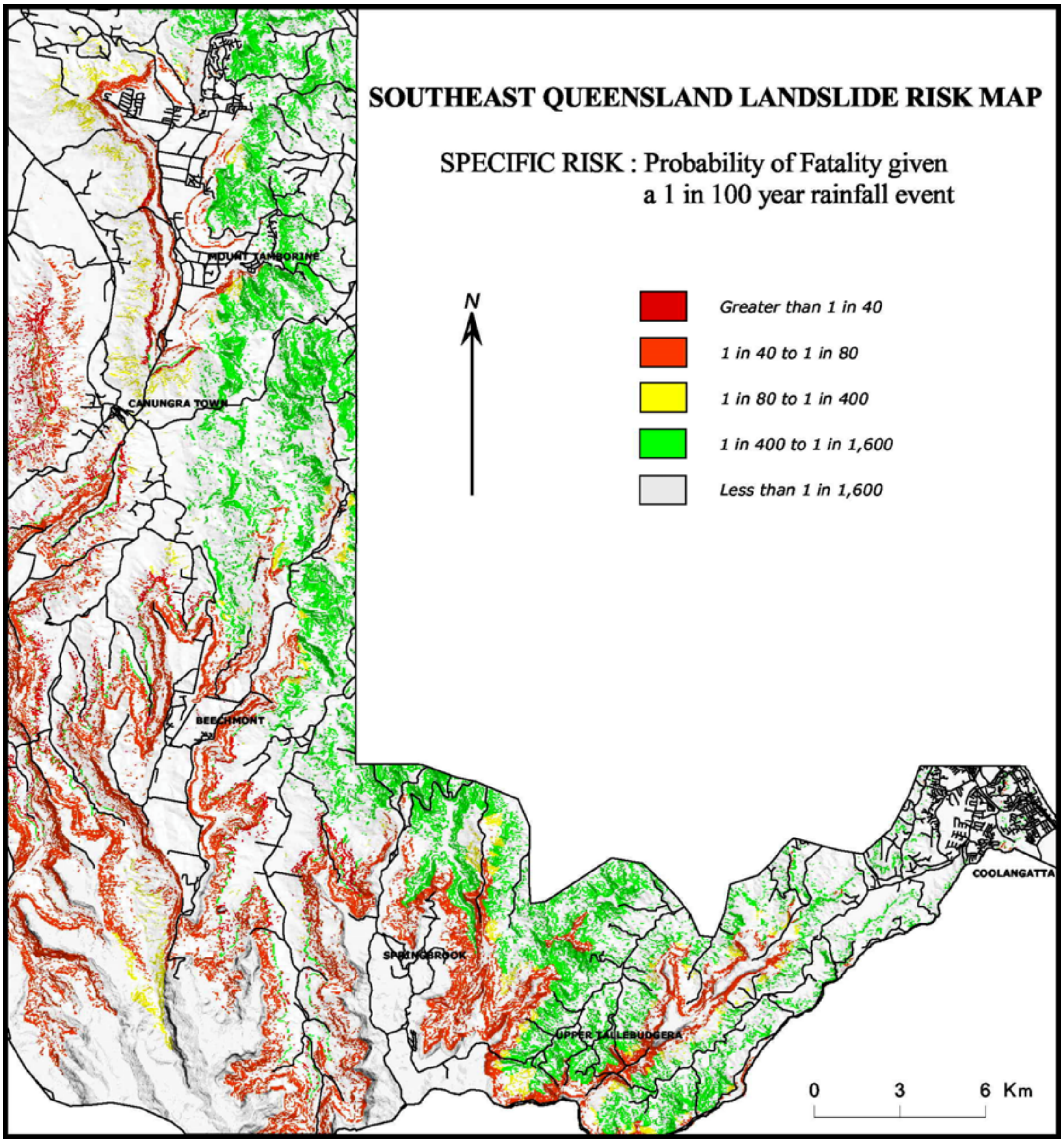

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Figure 7.6. Specific risk of fatality given a 100 year ARI rainfall event.

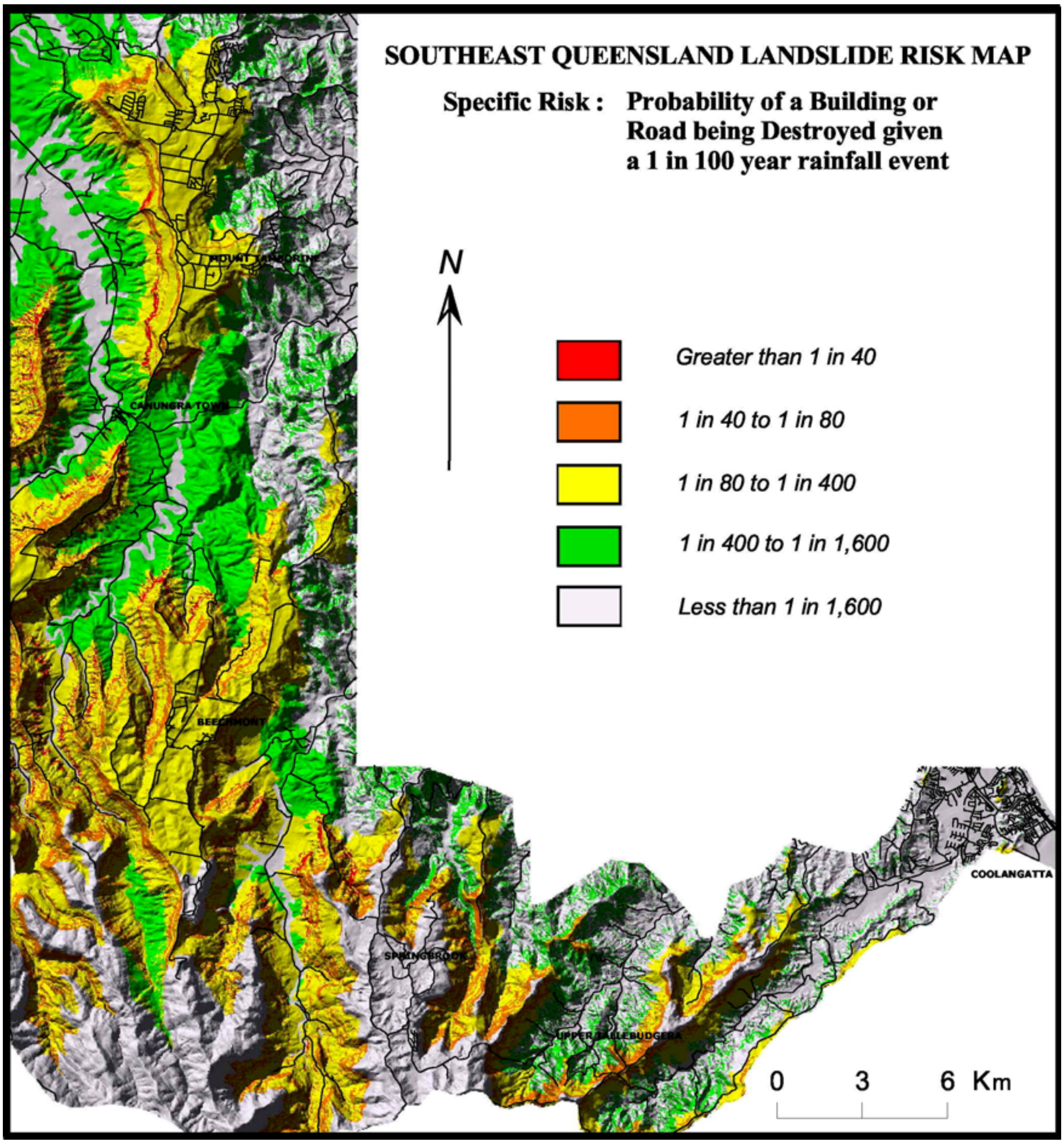

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Figure 7.7. Specific risk of destruction of a building or a section of road given a 100 year ARI rainfall event.

Total risk: *People* - to assess the total risk for people, the probability of impact (H) is multiplied by the vulnerability of persons (Vp) and then by the number people (Ep). The mean number of people per dwelling within the study area is 2.8 (Australian Bureau of Statistics, 1996). Building data was not available for the Beaudesert Local Government Area (LGA) and total risk for this region has therefore not been assessed. The total risk of fatalities given a 100 year ARI rainfall event is divided into six categories, shown in Figure 7.8.

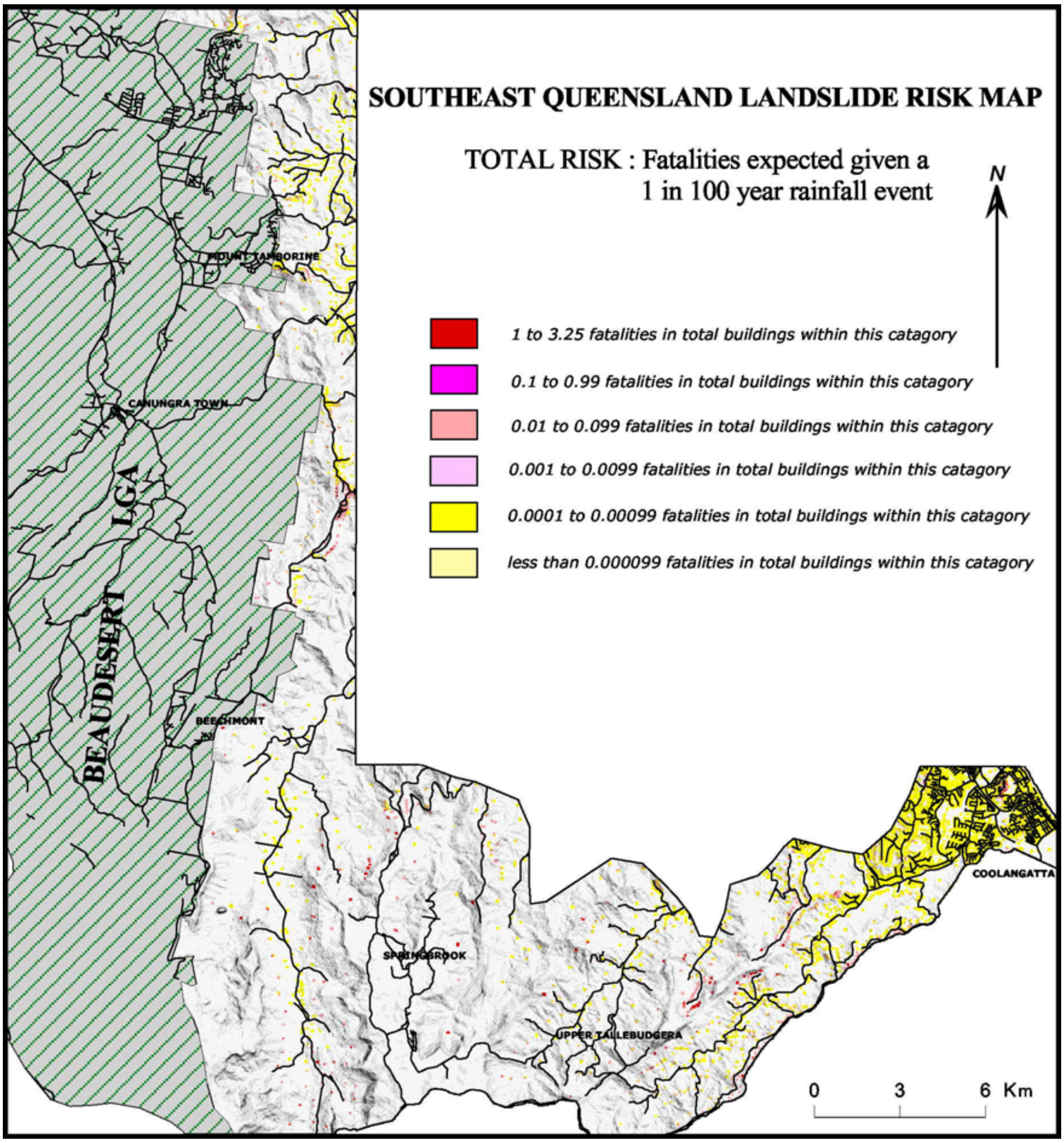

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Figure 7.8. Total risk of fatalities given a 100 year ARI rainfall event.

Buildings: the buildings considered in the total risk calculations were houses and blocks of flats as these were the only structures for which mean numbers of occupants could be calculated from the GIS data. To calculate the total risk for buildings the probability of impact (H) is multiplied by the vulnerability of structures (Vs) which is multiplied by the number of buildings (Es). The number of dwellings in the study region is 11,385. The total risk of building destruction from a 100 year ARI rainfall event is shown in Figure 7.9. Each dwelling is displayed with a 50 m buffer to aid visual interpretation.

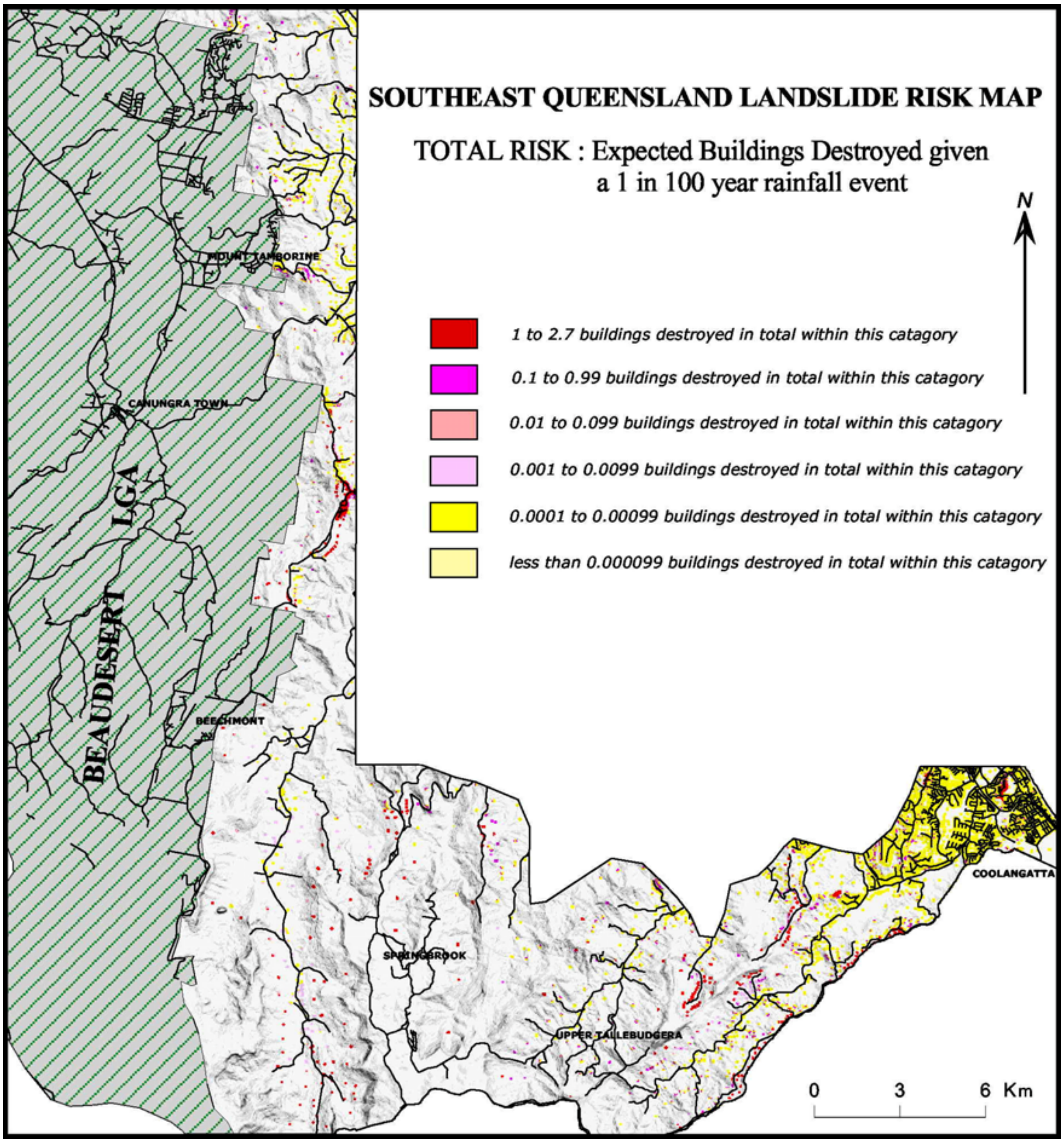

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Figure 7.9. Total risk of building destruction given a 100 year ARI rainfall event.

Roads: finding a suitable unit of measure for the calculation of road closures from road area per unit area is difficult therefore, an approach has been adopted here which does not incorporate the use of specific risk. In the case of road closure due to either blockage or destruction, total risk estimates are calculated using landslides mapped from the 1974 rainfall event and the present day road distribution network.

The expected road closures per kilometre per geologic/slope unit given a 100 year ARI rainfall event are calculated below (Equation 7.5). This estimate (Figure 7.10) is based on slide material blocking the road and/or destruction of a section of road (it should be noted that this estimate does not assess the volume of material that could be expected to block a road) within geological/slope units. Calculations are presented in Table 7.2. Not all roads have been captured digitally resulting in an incomplete analysis.

Equation 7.5. Total risk of road closures.

Expected number of road closures/km due to blockage or destruction given a 1 in 100 year rainfall event. = Total number of slides cutting roads resulting from the January 1974 event. / Total distance (km) of present day roads per geologic/slope unit.

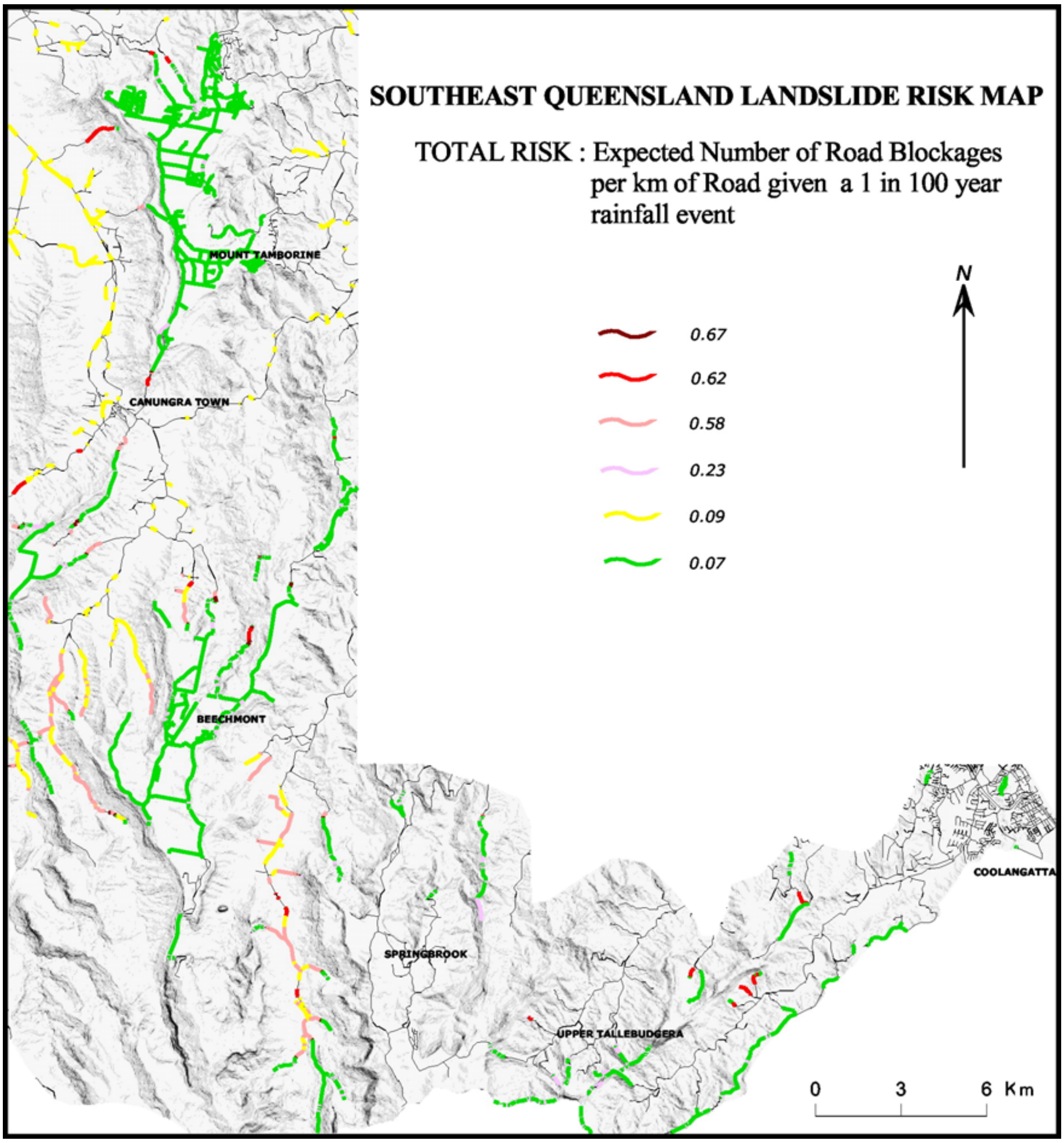

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Figure 7.10. Total risk for roads: expected number of road blockages per km of road given a 100 year ARI rainfall event.

Secondly, if the above calculation is multiplied by the vulnerability of roads to destruction (Table 7.2) an estimate of expected number of road closures/km due to destruction by landslide can be provided (Figure 7.11). Calculations are presented in Equation 7.6.

Equation 7.6. Total risk of roads to destruction.

Expected number of road closures/km due to destruction of road given a 1 in 100 year rainfall event = Total number of slides cutting roads / Total distance (km) of present day roads per geologic/slope unit × Vulnerability to destruction

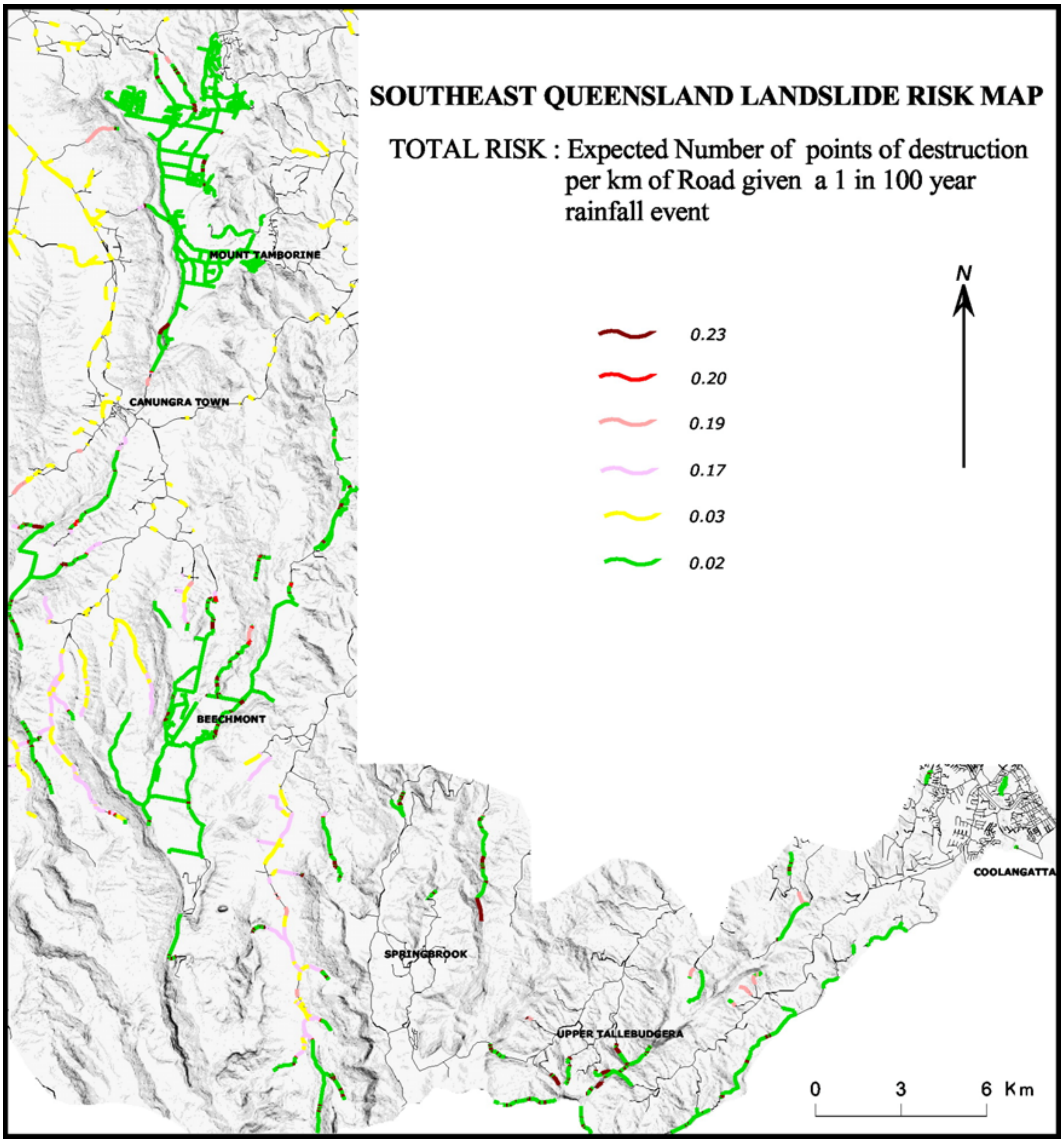

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Figure 7.11. Total risk roads: expected number of points of destruction per km of road given a 100 year ARI rainfall event.

Landslide in Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan.

Caboolture: There has not been a landslide assessment of the Caboolture local government area.

Debris flows may occur during periods of heavy rainfall on cleared steep slopes adjacent to gullies in the old rocks in the western and southwestern parts of the Caboolture study area, like they do in the Mapleton-Maleny area.

The Neranleigh-Fernvale beds do not occur in the Caboolture local government area but, in the western and southwestern parts of the study area, the Kurwongbah beds and Rocksberg Greenstone are metamorphosed rocks of the same age, which may be subject to landslides under similar circumstances to the Neranleigh-Fernvale beds.

In Caboolture Shire there are two areas of basalt that would be susceptible to landslides: the tail end of the Maleny Plateau in the far northwest; and Mount Mee (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001). Both are outside our study area.

The alluvial banks of rivers in the Caboolture area are probably landslide-prone, like those in Brisbane.

Pine Rivers: There has not been a landslide assessment of the Pine Rivers local government area, but landslides would probably occur in alluvium along the banks of rivers and creeks under circumstances similar to those in Brisbane.

The Tertiary sediments in the Pine Rivers area are 65 to 45 million years old and consist predominantly of mudstone, siltstone, sandstone, oil shale, brown coal and limestone of the Petrie Formation. Hofmann and Willmott (1984) stated that, on the bank of the South Pine River, small slides have occurred in soil and weathered Tertiary sediments. They noted landsliding on a hill in Brisbane with slopes of the order of only 7-11^{o} on unlateritised Tertiary sediments. Similar problems may occur on slopes in the Petrie Formation in the Pine Rivers study area.

Small exposures of Tertiary basalt occur in the far western part of the Pine Rivers study area, at Mount Glorious. Failures, like those in the Rosewood-Marburg area, may be associated with the basalts at Mount Glorious.

As in Brisbane, if the Enoggera Granite in Pine Rivers Shire is decomposed, then slumping may occur, and landsliding could happen in the Neranleigh-Fernvale beds in the Pine Rivers area under similar conditions to those in the Brisbane area.

In the Bunya Phyllite, rock slides have been reported in the bank of the Brisbane River (Hofmann and Willmott, 1984). There are extensive exposures of this rock in the Pine Rivers study area, so rock slides may happen on steep slopes. It is also possible that debris flows could occur during periods of heavy rainfall in the older rocks that cover much of the western and central parts of the Pine Rivers area.

Redcliffe: There appears to have never been a landslide assessment of Redcliffe ever carried out. During a brief reconnaissance field examination in April 2001, there was evidence of landsliding in cliffs of poorly consolidated material opposite Phillip Street in Scarborough. Debris slides, a small one of which was very recent, and rock falls with volumes up to 4 m^3 were observed in cliffs of deeply weathered basalt opposite Warde Street in Scarborough. A section of the cliff was overhanging and appeared ready to fall in the near future. At Scotts

Point, Woody Point, numerous rock falls have occurred from a 7 m high cliff. The fallen boulders are up to 6 m^3 in volume.

Brisbane: Hofmann and Willmott (1984) conducted a landslide susceptibility study of natural slopes in the City of Brisbane. They noted that 'on natural slopes, landslides have affected mainly Tertiary claystone of the Corinda Formation and the Quaternary alluvium along the Brisbane River.' The following is a summary of their observations of situations in which landslides may occur.

Along the Brisbane River, large slumps in alluvium can be triggered by lowering of the river level after prolonged or large floods, and minor erosion or slumps can be caused by tidal effects or heavy rainfall. Along creeks, alluvial bank failure can be caused by undercutting. Removal of trees has increased the incidence of landslides. In AGSO's Australian Landslide Database, the most spectacular report of river bank failure in Brisbane is of a landslide near North Quay on 7 February 1890. The *Sydney Morning Herald* of 8 February 1890 states that the Old Queens Wharf, a morgue, a jetty and a new sanitary wharf and shed were partly or wholly wrecked. Gangs of men were employed to save what could be saved. Gas and water pipes were also seriously interfered with. Hofmann and Willmott (1984) noted that there were widespread instances of alluvial bank failures along the Brisbane River following the 1974 flood. In Newlands Street, Fig Tree Pocket, a major landslide affected 10 residential blocks and a street, destroying part of a serviced subdivision.

The Tertiary sediments in the Brisbane area are 65 to 45 million years old and consist predominantly of claystone, mudstone, sandstone and siltstone with minor amounts of basalt, limestone, conglomerate and oil shale. They occur largely in the far northern, eastern and southern parts of the area. Fortunately, they are mostly in flat terrain, because problems can arise on slopes. Hofmann and Willmott (1984) noted that landsliding on a hill at Oxley had occurred in the 1970s as a result of clearing and excessive pore water pressure following heavy rain. Several houses were demolished because remedial measures were considered uneconomic. The slopes are of the order of only 7-11^o on unlateritised Tertiary sediments. On a steep bank of the Brisbane River, rock falls have occurred in Tertiary sandstone.

Hofmann and Willmott (1984) observed that, in the Tivoli Formation (part of the Ipswich Coal Measures), landslides have been noted, usually at gully heads, in completely weathered fine-grained sandstone associated with seepage, and in residual soil and colluvium in shales and siltstones. Shallow slumps and creep have occurred in soil on cleared slopes.

They also noted that, in deep soil of decomposed Enoggera Granite, there had been a few shallow slumps. We have estimated an angle of 15 degrees from their map as the threshold slope on which these took place.

Hofmann and Willmott (1984) also noted small rotational slides in soil and colluvium, chiefly on concave slopes around gully heads, on deforested slopes on the Neranleigh-Fernvale beds in the Brisbane area. Whilst these slumps happen on slopes as low as 11 degrees in association with seepage zones, they usually occur on slopes steeper than 17 degrees. They also noted soil slumps on a grassed slope of 11 to 17 degrees in a greenstone zone with seepage. They remarked on the apparent increased landslide susceptibility of greenstone-derived soils and of red colluvial soils derived from banded chert.

In the Bunya Phyllite, rock slides have been reported in the bank of the Brisbane River. Hofmann and Willmott (1984) also noted a large multiple rotational slide in weathered rock and colluvium overlying the phyllite north of the ferry landing at Dutton Park. This may have been triggered by a stormwater leakage and by seepage.

Ipswich: There has not been a landslide assessment of the entire Ipswich local government area, but Willmott (1987) investigated slope stability and its constraints on building in the Rosewood-Marburg area. He found few areas prone to slope instability, but noted some small landslides in the following situations:

- on the sides of gullies with slopes of the order of 10 to 15 degrees in the Walloon Coal Measures and the Marburg Formation, small to moderate-sized rotational slumps grading into mudflows can occur. These may be caused by groundwater seepage into the gullies, particularly when the slope has been cleared. From his map, we measured 8 degrees as the threshold for landslides on the Walloon Coal Measures, and 15 degrees on the Marburg Formation;

- on the steeper basalt slopes and scarps, small debris slides and steep rotational slumps can occur in deep soils and small pockets of colluvium, probably more commonly when the area has been cleared;

- on the gentler, intermediate to lower basalt slopes, small rotational slumps, adjacent to gullies and on the sides of local knobs, can occur in soils and local pockets of colluvium. They are probably caused by seepage. From his map we measured 11 degrees as the threshold for landslides in basalt;

Landslides have been noted on the banks of the Bremer River after floods, and on hills after clearing (David Kay, Ipswich City Council, personal communication, 1999).

Willmott (1983) noted debris flows on basalt scarps with slopes greater than 25 degrees, and also on cleared steep slopes adjacent to gullies in older rocks, in the Mapleton-Maleny area. It is thus possible that debris flows could occur during periods of heavy rainfall in hilly country in the older rocks of the far north east of the Ipswich area, and in the basalts of the Little Liverpool Range and The Bluff.

The Neranleigh-Fernvale beds have been mapped in the north-easrern part of the Ipswich local government area, and may be susceptible to small rotational slides and slumps under circumstances similar to those observed in Brisbane by Hofman and Willmott (1984).

AGSO's Australian landslide database records a major landslide at Tallegalla Hill, Minden. The locality was just west of our study area, and about 11 km from Rosewood and 10 km from Marburg. It was reported in the *Sydney Morning Herald* of 18 March 1890 as follows:

"A large hill…slipped bodily into a creek, by which it was surrounded with a roaring noise like that of an earthquake. Now where the hill stood is a sheet of water and five or six farms are not recognisable, the high land being now low and vice versa."

The *Sydney Morning Herald* of 19 March 1890 had noted that at least 323 700 m^2 had bodily shifted, sometimes to a depth of 12 m, and that entire farms were ruined and houses destroyed. If a mean depth of 6 m is assumed, then the volume of this landslide is estimated to be almost 2 million cubic metres. It was probably triggered by the tropical cyclone that crossed the south Queensland coast on 11 March 1890. This cyclone caused flooding in the Brisbane River. The landslide may have been a debris flow.

Mine subsidence is a well recognised problem in Ipswich, but it is not addressed in this report, which deals only with landslides on natural and cut slopes.

Redland: There appears not to have been a landslide hazard assessment of Redland carried out. In AGSO's Australian landslide database, there are records of two landslides on North

Stradbroke Island. The first happened at Amity Point in September 1936. A 6-7 m high sea cliff collapsed, burying two children under several tonnes of sand. One child died. The second was in 1998 when a 400 m long landslide happened near a sand mine.

Landslides occur in the canal estates in fissured clays developed on weathered Tertiary basalt of the Petrie Formation, apparently on slopes generally less than 10 degrees. Cuts of these slopes were generally in excess of 25 degrees (Len Cranfield, Geological Survey of Queensland, email communication, 12 April 2001).

Much of the mainland part of the Shire is underlain by Neranleigh-Fernvale beds, with some hilly terrain (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001). Slumps were observed on slopes steeper than about 11 degrees in red colluvial soils, derived from banded chert in the Neranleigh-Fernvale beds, at Mount Cotton, just south-east of Brisbane (Hofmann and Willmott, 1984).

Logan: We have been able to find no records of landslides in Logan City, nor does there appear to have ever been a landslide assessment of Logan carried out.

There is an area of possible pediment slope wash, about 1 km long, situated near the boundaries of Loganholme, Shailer Park and Cornubia, that may be deposits from one or a number of flash floods and/or small debris flows built up during periods of intense rainfall.

The most common form of landsliding in Logan is likely to be small failures in cut slopes on some of the higher hills of the Neranleigh-Fernvale beds.

Landslide hazard on uncut slopes

Based on observations outlined in the preceding section and by Hofmann and Willmott (1984), the slopes shown in Table 7.3 may be susceptible to landslide during periods of heavy rainfall, or when seepage occurs.

Because colluvium, pediment slope wash, and anthropogenic deposits consist of unconsolidated material, they could be prone to landslide, and have been included in Table 7.3. A landslide in dolerite colluvium in Tasmania was active on a slope of only 7 degrees (Lloyd Matthews, Mineral Resources Tasmania, personal communication, 1996) so this was chosen as the threshold for potential slope instability in unconsolidated materials. However, as the only significant mapped colluvium is that shed from quartzites of the Neranleigh-Fernvale beds (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001), a threshold of 11 degrees was chosen for the colluvium. Landslide susceptibility maps for uncut slopes in Caboolture, Brisbane and Ipswich are shown in Figure 7.12, Figure 7.13 and Figure 7.14

We do not have detailed contour information for Pine Rivers, so a natural slope landslide susceptibility map could not be produced.

Table 7.3. Uncut slopes susceptible to landslide.

Slope and geological formation	**Type of landslide**
Greater than 25 degrees	Small debris slides, rotational slumps, or debris flows, in deep pockets of soil or colluvium
17-25 degrees – Neranleigh-Fernvale beds, Bunya Phyllite	Rotational slumps in soil and colluvium, chiefly on concave slopes around gully heads. (NOTE: Slumps may occur on slopes as low as 11 degrees on greenstone-derived or red colluvial soils)
20-25 degrees – Rocksberg Greenstone	Small debris slides, rotational slumps, or debris flows, in deep pockets of soil or colluvium
15-25 degrees – Enoggera Granite	Shallow rotational slumps in deep soil of decomposed granite
15-25 degrees - Marburg Subgroup (Koukandowie Member), Tivoli Formation, Darra Formation, Hector Tuff	Small to moderate-sized rotational slumps, grading into mudflows, on the sides of gullies
11-25 degrees - Brassal Subgroup - Tingalpa Formation and Tivoli Formation; Archerfield Basalt Member of Oxley Group; Petrie Formation - basalt	Small slides near gully heads
11-25 degrees - basalt	Small rotational slumps, adjacent to gullies and on the sides of local knobs, in soils and local pockets of colluvium
11-25 degrees - colluvium (sand, soil, clay, rock debris). Some residual (non-transported) material may inadvertently be included.	Small rotational slides
11 degrees or greater - lowest river terrace, estuarine channels and banks; active stream channel	Slumps in river banks
8-25 degrees – Walloon Coal Measures, Blackstone Formation, Redbank Plains Formation	Small to moderate-sized rotational slumps, grading into mudflows, on the sides of gullies
7 degrees or greater – unlateritised Tertiary sediments (Corinda, Darra and Petrie Formations)	Rotational slides and slumps on hill slopes; rock falls and rotational slides and slumps on river banks
7-25 degrees – pediment slope wash (clay, scree, soil), anthropogenic deposits	Slumps or earthflows

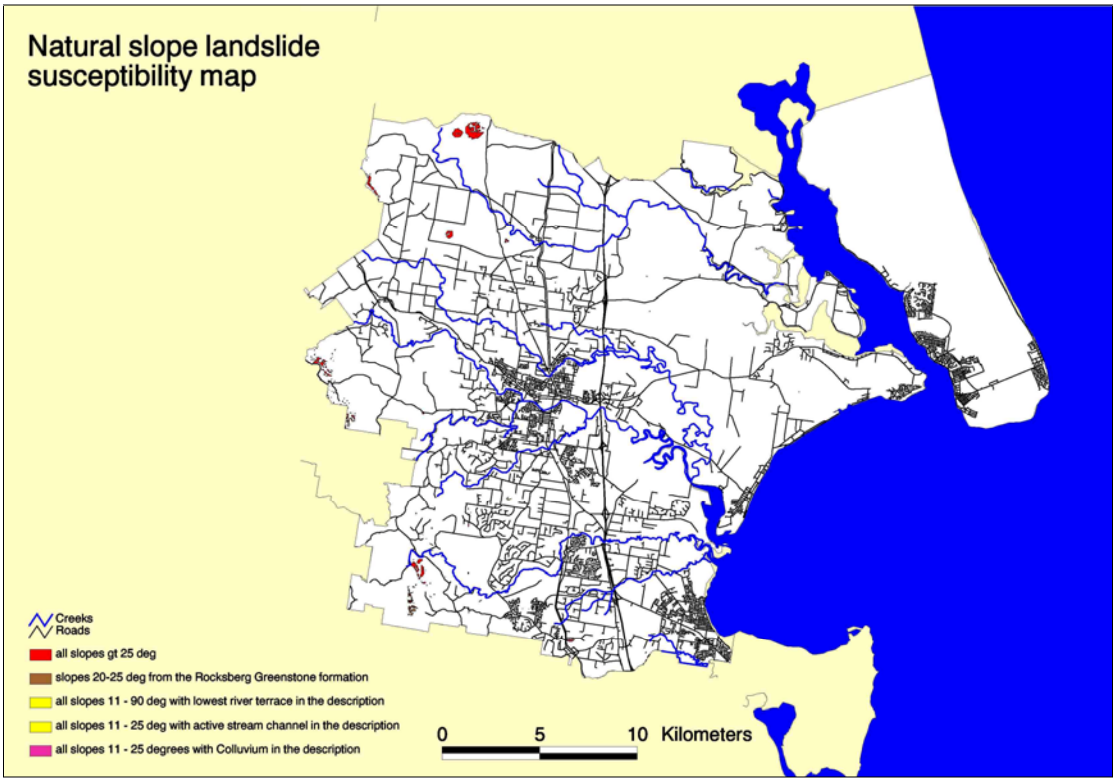


Figure 7.12. Caboolture natural slope landslide susceptibility map. Click here for High Resolution Image

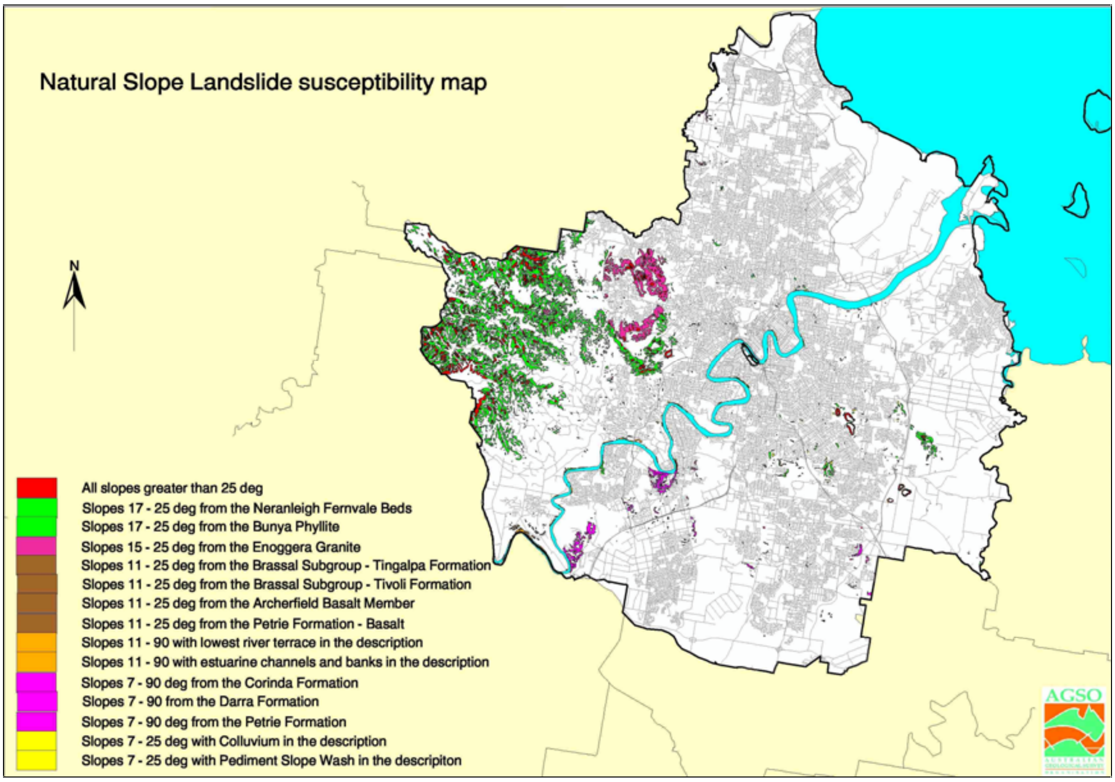
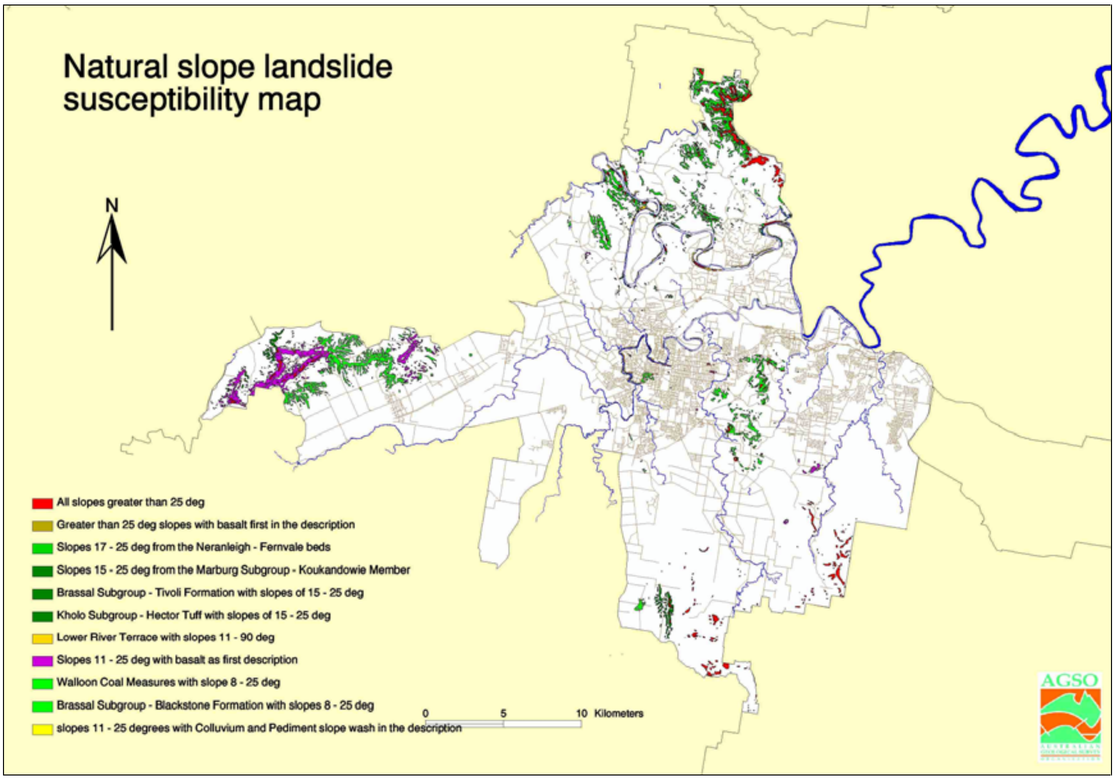


Figure 7.13. Brisbane natural slopes landslide susceptibility map. Click here for High Resolution Image



Click here for High Resolution Image

Figure 7.14. Ipswich natural slopes landslide susceptibility map.

Debris flows are a type of landslide triggered by the action of torrential rain on loose material (rocks and finer material) on a mountain side or escarpment. The boulders and finer material, mixed with water, flow as a torrent, scouring out a path down the slope. The boulders and some of the finer material are deposited first, while the remainder of the mud travels further as a flash flood. The landslide susceptibility areas in Figure 7.12 (Caboolture) Figure 7.13 (Brisbane) and

Figure **7.14** (Ipswich) does not take into account the fact that material from debris flows and flash floods runs out down-slope from the area of slippage.

The high country in the western part of Caboolture and Pine Rivers is a potential source of debris flows. These very fluid landslides frequently, but not always, follow stream channels. Those that are channelled can deviate, and continue to flow in the original direction, if the channel makes a sharp bend.

Because we have insufficient information about the frequency of landslide occurrence in south-east Queensland, apart from the Gold Coast, it is not possible to quantitatively assess the landslide hazard on uncut slopes.

Landslide hazard on cut slopes

Cut slopes tend to be more susceptible to landslide than uncut slopes because of:

- artificially steepening the slope with batters;
- potentially weakening the site with fill;
- loading the upper part of the slope;
- removing support from the base of the slope;

- clearing vegetation during development; and,
- watering developed land.

However, the risks can be, and frequently are, mitigated by carrying out the development with appropriate geotechnical advice.

As the assessment of landslide susceptibility and risk was carried out using a GIS, it was necessary to select cut slope landslide susceptibility polygons for which to estimate landslide risk for various scenarios, assuming the entire area is developed without appropriate mitigation measures.

The landslide susceptibility polygons were selected as follows:

- rock slopes that would have at least a 3 m high, 60 degree batter if a 10 m wide section of slope were cut and levelled. This would require a natural slope of at least 13 degrees; and,
- slopes in unconsolidated material (soil or colluvium) that would have at least a 3 m high, 45 degree batter if a 10 m wide section of slope were cut and levelled. This would require a natural slope of at least 10 degrees.

It was assumed that collapse of at least a 3 m high batter would normally be necessary to destroy a house and possibly cause the death of a resident.

The landslide susceptibility maps for cut slopes in Caboolture, Brisbane and Ipswich are shown in Figures 7.15, 7.16 and 7.17. A map could not be produced for Pine Rivers because of lack of DEM data.

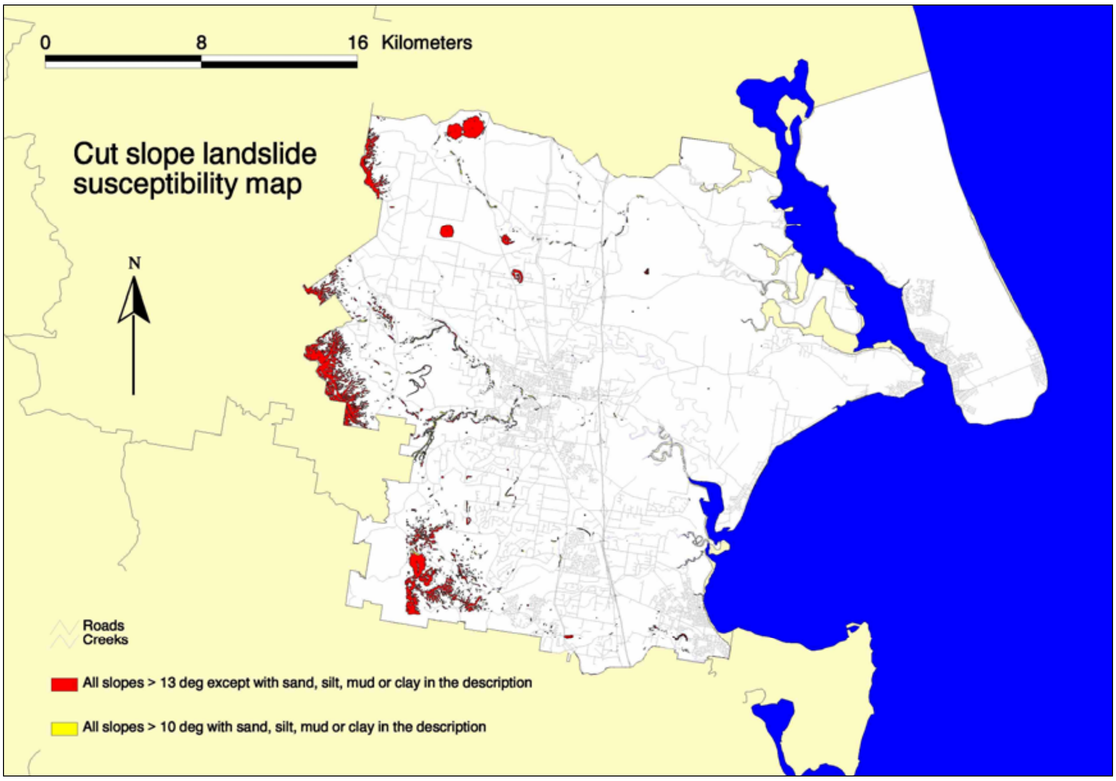


Figure 7.15. Caboolture cut slope landslide susceptibility map. Click here for High Resolution Image

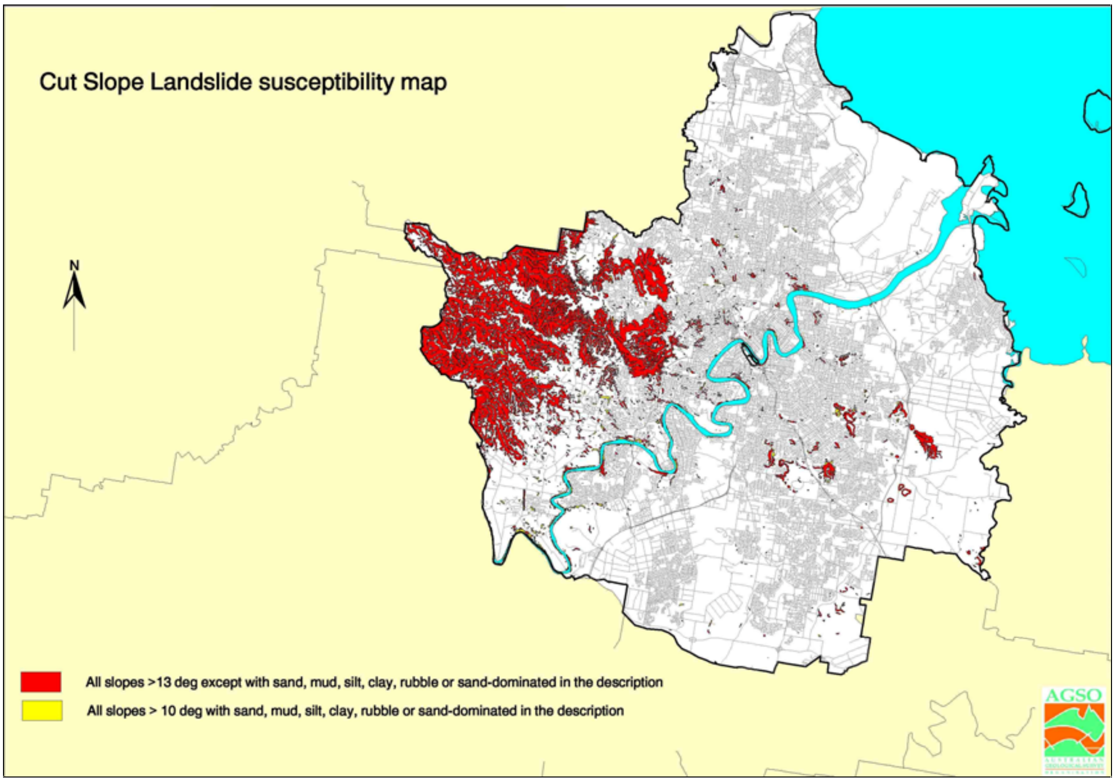


Figure 7.16. Brisbane cut slope landslide susceptibility map.

Click here for High Resolution Image

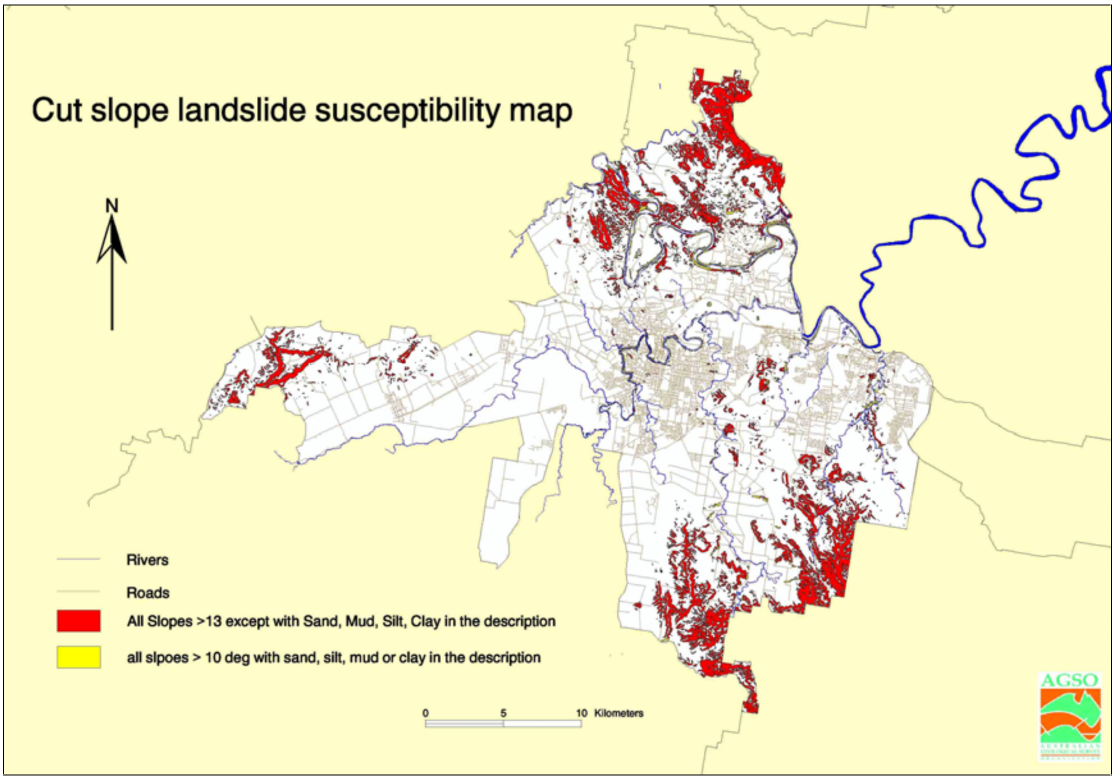


Figure 7.17. Ipswich cut slope landslide susceptibility map.

Click here for High Resolution Image

Landslide recurrence intervals

There are no detailed landslide logs, following rainfall events in south east Queensland, from which to estimate average recurrence intervals (ARI) of landslides on cut slopes. However, this has been done for developed slopes in Cairns (Michael-Leiba and others, 1999). To get an order of magnitude estimate for Caboolture, Pine Rivers, Brisbane and Ipswich, the cut slope failure rates observed following various rainfall intensities in Cairns were assumed to hold good for cut slopes in these areas also. However, the recurrence intervals of these rainfall intensities in south east Queensland would be considerably longer than in Cairns, because the rainfall is much lower.

The Bureau of Meteorology IFD (Intensity-Frequency-Duration) data for rainfall stations close to, or within the study areas were used to estimate the recurrence intervals at Caboolture, Pine Rivers, Brisbane and Ipswich by linear interpolation of data tabulated for average recurrence intervals of 1, 2, 5, 10, 20, 50 and 100 years, and in some cases by extrapolation of a log-linear graph plotted from these data. The results are shown in Table 7.4.

Table 7.4. Cut slope failure rate recurrence intervals for Cairns, Brisbane, Ipswich, Pine Rivers and Caboolture.

24 hour rainfall intensity (mm/h)	ARI Cairns (years)	ARI Caboolture (years)	ARI Pine Rivers (years)	ARI Brisbane (years)	ARI Ipswich (years)	Cut slope failure rate in Cairns (m^3/sq km)
7.86	1	3.7	3.7	8.5	22	33
10.5	2.3	12	12	33	100	108 (max) 0.98 (min)
12.3	3.9	27	27	72	230	180 (max) 1.39 (min)

These data are plotted in landslide recurrence graphs for Caboolture, Pine Rivers, Brisbane and Ipswich in Figure 7.18. Because of the scarcity and scatter of data, the line is drawn to pass through the same relative level on the error bars as in the corresponding graph for Cairns in Michael-Leiba and others (1999). This is because the graph for Cairns was better constrained because it had two additional points for higher rainfall intensities. The vertical bars on the graphs were derived from maximum and minimum failure rates logged after two tropical cyclones in Cairns. The maximum failure rates (tops of the vertical bars) were for landslides (mainly batter failures) logged along roads up the escarpment. The minimum failure rates (bottoms of the vertical bars) were for batter failures in residential areas.

Because most of the batter failures in Cairns occur in rocks much more deeply weathered than those in south east Queensland, the incidence of failures on unengineered batters in Cairns would be expected to be higher than in south east Queensland for corresponding rainfall intensities. Consequently, the hazard and risk in Caboolture, Pine Rivers, Brisbane and Ipswich would tend to be overestimated by this methodology for cut slopes for which no mitigation measures had been taken, and would be grossly overestimated for slopes developed with competent geotechnical advice.

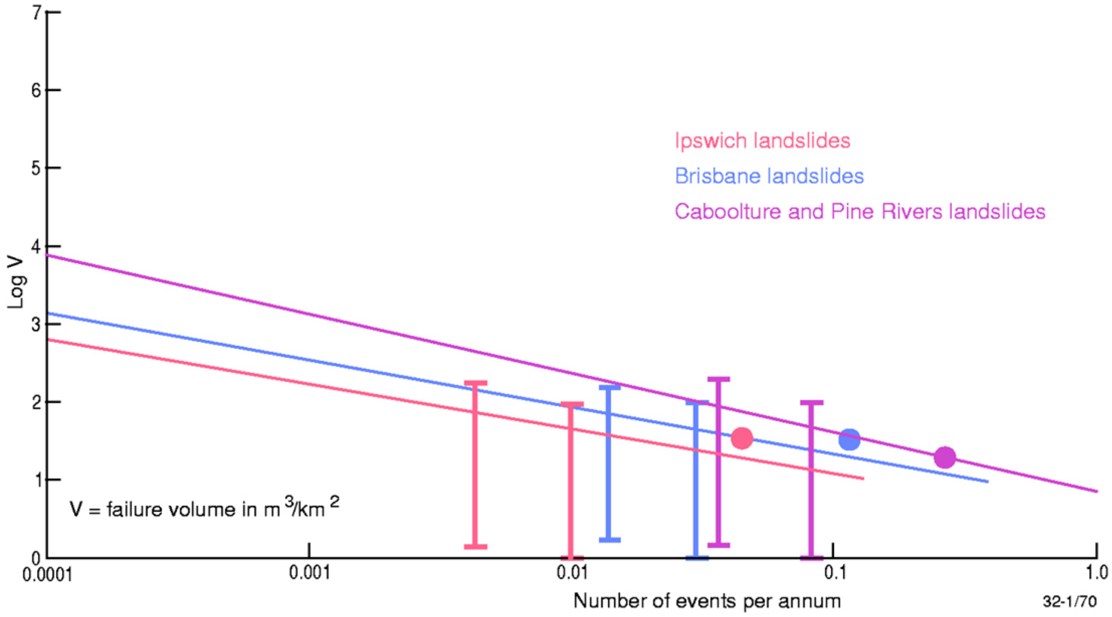


Figure 7.18. Recurrence relation for fully developed slopes.

From the landslide recurrence graphs, the failure volumes were read for an average recurrence interval of 100 years. If the mean thickness of the landslides is assumed to be 1.5 metres, the mean area, A (square metres) can be calculated by dividing the failure volume by 1.5. This is the landslide area per square km, that is per 1 million square metres, so the hazard for the scenario (the probability of a point in the susceptible area being impacted by a landslide, given that the scenario happens) is A divided by 1 million. The results for the 100 year rainfall event scenario are given in Table 7.5. These would apply to the landslide susceptibility areas for cut slopes in Figures 7.15 (Caboolture), 7.16 (Brisbane) and 7.17 (Ipswich).

Because of the very broad assumptions and uncertainties in the methodology used to derive these results, they should be considered to be a “back of an envelope” type of estimate only, usually giving an upper bound to the hazard values.

Table 7.5. Landslide hazard for the 100 year ARI rainfall scenario.

	Caboolture	**Pine Rivers**	**Brisbane**	**Ipswich**
Landslide volume (m^3/sq km)	229	229	91	46
Landslide area (m^2/sq km)	153	153	61	31
Landslide hazard (probability of impact at a point in a susceptible area)	0.0002 (1 in 7000)	0.0002 (1 in 7 000)	0.00006 (1 in 16 000)	0.00003 (1 in 30 000)

Landslide Risk Scenarios

Hazard is taken to be the probability of impact of a landslide at a point (Table 7.5), given that the scenario takes place, and vulnerability to be the probability of a building, person living in a building, or a section of road being destroyed if hit by a landslide. Both range in value from 0 (impossible) to 1 (certain).

The vulnerabilities for elements at risk from small debris slides, flows, slumps and rock falls on hill slopes in the Cairns study (Michael-Leiba and others, 1999) were assumed to be applicable also to Caboolture, Pine Rivers, Brisbane and Ipswich. The values are given in Table 7.1.

By multiplying the hazard values in Table 7.5 by the appropriate vulnerability in Table 7.1, the specific risk of destruction of resident people, buildings and roads in the 100 year ARI rainfall scenario can be calculated. The results are given in Table 7.6. These apply to the landslide susceptibility areas for cut slopes in Figures 7.15, 7.16 and 7.17. It must be remembered that these are rough estimates only; the uncertainty in them is not known, and they will tend to overestimate the risk.

Table 7.6. Specific annual risk of destruction on cut slopes in the 100 year ARI rainfall scenario.

	Caboolture	**Pine Rivers**	**Brisbane**	**Ipswich**
Specific risk – Resident people	0.000008 (1 in 100 000)	0.000008 (1 in 100 000)	0.000003 (1 in 300 000)	0.000002 (1 in 600 000)
Specific risk – Buildings	0.00004 (1 in 30 000)	0.00004 (1 in 30 000)	0.00002 (1 in 70 000)	0.000008 (1 in 100 000)
Specific risk – roads	0.00005 (1 in 20 000)	0.00005 (1 in 20 000)	0.00002 (1 in 50 000)	0.000009 (1 in 100 000)

Total risk on cut slopes: The landslide susceptibility polygons in Figures 7.15, 7.16 and 7.17 were interrogated using the GIS to determine the number of buildings and resident people they contain. There are 111 buildings and an estimated 322 people in Caboolture; 4699 buildings and an estimated 15 056 people in Brisbane; and 576 buildings and an estimated 1700 people in Ipswich. This was used to calculate the total risk of destruction figures in Table 7.7.

Again, it must be emphasised that these are "back of an envelope" type of estimates only; the uncertainty in the figures is unknown, but they are probably an overestimate.

Because we do not have detailed contour information, it is not possible at this stage to derive landslide susceptibility polygons that can be interrogated to ascertain the number of elements at risk, and hence to assess total landslide risk in the Pine Rivers area.

Table 7.7. Total risk of destruction in the 100 year ARI rainfall scenario.

	Caboolture	**Brisbane**	**Ipswich**
Number of resident people killed	0.002	0.05	0.003
Number of Buildings destroyed	0.004	0.07	0.004

Interpretation

Gold Coast Hinterland Region

Total Risk to People (Figure 7.8): There are about 1200 people living in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas that are subject to debris slides, flows and rock falls (slopes >25°), this is only about 4% of the population that is at risk from land instability. The remainder of the "at risk" population live in areas subject to rotational slides and slumps (slopes <25°). In areas with slopes >25° there is a maximum total risk of about 4.6 fatalities given a 100 year ARI rainfall event (Figure 7.8). By far the greatest total risk to people living in these areas from such an event is in the Beechmont Basalt Unit where about 224 people reside and it is estimated that about 3.2 fatalities could occur. The next greatest total risk occurs in the Neranleigh-Fernvale beds with slopes >25°, where an average of 0.64 of a fatality could occur. In areas with slopes <25° the population is about 30670, the total risk of a fatality is 0.4. The greatest total risk of fatality from landslides resulting within this geological/slope unit is in the Beechmont Basalt where about 0.38 fatalities could occur.

Overall the total expected risk from landslides for the Gold Coast Region given a 100 year ARI rainfall event is 5 fatalities. The expected number of fatalities in areas subject to debris slides, flows and rock falls is 4.6, substantially greater than for areas subject to rotational slides and slumps at 0.4.

Total risk to Buildings (Figure 7.9): There are about 431 dwellings in regions subject to debris slides, flows and rock falls (slopes >25°), this is only about 4% of the total number of at risk dwellings. The remaining buildings are in areas subject to rotational slides and slumps (slopes <25°). The greatest total risk by far to dwellings from landslides occurs in the Beechmont Basalt Unit on slopes <25°, here the expected number of buildings destroyed given a 100 year ARI rainfall event is about 2.7. The next greatest total risk of dwelling destruction occurs again in the Beechmont Basalt Unit on slopes >25°, here the number of buildings destroyed given a 100 year ARI rainfall event is about 1.3. The combination of the total risk of the Beechmont Basalt slope units accounts for 90% of the total risk for dwellings within the study area.

The total risk for the study area is about 4.5 buildings destroyed given a 100 year ARI rainfall event. In areas subject to debris slides, flows and falls, 1.8 buildings could be expected to be destroyed. This is less than half that for areas subject to slides and slumps where 2.7 could be destroyed. This estimate is based only on the present level and distribution of development and should not be transferred to proposed areas of development without reinterpretation.

Total Risk of Road Blockage and Destruction (Figure 7.10 and Figure 7.11): The total road length in areas subject to debris slides, flows and rock falls is 37 km. This is substantially less than the almost 700 km of road in areas subject to rotational slides and slumps (it must be noted that not all roads have been captured digitally). The only unit where roads are affected by debris slides is the Beachmont Basalt, which is transected by 13 km of roads that are impacted a total of three times from slides associated with the 1974 rainfall event. This suggests that on average within the Beachmont Basalt, a road blockage or destruction of an section of road caused by debris slides, flows and rock falls will occur every 5 km.

On slopes subject to rotational slides and slumps, roads impacted by landslides include those in the Beechmont Basalt, alluvium, Albert Basalt, Tertiary colluvium and the Mt. Gilles Volcanic units. Of these, the Mt. Gilles Volcanics, Tertiary colluvium and the Albert Basalt could given a 100 year ARI rainfall event be blocked or partially blocked every 1 to 2 km. These same roads could also be expected on average to have a section destroyed by landslide about once every 5 km. The Beechmont Basalt and alluvium are less at risk, on average they could be expected to be blocked once every 10 to 15 km and sections destroyed by landslide about every 50 km.

Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas

Fortunately, the low values of specific and total risk in Table 7.6 and Table 7.7 suggest that it is unlikely that existing buildings would be destroyed or people killed by landslides on cut slopes in Caboolture, Brisbane and Ipswich given a 100 year ARI rainfall event. However, this situation could change if more use is made of susceptible areas such as river banks or slopes requiring cut and fill. For debris flows, the 100 year ARI rainfall scenario may be sufficient to trigger a few flows from the escarpment in the far western part of Caboolture and Pine Rivers. These could cover, scour or flood roads in their path, and possibly cause flash flood or landslide damage to isolated buildings near the escarpment.

Redcliffe: Given the low lying terrain of the city, landslides are expected to be a minor problem and confined to rock falls and possible landslides along the low sea cliffs of Margate, Scarborough and Woody Point.

Brisbane: The maximum daily rainfall in Brisbane during the January 1974 floods was approximately equivalent to a 100 year ARI rainfall event. This triggered widespread failures in alluvial banks of the Brisbane River. Alluvial river bank failures would be expected to happen given a future similar scenario, along with possible landslides on hill slopes and river banks in unlateritised Tertiary sediments, and isolated landslides in pockets of colluvium or soil overlying older rocks, particularly near gully heads. Isolated small landslides may occur in road batters and cuts adjacent to buildings on hills.

Redland: Given the generally low lying terrain of the area, landslides are expected to be a minor problem confined to the Neranleigh-Fernvale beds, particularly on Mt Cotton; the low sea cliffs of North Stradbroke Island, Redland Bay and Wellington Point; the fissured clays developed on weathered basalt in the canal estates; and on the sand dunes of North Stradbroke Island. Landslide risk is considered to be very low, but the fatality at Amity Point should not be forgotten. The most likely cause of landslides in the mainland part of Redland will be from man-made cuts in hillsides underlain by the Neranleigh-Fernvale beds, where small wedge failures occur after rain, especially where prominent joints dip outwards into the excavation (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001).

Logan: Given the terrain of the city, landslides are expected to be a relatively minor problem and confined, if they occur at all, to areas of steeper land on the slopes of Mount Cotton and Daisy Hill. The most common form of landsliding in Logan is likely to be small failures in cut slopes on some of the higher hills of the Neranleigh-Fernvale beds (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001).

Limitations and uncertainties

Gold Coast Region

It is assumed that both landslide distribution and the distribution of development within geologic/slope units are random. This may in fact not be the case and may result in errors in hazard and risk calculations.

Research in these areas does not take into account failure on cut slopes and results should be related to natural slope failure only.

By dividing the risk analysis on the basis of slide type, ie. debris slides and rock falls on slopes >25° and rotational slides and slumps on slopes <25°, and calculating appropriate hazard values, the assumption is that all slides in either zone conform only to that slide type. This is not necessarily the case and may result in the overestimation of risk on slopes >25° and underestimation of risk on slopes <25°.

The assumption is that landslide intensity is uniform across a landslide.

Areas identified as having no landslide hazard may in fact be subject to minimal levels of residual hazard.

The calculations of vulnerability are based on the data derived from the Australian Landslide Database, the Australian Geomechanics Society (AGS, 2000) as well as the Cairns study (Leiba *et al*., 2000). The estimates do not represent an assessment of vulnerability specifically for the study site.

The assumption exists that hazard and risk are independent of landslide magnitude.

Hazard and risk are based on landslide occurrence rather than area or volume.

A significant number of roads have not been captured digitally. The distribution of these roads appears to be random throughout the study area thus eliminating possible bias between one geological/slope unit and another.

Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas

Nothing appears to have been published on landslides in the Caboolture, Pine Rivers, Redcliffe, Redland and Logan local government areas.

Landslides on cut slopes: Landslides have not been logged systematically after significant rainfall events to enable a local landslide recurrence relationship to be established so that a quantitative landslide risk assessment can be carried out. Data from Cairns were modified to take into account the lower rainfall in Caboolture, Pine Rivers, Brisbane and Ipswich. However, the landsliding mechanisms in Caboolture, Pine Rivers and part of Ipswich are undocumented, and the geology is different from Cairns. This may affect the applicability of the data. *The uncertainty in the Cairns specific risk estimates are of the order of one order of magnitude.*

The Cairns data assumed that the hazard is uniform over the entire hillslope. This oversimplification will underestimate the hazard in the parts of the slope immediately adjacent to cuts and fills, and will overestimate the hazard on parts of the slope distant from cuts and fills.

Because most of the batter failures in Cairns occur in rocks much more deeply weathered than those in Caboolture, Pine Rivers, Brisbane and Ipswich (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001), the incidence of failures on unengineered batters in Cairns would be expected to be higher than in these areas for corresponding rainfall intensities. Consequently, the hazard and risk in these areas would tend to be overestimated by this methodology for cut slopes for which no mitigation measures had been taken, and would be grossly overestimated for slopes developed with competent geotechnical advice.

Errors in the average recurrence intervals will have been introduced by the method of interpolation of the Bureau of Meteorology IFD data, but these are probably small in comparison with those introduced by importing Cairns observations into south east Queensland.

Debris flows: Debris flows and their deposits have not been specifically mapped in the Caboolture and Pine Rivers areas, and the extent of runout of debris flows during extreme rainfall events is unknown.

It is also not known what rainfall intensity or duration is necessary to trigger debris flows in the Caboolture and Pine Rivers areas.

Forecasting and warnings

The Bureau of Meteorology routinely includes a generic caution regarding the possibility of landslides during periods of heavy rain, such as those associated with cyclones. Given the very low probability and non-specific nature of the landslide threat, such warnings are probably adequate. There does not appear to be any justification for the establishment of an automated landslide monitoring system.

When slopes are developed using cut and fill, mitigation can usually be effected through proper geotechnical design. Mitigation of risk from debris flows, and flash floods from gullies, may be possible by engineering constructions such as levees and channels.

If it has not been done already, warning signs should be erected at cliffs when there is a potential for sand or rock to fall, causing injury or death. In the past four years, four children in Queensland have been temporarily buried as a result of two separate instances of their tunnelling into sand cliffs. If people had not been present to rescue them quickly, both incidents could have resulted in fatalities. Also, it should be noted that, for the whole of Australia, during the period January 1996 – June 1999, six out of the 12 landslides causing injury or death involved the fall or topple of a single rock!

CHAPTER 8: EARTHQUAKE RISKS

Trevor Jones, John Stehle, Rob Lacey and Denis Hackney

The Earthquake Threat

Earthquakes occur when stresses in the Earth exceed the rock's strength to resist, thus causing the sudden rupture of rocks and displacement along a surface called a fault. The fault may already have existed or may be newly created by the earthquake rupture. Energy from the fault rupture is transmitted as seismic waves that cause nearly all damaging earthquake effects.

The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML. Richter magnitude is determined by measuring seismic wave amplitude instrumentally and was developed by Charles Richter for California in 1935. The energy released by earthquakes varies enormously and so the Richter scale is logarithmic. An increase in magnitude of one unit is equivalent to an increase in energy released of about 33 times. For example, an earthquake with Richter magnitude 6 releases about 33 times the energy of an earthquake with Richter magnitude 5, and about 1000 times the energy of an earthquake with Richter magnitude 4. The Richter magnitude scale has been adapted to Australian conditions and is a suitable measure of Australian earthquakes except for the very largest events. The largest earthquakes are measured by the Moment Magnitude scale (Mw), preferably, or the Surface Wave magnitude scale (Ms).

Descriptions of the severity of earthquake ground shaking at any place may be given using intensity scales such as the Modified Mercalli Intensity scale. The Modified Mercalli (MM) scale describes the strength of shaking by categorising the effects of an earthquake through damage to buildings, landsliding, liquefaction, soil cracking and other types of ground failure, and the reactions of people and animals. A full description of the Modified Mercalli Intensity scale is provided in Appendix G.

The Modified Mercalli Intensity scale is useful because it is easily applied and understood, and because it can be used to extend our knowledge of earthquakes from observational effects described by witnesses, in cases where the event may not have been recorded by instruments (e.g., 19th Century earthquakes). However, Modified Mercalli intensity is a coarse measure of ground shaking. It does not correlate well with instrumental recordings of strong earthquake ground shaking. There are other difficulties associated with MM intensity as well. Instrumental recordings of earthquake strong ground motion are much preferred to MMI description, but they usually have not been available for Australian earthquakes.

The Australian continent is distant from the boundary between the Australian and Pacific tectonic plates. This narrow band of earthquake activity passing through Papua New Guinea, the South-West Pacific countries and New Zealand. South-East Queensland is situated more than 1500 km from this plate boundary. Nonetheless, strong earthquakes have occurred in Australia, and more will occur.

The most damaging earthquakes in Australia during the period 1950-2000 are listed in Table 8.1.

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events on the community makes them a costly natural hazard. Recent figures produced by the Bureau of Transport Economics (2001) put the historical cost of earthquakes in context. They estimated that the direct cost of natural disasters to the Australian community in the period 1967-1999 was about $37.3 billion, or an average of $1.13 billion per year. Of this total, floods contributed about 28%, severe storms about 25%, tropical cyclones about 24%, and earthquakes about 13%.

With increasing urbanisation and dependence on power, water, telecommunications and other lifelines, Australian communities are becoming increasingly vulnerable to earthquakes.

The epicentres of historic earthquakes in the South-East Queensland region are shown in Figure 8.1.

Table 8. 1 Most-damaging Australian earthquakes, 1950-2000

Date	Location	Magnitude	Damage Contemporary	Damage 2000 [1]
03/01/1954	Adelaide SA	5.4	$8.8 M	$100 M
22/05/1961	Robertson/Bowral NSW	5.6	$0.5 M	$4.7 M
14/10/1968	Meckering WA	6.9	$5 M	$39 M
10/03/1973	Picton NSW	5.5	$0.5 M	$3.2 M
02/06/1979	Cadoux WA	6.2	$3.7 M	$11 M
22/01/1988	Tennant Creek NT (3 events)	6.2, 6.3, 6.5	$1.1 M	$1.7 M
28/12/1989	Newcastle NSW	5.6	13 killed, $862 M insured damage, est. $1500 M total damage	$1994 M
06/08/1994	Ellalong NSW	5.4	$34 M	$39 M

[1] Source: ABS, 2001

The recorded history of earthquake activity in Queensland is brief in comparison to the time-scale of geological processes - too brief for us to obtain an accurate estimate of the true rate of earthquake activity in the area. According to Rynn (1987) the first earthquake report for Queensland was from Cape York Peninsula in 1866. Recent research, however, has brought to our attention apparently significant earthquakes in 1861 and 1862.

The following extracts are taken from the personal diaries of John and James Green, early pioneering settlers of the Nanango District of the South Burnett in South East Queensland who explored the Gympie-Cooloola/Fraser Island-Noosa-Mary Valley regions between 1850-1870 with the assistance of the native Kabi clans in the area. Edited versions of the text are found in de Grene (1996). We stress that these reports have not been authenticated or corroborated at the time of publication.

> *Tuesday 25th June 1861:*
> *The sun is an hour from setting. The natives have settled after a period of panic when the earth growled, the ground jumped and shook violently from a quake force deep within the soil. Trees swayed and the seawaters were in array swishing back and forth in quick succession over the sands exposed by the low waters. It was a short frightening experience for I had never taken part in such an occurrence.*

(Edited version in de Grene (1996, Vol. 3, pp. 60-61).) This account indicates moderate to strong earthquake shaking from a moderate magnitude earthquake, as indicated by the short duration of shaking.

Another, more vivid, account of earthquake activity is found in the diaries of the following year. On the afternoon of 3 September 1862 near the shores of Lake Cootharaba, north of Noosa:

> *There was an eerie quietness over the land. The birds had fled. There was no movement of the leaves - not a ripple on the water. David I noted was ill at ease. He said the earth spirits were angry. A great roar sounded beneath our feet and the lands shook violently. Trees heaved upwards and downwards - falling in many directions. I fell upon the ground and could not move so violent was the ground shaking and sliding - one way, then the next. I could not stand no matter my effort. The horses cried out in fear as they fell upon the each other trying to get upright and free all at the same time. It seemed an eternity before it ceased.*
>
> *There was a hush as we quietened the horses and secured them further so that they could not*

escape in their fear. I was fortunate to have placed the camp on high ground for the lake waters had risen considerably to a new shoreline on many feet and gained much depth of water….The great shaking came again and we were thrown to the ground as jolt after jolt came forth under the ground. Great waves rolled across the waters and crashed upon the new shores filling the waters with trash and debris. More shaking occurred soon after and again and again, until it was no more than rumbles in the ground.

The ground quake had indeed done its damage. I report that on seeking way to the ancient stone structures and its columns by new routes, I found that all had been changed. The point had gone - there was nothing but waters. The structures have seemingly collapsed, shattered upon the ground, only then to be covered by the new levels of the lake waters. It was as though all had been taken from my view in reasoning, not to be seen again by the naked eye though I knew of rough estimation where it had once been.

(Edited version included in de Grene (1996, pp. 40-42, Vol. 4).

The Green brothers' extraordinary account indicates strong earthquake ground shaking corresponding to a seismic intensity of at least MMVII (Appendix G). Their camp may have been close to the earthquake fault rupture if the change of the height of the lake relative to the shore is accurate. This change in water level would have resulted from some type of permanent ground displacement such as surface faulting, differential settlement, lateral movement or liquefaction. Other evidence that the camp was close to the earthquake fault rupture is the intensity of ground shaking from the aftershocks.

More research is needed to verify these accounts and to estimate the magnitudes of the earthquakes that the Green brothers described. A first check of Brisbane newspapers indicated no report of earthquake activity (Kevin McCue, AGSO, written communication, 2001).

Other notable Queensland earthquakes include the 1918 'Bundaberg' earthquake sequence and several earthquakes near Gayndah (Table 8.2). The Bundaberg mainshock had a magnitude of ML 6.3 and is the largest historic earthquake in eastern Australia. Its offshore location minimised the damage it caused, but damage was reported in Bundaberg, and in Rockhampton where

'chimney stacks fell down, cracks appeared in buildings, windows were broken … the event was widely felt in most suburbs in Brisbane …'

(Everingham and others, 1982).

Six moderate magnitude aftershocks, and presumably many more smaller aftershocks, occurred over the next four days. The earthquake was felt over a wide area in Queensland and northern NSW.

Several significant earthquakes have also occurred near Gayndah over the last 120 years or so. Moderate magnitude earthquakes occurred there in 1883, 1910 and 1935, the latter causing minor damage (Table 8.2). The 1935 earthquake was also felt over a wide area including South-East Queensland.

The earthquake hazard for South-East Queensland is, however, low by global standards (Giardini and others, 1999).

Earthquake risk assessment method

Earthquakes threaten communities most through building damage. Our earthquake risk assessment for the South-East Queensland community is based almost entirely on scenario analysis of damage to residential buildings in Queensland (houses and flats). These buildings comprise about 94% of all South-East Queensland buildings. Community risk is a function of the composition of the building construction types in the region, the extent of damage to each type of building, the uses to which buildings are put, and the potential for community disruption and business interruption through building damage.

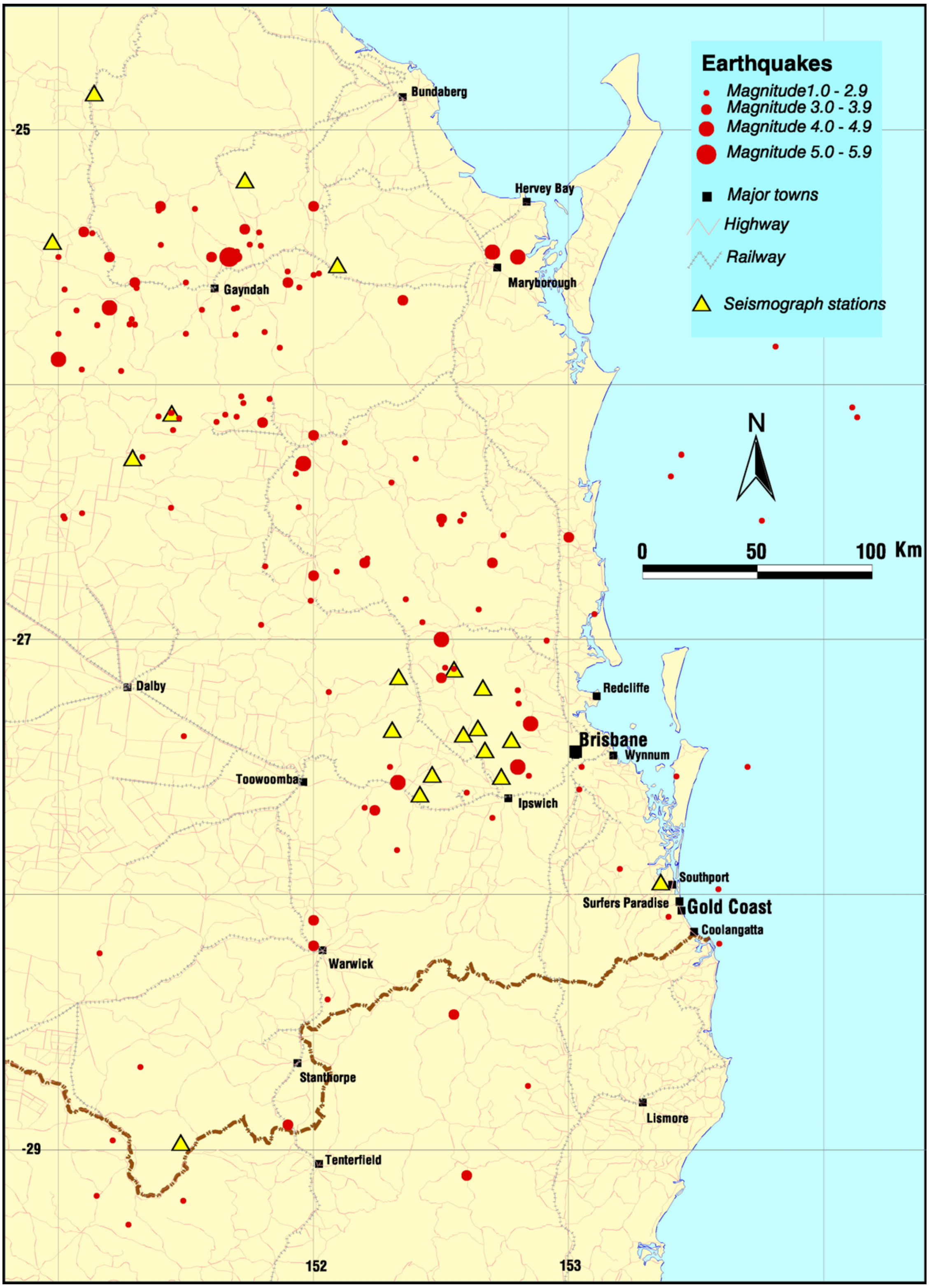


Figure 8. 1 Historic earthquakes in the South-East Queensland region

Table 8. 2 Significant historical earthquakes in the South-East Queensland region

Date	Time (UTC[2]) hr min	Lat (°S)	Long (°E)	Place	ML[3]	I_{max}[4]	Comments
25/6/1861				Felt near Noosa	4?	V?	First reported Queensland earthquake
3/09/1862				Felt near Noosa	5.0?	VII?	Second reported Queensland earthquake
24/11/1875	11 00	28.1	152	Warwick	3.9	IV	Felt MMV Allora
26/02/1877	21 45	27.5	152.8	Ipswich	4.3	IV	Felt MMIV Ipswich
10/08/1880	19 00	28.9	151.9	Bald Mountain	3.6	IV	Felt MMIV Bald Mountain
28/08/1883	16 55	25.5	151.67	Gayndah	5.9	VII	Damage to Gayndah, Bundaberg and Maryborough. Felt from Brisbane to Rockhampton
28/08/1883	18 20	25.5	151.67	Gayndah	5	IV	Felt in Gayndah, Maryborough and Rockhampton
24/11/1910	22 52	25.7	151.2	Gayndah	4.7	IV	Felt in Bundaberg and Rockhampton
01/05/1913	16 20	27	152.5	70 km NW Brisbane	4.8	V	Felt MMV Kilcoy, Esk and Crows Nest
06/06/1918	18 14	23.5	152.5	Offshore Bundaberg	6.3	VII	Damage in Rockhampton and Bundaberg. Felt from Mackay to Grafton to Charleville. Widely felt in Brisbane
06/06/1918	18 15	23.5	152.5	Offshore Bundaberg	5.1	III-IV	
06/06/1918	18 23	23.5	152.5	Offshore Bundaberg	5.5	III-IV	Felt MMIV Esk, Killarney
07/06/1918	19 00	23.5	152.5	Offshore Bundaberg	5.1	III	
08/06/1918	19 20	23.5	152.5	Offshore Bundaberg	5.7	III-IV	
09/06/1918	19 45	23.5	152.5	Offshore Bundaberg	5.1	III	
10/06/1918	20 15	23.5	152.5	Offshore Bundaberg	5.1	III	
12/05/1935	01 32	25.5	151.67	Gayndah	5.5	VI	Felt MMVI Gayndah, MMIII Brisbane
11/06/1947	10 03	25.48	152.7	Maryborough	4.3	IV	Felt MMIII Nambour 'Minor damage'
30/12/1951	21 40	25.9	151	Mundubbera	3	IV	Felt MMIV around Mundubbera
24/06/1952	01 44	25.5	152.8	Maryborough	4.8	IV-V	Felt MMIII Brisbane to Bundaberg
10/05/1955	22 36	26.7	152.2	Mt. Stanley	3.2	IV	Felt MMIII-IV Brisbane
17/11/1960	05 00	27.33	152.85	Mt. Glorious	4.4	III-IV	Felt MMIII Brisbane, Ipswich, Caboolture
25/03/1964	06 14	25.3	151.4	Mundubbera	3.9	IV	Felt MMIV at Gayndah. Damage in Mundubbera area
30/10/1984	06 29	26.31	151.96	Murgon	4.2	VII	Felt MMV-VII at Murgon. Damage to school, houses
14/08/1988	23 23	27.56	152.33	Gatton	4	V	Felt MMIV Gatton, Forest Hill, Laidley
25/10/2000	05 24	27.36	154.95	Offshore Brisbane	3.9	III	Felt South-East Queensland MMII-III

[2] UTC = Universal Coordinated Time = Australian Eastern Standard Time minus 10 hrs; [3] ML = Richter (or local) magnitude; [4] I_{max} = maximum seismic intensity measured on the Modified Mercalli Scale

The earthquake building damage assessment comprises the following processes.

- An earthquake hazard model was prepared for South-East Queensland. This model takes into account the likelihood of earthquakes occurring in the South-East Queensland region. The model also accounts for local site effects that can amplify earthquake ground shaking. These site effects are largely due to near-surface geological conditions. Numerous 'scenario' earthquakes were sampled from the earthquake hazard model as input for the building damage models.
- A South-East Queensland property database was prepared, based on the data provided by the eight LGAs. This database categorises buildings according to both their age and their usage.
- The damage to South-East Queensland residential buildings (houses and flats) was estimated using the HAZOZ earthquake loss software developed by AGSO (Stehle and others, in preparation.). This software estimates building damage using the capacity spectrum method described in HAZUS® (FEMA, 1999).
- Probabilistic loss estimates were determined for a range of Annual Exceedence Probabilities (AEP). Losses are expressed as the equivalent number of residences totally damaged. The results are presented at the level of Census Collectors District (CCD) and for the entire region.

Each of these processes is described more fully in the following sections.

Earthquake hazard in South-East Queensland

South-East Queensland regional earthquake hazard:

Four estimates of earthquake hazard have been prepared for the South-East Queensland region.

The basic model that was used to generate scenario earthquakes is the Tasman Sea Margin Zone (TSMZ), a single, uniform earthquake hazard source zone that extends from northern Bass Strait into Queensland as far north as the southern extremity of the Great Barrier Reef. The western margin of the TSMZ corresponds approximately with the 150 m AHD topographic contour west of the Great Dividing Range, and its eastern margin is located along the 200 m isobath at the eastern Australian continental shelf margin. The TSMZ was proposed by a panel of geological and seismological experts in Sydney in 2000 (Stewart and Jones, in preparation). The TSMZ is associated with the opening of the Tasman Sea and the separation of the New Zealand and Australian land masses. A maximum magnitude of 6.5 ± 0.5 is assumed for the Tasman Sea Margin Zone.

A further three estimates of earthquake hazard are included to give the reader an indication of the uncertainty in earthquake hazard assessment for South-East Queensland. Each estimate relates to a 10% probability of exceedence in 50 years at 'rock' or 'firm' sites. This probability corresponds to an AEP of approximately 1/475, or an average recurrence interval (ARI) of 475 years. The first of these estimates of hazard is found in *AS1170.4-1993* and its replacement, the draft *ANZS DR 00902* (Standards Australia, 2001). An 'acceleration coefficient' of 0.06 for the South-East Queensland area was taken from Table 2.3 of the standard. This value is equivalent to a peak horizontal ground acceleration (PGA) of 0.06 g, where 'g' is the acceleration experienced at the earth's surface under gravity. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993* has an acceleration coefficient in the range 0.05 - 0.1 g. The coefficient values across Australia range from a minimum 0.03 ('low' globally) to highs of up to 0.22 ('moderate' globally) in 'bullseye' areas.

The second of these estimates originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.1 g on rock, in line with their estimates of PGA for Queensland two to three times higher than previous estimates.

The third of these estimates is found in the work of Gaull and others (1990). The earthquake hazard maps in *AS1170.4-1993* were derived from this work. Gaull and others estimated a PGA value of 0.025 g for Brisbane.

Urban earthquake hazard in South-East Queensland

In addition to the regional earthquake hazard represented by, for instance, the state-wide hazard maps in *AS1170.4-1993*, earthquake hazard can vary considerably across a region as large as South-East Queensland, primarily because of local differences in site geology. This effect has been responsible for the concentration of damage in many earthquakes, including the 1989 Newcastle earthquake, the 1989 Loma Prieta (California) earthquake and the 1995 Kobe (Japan) earthquake. (In Kobe the focussing of seismic waves at the edge of a geological basin may also have had a significant role in producing the strongest shaking.) Ground shaking recorded from these earthquakes, and others, indicates that the localised earthquake hazard can vary by a factor of two or more depending on ground conditions.

South-East Queensland has been divided into three site classes that determine the relative severity of earthquake shaking (Site Classes B - D in Table 8. 3). A site class was assigned to each CCD.

The relative strength of earthquake shaking on each of the Site Classes B, C and D is described by a response spectrum for each site class. Figure 8. 2 plots the response spectrum for the site classes in South-East Queensland.

Table 8. 3 Earthquake site classifications for South-East Queensland

Site Class	Description	South-East Queensland setting
B	Rock. Mean shear wave velocity in the top 30 m assumed to be more than 1500 m/s.	All rock outcrop in South-East Queensland. The site class includes all rock units older than Tertiary (age greater than about 65 million years).
C	Thin sediments overlying rock. Sediments with natural periods of vibration less than 0.5 s (sediment thicknesses in the range 3-23 m approx.)	All Quaternary sediments with thicknesses estimated in this range. In South-East Queensland these are found along stream beds, alluvial plains, in estuaries, coastal plains, tidal deltas and beach deposits. Landfill may overlie these units.
D	1. Thick sediments overlying rock. Sediments with natural periods ≥ 0.5 s (sediment thicknesses in the range 24-70 m approx.); OR 2. Weathered profile in residual soils and colluvium overlying Tertiary geological units.	1. All Quaternary sediments with thicknesses estimated in this range. In South-East Queensland these are found along stream beds, alluvial plains, in estuaries, coastal plains, tidal deltas and beach deposits. Landfill may overlie these units; OR 2. All mapped Tertiary rock units. Extensive areas of Tertiary sediments and basalts are found in South-East Queensland.

See Chapter 2 for an abbreviated description of the geology of South-East Queensland.

Earthquake motion described in terms of response spectra is useful to engineers. Spectral acceleration is the maximum acceleration of an idealised single degree of freedom 'structure' relative to its 'foundations'. The period *T* is the time taken to complete one cycle of vibration.

The spectrum for Site Class B was developed by Somerville and others (1998), and is used as the response spectrum for earthquake shaking on rock in Australia in *ANZS DR 00902* (Standards

Australia, 2001). The spectra for Site Class C and Site Class D were developed by multiplying the values of the Site Class B spectrum by amplification factors derived for Eastern United States (EUS) by Schneider and others. The EUS amplification factors are used in the absence of appropriate amplification factors developed for Australian conditions. The EUS factors were developed for site conditions similar to those in many parts of eastern Australia, where hard Palaeozoic basement rock underlies relatively thin, much softer, Cainozoic deposits. The amplification factors for Site Class C were developed for New Madrid Class L28 ('soft' sediments of thickness 3-23 m) with an input PGA value of 0.075 g. The amplification factors for Site Class D were developed for New Madrid Class M28 ('soft' sediments of thickness 24-54 m) with an input PGA value of 0.075 g.

Earthquake ground shaking will be stronger on Site Classes C and D than it will be on Site Class B, for periods of vibration that could cause damage to buildings (Figure 8. 2). For example, at a period of T = 0.1 s (corresponding approximately to the natural period of one-storey residences), the amplification of ground shaking on Site Class C is expected to be about 0.44 g ÷ 0.19 g = 2.3 times stronger than the ground shaking on rock (Site Class B) at this period of vibration. Similarly, at the same period of vibration, the ground shaking on Site Class D is expected to be amplified by a factor of about 1.3 compared to the ground shaking on rock.

Low rise buildings with a natural period of vibration of around T = 0.1 s, including most residences, can readily take in energy from the earthquake ground shaking with this period of vibration. Generally then, low rise buildings on Site Classes C and D are likely to suffer more damage in earthquake scenarios than low rise buildings on Site Class B. The outcome for any particular earthquake, however, may differ because of the location of the earthquake in relation to the sediments, focussing of seismic waves, the possibility of surface faulting, the duration of earthquake shaking, etc.

In general, the amplification of ground shaking also changes with differing intensities of input ground motion. The chosen value of PGA on rock, 0.075 g, represents a compromise between PGA values for the weak earthquake shaking that could be expected for the frequently occurring events (i.e. relatively large AEPs), and the strong shaking that could be expected for very rare events (small AEPs).

Earthquake hazard scenarios for South-East Queensland

Earthquakes with four different magnitudes were used to generate hazard scenarios for South-East Queensland. The scenario earthquakes had magnitudes of 5, 5.5 (similar to the 1989 'Newcastle' earthquake), 6 and 6.5. Earthquakes in the range of magnitudes M5-6.5 dominate the source of earthquake hazard in Australia. Individual scenario 'earthquakes' were generated in each cell of a regular 10 km by 10 km square grid with sides of 300 km (i.e., a total of 900 scenario earthquakes for each magnitude). South-East Queensland is located at the approximate centre of the grid (Figure 8. 3). For each scenario earthquake, the PGA was calculated at the centroid of each CCD. The calculated value of PGA is a function of the distance between the scenario earthquake and the centroid of the CCD. We used the attenuation formula of Toro and others (1997) to calculate PGA at the CCD centroid. Scenario earthquakes of magnitude 5.5 or smaller were treated as point sources. Scenario earthquakes with larger magnitudes were considered to occur on faults of random azimuthal orientation, and the closest distance between the fault rupture and the CCD centroid was calculated in each case. The fault length varies with earthquake magnitude, and fault lengths were calculated using the relationships of Wells and Coppersmith (1994). The response spectra, scaled by the input value of PGA, were used as input into the building damage model.

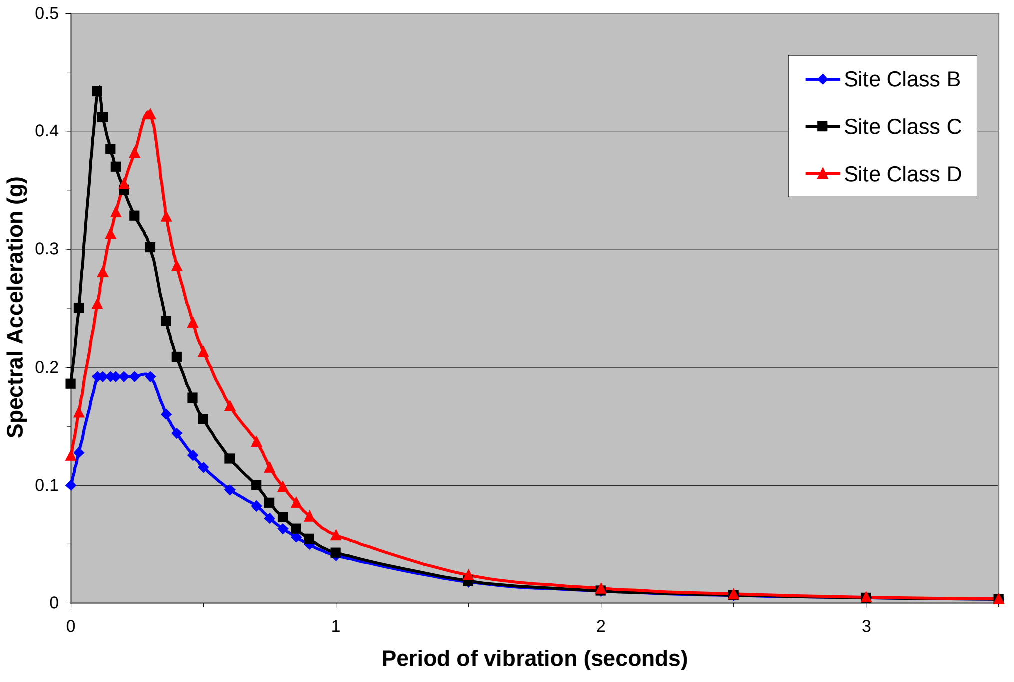


Figure 8. 2 Response spectra for South-East Queensland Site Classes B, C and D. Spectra are elastic and 5% critically damped. On this plot, spectra are tied to a Peak Ground Acceleration of 0.1 g on rock (Site Class B)

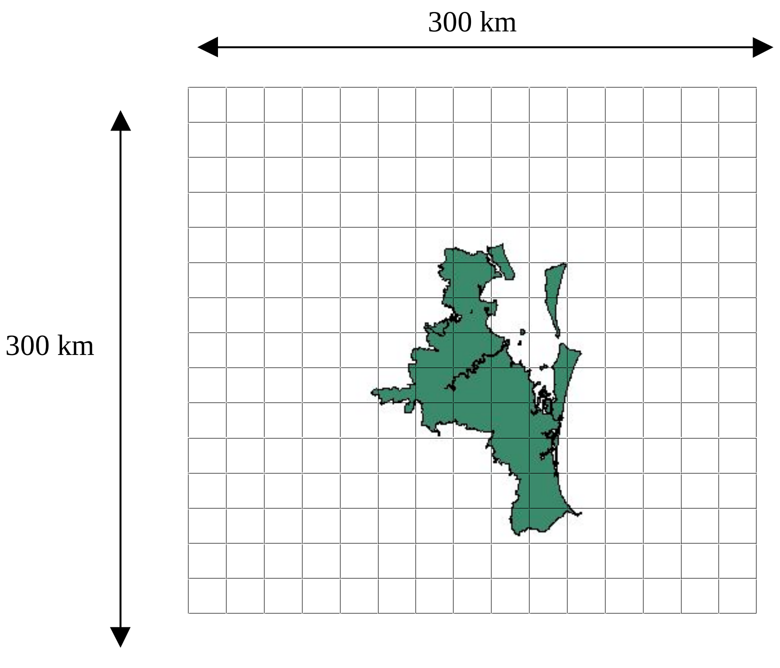


Figure 8. 3 Schematic of South-East Queensland study area and the regional grid used to generate scenario earthquakes.

South-East Queensland building database

The property databases developed by AGSO from data provided by the eight South-East Queensland LGAs were used in our assessment. This database contains information on every developed property in South-East Queensland. The information typically includes the age of original development (by decade) and property usage. In addition, we have assigned a building usage category that relates to our method of assessing community geohazard risk (see Chapter 3).

We have also estimated the composition of the residential building stock with regards to the type of load-bearing frame or wall (Table 8. 4). Several common types of residential building construction are described below.

Light timber frame buildings: Most South-East Queensland buildings are of this type. These low rise buildings usually have timber wall cladding but may have brick, fibro or metal exterior cladding. Most are residential buildings, or ex-residential buildings used for other purposes such as businesses.

Buildings with light timber frames behave in a ductile manner in earthquakes and can undergo relatively large displacements because of their non-rigid construction.

The high-set buildings on stumps are of special interest because they are found in Queensland but not outside tropical and subtropical Australia. We do not know the number of older (pre-war) ‘Queenslander’ timber houses in Queensland. Their performance in strong earthquake shaking has not been tested. If they are in good condition they will have vertical joints connected, will be tied down from piers to roof, and may be less vulnerable to earthquakes than houses built in the 1960s and 1970s (John Ginger, James Cook University, verbal communication, 1999). Many old ‘Queenslanders’ are not in optimum condition, however, and their performance could be poor, particularly if they are not tied to the stumps or if the stumps are not cross-braced.

The wall type ‘brick’ could include both unreinforced masonry and brick veneer construction types. Brick veneer structures have a light timber frame. We made the assumption that nearly all ‘brick’ houses are brick veneer because residential buildings with brick walls are most common in suburbs that developed since the 1960s. Brick veneer became an accepted construction method in Queensland in the late 1950s and has been the predominant brick form since then.

Reinforced masonry buildings with reinforced concrete floors (concrete block buildings with concrete slab floor): Reinforced concrete block is the presumed third most common type of house construction in South-East Queensland. We consider that concrete block buildings complying with modern wind loading standards will probably perform well under moderate seismic loadings. However, older concrete block buildings not built to either a wind or earthquake loading standard will be less earthquake-resistant than equivalent modern buildings complying with the standards.

Reinforced concrete frame with unreinforced masonry infill panels: This type of construction has been popular for low and medium rise residences, and public works-related buildings such as hospitals and schools. Infill panels are often brick, and brick or other cladding may conceal the frame. Masonry infill panels provide lateral resistance, unintentionally in some cases. Upon cracking of the masonry, increased lateral loads are transferred to the concrete frame. Collapse can occur upon disintegration of the masonry infill or through shear failure of the frame. If masonry is absent from the lower storey or storeys of a building, a ‘soft storey’ can form under low levels of earthquake loading. This phenomenon was observed some 250 km from the epicentre of the recent Gujarat, India, earthquake (John Stehle, AGSO, written communication, 2001). In the 1989 Newcastle earthquake these buildings did not suffer structural collapse although there was significant damage to masonry infills and cladding (Institution of Engineers, Australia, 1990). At least one structure in Newcastle had to be demolished due to ‘soft storey’ damage. Only one pre-code concrete building has suffered collapse in any New Zealand earthquake, and this building had a ‘soft storey’. Dowrick and Rhoades (2000) attributed this excellent performance to structural walls of concrete, concrete blocks or brick infill.

Unreinforced masonry: These usually older buildings often have cavity brick construction with the inner leaf and outer leaf attached by ties. One leaf acts as the load bearing element. Interior walls may also be unreinforced masonry and load-bearing. Floors may be of any material but in the oldest buildings they are usually timber. Unreinforced masonry is brittle, and historically has performed poorly in many earthquakes around the world, although its strength may be improved by the presence of cross walls (John Wilson, University of Melbourne, verbal communication, 1999). Most unreinforced masonry buildings in South-East Queensland are probably used as commercial premises, though some public buildings, including some schools, also have this form of construction. Some of these older buildings (e.g., the former wool stores along the Brisbane River) are being re-developed as residential units.

Old unreinforced masonry buildings, both domestic and non-domestic, were the most extensively damaged buildings in the 1989 Newcastle earthquake (Institution of Engineers, Australia, 1990). Corroded wall ties and weak lime mortar were two major contributors to masonry damage in the Newcastle earthquake and they could contribute to building vulnerability in the South-East Queensland climate. In the Newcastle earthquake, extensive cracking, loss or tilting of exterior walls, and fallen parapets, awnings and gable ends were widespread and in some cases caused deaths.

Reinforced concrete shear walls: These structures have massive shear walls poured in situ. The walls are usually load bearing walls. In older buildings, the walls often are quite extensive and the wall stresses are low but reinforcing is light. In newer buildings, the shear walls often are limited in extent, generating concerns about boundary members and overturning forces. Poorly located shear walls may introduce torsion into the structure, hence increasing the likelihood of damage. Nevertheless, we expect these buildings to perform relatively well in the earthquake loading scenarios of this study.

Table 8. 4 Estimated percentages of South-East Queensland construction types of houses and flats

Construction type	Houses	Flats
Light timber frame low rise	97.5%	69%
Reinforced concrete frame low rise	0	8.5%
Reinforced concrete frame medium rise	0	7%
Concrete shear walls medium rise	0	4%
Concrete shear walls high rise	0	2%
Reinforced concrete frame with unreinforced masonry infill panels low rise	0	1%
Reinforced concrete frame with unreinforced masonry infill panels medium rise	0	3%
Unreinforced masonry low rise	2%	0.5%
Reinforced masonry buildings with reinforced concrete floors (concrete block buildings with concrete slab floor)	0.5%	5%

Building damage models for South-East Queensland

AGSO's HAZOZ methodology makes use of the capacity spectrum method and defines damage by the interstorey drift ratio. The drift ratio is the ratio of relative lateral displacement of a building floor to the height of a building storey. Different drift ratios determine the structural damage states (slight, moderate, extensive, complete). Different damage states are then used to determine the damage cost. The seismic capacity spectrum performance parameters of Australian residential buildings have been determined by a group of experts (Stehle and others, in prep.).

Damage cost is defined as a percentage of replacement value, as follows:

Damage cost = cost of repair or replacement / total value (total replacement cost).

The cost of repair to non-structural damage to buildings is also assessed. Structural repairs relate to the load-bearing elements of the building. Non-structural elements can be sensitive to acceleration (e.g., ceilings, pipes and ducts) or to displacement (e.g., interior non-structural walls, exterior wall cladding, glass). Our calculations also include building contents damage, which are also modelled to be sensitive to acceleration.

The repair costs are apportioned as follows:

Structural damage	15/64 of building replacement value
Non-structural acceleration-sensitive damage	17/64 of building replacement value
Non-structural displacement-sensitive damage	32/64 of building replacement value
Contents	50% of building replacement value

These repair cost ratios are taken from HAZUS® (FEMA, 1999).

Method of calculating earthquake losses and uncertainties

The loss from each of the 900 scenario earthquakes, for each of the earthquake magnitudes (5, 5.5, 6 and 6.5), was calculated for each CCD. Loss is the equivalent repair or replacement cost, as mentioned above.

Each loss scenario was associated with a probability of occurrence from the hazard model. The level of damage in each CCD from individual scenarios ranges from negligible to high, depending on the location of the scenario event in relation to the CCD.

The damage level to houses and flats was calculated for each Census Collectors District (CCD), for each scenario event. Damage across the entire South-East Queensland region was also calculated for each scenario event. Cumulative loss curves for each CCD, and for the entire South-East Queensland region, were prepared by aggregating the probabilities of exceedence of various loss levels. A relationship describing the ARIs at which various levels of damage were exceeded was developed from the loss curve.

Statistical uncertainty/variation in the input ground motion, the building capacity curve and in the damage state thresholds are accounted for in the HAZOZ methodology. The result is that a group of buildings of the same building category and subject to the same ground motion will be in a range of damage states.

Results

A summary of the earthquake damage losses in the South-East Queensland region is given in Table 8.5 and plotted in Figure 8.4 and Figure 8.5. The losses are the minimum losses expected for the probability associated with that loss. For example, there is an annual probability of 0.2% that damage losses will be 0.31% of the total insured value, or higher than 0.31% (Table 8.5).

A probabilistic distribution of earthquake damage risk across the South-East Queensland region is shown in Figure 8.6. The annual risk to each CCD is shown. The risk is defined in terms of the percentage of the repair or replacement cost of a 'typical' residence including contents or, alternatively, the percentage loss of the repair or replacement cost of the residential building stock and contents (multiplied by an annual probability of on e). The percentages in the legend of Figure 8.6 must be multiplied by 10^{-6}. All of the scenario earthquakes were used to prepare the map.

Table 8. 5 Estimated damage for South-East Queensland residential buildings

ARI (years)	AEP	Damage (repair or replacement cost of equivalent no. of buildings destroyed)	Damage (repair or replacement cost expressed as % of total replacement cost)
100	1.0%	60	0.01%
200	0.5%	450	0.07%
500	0.2%	2000	0.31%
1000	0.1%	3900	0.60%
2000	0.050%	7100	1.1%
5000	0.020%	13 000	2.0%

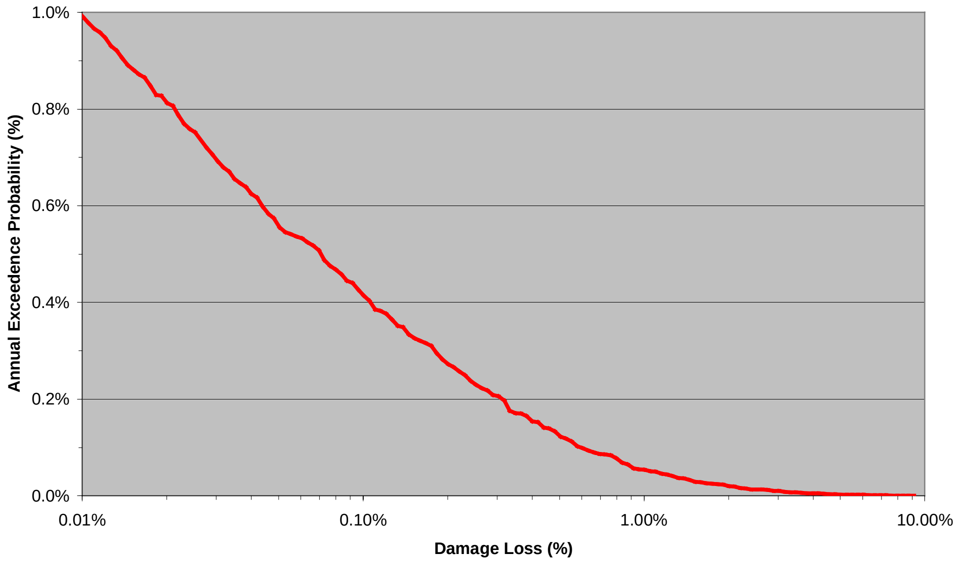


Figure 8. 4 Annual Exceedence Probabilities for residential building damage in South-East Queensland

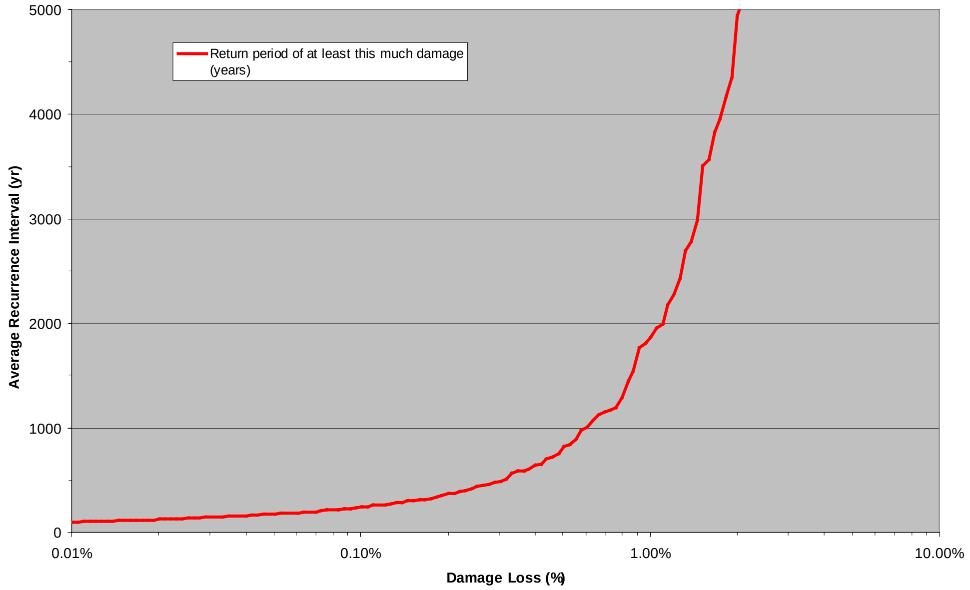


Figure 8.5 Average Recurrence Intervals for residential building damage in South-East Queensland

Discussion

The distribution of modelled earthquake damage reflects the locations of dwellings across the region. That is, modelled damage will tend to be concentrated in areas of high population density. Local site conditions will also have a significant influence on the distribution of damage (e.g., Figure 8.6) because residences situated on rock foundation will suffer less damage on average than residences on Site Class C or D (Table 8. 3).

Areas of South-East Queensland that contain significant numbers of flats are also estimated to suffer more damage than areas in which flats are not common. We have assumed that 0.5% of South-East Queensland flats are constructed of unreinforced masonry, 4% have a concrete frame with unreinforced masonry infill panels, and a further 17.5% have a concrete moment frame (Table 8.4). All of these types of building construction are expected to perform worse in earthquakes than buildings with timber frames, in particular the unreinforced masonry buildings. Only about 70% of flats are estimated to have a timber frame, whereas more than 95% of South-East Queensland houses are estimated to have a timber frame. The damage patterns would change with different sets of assumptions about the composition of the building stock.

The estimates of losses can be converted very easily to expected direct dollar losses by inserting replacement costs appropriate to South-East Queensland. A surcharge for demolition, debris removal and administrative costs could be applied.

Potential earthquake damage to non-residential buildings

Our estimates of the distribution of earthquake damage in South-East Queensland are biased because we have only modelled damage to residential buildings. Significant other costs could be incurred through repairing or replacing damaged non-residential buildings, and because of business interruption. Significant social and cultural costs to the community could also occur (many of them caused by building damage), but these are more difficult to quantify.

AGSO has not made estimates of earthquake damage to non-residential buildings in this study. Estimates of damage to structures used for public safety, utilities, essential services, medical purposes, logistics, government, and business and industry give a broader description of the community's capacity to respond and recover from a significant earthquake than an assessment of damage to residential buildings only. However, at the moment, we do not have specific information on construction types from which to estimate damage to these buildings.

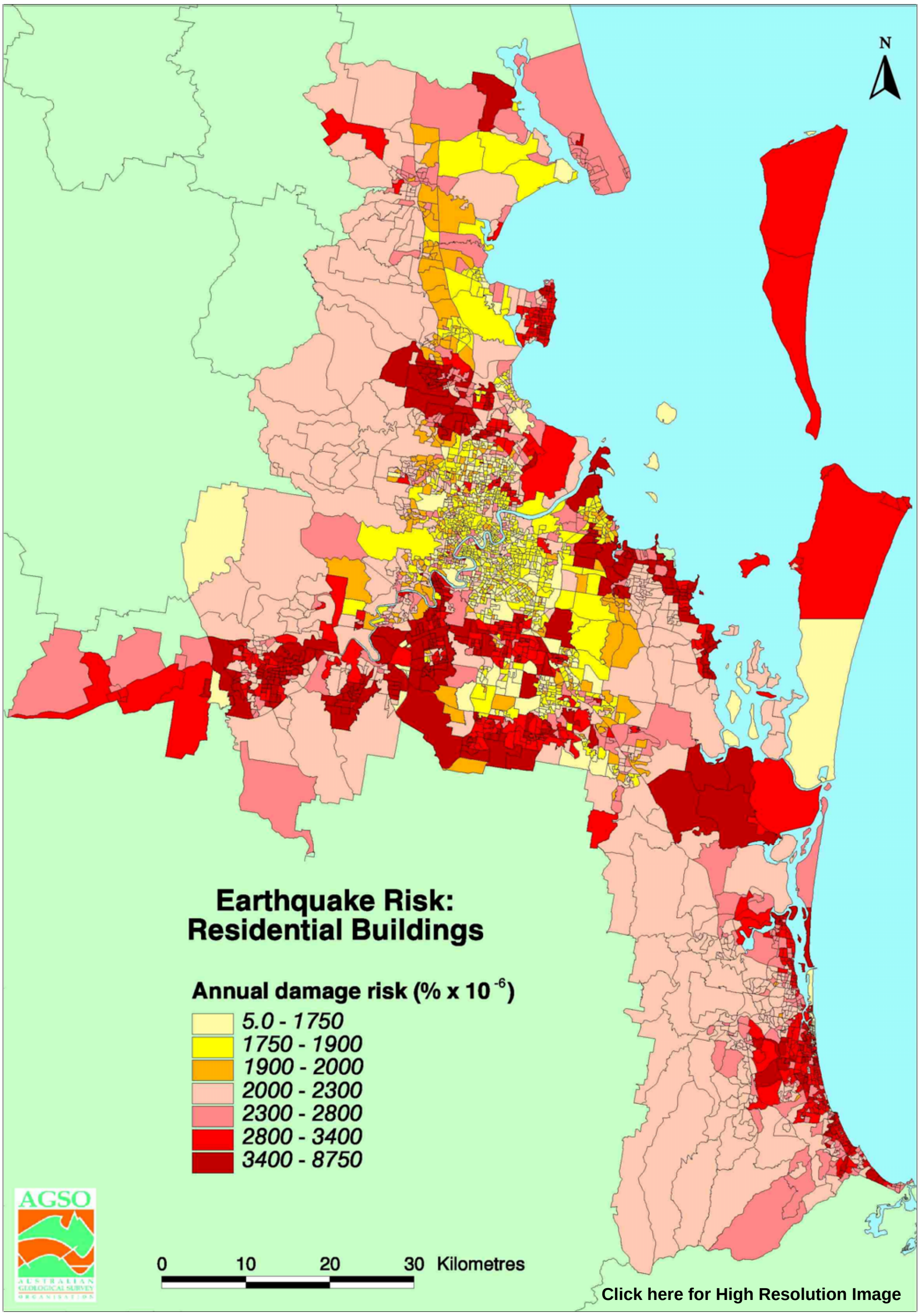


Figure 8.6 Annual earthquake risk to residential buildings. Units of annual risk are replacement value of a 'typical' residence including contents multiplied by 10^{-6} (see text)

Probability of casualties

The probability of death is low from any of the scenarios we considered. Dowrick (1998) published data on damage and casualties from New Zealand earthquakes. He estimated that the probability of death in, or beside unreinforced masonry or soft storey reinforced concrete buildings was about 3 in 10,000 for earthquake shaking of MM VIII. He also found that nearly all building-related deaths from New Zealand earthquakes occurred in, or near unreinforced masonry buildings, and that more than 90% of all earthquake related deaths in New Zealand occurred at a very high intensity of ground shaking (MM IX).

The probability of injury that is immediately life-threatening if treatment is not available may be about the same as the probability of death. The probability of non life-threatening injury is about 100 to 1000 times more likely, depending on the damage state of the building (FEMA, 1999).

We cannot exclude the possibility of casualties or deaths in South-East Queensland from earthquakes. The 1989 Newcastle earthquake caused deaths through collapse of non-structural elements such as awnings and through partial structural collapse. If all buildings were in conformance with current building standards, few deaths could be expected from a 'Newcastle' type earthquake.

What is the earthquake risk to South-East Queensland?

In summary, South-East Queensland faces a moderately low risk to its residential buildings from earthquakes. The level of earthquake risk in South-East Queensland is certainly significant when considered on a regional basis, and earthquakes should be considered in risk management strategies for the region.

The earthquake hazard in the South-East Queensland region is low by global standards (Giardini and others, 1999). The relatively minor historical seismicity, and its correspondingly minor impact on human activity in the South-East Queensland region, are testimony to this. However, we need to be aware of the short historical record and the consequences of a rare, damaging earthquake.

Although overall hazard is low, it is higher in the many parts of South-East Queensland that are built on unconsolidated sediments or on Tertiary geological units. These ground conditions are expected to amplify the ground shaking from future earthquakes.

We rate the vulnerability of South-East Queensland residential buildings to earthquake as low. The great majority of residential buildings in South-East Queensland (an estimated 95%) are of light timber frame construction. Timber frame buildings perform well in earthquake and this is a positive factor in the earthquake risk that South-East Queensland faces.

Suggested options for earthquake mitigation

Although the earthquake risk to South-East Queensland is not high, Local Governments and Queensland Government authorities could consider taking the following simple steps to mitigate earthquake risk.

Ensure the use of earthquake and wind loading provisions provided by relevant Australian Standards and the Queensland *Building Act*

We believe that wind loading standards and earthquake loading standards are highly effective mitigation tools.

Enforce appropriate ground amplification factors for domestic buildings

An appropriate amplification factor for low rise, new domestic buildings on Quaternary sediments in South-East Queensland is 2.3 (.Site Class C). An appropriate amplification factor for low rise, new domestic buildings on Tertiary sediments in South-East Queensland is 1.3 (.Site Class D).

In Table 2.4 (b) of *AS1170.4-1993*, the Site Factor for residential buildings is either unity ('normal soil') or 2.0 ('soft soil'). However, *AS1170.4-1993*, p.24, stated that (our bold emphasis):

> *'6. In locations **where the soil profiles are not known, a site factor (S) equal to** 1.5 should be used for general structures and **1.0 for domestic structures**.'*

A site factor of 1.0 is <u>not</u> appropriate for domestic structures in sediment areas in South-East Queensland.

As a guide, the geology map for South-East Queensland could be used to classify site conditions for development (see Chapter 2 for a geology map and see Table 8. 3 for the site classifications). In the simplest case, all areas of South-East Queensland underlain by Quaternary sediments could be considered Site Class C, and all areas underlain by Tertiary geological units could be considered Site Class D. All other areas of South-East Queensland could be considered Site Class B (rock).

The amplification factors in *ANZS DR 00902* (Standards Australia, 2001) are more appropriate than those in *AS1170.4-1993*, and their 'Shallow soil' sites have approximately the same amplification factors as those suggested here for Site Class C. *ANZS DR 00902* describes an amplification factor of 2.25 at a period of T = 0.1 seconds for 'Shallow Soil sites' with natural period less than T = 0.6 seconds.

<u>Adopt the South-East Queensland maps of natural period as an aid to urban planning</u>

South-East Queensland Local governments could adopt the South-East Queensland maps of natural period of ground vibration as an aid to engineering design of new structures. These maps were developed on an LGA basis and were included in the individual reports to eight Local Governments. The natural periods of vibration, of the sediments and the weathered profile of the Tertiary geological units, are described by these maps. Designers of new buildings with important functions could take these conditions into account in designing buildings to be non-resonant with their foundations.

LGAs could, for example, refer structural engineers to the maps of natural period in relation to building applications for General Structures of Importance II or III (*AS1170.4-1993*, Appendix A1).

Limitations and Uncertainty

We have made an earthquake risk assessment based on building damage and the study reflects the state of our methodology at present. Other aspects of risk assessment not covered in this study include assessments of:

- direct dollar losses such as the cost of repairing damage and the cost of business interruptions;
- direct social losses such as the cost of recovery from physical injuries and trauma, and the costs of relocating displaced persons;
- indirect economic and social losses which impact on the external community through damage in South-East Queensland; and
- the impact of secondary hazards including fire, hazardous material spills and debris.

Uncertainties and limitations in our results include the following:

<u>Uncertainties in estimates of regional earthquake hazard</u>

There is a fundamental problem with estimating hazard for ARIs longer than the complete historic record. The specific sources contributing to uncertainties in estimates of the hazard are many. Probably the most important are uncertainties in:

- the attenuation of ground shaking from earthquakes in the region - that is, the way in which the strength of earthquake shaking decays with distance from the earthquake. Uncertainty is present due to our incomplete knowledge of the attenuation process, and also due to the intrinsic variability of localised ground shaking;
- the definition of the Tasman Sea Margin earthquake source zone; and
- the level of earthquake activity within this source zone.

These uncertainties are manifest in the differences of the hazard estimates made by various authors.

Uncertainties and limitations in estimates of urban earthquake site amplification:

- The use of Eastern United States site classes and amplification factors for South-East Queensland is bound to be inappropriate to some extent. The degree of appropriateness or inappropriateness is not fully known, and locally developed site classes and amplification factors need to be developed to remove this source of uncertainty.
- The urban local site conditions were estimated using a medium-level process which included the use of limited geotechnical and geophysical data but not computer waveform modelling or the evaluation of local recordings of earthquakes. Locally recorded earthquake strong motion data were not available. The improved definition of site classes and their amplification factors using these techniques is an important step that would add considerable confidence to the damage assessments, and would also significantly reduce the uncertainties in the estimates of damage.
- Site class is assigned by CCD. The site classification does not have the resolution to be applied at an individual parcel level. Earthquake site classes were prepared for a very large South-East Queensland area with limited data. The geological mapping has largely the resolution of the regional map product from the Queensland Department of Natural Resources and Mines, and would contain inaccuracies at local levels. These data frequently do not contain a breakdown of Quaternary geology types, essential for good quality site class maps. For example, there may be no distinction made between sands and clays, or Holocene, Quaternary and in some cases Tertiary units. The available geotechnical data, although mostly of very good quality, were very localised and clustered, or located along transport routes. The microtremor data used to prepare the natural period maps were generally of good quality and cover extensive urbanised, sedimentary areas.

Uncertainties in the assessment of building performance:

- Estimates of the performance of different construction types of Australian residential buildings in earthquakes have benefited greatly from the input of a panel of expert structural engineers (Stehle and others, in preparation). However, the performance of Australian building construction types in earthquakes needs considerable further investigation. This work has national significance.
- In the methodology we used, buildings are aggregated into categories, based on construction type and usage, and the seismic performance of these categories is described probabilistically. Associated uncertainties in building performance are taken into account in the building damage state calculations.
- We have estimated the composition of the South-East Queensland residential building inventory (Table 8. 4) and errors in our assumptions will perturb the estimates of building damage. The estimates of damage are particularly sensitive to the numbers of unreinforced masonry and concrete frame buildings with unreinforced masonry infill panels in South-East Queensland.
- There are uncertainties in how building condition will affect seismic performance. We have not taken into account building condition in our modelling. Building condition could play a major role in damage scenarios. This effect was indicated by heavy nonstructural damage to buildings in Newcastle from shaking in the 1989 earthquake (Institution of Engineers, Australia, 1990). The marine climate of Newcastle was a contributing factor to the poor condition of many of its buildings. However, South-East Queensland does not have anywhere

near the percentage of unreinforced masonry or brick veneer buildings that Newcastle does, so this may not be as important a factor for South-East Queensland as it was for Newcastle.

Community Awareness

The broad community probably has little perception that earthquakes pose a significant threat to South-East Queensland. This is understandable because the rate of earthquake activity is low and the historical impact of earthquakes in southern Queensland is low. Moderate to strong earthquakes such as the 1918 ‘Bundaberg’ earthquake and the 1935 Gayndah earthquake are not known to most residents.

The risk from earthquakes in South-East Queensland is largely from low probability, high consequence events, and these events are unlikely to occur in any individual’s lifetime. Therefore these events may hold little fear for individuals, even if they are aware of the risks involved.

However, strong earthquakes have the potential to impact across large communities. Should they occur, losses can be very high when aggregated across the community. Effective management of this type of risk may be based appropriately at community or corporate levels, and there may be little that individuals should do about this type of risk beyond ensuring they have adequate insurance.

At the community level or beyond, mitigation measures such as building and planning codes, protection of essential facilities and services, and insurance probably rate highly in terms of effectively and economically treating risk.

Further Information

More detailed information on the levels of exposure of individual neighborhoods or properties to the various earthquake risks outlined here should be referred to the respective local government council.

CHAPTER 9: FLOOD RISKS

Miriam Middelmann, Bruce Harper and Rob Lacey

The Flood Threat

A simple definition of flooding is *water where it is not wanted* (Chapman, 1994). Four different mechanisms can cause flooding including heavy rainfall, storm surge, tsunami and dam failure (ARMCANZ, 2000). In this chapter we discuss flood risk associated with heavy rainfall, and briefly, flood risk associated with dam failure.

Riverine flooding occurs when the amount of water reaching the watercourse or stream network exceeds the amount of water which can be contained by the network and subsequently water overflows out onto the floodplain. Several factors influence whether or not a flood occurs, including:

- the total amount of rainfall falling over the catchment;
- the geographic spread and concentration of rainfall over the catchment, i.e. spatial variation;
- rainfall intensity, duration and temporal variation;
- antecedent catchment and weather conditions;
- ground cover;
- the capacity of the watercourse or stream network to carry the runoff; and,
- tidal influence.

This complex set of factors influences whether or not flooding occurs in a catchment, consequently it is difficult to define the causes or the impacts of an 'average' flood. Put simply, no two floods in the same catchment are ever identical. To overcome this problem, floodplain managers and hydraulic engineers rely on a series of design flood events and historical rainfall and flood level information. It is upon these that this report is based.

Localised and/or flash flooding typically occurs when intense rainfall falls over a small sub-catchment which responds to that rainfall in six hours or less. In urban or rural areas where drainage is poor, the risk of localised flooding is high under such circumstances. Widespread flooding, by contrast, occurs following rainfall of high intensity or long duration over the whole, or a large proportion of a catchment. Runoff is typically less in areas where the percentage of vegetation is high, as vegetated areas allow high infiltration until the earth is saturated. Where the ground is pre-saturated, such as following a long wet period, medium rainfall events may then cause flooding as runoff begins almost immediately. Flood levels in urban areas quickly rise where the percentage of impermeable surfaces in the local catchment, such as buildings, roads and car parks, is high. On sloping concrete and bitumen surfaces, for example, runoff is almost immediate.

Average recurrence interval (ARI) or annual exceedance probability (AEP) are statistical benchmarks used for flood comparison. ARI is the average, or expected, value of the number of years between exceedances of flood events of a given magnitude (gauge height or discharge volume). AEP is the probability of a flood event of a given magnitude being equalled or exceeded in any one year. The Probable Maximum Flood (PMF) is the limiting-value flood which can reasonably be expected to occur. It is usually perceived as having an ARI of between 10 000 and 10 000 000 years (Nathan & Weinmann 1999, Laurenson 1994 in ARMCANZ, 2000).

Flood levels are typically related to the Australian Height Datum (AHD), which is approximately Mean Sea Level (MSL). Accordingly, the 'gauge height' of floods varies depending on the location of the gauge and its relative elevation in the floodplain. The depth of any flood is then calculated as the difference between the flood water level elevation and the local ground elevation relative to the AHD.

Cost of flooding

Major flooding causing inundation of large areas, isolating towns and disrupting road and rail links occurs on average about every ten years somewhere in the South-East Queensland region. Smith (1998) estimated that around 35% of the buildings at risk from flooding in Australia are located in Queensland, with 21% being in the South-East Queensland region. The large numbers of buildings at risk of flooding in South-East Queensland is exacerbated by the absence of State-wide floodplain management regulations which might typically aim to preclude residential development in areas subject to flooding up to the 1% AEP (100 year ARI) level. In Queensland such regulations are left to individual Local Government Authorities (LGAs) to establish.

The average economic cost of **urban** flooding (stormwater and mainstream flooding[1]) in Australia is estimated to be in the order of $200 million per year at 1998 dollar terms (ARMCANZ 2000). The estimate is however based on the DPIE (1992) study and significantly underestimate flood damage. The more recent study by Smith (1998) estimated annual average **urban** flood damage in Queensland alone at about $100 million.

Economic loss due to flooding varies widely from year to year and is dependent on a number of factors, for example, flood severity and location. During the 1974 Brisbane floods, for example, the flood damage in 1998 values was $700 million, however, damage was much lower in both previous and subsequent years (ARMCANZ, 2000).

In recent years good work has been undertaken by a number of local governments to minimise flood risk through stringent development application guidelines, however, flooding remains a large problem for many areas across the region.

The Flood Phenomenon

Heavy rainfall capable of causing flooding (flash and non-flash) in South-East Queensland can arise from a number of different meteorological mechanisms, as described below:

Severe Thunderstorms
- isolated storms typically cause flash flooding in relatively small catchments
- organised systems may extend to affect more than one catchment

Tropical Cyclones
- capable of causing widespread flooding across the South-East region
- typically heaviest rainfall is associated with coast-crossing and decaying phases
- may interact with and draw the monsoon trough southwards creating an extensive rainfall event over the whole state (e.g. BoM, 1974 - refer to Figure 9.1)

East Coast Lows
- capable of causing widespread flooding across the South-East region (e.g. BoM, 1996)
- more common in autumn and early winter
- establish large scale moist onshore flow conditions

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[1] The dollar loss to buildings affected by mainstream flooding is significantly larger though the number of properties affected are less than for stormwater flooding.

- heavy rainfall triggered by upper level coupling creating large scale lifting of the onshore flow

Other

- fronts and troughs
- low pressure systems
- coastal convergence
- high pressure intensification in the Tasman Sea, combined with upper trough interaction.

All of these events are also influenced by the regional topography which provides significant orographic lift to assist the creation of favourable conditions for heavy rainfall. The detailed characteristics of these meteorological situations is discussed in Chapters 4 (cyclones), 5 (east coast lows) and 6 (thunderstorms).

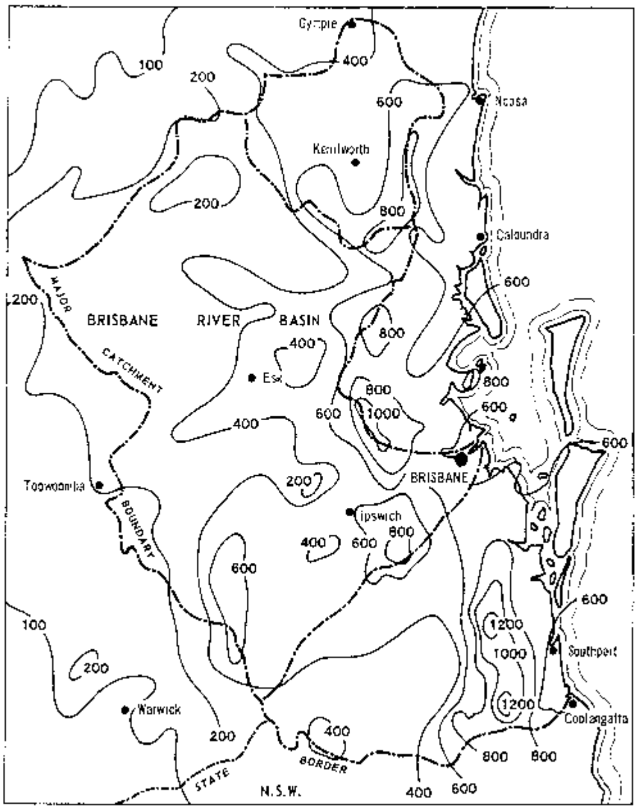

Figure 9. 1 Rainfall isohyets (mm) over the five day period of the January 1974 floods

Major river systems in South-East Queensland

South-East Queensland is crossed by a number of major river systems and numerous creeks. Typically the headwaters rise in the Great Dividing Range to the west and the rivers traverse the coastal plains in a generally eastward direction, emptying into Moreton Bay, The Broadwater or the Pacific Ocean. The rivers are fed by an average annual rainfall which varies between 800 mm and 1500 mm across the region and has helped create a particularly fertile region which, prior to European settlement, supported a large number of aboriginal communities. From the earliest days of European settlement, many rivers provided not only abundant fresh water supplies and fertile adjacent lands but also served as important transportation corridors. In the past 100 years the extensive urban development of the region has impinged onto many areas of the floodplains and several river courses have been altered through the creation of water storages in their upper reaches and dredging or reclamation works in their lower reaches.

An overview of the major river catchments in South-East Queensland was shown in Figure 2.3 and in more detail in Figures 9.2 – 9.7. The northern coastal region is drained by the Caboolture River, Burpengary Creek, North and South Pine Rivers and the northern creeks of Brisbane which flow to Moreton Bay. The Brisbane-Bremer River system is the major catchment in the region and includes a number of urban creeks including Oxley and Bulimba Creeks on the southern side and Moggill and Enoggera Creeks in the north. The southern coastal region is traversed by the Logan River and its major tributary, the Albert River, which empties into the southern extent of Moreton Bay, whilst the Pimpama, Coomera and Nerang River systems empty into The Broadwater. An extensive network of rainfall and river height reporting stations cross the region that provide data on flood events used for both operational warnings and investigations into the probability of occurrence of extreme floods.

Caboolture River and Burpengary Creek System

The Caboolture River is situated about 40 km north of Brisbane and has a total catchment area of 370 square kilometres (CSC 1994a). It rises in the D'Aguilar Ranges and flows in an easterly direction towards the coast, passing through Caboolture and entering Deception Bay (the northern part of Moreton Bay) near the township of Beachmere. Its major tributaries include Wararba, Sheep Station, King John and Lagoon Creeks. The topography is steep in the upper portions but flattens out progressively towards the coast, forming a mature floodplain in the middle and lower reaches. Downstream of Caboolture, the floodplain is very flat and consists of scattered swamps and extensive areas that are highly floodprone. Other than the townships of Caboolture (12 km from the mouth) and Morayfield, Beachmere is the only other significant urban area on the lower floodplain, which is otherwise characterised by rural industry, pastures and pine forest plantations. Figure 9.2 indicates the extent of the Caboolture River catchment.

Burpengary Creek, the creek system immediately to the south of the Caboolture River catchment, also flows in a general easterly direction to the northern end of Deception Bay, just south of the Caboolture River mouth (Figure 9.2). The topography is generally flat and, other than the township of Burpengary which has some flood-affected residential properties, the land use is largely rural industry.

Pine River System

The Pine River catchment drains in a generally easterly direction from the relatively steep D'Aguilar Ranges towards the flat coastal plains of Bramble Bay between Sandgate and Redcliffe. North Pine River and South Pine River join some 7 km upstream from the mouth, where the combined system forms an extensive coastal estuary. The tidal influence extends upstream in the North Pine to Young's Crossing, and in the South Pine to the Bald Hills Railway Bridge. The major river catchments of Pine Rivers are shown in Figure 9.3.

The North Pine rises near Mt Pleasant towards the northwest corner of the catchment while its major tributary Laceys Creek flows from the south. Approximately 18% of the North Pine catchment consists of State forest, 1% is national park and the remainder is rural. The North Pine Dam was constructed 5 km upstream of Petrie in 1976 and forms the 2000 hectare Lake Samsonvale. The dam provides water supply to Brisbane, Pine Rivers and Redcliffe. Just downstream, Sideling Creek was also dammed for water supply purposes in 1959 and forms the smaller Lake Kurwongbah. The main urban areas of the North Pine catchment are located downstream of the dam and include Petrie, Lawnton and Strathpine.

The South Pine River rises in the D'Aguilar Ranges to the south and flows in an easterly and northeasterly direction towards Bramble Bay. Cedar Creek is the major tributary which joins the river 4 km upstream of Cash's Crossing. At this point the river forms an extensive floodplain area which extends through the urban areas of Albany Creek, Strathpine and Bald Hills. Grazing and rural residential are the major land uses in the catchment.

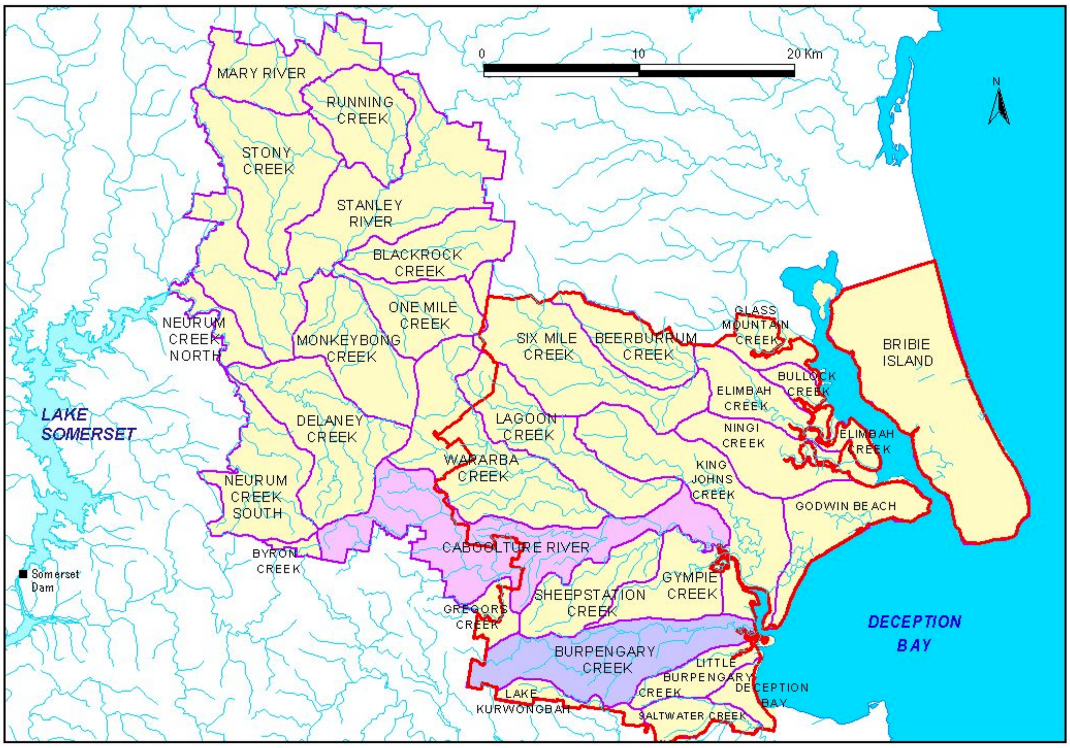

Figure 9. 2 Caboolture River catchment

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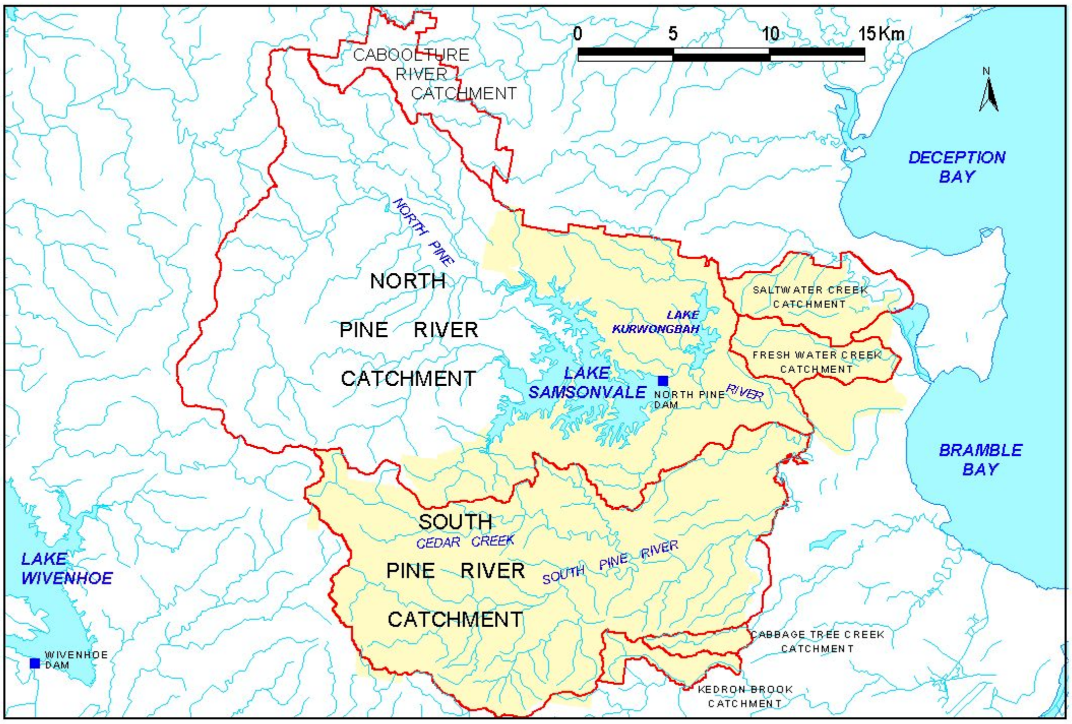

Figure 9. 3 Pine Rivers catchment

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Brisbane and Bremer River System

The Brisbane River catchment (Figure 9.4) is the largest in the region and covers an area of 13 570 square kilometres (BCC 1998). The catchment is bounded to the west by the Great Dividing Range and by a number of smaller coastal ranges to the east and north. Most of the catchment comprises of forest and grazing land, with the exception of the Brisbane – Ipswich metropolitan regions and numerous small rural townships. The headwaters are at the northerly extent of the catchment bounded by the Brisbane Range. The overall length of the main stream is approximately 300 km.

The major tributaries of the Brisbane River are best summarised in terms of its principal sub-catchments, which include:

Upper Brisbane

This comprises Cooyar and Emu Creeks which have their headwaters in the Great Dividing Range to the northwest. This area has the lower average annual rainfall.

Somerset

This is formed by the Stanley River, which rises in the foothills of the Conondale and D'Aguilar Ranges to the northeast. Somerset Dam, a major water supply and flood mitigation dam, is located just upstream of the junction of the Stanley and Brisbane Rivers.

Wivenhoe

Consists of Cressbrook Creek, bounded by the Great Dividing Range to the west. This catchment is dominated by Wivenhoe Dam, the largest dam in the South-East, which when filled extends upstream to Somerset Dam.

Lockyer

The Lockyer Creek is bounded by the Great Dividing Range to the south and west and represents the largest of the sub-catchments of the Brisbane River. Other major tributaries include Laidley and Tenthill Creeks. The lower floodplains of the Lockyer Valley support intensive agriculture, including vegetables and small crops.

Bremer

The Bremer sub-catchment occupies 1500 square kilometres of the southernmost corner of the Brisbane River catchment (IRIT 2000) and is bounded by the Macpherson Ranges to the south. The Bremer River flows through the City of Ipswich and joins the Brisbane River near Moggill. Warrill Creek, the major tributary, accounts for almost two-thirds of the catchment area and joins the Bremer approximately ten kilometres upstream of Ipswich. Heavy rainfall in the Bremer-Warrill headwaters can cause major flooding of Ipswich as well as agricultural and rural areas throughout the catchment. Localised flooding in the Ipswich area can also be caused by the Bundamba and Woogaroo Creeks. During heavy rainfall, these small creeks rise very quickly and can cause significant flooding in urban areas. Flooding in the Ipswich area can also occur due to backwater flooding from the Brisbane River when it is in major flood. Tidal effects from Moreton Bay are still felt at Ipswich, some 80 km from the mouth of the Brisbane River.

Lower Brisbane

This covers the catchment from the confluence with the Bremer, through to the river's mouth into Moreton Bay. Much of this is within the metropolitan regions of the City of Brisbane. Flooding in the Brisbane City area can also be caused by local tributaries including Oxley and Bulimba Creeks on the southside, and Moggill and Enoggera Creeks in the western and northern suburbs. During intense rainfalls, the suburban creeks rise very quickly and can cause significant flooding of streets and houses.

Major Brisbane Creeks

Brisbane City is traversed by many creeks (Figure 9.5), some of which cause local flash flooding problems. Approximately six to twelve hours of rain in excess of 100 mm on an already wet catchment is typically needed to cause significant flooding. Some of the larger creeks are also subject to backwater effects from the Brisbane River.

The following creeks flow through the northern suburbs of Brisbane into Moreton Bay:

Kedron Brook

The headwaters of Kedron Brook are in the Ferny Hills area but it is also fed from Cedar Creek which rises in the Upper Kedron area near Brisbane Forest Park. The creek flows through Keperra, Stafford, Enoggera, Grange and Toombul before entering Shultz Canal adjacent to the airport and flowing into Moreton Bay at Nudgee.

Cabbage Tree Creek

This small creek has its headwaters near Arana Hills and flows eastwards through Bridgeman Downs, Carseldine and Zillmere, entering Moreton Bay near Shorncliffe. Little Cabbage Tree Creek rises in West Chermside and flows through Aspley, joining the main stream at Carseldine.

Downfall – Nundah Creek

This small creek rises near McDowall and flows through Chermside and Virginia. It then becomes Nundah Creek at Zillman Waterholes and passes through the Boondall Wetlands to enter Moreton Bay at Shorncliffe, joining with Cabbage Tree Creek.

The following creeks flow into the Brisbane River and are usually subject to backwater effects when the Brisbane River is in flood:

Enoggera Creek

The headwaters of Enoggera Creek are in the D'Aguilar Ranges near Mt Nebo. It flows through Brisbane Forest Park into the Enoggera Reservoir, then via The Gap, Bardon and Ashgrove. It is joined by Ithaca Creek at Kelvin Grove, which rises near Mt Cootha and passes through Bardon and Ashgrove. In the lower reaches Enoggera Creek becomes Breakfast Creek and continues on through Herston to enter the Brisbane River at Newstead.

Moggill Creek

The headwaters of Moggill Creek are on the southern side of Mt Cootha. The creek flows through Brookfield and Kenmore and enters the Brisbane River just upstream of Jindalee Bridge.

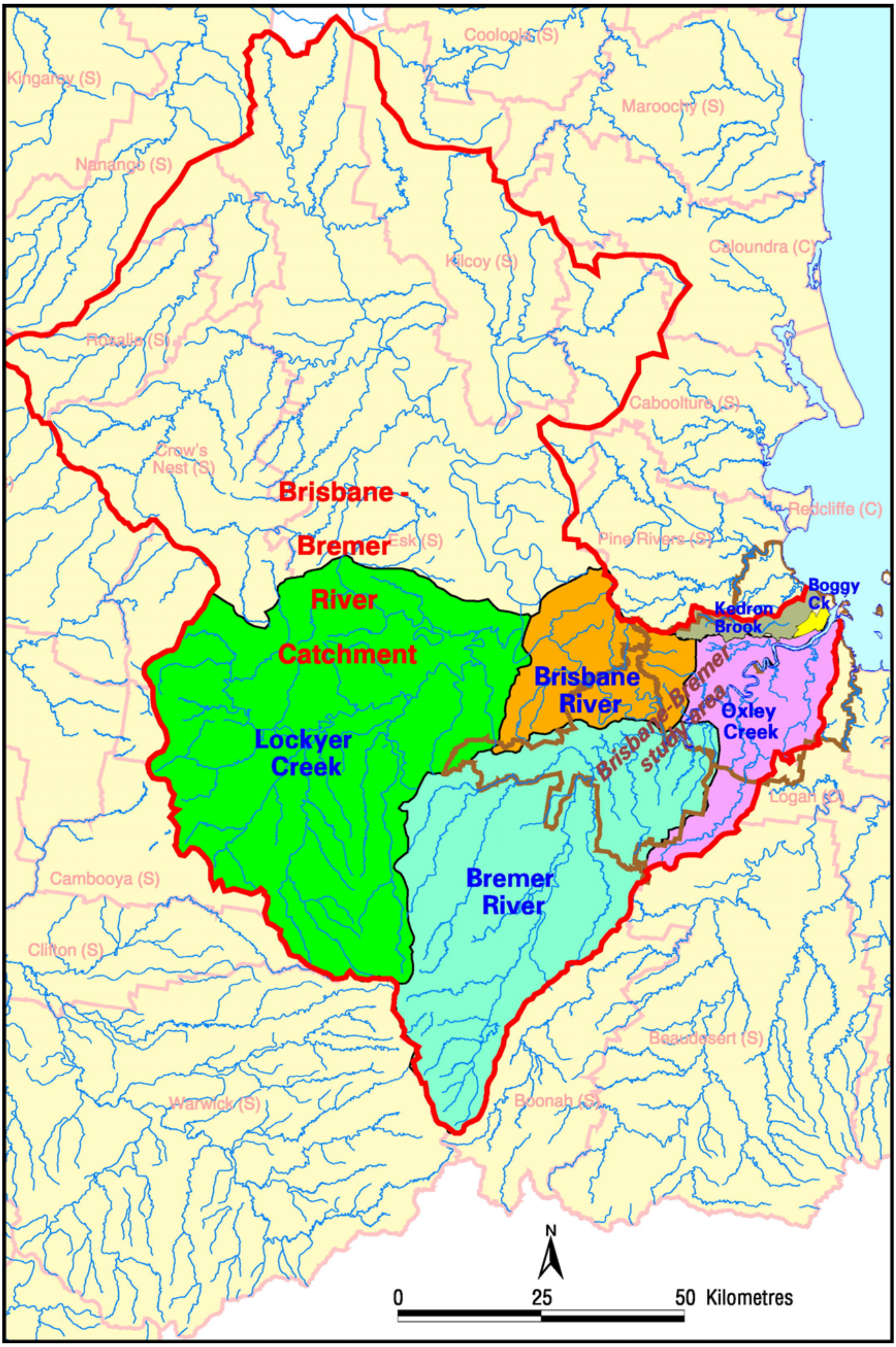

Figure 9.4: Brisbane-Bremer River catchment

Click here for High Resolution Image

Figure 9.5: Brisbane major creek catchments

Click here for High Resolution Image

Bulimba Creek

The headwaters of Bulimba Creek are in the Eight Mile Plains area. It flows through the suburbs of Wishart and Carindale before entering the Brisbane River near Hemmant.

Oxley Creek

Oxley Creek is the largest of the metropolitan creeks and has a relatively long flood concentration time. It rises in the area south of Greenbank Military Training Area and flows through the suburbs of Forestdale, Acacia Ridge and Rocklea. The main flooding problems are in the lower reaches around Rocklea and Corinda.

Logan - Albert River System

The Logan-Albert River system has a total catchment area of 3875 square kilometres and lies in the southeast corner of Queensland. The catchment extends from the McPherson Ranges in the south on the Queensland-NSW border, north to the Logan City - Beenleigh area. The major tributaries are the Albert River and Teviot Brook. Smaller tributaries include Running, Christmas, Burnett and Canungra Creeks in the headwaters. Major flooding is experienced in both rural and urban areas of the catchment. Scrubby and Slacks Creeks in the lower reaches of the Logan River can be subject to flash flooding as well as backwater flooding during major river flood events. The Logan-Albert River system is shown in Figure 9.6.

Pimpama, Coomera, Nerang, Tallebudgera and Currumbin catchments

The Pimpama River catchment (Figure 9.7) is located to the south of the Logan River and has an area of about 130 square kilometres, with about 60% of the area to the east of the Pacific Highway (GCCC 1999a). West of the highway the catchment is bounded by the Albert River catchment. The catchment is relatively undeveloped.

The Coomera River catchment is located immediately south of the Pimpama River (refer to Figure 9.7). It rises in the McPherson Ranges, passing around Canungra, Coomera and Oxenford and entering the northern Broadwater through Hope Island (GCCC 2000). There are a number of major tributaries and the lower reaches of the river are tidal, dividing into several channels forming islands on the lower floodplain. The land use distribution varies from rural in the upper reaches to large scale resort and residential along the lower floodplain tributaries. These include The Anabranch and Saltwater Creek. Coombabah Creek is another tributary which flows northwards into the Coomera from Coombabah Lake, an area of ecological importance.

The Nerang River catchment is located in the southeast corner of Queensland and covers an area of 480 square kilometres (Figure 9.7). From its headwaters in the McPherson Ranges, the Nerang River flows in a northeasterly direction, through the Numinbah Valley, before entering Advancetown Lake created by the Hinze Dam where the Little Nerang River joins it. Downstream from the dam, it passes Nerang before turning eastwards to Benowa, Broadbeach Waters, Bundall and Surfers Paradise, entering the Pacific Ocean via The Broadwater and the Gold Coast Seaway. Mudgeeraba Creek drains a catchment of about 100 square kilometres extending south to Springbrook and enters the Nerang River only a few kilometres from its mouth. Mudgeeraba Creek is subject to flash flooding. Approximately two thirds of the catchment for the Nerang River is rural, mostly forested, open space with some grassland open space, such as golf courses and rural residential areas (GCCC 1997a & 1999b). The remainder of the catchment is urban, comprising residential, high density residential, commercial and industrial areas. The Nerang River floodplain system has an area of about 65 square kilometres, much of which has been subject to development over many years and now consists of an extensive network of tidal canal estates. The only remaining undeveloped region is the Merrimac/Carrara floodplain comprising about 22 square kilometres between the Nerang River in the north and Mudgeeraba Creek in the south. Depending on the flood situation, the Hinze Dam, which commands about 42% of the total catchment area, reduces the severity of downstream flooding of the Nerang system, although a recurrence of rainfalls similar to, or higher than, those in the 1974 record flood would still cause significant flooding.

In the southern Gold Coast area, Tallebudgera and Currumbin Creeks are adjacent catchments of 97 square kilometres and 63 square kilometres respectively. The headwaters are towards the southwest near Springbrook and flow essentially northeast to the sea. Both catchments are rural in the upper reaches but heavily developed in the lower reaches and floodplains with several lake/canal developments. Tallebudgera Creek is tidal for approximately 10 km upstream while Currumbin Creek is tidal downstream of a weir about 8 km from the mouth.

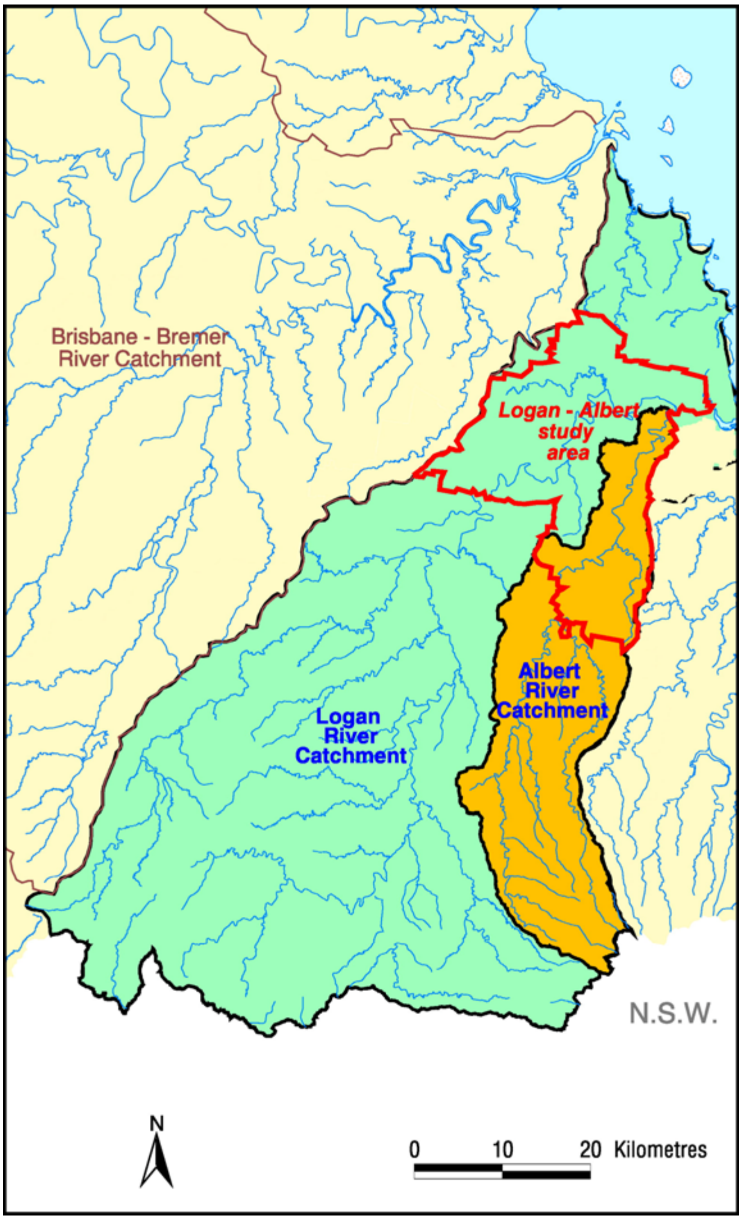

Figure 9.6: Logan-Albert River system

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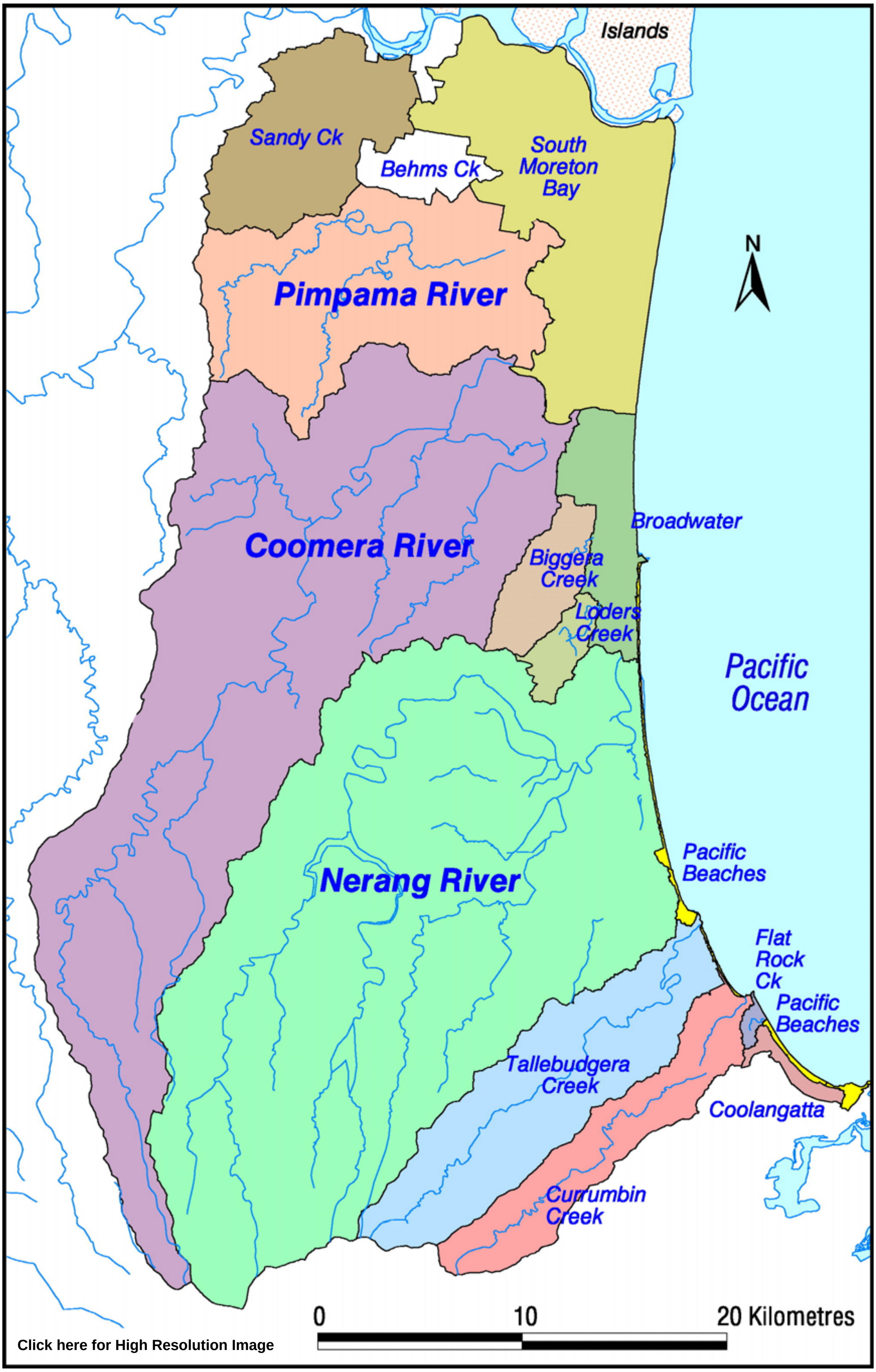


Figure 9.7: Pimpama, Coomera, Nerang, Tallebudgera and Currumbin catchments

Major Dams

There are 16 major dams and reservoirs throughout the South-East Queensland region which act either to provide water supply storage, irrigation, or to assist in flood mitigation. A summary of the dam characteristics are given in Table 9.1 and are derived from various sources (mainly R. Ash, 2000, personal communication, and DNR, 2000a). The effectiveness of their mitigation capacity is a function of the inflow rate to the reservoir and the regulatory controls (gates, valves etc) available, which varies significantly from dam to dam. Wivenhoe Dam (on the Brisbane River) is the principal flood mitigation control in the Brisbane River system, followed by Somerset Dam (located on the Stanley River immediately upstream of Wivenhoe). Jointly, these dams have a major impact on the hydrology of the system but their presence alone is not sufficient to prevent major flooding in some situations. Other than the Hinze Dam on the Nerang River, the remaining dams throughout the South-East region have, by comparison, only a minor flood mitigation capability and the majority have unregulated spillways.

Dam break is an emergency response issue which cuts across LGA boundaries and is the responsibility of the Department of Natural Resources (DNR) or the South-East Queensland Water Board (SEQWB).

A series of detailed operational plans are maintained by the dam operators that generally seek to optimise the design water supply level with regard to the expected inflow of flood waters. Controlled water releases are then made based on inflows and the flood mitigation capacity of the dam, but may also need to consider impacts on communities from other uncontrolled downstream tributaries.

Table 9. 1 Dams in South-East Queensland

Damsite	River/Creek	Type	Completion (year)	Full Supply Capacity (ML)	Crest Capacity (ML)
Wivenhoe	Brisbane	Rock fill	1985	1 150 000	2 930 000
Somerset	Stanley	Concrete gravity	1959	369 750	893 950
North Pine	North Pine	Earth and rock embankment	1976	200 000	295 000
Hinze	Nerang	Earth and rock embankment	1976 and 1989	164 969	310 190
Moogerah	Reynolds	Concrete arch	1961	83 700	139 000
Cressbrook	Cressbrook		1982	78 300	n/a
Maroon	Burnett	Earth and rock embankment	1973	37 500	86 400
Atkinson	Buaraba		1970	31 300	n/a
Perseverance	Perseverance		1965	30 300	n/a
Lake Manchester	Cabbage Tree		1916	25 700	n/a
Clarendon	Lockyer		1992	24 300	n/a
Lake Kurwongbah	Sideling		1958	15 400	n/a
Leslie Harrison	Tingalpa	Concrete		13 000	n/a
Little Nerang	Little Nerang		1961	8 400	n/a
Bill Gunn	Laidley			6 940	n/a
Enoggera	Enoggera		1866	4 500	n/a

The operation of all major dams is strictly controlled and is subject to regular detailed inspection and monitoring to ensure that the structural integrity of the dam is maintained at all times (SEQWB, 1998 a & b). The principal threat to any dam's integrity occurs when the inflow of floodwaters exceeds the combined storage and outflow available, and the dam is subjected to overtopping in an uncontrolled manner. In extreme situations, the priority of preventing overtopping will override the flood mitigation objectives at regulated dams and result in large controlled releases of flood waters. In these cases, procedures are in place to alert the relevant emergency authorities to ensure the public are adequately warned; flood-prone low level crossings are closed and if necessary, evacuations are undertaken. Normally, these impacts are relatively minor and there is more than adequate time available to issue warnings and make special arrangements. However, due to the need for extreme caution, not all of the ultimate capacity of the dams will normally be available for flood mitigation purposes.

Somerset Dam is a concrete gravity structure and is presently rated to withstand overtopping at the estimated PMF. Wivenhoe Dam is a central core rockfill dam, which is not resistant to overtopping, and operational procedures are designed to ensure that water releases will be scheduled to enable the dam to pass the PMF without overtopping. If necessary, Somerset Dam will be allowed to be overtopped to assist in preserving the structural integrity of Wivenhoe Dam (SEQWB 1998b). North Pine dam has similar structural characteristics to Wivenhoe Dam but is principally designed for water supply needs.

If overtopping or unexpected structural failure was to occur (e.g. extreme earthquake and/or undetected faults) then there exists a possibility that a dam will fail. The probability of this occurring is expected to be generally lower than the probability of a PMF occurring. The exact manner of the failure may vary widely and the consequences of the failure downstream will depend upon the floodplain characteristics and whether or not a flood is currently in progress.

Contrary to the popular perception, flood waves from dam breaks travel relatively slowly - at only a few kilometres per hour - except in close proximity to the dam. In particularly steep catchments, such as below the Hinze Dam, the flood wave celerity may be quite high attenuating down to Nerang township, making it unlikely that residents would have plenty of warning in the event of dam failure. Emergency Action Plans are available for all the major damsites which document procedures to be followed in the unlikely event of a severely overtopped dam or a dam failure (e.g. DNR, 2000 b; SEQWB, 1993 a, b, c & d). These plans also identify critical hazard locations in the region and are used by emergency services under the coordination of State and Local Government officers.

Studies have been undertaken for a number of dams in South-East Queensland which estimate the extent of possible downstream impact of a dam break flood wave and include the predicted depth of inundation and the time of arrival, which can be several hours after the dambreak. Table 9.2 summarises the estimated extent of impacts of dam break for the major South-East Queensland dams. For example, Wivenhoe Dam is predicted to be able to fully contain an unexpected breach of Somerset Dam under non-flood conditions. Under extreme flood conditions, it becomes more vulnerable to overtopping if a Somerset dambreak occurs and the operational procedures are designed to minimise that possibility. North Pine Dam is the only major dam immediately upstream of an urban area. Hinze Dam on the Nerang River is owned by Gold Coast City Council and is currently being reassessed for dam break impacts. Under the *Queensland Water Act 2000*, all authorities are now on notice and where dams fall into specified criteria, than a dam failure impact assessment must be undertaken and the dam licensed.

Table 9. 2 Approximate extent of the estimated impact of dambreaks

Damsite	Downstream Impacts		Furthest Locality Affected
	Km	hr	
Wivenhoe	150	30 - 36	Brisbane Port
Somerset	75	10	Wivenhoe Dam
North Pine	10	0 - 3	Petrie
Moogerah	35	10 - 20	Harrisville
Maroon	60	15 - 19	Beaudesert

The South-East Queensland flood experience

Floods are classified by the Bureau of Meteorology (BoM, 1999b) depending on the local flood gauge height and the resulting level of local community impact as follows:

1. **Minor flooding:** *This causes inconvenience such as closing of minor roads and the submergence of low level bridge.*

2. **Moderate flooding:** *This causes the inundation of low lying areas requiring the removal of stock and/or the evacuation of some houses. Main traffic bridges may be closed by floodwaters.*

3. **Major flooding:** *This causes inundation of large areas, isolating towns and cities. Major disruptions occur to road and rail links. Evacuation of many houses and business premises may be required. In rural areas widespread flooding of farmland is likely.*

This classification is a measure of a particular community's vulnerability to flooding and does not necessarily mean that a major flood has a low probability of occurrence (see the later section of this chapter, on flood prediction). Only those rivers which are a part of the Bureau of Meteorology warning system are subject to this standard classification. Many rivers which represent relatively lower flooding hazards are separately monitored by the respective LGAs.

Figure 9.8 summarises the historical record of highest annual floods for a number of long term gauge sites on the major river systems in the southeast region, derived from Bureau of Meteorology and DNRs records. As Figure 9.8 shows, the record for Brisbane (159 yr) is the longest in the region, followed by Ipswich (107 yr), the Nerang (80 yr) and the Logan (53 yr). The records are, however, incomplete, with many sites having less than 30 years of recorded levels.

In the last century, the Australia Day floods of 1974 were the worst period of flooding across the South-East Queensland region, although the 1931 flood was probably more severe locally in the Caboolture and Pine Rivers catchments. The floods of the mid to late 1800s recorded higher levels than the 1974 flood, however, a lower population, fewer buildings and less infrastructure in the region in the 1800s suggest that damage losses were much smaller despite a sparsity of information on the early events. Plates 9.1,9.2 depict flooding Melbourne St., South Brisbane in February 1893 and January 1974. The following discussion in provides some further insight into historical flooding episodes in the southeast.

(a) Caboolture River and Burpengary Creek

Caboolture has always experienced nuisance flooding affecting properties along the Caboolture River, King John Creek and Lagoon Creek, as well as closing local roads (CSC

1994a) (Plate 9.3). Burpengary Creek at Burpengary has historically suffered reasonably consistent low-level flooding problems in areas around Dale St, Henderson Rd, Springfield Dr and Mathew Crescent (Plate 9.4). Table 9.3 summarises selected flood levels in the Caboolture region.

The 1931 flood event (Plates 9.5-6) was probably the most severe in the Caboolture catchment, followed by the 1972 flooding. The floods of December 1991 and January 1974 were also severe floods. A further flood in 1951 is remembered by some local residents. Beachmere is also subject to storm surge flooding.

In addition to nuisance flooding affecting buildings, flooding has caused agricultural losses and disrupted transport and communication links in the region as indicated by *The Brisbane Courier* (7 February, 1931).

> *Great losses in stock and farm produce have occurred in various parts of the district. The train services have again been restored. A rail motor arrived at 1.30 p.m. from Brisbane with passengers, mails and papers. The Gympie mail train departed for its destination shortly after the arrival of the rail motor.*

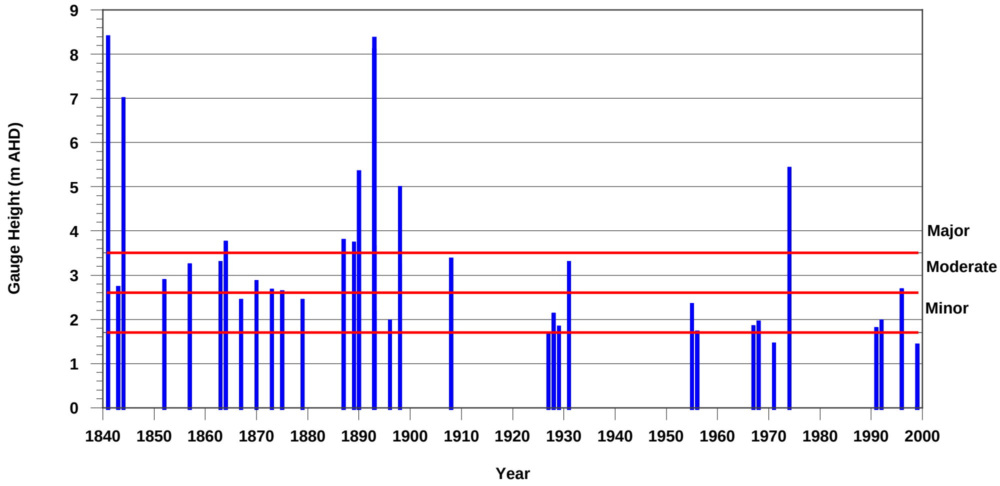
Table 9. 3 Selected flood levels in the Caboolture region (from CSC 1994a)

River	Height Station (m AHD)	Feb 1931	Dec 1970	Feb 1972	Jan 1974	Apr 1988	Apr 1989	Dec 1991	Mar 1992	May 1996	Feb 1999
Burpengary Ck	Rowley Rd		13.10	13.75	13.36	12.95	13.28	13.65		13.40	13.61
	Morayfield Rd			7.54		6.56	6.97	6.90			6.95
Caboolture	Litherland's X-ing			21.60			20.05	21.47			20.02
	Caboolture River s/g			18.71			17.42	18.89			
	Morayfield Rd		7.39	8.62	8.14	7.39	7.92	8.03	7.16	7.67	7.42
	Dux St		6.50	7.88	7.42		6.97	6.92		6.60	6.56
	Beachmere Rd/Rv	3.40	2.80	3.30	3.17		2.81	2.66		2.59	
King John Ck	McConachy Rd		15.21	14.91		15.40	15.25	14.85			14.78
	Bribe Is Rd		3.98	4.49?			3.65	3.71		3.86	4.26
	Beachmere Rd		2.07	2.33			1.93	1.18			
Lagoon Ck	Bruce Highway u/s		6.04	6.98		6.80	7.08		6.65		6.82
Sheepstation Ck	Morayfield Rd		6.00	7.72			6.77				6.62

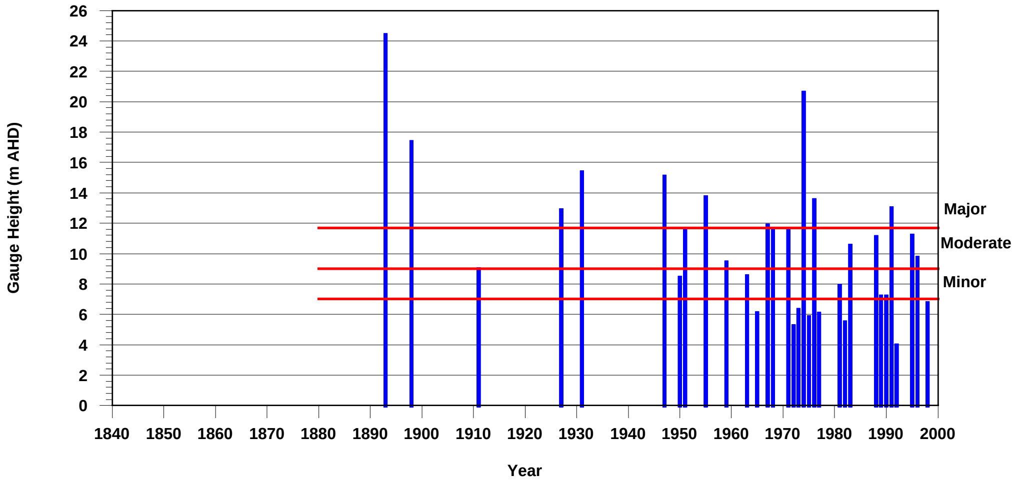
(b) Pine River System

Anecdotal evidence suggests that the flood of February 1931 was the largest known flood also in the Pine River system, followed by the flood of February 1893. Unlike the 1931 flood, *The Brisbane Courier* (10 February, 1893) indicates that flood damage in 1893 was confined to the agricultural district of Pine though the bridge over Cash's Crossing was completely washed away. Of the floods recorded, only those of January 1974 and 1972 were smaller than the 1931 and 1893 floods. In the last two decades, the floods of December 1991 (Plate 9.7) and 1989 have been the largest. The relative magnitude of each flood however varies from creek catchment to catchment and from river reach to reach. Table 9.4 shows selected flood levels in the Pine Rivers region.

(a) Brisbane River at Brisbane City



(b) Bremer River at Ipswich



(c) Logan River at Waterford

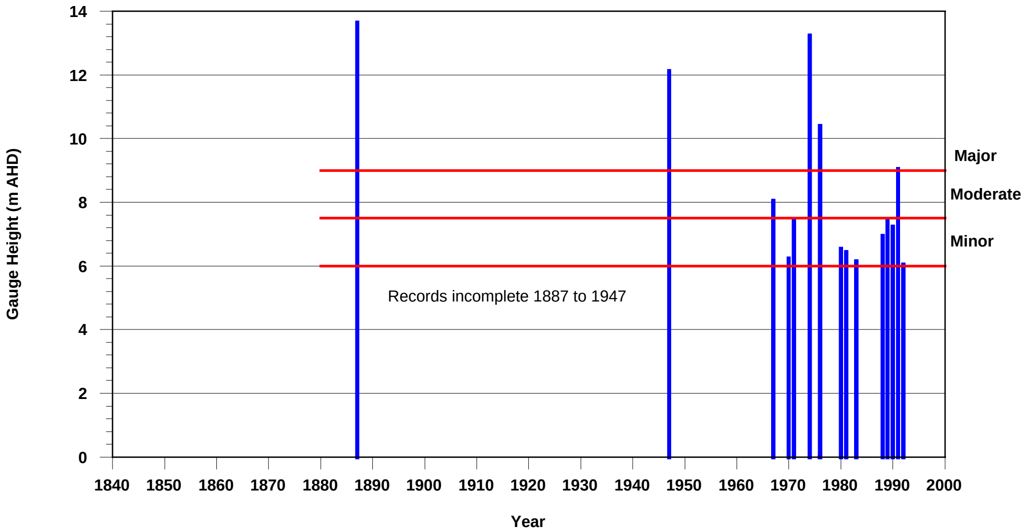
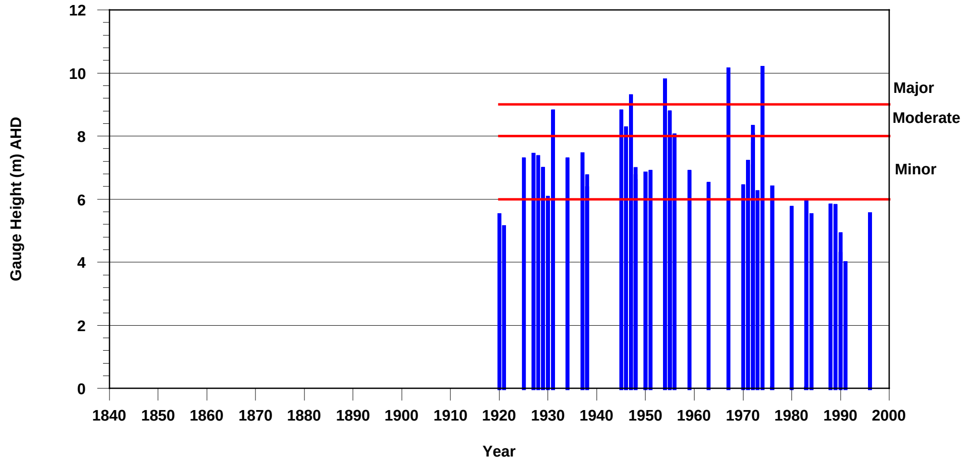
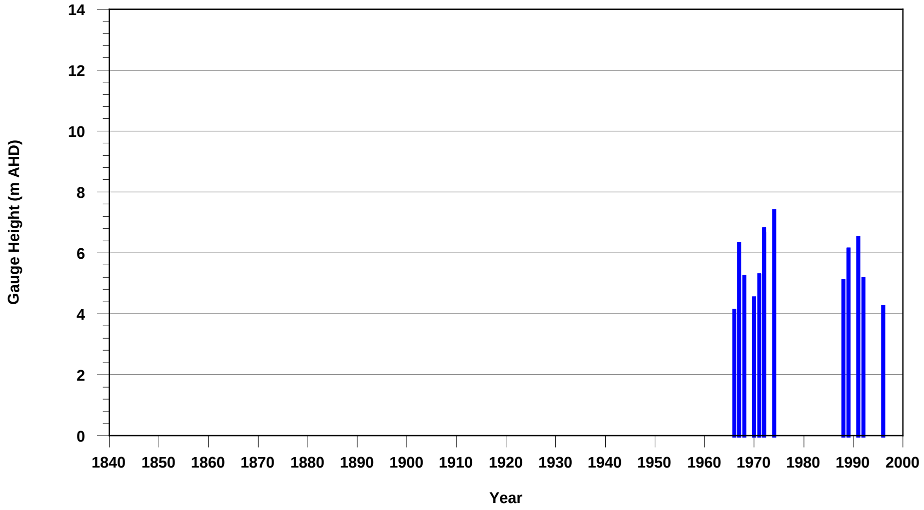


Figure 9.8: Historical floods in the South-East Queensland region (cont'd on next page)

(d) Nerang River at Clearview



(e) Pine River at Drapers Crossing



(f) Caboolture River at Upper Caboolture

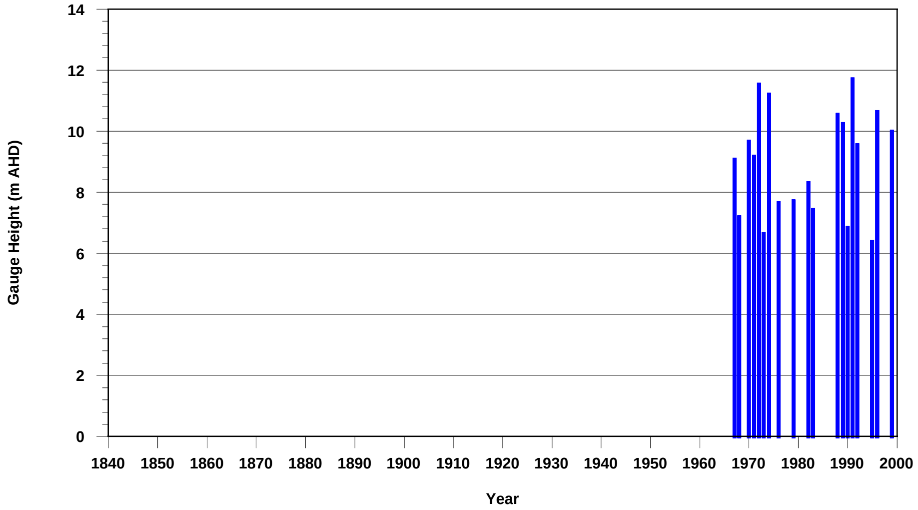


Figure 9.8: Historical floods in the South-East Queensland region (cont'd)

A report of the 1931 flood from *The Brisbane Courier* (7 February, 1931) indicates flood damage to agriculture and buildings in Pine Rivers as well as disruptions caused by flooding, as follows:

> ***Petrie, February 6****. Nearly 30 in. of rain has fallen since the early part of last week, over 19 in. being recorded in the 24 hours ending 9 a.m. today. The Pine River reached its highest during the early part of last night, when a height of 4 ft. above the 1893 level was touched. Cultivation paddocks have been ruined, whole flats being washed bare, while tons of sand and gravel have covered lucerne paddocks. Losses of stock have occurred, and fencing has been swept away. All the buildings of the Wembley Kiosk, on the River Reserve, have been swept away, even the bowser being destroyed. The flood waters on the north side rose so rapidly that the house of Mr W. Barber was surrounded before he and his family could escape, and it was only by firing a rifle that he was able to let neighbours know his plight. Boats had to be procured before they could be rescued. Other residents took refuge in the Show Hall. The kiosk at Cash's Crossing was destroyed, and practically every culvert in the district has been washed away. Milk suppliers have been held up, and all the traffic at Whiteside and Dayboro-road was washed away yesterday.*

Table 9.4 Selected flood levels in the Pine Rivers region

Creek/River	Height Station (m AHD)	Apr 1989	Apr 1988	Jan 1974	Feb 1972	Dec 1970	1967	1966
Conflagration Creek	South Pine Rd	9.2	8.9	9.7			8.8	6.5
Freshwater Ck North	Old Gympie Rd	16.1		16.7			16.2	
Freshwater Ck	Goodfellows Rd		16.5	16.8			17.4	17.3
Albany Ck	Albany Ck Rd			16.2			15.7	
Sandy Ck	Albany Ck Rd			16.1			15.3	
Colthards Ck	Harvey St	4.7	4.2	4.6			4.1	
Saltwater Ck	Anzac Ave			2.8				
Yebri Ck	Gympie Rd						8.9	
One Mile Ck	Yebri St						10.1	
Todds Gully	Todds Rd						7.2	7.1
Four Mile Ck	Samsonvale Rd			19.8			19.2	
Kedron Brook	Dawson Pde			42.6	41.7	41.6		
North Pine R	Gympie Rd bridge Petrie	5.7		5.1				
South Pine R	Gympie Rd between Mott and Kremzow	5.2	4.1	5.2				
	South Pine Rd	11.9	10.1	12.5		8.5	9.6	

(c) Brisbane – Bremer River system

Flood records held by the Bureau of Meteorology and DNR extend back as far as the 1840's for Brisbane, and as far back as the 1893 floods for Ipswich. Selected flood levels on the Brisbane River are shown in Table 9.5 and for the Bremer River in Table 9.6.

Like most cities, Brisbane and Ipswich are subject to i) river flooding, ii) creek flooding and iii) flash flooding. For instance, the numerous creek systems (e.g. Warrill, Purga, Bundamba, Six Mile, Goodna and Woogaroo Creeks) which feed into the Bremer and Brisbane Rivers can result in severe flooding. These systems have a response time of less than six hours, which places them in the 'flash flood' category. For example, flooding in Bundamba Creek in 1991 caused extensive damage to industrial and residential buildings in the suburb of Bundamba (K. Durham, 2001, written communication).

Table 9. 5 Selected flood levels on the Brisbane River

River Height Station (m AHD)	February 1893	February 1931	March 1955	January 1974	May 1996	February 1999
Gatton	16.33	9.14	9.14	14.63	11.40	8.50
Laidley	-	-	-		8.50	-
Lyons Bridge	-	-	17.46	16.54	16.41	12.55
Lowood	26.39	18.44	18.14	22.02	12.38	10.87
Mt Crosby	32.00	21.78	20.72	26.74	14.10	-
Ipswich	24.50	15.50	13.80	20.70	11.30	6.85
Moggill	24.50	15.40	13.70	19.93	7.10	3.58
Jindalee	17.90	9.60	7.30	14.10	4.55	2.25
Brisbane City	8.35	3.32	2.36	5.45	2.70	1.41

Table 9. 6 Selected flood levels on the Bremer River

River Height Station (m AHD)	January 1974	February 1976	May 1983	December 1991	May 1996
Harrisville	6.18	5.95	5.65	5.90	5.91
Amberley	10.18	8.60	6.34	7.53	6.75
Rosewood	7.62	6.00	5.60	6.04	6.33
Walloon	8.70	5.08	6.56	7.30	7.60
Ipswich (David Trumpy Br)	20.70	13.65	10.65	13.10	11.31

1800s

The floods of 1841 and 1893 reached over 8 m AHD on the Brisbane City Gauge at the river end of Edward Street. This represented a depth above highest tide level of approximately 6.5 m. On the Bremer River, the February 1893 flood measured 24.5 m at its peak.

Three separate flood events occurred in February 1893 in Brisbane. The first flood event was the largest, peaking at 8.43 m at Brisbane City on the 5 February and resulted in substantial flood losses. The second flood was minor, peaking on 12 February. The third flood peaked on 19 February and registered 8.09 m at Brisbane City. At Bulimba, New Farm, Fortitude Valley, Breakfast Creek road, and the Hamilton, the third flood was several inches higher than the peak of the first flood (*The Telegraph*, 20 February, 1893), though flood damage across Brisbane was considerably less from the third flood because of the extensive damage already suffered in earlier floods. Figure 9.9 shows the extent of inundation in Brisbane during the February 1893 floods.

Figure 9.9: Map showing the extent of inundation in Brisbane during the February 1893 floods (Irrigation and Water Supply Commission, Queensland; courtesy of John Oxley Library)

A contemporary account (*The Brisbane Courier*, 6 February, 1893) illustrates the impact of flooding in Brisbane in 1893 as follows:

> *A number of lives have been lost; hundreds of persons have been deprived of their homes and of their little possessions, and the loss of merchantable goods cannot at*

present be estimated….Brisbane was last night without communication by road, rail or telegraph with any of the outlying districts, as indeed it has been since Friday night, so that the facts procurable were simply those relating to the immediate vicinity of the capital…

Last night the water was between 11 ft. and 12 ft. above the flood mark of 1890…….No gas has been available since an early hour on Saturday night, and though some lamps in the Queen and George streets were lit by Messers. Barton, Whit and Co. from electricity generated at the Government Printed Office, this served to light but a small portion of the inundated streets…...

In the list of public disasters must be placed the destruction of the Indooroopilly Railway Bridge…..Apart from the national disaster, the sense of which was appreciated by all, there was the sentiment that one of the most picturesque of the local landmarks had gone.

The Brisbane Courier and *The Telegraph* of 6 February 1893 provide detailed descriptions of the sequence and depths of flooding during the period of inundation, particularly in Brisbane City. Depths of up to 15 – 16 ft. were reached in areas between Queen and Alice streets and the river on the one side and Albert Street on the other (*The Brisbane Courier*, 6 February, 1893). The papers also describe in detail other flooded areas (including evacuation details), in particular, Kangaroo Point, South Brisbane, New Farm, Milton, North Quay, Fortitude Valley, Newstead, Toowong, Indooroopilly, Rocklea, Sherwood, St Lucia and Oxley Point. A contemporary account from *The Telegraph,* Monday Evening, 6 February, 1893, follows.

…….all that portion of the city bounded by George and Ann streets and the river was yesterday submerged to a varying extent, except as regards the hill on which the Post Office stands, the west end of Queen Street…and the high portion of Elizabeth, Charlotte, Margaret, Mary and Alice Streets.

On Friday, Saturday and Sunday, crows of people watched the progress of events at Victoria Bridge (Plate 9.8)*, a structure that was at once invaluable as a means of communication between North and South Brisbane and admired by the reason of the manner in which it withstood the attacks of the objects large and small which every minute struck it throughout its entire length. Dwelling houses commenced to come down the river in earnest at about 3.30 p.m. on Saturday, and from that time on to Sunday night fully 100 houses and large sheds must have passed the bridge. It was marvellous to see the way in which even the largest dwellings were crushed up against the piers and girders. All the houses which had previously been wreaked floated down square, with their corrugated iron roofs showing. On contact with the bridge the edifices were crushed up instanter. The crushing sound – heard for a mile – tole its own tale of misfortune. So continuous and terrible was the crashing of houses on Saturday night that many persons living near the bridge found it impossible to sleep, what with the noise and the consciousness of others people's misfortune. Most of the houses were furnished and no-one could say with certainty that some of them were not occupied by human beings, who were thus hurled to eternity without the power to make the slightest effort to save themselves. At Toowong on Saturday night screams were frequently heard from across the river. A resident of Toowong informs us that from Emma Street a row of three houses could be seen on the south side. Loud noises as of timber collapsing were heard at about 10 p.m. on Saturday, and a light was seen in one of the houses. A minute later the three houses had gone. Many residences are known to have been swept away from the Orleigh Estate, West End, in addition to others from various riverside positions between the bridge and the up-county limit of the flood…*

Numerous and varied were the things piled against Victoria Bridge on Saturday and Sunday by the current, but for size, as well as by reason of circumstances of the affair, the collision with the Stanley Street west swimming bath takes the lead. Etc etc

On Sunday at 9.30 am, a big barn filled with hay went down the stream. It struck the second pier from Queen Street and burst. For about half an hour a good deal of the barn and its contents hung against the pier, but the wreckage then disappeared.

No less than three large punts fouled the bridge, one on Saturday at about midnight, and the others on Sunday at about noon. The first remained fast for over an hour, and its great lifting power must have caused a considerable straining of the bridge. The two punts which came down on Sunday hung on the bridge, and did not disappear till some time during the night……….

In addition to houses and sheds, there came down the stream live stock, farm produce, furniture, fencing, trees, and pieces of land held together be reeds and scrub, and having the appearance of miniature islands. At about 4 p.m. on Saturday no less than seven ricks of new hay floated past the bridge in a cluster, a sure sign of a rising river. Numbers of the animals were alive when they passed the bridge. Snakes were plentiful among the debris and specimens of very strange species were secured.

The end, so far as the bridge was concerned (Plate 9.9*), came at about 1 am today, when nearly half of the structure on the northern side gave way, but the explanation of this is no doubt that the current being stronger and deeper there, gradually washed out the piers at the base. The bridge was also slightly damaged by the flood of March 1890 at the end which has now give way…*

Drinking water shortages in Brisbane and the resumption of communications within Brisbane and with the surrounding region and are described in *The Brisbane Courier* (10 February, 1893):

Many portions of South Brisbane and Kangaroo Point have been put to great straits on account of the almost total absence of drinking water. The waterworks authorities ascribe this almost solely to the particularly heavy demand on the mains at present, and do not know of any bursts which could cause the difficulty. As a matter of fact there was no water in the taps on Kangaroo Point last night. A thorough inspection is being made by the board's engineer and foreman with a view of arriving at a method of reducing the inconvenience. As the health of many parts depends on obtaining water for scouring and general cleansing just at present, it is hoped that those who make use of the water will be as careful as possible. It is said that all regulations regarding the use of the water are being set aside, in some cases people not even taking the trouble to put nozzles on their hoses.

Queen Street yesterday presented a very animated appearance contrasted with that of the past few days. Communication with the south side of the river by means of the ordinary steam and boat ferries was opened; railway communication restored for several miles around the city; and hundreds of visitors had apparently flocked into town from the surrounding districts to obtain a glimpse of the scene which had been depicted in the morning and evening papers and also with an eye to business.

Communication has now been restored with Rockhampton and North Gympie, Maryborough, Bundaberg, Beenleigh, Nerang, Southport, all stations on Bay-line as well as Sydney. Business to the North still considerably delayed, but 'urgent' messages can be sent.

An extract from *The Brisbane Courier* (8 February, 1893) details the impact of the 1893 floods on Ipswich:

> *The flood at Ipswich* (Plates 9.10-11)*, as in Brisbane, has been terribly disastrous, an enormous amount of damage being done and loss and suffering caused* (Plate 9.12)*. The flood reached its maximum height about three o'clock on Sunday morning, being then fully 16 ft. above the previous highest record of 1890. Three-fourths of Ipswich was then under water, and hundreds of homeless people had to take refuge in the churches, schools, and other buildings above floodmark* (Plates 9.13-14).
>
> *North Ipswich was almost entirely submerged, the railway workshops and the woollen and cotton mills flooded. The Bremer Bridge was some feet under water, but the structure is believed not to have been injured.*
>
> *Four members of the family of Mr Peter Jackson, an engine-driver, who was himself absent at the time, were drowned at Blackwall, about five miles from Ipswich. They were endeavouring to escape from their house in a boat, when the craft capsized, and Miss Katie Jackson and three younger children were drowned. Miss Mary Jackson and a Mr Rowe remained in the house, which was shortly afterwards swept away and dashed against a tree, into the branches of which they succeeded in climbing. They were rescued with great difficulty and danger after being twenty-two hours in the tree, and the heroic conduct displayed throughout by Miss Jackson has excited great admiration. Constable Sangster was drowned while attempting to rescue them.*
>
> *At Blackstone and Bundamba the full effects of the flood were felt, the latter place being almost entirely under water……..*[there has also been a] *disaster at the Tivoli Colliery, by which seven persons were drowned.*

1974

Since 1893, the largest flood in the Brisbane-Bremer system was in January 1974 (Plates 9.15-16), and although a flood of smaller magnitude than the 1893 floods, it is the most severe example of urban flooding in Australia to date (Plates 9.17-19). The 1974 flood rose to a height of 5.45 m at Brisbane City and to a height of 20.7 m on the Ipswich flood gauge located at David Trumpy Bridge (Plates 9.20-22). The Bremer River flooded ahead of the Brisbane River. Creek flooding (Bundamba, Six Mile, Goodna and Woogaroo), had the effect of dividing the eastern part of Ipswich into five separate isolated communities. As the Brisbane River flooded it dammed the Bremer and compounded creek flooding. This kept the flood level in Ipswich at a record height for four to five days (K. Durham, 2001, written communication).

The 1974 flood caused widespread damage in Brisbane (Plate 9.23) and Ip swich (Plates 9.24-25). Flooding from the Brisbane River alone resulted in at least an estimated $200 million worth of damage at the time (based on SMEC 1995 flood study). At least 13 000 properties were affected (Cities Commission 1975). This excludes flood losses in Brisbane resulting from the Brisbane Creek catchments, and the severe flooding of the Bremer River affecting Ipswich (Smith 1998). Although the Wivenhoe Dam (completed in 1985) is capable of significantly attenuating some events in the Brisbane River, widespread flooding across the lower reaches of the Brisbane River remains a real threat for at least 18 000 property owners in Brisbane during an event with a 1% AEP. This includes flooding from the Brisbane River and the major creeks. Wivenhoe Dam has no mitigating effect on the Bremer River, acting only to control the downstream level of the Bremer River as it joins the Brisbane River.

A number of contemporary accounts follow, which indicate the impact of the 1974 flood in the Brisbane-Bremer catchment and on the region as a whole:

> *The Telegraph*, 26 January, 1974: *Floodwaters lapped the main Brisbane Airport runways today….trains did not run….the Brisbane City Council has appealed to people not to use buses because services might be cancelled…….Brisbane airport is closed with no indication of when it might open….Floodwaters have cut the Bruce Highway, isolating Gympie from the south. A Gympie police official said the only way out of the city was to the north….No trains would be running for an indefinite period, a spokesman for the Railways said today. He said that railway lines at Mayne and at Albion were completely under water with depths of more than 1.2 m (4 ft.). A bridge has collapsed between Wacol and Darbra. Both suburban and country trains have been discontinued* (Plate 9.26)*….Hundreds of people were evacuated from rooftops by a fleet of speedboats. Record flooding was reported in the Enoggera Creek at the Enoggera Reservoir. Most suburbs were blacked out during the night…..Flooding is expected to increase to record levels in all creek systems today as the rain keeps falling. The worst hit are Mogill Creek, Enoggera-Breakfast Creek, and Kedron Brook.*
>
> *The Queensland Times*, 28 January, 1974*: A handful of Council workers assisted by a small army of volunteers evacuated scores of Leichhardt families from their homes early yesterday morning as waters reached a new peak in the su burb* (Plates 9.27-28). *To worsen matters, the entire suburb was blacked out late Saturday night and this was the situation yesterday…….Worst affected were the Queensland Housing Commission estates and some private homes in the lower Chubb Street area. Floodwaters, which were over a kilometre wide at One Mile yesterday* (Plates 9. 29-30)*, completely swamped dozens of Housing Commission homes around Denman, McNamara, and Casey streets.*
>
> *Floodwaters which surged through backyards and under homes in Coleman Street created a health hazard when they flooded outhouses. Debris and raw effluent floated on relatively still floodwater. In most cases, only the tops of homes were visible. A few were completely submerged while only the roofs of others were above the raging Bremer which flowed at about twenty knots throughout the day…….Stock as well as houses was threatened when floodwaters from the Warrill Creek surged up to threaten homes in Phillip Street, lower Chubb Street and Cafferky Street. Several houses on the Amberley side of Warrill Creek were completely submerged or only visible by their roofs when the flood peaked at about 2 p.m. Another peak was expected about 2 a.m. today…….RAAF Amberley runways were completely submerged, forming a sea of water at least three kilometres wide.*
>
> *The Courier-Mail*, 29 January, 1974: *The raging Brisbane River continued to rip the heart out of the near-crippled city, tearing vessels from their moorings and washing into more than a dozen suburbs causing disruption to essential services. Several areas were without electricity, water and gas. The flood virtually paralysed the city, cutting most major roads and badly damaging scores of others. The city's commuters face a grim task this morning getting to work because bus and rail services are restricted severely…..Some major city department stores have told their employees to stay home. There were fears last night that the floods may cause food shortages. Huge quantities of food were lost yesterday when waters swamped warehouses in the Brisbane and Ipswich areas. Water feet deep flowed through parts of the inner city causing huge losses to stores and warehouses in the Mary Street - Albert Street area* (Plate 9.31)*. Soldiers and firemen worked for hours pumping water from the main Edison telephone exchange in Elizabeth Street where floodwater threatened to ruin equipment……The Weather Bureau expects the Brisbane River to flow at its flood*

height of 6.7 m (22 ft.) for 16 hours until about 4 p.m. today. The level will be about 2.7.m (9 ft.) below the record height in 1893…….State Government authorities estimated last night that about 5000 people are homeless in the city. The worst hit suburbs yesterday included Jindalee, Sherwood, Indooroopilly, Yeronga and Milton. But police said most southern and western suburbs had been affected. Some of the people moved by boat during the day had only just returned to their flood ravaged homes when the waters rose again, trapping them. More than 30 relief centres operated in the city last night to house and feed the flood victims.

The Australian, 31 January, 1974*: The death toll mounted to 15 yesterday in the worst floods in Brisbane and the Gold Coast this century. Police fear more bodies will be uncovered as the massive clean up begins. Police yesterday recovered three bodies in the South Brisbane area, one of the worst hit parts of the flood-torn city.*

Another body was found in floodwaters near Chinderah, on the Gold Coast. Included in the 15 are an Army rescue worker and an Ipswich chemist, both missing, believed drowned. Police are still searching for two people missing in the Taringa and Indooroopilly areas. Officials said last night it will be months before a final figure could be placed on the cost of flood devastation throughout the State.

Because milk supply is still in jeopardy, despite daily consignments from Nambour, Caboolture, Southport, and Booval. Wholesalers said that despite heavy losses, millions of dollars worth of foodstuffs had been saved……Rescue helicopters yesterday ferried food, medical supplies, soft drinks for children and pumps to Jindalee and Jamboree Heights, which are still isolated by floodwaters…..He said about 50 homes had been washed down the Bremer and Brisbane rivers. About 12 000 people were facing destitution. Yesterday, the RAAF airlifted pumps, medical supplies and food to Ipswich and a large repair gang from the Amberley air base today will help with the clean up. Ipswich council will give top priority to opening the Brisbane-Ipswich road today.

The Telegraph, 1 February, 1974*: Fifty houses were washed away* [this number appears to vary depending on the source] *at Ipswich by the Bremer River flood. Many disappeared leaving no trace. Stumps of others only remained after the floodwater receded. The worst hit areas are Sydney Street, Brassall, Keong Street, Ipswich and Woodend Road, Woodend. At Sydney Street fourteen houses have been washed down the river and another three had been badly damaged…..Mrs Fullerton was only one of the fourteen families who on Sunday night watched as their homes were picked from their stumps and smashed into pieces on the Hancock Bridge which separates Brassall from Ipswich City. Mr G. Bryne was luckier than his neighbours. Today his brick house still stands but walls have been gouged out and most of the furniture washed downstream.*

The Telegraph, 4 February, 1974*: Flood clean-up work at the weekend had allowed 6000 families to move back to their homes in Brisbane and Ipswich, the Premier, Mr Bjelke-Peterson, said today. But 2000 houses in Brisbane and 700 in Ipswich still were unfit for habitation……Mr Bjelke-Petersen said the survey showed that some 8000 houses in Brisbane had been damaged, submerged or destroyed. Proportionately, Ipswich had suffered far worse, with 4000 houses damaged or destroyed, he said. The Lord Mayor, Alderman Clem Jones, said yesterday 13 750 Brisbane houses were affected by the floods. This figure would include houses that ranged from destruction to slight damage and houses that had water only under them…..The State Government had distributed almost $3 million for food, clothing, bedding and cooking utensils to alleviate immediate hardship. He said the area - by area totals of flood - ravaged houses remaining included: Ipswich 719, Ashgrove*

164, Indooroopilly 18, Red Hill two, Taringa 116, Toowong 38, Torwood 309, South Brisbane 63, Fairfield 326, Oxley 231, Valley 162, Rocklea 148, Sherwood 139, Graceville 138, Chelmer 149, Waterford 11, and Woodridge seven.

A total of 94 flats and four home unit blocks also had been damaged and still were affected. Mr Bjelke-Petersen said the Woogaroo Creek Caravan Park, Goodna, was a grim story on its own. "There were 91 caravans in the park the day before the floods," he said. "Of these, 85 were occupied. After the area around the part emerged from the flood, only 17 of the caravans were left."

Though reliable records of flooding in the Bremer River affecting Ipswich date back to only 1893, other sources refer to floods dating back to as early as 1839:

according to the statement of one who resided here [Ipswich] *at the time, the river overflowed its banks* [in 1839] *to the extent of 54 ft, completely filling all the gullies leading from the Bremer to the main streets of the town, and inundating the country to the eastward of the Main Range for many miles* (*Moreton Bay Courier*, 30 May 1857 in Mills, 1992).

An extract from *Australian Pioneers and Reminiscence* (Bartley, 1896, p. 271 in Mills 1992) briefly describes other early major floods:

1841 – Bremer, Purga and Warrill Creek in full flood. The water rose 70 ft. at Ipswich and no such flood again seen until the 1893 trouble [94 ft. 4 in. at Ipswich port station]. *In the floods of 1857, 1863, 1864, 1870 the water rose 45 ft to 50 ft in Ipswich. The 1887 flood is said to have risen 50 ft in Ipswich which is 5 ft above 1864 and 1870. The flood of May 1857 was the outcome of six weeks long continued rather than heavy rain. That of 1863 was February autumn one 15.14 in of rain fell in sixteen days. In March 1864 an equinoctial gale brought the floods. The night of the eighteenth was terrific. A hurricane blew. The river rose 50 ft in twelve hours at Ipswich. The deluge of March 1870 consisted of 24.25 in of rain in a little of four days; 8.20 in being the maximum fall in twelve hours.*

The flood of 1890 appears to have been slightly higher than the 1841 flood with the Ipswich port station recording 73 ft. 4 in (*Queensland Times*, 17 March, 1908, in Mills 1992). The floods of 1898 and 1908 recorded 60 ft. 0 in. and 52 ft. 0 in. respectively at the Ipswich port station (*Queensland Times*, 17 March, 1908, in Mills, 1992).

(e) Logan and Albert River system

Reliable records of large floods in the Logan-Albert Rivers extend back as far as 1887 - the largest known flood in the Logan-Albert. *The Brisbane Courier* (26 January, 1887) describes some of the impact of the 1887 flood on the local communities:

On Friday both the Logan and Albert rose with fearful rapidity in the early morning between one and three. A great number of the residents at Alberton, Beenleigh Pocket, and Bethania, and on the other side of the Logan, were with difficulty rescued some, from housetops or out of the gable window of the houses………The S.S. Fanny which was moored at Yatala was a godsend. Captain John Burke and his men rendered noble service as they rescued and took aboard fifty-four souls, who would have perished without their timely assistance…… At Yatala and Beenleigh the river was fully a mile wide. At Loganholme and Waterford it was considerably wider, nearly the whole cultivation of the district being underwater. The following fatalities have been reported: A young man named W. Eggersdorff, his wife, and three children are drowned. Mr John Brown, of Yatala Saw-mills, and a kanaka are drowned, and it *is feared Mr and Mrs Walls and family, State school, Loganlea, are also lost, considering that only two or three boats were available when the crisis came. It is believed that no lives have been lost at Pimpama Island, Alberton, Beenleigh, Waterford, or up to the Logan Village, except those mentioned. The rivers are now falling and therefore no further fatalities are expected. There are fully sixty or seventy families washed out of their homes……On Sunday last, according to what the Waterford people state and to judge by the flood marks, the water had certainly been about 12 ft. higher than it had ever been before within the recollection of any resident. All Waterford was flooded, and on the south side of the river the scene was one of desolation. Places I know on which houses had stood were now quite bare, and from the appearance of the surroundings I believe that the railway bridge has been washed away……….Telegraphic communication is completely stopped. It will be impossible to tell the extent of damage done until the water subsides completely, but I should judge that desolation stretches away far beyond Yatala. The persons whom I saw yesterday had scarcely any clothes, and were homeless. The water rose, it seems, in the night so suddenly that the occupants of houses had only time to save themselves in what they stood. Food must be scarce, and when I left the Morning Star Hotel it was full of refugees. Those who know the high position of that hotel can judge what sort of a flood this has been when I say that the water was nearly 2 ft. high at one time in the bar.*

Since 1887, there have been several major flood events. The flood of January 1974 (Plate 9.32) was the most severe in the lower reaches of the Logan-Albert River system in the twentieth century, as well as the most severe flood in the Brisbane–Bremer and Nerang River systems. It has been estimated that the 1974 event had an ARI of greater than 100 years (1% AEP) in the Logan and Albert Rivers (Smith 1998). Selected flood levels on the Logan and Albert River system are shown in Table 9.7.

Table 9. 7 Selected flood levels on the Logan and Albert River system

River	Height Station (m AHD)	Jan 1887	Feb 1893	Jan 1947	Jan 1974	Feb 1976	Feb 1991	May 1996
Logan R	Dulbolla		15.24		10.06	12.00	14.40	11.80
	Round Mountain				15.33	16.12	16.85	13.20
	Yarrahappini				20.75	18.54	18.78	14.85
	Macleans Bridge	22.30			21.67	18.18	18.50	15.00
	Waterford	13.70			13.28	10.38	9.06	7.50
	Eagleby	7.58			7.25	5.28	5.00	3.94
Albert R	Lumeah			10.06	8.04	9.25	9.01	9.95
	Bromfleet				16.36	14.88	9.53	13.97
	Wolffdene				13.69	9.77	4.86	8.73
Teviot Brook	Boonah				-	8.16	8.50	6.77
	The Overflow			14.30	12.90	12.50	13.42	8.66

The impact of the floods on roads in the South-East Queensland region is indicated in a report from *The Courier-Mail* (1 February, 1974), as follows:

The Main Roads Department warned motorists last night to use the Pacific Highway between Brisbane and the Gold Coast, with 'extreme caution.' The Acting Commissioner (Mr J. Andrews) said floods had damaged approaches and abutments of three bridges - the Logan and Albert, at Beenleigh, and the Coomera at Oxenford. There were a number of other weak spots on the highway…..

The second largest flood in the last century in the Logan-Albert River system, that of January 1947, also flooded the Pacific Highway, and cancelled bus and train services to Brisbane. Destruction of the Waterford Bridge (Plate 9.33) also affected goods transport (*The Courier-*

Mail, 29 January, 1947). More recently, severe floods have occurred in the upper reaches of the Logan River in February 1976 and February 1991.

(f) Pimpama-Coomera-Nerang-Tallebudgera-Currumbin River/Creek System

Since river height records began in 1920, there have been six floods which have caused moderate to major flooding. Four of these, 1931, 1947, 1954 and 1974, were the results of cyclonic activity. The 1967 event resulted from a moist tropical low-pressure system and the 1974 event was the result of thunderstorm activity associated with a trough extending through the area. Table 9.8 provides a summary of some recorded levels. The raising of the Dam in 1987-1989 has improved flood mitigation in the catchment but has not removed the threat during a 1% AEP flood to some 21 000 properties in the region, of which about 40% of the properties would have overfloor flooding.

Table 9. 8 Selected flood levels on the Nerang River system

River Height Station (m AHD)	Feb 1931	Jan 1947	Feb 1954	Jun 1967	Jan 1974 (1)	Jan 1974 (2)	Apr 1988	May 1996
Hinze Dam	n/a	n/a	n/a	n/a	n/a	n/a	4.28	3.24
Clearview	8.84	9.32	9.83	10.18	10.22	9.16	5.86	5.48
Evandale	2.85	2.62	2.87	2.25	-	2.87	-	-

Of the floods in the last century, the January 1974 flood was the largest (Plate 9.34). For the Nerang River System, an ARI of about 1 in 65-70 years has been applied. For the Coomera River an ARI of greater than 100 years (1% AEP) has been estimated (Smith 1998). The flood is estimated to have directly affected at least 1000 residential dwellings (Smith 1998).

The following newspaper reports give an indication of the impact of the 1974 floods on the Gold Coast area:

> *The Telegraph*, 31 January, 1974*: Gold Coast City Council and Albert Shire Council probably will complete collection of mountains of discarded furniture, carpet underlay and other effects by the end of this week. Ruined by floods, this is piled on footpaths now. Telephone services are returning to normal and roads are opening up quickly in the Gold Coast hinterland. I arrived in Surfers' Paradise yesterday on one of the first buses to get through the flood-scarred Pacific Highway. There are many detours where the highway has been washed away, and my coach tore off its muffler in a deep rut. In two days, 1250 mm (50 in.) of rain fell in the mountain area, behind the Gold Coast, and floodwaters raced down the valleys tearing through hundreds of homes. The Nerang River rose from a quiet 4.3 m (14 ft.) to a raging 9.5 m (31 ft.) in less than a day. Little Tallebudgera Creek, a tributary, became a wild torrent. In twenty minutes it gouged thousands of cubic yards of soil from the garden which separated Tom Sumpton's home from the creek and began eating away the foundations of the house.*

> *The Australian*, 31 January, 1974: *The death toll mounted to 15 yesterday in the worst floods in Brisbane and the Gold Coast this century……Another body was found in floodwaters near Chinderah, on the Gold Coast…..*

> *The Courier-Mail*, 1 February, 1974: *Queensland's floods are expected to wipe tens of millions of dollars off real estate values and to put into question some planned projects …..On the Gold Coast, the floods in canal estates* [Plate 9.34] *have involved some of the most expensive land in Australia, where single lots were changing hands at $100 000 and more….Gold Coast houses involved in the flooding were generally in the upper bracket - up to $250 000, with $85 000 not uncommon. Some may be*

total write-offs, according to preliminary information. Internal damage has been colossal.

Though no official records are available for the flood of 1887, it was of greater magnitude than the 1974 flood (Smith 1998). A report from *The Brisbane Courier* (27 January, 1887) follows:

The creek on Saturday was a surging mass of discoloured water, travelling about eight miles an hour and carrying down with it huge trees, logs and all descriptions of farm produce - pumpkins, passionfruit, water-melons; two horses were seen, a calf or two, five or six boats….The water rose at Nerang up to the back of the houses in the main street. The storehouse on the wharf was submerged. A valuable piano belonging to Mr Philpott was stored in it. The water was, when at its highest, washing over the bridge at the township. The mouth of the creek has been altered to some extent. At the bathing-houses there is now 6 ft. of water at the doors; several of them were overturned. The end of the old jetty was carried away and the pile-driver used for the erection of the new one was also washed away. This will be a heavy loss to the contractors. No mails reached us on either Friday or Saturday. Cobb and Co's driver, Charlie, got through with one on Sunday at considerable risk to himself, but the postmaster declined to relieve the anxiety of those who were anxious about friends in town by opening the mail until his regular time on Monday morning. Considering that telegraphic communications had been interrupted from Friday morning, this showed a great want of consideration for the public…… Another informant says……..The Bay was all discoloured with flood water from the Coomera and Nerang rivers, the latter of which was within 2 ft. of the 1868 flood which residents remember nineteen years ago.

A report of the June 1967 flood (Plate 9.35), the second largest flood of the twentieth century, indicates some of the areas particularly badly affected by the inundation:

The Courier-Mail, 14 June, 1967: *Canal development estates of the Pacific Highway were among the worst hit during the floods. Some of them - Santa Barbara, Rio Vista, Miami Keys, and Rialto Estates - had families evacuated when the flood approached its peak. Homes on these estates were among those suffering high damage from the flood.*

As the waters fell yesterday morning, the full extent of road damage became apparent - and it was enormous. Cavill Avenue, Surfers' Paradise, had been transformed into a 300 yard long pothole with the bitumen almost entirely ripped away. The main one-way sections of the Pacific Highway were also badly damaged and there was scarcely a road or street of the Gold Coast unscathed.

Information on floods in the Coomera River is less extensive, especially in the floodprone lower reaches, but significant floods are known to have occurred in 1967, 1974, 1976 and 1989.

Flood Prediction, Planning and Mitigation

Throughout Queensland, local governments are responsible for establishing regulations in regard to land use planning and approvals. Whilst there is no State legislation ensuring consistency in approach to flood risks, many local governments have adopted similar guidelines and procedures through the exchange of professional engineering and planning advice and knowledge gained from the flood management experience in other states. Stormwater and small catchment flooding standardised design needs have been addressed for a number of years by the Queensland Urban Drainage Manual (QUDM, 1994). In regard to broader floodplain management issues, a national guideline has only recently been completed (ARMCANZ, 2000). Currently DNR is working with representatives of various local governments and other interested parties to establish total management planning (TMP) guidelines for floodplain and stormwater management for adoption by all Queensland authorities over time.

Flood prediction for planning purposes differs from flood warnings in respect of the need to estimate the long-term probability of flood impacts so that appropriate planning decisions can be made to minimise the impact. In many other respects, however, the same basic tools are required, namely:

1. historical rainfall and runoff data across a catchment;
2. historical river height and discharge information;
3. catchment topography and land use;
4. surveys of river and floodplain levels and cross sections;
5. models of the hydrologic processes (rainfall, runoff, infiltration, concentration etc);
6. models of the hydraulic processes (propagation, attenuation etc).

Typically, such analyses are undertaken by hydrologists and specialist civil engineers skilled in the physical understanding of rainfall patterns and the fluid mechanics of flood propagation. The results of such studies are often required to set design clearances for public works such as roads, bridges or the height of levee systems.

Items (1) and (2) are essential for describing the statistical nature of the flood hazard. Such data then permits the calibration and verification of the various models derived in (3), (4), (5) and (6) which, depending on the application, may be numerical (mathematical) or physical scale-models. Using statistical analyses of the historical rainfall data, a well-calibrated model is then capable of predicting the impact of floods that are beyond the present limit of experience or even the present or future extent of community development on the floodplain. They can also be used to estimate the ARIs of past and future floods, and to test potential flood mitigation strategies, such as the clearing of choked channels, constructing new channels, levees, detention basins or dams. They can also be used to delineate planning zones where regulations might be made to the minimum property height or floor level allowed, or to limit the amount of infilling in a floodplain to prevent the raising of flood levels. Such models are increasingly being used to manage environmental assets dependent on flooding, such as wetlands.

The above data collection and modelling process leads to a statistical description of flooding for a specific community. It remains then to adopt planning regulations that seek to limit the impact of flooding on that community in an effective manner (socially, environmentally and economically). As the impacts may differ considerably between communities, even on the same floodplain, it is logical that regulations might vary in response to that impact. However, it is usual for a specific ARI flood level to be proclaimed, or in its absence the historical flood-of-record, as the limit for planning purposes. This is then termed the 'designated flood' level for planning purposes. A small freeboard allowance is then applied above the designated level to provide a measure of safety and to allow for vessel wash effects. The most common designated flood level adopted in South-East Queensland is the 100 year ARI or 1% AEP level (Smith 1998).

In the following sections the approach taken by individual LGAs in the study region to manage the community flooding problem is briefly summarised. Indicative AEP flood levels are provided for selected locations in Table 9.9. Information has been drawn from Smith (1998) or has been specially made available to this study by the LGA concerned. Councils provide information on the likelihood of flooding within the area in which an individual property is located upon enquiry.

Caboolture River and Burpengary Creek system

Flood studies have been carried out for the Caboolture River system (CSC 1994a), Burpengary Creek (CSC 1990), Little Burpengary Creek (CSC 1994b), Gympie Creek (CSC 1994c), Six Mile Creek (CSC 1994d) and Wararba Creek (CSC 1995 & 1999) which provide estimates of the 10, 50 and 100 year ARI flood levels. No estimate of the PMF is currently available. The models have been calibrated using the February 1972, April 1989 and December 1991 floods. The designated flood for planning purposes is the 100 year ARI with a 0.1 m freeboard and there are controls placed on filling in the floodplain.

The region has extensive low lying coastal lands and these are impacted by storm surge, which is discussed in Chapter 4, especially in regard to Beachmere. Estimates of the coastal storm surge levels have been included in the various flood studies because of their influence on the lower floodplain tailwater during a flood. However, this impact is limited to the lower 5 to 6 km of the river for most ARI scenarios. Likewise, the effect of possible sea level rise due to enhanced-Greenhouse has also been investigated in the model studies and found to only influence the lower reaches near the mouth.

A selection of predicted flood level ARIs is given in Table 9.9. For any particular flood event, studies show how the different parts of the floodplain can have significantly different responses depending on the rainfall distribution. For example, the 1972 flood severity in the Caboolture River generally increased travelling down the floodplain. In the upper reaches it represented a 20 yr ARI, the middle reaches a 40 yr ARI, and a 50 yr ARI in the lower floodplain. At the mouth however, the levels were only a 10 yr ARI. Similar behaviour is predicted in the tributary streams King John and Lagoon Creeks.

The flood studies have also considered the potential impact of (presently planned) future urbanisation of Caboolture Shire, which is likely to increase surface runoff over time. The results show that although impacts on the major watercourses are expected to be negligible up to the 100 yr ARI, some local stormwater systems may be significantly affected and their capacities may need to be reassessed.

Burpengary Creek studies have focussed on the residential flooding problems in Dale St and Springfield Dr which have been of regular concern to affected residents. A number of mitigation options were identified for consideration by Council (CSC 1990).

Redcliffe City

There are no major river or creek systems in the Redcliffe City area. Some localised storm water surcharge can occur in specific areas during very heavy rain episodes. Council is currently updating its information base in this regard. Storm surge threats are addressed in Chapter 4.

Pine Rivers system

Numerous flood studies have been undertaken for Pine Rivers and are held by the Pine Rivers Shire Council. The modelling studies are used for setting development conditions and in road network planning. Selected predicted flood levels for various locations are shown in Table 9.9.

The flood studies take into account the ultimate development of the catchment and development conditions have been set according to the flood level results of the studies. Pine Rivers Shire Council will not allow development filling in land inundated by a 50 year ARI creek flood, a 100 year ARI river flood or a 100 year ARI tidal surge. Park contributions cannot include land below the 20 year ARI flood line calculated assuming revegetation of the waterway. Catchment Management Plans are being prepared so to enable revegetation of waterways without adversely affecting flood levels (Peter Stonadge, written communication, 2001). Due to the relatively late development of Pine Rivers Shire, the impact of floods on developed properties is small because of the early development controls put in place. Creek and river flooding, however, cause a number of road closures.

Predicted flood levels for Sandy Creek are currently being reassessed following recent mitigation. New catchment management plans are being prepared for Four Mile Creek and the South Pine River. Predicted levels for the North Pine River, South Pine River and Kendron Brook are available from the Brisbane River and Pine River (Dam Burst Study), South-East Queensland Water Board, DNR and the Brisbane City Council Flood Study.

Brisbane - Bremer River system

Numerous flood studies have been done on the Brisbane creeks (Breakfast, Bulimba, Cabbage Tree, Cubberla, Kedron Brook, Lota, Moggill, Norman, Nundah, Oxley, Pullen Pullen, Wolston and Wynnum creeks). Each flood study has been calibrated against several historical flood events. Further information on these studies (completed between 1992 and 2000) and earlier studies can be obtained from Brisbane City Council. Recent modelling for the Brisbane River undertaken by Brisbane City Council in conjunction with Sinclair Knight Merz is still under investigation and so was not available for use in this report. The modelling used in this report is based on historical river flooding levels and modelling of 1% AEP flood levels for the Brisbane creeks, based on a 1984 study.

Ipswich City Council in conjunction with Sinclair Knight Merz has recently completed a comprehensive flood study which covers the urbanised areas of Ipswich City (IRIT, 2000), the flood modelling of which is used in this study. The study encompasses the Bremer River (from Warrill Creek to the Brisbane River), its major tributaries (Bundamba, Purga, Deebing, Ironpot, Mihi and Sandy Creeks), the Brisbane River (from Woogaroo Creek to Kholo Creek) and its major tributaries (Six Mile, Goodna, Woogaroo, and Sandy/Camira Creeks). The flood models have been calibrated against the January 1974, June 1983, April 1989, December 1991 and May 1996 events and take account of actual water release operations at Somerset Dam and, post-1985, Wivenhoe Dam. The analyses provide estimates of the 2 year, 5 year, 10 year, 20 year, 50 year, 100 year, 200 year, and 500 year ARI events and the PMF, for both existing and future urbanisation of the catchment. A number of flood mitigation options have also been assessed in detail, including use of detention basins, changes to dam operations and construction of levee banks.

The studies confirm that a range of storm scenarios may cause flooding in the area, namely

Local tributary storm: localised short duration (two to six hour), producing fast flow velocities and high flood levels in the upper reaches.

Bremer River storm: more widespread longer duration, producing high discharges at the lower end and backwater effects in local tributaries.

Brisbane River storm: regional extent and long duration (30 hour), producing high peak discharges at the junction of the Bremer River and with tributary backwater effects.

These various storm scenarios were combined and their predicted flood profiles overlapped to determine the maximum envelope of flood levels in the area. The study shows that the Brisbane River flooding scenario predominantly influences flooding in both the Brisbane

River and Bremer River tributaries. Flooding in the upper reaches of the tributaries was generally found to be due to local catchment flooding effects.

The Brisbane River is tidally affected as far as the Bremer River with a range of 2.8 m at Ipswich. The model studies also considered the influence of tide and storm surge levels on predicted flood levels. Combining the 100 year ARI flood and 100 year storm surge tailwater condition with an enhanced greenhouse allowance of 300 mm for sea level rise produced a maximum increase of 80 mm in flood heights near Ipswich.

The degree of future urbanisation was determined from the Ipswich City Council Strategic Plan and its effects were tested against the 20 year and 100 year ARI floods. Principal impacts were estimated to be localised to the Deebing, Ironpot, Mihi, Six Mile and Goodna Creek areas. In the larger tributaries the effect of urbanisation is predicted to actually reduce flood levels slightly due to reductions in the time of concentration of the runoff. The effects of floodplain infilling have not yet been determined in detail.

Present planning regulations specify the 20 year ARI flood level for existing development, which applies for the established central city region. For new developments, the 100 year ARI level is used to provide increased protection for the future growth of the city. A 300 mm freeboard is also applied in all cases. A selection of predicted ARI flood levels is provided in Table 9.9. These are based on the present catchment conditions and assume a tailwater at the mouth of the Brisbane River of MHWS (ie. without storm surge allowance).

Logan–Albert River system

The northern side of the Logan River (Logan City) falls within the jurisdiction of Logan City Council. The southern side of the Logan River (Albert River - Beenleigh area) falls within the northern part of Gold Coast City Council (refer to Figure 9.10).

The Logan City area is affected by flooding in the Logan River and its main tributaries of Scrubby/Slacks Creek and the smaller Native Dog Creek further to the east near Redland. A comprehensive flood modelling study of these areas has been undertaken in association with the other regional councils affected by the Logan – Albert River System (SROC 1994). Logan City has implemented comprehensive flood planning practices and approvals based on the results of that study. This culminated in the gazettal of Logan's Local Law No 6 (Floodplain Management) in 1998 which controls building, filling and excavation within the floodplain based on a hazard and risk classification. Prior to 1998 and the SROC study of 1994 the Council implemented a policy in relation to 'rezoning, subdivision and building in areas liable to flood'.

The urban centres of Logan began to expand rapidly during the early 1970s, just prior to the disastrous flooding of January 1974, which swept away several houses in the floodplain. This flood has served as a benchmark event for local government controls on development since that time. Consequently, only a very small proportion of the existing urban development is severely affected by flooding. However, there is a significant accumulation of urban development around the fringes of the main floodplain which is based at, or only just above, the 1974 flood level. There are also some significant areas which are at, or just above the 50 year ARI and 100 ARI flood levels that have been designated as the flood planning criteria in those areas.

The 1994 study extends earlier investigations dating back to 1982 and represents a base case condition for all future proposals for floodplain development. The model has been calibrated on the basis of the 1974, 1976, 1990 and 1991 floods, for which streamflow and river height data was available. The river is also tidally affected from Moreton Bay and the design flood events for the 10, 20, 50 and 100 year ARI have been estimated coincident with the peak of a typical spring tide event. The model has also been used to estimate the impact of flooding across the future planned fully developed urban areas and to set limits on the infilling to be allowed in certain areas. Extensive application of the model is used to ensure that the cumulative impacts of filling and excavation are controlled. This is to ensure that floodplain storage and the conveyance of floodwaters is maintained and that flood levels determined and set as part of the 1994 study are not compromised. In addition to the design event levels, the January 1974 flood has been specially remodelled for the floodplain in this ultimate developed condition. The relativity in levels between the ultimate catchment January 1974 flood levels and the design 100 year ARI levels in the main Logan River vary slightly but the 1974 flood is higher than the 100 year ARI by as much as 0.5 m. This places the levels of the ultimate 1974 flood somewhere near to the 125 year ARI level.

Table 9.9 presents a selection of predicted ARI flood levels throughout Logan City and some selected design levels for the Albert River. The Logan and Albert designated flood levels are derived from a repeat of 1974 rainfall on a fully developed catchment in accordance with the respective LAs' strategic plans being run through a cumulative development hydraulic model. Unlike Logan City, there are no areas of urban development significantly affected by flooding of the Albert River at lower ARI levels.

Redland Shire Council

There are no major river or creek systems in the Redland Shire other than Tingalpa Creek. It is impounded by the Leslie Harrison Dam within a few kilometres of its mouth in Moreton Bay to form the Tingalpa Reservoir. Flooding impacts are, therefore, limited to localised storm water surcharge in smaller watercourses and storm water systems. Storm surge threats were addressed in Chapter 4.

Gold Coast

Gold Coast City is the largest provincial city in Australia and has undergone very significant urban development across the coastal plains between Southport and the NSW border over the past 40 years. Some of its river floodplains were extensively developed when the general appreciation of flood risk, hazard and flood damage was less sophisticated than it is today (GCCC 1999a). There are significant pressures still to utilise the undeveloped flood prone areas that now provide for the storage of significant volumes of floodwaters during major flood events.

Gold Coast City Council has acted proactively to address the flooding hazards over many years and a significant number of individual flood studies have been undertaken, with more underway or planned. A three fold strategy has been adopted which involves extensive community consultation, as follows:

1. Flooding prevention through town planning revisions, leading to the development of a comprehensive planning scheme (consistent with the *Integrated Planning Act*)

2. Physical flood mitigation options in consultation with the community to reduce specific hazards

3. Counter disaster measures to provide warnings, inundation maps and procedures

Gold Coast City Council City Council received a National Commendation from Emergency Management Australia in the Safer Communities Awards for the Council's Nerang River Flood Mitigation project in 2000. The project is designed to address the increasing population of people living in flood affected areas and the serious potential for overfloor flooding. Council has addressed these issues through strategies such as the introduction of stricter land use controls and risk communication.

The extent of the Gold Coast flood problem is summarised in Figure 9.10 which lists the various river catchments affecting the region and the many issues and impacts for the community.

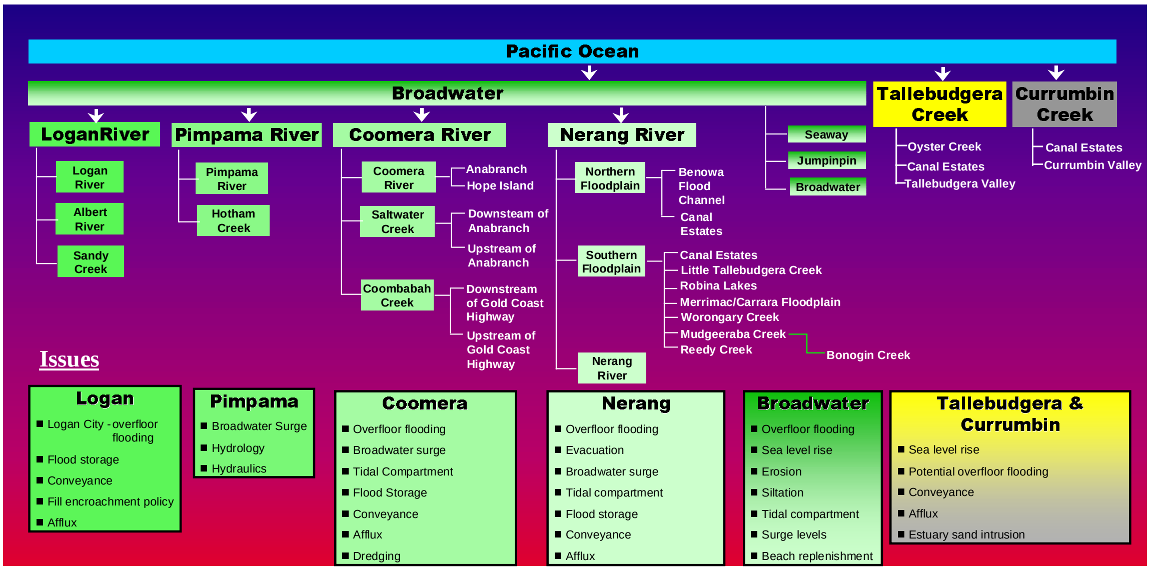


Figure 9. 10 Flooding issues for Gold Coast City catchments (GCCC 1999a)

Pimpama River:

This area is relatively undeveloped and has not been studied in detail at this time. Much of the land east of the Pacific Highway is below 2.5 m AHD and some areas are likely to be surge and flood affected (1999ab). The flood paths are not well defined and detailed two-dimensional modelling may be required.

Coomera River:

Guidelines for development in the Coomera River system date from 1987 and were designed to ensure that proposed developments should allow for the passage of a range of floods without any resultant impact on flood levels for existing properties or facilities (1999ab). This has resulted in residential development minimum floor levels being set to what at that time was deemed to be the 100 yr ARI and a number of other flood sensitive design requirements were imposed. In spite of these requirements, the peak flood levels derived from a series of model studies over the past ten years (e.g. GCCC 1997b) shows that there is an upward trend due to cumulative development effects. There are concerns also that the potential rainfall rate within the catchment may be presently underestimated. Accordingly, increasingly more stringent development requirements are being proposed for this complex network of waterways which continues to be favoured by developers. The major resort developments presently contained within the floodplain include Sanctuary Cove, Hope Island Resort, Monterey Keys and Oyster Cove. The current flood planning level is taken to be the higher of a repeat of the January 1974 flood flow or the 100 yr ARI. The greatest differences between these levels are generally in Saltwater Creek where the 1974 level would be about 0.3 m higher. Table 9.9 provides a selection of predicted flood levels for the area.

The Nerang River:

This river system represents the single greatest flood threat to the local community because of its central role in servicing a myriad of manmade and natural waterways that epitomise the Gold Coast lifestyle and environment. The river has been much studied, the first comprehensive numerical model being developed in 1988. Many studies have been done since that time in response to technical advances and the rapidly changing characteristics of the developing floodplain.

During a major flood, high flows in the river overtop the northern bank at Ashmore and the southern bank at Carrara, and flow onto the Carrara floodplain. Inflows from Mudgeeraba and Worongary Creeks flow onto the floodplain. The Nerang River then breaks its banks at Carrara. These two floodplains then meet if the flood is sufficiently high and force their way east through the tidal canal estates which now occupy what was also a part of the original river floodplain. Ultimately the river discharges into the lower part of The Broadwater and then into the ocean via the Gold Coast Seaway. As well as the canals, there are complex weir and lake systems which provide some flood storage during major events. To the north of the river, the Ashmore and Benowa flood channels and the Sorrento canal system provide an alternative path for floodwaters to The Broadwater and help to reduce levels further south near Carrara.

Gold Coast City has undertaken extensive community damage assessments (GCCC 1997c) and it is accepted that development in the Nerang River floodplain must not increase peak flood levels because of the already high level of potential damage. The Merrimac / Carrara Floodplain Advisory Committee was established in 1996 to advise Council on the planning, development and management of the floodplain and has produced the Guragunbah Hydraulic Master Plan (GCCC 1997a) for this purpose. One of the many requirements of this plan is that the flooding impacts of any future developments must be tested to ensure that the development, either singly or cumulatively, does not cause, or has the potential to cause, ‘real damage’. For the Nerang River and some other major rivers in Gold Coast City this means that development should not cause afflux that would worsen flooding or create new flooding.

The designated flood for planning purposes is the 100 yr ARI. Table 9.9 presents a selection of predicted flood levels across the Nerang River floodplain.

Tallebudgera and Currumbin Creeks:

Hydrologic and hydraulic investigations of these creek systems have also been undertaken (GCCC 1997d, 1999a) although the recent reappraisal of rainfall estimates may have altered some of the original flowrates and a future update may be done. The lower reaches of both creeks are heavily developed with a number of canal estates.

Flood velocities in Tallebudgera Creek are quite high upstream of Lakewoods Estate due to the steep bed gradient and narrow stream width. Further downstream at Elanora, the creek meanders and increased friction results in an increase in flood levels upstream. Velocities at the mouth can also be high during major flood events. Most of the floodplain areas which have been developed do not become inundated up to the 100 year ARI event. Regions behind Palm Beach are the most affected and some properties will experience overfloor flooding at the 100 yr ARI level. Currumbin Creek exhibits similar behaviour, with higher velocities in the upper reaches and at the mouth. Table 9.9 presents selected flood levels from hydraulic studies.

Ocean Water Levels:

All of the above studies rely on estimates of the effects of tide and storm surge on the river tailwater during a flood event. Additional studies have considered these effects, together with the potential impact of rising sea level due to the enhanced greenhouse effect (ie. global warming).

Floodplain Management:

A range of individual initiatives across the region is now being amalgamated into a comprehensive floodplain management framework (GCCC 1999a). The key approaches include:

- Designated flood events for each specific land use, i.e. residential, commercial, industrial
- Allowable degrees of hazard for access to development, i.e. depth of water, velocity
- A risk management strategy for each land use to establish building platform and floor levels
- Special consideration for non-habitable spaces, on-site stormwater detention and redevelopment issues

Flood Mitigation:

A number of options have been investigated for reducing the impact of floods across the region. These include conveyance improvements to channels, bridges, weirs, amendments to road infrastructure and the possible raising of Hinze Dam. Recent development applications have incorporated synergies with the Council's physical works flood mitigation strategy for the Nerang River. For example, the raising of the Hinze Dam, in 1989, is predicted to have lowered flood levels by between 200 mm and 650 mm across the Nerang River floodplain for a repeat of the January 1974 rainfall. There remains further scope to raise the dam and to gain further protection from major floods. An artificial outlet to the sea has also been explored as an option for the Nerang River flooding problem.

Table 9.9 Summary of predicted flood levels in South-East Queensland

Local Authority	**River or Creek System**	**Location**	**Predicted Flood Levels (m AHD)**				
			10% AEP	**2% AEP**	**1% AEP**	**0.2% AEP**	**PMF**
Caboolture Shire	Caboolture R	River Mouth	1.87	2.18	2.30	-	-
		Riversleigh	2.80	3.17	3.32	-	-
		Bruce Hwy (u/s)	5.77	7.31	7.88	-	-
		Morayfield Rd	7.58	9.02	9.62	-	-
	King John Ck	Beachmere Pd	2.33	2.94	3.20	-	-
		Caboolture Rd	4.08	4.55	4.68	-	-
		Bruce Hwy	6.29	7.06	7.39	-	-
		Pumicestone Rd	8.14	8.72	9.03	-	-
		Beerburrum Rd	11.91	12.49	12.52	-	-
	Lagoon Ck	Bruce Hwy (u/s)	6.50	7.59	7.80	-	-
		Railway Crossing	10.61	11.59	11.89	-	-
	Burpengary Ck	Oakey Flat Rd	-	-	28.60	-	-
		Rowley Rd	-	-	14.38	-	-
		Dale St area	-	-	11.75	-	-
		Bruce Hwy (south)	-	-	7.98	-	-
	Little Burpengary Ck	New Settlement Rd	20.16	20.35	20.42	-	-
		Ruatoka Ct	14.62	14.74	14.79	-	-

Local Authority	River or Creek System	Location	Predicted Flood Levels (m AHD)				
			10% AEP	2% AEP	1% AEP	0.2% AEP	PMF
		Philips St	13.66	14.11	14.25	-	-
		Old Bay Rd	4.89	4.97	5.01	-	-
		Blue Pacific Rd	2.94	3.07	3.13	-	-
	Six Mile Ck	Beerburrum Rd	21.49	22.70	23.03	-	-
		Bruce Hwy	15.11	16.37	16.83	-	-
	Gympie Ck	Railway Bridge	14.79	15.38	15.62	-	-
		Bruce Hwy	5.32	6.18	6.50	-	-
	Wararba Ck	Bellmere Rd	9.30	11.30	12.08	-	-
		Richards Court	14.43	14.49	14.98	-	-
Pine River Shire	Conflagration Ck	South Pine Rd U/S	-	9.6	-	-	-
	Cabbage Tree Ck	Francis Rd	55.4	56.0	56.2	-	-
	Freshwater Ck North	Anzac Ave	6.2	-	6.6	-	-
	Freshwater Ck	Brays Rd	6.6	-	7.2	-	-
	Albany Ck	Albany Creek Rd U/S	-	16.5	16.6	-	-
	Colthards Ck	Gympie Road U/S	6.9	8.0	-	-	-
	Saltwater Ck	U/S Bruce Highway	17.0	17.7	18.3	-	-
	Yebri Ck	Anzac Ave U/S	-	12.3	-	-	-
	Terrors Ck (Dayboro)	William St. west	-	52.9	-	-	-
Brisbane City	Brisbane R	Mt Crosby Weir	18.65#	21.7*	23.6	-	-
NB: # Indicates 25 year ARI.		Moggill	11.35#	14.40*	16.20	-	-
		Jindalee UQ Vet Farm	7.30#	9.85*	11.50	-	-
		Port Office	2.10#	3.15*	3.85	-	-
*Indicates 55 year ARI	Breakfast Ck	Kelvin Grove Rd	5.84	6.96	7.77	-	-
		Opp Mann Park	2.60	3.41	4.00	-	-
		Opp Newstead House	1.09	1.13	1.17	-	-
	Oxley Ck	Mouth of Oxley Ck	1.26	1.60	3.50	-	-
		Corinda High School	4.27	5.71	6.71	-	-
		Beatty Rd	7.37	9.56	10.22	-	-
	Bulimba Ck	Greenwood St	22.52	23.03	23.39	-	-
		Merion Pl	11.24	12.11	12.37	-	-
		Old Cleveland Rd	6.65	7.42	7.98	-	-
		Doughboy Pde	2.35	2.83	3.02	-	-
		Aquarium Ave	1.72	2.04	2.00	-	-
	Norman Ck	Caswell St	3.02	3.61	3.97	-	-
	Moggill Ck	Fortrose St	9.88	11.02	11.48	-	-
	Kedron Brook	Osbourne Rd	33.00	33.81	34.25	-	-
		Hayward St	20.16	21.10	21.61		
		Kedron Park	9.86	10.52	10.88	-	-
	Cabbage Tree Ck	Old Northern Rd	43.28	43.53	43.84	-	-
		Pineapple St	13.07	13.78	14.43	-	-
		Braun St	2.46	3.40	3.76	-	-
Ipswich City	Brisbane R	Kholo Bridge	18.45	29.04	31.42	32.68	44.64
		Mt Crosby Weir	14.65	24.78	27.11	28.58	41.10
		Moggill Gauge	7.14	16.19	18.26	20.61	33.27
	Bremer R	Hancock Bridge	15.69	20.49	22.05	24.67	36.27
		David Trumpy Bridge	12.41	16.94	18.60	20.79	33.39
		Warrego Hwy Bridge	9.88	16.23	18.30	20.72	33.34
	Six Mile Ck	Redbank Plains Rd	32.80	33.04	33.19	33.46	34.60
		Ipswich Rd	6.82	15.80	17.87	20.22	32.81

Local Authority	River or Creek System	Location	Predicted Flood Levels (m AHD)				
			10% AEP	2% AEP	1% AEP	0.2% AEP	PMF
	Goodna Ck	Kruger Pde	15.23	15.60	17.14	19.44	31.84
		Brisbane Tce	7.56	15.11	17.14	19.44	31.84
	Bundamba Ck	Swanbank Rd	31.10	31.55	31.73	32.35	35.11
		Cunningham Hwy	25.61	26.05	26.24	26.79	33.36
		Brisbane Rd	16.10	16.78	18.30	20.73	33.36
Logan City	Scrubby Ck	Princess St Marsden	11.56	12.08	12.29	-	-
		Logan Mway Xing	8.94	9.70	10.15	-	-
		Railway Bridge	7.46	9.38	10.15	-	-
		Slacks Ck Junction	7.46	9.37	10.15	-	-
	Logan R	Chapmans Flat	10.39	13.09	13.8	-	-
		Waterford Bridge	9.18	11.77	12.64	-	-
		Railway Bridge	7.80	9.99	10.72	-	-
		Slacks Ck Junction	7.46	9.37	10.15	-	-
		Edens Landing	6.73	8.57	9.33	-	-
		Pacific Highway	5.47	6.86	7.46	-	-
		Albert R Junction	3.24	4.56	5.11	-	-
		Native Dog Ck Junc	2.15	3.55	4.18	-	-
Gold Coast City NB: *indicates 20 yr ARI	Albert R	Stanmore Rd	9.65	12.18	13.18	-	-
		Windaroo Ck	7.68	9.67	10.43	-	-
		Pacific Hwy	6.40	8.08	8.71	-	-
		Beenleigh	5.23	6.83	7.47	-	-
	Coomera R	Pacific Hwy (d/s)	3.81*	4.06	4.32	-	-
		Hope Island Resort	2.77*	3.02	3.25	-	-
		Oyster Cove	2.06*	2.3	2.45	-	-
		Sanctuary Cove	2.03*	2.38	2.49	-	-
		Paradise Point	1.56*	1.88	2.14	-	-
		Coombabah Lake	1.78*	2.09	2.34	-	-
	Nerang R	Nerang	5.00*	5.73	6.28	-	-
		Royal Pines Resort	3.59*	4.19	4.67	-	-
		Sun Lakelands	3.25*	3.87	4.41	-	-
		Sorrento	2.97*	3.47	3.97	-	-
		Clear Island Waters	3.27*	3.90	4.40	-	-
		Bond University	3.02*	3.65	4.11	-	-
		Mermaid Waters	3.00*	3.58	4.07	-	-
		Broadbeach Waters	2.66*	3.22	3.69	-	-
		Isle of Capri	2.19*	2.71	3.19	-	-
		Paradise Waters	1.64*	2.05	2.49	-	-
	Tallebudgera Ck	Gold Coast Hwy	1.54	1.98	2.21	-	-
		Pacific Hwy	1.79	2.32	2.57	-	-
		Tallebudgera Connection Rd	3.32	3.77	3.94	-	-
	Currumbin Ck	Gold Coast Hwy	1.53	1.96	2.15	-	-
		Thrower Drive	1.57	30.20	2.21	-	-
		Pacific Hwy	1.61	2.03	2.25	-	-
		Pine Lakes Entrance	1.65	2.10	2.31	-	-

Flood damage

Flooding affects all people, buildings and infrastructure which fall within the zone of inundation, as well as those which fall outside the zone of inundation but which either directly or indirectly use the affected facilities, whether it be roads, a hospital or a fuel refinery. Figure 9.11 summarises the various categories of urban flood damage. Flood damage at the most basic level can be divided into tangible (i.e. financial), or intangible (i.e. social) terms (ARMCANZ, 2000). Direct economic costs are easy to estimate from loss of contents, structural damage and external damage. Indirect costs (such as loss of opportunity [e.g. closure to schools], financial [e.g. loss of production] and clean up costs) are harder to express in dollar terms. Intangible or social costs (e.g. emotional trauma) are even harder to estimate, though the impact of flooding on a person may last long after the tangible costs have ceased to be significant. Appendix H describes the outcomes of flooding in South-East Queensland and some of the impacts. The appendix is limited, and may be enhance in future dedicated projects.

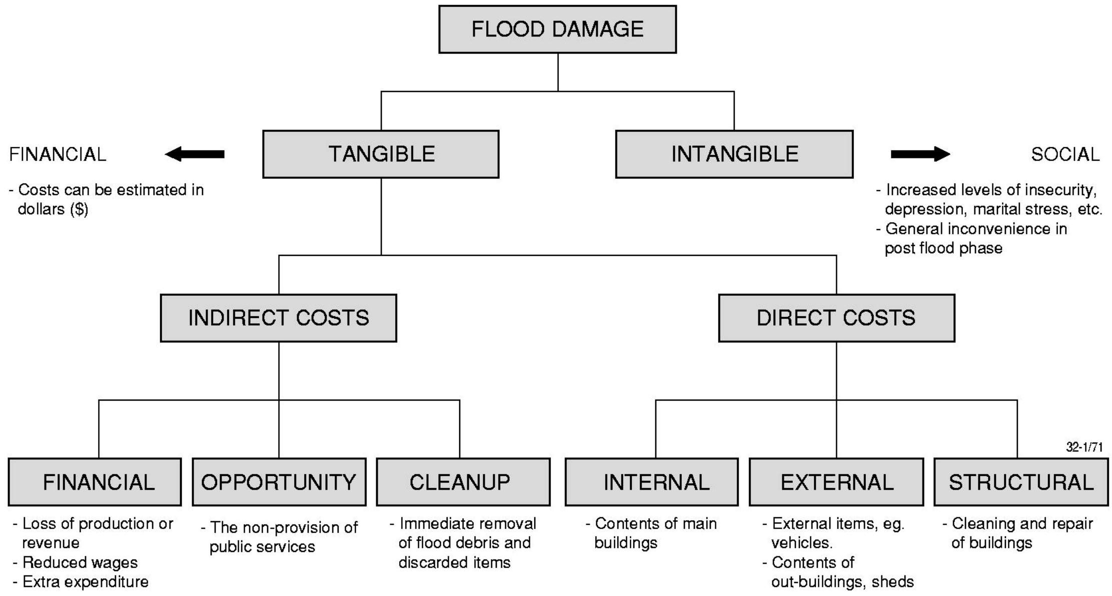


Figure 9.11: Categories of urban flood damage (ARMCANZ, 2000)

In this study, residential building flood damage only is estimated. Flood damage to buildings can be separated into contents and structure damage. The greatest increase in damage to single storey residential buildings for both structure and contents occurs within the first half metre of overfloor flooding. Almost all damage to contents occurs within the first metre of overfloor flooding. Damage to structure, however, increases almost linearly (after a sharp increase in about the first half metre of overfloor flooding) and damage can still be increasing at 3 m (Blong 2001). Due to the large scatter common with flood damage, stage damage curves are not accurate for determining the damage costs to individual buildings. They are, however, valuable in estimating total damage.

Prior to overfloor flooding, damage is restricted to the external building, gardens and fences; and tools, lawnmowers and other items stored below floor level. As soon as overfloor flooding occurs, there is a large increase in flood losses with damage to floors, built-ins, plasterwork, plumbing and electrical, internal decoration and contents. As water depth overfloor increases, so does the risk of extensive damage and structural failure. Blong (2001), for example, showed that where overfloor flooding reached a depth of about 1 m in single storey residential houses, damage to the building (ie excluding contents) ranged 9-25% of the building value, depending on the duration of inundation. Where overfloor flooding reached a depth of about 3 m, damage increased to 34-52%.

Velocity is also a major factor in determining percent damage, with high velocities capable of causing building collapse even in relatively shallow waters. Black (1975), for example, showed that building failure of weatherboard houses could occur when water over the floor is more than one metre and water velocities are more than about 2 m/sec. At lower velocities and greater depths, and at higher velocities and lower depths, building failure may also occur. Building construction/materials are also factors which influence susceptibility to structural failure. Typically, brick veneer residential buildings can withstand higher velocities and depths than single storey weatherboard residential buildings before building failure occurs (Black, 1975). Building age can play a contributing factor to the amount of flood losses, as age can indicate the condition of the building and materials used in construction.

Duration of inundation and amount of sediment also influence the amount of flood damage. For contents loss, factors such as the elevation/location of contents, warning time and awareness also play a major role in the resultant flood damage. A warning time of twelve hours, for example, can provide sufficient time for people to save much of their contents as long as **they are aware and prepared.**

Damage assessments for commercial/industrial buildings are more difficult to determine, though the dollar loss resulting from these greatly exceeds that for residential buildings. The potential mean annual flood damage for industrial buildings (Rand 0.94 m) in Vereeniging, South Africa, for example, far exceeded mean annual damage for residential buildings (Rand 124 000) for the same area (Booysen and Viljoen 1996 in Booysen, Viljoen and de Villiers 1999).

Modelling of flood damage assumes that the buildings have not already been damaged extensively prior to flooding from other hazards. This, however, is not always the case as demonstrated for example in Mackay, Central Queensland. In 1918, severe wind and storm tide preceded landbased flooding, so that the damage caused by riverine flooding in Mackay was minor compared to the damage already inflicted by wind and storm tide.

Limitations and uncertainties - Flood scenarios

Before examing flood risk in the South-East Queensland region it must be pointed out that significant uncertainties are associated with the estimates of damage losses presented here. Sources of uncertainty include, but are not confined to:

Uncertainty in the hazard models:

Uncertainties originate from the inherent variability of floods, inaccuracies in the individual hazard models used, and variations in the modelling within and between catchments. Edge effects were also created when modelling flood depths using the digital elevation model (DEM). Some of the variation between modelled scenarios for each catchment is mentioned below:

1. Caboolture River and Burpengary Creek:
   - 2% and 1% AEP scenarios available.
2. Pine Rivers:
   - 2% and 1% AEP scenarios available but insufficient data to model flood depth.
3. Brisbane-Bremer River:
   - Brisbane River - mapping based on historical flood levels;
   - Major Brisbane Creeks - modelled 1% AEP scenario; and,

- Ipswich 2% and 1% AEP scenarios available.

4. Logan-Albert River:
    - Logan LGA – designated flood scenario available. This varies between applying a 50 year ARI in the upper reaches of Scrubby/Slacks and Native Dog Creeks and a 125 year ARI in the lower reaches and the main Logan River; and,
    - Gold Coast LGA – 2% and 1% AEP scenarios available.
5. Pimpama, Coomera, Nerang, Tallebudgera and Currumbin River/Creeks:
    - 2% and 1% AEP scenarios available, but include a storm surge component along the Broadwater and at Paradise Point.

The uncertainties are, however, building specific and generally affect only part of the study area within a catchment. As loss is shown as a percent damage per building (i.e. it is an average across residential buildings affected **and** unaffected by flooding), it is unlikely that these uncertainties affect damage loss estimates.

Uncertainty in the digital elevation model (DEM):

A DEM was developed for each catchment with a 10 m grid size. Though, a finer resolution grid size would improve the accuracy of the flood damage modelling, particularly when interpolating in the canal estates, the elevation model was developed for a broad-scale study and hence will contain inaccuracies at the individual parcel level.

Uncertainties and incompleteness of the property inventory:

Uncertainties and incompleteness of the property inventory for information such as feature description (particularly relevant for identifying the more critical facilities) and floor height. The key values of floor height and ground height were taken from the detailed property database described in Chapter 3. Floor heights have been estimated on the basis of building age rather than field survey, as was done by the *Cities Project* in Cairns, Mackay and Gladstone. A broad generalisation has been adopted where houses built up to and including 1980 will have a suspended floor at least 0.8 m above ground level and houses built after 1980 will be on a slab (0.3 m above ground level). No allowance has been made for the high-set 'Queenslander' style house so common in northern Queensland. Observation of high set houses in coastal areas of South-East Queensland indicates that where such houses exist the under-house areas have almost all been enclosed, thus making them two story houses with floor heights at 0.3 m. Again these are perhaps conservative assumptions. Non-residential buildings are all assumed to have a floor height of 0.3 m above ground level. Though the floor height inventory may not be accurate at the individual property level, it has been used to provide a good indication of relative flood damage losses.

Uncertainty in the flood loss curve:

The damage (% sum insured) provides a good estimate of residential building flood losses, though it may not be accurate at the individual property level. The assumptions made when applying the loss curves in this context will be discussed later.

The analysis of flood losses does not consider non-residential structures such as commercial, industrial and infrastructure facilities. As stated earlier, damage to these types of facilities can be very costly to the community, both in the tangible and intangible effects they cause. Nor does the assessment consider direct or indirect economic or social losses, or casualties. Hence, potential damage is an underestimate and further analysis is required to develop a more comprehensive understanding of how the community could be affected. In the following analysis, direct dollar losses for residential buildings are not calculated because of the additional uncertainties and complexities involved.

Considering the uncertainties and on-going refinements to the modelling, the data may alter as a result of regular updating. The information provided here is, however, a best estimate using the best available data at the time.

Comparative flood risk

The modelled impact of flooding is presented for the urban centres as shown in Table 9.10. The results are shown by river system/catchment.

Table 9.10: Urban centres in the study area

River Systems/catchment	Urban centres
Caboolture River and Burpengary Creek	Caboolture
Pine Rivers	Pine Rivers
Brisbane – Bremer River	Brisbane and Ipswich
Logan – Albert River	Logan City and Beenleigh
Pimpama, Coomera, Nerang, Tallebudgera & Currumbin R/Cks	Gold Coast City

Two modelled flood scenarios (2% AEP or 50 year ARI, and 1% AEP or 100 year ARI) are presented for each catchment, the limitations of which were stated earlier. The hazard mapping used in this study is that currently in use for floodplain management in the respective local government area (LGA). Where two local governments fall within one catchment (i.e. Brisbane and Ipswich), then the flood mapping adopted by both Councils was combined to assess flood risk across the river system. The Logan-Albert was also modelled as one river system, though Logan (to the north of the Logan River) falls within the Logan City Council LGA and Beenleigh falls within the jurisdiction of Gold Coast City Council.

Typically, a polygon showing only the extent of inundation was available from local Councils. Therefore, a ten metre DEM was used to model flood depths based on the flood mapping available for each catchment. Ideally, flood damage for the more extreme events (e.g. 0.2% AEP and PMF) should be modelled, however, hazard modelling for the more extreme events was unavailable except for Ipswich. The modelling identifies the:

- number of developed properties inundated by catchment;
- number of developed properties by catchment with overfloor flooding;
- percent of buildings with overfloor flooding of each feature type for the region;
- percent inundated residential properties by catchment;
- damage (% sum insured) for residential buildings, by CCD, catchment and region; and,
- number of the more critical facilities affected.

Flood risk to developed properties

Table 9.11 shows the modelled flood risk on developed properties during the 2% and 1% AEP scenarios. Across the region more than 47 400 developed properties are affected by flooding, of which more than half are affected by overfloor inundation. In both the 2% and 1% AEP scenarios, the greatest number of developed properties at risk from flooding fall within the Brisbane-Bremer catchment followed by the Pimpama-Coomera-Nerang-Tallebudgera-Currumbin river system. The percentage of developed properties having at least some water on the property in the Gold Coast area (20% during a 1% AEP flood event) is, however, much higher than in the Brisbane and Ipswich areas (10% in 1% AEP event). Of those properties inundated, the Brisbane-Bremer catchment has a higher percentage of buildings with overfloor flooding (65% in Brisbane-Bremer compared with 40% in the Gold Coast in a 1% AEP event). The number of buildings (and depth) of overfloor flooding is important when estimating flood damage as shown later.

Table 9.11: Flood risk to developed properties during the 2% and 1% AEP scenarios

River/creek systems	Total number of developed properties	Percent inundated of catchment		Properties inundated (any depth)		Overfloor inundation	
		2% AEP	1% AEP	2% AEP	1% AEP	2% AEP	1% AEP
Caboolture R and Burpengary Ck	37 254	1%	2%	524	824	255	428
Pine Rivers	38 390	0.4%	0.5%	156	203	No data	No data
Brisbane–Bremer R[1]	366 625	5.1%	5.9%	18 877	21 777	12 812	14 070
Logan–Albert R[2]	68 881	6.5%	6.7%	3636	3738	2729	2796
Pimpama, Coomera, Nerang, Tallebudgera & Currumbin [3]	106 881	10.5 %	19.6%	11 201	20 945	3376	8365
Total	**618 031**	**5.6%**	**7.7%**	**34 394**	**47 487**	**19 172**	**25 659**

1. For the Brisbane River only historical flood levels were available. For the major Brisbane Creeks only the 1% AEP scenario was available.
2. The designated planning scenario was used for the northern side of the Logan River. This varies between a 50 year ARI in the upper reaches of Scrubby/Slacks and Native Dog Creeks and a 125 year ARI in the lower reaches and the main Logan River. For the southern side of the Logan the 50 and 100 year ARI scenarios used.
3. Includes a storm surge component along the Broadwater and at Paradise Point.

Ipswich contributes only about 16% of the buildings affected in the Brisbane-Bremer river system during a 1% AEP event, with Brisbane alone having more than 18 300 developed properties affected by flooding. The number of buildings affected by a 1% AEP flood in Brisbane is likely to be an underestimate for a least two reasons. First, the hazard modelling of the Brisbane River is based on historical data, of which most of the flood levels are for recurrence intervals less than a 100 year ARI. Second, modelling of the major Brisbane creeks is based on 1983 data. Though the creek modelling for Brisbane was completed prior to the completion of Wivenhoe Dam in 1985, the size of the dam, and hence the mitigating effect of the dam on flooding in Brisbane was incorporated into the hazard model. Hence, an increase in the number of buildings on the floodplain in the intervening seventeen year period mean that the number of buildings affected by major creek flooding is likely also to be an underestimate.

Several thousand additional developed properties could be isolated by the floodwaters across the region, particularly in the Gold Coast and Brisbane areas. These properties could either be completely isolated by floodwaters or cut off by flooded access roads, though escape by foot (for able-bodied people) on dry land may be possible. **It is recommended to consider ‘potentially inundated’ those areas likely to be isolated and to evacuate people.** This allows a factor of safety in the event that the resolution used in the modelling is not sufficient to define accurately the boundary of inundation. Furthermore, localised stormwater flooding, in addition to riverine/creek flooding will increase the area affected by inundation and/or the numbers of properties isolated.

The area covered by a floodplain can be much larger than the area inundated during a 1% AEP flood. That is, the area up to, and including the PMF forms the floodplain though the 100 year ARI flood levels (1% AEP) are those commonly used as the designated planning scenario. As mentioned earlier, the PMF is rare and there are few rivers in Australia for which the PMF has been modelled. Depending on the topography of a river system, the number of buildings affected during a PMF (and/or other extreme scenarios) may increase significantly over the 1% AEP scenario. In Ipswich, for example, where the topography is quite hilly, the increase in number of buildings affected by flooding is five fold. Where the topography is flat, however, the increase may be marginal.

Properties affected by overfloor flooding

Properties affected by overfloor inundation (of any depth), as a percent of function, is shown in Table 9.12. Logistics, transport and storage facilities have the greatest percent of buildings affected by overfloor flooding (16%), followed by business and industry, and community facilities. This is similar to storm tide; however, the percent of function affected by riverine flooding is much greater than that affected by storm water inundation at the same recurrence intervals. For example, four times more logistic, transport and storage facilities are affected by riverine flooding than by storm surge inundated.

Table 9.12: Properties affected by overfloor inundation, as a percent of function, across the South-East Queensland study area

Function	Percent (%) overfloor inundation of feature type	
	2% AEP	1% AEP
Houses	2.4	3.1
Flats	3.3	5.7
Commercial accommodation	4.2	6.8
Business & industry	8.9	10.2
Logistic, transport & storage	16.0	16.4
Public safety & health	3.7	4.9
Community, education & sport	7.7	8.4
Utilities	5.2	5.9

Note: The total number of buildings in Redcliffe, Pine Rivers and Redland are included in the number of buildings in the study area though no inundation numbers are included for these areas in the statistics.

Residential properties by catchment

Table 9.13 shows residential properties as a percent of inundated developed properties and as a percent of all residential properties.

Table 9.13: Percent inundated residential properties by river system

River/creek systems	INUNDATED RESIDENTIAL PROPERTIES			
	% of properties inundated		% of all residential properties	
	2% AEP	1% AEP	2% AEP	1% AEP
Caboolture R & Burpengary Ck	95.6	94.9	1.4	2.2
Pine Rivers	79.5	81.8	0.3	0.5
Brisbane – Bremer R.	81.6	82.7	4.5	5.2
Logan – Albert R	92.4	92.5	5.1	5.3
Pimpama, Coomera, Nerang, Tallebudgera & Currumbin	95.9	96.1	10.7	20.1

Residential properties (houses and flats) are the overwhelming majority (about 89%) of inundated properties, though only between 5% (2% AEP scenario) and 7% (1% AEP scenario) of residential properties in the region are affected. Though a large percentage of affected buildings are residential, only a small amount of residential properties are actually affected - less than 6% for all river systems with the exception of the Gold Coast area where 20% of residential properties are affected in a 1% AEP scenario.

Damage (percent of sum insured) for residential buildings

Damage (percent sum insured) has been derived using a combined structure and contents loss curve for single storey residential buildings based on that in Blong (2001), which has been designed for the insurance industry. The curve is preliminary and needs to be tested against large amounts of insurance data, however, it provides a good estimate of flood damage. Though the curve provides larger losses than older Australian loss curves, it probably underestimates potential flood damage for single storey residential buildings, because many people are underinsured and because factors such as structural collapse and velocity were not considered specifically. Available data sets suggest that the ratio of building to contents vary. Here, a content to building ratio of 0.3 was deemed the most suitable.

The framework used for modelling damage for residential buildings is shown in Table 9.14. This has been developed from the loss curve shown in Figure 9.12. Residential buildings were divided into six categories, including i) not inundated, ii) inundated but not overfloor, and into iii-vi) four categories of overfloor flooding as shown in Table 9.14. The median was taken of each of the four categories of overfloor flooding to calculate percent damage. Where water depth overfloor exceeded 2 m, than percent damage for 2.5 m water depth overfloor was used, to reflect that the curves were designed for single storey residential buildings which typically have a height of about 3 m.

Percent damage by CCD was derived by multiplying percent damage at water depth A with the number of residential buildings affected at depth A. This was repeated for depths B through F within the CCD. The product (of percent damage multiplied by the number of residential buildings) at depths A through F were then summed and divided by the total number of residential buildings in the CCD. This was repeated for each CCD. Percent damage by catchment and region (see Table 9.15) was derived in a similar manner.

Table 9.14: Framework used for modelling damage for residential buildings

Water depth		Damage (% sum insured)
Range	**Median used for calculating % damage**	
A. Not inundated	Not inundated	0
B. Inundated but not overfloor	-0.3 m	0.9
C. Overfloor >0 – 0.5 m	Overfloor 0.25 m	16
D. Overfloor >0.5 – 1.0 m	Overfloor 0.75 m	28
E. Overfloor >1.0 – 2.0 m	Overfloor 1.5 m	38.6
F. Overfloor >2.0 m	Overfloor 2.5 m	49.2

Though the best loss curve currently available, the loss curve has some obvious limitations when applied in this context, as summarised, but not confined to, those listed below:

- constructed for single storey residential buildings, but used here for all residential buildings;
- does not take into account high set homes, though many have been converted to habitable space, whether legally or illegally;
- damage to commercial/industrial buildings and other critical facilities are unknown and yet will contribute a large amount to damage losses;

- does not take into account buildings which may suffer 100% damage through structural failure, or suffer from 'domino effects' (e.g. collapse of one building causing greater damage to another building through its impact on it);
- median percent damage used to represent a range of inundation depths (e.g. for residential buildings with overfloor flooding up to 0.5 m, percent damage was derived from the median water depth, i.e. 0.25 m and a damage of 16% damage was applied, see Table 9.14);
- potential damage estimated – assumes nothing has been done to minimise damage (e.g. removal of contents);
- contents/building ratio varies. The loss curve used a contents/building ratio of 0.3 m;
- does not take into account other site specific factors which influence degree of damage other than water depth, of which velocity is the most important excluded factor. Building type is another important exclusion.

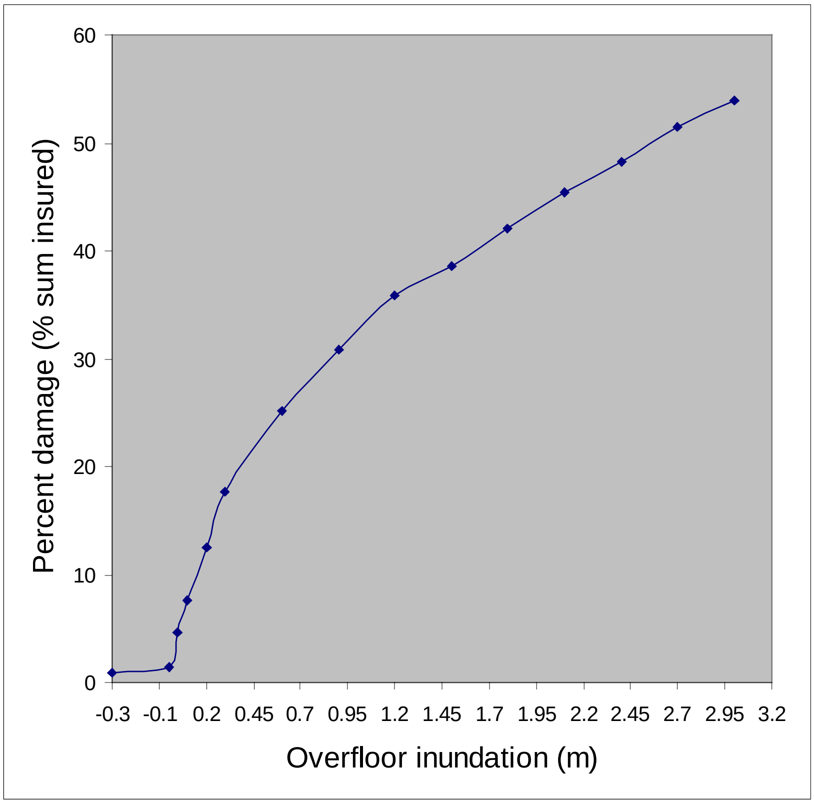


Figure 9.12: Structure and contents combined loss curve (From Blong 2001)

Percent damage for residential buildings by catchment and for the South-East Queensland study area is shown in Table 9.15. Damage is shown as a percent of sum insured. Damage for Pine Rivers could not be calculated because a suitable DEM (or contours from which to derive a DEM) was unavailable to model flood depths. Damage at Pine Rivers is expected to be low, particularly when compared with the other catchments.

Table 9.15 shows that every building in the South-East Queensland study area will suffer, on average, 1.09% damage during a 1% AEP flood event. The Brisbane-Bremer river system contributes more than half of the total flood damage to the region and double the amount of flood damage contributed by the Pimpama-Coomera-Nerang-Tallebudgera-Currumbin River system. The Pimpama-Coomera-Nerang-Tallebudgera-Currumbin River system, contributes about double the flood damage of the Logan-Albert River system during an event with a 1% AEP. Flood damage in Caboolture is small when compared with the rest of the region.

Table 9.15: Damage (% sum insured) per building

River/creek system	Number of residential properties	% damage (% sum insured)		% of total damage 1% AEP
		2% AEP	1% AEP	
Caboolture R. – Burpengary Ck.	36 128	0.19	0.34	1.8
Brisbane-Bremer R.	345 648	1.04	1.18	58.3
Logan-Albert R.	65 578	1.38	1.43	13.4
Pimpama, Coomera, Nerang, Tallebudgera & Currumbin R/Cks.	100 637	0.87	1.84	26.6
Total of riverine flood affected catchments	547 991[1]	1.00	1.28	100
Total South-East Queensland study area	**644 686[2]**	**0.85**	**1.09**	**100**

1. This includes the Caboolture, Brisbane, Ipswich, Logan and Gold Coast study areas.
2. The number of residential properties includes the Caboolture, Redcliffe, Pine Rivers, Brisbane, Ipswich, Logan, Redland and Gold Coast study areas.

The South-East Queensland region has the largest number of buildings affected in a 1% AEP flood event than any other region in Australia. This is partly because a single event (e.g. a cyclone), can cause rainfall across the region resulting in the flooding of several rivers, each flanked by urban development. However, each of the rivers in the region are unlikely to all suffer exactly a 1% AEP flood during the same episode of flooding. For example, the January 1974 flood in the Brisbane River was estimated to have had an ARI of about 75 years. However, in the Nerang River the flood of January 1974 had an ARI of 65-70 years, whilst in the Coomera and the Logan-Albert rivers an ARI of greater than 100 years has been estimated.

Damage for residential buildings by CCD (remembering the uncertainties mentioned earlier) is shown as an average percent damage per building for the region during 2% AEP (Figure 9.13) and 1% AEP (Figure 9.14) scenarios and by catchment for the 1% AEP scenarios in Figures 9.15-9.18. Using this method, the high damage sustained by some buildings in a CCD is diluted by the number of buildings not affected by flooding.

Damage from flooding is localised along the watercourses across the region and constrained by topography. The geographical extent of the CCDs varies greatly across the region. Typically, those CCDs located in the inner city are small, while those located on the rural/urban fringe are geographically large. However, the number of residential buildings located in a large rural CCD (e.g. Kholo, Ipswich) may be less than in a much smaller inner city CCD. Where residential buildings cover only a small portion of the CCD, the whole CCD will reflect the damage as affected by those few buildings. Therefore, though a CCD located at the rural/urban fringe may have a high percent residential building damage, fewer buildings may be affected by flooding than in the small urban CCD even though the damage in the rural CCD is depicted as covering a large area.

Residential building damage by CCDs varies across the region by 45%. Damage is greatest in the Brisbane-Bremer catchment, with the highest damage in any one CCD estimated at 45%. The CCDs with the greatest damage, falling in the suburbs of Fairfield (Plate 9.23), Rocklea, Chelmer, Saint Lucia (Plate 9.23), Toowong and Graceville (all with residential damage >30%) are areas which suffered substantially in the flood of January 1974. The largest damage for any one CCD in the Logan-Albert area is 24% and falls in the suburb of Waterford West (Plate 9.32). The largest residential building damage for any one CCD in the Pimpama-Coomera-Nerang-Tallebudgera-Currumbin catchment is 23% and in the Caboolture-Burpengary catchment a low 10%.

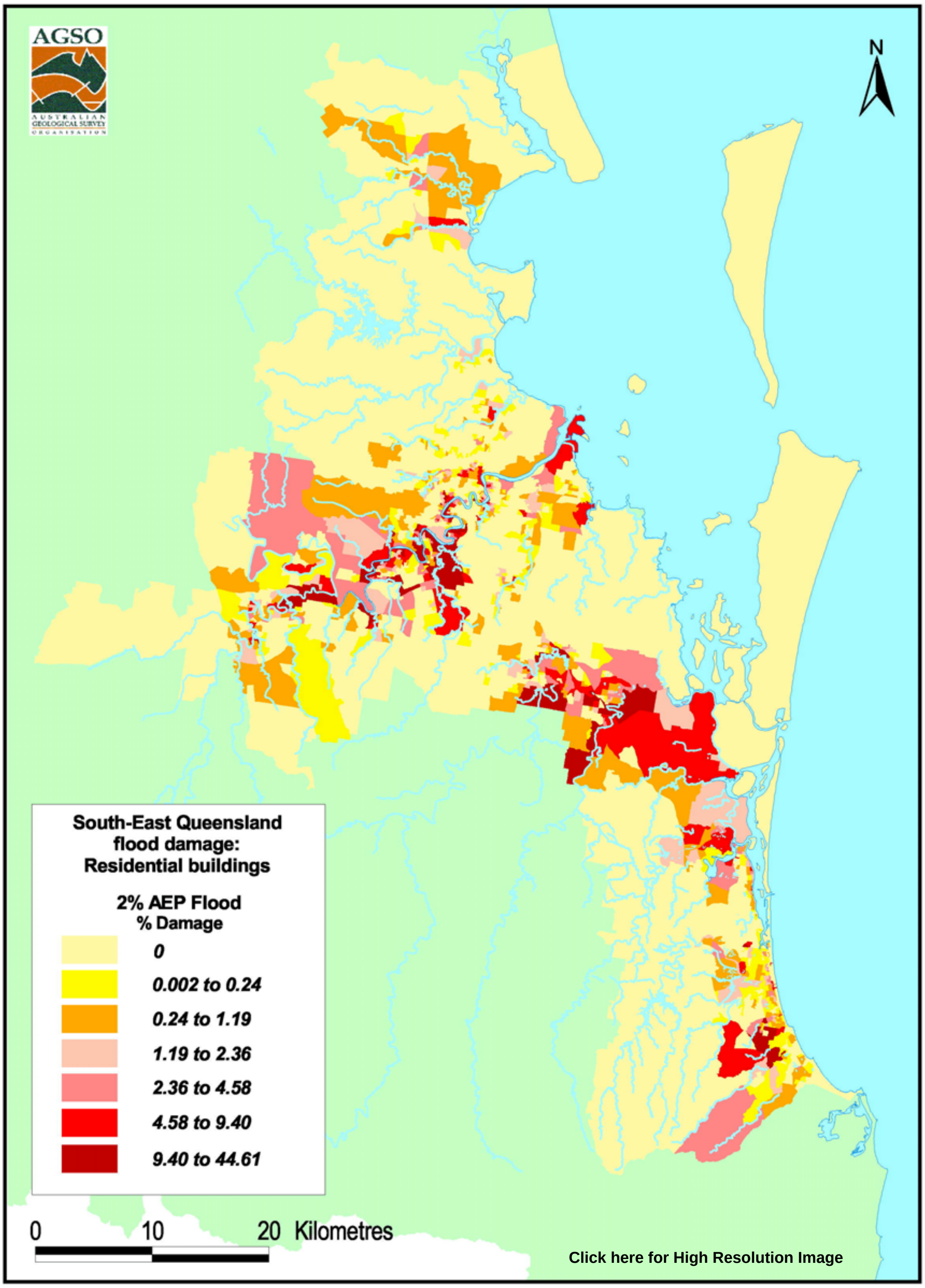


Figure 9.13: Damage (% sum insured) by CCD for residential buildings, 2% AEP, South-East Queensland region

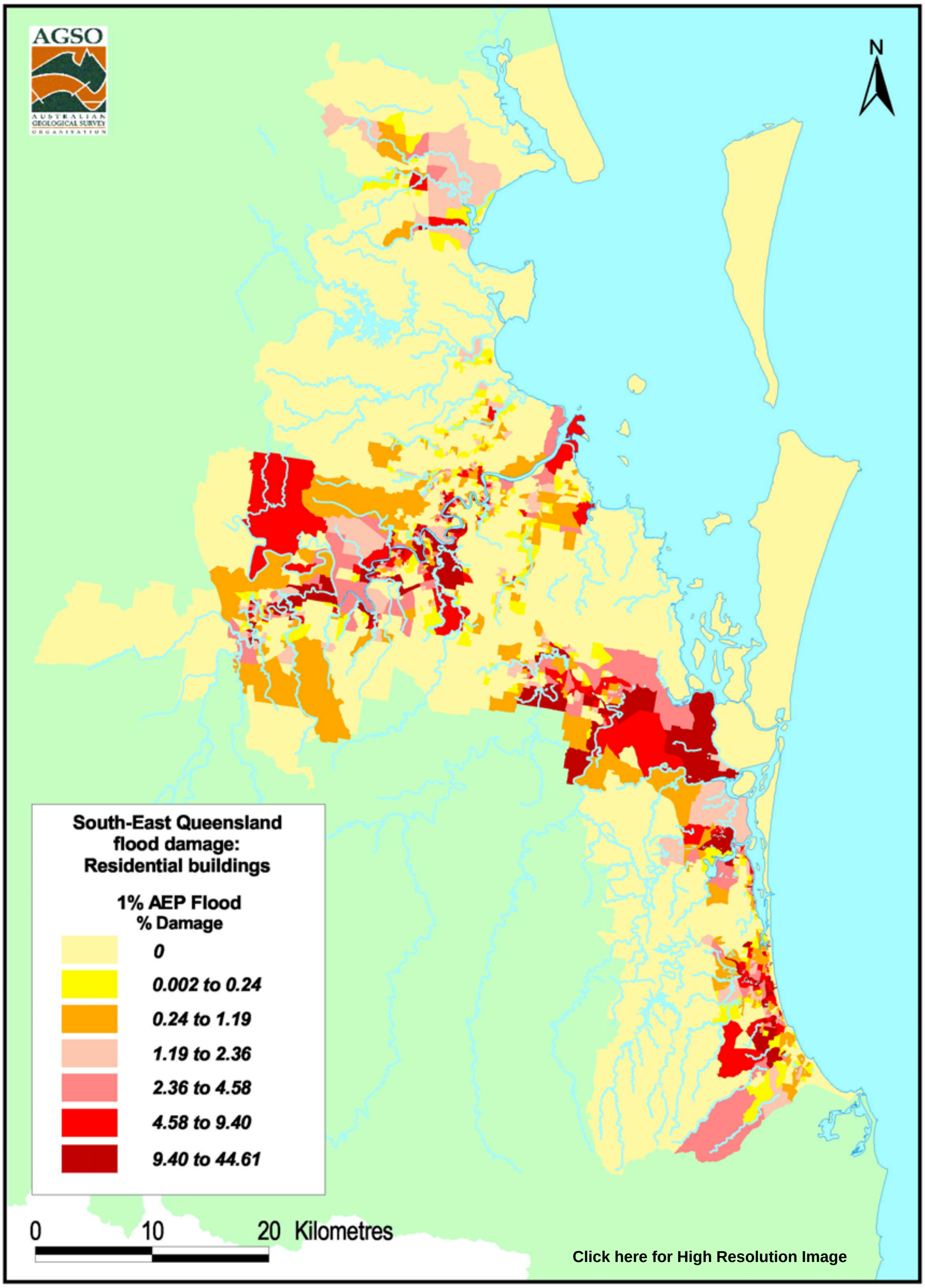


Figure 9.14: Damage (% sum insured) by CCD for residential buildings, 1% AEP, South-East Queensland region

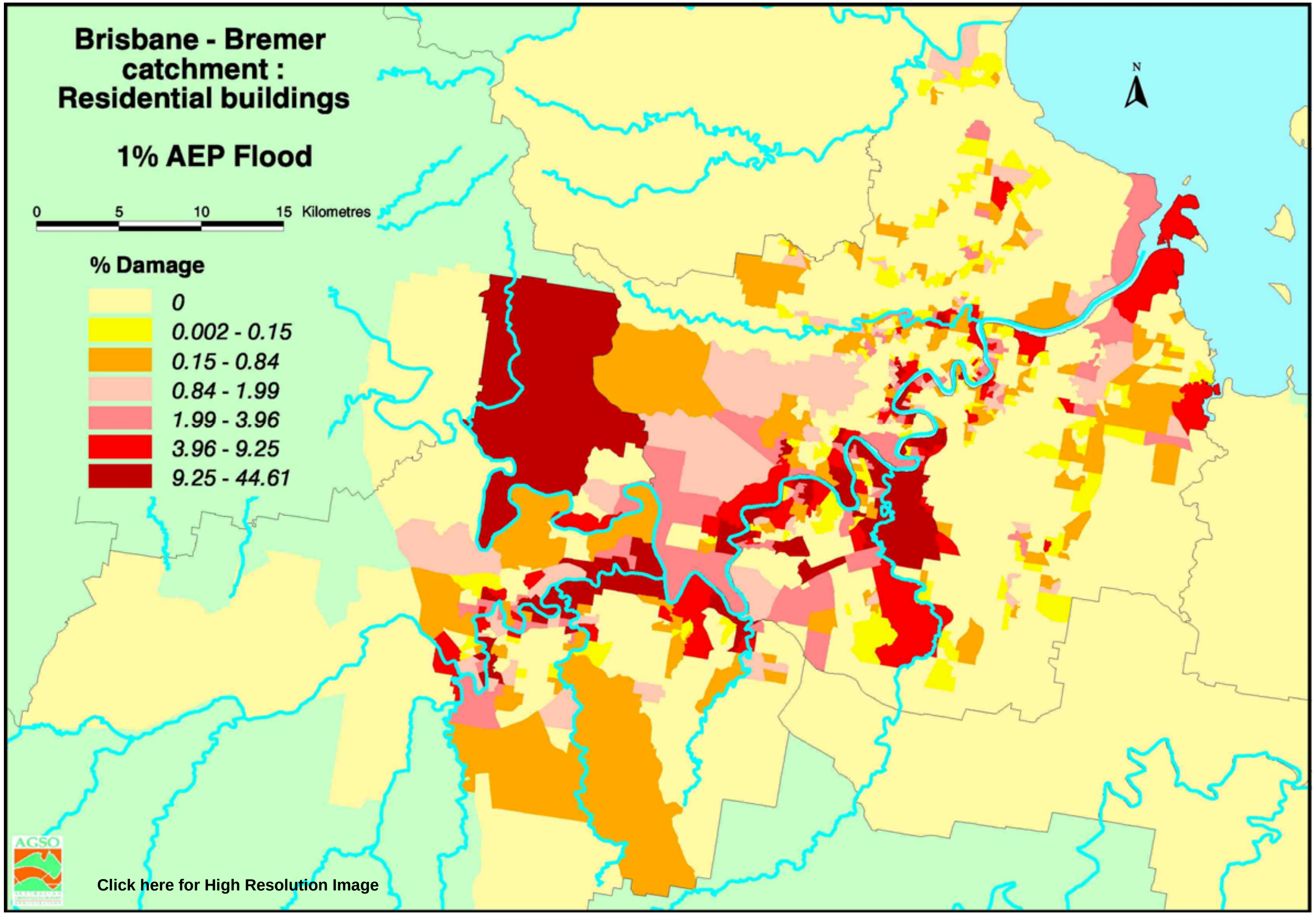


Figure 9.15: Damage (% sum insured) by CCD for residential buildings, 1% AEP, Brisbane-Bremer River catchment

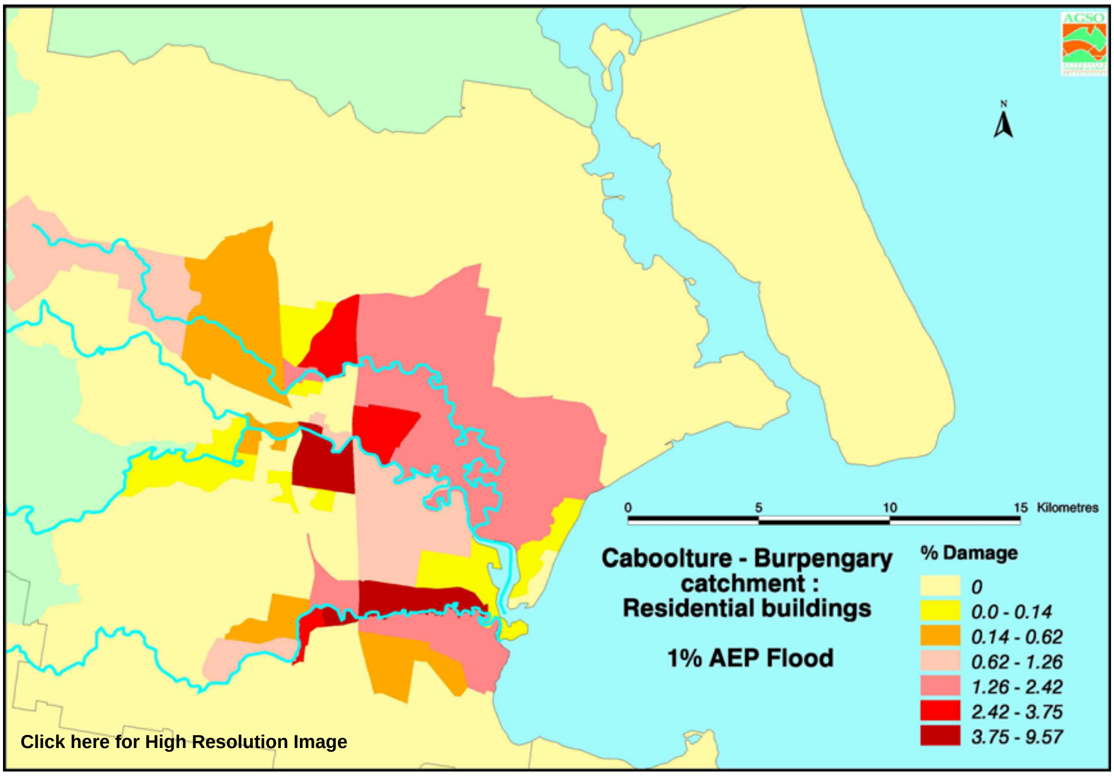


Figure 9.16: Damage (% sum insured) by CCD for residential buildings, 1% AEP, Caboolture River – Burpengary Creek catchment

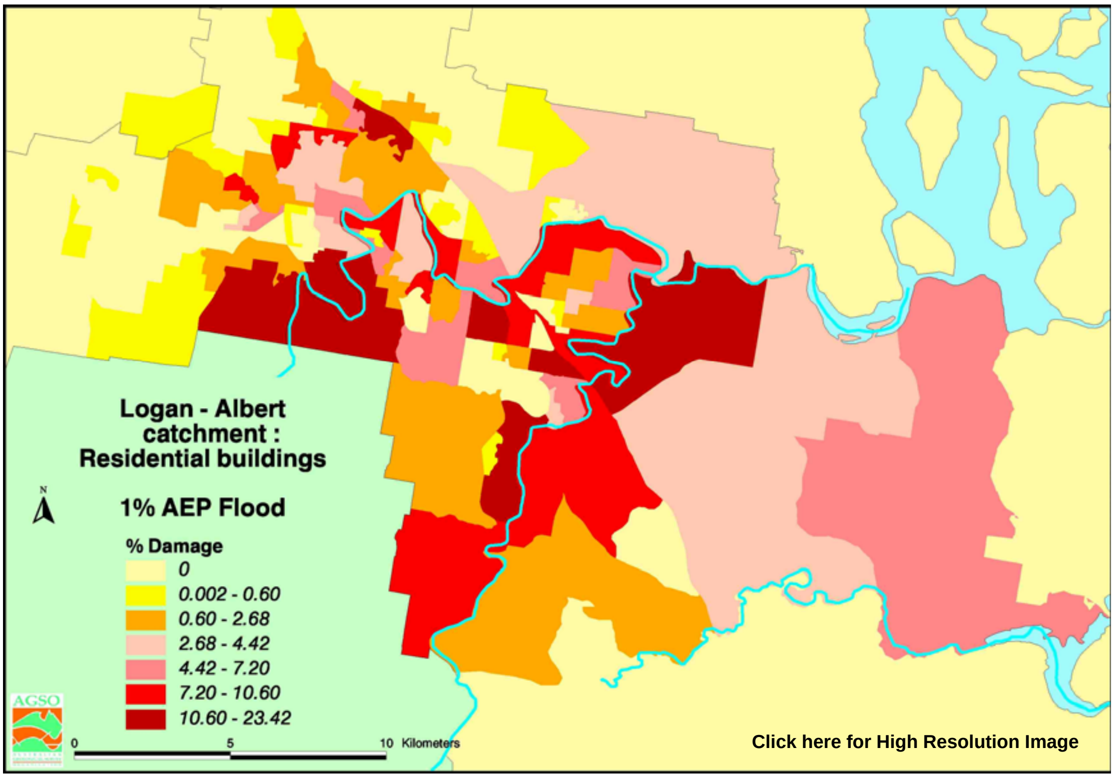


Figure 9.17: Damage (% sum insured) by CCD for residential buildings, 1% AEP, Logan-Albert River catchment

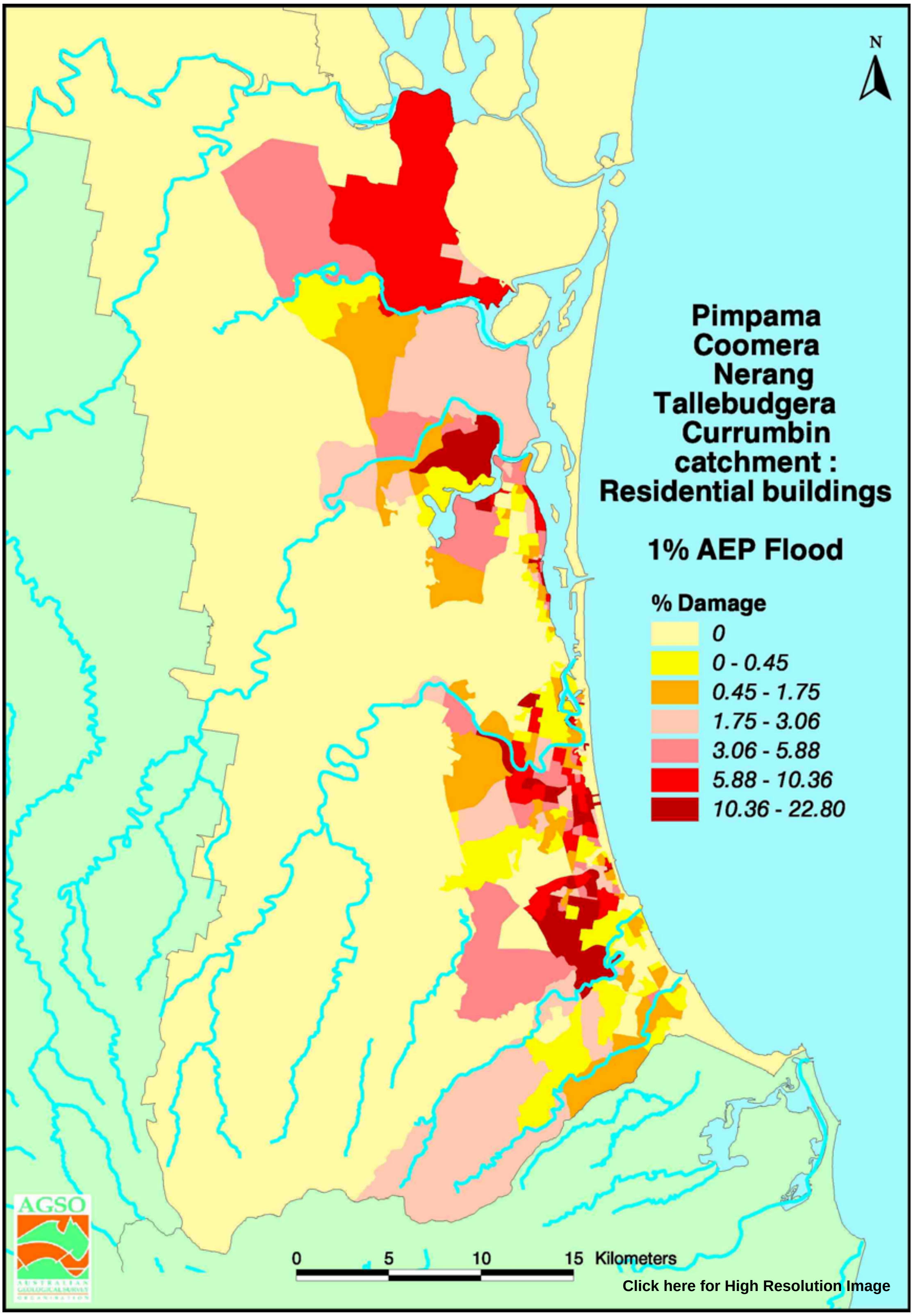


Figure 9.18: Damage (% sum insured) by CCD for residential buildings, 1% AEP, Pimpama-Coomera-Nerang-Tallebudgera-Currumbin catchment

Critical facilities

The greatest number of critical facilities affected by flooding are located in the Brisbane – Ipswich area followed by the Gold Coast area. Keeping in mind the uncertainties mentioned earlier, the particularly sensitive facilities likely to be affected by flooding during a 1% AEP event across the region are detailed as follows:

- two ambulance stations, one each in Caboolture and Brisbane;
- five fire stations, one each in Caboolture and Gold Coast, and three in Brisbane;
- a police station in Brisbane;
- the emergency services operations centre in Beenleigh;
- the air sea rescue, rescue helicopter base and Australian volunteer coastguard, all in the Gold Coast;
- a private hospital in Brisbane;
- nine telephone exchanges, of which six are in the Gold Coast, two are in Brisbane and one in Ipswich;
- thirteen substations, of which eight are in Brisbane, one in Ipswich, one in Beenleigh, and three in Gold Coast;
- a power station in Brisbane;
- three sewage treatment plants, one each in Caboolture, Gold Coast and Ipswich;
- six oil/fuel depots, of which one is in Logan, two in Ipswich and three in Brisbane;
- four railway stations, one each in Logan and Ipswich, and two in Brisbane;
- an airforce base in Ipswich and army barracks in Brisbane; and,
- an aerodrome and aircraft maintenance hanger, both in Brisbane.

Roads

Several hundred kilometres of road would be inundated across the region. A further few hundred kilometres of road could be isolated or cut off by the floodwater though evacuation by foot on dry land may be possible. Though inundated, some of the road may still be passable by vehicles. Evacuation by vehicle becomes increasing difficult and dangerous as water depths rise and velocities increase. Typically, small, low and light cars can only drive safely through water where depths are less than 0.3 m. Larger, higher and heavier cars can only drive safely though water less than about 0.4 m deep (ARMCANZ 2000).

Percent residential building damage and the community vulnerability index

Figure 9.19 shows the product of percent residential building flood damage by CCD and the community vulnerability index by CCD for the 1% AEP flood scenario. The higher the number, the greater the degree of overall risk during a 1% AEP event. The CCDs with the highest value fall in the suburbs of Chelmer, Fairfield, Saint Lucia, Toowong and Rocklea (value >17). These are the same CCDs which are worst affected when only damage is considered. Consideration of vulnerability, however, changes the ranking of CCDs. For example, two of the CCDs which fall in the suburb of Rocklea have a high percent damage but lower community vulnerability (relative to the other CCDs), therefore their overall rank falls somewhere inbetween.

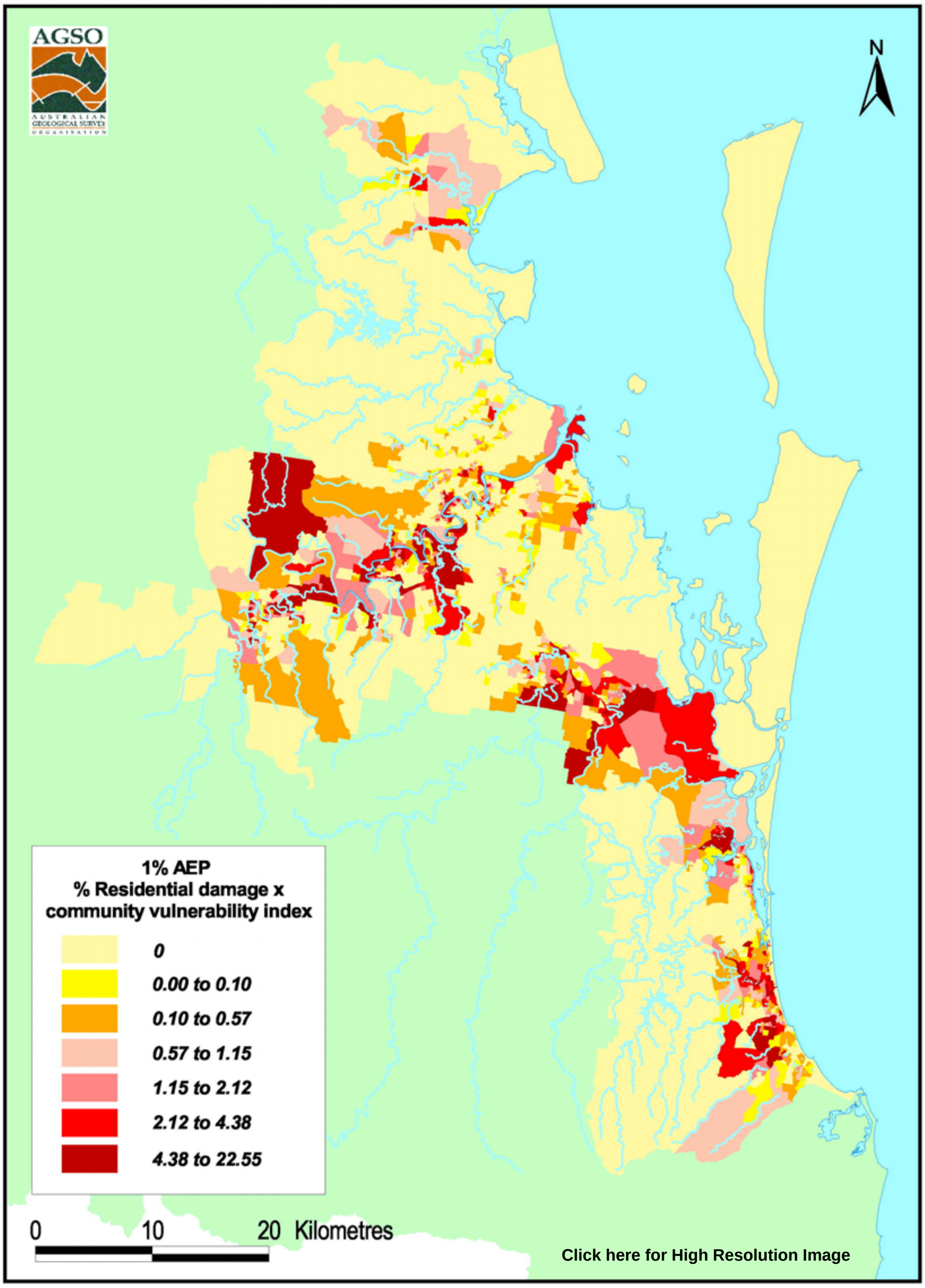


Figure 9.19: Percent residential building damage by CCD multiplied by the community vulnerability index by CCD for the South-East Queensland study area

Community Awareness

Community awareness for flooding is generally poor. Some common examples of misled perceptions are:

- a ‘1 in 100 year’ (100 year ARI) flood occurred twenty years ago, therefore another flood of that magnitude won’t occur for another 80 years;
- buildings which fall within the ‘1 in 100 year’ flood line are at risk of flooding. Those buildings which fall outside the ‘1 in 100 year’ line will never be flooded;
- because it hasn’t happened before it can’t happen;
- a belief in immunity from hazards; and,
- construction of a levee has made the area behind it flood free.

There is also frequently confusion as to how flood levels affect individuals and their properties, and a poor understanding by the media of the forecasts and flood warnings, often resulting in misinterpreted information reaching the general public.

Some of these issues are slowly being addressed. Logan City Council, for example, has established a pilot project whereby some 275 houses affected by flooding from Scrubby Creek were notified of their respective building floor height expressed as a height relative to the flood gauge. This personalising of the flood risk raises awareness amongst at risk households, thereby giving them the opportunity to reduce flood losses to their individual homes in the event of a flood. The Nerang River Flood Mitigation Community Consultation Project also aims to raise awareness of flood risk in the local area. Furthermore, it aims through community consultation, to develop a preferred list of treatment options to reduce flood hazard and risk.

Figure 9.20 shows how experience can greatly reduce flood damage (compared to inexperience) with increased warning time of up to about twelve hours. Experience could easily be substituted with awareness and inexperience with lack of awareness. **Therefore, an aware community is likely to be a less vulnerable community because of its ability to prepare for an event.**

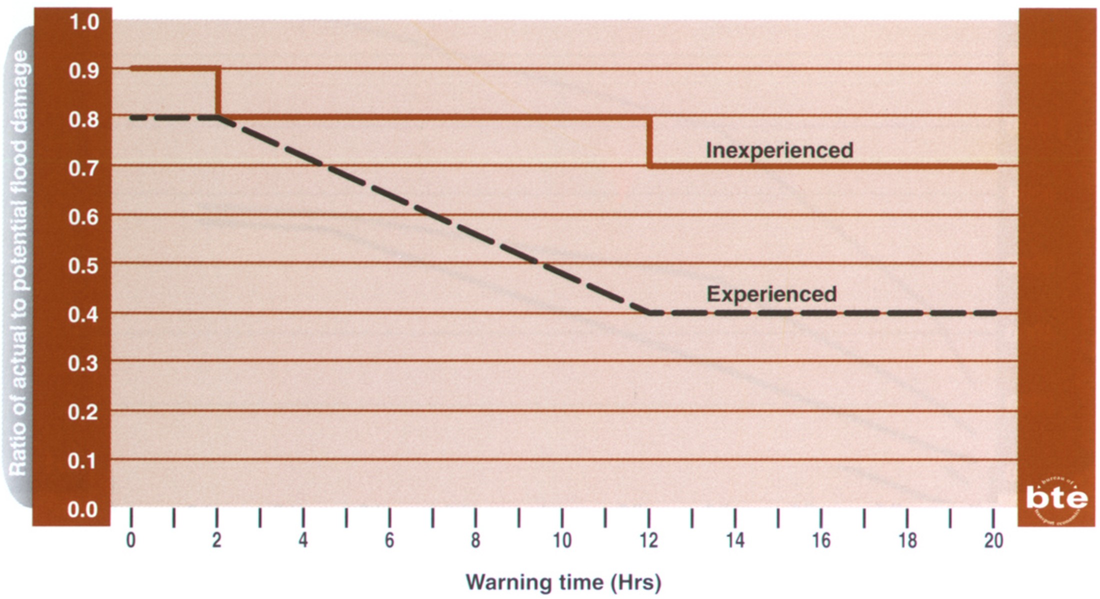


Figure 9.20: Affect of experience and warning time on actual flood damage (Bureau of Transport Economics 2001).

Interpretation

Historical records show that the South-East Queensland region has a long record of moderate to major floods. In the last century, the Australia Day floods of January 1974 resulted in the most widespread damage across the region and represent the most severe example of urban flooding to date in Australia. Each river system in South-East Queensland can flood independently, however, as the 1974 flood showed, each of the rivers in the region can flood within days of each other, causing widespread and prolonged disruptions and damage across the South-East Queensland region.

In the Brisbane River system approximately 13 000 buildings were affected in the January 1974 flood. In the Bremer River subcatchment, approximately 2000 properties in Ipswich were affected by the same flooding episode, 41 houses swept away and 600 houses fully submerged (Smith, 1998). A reoccurence of the 1974 flood today, would result in approximately 4700 developed properties being affected in Ipswich alone. The more than double increase in the number of developed properties affected in Ipswich is the result of the increase in urbanisation on the floodplain over the intervening 26 year period.

In the Gold Coast region, the January 1974 floods directly affected approximately 1000 residential dwellings. Although there has been a large increase in population in the Gold Coast and widespread residential development has occurred within the 1974 inundation zone, if a repeat of the 1974 rainfall were to recur, peak flood levels could be lower because of the floodplain mitigation works that have been undertaken. The strong floodplain planning strategy adopted by Council and advances in its flood emergency planning and response are important risk mitigation strategies adopted by Council.

Flooding of the Logan-Albert Rivers in January 1974 resulted in the destruction of several houses. As urban expansion in Logan began only in the early 1970s, just prior to the 1974 flood, the 1974 flood has since served as a benchmark event for local government controls on development. Flooding also occurred in the Caboolture River - Burpengary Creek and Pine Rivers catchments during the January 1974 floods, though the impact was much less than further south.

Contemporary reports of flooding since records have been kept indicate the immeasurable economic and social cost of flooding, for example, through building and contents damage, damage to infrastructure, agriculture losses, disruption of normal services (e.g. mail and rail) and loss of life. However, despite the historical evidence of the impact of flooding in the South-East Queensland region, occupation of flood prone land continues and the number of people who will be affected by flooding has not diminished.

Early evacuation of people from homes in flood affected areas minimises the risk of drowning especially in areas where water depth exceeds about half a metre (depending on velocity) and buildings are likely to have water overfloor. The movement of smaller items onto tables, shelves and into roof cavities (where the water level is not expected to exceed this level), or the movement of house contents and/or the family car to higher ground away from the flooding, are all methods of reducing the economic and social cost of flooding. As indicated earlier, the expected damage from flooding is directly proportional to the amount of awareness, with an improvement in awareness and preparedness resulting in a sharp decline in damage.

An effective flood warning system (as operated by the Bureau of Meteorology in conjunction with local government - described in more detail later) is therefore crucial to the provision of an adequate warning period for flood preparations and/or evacuation in flood prone areas.

Given the limited warning period available for the rivers and creeks in South-East Queensland (some rivers have less than twelve hours), local government needs to give considerable attention to detailed counter disaster planning and risk communication. To be fully effective, this requires the involvement of the communities at risk.

Local governments across the region have been faced with three choices regarding further development of its floodplains:

1. Prohibit development;
2. Permit some development with rigorous conditions; and,
3. Permit development on land already zoned.

The decision made, for example, to permit some development with rigorous conditions in flood-prone land in the Gold Coast area was one made carefully after considering the alternatives. That is, that to prohibit development was virtually impossible without compensation/injurious affection; and to permit development on land already zoned would have increased flood damage and worsened the existing situation.

Forecasting and Warnings

Flood warning is an integral component of counter disaster arrangements for a community at risk from flooding. The aim of a warning system is to minimise loss of life and property damage by warning people of the likelihood and size of a flood so that they can evacuate, shift property or stock to higher ground, or implement other temporary flood loss reduction measures. Warnings are of limited value unless they are delivered in a timely and effective manner and property owners and residents in the flood-threatened area have trust in the warning and take appropriate action in advance of being flooded.

The responsibility for flood forecasting and warning services in Australia rests with the Commonwealth Bureau of Meteorology. In Queensland, the effectiveness of the flood warning system depends on the cooperative involvement of the Bureau of Meteorology, State Government agencies and Local Government working with flood-threatened communities. The Queensland Flood Warning Consultative Committee (FWCC) is a joint Commonwealth, State and Local Government Committee which coordinates the development and operation of flood warning services in Queensland. The roles of the primary agencies involved in the flood warning system, as recommended by the FWCC, are outlined in Figure 9.21.

The development and provision of flood warning services in Queensland is the role of the Bureau's Flood Warning Centre (FWC) in Brisbane. The FWC operates up to 24 hours per day depending on the severity and extent of flooding. The basic components of the flood forecasting system are:

(a) Data collection & transmission

Rainfall and river height data are collected from over 1000 sites throughout Queensland via radio and telephone telemetry from automatic stations and via telephone-computer links from volunteer observers.

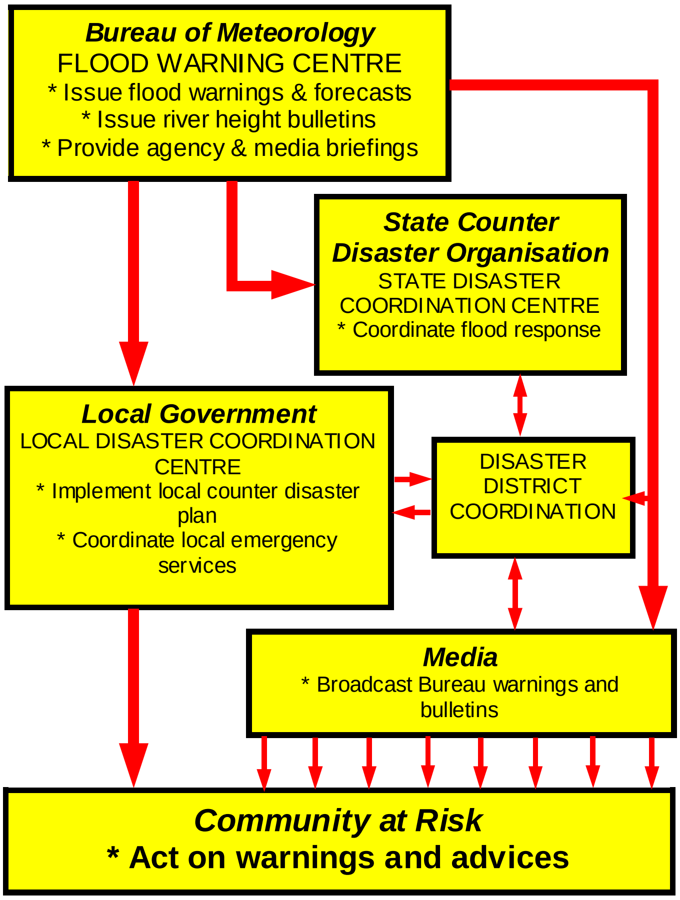


Figure 9.21 Roles and responsibilities within the flood warning system

(b) Meteorological & hydrological forecasting

The collated data is analysed using a range of techniques including simple empirical relationships and complex computer catchment simulation models to predict the likely timing and severity of flooding. The impact of forecast weather and rainfall conditions is also assessed.

(c) Flood warning services

River height bulletins:	These contain the latest observed river heights at selected locations within a river basin and are issued up to six times daily.
Flood warnings:	Provide a summary of existing conditions within a river basin and predictions of river heights at key locations (towns, bridges, rural centres).
Professional advice:	FWC staff provide direct assessments of flood conditions to emergency agencies and Local Government officers.
Media briefings:	Extensive briefing of radio, television and newspaper news services are provided as requested.

The FWC operations are summarised in Figure 9.22 and a typical ALERT flood warning installation is shown in Figure 9.23. Table 9.16 lists the number of rainfall and stream gauging stations in the South-East Queensland region which provide data to the warning system either via telephone or VHF radio. In recent years a number of radio-based rainfall and river height stations have been installed under joint Bureau, State and Local Government funding arrangements. The VHF radio ALERT systems are primarily used in small catchments with short warning times and automatically report either a 1 mm increment in rainfall, or a rise or fall in water depth of a pre-determined amount (say 5 cm). Local Authorities with their own computerised base stations can receive the ALERT data in 'real time', and are then able to assess current flood conditions in a most expedient way.

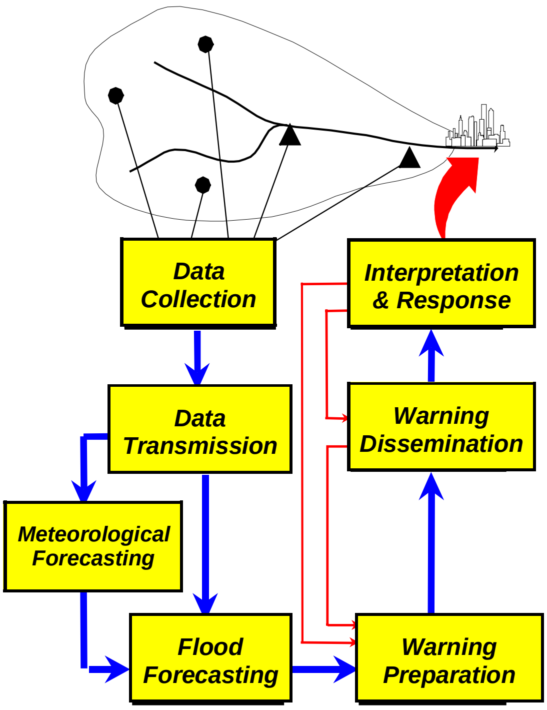


Figure 9. 22 Flood Warning Centre operations

Figure 9. 23 A typical ALERT installation

Table 9. 16 Summary of rainfall and river height gauging stations in South-East Queensland.

River System	Telephone Telemetry	Radio ALERT Systems	
	No. Stations	**No. Stations**	**Cooperating Authority**
Pine River	1	29	SEQWCo
Brisbane Valley, incl Brisbane and Ipswich Creeks	31	126	SEQWCo Brisbane City Ipswich City
Logan – Albert	21	13	Logan City
Nerang - Coomera	6	16	Gold Coast City
TOTAL	**59**	**184**	

The Bureau of Meteorology is able to provide summary brochures to the public which describe the flood warning procedures for particular river systems and give guidance on interpreting gauge forecasts.

During floods, Councils work closely with the Bureau of Meteorology in the provision of information to flood-threatened communities.

Further Information

More detailed information on the level of flood risk of individual neighbourhoods or properties should be referred to the respective local government council.

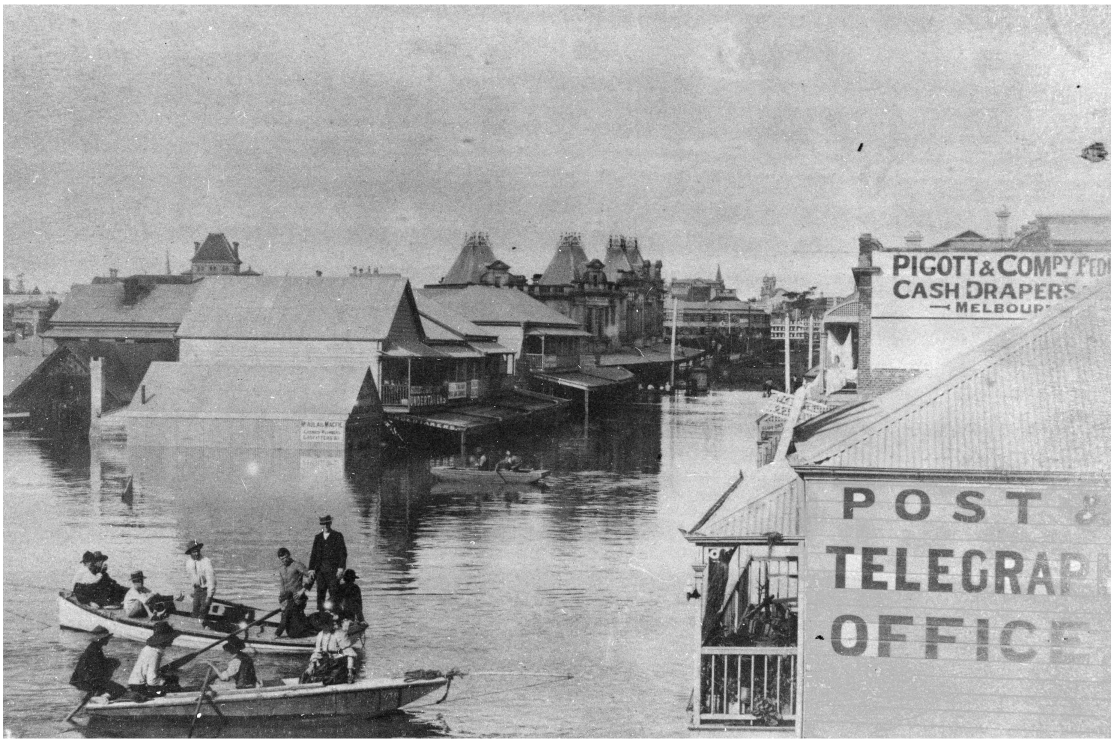


Plate 9.1: Brisbane, February 1893 – Flooding in Melbourne St, South Brisbane
(Plate: courtesy of John Oxley Library)

Plate 9.2: Brisbane, January 1974 – Aerial view of South Brisbane showing the southern end of the Victoria Bridge leading into Melbourne St. (Plate: courtesy of John Oxley Library)

Plate 9.3: Caboolture, 11 December 1991 – View south of flooding from Centre Point Plaza car park in Elliot St. (Plate: courtesy of Caboolture Shire Council Local Studies Collection)

Plate 9.4: Caboolture, 5 February 1931 - Matthew Terrace (opposite the railway station) looking north from King St after the peak of the flood (Plate: courtesy of Caboolture Shire Council Local Studies Collection)

Plate 9.5-6: Caboolture – 1931 - View south from the present Elliot St over the present Centenary Lakes/Caboolture Sports Centre area. Morayfield road on left. Top: Flood, January. Bottom: No flood, 5 February, 1 pm (Plate: courtesy of Caboolture Shire Council Local Studies Collection)

Plate 9.7: Pine Rivers, 12 December 1991 - Cars engulfed by flooding of the South Pine River over the Bald Hills Flats, Gympie Road, Strathpine (Plate: courtesy of Pine Rivers Local Studies Library)

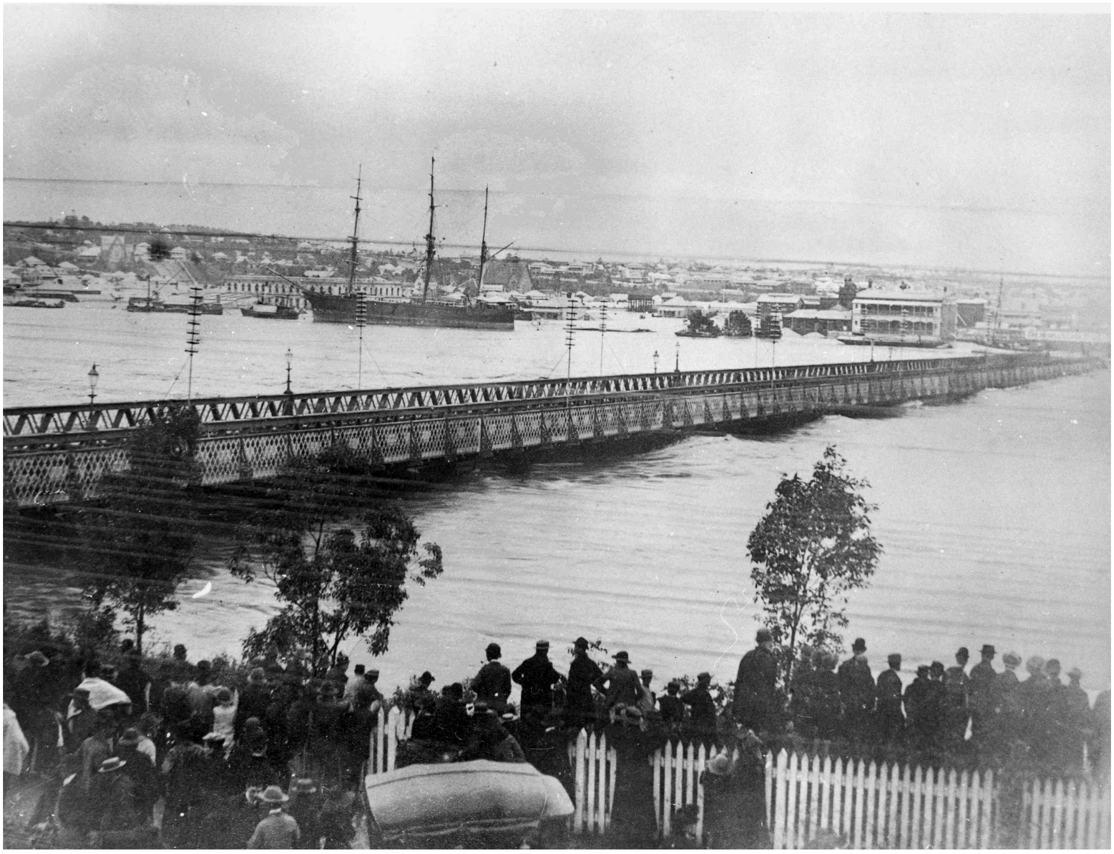
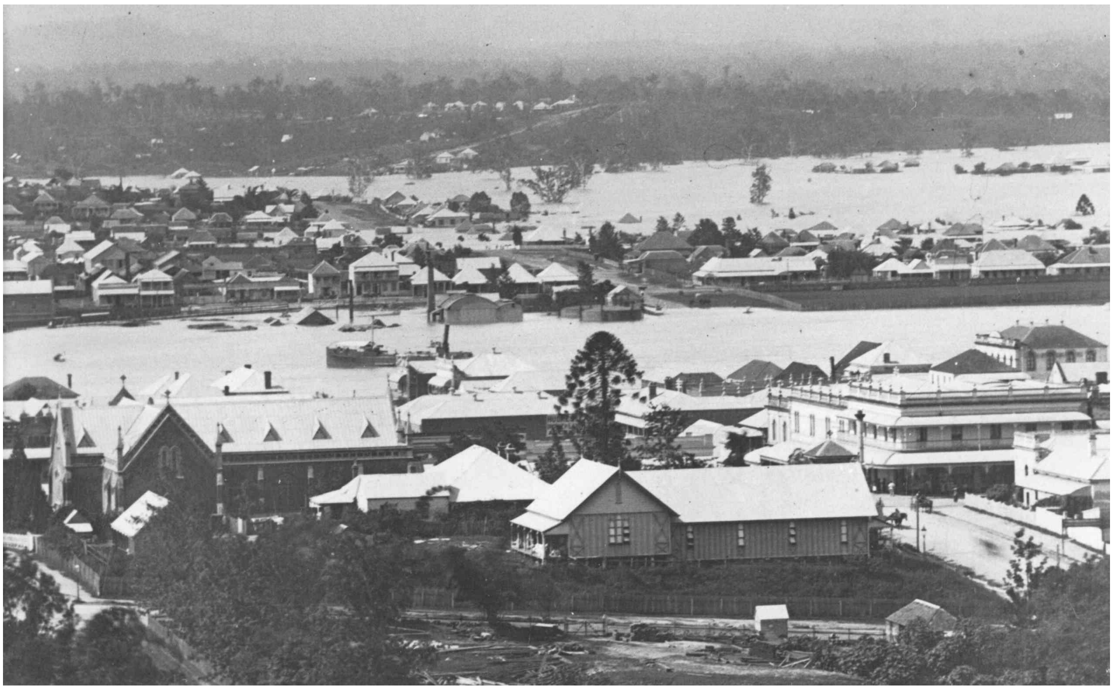
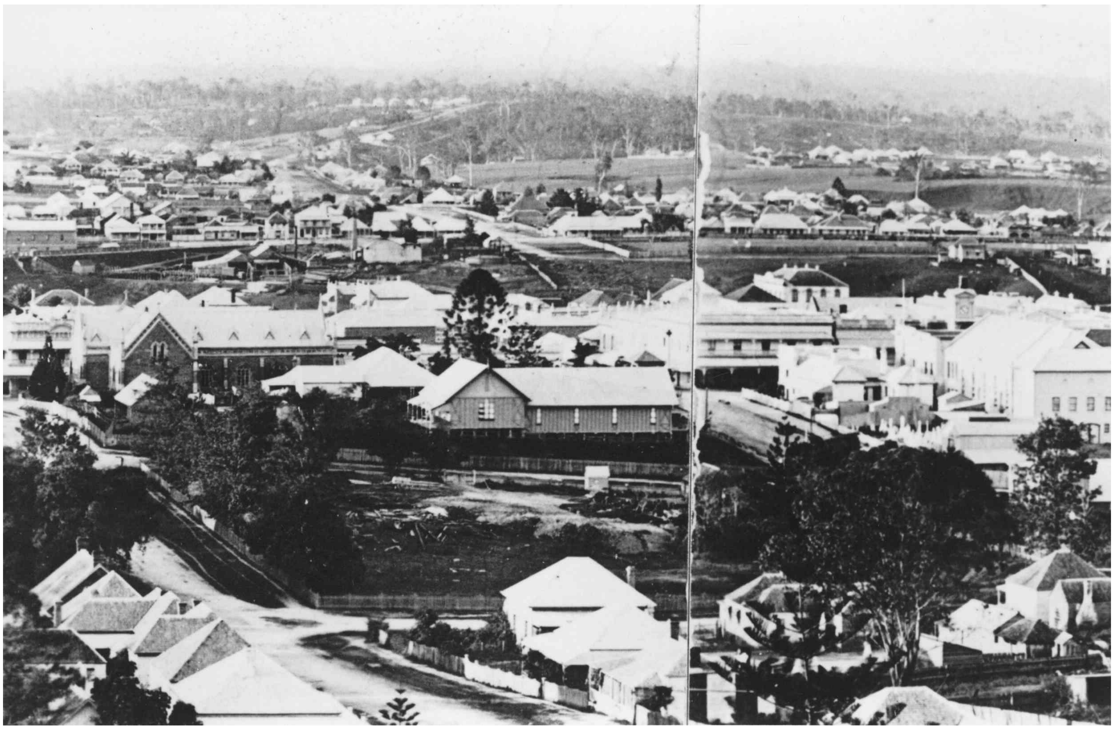


Plate 9.8: Brisbane, February 1893 – Floodwaters lapping the Victoria Bridge prior to it being heavily damaged by the floodwaters and floating debris (Plate: courtesy of John Oxley Library)

Plate 9.9: Brisbane, February 1893 – Looking towards South Brisbane after the 1893 flood at the Victoria Bridge, damaged in the flooding (Plate: courtesy of John Oxley Library)





Plates 9.10-11: Ipswich – View north from top of Ellenborough St., Ipswich - 1893. Top: Flood, February. Bottom: No flood, about May (Courtesy of Hughes collection, Ipswich Historical Society. Plate: Whitehead Studios)

Plate 9.12: Ipswich, February 1893 – Flood damage, Wharf St, looking south (Courtesy of Hughes collection, Ipswich Historical Society. Plate: B. Taylor, courtesy A. Geertsma).

Plates 9.13-14: Ipswich – View from the Ipswich general hospital towards Churchill St and the St Stephens Presbyterian Church. February 1893. Top: Flood. Bottom: No flood (Plate: courtesy of Hughes collection, Ipswich Historical Society)

Plate 9.15: Ipswich January 1974 – Flood - Aerial view taken after the height of the flood (Plate: courtesy of Hughes collection, Ipswich Historical Society)

Plate 9.16: Brisbane, January 1974 – Flood – Oxley Creek, looking north, Corinda (Plate: W. Muller)

Plate 9.17: Brisbane, January 1974 – Central Avenue, Sherwood. Looking east towards Oxley Creek and the Tennyson Powerhouse (Plate: courtesy of John Oxley Library)

Plates 9.18-19: Ipswich - Looking down East St to the north, near intersection with Limestone St, towards David Trumpy Bridge. Top: 28 January 1974 – Flood (Courtesy of Hughes collection, Ipswich Historical Society. Plate: A. Wright). Bottom: November 2000 – No flood (Plate: M. Middelmann)

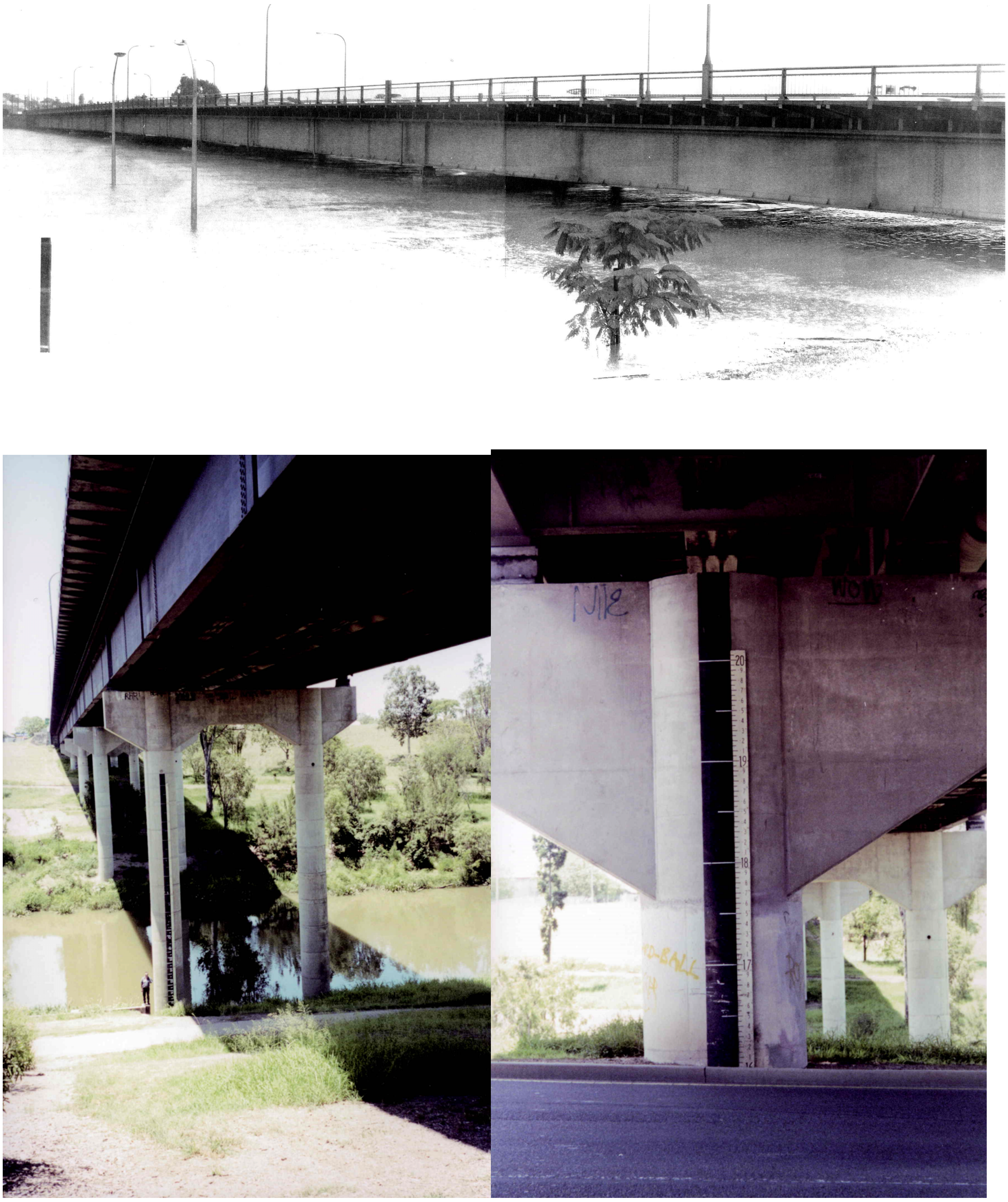


Plate 9.20-22: Ipswich - David Trumpy Bridge. Top: January 1974 – Flood (Courtesy of Hughes collection, Ipswich Historical Society. Plate: P. Willey). Bottom left and right: November 2000 – No flood (Plate: M. Middelmann)

Plate 9.23: Brisbane, 29 January 1974 – Flooding of the Brisbane River on both sides of the University of Queensland, St Lucia. On the opposite bank behind the university are the inundated riverside suburbs of Fairfield (left) and Yeronga (right). Taken at 10 am (Plate: courtesy of John Oxley Library)

Plates 9.24-25: Ipswich - Limestone St, looking back to the intersection with East St. Top: January 1974 – Flood (Courtesy of Hughes collection, Ipswich Historical Society. Plate: P. Willey). Bottom: November 2000 – No flood (Plate: M. Middelmann)

Plate 9.26: Brisbane, January 1974 – Flood – Railway shunting yards at Tennyson near Ipswich road (Plate: W. Muller)

Plates 9.27-28: Ipswich - Old Toowoomba Road near One Mile Shopping Centre, Leichhardt, looking towards town. Top: 27 January 1974 – Flood, 9 am (Courtesy of Hughes collection, Ipswich Historical Society. Plate: A. O'Donoghue). Bottom: November 2000 – No flood (Plate: M. Middelmann)

Plates 9.29-30: Ipswich - One Mile Hotel looking towards Leichhardt. Top: January 1974 – Flood (Courtesy of Hughes collection, Ipswich Historical Society. Plate: P. Willey). Bottom: November 2000 – No flood (Plate: M. Middelmann)

Plate 9.31: Brisbane, 28 January 1974 – Aerial view of Brisbane City showing the extent of flooding in the Brisbane Botanical Gardens (bottom left) up to Elizabeth St (Plate: courtesy of John Oxley Library)

Plate 9.32: Logan, January 1974 – Flood - One of the houses lost during the 1974 flood in Tygum Lagoon area, Waterford West. The site is now a Council park (Plate: J. Ebbelinghaus)

Plate 9.33: Logan, January 1947 – Flood – Logan City. Remains of Waterford Bridge (Plate: courtesy of John Oxley Library, Brisbane)

Plate 9.34: Gold Coast, January 1974 – Floods in the Miami Keys area back to Bermuda St. T.E. Peter Drive is covered in water (Plate: R. Anthony)

Plate 9.35: Gold Coast, June 1967 – Looking west of Surfers Paradise towards the flooding in the Bundall and Benowa area (Plate: courtesy of Gold Coast Local Studies Library)

CHAPTER 10: HEAT WAVE RISKS

Ken Granger and Michael Berechree

The Heat Wave Threat

According to Coates (1996), heat waves kill more people than any other natural hazard experienced in Australia. She reported that in the period between 1803 and 1992 at least 4287 people had died in Australia as a direct result of heat waves. This was almost twice the number of fatalities attributed to either tropical cyclones or floods over much the same time-frame. Coates' figures are not broken down according to the state or territory in which the deaths occurred, however, a database developed by her colleague at the Natural Hazards Research Centre (NHRC) at Macquarie University, Kylie Andrews, based on press reports covering the period between 1907 and 1992, indicated that about 18% of the national heat wave deaths occurred in Queensland – 681 deaths in Queensland out of a national total of 3843 - (Russell Blong, NHRC, personal communication, 2000). NSW, with 33% of the total, suffered the greatest number of deaths. Interestingly, the Andrews data indicates that males were significantly more at risk than females (449 males deaths to 222 female deaths) though this trend has been significantly less marked in the past few decades as the number of men engaging in hard physical labour out of doors has decreased.

As well as significant loss of life, heat waves can also cause significant economic losses through livestock/crop losses and damage to roads, railways, bridges, power reticulation infrastructure, electrical equipment, and so on (EMA, 1998). Heat wave conditions also lead directly to significant increases in demand for electricity to power domestic air conditioners. This demand can exceed the available capacity of the generating system, leading to load shedding – which in turn exacerbates the heat wave impact on people.

Regardless of these statistics, heat wave is probably the most under-rated of all natural hazards.

The Heat Wave Phenomenon

There appears to be no official Australian definition of a heat wave, however, the American Red Cross (*www.redcross.org/disaster/safety/heat.html*) define it simply as a 'prolonged period of excessive heat and humidity'. This is a useful definition because it emphasizes the combined effects of both air temperature and humidity.

Temperatures that would indicate whether a specific location was under the effect of a heat wave would be in the top 5% for a continuous three-day period. In South-East Queensland, heat waves typically occur between November and February, but days of excessive heat can occur between October and March. During these events the predominant wind is generally from the south-west to the north-west, i.e. from the interior of the Continent. Winds from these quarters have the potential to nullify the cooling effects of any sea breeze.

The difficulty in defining a heat wave in Australia has been in establishing an acceptable threshold and duration of an event, and relating it to the climatology of the area under investigation. The United States National Weather Service uses the measure of *apparent temperature*, T_a, which is based on the work of Steadman (1979, 1984), to produce a *heat index*. The Steadman heat index is summarised in Table 10.1. Similar indexes have also been published by Henderson-Sellers and Robinson (1986), for example.

The use of apparent temperature for an individual day can assist in the evaluation of heat related stress associated with outdoor activities. It should also be noted that the atmospheric temperature within an enclosed space, such as a house with all of its doors and windows closed, or a motor vehicle, will be significantly higher than the ‘screen’ temperature quoted on the evening weather report.

Relative Humidity(%)	Atmospheric temperature (°C) 26	28	30	32	34	36	38	40	42	44
0%	25	27	28	30	32	33	35	36	37	38
10%	25	27	28	30	32	33	35	37	39	41
20%	26	27	28	30	32	34	37	39	42	46
30%	26	27	29	31	33	36	39	43	47	52
40%	26	28	30	32	35	39	43	48	54	60
50%	27	28	31	34	38	43	49	55	62	
60%	27	29	33	37	42	48	55	62		
70%	27	31	35	40	47	54	63			
80%	28	32	38	44	52	61				
90%	28	34	41	49	58					
100%	28	36	44	56						

At an apparent temperature, T_a of:

32-40	Heat cramps or heat exhaustion possible
41-54	Heat cramps or heat exhaustion likely, heat stroke possible
54-more	Heat stroke highly likely

. Exposure to full sunshine can increase the heat index value by up to 8°C.

Table 10. 1 Apparent temperature heat index (based on Steadman, 1979 and 1984)

The South-East Queensland Heat Wave Experience

The records of fatalities caused directly or indirectly by heat wave are, at best, fragmentary for South-East Queensland. They have, none-the-less, been recorded in the region since at least 1899. Perhaps the most severe heat wave, in terms of fatalities, occurred in late January 1940, when at least 80 people died (51 males and 29 females). Most recently, between 19 and 21 January 2000, a heat wave reportedly killed 22 people in the region. The victims died of heat associated stress, with most of the victims being elderly residents of Brisbane, many of whom lived alone and had closed themselves away inside their homes for ‘security’.

Using a threshold for temperature that is within the top 5% of daily maximum temperatures for a continuous three-day period in the South-East Queensland area, at least 18 heat wave events have been identified since 1899 giving an ARI of, at most, 5 to 6 years. January is clearly the most common month in which to experience a heat wave episode.

The episodes identified from this analysis were:

1-3 January 1899	4-6 March 1929	6-8 February 1978
1-7 January 1903	24-26 January 1940	18-21 December 1985
1-5 January 1905	3-6 January 1942	14-16 January 1987
5-7 March 1919	5-8 December 1952	6-9 January 1994
9-12 January 1924	18-21 November 1968	6-8 November 1994
16-18 January 1929	23-25 December 1972	19-21 January 2000

Heat Wave Risks

The level of discomfort experienced in warm, moist tropical and sub-tropical conditions is determined by a range of climatic variables, principally air temperature, humidity and wind; as well as cultural variables including clothing, occupation and accommodation; and physiological variables such as health, fitness, age and the level of acclimatisation. The main factor involved in the degree to which we feel uncomfortable in such conditions is not so much because we feel hot, but rather we sense how difficult it has become for us to lose body heat at the rate necessary to keep our inner body temperature close to 37^{o}C. Put simply, in still air the higher the humidity, the less effective are the body's mechanisms for evaporative cooling through sweat.

The body responds to this stress progressively through three stages:

- **heat cramps** – muscular pains and spasms caused by heavy exertion. Although heat cramps are the least severe stage they are an early signal that the body is having trouble with the heat;
- **heat exhaustion** – typically occurs when people exercise heavily or work in a hot, humid place where body fluids are lost through heavy sweating. Blood flow to the skin increases causing a decrease of flow to vital organs. This results in mild shock with the symptoms of cold, clammy and pale skin together with fainting and vomiting. If not treated the victim may suffer heat stroke;
- **heat stroke** – is life threatening. The victims temperature control system, which produces sweating to cool the body, stops working. The body temperature may exceed 40.6^{o}C potentially causing brain damage and death if the body is not cooled quickly.

(based on material from the American Red Cross web site)

The suggested responses to heat wave conditions include:

- slow down – avoid strenuous activity. If this can not be avoided, do it during the cooler parts of the day e.g. between 4.00 and 7.00 am;
- stay indoors as much as possible and stay out of the sun. If air conditioning is not available, stay on the lowest floor. Try to go to a public building with air conditioning, such as a shopping centre, each day for several hours. Whilst electric fans do not cool the air, they do help sweat to evaporate, which in turn cools the body. Ensure that the building you are in has adequate ventilation;
- wear lightweight, loose fitting, light coloured clothes;
- drink plenty of water regularly. Avoid drinks with alcohol or caffeine in them. They may make you feel good briefly, but they make the effects of the heat on the body worse. This is especially true of beer which dehydrates the body;
- eat small meals and eat more often. Avoid foods that are high in protein which increase metabolic heat; and,
- check on elderly relatives or neighbours, especially if they are living alone, and ensure that they also follow these risk mitigation measures.

(also based on material from the American Red Cross web site)

The anecdotal evidence of the heat wave event of January 2000 indicates that many elderly people, and indeed many people in other susceptible groups of the population, are largely ignorant of the risks posed by heat waves, or of the simple steps that can be taken to reduce those risks. There is clearly a need to improve public awareness of the risks associated with heat wave and possibly to adopt the US warning methods using a heat index. There is absolutely no reason why such an index could not be introduced and accepted in Queensland given that its cold climate equivalent, the wind chill factor index, is already widely accepted in the southern states. There is also a need to actively involve those community agencies, such as Meals on Wheels and Blue Nurses, that have regular contact with some of the more susceptible individuals, to promote the awareness message.

Total Risk Assessment

It is clear that whilst a heat wave weather sequence will be felt more-or-less equally across the entire area, its impact will be greatest on those who are most susceptible. The elderly, especially those living alone, would seem to be the most susceptible group. Whilst a good number of elderly people who are living alone may reside in 'managed' communities such as retirement villages, and consequently have a degree of regular contact, a very large number remain isolated in their homes within the general community.

The very young also constitute a susceptible group, however, it is likely that they will have a parent or other carer to look after their well being. We do not have any information on the distribution or numbers of other susceptible groups such as the homeless and the physically or mentally disabled, so have adopted the over 65 years living alone group as our measure of risk exposure.

The distribution of people over 65 years and living alone, based on the proportion they represent of the total population in 1996, is shown in Figure 3.20. In absolute terms, however, it should be noted that in South-East Queensland there were 51 784 people that were within this group in 1996. The suburbs in which the top 1% of CCD with this group of people present (i.e. the highest heat wave exposure) are located are (in alphabetical order):

As has been shown in earlier chapters, by relating the level of exposure (in this case the number of elderly who are living alone) to the respective hazards at the CCD level to the level of the CCD's contribution to overall community vulnerability (the vulnerability index detailed in Chapter 3), it is possible to derive an index of risk. The urban heat wave risk surface derived from that index is shown in Figure 10.1. As described in earlier chapters, the higher the index number the greater is the overall risk posed by heat wave.

The top 1% of urban CCDs by heat wave risk index are located in (alphabetical order):

> Ashmore, Aspley, Benowa, Bongaree, Caboolture, Chermside, Cleveland, Coombabah (2), Deception Bay, Durack, Elanora, Fitzgibbon, Greenslopes. Keperra (2), Lawnton, Mount Gravatt, Mount Warren Park, Nerang, New Farm, Ormiston, Robertson, Runaway Bay, Sandgate, Scarborough (2), Southport, Thornlands and Upper Mount Gravatt.

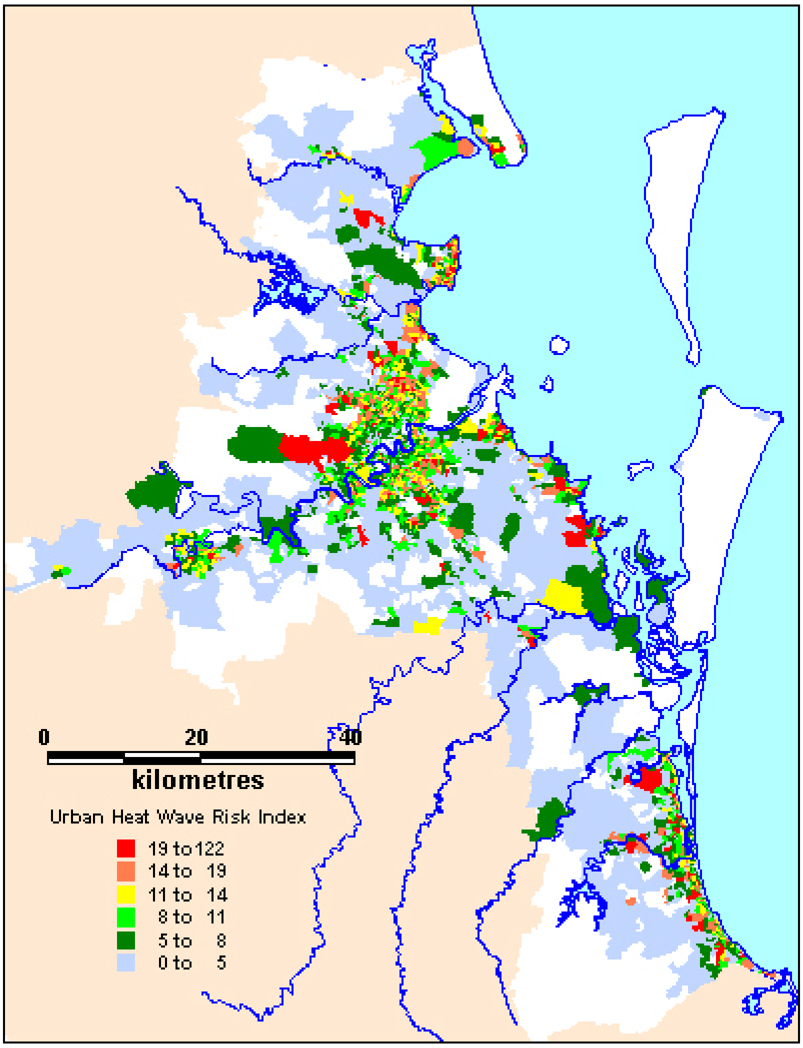


Figure 10.1 Heat wave total risk distribution

Click here for High Resolution Image

Community Awareness

As with other hazards dealt with in this study, there appears to be a significant lack of community awareness of the risks associated with heat wave, even though the region experiences such events with some regularity. In briefings and presentations given during the South-East Queensland research, even experienced disaster managers expressed surprise at the rate of fatalities attributed to heat waves compared with cyclones and floods. It is clearly a widely overlooked, even unknown, killer.

There are, however, various Workplace Health and Safety requirements in place aimed at protecting workers, school children and so on from the stress of high temperatures in the workplace, school and so on. The general public, in particular the elderly lady closed up by herself in her home in the suburbs, does not have the same degree of oversight or protection.

Forecasting and Warnings

Unlike their US counterparts, the Bureau of Meteorology does not issue specific ‘heat wave warnings’, though at times of extended hot weather, advice will be included in normal weather forecasts advising of the dangers of heat stress. The use of a ‘heat index’ has yet to be established in Australia.

CHAPTER 11: BUSHFIRE RISKS

Ken Granger, Dave Luxton and Michael Berechree

The Bushfire Threat

Whilst bushfires in South-East Queensland have seldom been as severe as the worst fires that have occurred in the southern states, (such as the 'Ash Wednesday' fires that claimed 75 lives in South Australia and Victoria in 1983,) serious fires have occurred in the region during most months of the year. Contrary to the widely held belief, bushfires do destroy property (including urban property) and they do kill people in South-East Queensland.

The most notable events in recent years were the fires of September and November 1994 which burnt through more than 4800 ha of exotic pine plantation and destroyed both rural and urban property on the Sunshine Coast and in Caboolture, Pine Rivers, Brisbane and other local government areas. These fires also injured nine fire fighters, seven very seriously. More recently, some 2000 fires (90% of them deliberately lit) were reported throughout the region over a three week period in August-September 2000.

The increasing popularity of rural residential living and the preservation of natural areas within urban developments in South-East Queensland (so-called 'wildlife corridors') brings with it an increasing level of risk. These 'wildlife corridors', unless well managed can easily become 'wildfire corridors' under conducive fire conditions. Put simply, any patch of bush will burn, regardless of whether it is in a State Forest, National Park, in farmland, along creek lines or in a neighborhood playground – if the conditions are 'right' for a fire and a source of ignition is present.

The bushfire season for South-East Queensland typically extends from mid to late winter through to early summer. The greatest danger occurs in the period towards the end of winter and into spring, especially if a good summer 'wet' season which produced abundant growth of grass and other fuel, is followed by a winter of low rainfall and lengthy periods of dry westerly winds. The risk generally eases following the first rains of the spring thunderstorm season and is largely absent during the summer 'wet' season. The 'wet', however, produces the conditions for lush growth that will, by the following winter, provide the fuel for the next fire season – and so the cycle continues.

Unlike most of the other hazard phenomena dealt with in this study, with bushfires there is a clearly defined philosophy of responsibility, namely, that if you own the fuel, you own the fire. According to the 'basic philosophy of operation' of the Queensland Fire and Rescue Authority (QFRA) Rural Fire Service (Rural Fire, 1999):

> *Fire control is a property owner's responsibility, supported in an organised manner by the community through the Rural Fire Brigades.*

Queensland rural fire authorities (including Rural Fire Brigades, National Parks Service, Forestry Service and local governments) have always supported a regime of fuel management in bush areas under a system of permits issued by local Fire Wardens. These permits are aimed at:

> *encouraging hazard reduction burning through the provision of legal protection for responsible users of fire and punitive action for irresponsible users*. (Rural Fire, 1999)

In the urban-rural interface areas that make up much of the South-East Queensland study area, however, until the destructive fires of 1994, there had been significant pressure to minimise, if not curtail, hazard reduction burning activities. These pressures came largely from lobby groups including environmentalists (who argued that any fire was destructive) and those whose medical conditions could be aggravated by the smoke from fuel reduction burn-offs. Since those fires (and the fatal fires in NSW earlier in that same year), however, there has been significantly less resistance and hazard reduction practices are widely followed throughout the region.

The Bushfire Phenomenon

For a bushfire to start and to be sustained, three things are needed:

- there must be fuel available to burn;
- there must be sufficient heat to cause and maintain ignition; and,
- there must be sufficient oxygen to sustain combustion.

If any one of these is absent or inadequate the fire will either not start in the first place, or will not spread.

The fuel for a bushfire is made up of the available vegetation, together with any other combustible materials, (such as houses,) that become involved. Most of the natural vegetation communities of the region are 'fire climax' types that have evolved to the point where they rely, to varying degrees, on fire for regeneration. These include the various eucalypt-dominated forests and woodlands, as well as the *walum* heathlands and *Melaleuca*-dominated wetlands. These vegetation types and their distribution throughout the region are well described in Poole and others (1996). Cultivation, including pasture, tree crops and exotic pine plantations, are also significant sources of fuel.

The heat needed to start a bushfire can be provided by something as simple as a match or cigarette butt, or by something as dramatic as a lightning stroke. Of course, the higher the atmospheric temperature is in the first place, the easier it is for these sources to get things going. In the South-East Queensland region, in spite of its reputation for spectacular thunderstorms (see Chapter 6), the vast majority of bushfires are started either by human carelessness (e.g. a discarded cigarette butt or a poorly supervised burn-off) or human stupidity and wanton criminality (the deliberately lit fire e.g. by bored children or by car thieves disposing of stolen cars by setting them alight in bushland). Once the bushfire is established it generates its own heat.

The oxygen required for combustion is provided by the atmosphere and is constantly being replenished by the winds, either created by the fire itself, or by the atmospheric winds. Higher winds mean more oxygen and more intense flames.

The intensity of a bushfire, and thus its destructive potential, is determined by three factors that are related to these three basic elements. The first is heat yield. The heat yield of most native vegetation types in Australia is extremely high. Eucalypt trees and regrowth scrub, the *Melaleucas* of the wetlands, the *Banksia* and other species of the *walum* heath, and the exotic pines of the plantations, all produce naturally volatile substances. These fuels invariably produce more intense fires and yield more heat than does grass. The greater heat energy released by scrub and forest fires make them potentially more damaging to houses and other buildings than are grass fires. They also produce airborne embers and firebrands which can start spot fires well ahead of the fire front. Grass fires, by comparison, consume the available fuel much more quickly and produce few embers.

The second factor is the rate of spread. This can be influenced by two main conditions – terrain and weather. Fires burn more rapidly and with greater intensity on up-slopes than they do on down-slopes or on the flat. Generally, the steeper the up-slope, the greater the speed and intensity of the fire. Rising temperatures and wind velocities, and decreasing humidity, directly contribute to an increase in both the rate of fire spread and its intensity. As fuels dry out, ignition becomes easier and the rate of spread increases. Winds can also assist the spread of fire by carrying heat and burning embers to new fuels (causing spot fires ahead of the fire front) and by bending the flames closer to unburned fuels ahead of the fire. Doubling the wind speed will quadruple the rate of spread of the fire.

Preliminary findings from *Project Vesta*, a joint CSIRO – WA Department of Conservation and Land Management research program, indicate that fire spread can be significantly greater than previously estimated where there is a developed shrub layer that is taller than one metre, and where wind speed exceeds 15 km/hour. There appears to be a wind speed threshold at around 12 to 15 km/h, below which fire can spread relatively slowly, but a slight increase in wind speed can result in large increases in the rate of fire spread . It has also been found that wind speeds within forest areas can be highly variable, giving rise to significant variability in fire spread rates (CSIRO, 2000).

Hot, dry air can lower the moisture content of forests and grasslands to around 5% (and in extreme cases to 2-3%,) greatly increasing the spread of fire. The worst fire weather conditions in South-East Queensland (high temperatures, low humidity and strong winds) tend to occur when deep low pressure systems develop over southern Australia, bringing strong dry westerly winds from the continental interior to the coast. This was the situation during the major fires of November 1994 and again in August-September 2000.

The third factor is the amount and nature of the fuel available. This can be influenced by the nature of the preceding growth season – a wet summer will give rise to much more growth than will a dry summer; the length of time since the area was last burnt (either by a previous bushfire or by fuel reduction burning); and by other land management practices such as cultivation, slashing, irrigation and so on.

It should be recognised that under some situations, the intensity of a bushfire can reach such a level that it simply can not be put out by currently available or practical suppression measures. Fire authorities in Australia acknowledge that this situation is unlikely to change in the foreseeable future.

The South-East Queensland Bushfire Experience

The history of bushfires in South-East Queensland has, until very recently, been poorly recorded. It is clear, however, that they are not just a recent phenomenon. For example, according to extracts from the records of the Caboolture Divisional Board, in 1883 a Mr. Walsh of Humpy Bong (i.e. Redcliffe) threatened to 'expose' the Board through the press, complaining of the danger of trees falling across the road due to bushfires, one tree having already fallen on his horses (CSC, 1979). These extracts also record the payment of 10/- to a Mrs. William Grigor of Glasshouse Mountains in 1898 for extinguishing fires on bridges in the area.

The most complete record of bushfires in South-East Queensland has been compiled by Tania Philips, the Community Awareness Officer in the Rural Fires Division of QFRA. Table 11.1 is based on the records she has made available.

Table 11. 1 Major bushfire seasons in South-East Queensland 1926-2000

Season	Remarks
1926	Extensive fires destroyed forests, farms, sugarcane, banana plantations and dwellings through the south-east corner of the State.
1929/30	37 fires investigated throughout the State.
1944/47	No records available
1957/58	Severe fire season during late 1957, early 1958. Dry conditions, lots of fires throughout the State. No detailed reports of large fires recorded.
1964/65	Large fire on Fraser Island burnt out 32 800 ha.
1968/69	Moderate to severe fire season with major fires occurring at - 1. 19/11/1968 - Brookfield fire threatened the western suburbs of Brisbane, eventually destroying 12 000 ha of forest and grassland. 2. Forestry personnel attended 326 fires which burnt 125 700 ha of forest and other property.
1976/77	September 1976. Major fires burnt a total of 600 000 ha in the South Burnett, Nanango and Brisbane areas.
1977/78	9/77 A.P.M. Pine Plantation at Petrie fire destroyed 300 ha pine forest and 350 ha native forest.
1981/82	Moderate to severe fire season recorded with major wildfires occurring at - 1. Springbrook, Beechmont, Lower Beechmont areas September 1981. 2. Severe fires on Moreton, Stradbroke and Macleay Islands during August-October.
1986/87	A moderate fire season with large fires occurring in the Mt. Glorious, Mt. Nebo and Noosa areas.
1991/92	A severe to extreme fire season with large fires occurring in the Sunshine Coast Hinterland (Bald Knob, Landsborough, Mapleton) which claimed the life of a volunteer fire fighter on 10/9/1991 at Palmwoods. Extreme fires in Gold Coast hinterland. At Mt. Tamborine fire destroyed three houses and claimed the life of one civilian (Sept 1991).
1992/93	Moderate fire season with major fires destroying four houses and several vehicles in the Coominya rural-residential area near Esk.. 40 000 ha burnt in Esk Shire.
1993/94	Jan. 1994 4000 ha burnt at Mount Glorious, Wivenhoe area and fires threatened Mount Nebo township and community.
1994/95	Severe fire season . 682 major fires occurred across the State in September and November. Major outbreaks occurred on 27-29 September and again on 4-7 November. Twenty three houses were destroyed, as well as farm building, fences and livestock. 3000 people were evacuated from their homes. Beerburrum State Forest suffered huge losses of plantation timber. Nine volunteer fire fighters were injured, with seven 7 suffering extensive burns, north of Caboolture.
1995/96	During November and December fires threatened homes in South-East Queensland. One house lost near Ravensbourne and $3m worth of pine forest destroyed.
2000/2001	August 2000 Hundreds of bushfires occurred in South-East Queensland (majority deliberately lit). Three buildings, two caravans and a vehicle lost.

Certainly the most extensive and severe fires in recent times were those on September and November 1994. The destruction wrought by these fires on Bribie Island during these fires is illustrated in Figures 11.1 and 11.2. It is worth noting that the vegetation that burnt was tall *Banksia*-dominated *walum* that had not been burnt for many years. Apart from the abundant and well cured ground litter fuel, most species in this vegetation form will burn well, even when green, because of the volatile oils contained in their leaves.

Figure 11. 1 Extent of bushfire damage on Bribie Island, November 1994 (CSC Photo).

Figure 11. 2 Detail of the November 1994 Bribie Island fire damage at Woorim (CSC photo).

The fires were extremely intense and moved very quickly. They left behind them only bare sand and white ash. Fortunately only a few old sheds and fences were destroyed. Only limited damage was done to a few houses and gardens on the bush interface. The contrast between the green (non-flammable) and mown grass on the Bribie Island Golf Course and the devastation of the surrounding bush can clearly be seen in Figure 11.2.

Even with the incomplete record provided in Table 11.1, the ARI of significant bushfire episodes in South-East Queensland is approximately five years.

Bushfire Risks

In the context of this study, which has an emphasis on the urban environment, the primary risks posed by bushfires are to those areas on the urban fringe, or at the interface between the 'bush' and built up areas. The key risk is to buildings and to those elements of infrastructure that are either flammable (e.g. timber power poles and wooden bridges) or susceptible to the heat generated by bushfires (e.g. power supply switching gear and electronic equipment). People are also at significant risk, especially if they are caught in the open or in vehicles that are inadequately protected. This is a particular risk where rapid shifts in wind direction and speed cause the fire to change direction and speed without warning.

When considering the risk to people, the risks faced by fire fighters, most of whom are volunteers, should not be overlooked. This risk was highlighted recently by the deaths of several fire fighters in other states and the serious injuries suffered by nine volunteer fire fighters near Beerwah (the so-called 'Bell's Creek fire') in November 1994. These fatalities and serious injuries can, in virtually all instances, be attributed to a lack of appropriate hazard mitigation (i.e. fuel reduction) prior to the dangerous fire conditions occurring.

There are four main mechanisms by which bushfires cause damage. The first, and most obvious, is direct exposure to flames. Exposure to flames is typically only a threat where vegetation or other fuel is allowed to accumulate under, against, or on the exposed building. Similarly with infrastructure elements, fuel must be present close to the pole, bridge timbers and so on, for it to be affected directly by flames.

The second mechanism is burning debris. Buildings are at risk from wind-blown sparks and embers that can be carried significant distances from the fire front. They can also be propelled at great speed by the strong winds generated by the fire and be of a size large enough to smash unprotected windows. Sparks and embers can enter the building through openings such as open or broken windows or unlined eaves, thus introducing a source of ignition to the interior of the building. Sparks can start small fires in curtains, carpets and other interior furnishings. These can develop rapidly and destroy the building from the inside. Similarly, sparks can lodge in combustible material close to, on the roof of, or even under the building, thus causing exterior fires that can quickly envelop the building.

The third mechanism is radiant heat. Bushfires generate extreme heat levels at their active front. As the fire travels forward, this extreme heat lasts for only a few minutes, however, it is sufficient to fracture glass or cause combustible items inside the building, such as fabric and paper, to burst into flame. Radiant heat is also a significant threat to heat-sensitive power supply and other electronic equipment.

The fourth mechanism is the strong winds generated by the fire. Wind speeds in excess of 42 m/s (120 km/h) can be experienced in fires. This is somewhat greater than the wind loading standard applicable to most urban buildings in South-East Queensland (mostly 30 m/s). Such winds can cause direct damage, e.g. by unroofing buildings; it can cause impact damage by propelling debris, including burning debris, at considerable velocity; trees or power poles may be toppled , especially if weakened by the fire.

A significant secondary bushfire hazard is smoke. Fire smoke can produce direct physical effects on people, especially in those with respiratory illnesses such as asthma and emphysema, as well as psychological effects. Stress and anxiety levels in many people can be raised simply by the smell of fire smoke on the air. Smoke can also reduce visibility to the extent that roads, and even airports, may need to be closed temporarily.

There is perhaps a perception that only buildings in rural areas are at risk from bushfires. There is little doubt that they make up the bulk of buildings destroyed, however, buildings in urban areas are also at risk – as was demonstrated on Bribie Island and elsewhere during the 1994 fires. Ahern and Chladil (1999), using data from three severe historic fires in which urban houses were destroyed (the 1967 'Black Tuesday' fires in Hobart, the 'Ash Wednesday' fires in the Otway area of Victoria in 1983 and the Como-Jannali fires in NSW of 1994), have calculated that 95% of all urban buildings destroyed in bushfires were within 100 m of the bush interface. Buildings destroyed beyond that range were almost universally victims of ember spotting. The greatest distance recorded (in the 1967 Hobart fires) was 684 m from the vegetation boundary. Ahern and Chladil observe:

> *Consider also, the case of common suburban lot dimensions. Assuming an average lot depth of 40m, we can account for about 64% of all houses burnt* [as] *actually being adjacent to the vegetation boundary. If one allows 30m for a road reservation we are 70m from the vegetation boundary and have accounted for about 75% of all burnt houses. Only 13% of all houses burnt were beyond a distance equivalent to a house lot, a road reservation and another house lot.*

It should be noted that 'vegetation boundary' relates to 'bush' rather than grassland vegetation.

The potential for bushfire spread has, since the 1960's, been measured using the various versions of the McArthur Forest Fire Danger Meter and the McArthur Grassland Fire Danger Meter. The 'fire danger', based on input including weather variables and fuel variables, is rated from low to extreme. These ratings form the basis for public warnings and govern the introduction of fire bans and other restrictions on the use of fire.

Under the *Queensland Building Act,* which calls up the Building Code of Australia, all buildings constructed since 1993 in those areas so designated by each local government authority as being bushfire prone, must comply with standard AS 3959-1991 *Construction of buildings in bushfire-prone areas* (Standards Australia, 1991). AS 3959-1991 specifies only minimum standards that are intended to improve the performance of buildings against burning debris. Other passive risk reduction measures, such as correct siting of the building, the provision of suitable landscaping to act as a barrier to the oncoming fire, and the protection of windows, should also be considered. Guidance on the siting and design of residential buildings in bushfire prone areas of Queensland is provided in DHLGP & QFS (undated).

More recently, a national position on development and building in bushfire prone areas has been developed. The relevant codes and standards to give effect to this agreed position will be published in late 2001. The objective is to produce developments that are designed to minimise the impact of bushfire on the community and the built environment. They will be performance-based and allow for regional variation. Risk reduction will be achieved by limiting development to areas with 'acceptable bushfire risk' and by imposing standards which embrace the survivability of structures and their occupants if subject to bushfire attack. Included will be the concept of 'defensible space' which aims to maximize the opportunity for interventions by property owners and suppression agencies to further improve survivability of structures and their occupants.

Guidelines have also been published that are designed to assist local governments identify those areas under their jurisdiction that are bushfire prone, and consequently subject to the provisions of the Building Code; and to establish standards for the planning of subdivisions in bushfire prone areas (QFRA,1998). These guidelines encourage local governments to prepare fire hazard maps based on 'fire loading factors' derived from an assessment of the topography, aspect, fire history and vegetation cover of the area. Fire hazard mapping, employing the recommended fire loading factor methodology has been undertaken by the Rural Fire Service using GIS. This data has been kindly made available to this study and the mapping of South-East Queensland is shown in Figure 11.3.

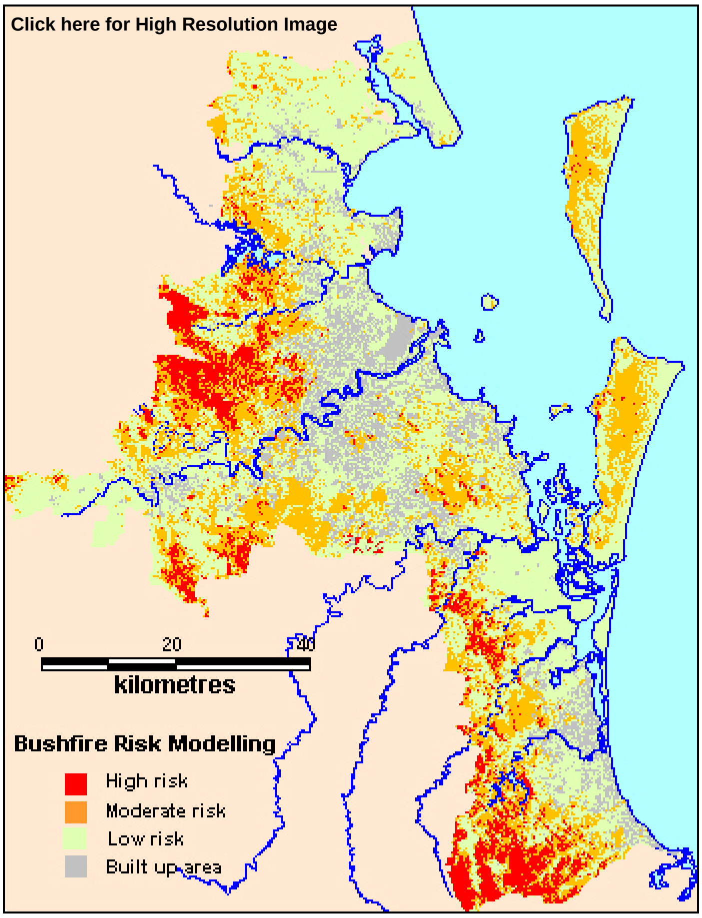


Figure 11. 3 South-East Queensland fire loading factor zonation

It must be emphasized that this mapping does **not** show where bushfires can occur, but rather it shows those areas in which the hazard is sufficiently great to require specific risk reduction strategies, such as the construction of fire breaks, the siting and construction of roads to avoid cul-de-sacs, and the stipulation of minimum domestic water storage requirements, to be required as part of the subdivisional siting and planning process.

Excluding the urban built-up areas and the road network, approximately 3850 sq km of the South-East Queensland study area (or 75% of the total) could be subject to bushfire, simply because it is under vegetation. The study area, however, contains 195 sq km of high loading factor and 505 sq km of medium loading factor land classified under the Rural Fire Service mapping. This represents 3.8% and 9.7% respectively of the total study area. A number of suburban areas and rural villages lie within, or abut, areas classified as having at least a medium fire loading factor and several rural villages. The edges of these areas at least have a significant exposure to bush fire.

These risks can, to a degree, be balanced by the provision of fire services. These are provided either by rural brigades, urban brigades or by other agencies such as the Forest Service (in State Forests) and National Parks Service (in National Parks). Figure 11.4 shows the boundaries of the areas covered by rural and urban fire brigades in the study area. There are 38 rural brigades that are cover land within the region.

Click here for High Resolution Image

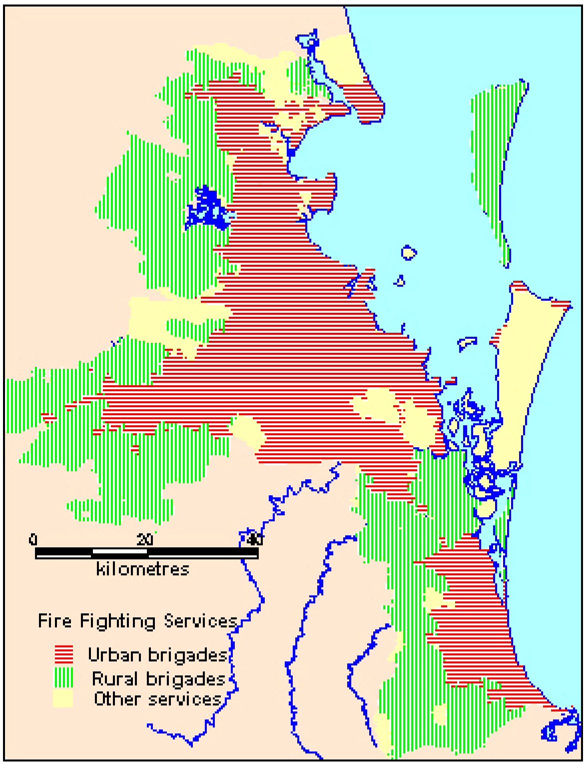


Figure 11. 4 South-East Queensland fire suppression agencies

The management of fuel reduction is underpinned by a predominantly volunteer network of fire wardens. Their role is to manage the Permit to Light Fire system. Fire wardens are regarded as the pre-fire experts and the objective of the permit system is to promote the responsible use of fire as a land management and hazard reduction tool. The universal application of this system throughout Queensland provides the legal mechanism by which to substantially control ignition from man made sources

The role of the fire warden is to consider applications for Permits to Light Fire and issue, or refuse to issue, permits. Permits issued are conditional in that they require the permittee to ensure that fire is used and maintained in a safe and responsible manner. An added incentive for compliance with the permit system is the provision of relief from civil liability to permittees. Permits may also be issued by urban brigades of the QFRS.

Support for rural brigades in LGA such as Caboolture, Pine Rivers and Gold Coast includes collecting the rural fire service levy that is rated at a level recommended by the rural brigades. Some councils also provide funds to assist with administration of their local Rural Fire Brigade Groups and the purchased numerous water supply tanks in areas with identified need. During bushfires council also provide water tankers and earthmoving equipment to assist in suppression activities.

Interpretation

The experience of the 1994 and 2000 fires should have removed any illusions that bushfire is not a serious threat in South-East Queensland. Those fires came very close to having a destructive, and potentially fatal, impact on urban areas, especially in the hinterland areas. The major threat, none the less, remains in the rural and rural fringe areas, including rural villages such Springbrook, Mount Glorious and Mount Nebo.

The fuel management regime and other mitigation measures undertaken by LGAs and other agencies since 1994 certainly proved to have been effective during the more recent episode of rural fires in August - September 2000.

There are no appropriate statistics available by which to measure bushfire total risk.

Community Awareness

In spite of the experience of the widespread fires in the region in 1994, and the spate of fires in September 2000, there appears to be a persistent view in the community at large that South-East Queensland does not have a significant bushfire risk. There seems to be many reasons for this false perception, not least of which is the view that South-East Queensland is 'too wet' for serious fires, that bushfires are only a problem in the southern states such as Victoria, or that bushfires only occur in rural areas.

Even amongst people in the higher risk urban fringe areas, there has been a general decline in experience and knowledge of bushfire and fuel management. The popularity of rural residential development and the increased number of properties now managed by 'weekend' farmers has taken large areas rural land out of ongoing management. Many residents of these areas also have a strong attachment to what they see as the 'natural' environment. One outcome of these changes in land use and land management has been that regrowth, scrub and litter fuels are allowed to build up in a haphazard manner – often because of the landholder's mistaken view that the use of fire as a land management tool is 'wrong', even 'environmental vandalism'.

Perhaps as potentially dangerous is a general lack of awareness as to what to do should a bushfire threaten especially in urban/rural interface areas. A common (and natural) response is to flee or, in the case of most police officers, to order people to evacuate their homes. Experience in South-East Queensland and elsewhere has shown repeatedly that this type of response increases the risk of both fatalities (people caught in the open or in their cars during an evacuation) and the loss of property (if there is nobody there to douse small spot fires in or around the house before they grow to an uncontrollable degree).

Rural fire brigade volunteers throughout the rural areas, however, play an important part in educating and assisting people in these areas, whilst some councils are taking an active part in requiring landholders to better manage potential bushfire fuel loads..

Forecasting and Warnings

The fire danger rating system in common use throughout eastern Australia has come to be known as the McArthur Fire Danger Rating System after the late A.G. McArthur who developed the system. The McArthur Fire Danger Rating System is based on a large amount of experimental work that has been carried out over the years and continues to be revised and refined through ongoing research. The system provides a means of estimating fire behaviour across a wide range of common fuel types and is currently available in both circular slide rule and electronic forms. They integrate the combined effects of fuel moisture content and wind velocity to calculate a basic fire danger index. The resultant indices can be related to fuel quantity and slope to predict head fire spread rates and other fire behaviour characteristics such as flame heights and spotting potential.

The indices are also directly related to rates of forward spread on a scale of 1 to 100. An index of 100 represents the near-worst possible fire weather conditions that are likely to be experienced in Australia. They are also divided into five fire danger classifications of low, moderate, high, very high and extreme. The index number is directly related to rate of spread, ignition probability and suppression difficulty. At an index of 1 fires are virtually self-extinguishing, whilst at an index of 100 fires will burn so rapidly and intensely that control is virtually impossible.

When fire danger conditions are expected to become very high to extreme, corresponding to a Fire Danger Index of 40 or above on the McArthur Mark IV Grassland Fire Danger Meter, the Bureau of Meteorology issues Fire Weather Warnings. Warnings are broadcast to the general public via radio and television. Fire authorities will respond as required when Fire Weather Warnings are received and in most instances implement fire restrictions over the affected region.

The Bureau of Meteorology issues fire weather forecasts for South-East Queensland each day throughout the fire season. These forecast contain information about expected temperatures, atmospheric moisture, wind speeds and direction and the corresponding fire danger rating for the following three days. During an ongoing major fire event, the Bureau of Meteorology issues special spot forecasts detailing current and expected conditions in the area of the fire.

Recent developments in the use of AVHRR satellite imagery and its analysis have enabled the development of map products that provide information about the quantity, condition and distribution of available fuel across Queensland. This information is now available on the rural fire service website (www.ruralfire.qld.gov.au) and is a valuable tool for planning and monitoring fire management, particularly in broad acre areas.

Further Information

More detailed information on the levels of exposure of individual neighborhoods or properties to the various bushfire risks outlined here should be referred to the QFRA or respective local government council.

CHAPTER 12: A MULTI-HAZARD RISK ASSESSMENT

Ken Granger and Trevor Jones

Overview

On a global scale, Australia, as a whole, is a very safe place. We do not suffer the losses from cyclones and floods experienced in countries such as China or Bangladesh, nor are we exposed to the threat of great earthquakes, like those experienced in recent times in Chile, the west coast of the USA, Japan, Taiwan and Turkey. Australia, however, is far from immune from the impact of significant natural disasters, given that such events cost the Australian community around $1.14 billion annually. The recent Bureau of Transport Economics (BTE) study into the economic costs of natural disasters in Australia (BTE, 2001) shows that over the period 1967 to 1999, Queensland experienced 71 major disasters with a total estimated cost of $7.9 billion (1999 dollar value), second only to the NSW total of $16.0 billion from 83 major disasters. It should be remembered, however, that for the last 24 years of this 34 year period Queensland has been relatively free of major cyclone and flood disasters.

The risks posed by natural hazards in the region are clearly significant, though perhaps not as widely recognised as they deserve to be given the region's disaster history. A multi-hazard risk assessment is, therefore, clearly required.

Our approach in developing this multi-hazard risk assessment of South-East Queensland has been consistent with the general risk management process outlined in *AS/NZS 4360:1999 Risk management* (see Figure 1.1) and its evolving application in the emergency (or disaster) risk management field. So far in this report we have:

- established the risk study context and process;
- identified the key risks faced by the South-East Queensland community that are posed by a range of natural hazards; and,
- analysed and characterised those risks.

In this chapter we evaluate these risks and prioritise their significance to the South-East Queensland community.

Risk Evaluation and Prioritisation

Several methodologies have been described in the literature for evaluating and prioritising risk as the first step towards establishing treatment priorities and strategies. The method that has gained wide recognition amongst Australian emergency managers is the 'SMAUG' approach based on the work of Kepler and Tregoe (1981). In this instance, SMAUG is not J.R.R. Tolkien's dreaded dragon, but an acronym standing for:

Seriousness, **M**anageability, **A**cceptability, **U**rgency and **G**rowth

The method involves rating each risk in relation to these criteria as being high, medium or low (see, for example, the discussion of this approach in Salter, 1997). The risk management standard (*AS/NZS 4360:1999*) provides a similar approach based on a matrix to rate risk likelihood qualitatively against its consequences (see Standards Australia, 1999, Appendix D).

Although both of these approaches provide a useful method for reaching a qualitative (and subjective) evaluation of risk, especially for a single hazard impact on a relatively small community, they are significantly less useful when applied to a multi-hazard risk evaluation and prioritisation for very large and complex communities such as that covered in this study. The quantitatively-based total risk approach that we have adopted in this study provides a more objective means of identifying the risks that pose the greatest threat to the South-East Queensland community and to its constituent neighbourhoods. To achieve this we have measured the input of the three key variables in the total risk relationship described in Chapter 1 – namely the hazards, the community elements exposed to those hazards and the relative vulnerability of those elements.

Risks compared: Although there is still some way to go before we can produce a single statistic that is able to measure total risk across all hazards, we have been able to produce statistics that do provide a comparison of the community's exposure to some major hazards.

Building damage is the single, best indicator of risk. That is, the level of building damage can be used to rank risks from various natural hazards (when considered against its probability of occurrence). Building damage can also be used to estimate risk in absolute terms, although such estimates will be incomplete. Other potential direct and indirect costs to the community, for example from casualties or from business interruption, are also important sources of risk. However, the damage to buildings may be the largest component of direct damage from natural hazard disasters (Bureau of Transport Economics, 2001).

Average annual damage or average annual cost figures are commonly used in the insurance industry and other areas with an interest in the cost of disasters. The BTE study, for example, shows that Queensland's average annual cost of natural disasters over the 1967 to 1999 time frame was $239 million, of which 46.7% was contributed by floods, 37.5% by cyclones and 15.6% by severe storms. There were no damaging earthquakes in Queensland during the time frame. However, the proportion of the NSW average annual damage bill of $484.1 million contributed by the Newcastle earthquake is 29.1%, compared with 26.5% for flood, 40.0% for severe storm and 3% for bushfires.

The use of building damage as a surrogate indicator for exposure across all elements at risk clearly imposes limits. However, it is clear that in Australian urban areas, damage to buildings has been the largest component of both direct and indirect damage in natural disasters. The contribution of building damage to the total estimated costs in four Australian natural disasters are shown in Table 12.1.

Table 12.1 Contribution of building damage to costs associated with four disasters (based on data from Tables 5.1, 5.2, 5.3 & 5.5 in BTE, 2001)

	Lismore flood 1974	Cyclone *Tracy* 1974	Ash Wednesday bushfires 1983	Nyngan flood 1990
% of direct costs	49	91	61	72
% of indirect costs	26	71	32	45
% of total costs	44	88	59	65

The estimated intangible costs (e.g. from fatalities and injuries to people) have been excluded from the totals.

A comparison of estimated residential building damage from earthquakes and from severe winds from tropical cyclones, for the entire South-East Queensland region, is shown in Figure 12.1. For earthquakes, damage losses are defined in terms of the percentage of the repair or replacement cost of a 'typical' residence including contents or, alternatively, the percentage loss of the repair or replacement cost of the entire residential building stock and contents. For cyclonic winds, damage losses are expressed as a percentage of the total insured value of a 'typical' residential building and its contents. Alternatively, the damage losses for wind can be considered as a percentage of the total insured value of all of the residential buildings and their contents.

The damage losses are the minimum losses expected for the probability associated with that loss. For example, for earthquakes, there is an annual probability of 0.5% that damage losses will be at least 0.007% of the total insured value.

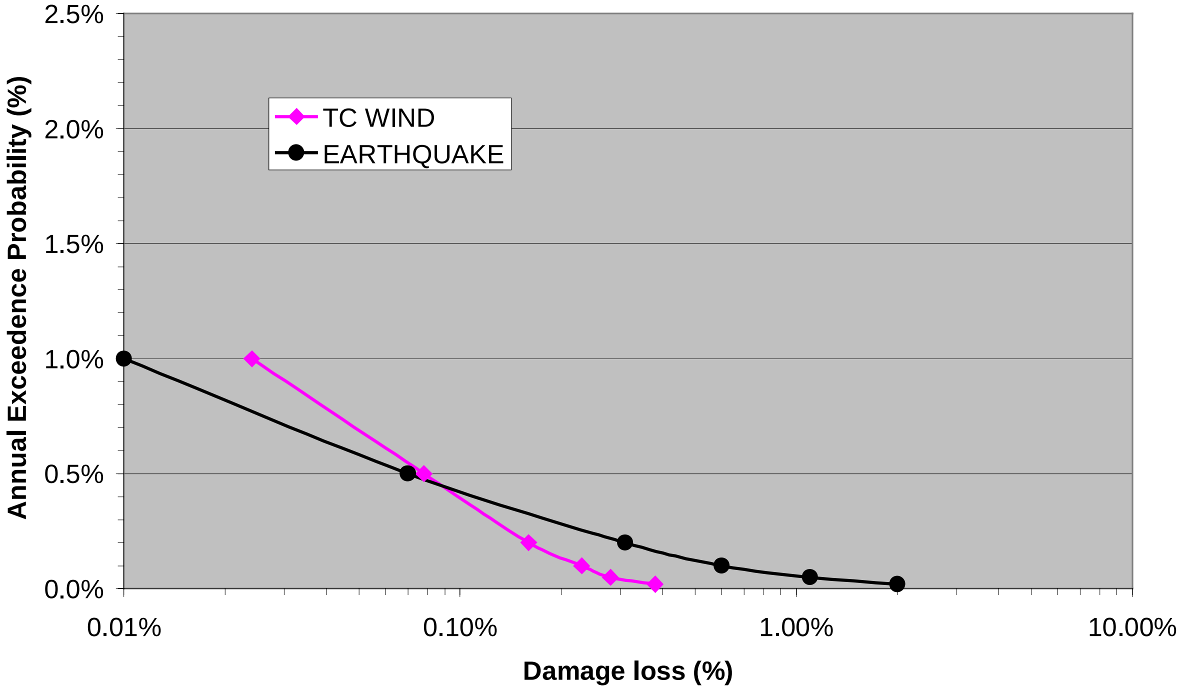


Figure 12.1 Comparison of percent building and contents damage from earthquake and cyclone wind

The uncertainties in the results are not shown in Figure 12.1. Because of the very large uncertainties, the risks posed by earthquakes and by severe winds from tropical cyclones, as determined from residential building damage alone, cannot be distinguished apart in Figure 12.1. Risk is related to the area underneath the curve. An important feature of the risk from tropical cyclone winds, and especially from earthquakes, is that a significant amount of all the risk from these hazards is attributed to extreme events. That is, relatively frequent events will not cause high levels of damage, particularly from earthquakes. However, very rare events have the potential to cause large amounts of damage (and earthquakes apparently more than cyclonic winds).

The risks posed by storm tide inundation and flooding are also compared. Structure and contents loss curves for flood damage (Blong, 2001) are used to estimate the percent damage loss. The impact of storm tide inundation compared to flood inundation when determining damage estimates is unclear. It is considered, however, that salt water will inflict greater damage and this has been incorporated in the storm tide damage loss shown in Figure 12.2. Though no modelling was available for riverine flood with AEPs less than 1%, damage from riverine flood significantly exceeds damage from storm surge inundation for AEPs of 2% and 1% (Figure 12.2).

Although Figures 12.1 and 12.2 are both based on percent damage loss they are not directly comparable. Earthquake and tropical cyclone wind damage losses are based on aggregated damage estimates from numerous scenario events randomly imposed on areas within the region, whereas storm tide and flood damage estimates are based on inundation levels with a particular AEP imposed over the entire region. It is considered that altough the latter estimates will overestimate regional risk, they represent the numbers that disaster managers need to base their plans, especially for carrying out precautionary evacuations.

Clearly, the estimates of damage in the figures contain many limitations and uncertainties, and the comparisons of risk must be taken as indicative. We refer the reader to the individual hazard chapters for discussions of some of the limitations and uncertainties.

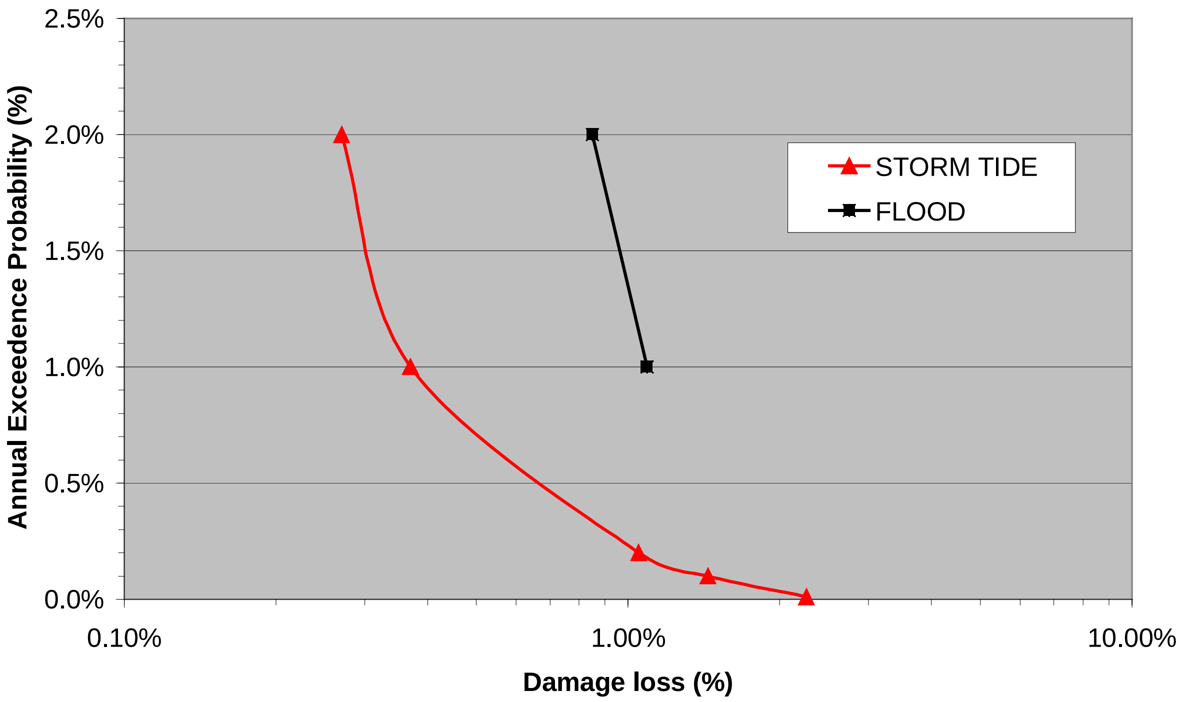


Figure 12.2 Comparison of percent building and contents damage from storm tide inundation and flood

Risk Thresholds

It is difficult, if not impossible, to be categorical about levels of acceptable or tolerable risk. Such risk criteria vary greatly over time, from circumstance to circumstance and from the different perspectives of each individual member of the community. For example, many people will tolerate the minor levels of flooding that might occur once every five or so years, especially if it affects few properties. The community generally will be less tolerant of moderate to major flooding that causes widespread dislocation and damage. Major levels of inundation or wind damage that kill people and produce massive economic loss are typically 'unacceptable'. Whilst this seems to be an eminently reasonable approach, it can also be viewed as being unrealistic, especially where the event that creates tragic losses is very rare.

It is relatively easy and inexpensive to control, or even eliminate, the nuisance levels of flooding that most people tend to tolerate. It is, however, economically impractical, if not physically impossible, to eliminate the risk of rare but catastrophic levels of riverine or storm tide inundation. Similarly, it would be prohibitively expensive to build structures to withstand the impact of the largest likely earthquake or the strongest likely wind. There is an inverse relationship between risk acceptability and risk controllability. The widely adopted response to this paradox is to establish thresholds of risk that are economically viable to implement and socially acceptable. Events that exceed those thresholds are coped with, if, and when they occur. In South-East Queensland the following thresholds, based on local government planning thresholds or Australian Standards, are either explicitly or implicitly accepted, probably with minimal community input:

- for destructive winds - under the criteria established in *AS 1170.2-1989*, no building should fail unless exposed to wind loads greater than those for which there is a 5% probability of exceedence in any 50 year period (i.e. an ARI of around 1000 years);

- for storm tide – varies between LGA with coastal exposure but generally those LGA require ground fill levels of new urban subdivision development to be above the level of the 100 year ARI storm tide event (plus allowance for other factors), and new building floor levels to lie above the level of the 100 year ARI storm tide plus 0.3 m;
- for flood – again these vary between the various LGA, however, most require ground fill levels of new urban subdivision development to be above the level of the 100 year ARI flood, and new building floor levels to lie above the level of the 100 year ARI flood plus 0.3 m;
- for earthquake - the criteria established in *AS1170.4-1993* are the minima to prevent buildings suffering structural collapse under earthquake loads for which there is a 10% probability of exceedence in any 50 year period (i.e. an ARI of around 500 years). More stringent design standards are required for structures used for what we have termed 'critical facilities'.

This approach would seem to set inconsistent standards of 'risk acceptance' and is certainly not unique to South-East Queensland. The thresholds for earthquake and severe wind have largely been set by agencies outside South-East Queensland, especially those involved in establishing the various standards for structures under the Australian Building Code. For hazards for which no Australian standards exist (flood and storm tide), local government planning guidelines play a larger part in setting thresholds.

These thresholds do not generally address the risks to structures (and consequently people) built before their introduction. The vulnerability of older structures to earthquake loads, for example, has, as a result of the losses experienced in the 1989 earthquake in Newcastle, been addressed through the publication of *AS 3826-1998 Strengthening existing buildings for earthquake* (Standards Australia, 1998). A similar engineering guideline (rather than a standard) for upgrading older houses in high wind areas has also been published for both non-cyclone areas (Standards Australia and ICA, 1999a) and cyclone areas (Standards Australia and ICA, 1999b). These documents, which provide guidance relating to the improvement of older buildings, are not mandatory in their application. No equivalent document exists for storm tide or flood.

Is South-East Queensland a Risky Place?

The numbers published in the BTE study do not permit a breakdown below the state level, however, given that 53% of the State's total population and an even greater proportion of its commercial and infrastructure development is concentrated in the study area, it seems reasonable to assume that it represents a major source of the State's risk exposure. Indeed, our analysis enables us to make the following judgements regarding the 'riskiness' of South-East Queensland **at threshold levels**:

Flood: It is clear from this analysis that river and creek flooding represents the greatest regional risk overall. Furthermore, the aggregate potential losses across the study area from river flooding at the 1% AEP level represents the highest aggregate urban flood risk in Australia. Flooding across the region affects at least 47 400 developed properties during an event with a 1% AEP (100 year ARI), with many more properties being completely isolated by the floodwaters. Of this number, more than half of the buildings are affected by overfloor flooding. This compares with 1760 properties with overfloor flooding in the Hawkesbury-Nepean catchment of NSW for the same AEP level of flooding (Smith 1991).

Damage (as a percent of sum insured) per building across the entire study area is about 1.1% per building (including contents) during a 1% AEP event, with more than half of the damage falling within the Brisbane-Bremer catchment. About 27% of the damage falls within the Pimpama-Coomera-Nerang-Tallabudgera-Currumbin catchment, 13% in the Logan-Albert and 2% in the Caboolture-Burpengary catchment (flood damage for Pine Rivers could not be calculated because of the lack of a suitable DEM from which to model flood depths). The areas with the greatest damage (e.g. Fairfield, Rocklea, Chelmer, Saint Lucia, Toowong and Graceville) are areas which suffered substantially in the floods of January 1974.

Storm Tide: Across the region as a whole there is a low risk from storm tide inundation, however, the aggregate potential at the 1% AEP level represents the highest such aggregate risk in Australia. There are 9550 developed properties across the region that would be exposed to overfloor inundation in a 1.0% AEP (100 year ARI) storm tide event. This represents about 1.5% of all developed properties exposed at the 'design' level event. By contrast, Cairns has 3800 buildings and Mackay 2170 buildings likely to have overfloor inundation from a 1% AEP storm tide (it is emphasised that, in South-East Queensland, it would be unlikely that this aggregate number would be reached as the result of a single cyclone). The number of properties with overfloor inundation increases to about 44 000 in a 0.01% AEP (10 000 year ARI) storm tide event. This represents about 6.7% of all developed properties in the region. The neighbourhoods that do have a high storm tide risk index tend to be in the areas of older residential coastal development (particularly Bongaree, Brighton, Lota and Sandgate); rural or rural village-type communities (e.g. Beachmere, Boondall, Ningi, Nudgee Beach and Toorbul); some of the more modern canal estates (most notably Birkdale, Cleveland and Hope Island); and some of the areas containing commercial/industrial development on the lower reaches of the Brisbane River (e.g. Albion, Hemmant and Pinkenba). It is apparent that most of the LGAs that have a recognised storm tide risk in the region have established, or are moving to establish, the 100 year ARI storm tide level for their planning threshold.

Tropical Cyclone Wind: Analysis of tropical cyclone wind impact on the region indicates a low to moderate level of risk. For the 1% AEP (100 year ARI event) an equivalent damage loss of 150 insured dwellings with contents can be expected. This increases to 1500 dwellings for the 0.01% AEP (1000 year ARI design event), or, 0.23% of total insured value of building and contents for the region. The expected damage to older settlements near the coast is estimated to be almost 100 times greater than the average residential damage across the entire region. Brighton, Sandgate, Shorncliffe, Wynnum, Manly, and Lota are examples of those suburbs most at risk of damage. Coolangatta, Surfers Paradise and Burleigh Heads are also expected to suffer significantly higher wind damage than the regional average. Residences that are not shielded by other buildings, such as those in semi rural areas, are also expected to suffer higher damage rates than residences of similar age in more densely urbanised settlements. Tree and branch-fall also represents a significant threat to assets such as buildings, cars and telecommunications. Roads can also become blocked and underground utilities dislocated.

Earthquake: The level of earthquake risk in South-East Queensland is low to moderate when considered on a regional basis, and earthquakes should be considered in risk management strategies for the region. Although damaging earthquakes are relatively rare in Australia, the high impact of individual events on the community has made them a costly natural hazard. There have been few reports of earthquakes causing significant damage in South-East Queensland. However, we need to be aware of the short historical record and the consequences of a rare, damaging earthquake, such as the magnitude 6.3 offshore 'Bundaberg' earthquake in 1918. Although overall hazard is low, it is higher in the many parts of South-East Queensland that are built on unconsolidated sediments or on Tertiary geological units. These ground conditions are expected to amplify the ground shaking from future earthquakes. The amount of damage likely to occur in a design level event (a 0.2% AEP earthquake) would equate to the total damage to about 2000 dwellings.

South-East Queensland faces a moderately low risk to its residential buildings from earthquakes. We rate the vulnerability of South-East Queensland residential buildings to earthquake as low. The great majority of residential buildings in South-East Queensland (an estimated 95%) are of light timber frame construction. Timber frame buildings perform well in earthquake and this is a positive factor in the earthquake risk that South-East Queensland faces.

East coast lows: The major impact of east coast lows on South-East Queensland will be in terms of potential storm tide and severe waves, wind damage and flooding. These hazards pose a significant threat of both fatalities and economic loss in localised areas. The incidence of these types of storms can fluctuate from one year to the next. The long term average annual occurrence is about 2.5 storms per year but since 1960 the average has increased to 3.7. The effect of these storms on coastal areas can be severe, frequently with loss of life and property from flooding and maritime incidents. We have not, however, quantified the level of that risk.

Thunderstorm: Thunderstorms can bring with them destructive winds, hail, heavy rainfall, lightning and tornados. This analysis estimates the 100 year ARI wind associated with thunderstorms to be about 170 km/h and the 1000 year ARI winds at about 220 km/h, while reports have been made of accompanying hail up to 120 mm in size. The South-East region is particularly susceptible to severe thunderstorms, especially during the summer months. It can be anticipated that at least one damaging thunderstorm could impact somewhere in South-East Queensland in any given year with about 20 occurring in the region. The frequency of these events appears to be increasing. Whilst the areas affected will be much smaller than that affected by a tropical cyclones or east coast lows, the impact could still be both lethal and destructive. We have not, however, quantified the level of risk.

Heatwave: At least 18 heat wave events have been identified since 1899 giving an ARI of, at most, 5 to 6 years. January is clearly the most common month in which heat waves occur. At least 681 deaths have occurred as either a direct or indirect result of heatwave in Queensland. Anecdotal evidence indicates that many elderly people, and indeed many people in other susceptible groups of the population, are largely ignorant of the risks posed by heat waves, or of the simple steps that can be taken to reduce those risks. There is clearly a need to improve public awareness. We have not, however, quantified the level of risk.

Landslide: Within the Gold Coast hinterland region and in particular the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas, the risk posed from landsliding from a 100 year ARI rainfall event is low to moderate. On slopes >25° a maximum of about four fatalities and up to two dwellings could be destroyed. Individuals living in the Beachmont basalt geological unit are particularly at risk. On slopes <25° the number of fatalities is significantly less at about 0.3, with about 2.7 dwellings destroyed. Roads traversing slopes >25° are few, however the 13 km of road in these areas is on average expected to be blocked a total of three times. Some sections of roads on slopes <25°, are expected on average to be blocked or partially blocked every 1 to 2 km and have a section destroyed by landslide about once every 5 km. In the Caboolture, Pine Rivers, Brisbane, Ipswich, Redcliffe and Redland areas the risk posed by landsliding is very low and it is unlikely that existing buildings would be destroyed or people killed by landslides on cut slopes.

Bushfire: In the context of this study, which has an emphasis on the urban environment, the primary risks posed by bushfires are to those areas on the urban fringe. The key risk is to buildings and to those elements of infrastructure that are either flammable (e.g. timber power poles and wooden bridges) or susceptible to the heat generated by bushfires (e.g. power supply switching gear and electronic equipment). People are also at significant risk, especially if they are caught in the open or in vehicles that are inadequately protected. This risk was highlighted recently by the deaths of several fire fighters in other states and the serious injuries suffered by nine volunteer fire fighters near Beerwah (the so-called 'Bell's Creek fire') in November 1994.

Major floods, storm tides and storms all hold the potential to cause significant economic harm and kill people. The warning systems and other mitigation strategies already in place in the region, however, should help to minimise both loss of life and economic harm if the warnings issued are acted upon in an appropriate and timely manner. For this to be achieved, however, the community must be aware of the risks they face and understand the warnings and their significance to them.

Reducing Risk

The development and implementation of risk management strategies for South-East Queensland lies outside the remit of the *Cities Project*. Our experience in working with people involved in emergency risk management in South-East Queensland and elsewhere, has, however, given us some insight into key aspects of risk reduction that are offered here as observations, rather than as suggestions. They are certainly not put forward as recommendations.

As has been emphasised at several stages in this study, the only way to reduce or eliminate risks posed by natural hazards is to reduce or eliminate one or more of the three risk variables – the hazard, the elements exposed to the impact of that hazard and the vulnerability of those elements. For any tangible steps to be taken, however, a strong risk culture and the information to sustain it must be developed.

Risk culture: At a philosophical level at least, one of the most potent forms of risk minimisation is the development and nurturing of a strong risk management culture across the community. It has, for example, been frequently observed that emergency risk management is most effective where it is an integral part of overall community risk management. Similarly, disaster planning is most effective where it is managed as an integral part of total community planning. In the vast majority of cases, however, these processes and activities tend to be divorced from the mainstream of community governance, even within organisations that are clearly committed to public safety, as are each of the LGAs in the study area. The compartmentation and isolation of emergency risk management from the mainstream of community governance can best be attributed to the lack of a broadly-based culture of risk management.

Risk management has clearly taken root amongst the LGAs in the South-East Queensland study area, though it is still at an early, and perhaps, fragile stage of development. This commitment can be largely attributed to the pioneering efforts of various LGA disaster coordinators, engineers and planners since the 1980s. The activity is clearly underpinned by the development and promotion, by the Department of Emergency Services (DES), of practical guidelines for local governments to follow in pursuing 'disaster risk management' (Zamecka and Buchanan, 1999).

A mature risk management culture will see the decisions made by the executive, administrative, public health, planning, environmental, engineering, fiscal, legal and emergency management elements become more integrated, consistent and coordinated. The outcome would see the interdependencies of strategic decisions in each of those areas acknowledged and their consequences taken into account in a more transparent and seamless process. Such an approach would also tend to widen the planning timeframe from the current two or three year, electorally constrained, horizon to one of 10, 20 or even 50 years.

Risk information: For a comprehensive risk management culture to flourish, it is necessary for it to be underpinned by a strong and effective information infrastructure. We see the development of such an infrastructure as being the most fundamental of all risk reduction strategies. It is also one of the most cost effective strategies, given that most of the information required is already collected, maintained and used by South-East Queensland LGAs and the other authorities that have a role in community risk management. This aspect is considered in detail in a report on the *Cities Project's* experience of implementing key aspects of the Australian Spatial Data Infrastructure (ASDI) in the Cairns case study (Granger, 1998). A similar strategy was adopted for this study.

Whilst much of the basic information required for risk management, such as street layout, property information, land use and demographic aspects, is already available, there are several themes that we have found to be poorly addressed. Three themes stand out:

- historical information: whilst the Bureau of Meteorology, QUAKES and AGSO maintain their own information on hazard history, and other bodies in the community such as local historical societies, libraries and media outlets each maintain collections on the community's experience of disaster, there is no consolidated index or coordination of information about the South-East Queensland history of disasters and their impact on the community;

- modern event experience: South-East Queensland has not experienced any significant disaster impacts for several years so there has been little need for post-event research to be conducted, as has been the case in Cairns, for example, following Cyclones *Justin*, *Rona* and *Steve*. Much of this post-event information, such as the recording of earthquake aftershocks or the nature of flood damage, is highly perishable – if it is not collected during the event it will be lost forever. Without such detail of real events it is not possible to reduce the uncertainty that exists in our models and basic information. The requirement to collect key event information needs to be entrenched in the doctrine of disaster response, with appropriate resources identified in disaster plans and made available to undertake the collection and management of that information; and,

- technical information: much background technical information is being routinely collected by commercial consultancies to meet the requirements of various standards such as the Australian Building Code. The collection and analysis of geotechnical information on which to base the design of building foundations is a case in point. This information is of great significance to improving the accuracy and relevance of risk assessments. Whilst there are obvious commercial (and possibly legal) sensitivities concerning such information, its value to the wider aspects of community safety is not being realised because there is no central inventory of the existence of such information – let alone an archive of the detail.

There has been significant public investment in the development of systems to monitor hazard phenomena and to provide warnings of an impending impact. This important investment has not, however, been matched by the level of investment in information that enables the warnings or risk forecasts to be translated into information of relevance to members of the community. There is clearly a need for a greater level of investment in risk information.

Emergency management: The emergency management process has been based on consideration of the prevention, preparedness, response and recovery phases of disasters (known as PPRR). Under the adaptation of *AS/NZS 4360:1999* to emergency risk management, these traditional components of emergency management can be seen as risk treatment options. The emphasis is on the treatment of residual risks (i.e. the risks that can not be eliminated or reduced by other means), especially in the preparedness, response and recovery phases. Most risk reduction options, however, clearly focus on prevention.

The preparedness phase emphasises disaster planning, community awareness, training and exercising and the provision of appropriate resources such as communications equipment (see EMA, 1993). It is important, therefore, for emergency planning to be based on sound risk assessments and realistic risk scenarios, otherwise plans may be inappropriate, awareness will be inadequate, training and exercises will not be based on realistic scenarios and resources may not be appropriate. Evacuation planning provides a good example. If such plans are based on an assessment that badly underestimates the numbers of people at risk and the timing for an evacuation, many people could be placed in serious jeopardy by reacting too late and with too few resources. Conversely, if the estimates are too conservative, large numbers of people who did not need to be evacuated could easily overwhelm evacuation resources and shelters.

The detailed information and decision support tools provided to South-East Queensland LGA as a result of this study can be used to produce threat-specific plans on which to base all aspects of the preparedness phase. They enable, for example, the development of disaster response and recovery plans for specific levels of cyclone or flood risk, well in advance of any event, and to use the scenarios on which they are based to run realistic exercises and training serials.

The risk scenarios also provide a capacity to model and forecast impact consequences so that the response phase can be managed more effectively. In Cairns in 1999, for example, the data developed under the *Cities Project's* Cairns multi-hazard risk assessment was used by the local counter disaster staff together with the Cairns City Council's own flood model data to forecast the likely impact of the flood that was developing in the Barron River following the passage of Cyclone *Rona*. The information derived from this scenario modelling was then used to successfully plan and carry out the evacuation of more than 1500 people, assessed as being at risk, before the flood peak was reached. That evacuation was conducted at 2.00 am!

The same modelling is also appropriate for rehearsing and planning for the recovery phase. There are examples in the literature of GIS being used to model the impact of a damaging earthquake and to forecast the requirements for short term and long term post-event shelter. Similarly it is possible to model the physical impact on lifelines and the consequences of their loss on the community.

Use of the scenario analysis technique develops 'future memory', i.e. disaster responders develop an understanding of what will happen when such an eventuality occurs so that their actions are based on 'experience' when it eventually does happen. This process could be reinforced by the development of role-play simulation 'games', such as *SimCity*, designed around real South-East Queensland urban centres.

Reducing hazards: Apart from reducing or eliminating bushfire fuels, and stabilising some slopes to prevent landslide occurrence, we have no capacity to reduce the magnitude or severity of any natural hazard phenomenon. On present indications, however, over the next 50 years at least, climate change and an associated rise in sea level are likely to increase both the incidence and severity of most hazards that have an atmospheric origin, including tropical cyclones, storm tide, floods, storms and landslides. Climate change may also increase the incidence and/or severity of heat waves and bushfire. Such changes should obviously be taken into account in planning decisions being taken now to ensure that future risk is at least minimised. It is also important that this process of change is effectively and closely monitored.

Monitoring and warning systems: For all of the hazards considered in this study, with the exception of earthquake, warnings of impending impact are already provided in one form or another. A report produced by the Institution of Engineers, Australia (Institution of Engineers, 1993) provides a useful hypothetical example of the benefits of this approach in the following terms:

> *Flood warning systems now feature real time data collection networks linked to computer based flood models. These systems not only identify and track floods down a river but also enable emergency services to quickly assess the impact of various scenarios of increased or decreased rainfall, changing tidal conditions in the lower reaches of the river and varying tailwater effects at the river mouth due to storm surge and wave setup. Based on these scenarios, authorities can take more effective action to save lives and minimise damage to property. Even in a catchment with only one thousand flood prone homes, accurate advanced information on flood levels which enables residents to move contents and motor vehicles to locations above flood waters can result in a saving of $10 000 per household.* ***This $10M savings is a direct benefit to the community every time such a flood occurs.***
>
> (emphasis in original)

The coverage and sophistication of most of the monitoring and surveillance systems is constantly improving. There are plans, for example, to introduce Doppler radar to measure wind speed in storms and cyclones and thus improve both warnings and our knowledge of extreme wind speeds. There is also significant scope to improve on the existing seismic monitoring network in the South-East Queensland region so that instrumental recording of the smaller and more frequent events can help build up our knowledge of the region's seismic environment.

Nonetheless, warning systems will be much more effective if the community is aware of their existence and of the implications of warnings. Whilst there is some scope to improve the timeliness and accuracy of warnings, their value will only be increased when individuals are able to relate warning information to their own circumstances and translate that information into risk reduction action. To achieve this it is necessary to increase public awareness by combining appropriate risk information and warning information.

Reducing vulnerability: It is widely recognised by emergency managers that 'an aware community is a prepared community'. To put the reverse argument, all of the investment in risk information, warning systems, risk science and emergency planning is completely wasted unless it also influences the community to adopt risk reduction strategies.

Risk communication: An effective strategy of risk communication is essential. For example, a typical public flood warning will be expressed in terms of a height on the reference flood gauge. Few people in urban areas can translate that level, with any certainty, to their own property in terms of how high the water would reach. The value of the warning is consequently diminished because few individuals know what action they should take in response.

A considerable literature on risk communication has emerged over the past decade or so (see, for example, the review by Marra, 1998). One of the most coherent examples we have encountered is that promoted by the US Environmental Protection Agency (EPA). Their approach devolves from the basic tenet that, in a democracy, people and communities have a right to participate in decisions that affect their lives, their property, and the things they value. The EPA approach is based on the following 'seven cardinal rules' (word in italics are quoted from EPA, 1988):

> Rule 1 – accept and involve the public as a legitimate partner: *the goal of risk communication in a democracy should be to produce an informed public that is involved, interested, reasonable, thoughtful, solution-oriented, and collaborative; it should not be to diffuse public concerns or replace action.*
>
> Rule 2 – plan carefully and evaluate your efforts: *there is no such entity as "the public"; instead, there are many publics, each with its own interests, needs, concerns, priorities, preferences, and organisations.*
>
> Rule 3 – listen to the public's specific concerns: *people in the community are often more concerned about such issues as trust, credibility, competence, control, voluntariness, fairness, caring, and compassion than about mortality statistics and the details of quantitative risk assessment.*
>
> Rule 4 – be honest, frank and open: *trust and credibility are difficult to obtain. Once lost they are almost impossible to regain completely.*
>
> Rule 5 – coordinate and collaborate with other credible sources: *few things make risk communication more difficult than conflicts or public disagreements with other credible sources.*
>
> Rule 6 – meet the needs of the media: *the media are frequently more interested in politics than in risk; more interested in simplicity than in complexity; more interested in danger than in safety.*
>
> Rule 7 – speak clearly and with compassion: *tell people what you cannot do; promise only what you can do, and be sure to do what you promise.*

Governments, at any level, can only hope to reduce risk if their risk reduction strategies are accepted and supported by the community. Risk communication is the most democratic way of achieving that support.

Efforts to inform the community about risks are not always viewed with the same passion and altruistic values as those held by risk communicators. They are often met with opposition from small, but influential, sectors. The most common negative reactions relate to the belief that such information will have a negative impact on real estate values, and/or, will 'scare away' tourists or investment. Whilst there has been only limited research into the overall economic impact of risk communication, the anecdotal information that we have seen indicates that such negative beliefs are wrong. They do, nevertheless, excite levels of passion and political 'outrage' that typically leads to the dilution, if not termination, of public awareness efforts.

Strengthening buildings: Adherence to building codes is rightly seen as being a very effective strategy for risk reduction, given that much of the losses encountered in disasters come from damage to buildings. All Queensland LGAs enforce the provisions of the Australian Building Code which established minimum standards for construction to safely withstand established levels of earthquake and wind risk. A standard for construction and subdivisional design in bushfire prone areas is also close to publication. Whilst these standards reduce the risk to new buildings, standards and guidelines have also been developed to 'retrofit' older buildings to similar levels of safety against earthquake and wind loads, as described above. Preliminary consideration is also being given to the development of comparable standards for design and construction in areas prone to landslide and to inundation hazards such as flood and storm tide.

It is clear that many existing buildings in South-East Queensland are susceptible to wind, in particular, and to earthquake damage. Councils could compile local databases of these buildings and assess whether mitigating action is necessary. Mitigation schemes could include elements of:

- regulations that make wind or seismic upgrade mandatory when any major renovation, alteration, addition or change of use is undertaken by the owner. *SAA HB132.1* and *SAA HB132.2* (Standards Australia & Insurance Council of Australia, 1999a and 1999b) contain recommendations for structural upgrade of dwellings for severe wind. *AS3826-1998*, (Standards Australia, 1998) contains recommendations for retrofit of buildings for earthquake;
- incentives through rating reductions for buildings that have undergone retrofitting;
- alternatively, disincentives through rating rises that increase over time if no mitigating action is taken;
- incentives to rebuild rather than renovate, alter or add; and,
- a broader State or National mitigation scheme that consults the insurance industry.

Critical facility protection: The loss or isolation of critical facilities such as hospitals, airports, fuel depots, power substations, cold stores and emergency service facilities, will greatly magnify the impact of disaster on the community. Whilst such facilities remain exposed to disaster impact, plans to protect them are called for. Such protection may be as simple as ensuring the priority allocation of sandbags to the facility. It may be as routine as ensuring that the facility has an adequate uninterruptible power supply (UPS) or a stand-by generator with adequate fuel to cover the loss of reticulated power supply. Or it may embrace costly structural defences such as the construction of permanent protective berms or levees and the development of redundant capacity at other facilities that could cope with the potential loss of one component in a critical system.

Such mitigation efforts are targeted to maximise community protection with a minimum of effort and cost.

Reducing exposure: The simplest way to reduce risk is obviously to keep people and development out of areas that are prone to regular and/or significant hazard impact such as floods. Such an approach has already been adopted in South-East Queensland with the various council inundation policies for new development.

Queensland's *Integrated Planning Act* (IPA), which came into force in 1998, also has the potential to be used to reduce community risk. This legislation enables local governments to include, within their urban planning schemes, specific constraints on development that are aimed at managing risk. The IPA does not establish levels of constraint for different hazards, such as an ARI of 100 years as the State-wide constraint for development in floodplains, but leaves the setting of such thresholds to the individual local government.

The IPA also contains provisions that enable councils to change past planning decisions that did not take into account community safety issues. A land use approved under a previous planning scheme can, for example, now be changed without compensation to the owner, but only after the owner has been allowed two years to substantially commence redevelopment on a site with a previous use.

To be effective, however, planning policy must take both a long-term view (preferably with at least a 20-year horizon), and a holistic perspective, especially as the centre of development moves away from historical urban centres as the community expands. This study, for example, has provided new earthquake hazard information. Councils could use that information to ensure that new development does not introduce unnecessary risk. Councils could, for example, adopt the South-East Queensland earthquake hazard map to inform developers and their engineers of ground conditions with regard to earthquake.

The planning regulation corollary to the 'retrofit' codes for existing buildings is the policy of relocation or compulsory acquisition of properties with an unacceptably high degree of exposure. Such programs are usually expensive and marked by controversy, however, they are clearly effective in reducing risk.

Engineered defences for inundation: The classic response to inundation risk mitigation has been to turn to structural defences such as levees, dams, flood detention basins and fill that are designed to reduce or eliminate exposure to the hazard. There is a view, however, that:

- they are invariably expensive;
- they frequently fail to provide the levels of protection that are attributed to them because of inadequate design and/or poor maintenance;
- they foster a false sense of security in the community that they are supposed to protect, with the result that when they fail, the community is exposed to a much greater degree of loss; and,
- the levels on which they are based (e.g. the modelled Q100 flood line) can change dramatically (either up and down) as better science, modelling techniques and information is applied, and as external factors, such as vegetation protection regulations, take effect.

The degree of protection from flood in the Brisbane River afforded by the construction of the Wivenhoe Dam provides a good example. There is a widely held view within the Brisbane community, for example, that the construction of Wivenhoe Dam will prevent a repetition of the 1974 flood, and consequently, Brisbane is now flood-free. Whilst Wivenhoe Dam has undoubtedly improved the management of flood waters, it certainly will not eliminate all floods in the Brisbane River, let alone floods originating in the Bremer River portion of the catchment. The urban myth surrounding the flood prevention capability of Wivenhoe Dam would even appear to have spread to the Logan River - we encountered one story in which some people on the Logan River actually believed that the Wivenhoe Dam provided them with flood protection!

There is an increasing tendency to emphasise non-structural mitigation measures (such as those discussed above) and to regard structural defences as the risk reduction strategy of last resort. Where structural mitigation is being considered, however, the risk assessment methodology we have employed in this study provides the basis on which to undertake a cost-benefit study. The risk assessment approach also enables proposed risk reduction strategies to be modelled and their effects tested against the criteria that they aim to meet.

The Wider Picture

This study has concentrated on the risks posed directly to the South-East Queensland community. Where appropriate, however, attention has been drawn to factors that lie outside the control or influence of the South-East Queensland community that may exacerbate those risks. Attention has also been drawn to facilities located within South-East Queensland, the loss or isolation of which could have significant consequences beyond the borders of the LGA in which they are sited. It is appropriate, therefore, to consider the risks to South-East Queensland in a wider geographic context.

Clearly, the most significant factor that influences the vulnerability of the South-East Queensland community is its reliance on external sources for all of its fuel, most of its power supply and much of its food, water and personal requisites. The dislocation of any or all of these services, or their isolation from South-East Queensland, would have a very significant impact on the South-East Queensland community, even if South-East Queensland itself were not directly affected by the particular hazard impact. The loss of supply from the Gladstone power station, which generates half of the State’s total power, for example, would greatly reduce the amount of energy available for use in South-East Queensland. The isolation of the major fuel storages and refineries at the mouth of the Brisbane River, for example, could see many motorists, transport operators and plant operators run out of fuel in two to four days. There is little, if any, redundancy to provide an alternate supply to the South-East Queensland.

Brisbane, through its history and size, is clearly the economic and administrative ‘centre of gravity’ for the South-East Queensland region. It is natural, therefore, that most of the region’s high-order and strategic services are located within its boundaries. The distribution systems that support them are also, by necessity, extremely efficient. It is a highly productive and prosperous arrangement which has undoubted economic, administrative and political benefits - under ‘normal’ circumstances. Under the conditions experienced in disasters, however, such a concentration could significantly **increase** community risk, not only to Brisbane City, but to the entire region, if not the whole State and significant portions of northern NSW, especially if key resources and distribution infrastructures are sited in locations that have a significant exposure to hazard impacts. Such circumstances may not be all that ‘abnormal’, especially if one takes a view of risk that is somewhat longer than the term of elected officials or the construction phase of a major development project. It is not until one takes a longer temporal and wider regional view of risk that the significance of these issues becomes apparent.

Under existing legislation and administrative arrangements in Queensland there is little that individual local governments can do to influence planning and development decisions in other local government areas that have the potential to impact on their long-term safety and sustainability.

Given that it is more than 25 years since the last significant disaster event in South-East Queensland, there is a significant degree of ignorance and complacency in the wider community regarding risk. A concomitant reluctance on the part of policy makers to commit to community safety has also been evident, especially if it is perceived to be at the expense of ‘development’. There are indications, however, that this situation is changing. This wind-shift is, in no small way, attributable to the publication of *AS/NZS 4360* and its adoption by the Department of Emergency Services as the basis for emergency risk management throughout the State. It has also been given some additional focus by changes to the guidelines that govern the Natural Disaster Relief Arrangements (NDRA) payments from the Commonwealth.

The Commonwealth Government revised its NDRA guidelines in 1998. The continued payment of the Commonwealth funding contribution to the restoration of public assets following disasters has been made explicitly conditional on there being evidence that the receiving public body (State or local government) can demonstrate that they have taken steps towards reducing the risks posed by recurrent hazards in the area that was affected. It should be noted that NDRA payments are only designed to return damaged assets to their pre-disaster state – it does not cover the costs of upgrading the assets to reduce their risk exposure. It is important to note that if mitigation measures are not increased in Queensland, the State risks not only recurring damage from disasters but also an increased shift in the NDRA cost burden from the Commonwealth Treasury to the State Treasury.

Queensland authorities see the principal challenge for the continued success of this ‘wind shift’, from an emphasis on response and recovery, to one of mitigation and risk reduction, as being one of securing the necessary funding through the establishment of a ‘National Disaster Mitigation Fund’. Queensland has been an advocate of such a fund, with the Premier writing to the Prime Minister in 1999 seeking the Commonwealth’s support. To date no progress has been made (Lesley Galloway, DES, personal communication, 2000).

Queensland authorities have also begun to develop a strategic view of risk mitigation at the State level. In December 1998, the Queensland Cabinet established the State Disaster Mitigation Committee (SDMC) to improve disaster mitigation in Queensland. The SDMC is a whole-of-Government committee, with representatives from ten State Government Departments (chaired by the Director-General, Department of Emergency Services (DES)), two Local Governments and the Local Government Association of Queensland (LGAQ).

From material provided by DES, the role of the SDMC is:

> *To provide advice to the Minister for Emergency Services on disaster mitigation issues through the Central Control Group of the State Counter Disaster Organisation (chaired by the Director General, Department of State Development).*

The efforts of the SDMC are designed to assist LGAs with planning for disaster mitigation, together with developing whole-of-Government strategies to incorporate disaster mitigation considerations in the full range of legislative and planning frameworks. These include a State Planning Policy on land use planning for disaster mitigation (under the *Integrated Planning Act*); the proposed State Infrastructure Plan (being developed by Department of State Development); and the State’s capital works programs.

The SDMC has:

- defined disaster mitigation as ‘the process of identification and analysis of potential hazards with a view to formulating options and strategies designed to reduce risk and minimise the effects when disasters occur’;
- established the parameters of an all-hazard risk management approach by developing a comprehensive reference book, *Disaster Risk Management* (Zamecka and Buchanan, 1999), which is based on the practical application of the *AS/NZS 4360:1999.* A companion guide, *The Disaster Risk Management Guide: A How–To Manual for Local Government*, has also been developed by DES;
- commenced the determination of criteria to be used in setting priorities for disaster mitigation across the State;
- evaluated existing Commonwealth and State programs’ abilities to fund disaster mitigation activities;

- developed funding criteria for the $3 million Natural Disaster Risk Management Studies Program (NDRMSP) which was formally released by the Commonwealth Minister for Finance and Administration in March 2000; and
- conducted a broad disaster awareness and education program directed at Local Governments and the community.

Whilst the State-level strategy is being addressed by the SRMC, it is perhaps significant that the South-East Queensland Regional Organisation of Councils (SEQROC), the strategic grouping of the 18 local government councils of the South-East, do not have a 'risk mitigation' or 'risk management' working group. They do have:

- a Planning Working Group to look at regional strategic planning issues;
- a GIS and IT Working Group which provides a forum for GIS and IT officers with the view to maximising compatibility of systems and to address standards issues;
- an Environmental Health Working Group to consider regional health and hygiene issues, animal management and related regulations;
- a Waste and Recycling Working Group to develop a uniform approach to waste management;
- an Environmental Management Working Group to consider regional approaches to issues such as vegetation and waterways management;
- a Rural Issues Working Group to consider issues such as rural viability and service delivery;
- a Transport Working Group that considers regional transport planning proposals;
- an IT and Knowledge Based Clusters Working Group to, amongst other objectives, promote e-commerce for small and medium businesses across the region;
- a Telecommunications (Facilities) Working Group to develop common approaches to the siting of mobile phone towers; and
- a Biosolids Working Group to investigate options for the disposal of sewerage sludge, etc.

Whilst some of these working groups undoubtedly take into consideration issues of community safety, there is no working group established explicitly to consider, coordinate policy or to make recommendations on issues of community safety and risk reduction on a region-wide basis. Hopefully, this study will prompt SEQROC and its member councils to consider such an addition.

The existing disaster management arrangements also seem to work against a regional approach to risk management. Each local government is responsible, under the *State Counter Disaster Organisation Act*, for developing its own local disaster plan. There are also district disaster plans drawn up to cover 'disaster districts'. These districts are based on the QPS Districts, which have been designed to maximise police administrative efficiency, not the provision of disaster management. Brisbane City, for example, is split between two police districts with the Brisbane River as their common boundary – not an ideal arrangement when considering flood management, for example.

A region the size, complexity and significance of South-East Queensland probably demands a different disaster management arrangement to make regional risk reduction an explicit objective rather than an afterthought once the disaster has happened.

Where to From Here?

At the beginning of this multi-hazard risk assessment of South-East Queensland we stated that it was 'a starting point, rather than an end in itself'. This needs to be restated at the conclusion.

There is opportunity to build on this assessment. For example, there has been a deliberate avoidance of undertaking economic assessments of potential loss as there are not the sufficiently complex models and data on which to base such an assessment at this time. It is clear that to enhance this assessment with a soundly based economic dimension would be a relatively minor undertaking with major advantages. We have also confined our assessments to scenarios that are based on present-day climatic conditions. Further work is required to understand the longer term risks associated with climate change, especially where it relates to sea level rise and the possible increase in the frequency and/or severity of cyclones and intense rainfall episodes.

A general lack of data has limited our consideration of the risks to lifelines such as power and water supply and their interdependencies. We are confident that those data will become available in the future and when they do, this study should be updated and its assessments re-evaluated.

Turning the information and the risk assessments provided here into risk reduction strategies is a task for others, particularly the South-East Queensland LGAs and their respective communities.

We are greatly encouraged by the action that has already become evident in the region and elsewhere. A strong level of commitment to risk management is beginning to emerge. We are confident that South-East Queensland is well on the way to becoming a much safer, more sustainable and prosperous community.

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APPENDIX A: ABBREVIATIONS AND ACRONYMS

ABS	Australian Bureau of Statistics
AC	asbestos cement
AEMI	Australian Emergency Management Institute
AEP	annual exceedence probability
AGSO	Australian Geological Survey Organisation
AHD	Australian Height Datum
ANU	Australian National University
ARI	average recurrence interval
AVHRR	Advanced Very High Resolution Radiometer
AWS	automatic weather station
BLEVE	boiling liquid expanding vapour explosion
BoM	Bureau of Meteorology
BPA	Beach Protection Authority
C	Celsius
CBD	central business district
CCD	Census Collection District
CHEM	Chemical Hazards and Emergency Management (Unit)
cumec	cubic metres per second
DCILGP	Department of Communication and Information, Local Government and Planning
DDC	Disaster District Coordinator
DEM	digital elevation model
DES	(Queensland) Department of Emergency Services
DNR	Department of Natural Resources
EDRI	Earthquake Disaster Risk Index
ENSO	*El Niño* - Southern Oscillation
FEMA	(US) Federal Emergency Management Agency
FWC	Flood Warning Centre
FWCC	(Queensland) Flood Warning Consultative Committee
GIS	geographic information system
GMDS	Global Marine Distress and Safety System
GMS	Global Meteorological Satellite
ha	hectares
HAT	highest astronomical tide
hPa	hecto-pascals
HQ	headquarters
h(s)	hour(s)
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
JUMP	Joint Urban Monitoring Program
km	kilometres
km/hr	kilometres per hour
LDC	Local Disaster Committee
LPG	liquid petroleum gas
m	metres
max	maximum
min	minimum
ML	Local (or Richter) magnitude
mm	millimetres
MM	Modified Mercalli intensity
m/sec	metres per second
MEOW	maximum envelope of water
MMI	Modified Mercalli Intensity

MPI	maximum potential intensity
MSL	mean sea level
NIBS	(US) National Institute of Building Sciences
NOAA	(US) National Oceanographic and Atmospheric Administration
PGA	peak ground acceleration
PMF	probable maximum flood
PNG	Papua New Guinea
PVC	polyvinyl chlorate
QFRA	Queensland Fire and Rescue Authority
QPS	Queensland Police Service
QUAKES	Queensland University Advanced Centre for Earthquake Studies
RAN	Royal Australian Navy
RFDS	Royal Flying Doctor Service
SEIFA	Socio-Economic Indexes for Areas
SES	State Emergency Service
SOLAS	Safety of Life at Sea
SST	sea surface temperature
TC	tropical cyclone
IDNDR	International Decade for Natural Disaster Reduction
SCDO	State Counter Disaster Organisation
SEQWB	South-East Queensland Water Board
SEWS	Standard Emergency Warning Signal
SLA	Statistical Local Area
SOI	Southern Oscillation Index
SP	short period (seismograph)
TCCIP	Tropical Cyclone Coastal Impacts Program
TCWC	Tropical Cyclone Warning Centre
temp	temperature
UHF	ultra high frequency
UNDRO	United Nations Disaster Relief Organisation
UNEP	United Nations Environment Program
UTC	Universal Time
VC	vitreous china
VHF	very high frequency
WMO	World Meteorological Organisation
WWSSN	World Wide Standardised Seismograph Network

APPENDIX B: THE SEIFA INDEXES

The following tables list the variables used by the Australian Bureau of Statistics the produce the Socio-Economic Index for Areas (SEIFA) index values used in this study. For further details of the SEIFA indexes and the methodology used to construct the most appropriate reference is ABS (1998b).

Table B1: Variables used in the SEIFA *Index of Socio-Economic Disadvantage*

Variables with weights between 0.2 and 0.3:

- persons aged 15 and over with no qualifications (%)
- families with income less than $15,000 (%)
- families with offspring having parental income less than $15,600 (%)
- females (in labour force) unemployed (%)
- males (in labour force) unemployed (%)
- employed females classified as 'Labourer & Related Workers' (%)
- employed males classified as 'Labourer & Related Workers' (%)
- employed males classified as 'Intermediate Production and Transport Workers' (%)
- persons aged 15 and over who left school at or under 15 years of age (%)
- one parent families with dependent offspring only (%)
- households renting (government authority) (%)

Variables with weights between 0.1 and 0.2:

- persons aged 15 and over separated or divorced (%)
- dwellings with no motor cars at dwelling (%)
- employed females classified as 'Intermediate Production & Transport Workers' (%)
- employed females classified as 'Elementary Clerical, Sales & Service Workers' (%)
- employed males classified as 'Tradespersons' (%)
- persons aged 15 and over who did not go to school (%)
- Aboriginal or Torres Strait Islanders (%)
- occupied private dwellings with two or more families (%)
- lacking fluency in English (%)

Table B2: Variables used in the SEIFA *Index of Economic Resources*

Variables with weights between 0.2 and 0.4:

- households owning or purchasing dwelling (%)
- dwellings with 4 or more bedrooms (%)
- families with family structure other than two parent or single parent with dependent offspring or consisting of a couple only, and income greater than $77,999 (%)
- families consisting of a couple only, and with income greater than $62,399 (%)
- families consisting of a single parent with dependent offspring, with income greater than
- $31,199 (%)
- mortgage greater than $1,300 per month (%)
- rent greater than $249 per week (%)

Variables with weights between 0 and 0.2:

- households purchasing dwelling (%)
- households owning dwellings (%)
- dwellings with 3 or more motor cars (%)
- average number bedrooms per person (%)

Variables with weights between -0.2 and 0:

- households in improvised dwellings (%)
- households renting (government authority) (%)
- households renting (non-government authority) (%)
- dwellings with 1 or no bedrooms (%)
- rent less than $74 per week (%)
- families consisting of a single parent with dependent offspring, with income less than $15,600 (%)

Variables with weights between -0.3 and -0.2:

- families consisting of a couple only, and with income less than $15,600 (%)
- families with family structure other than two parent or single parent with dependent offspring or consisting of a couple only, and income less than $26,000 (%)
- families consisting of a two parent family with dependent offspring, and income less than $26,000 (%)
- dwellings with no motor cars (%)

Table B3: Variables used in the SEIFA *Index of Education and Occupation* (ABS, 1998b)

Variables with weights between 0.2 and 0.4

- employed males classified as ‘Professionals’ (%)
- employed females classified as ‘Professionals’ (%)
- persons aged 15 and over at CAE or university (%)

Variables with weights between 0 and 0.2:

- employed males classified as ‘Associate Professionals’ (%)
- employed females classified as ‘Advanced Clerical & Social Workers’ (%)
- employed males classified as ‘Advanced Clerical & Social Workers’ (%)
- employed males classified as ‘Intermediate Clerical, Sales & Service Workers’ (%)

Variables with weights between -0.2 and 0:

- employed females classified as ‘Tradespersons’ (%)
- employed males classified as ‘Tradespersons’ (%)
- employed females classified as ‘Elementary Clerical, Sales & Service Workers’ (%)
- employed females classified as ‘Intermediate Production & Transport Workers’ (%)

Variables with weights between -0.4 and -0.2:

- employed males classified as ‘Intermediate Production & Transport Workers’ (%)

- employed females classified as ‘Labourer & Related Worker’ (%)
- employed males classified as ‘Labourer & Related Worker’ (%)
- males (in labour force) unemployed (%)
- females (in labour force) unemployed (%)
- person aged 15 and over who left school at or under 15 years of age (%)
- person aged 15 years and over with no qualifications (%)

APPENDIX C: METHODOLOGY FOR ASSESSING RELATIVE COMMUNITY VULNERABILITY IN SOUTH-EAST QUEENSLAND

Ken Granger

In Chapter 1 we described the approach adopted by the *Cities Project* to assess community risk. At the heart of that approach is the view of total risk as being the outcome of the interaction between a hazard phenomenon, the elements at risk in the community and their degree of vulnerability to that impact. The relationship was summarised in the expression:

$$\textbf{Risk}_{\textbf{(Total)}} = \textbf{Hazard x Elements at Risk x Vulnerability}$$

In Chapters 2 and 3 we describe individual aspects of the specific community under study and the contribution they make to community vulnerability. We also present an assessment of their relative contribution to the overall vulnerability of that community. In this Appendix we describe the methodology we have developed to produce that relative assessment and the philosophy that underpins it.

The Challenge

A large amount of high resolution data has been accumulated on the hazard phenomena, properties, infrastructure and people across South-East Queensland. The resolution and scope of this information varies between the eight local governments included in the South-East Queensland project area, however, there is a broad range of information that is common and consistent across the region. Whilst those data provide a detailed quantitative description of specific aspects of the each community's risk environment, they do not, of themselves, provide an adequate measure of overall community vulnerability. Nor do they individually reflect the relative levels of vulnerability across the community. We considered it to be highly desirable, however, to be able to identify those parts of the community under study that would provide a potentially disproportionate contribution to community risk, regardless of the hazard involved, because of the number and nature of the elements at risk they contained.

The challenge, then, is to develop a measure, or index, that enables us to rate neighbourhoods (as represented by CCDs) on the basis of their contribution to overall risk.

Vulnerability Indexes

There is little in the risk management or disaster management literature to use as a guide to construct such an index. Whilst the two workshops held at the Australian Emergency Management Institute (AEMI) at Mount Macedon in April and September 1995 contributed significantly to our understanding of vulnerability as a concept, they were not conclusive where the development of a 'vulnerability index' was concerned.

One of the few worked-through examples of a 'risk index' we have found is the Earthquake Disaster Risk Index (EDRI) approach developed by Dr Rachel Davidson (1997), now at the University of North Carolina at Charlotte. EDRI has been used recently to compare the earthquake risk in some 72 cities around the world as part of the *Understanding Urban Seismic Risk Around the World* Project.

The philosophy behind EDRI is similar to that which underpins the *Cities Project*. It is summarised by Davidson and Shah (1998) in the following terms:

> *Using a holistic approach, the EDRI attempts to measure the risk of an urban earthquake disaster. This is a broader concept than just the expected frequency of future earthquakes, or even their expected impact in terms of the number of deaths, injuries, or damaged buildings. In assessing earthquake disaster risk, the economic, social, political, and cultural context of the earthquake hazard plays a role too. An earthquake disaster is considered to be a function of not only the expected physical impact of future earthquakes, but also the capacity of the affected city to sustain that impact, and the implications of that impact to the city and to world affairs.*

EDRI is based on data considered to 'measure' the contribution to overall risk under five factors described as follows:

- ***Hazard*** - *Severity, extent, and frequency of the geological trigger phenomenon to which the city may be subject.*
- ***Exposure*** - *Size of the city. Number of people and physical objects, and the amount and type of activities they support.*
- ***Vulnerability*** - *How easily the exposed people, physical objects, and activities may be affected in the short or long-term.*
- ***External Context*** - *How impact within a city affects people and activities outside the city.*
- ***Emergency Response and Recovery Capability*** - *How effectively and efficiently a city can reduce the impact of an earthquake through formal, organised efforts made specifically for that purpose.*

Davidson's index is built on a range of weighted 'indicator' values that are combined to provide a standard measure by which to compare 'earthquake disaster risk' of individual cities.

The urban geography literature of the 1960's also contains examples of research aimed at classifying areas within cities to reflect particular features such as socio-economic status. Berry and Horton (1970), for example, provide a good overview of this research. Most of these examples, however, rely on sophisticated statistical analysis such as factor analysis and analysis of variance.

The approach we have developed here is similar in most basic respects to both EDRI and the classic geographic numerical taxonomy studies. It differs from EDRI, however, in two main ways. First, it is being used to assess the risk to a range of hazards across a single city, and second, we have not been constrained by selecting indicators that are available 'universally'. It differs from the sophisticated multi-variate statistical techniques in that it was undertaken using the analytical tools of the MapInfo GIS and Microsoft Excel software products rather than specialised and sophisticated statistical analysis software. This computationally less demanding approach was felt to be important given that our methodology is intended for use by local governments and others responsible for undertaking risk assessments at the local level who would not necessarily have access to the more sophisticated tools.

We have also constructed it to better 'fit' our risk assessment process described in Chapter 1, especially the 'five esses' approach to the analysis of vulnerability.

The approach we have developed was first used in the Cairns case study (Granger and others, 1999). In the Cairns study we chose to present our analyses at the suburb level given that most members of the community already identify themselves at home and at work with a suburban locality. For the South-East Queensland study, however, we have adopted a different strategy, namely constructing the analysis at the level of the CCDs used in the 1996 national census. There are 3219 CCD covering the full South-East Queensland region under study. These units typically contain approximately 200 households.

We have chosen this approach for two reasons. First, suburb boundaries do not match well with CCD boundaries across the region, so it was difficult to adequately translate the census-derived statistics to the suburban level. Second, the variation in suburb size would significantly distort the statistics to such an extent that the results would have been largely meaningless.

Assumptions

Because we are interested in showing the relative importance of each CCD to overall community vulnerability it was assumed that the most appropriate statistic to use would be the rank of the CCD in each measure. The use of rank is not without its problems. Inclusion of several variables that are highly correlated, or indeed derived from the same basic statistic, will obviously bias the outcome. Similarly, the inclusion of variables that have little, if any, bearing on community vulnerability could also distort the results. We feel, however, that with the careful selection of variables, rank is an appropriate statistic to reflect the relative significance of CCDs.

A systematic sensitivity analysis of the Cairns methodology was undertaken for AGSO by the James Cook University Centre for Disaster Studies (King, Moloney and MacGregor, 2000). This analysis broadly verified the statistical integrity of the method. It also endorsed the philosophical basis of the method.

The Setting

Given that the ‘setting’ group of variables relates mainly to external factors (e.g. the source of power supply), or to factors that apply equally across all suburbs (e.g. jurisdictions), only four variables were selected.

Terminal facilities: The facilities that provide the interface between the study area and the rest of the world are extremely important. The facilities selected for inclusion are those that facilitate the entry of goods or services into the study area (e.g. power substations and fuel depots), export of goods from the study area (e.g. bulk loading facilities) and bi-directional facilities (e.g. airfields and telephone exchanges). In determining CCD rank, those facilities that have both an import and export function were weighted by a value of 2, whilst those with either import or export functions only were weighted by a value of 1. Those of international significance are further weighted by a multiplier of 3 (e.g. Brisbane International Airport would have a value of 6); those of national or state-wide significance are multiplied by 2 (e.g. the headquarters of a State Government department would have a value of 4). The terminals selected in the Council area are listed in Table 2.2.

Population: Clearly the most significant element at risk is the population of the community. CCDs were ranked on the basis of their total population ranging from highest value to lowest value. The reasoning is that the larger the population, the greater the number of elements at risk and thus the greater the level of vulnerability.

Population density: CCD boundary design aims to encompass neighbourhoods of roughly equal size. To balance the absolute population figures, which are sensitive to CCD boundaries, we have also included population density, taken as the number of people per square kilometre. CCDs are ranked from the most densely populated to the least densely populated on the assumption that more densely populated areas carry a higher level of vulnerability.

Gender: The gender ratio measured in terms of the number of males for every 100 females provides a crude measure of the structure of the population. At the CCD level, it appears sensitive to the presence of institutions such as nursing homes, boarding schools and prisons where highly skewed gender ratios can be expected. CCDs were ranked from lowest value (least masculine) to highest value (most masculine) on the possibly questionable, but widely held assumption, that males are more resilient than females.

Suburb-level composite: A composite view of the setting group of variables at the CCD level was produced by simply adding the ranks for each CCD for each setting variable and standardising the sum by expressing it as a percentage of the maximum possible setting rank sum (ie the number of CCDs times 4 – the number of variables in the 'setting' group). This is the 'setting vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the setting category.

Shelter

Eight variables were selected to represent the shelter group of elements at risk.

Houses: Houses provide the most widespread form of shelter in the community and, consequently, they are considered to make a specific contribution to community vulnerability. CCDs were ranked on the number of houses included in the 1996 census data provided in ABS (1998a) even though it is now four years out of date. This is clearly a problem in an area like South-East Queensland where growth since 1996 has been large and rapid, but uneven. It was considered preferable to use this source, rather than sources such as local government land use data, for consistency across the region. CCDs are ranked from largest number of houses to smallest, on the assumption that more houses equate to higher levels of vulnerability.

Average house occupancy: CCDs were ranked on the average number of people living in separate houses at the 1996 census. This is a reasonable measure of household size. CCDs were ranked from highest value to lowest value on the basis that larger households are more vulnerable than small households.

Flats: Flats are the second most significant form of shelter. The census data provides tallies of the number of individual dwelling units rather than buildings. CCDs were ranked from highest value to lowest value on the same basis as used for houses.

Average flat occupancy: Household size in flats was assessed from the average number of people living in flats in each CCD. These data were also taken from the 1996 census and relate to the occupancy of individual flats. CCDs were ranked from largest average household to smallest average household.

Residential ratio: The proportion of properties used for residential purposes to the total number of properties provides a measure of relative dominance of residential land use. Residential buildings were taken to include houses and flats and were based on land use data provided by each of the local governments in the region. The strategy of ranking CCDs from highest residential ratio value to lowest ratio value reflects the disaster management priority given to people before other elements at risk. This variable also provides some degree of update on the population distribution changes since the 1996 census.

Road network density: The road network provides the means for people to move to and from shelter. The assumption is made that the more dense the network, the greater will be urban mobility. Nodes (i.e. road intersections) were extracted from the road network data used in the GIS and the ratio of nodes to total road length in each CCD was tallied to give a measure of network density. This was chosen as a better measure of network density than road length alone; the ranking of the larger, rural CCDs can be inflated due to the longer road lengths involved, even if the density of the network is very low.

Cars: Private cars are clearly amongst the most important assets owned by households. They are also susceptible to damage or loss from a wide range of hazards. CCDs were ranked on the estimated total number of cars to which households had access. This figure was derived from the statistics provided in the 1996 census data for household access to vehicles. Whilst it may not be a completely accurate absolute measure, it is felt to be a good relative measure. CCDs were ranked from most cars to least cars as simple measure of the number of elements-at-risk present.

Households with no car: This variable has both socio-economic significance and great relevance for emergency managers should evacuations be required. The value used here is the proportion of households within each CCD that do not have access to a car according to the 1996 census. CCDs are ranked from greatest proportion of car-less households to lowest proportion on the assumption that households with limited independent mobility are more vulnerable.

Suburb-level composite: A composite view of the shelter group of variables at the CCD level was produced by simply adding the ranks for each CCD for each shelter variable and standardising the sum by expressing it as a percentage of the maximum possible shelter rank sum (ie the number of CCDs times 8 – the number of variables in the ‘shelter’ group). This is the ‘shelter vulnerability index’ used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD’s contribution to overall community vulnerability within the shelter category.

Sustenance

The variables potentially available for use to assess the vulnerability derived from the facilities that sustain the community differ from local government to local government across the region because of the wide disparity in available relevant data. Five variables were available consistently for each area and these were adopted as the standard measures for the sustenance group of elements at risk.

Logistic facilities: These facilities contribute significantly to the sustainability of the community given that they handle, store or distribute food, fuel and other essential commodities. Their loss or dislocation would significantly limit the viability of the community. The total number of properties classified as having a logistic or transport and storage function, based on council land use data, are tallied for each CCD. CCDs are ranked from largest number of logistic facilities to the lowest. No attempt is made to weight facilities on the basis of their size or function though this may be considered as a future refinement.

Water supply facilities: The number of above-ground facilities supporting the water supply and sewerage systems, such as treatment plants, pumping stations and reservoirs, have been tallied for each CCDs. These data are based on council land use data and other sources, including field inspections and the UBD. Again, CCDs were ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

Power supply facilities: The number of above-ground facilities supporting the power reticulation system, especially power substations and switching yards, have been tallied for each CCD. These data are based on council land use data and details provided by both Energex and Powerlink. Again, CCDs were ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

Telecommunications facilities: The number of telephone exchanges, as identified by Telstra, were tallied for each CCD. CCDs were again ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

Lifeline length: Unfortunately, not all councils in the South-East Queensland region have available detailed data on their utility assets in a form suitable for this study, nor was it possible to obtain adequate data on telecommunications and some power reticulation infrastructure. It was considered that the total length of road in each CCD would be a suitable (and available) surrogate. We feel that this is reasonable because lifelines such as water supply, sewerage, power supply and telephone cabling are closely related spatially to the road network. CCDs are ranked on from the highest value(s) to the lowest.

Suburb-level composite: A composite view of the sustenance group of variables at the CCD level was produced by simply adding the ranks for each CCD for each sustenance variable and standardising the sum by expressing it as a percentage of the maximum possible sustenance rank sum (ie the number of CCDs time 5 – the number of variables in the 'sustenance' group). This is the 'sustenance vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the sustenance category.

Security

Eight variables were selected to represent the elements at risk that influence community security. In this context security is seen as including health, wealth and the protective services provided. Two of the variables used here have been derived from the *Socio-Economic Indexes for Areas* (SEIFA) produced by the Australian Bureau of Statistics from the 1996 census. The SEIFA methodology is described in detail in ABS Information Paper 2039.0 (ABS, 1998b).

Public safety: Ambulance, fire, defence force, police, SES, life saving and coast guard facilities, together with hospitals and other medical facilities, provide the bulk of the protective services required by the community. Their loss or dislocation would have a disproportionately large impact on overall public safety. The tally of these facilities in each CCD, based on council land use data and other collateral sources (including the Department of Emergency Services, the College of General Practice and the Department of Health) is used. CCDs are ranked from the largest number of facilities to the smallest number. No attempt has been made to weight the tally on the basis of the size or importance of each facility.

Business premises: These facilities make a significant contribution to the overall economy and employment situation, as well as facilitating the production and distribution of goods and services. Again, the tally of facilities classified as having a business or industrial function in each CCD, based on council land use data and other collateral sources, is used. Again, CCDs were ranked from largest number to smallest number without weighting.

Relative Socio-Economic Disadvantage: The SEIFA *Index of Socio-Economic Disadvantage* has been compiled by the ABS by undertaking a principal components analysis on 20 weighted variables from the 1996 census. The attributes, such as low income, low educational attainment, high unemployment and jobs in relatively unskilled occupations, were selected to highlight disadvantage (see Table C1). The resulting index has been standardised to have a mean of 1000 and a standard deviation of 100 across all CCDs in Australia. This means that around 95% of index scores across Australia are between 800 and 1200. A value above 1200 reflects a significantly high degree of advantage, whilst a value of less than 800 reflects a significantly high level of disadvantage. CCDs are ranked from lowest index value (most disadvantaged) to highest (least disadvantaged).

Economic Resources: SEIFA also provides an *Index of Economic Resources*. This index is based on a profile of the economic resources of families. It is compiled from 22 weighted variables that reflect the income and expenditure of families, including measures of income, rent and home ownership (see Table C2). This index is also standardised with a national mean of 1000 and a standard deviation of 100. Again CCDs were ranked from lowest index value (lowest resource levels) to highest value (greatest resources).

People under 5 years of age: The very young are felt to be physically less resilient in the face of disaster impacts than older children and adults. For this attribute, we have taken the proportion of the total CCD population at the 1996 census that was under five years of age. CCDs are ranked from greatest proportion to smallest proportion.

People over 65 years of age: The vulnerability of the elderly to disaster impact is similar to that of the very young. Here we have taken the proportion of the total CCD population at the 1996 census that was over 65 years of age. Again, CCDs are ranked from greatest proportion to smallest proportion.

Households renting: The proportion of households that were renting their accommodation is also seen as an indicator of economic susceptibility. The statistic is calculated as the proportion of all households that are renting their accommodation. CCDs are ranked from largest proportion to smallest proportion.

Unemployment: A widely used indicator of economic vulnerability is the rate of unemployment. The rate for each CCD is included in the 1996 census data and was used here because of its availability and consistency with other measures. We have assumed that whilst the actual rates of unemployment may have changed since 1996, the relative distribution probably has not. CCDs are ranked from highest unemployment rate to the lowest.

Suburb-level composite: A composite view of the security group of variables at the CCD level was produced by simply adding the ranks for each CCD for each security variable and standardising the sum by expressing it as a percentage of the maximum possible security rank sum (ie the number of CCDs time 8 – the number of variables in the 'security' group). This is the 'security vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the security category.

Society

Eight variables are used to reflect the social elements at risk.

Community facilities: A wide range of practical, social and cultural services support the community. These range from schools, churches and libraries, to sporting and social clubs, and from public toilets to government offices. The number of such facilities in each CCD, based on council land use data and collateral information, was tallied and CCDs ranked from greatest number to least number.

Large families: In a disaster situation, especially where evacuations are involved, larger families are frequently at a disadvantage. In this context 'large' families were taken to be those with three or more children or other dependants living at home. The proportion of the total number of families that are classed as 'large' in each CCD was calculated from the 1996 census data. CCDs are ranked from greatest proportion to lowest proportion.

Single parent families: Single parent families, especially those who are 'women-led', are also felt to be particularly vulnerable, both socially and economically. The 1996 census data does not permit women-led single parent families to be separately identified from the total, though it seems safe to assume that the majority of such families will have a female as the sole adult. This is supported by the fairly strong correlation between high values of single parent households and high femininity values from the ‘setting’ group. The proportion of all families which have only a single parent present was calculated and CCDs ranked from largest proportion to smallest proportion.

Visitors: Visitors are considered to have a greater inherent level of vulnerability than do residents because of their lack of familiarity with the local environment and their relative isolation from the general community. In many tourist destinations they are also the group that has the greatest concentration of non-English speakers. The percentage of visitors (both overseas and domestic) in the total CCD population in the 1996 census is used. CCDs are ranked from greatest proportion of visitors to lowest.

Education and Occupation: The third SEIFA index included in this study is the *Index of Education and Occupation*. This index is based on an analysis of 18 weighted variables selected to reflect the educational and occupation structures of communities (see Table C3). High scores reflect communities with high concentrations of people with higher education or undergoing further education and with people employed in higher skilled occupations; conversely low index values indicate low educational levels and largely unskilled employment categories. CCDs are ranked from lowest index value (low education and occupation status) to largest index value (high education and occupation status).

New residents: People who had lived at their census address for less than five years have been included as an indicator of the potential lack of awareness of the local disaster environment and of potentially low levels of community coherence. Whilst the census data on these ‘new residents’ include longer-term residents who have simply moved residence within the area, the great majority have moved from other statistical local areas (SLA). CCDs are ranked on the proportion of the total population that were living at a different address to that at the 1991 census with ranking from greatest proportion to least proportion.

No religious adherence: Lack of strong social links, such as adherence to a religion, is seen as an indicator of weaker community ties, and thus susceptibility. CCDs were ranked on the proportion of the total population who indicated in their response to the 1996 census that that they had ‘no religion’, from greatest proportion to least proportion.

Elderly living alone: Experience with evacuations and disaster response, and with hazards such as heat wave, suggests that elderly people who are living alone represent a special category of people in the community who are especially susceptible. Not only do they have general lower mobility, they tend to be somewhat isolated, apart from support by services such as home nursing and meals on wheels. The proportion of the total population who are over 65 years of age and living alone in each CCD at the 1996 census is the statistic used. CCDs are ranked from largest proportion to smallest proportion.

Suburb-level composite: A composite view of the societal group of variables at the CCD level was produced by simply adding the ranks for each CCD for each societal variable and standardising the sum by expressing it as a percentage of the maximum possible societal rank sum (ie the number of CCDs time 8). This is the ‘societal vulnerability index’ used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD’s contribution to overall community vulnerability within the societal category.

Composite Ranking

To provide a composite rating of the **relative contribution of each CCD to overall community vulnerability**, the ranks for all variables for each CCD are summed and standardised by expressing them as a percentage of the maximum possible total rank sum (ie the number of CCDs time 33). This produces the composite index used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability.

Ranking Strategy

Where values of a given variable were equal in two or more CCDs, the same rank was applied to each. Where there were multiple CCDs with no value recorded (e.g. no power supply facilities present) a strategy was adopted to rank the zero-value CCDs with the median value of remaining ranks so as to maximise the difference between low and no values. For example, in a set of 100 CCDs where only the first 20 had values, rather than giving all the zero values a rank of 21, they were given the rank of 60 (i.e. the mid point of the remaining values).

Further Development

It is clear that this methodology is still evolving and that it requires further work. We would welcome any suggestions, comments and/or advice, that readers may have to further improve it.

Weighting: Apart from the 'terminals' variable, no attempt has been made to weight the individual variables within each group. Our research has not reached the stage where we can confidently judge the relative significance of, for example, houses as opposed to flats, as opposed to the road network, in the shelter group; nor can we yet judge the relative contribution of each group to the overall evaluation.

There is, none-the-less, a weight inferred by simply including the attribute in the assessment.

Facility importance: By contrast, the importance of individual facilities such as airports, hospitals, rail terminals, ports and police headquarters to overall community vulnerability are probably under-stated because they are each simply dealt with as a single facility. This is particularly an issue for those facilities, such as airports and police stations that have only limited distribution, but service a wide area. Further research is needed to incorporate their catchment or service areas in addition to the neighbourhoods in which they actually are located. Established geographic techniques, including distance decay and nearest neighbour analysis, are likely to hold potential.

A similar problem arises with facilities that have dual or multiple functions - should they be counted in more than one attribute? Where we have adequate information we have added 'facilities' to reflect those additional functions. For example, where the local counter disaster coordination centre is housed in the council offices, a 'public safety' facility has been added.

Further consideration is also needed to take account of the functional significance of facilities and the degree to which the functions they provide can be taken up by other facilities in the event of loss or isolation. Functional significance can be measured in terms of the extent of the impact of a facility being lost. A local 'corner store', for example, has a relatively localised catchment and people who rely on it can easily find an alternate source of the same services in an adjacent neighbourhood or at a higher order facility such as the suburban supermarket or regional shopping plaza. It has a low order of functional significance and a high degree of redundancy. A fuel refinery, power station or an international airport, by contrast, have at least international, national and State-level significance, in addition to their local significance. The loss of those facilities would cause a significant dislocation to the local, state and national economies, especially if alternate facilities within the region did not have the capacity to easily handle the extra demand. Such facilities have a high order of functional significance and a low degree of redundancy.

Conclusion

Regardless of the obvious limitations in the methodology employed here to provide a measure of the relative contribution each neighbourhood makes to overall community vulnerability, we do not believe they invalidate it, or the assessment it has produced. Whilst it is hardly a scientific test, the assessment fits our intuitive assessment fairly well - it contains no surprises. Its application in other centres will undoubtedly produce further refinements. We are none-the-less encouraged by the endorsement of our methodology by King and MacGregor (2000) who make the comment:

> *The selection of the social indicators is based on the definitions of the elements of vulnerability in the model. Thus rather than debate the pros and cons of different variables, or attempt to weight some of the indicators, which we know will change the ranking of individual communities, it is worthwhile refining the (*AGSO*) model towards adoption as a standard for measuring vulnerability. If we use a standard in all locations as a basis for* (measuring) *vulnerability to multiple hazards, measurements can be recalculated and added to relatively easily, thereby maintaining a continually available classification of community vulnerability for all communities.*

We certainly see our the method described here as the first step on what will hopefully be a fruitful journey.

APPENDIX D: TROPICAL CYCLONE IMPACTS IN SOUTH-EAST QUEENSLAND

Date of event / cyclone	Impact
17-19 Mar 1864	Long period of gales in Brisbane. Finished and unfinished houses, stores, sheds, awnings, and signs blown down; roofs and portion of roofs carried away; trees blown down and gardens devastated. Tremendous gales off the coast on 18th. Stone jetty washed away at Cleveland. Considerable wind and rain damage at Toowoomba and trees down at Gladstone. Severe flood at Maryborough reached 27 feet (8.2m) above low water. Water reached the eaves of cottages and one homestead was swept away. The barque *Panama,* 414 tons, was wrecked on the 18th on Breaksea Spit near Sandy Cape with 10 people on board. At 4 am on 19th wind shifted from ESE to NW with increased violence. The ship was then driven onto the beach and broke in two. One of the crew drowned and ten were lost and never seen again.
21 Apr 1867	Severe flood and gale at Brisbane and Ipswich; loss of life occurred; houses were unroofed and damage was done to the new Victoria Bridge works.
26-28 April 1867	Heavy gales and floods in South-East Queensland. Wind lasted several hours at Ipswich (27th) and trees uprooted in all directions with some houses damaged and cattle killed or maimed by falling branches. Great damage done to crops and railway embankments. At Logan (27th), trees uprooted in all directions. At Warwick verandah coverings torn to ribbons. Lowest wharves covered by floods in Brisbane. Many dwelling houses flooded. Fences were blown in all directions, windows were smashed and verandahs carried away. Trees were blown out of the ground. Wind lifted house off its foundations and carried it 9 metres. Barometer down to 993 hPa at sea level in Brisbane. Floods destroyed the bridge at Ipswich.
19-25 Jan 1887	Heavy gale and rains over southern part of Queensland with intense damage. 19th-21st - W to NW gale off Double Island Point with telephone lines down along the coast - Goodna flooded, houses under water. 22nd - rail lines cut out of Brisbane - Bowen Bridge 5 feet (1.5m) under water at 4pm, washed away by 6.30pm. 23rd - very high flood Brisbane with several lives lost by drowning and widespread property damage. 24th - 18 inches of rain (457mm) in 24 hours at Brisbane - railway line washed away; Laidley- boats rescuing people; South Brisbane - two men drowned - enormous amount of timber lost to sea - all the bathing houses washed away at Sandgate - large trees blown down in different directions - fearful loss of property on the Logan River with the destruction of the railway bridge. 25th - The steamer *Barrabool* ran aground in Brisbane River and two sailors drowned. Flooding also at Bundaberg, Maryborough and Gympie (river 40 feet (12.2 m) above normal). One newspaper (Maryborough *Chronicle*) had the loss of life around Brisbane as 70.
11 Mar 1890	TC crossed south Queensland coast. Brisbane River flooded. 24 hour rainfall totals to 360 mm. Barometer at Maryborough 996 hPa 9.30 pm 9th with freshening and veering SW to NW winds, barometer down to 985 hPa 7 am 10th. Flood at Gympie 47 feet (14.3 m) above normal. Cyclonic affects at Gunalda 9th/10th
2 Apr 1892	TC recurved over Brisbane with 2 deaths. Wind raged from 8am to 4pm Sat 2nd and the lowest barometric pressure at Brisbane (corrected to sea level) was 991.5 hPa at 2.30 pm. Clement Wragge quoted the wind strength in Brisbane at 60 to 70 knots. 4.94 inches (125mm) of rain fell in Brisbane during the storm. Details of damage in inner parts of Brisbane: City - fences down, glass cracked, iron structure blown over and landslide at North Quay. New Farm area – several houses partially unroofed and balconies badly damaged at Bowen Terrace. Chimney blown over at Teneriffe. South Brisbane- sheds and outhouses unroofed, fences down, house unroofed on Julia St and church destroyed on top of Highgate Hill. Kangaroo Point - several houses destroyed

Date of event / cyclone	Impact
	and unroofed, St Mary's Church of England (stone building) badly damaged. Spring Hill- roof from house hit horse and killed it. Another house unroofed in Upper Edward Street and fences down. Botanic Gardens- large shade trees levelled, snapped off close to roots. Red Hill- two shops completely demolished in Musgrave Road, a veranda blown away in Cairns Street and a house destroyed corner of Latrobe Terrace and Enoggera Terrace. Brisbane River- wind blew funnel of *Bonito* off, three of the crew blown overboard and one drowned. Samford Road –farmer killed when his cart overturned trying to dodge fallen trees. Breakfast Creek - rose rapidly at high tide at noon and kept rising during the afternoon, flooding low parts. House blown over at Eildon Hill and some houses partially unroofed and verandas wrecked at Hamilton. Beenleigh - a great deal of damage, iron ripped from many roofs, windows blown in, trees uprooted and fences blown down. Widespread damage Southport and Tweed. Schooner *Bellringer* with cargo of 49,000 feet of cedar driven ashore at Stradbroke Island.
21 Jan 1893	TC recurved over Brisbane. Many trees uprooted , signboards carried away and a few houses in the suburbs demolished. At Maryborough on the 21st, winds were southerly in the morning, west in the afternoon and turned cyclonic north-westerly in the evening with the greatest force at night.
11 Feb 1893	Short lived TC crossed the coast at Bustard Heads adding to Brisbane floods. Schooner (150 tons) wrecked at Inskip Point and the body of a man washed ashore. Bar dropped to 982 hPa on the *Fitzroy* in Hervey Bay on the night of the 10th/11th.
17 Feb 1893	TC crossed the coast at Bundaberg. Floods in Brisbane River rose again and at 1020 am 19 Feb came within 25 cm of peak reached a fortnight earlier. Two children drowned. TC-induced tornado in Moreton Bay levelled 20 m wide path in forest and lifted boats out of water. Blew down several houses. House at Redcliffe blown along some distance and buggies lifted into trees. Floods from Rockhampton to Grafton.
19 Feb 1894	TC passed east of Brisbane. 0.58 m storm surge measured on the Moreton Bay tide gauge.
11 Jan 1911	TC passed from the Gulf south through inland Queensland. Severe damage at Marburg and gales experienced along the whole South-East Queensland coast.
2 Apr 1927	Severe TC east of Gold Coast. Record high tide Gold Coast. One drowning and shipping disrupted.
14 Feb 1928	TC crossed the coast at Brisbane. Subsequent serious floods in South-East Queensland with 5 people drowned. Around 6am to 7am Tuesday 14/2/1928 a severe gale hit Coolangatta and Tweed Heads fairly suddenly. The winds veered from NE to E to SE. Tweed Heads Pacifique and Wells Hotels badly damaged. Heavy timber from front balconies became missiles, damaging many buildings in town which then suffered water damage. A whole section of roof with hardwood battens and 22 sheets of iron lifted and carried 120 yards. Buildings also unroofed near the Railway Station. Coolangatta: Hotel Grande had its balcony destroyed. House unroofed in Rainbow Bay. House lifted off its stumps in Dixon Street and wrecked. Tree uprooted on Greenmount Hill. Bilinga: several houses and buildings damaged. Murwillumbah: roofing iron torn off a number of houses. Several chimneys toppled over. Trees uprooted. Mullumbimby, Byron Bay and Bangalow – houses unroofed and trees blown down. Tweed Valley: house unroofed at Barneys Point and crops badly damaged. Two houses completely unroofed at Duranbah and farm buildings damaged. House unroofed at Bingham Point. Cudgen Headland (now Kingscliff) – trees uprooted and house lifted off blocks. Casino – damage to buildings with sheets of iron torn off roofs. Water damage to most premises. Lismore – damage to telephone lines and crops. Glen Innes - immense damage to crops from wind and rain, trees also down. Grafton: South Grafton flooded. Killarney: 9.5 inches in one hour - Condamine River rose 17 feet in 40 minutes.

Date of event / cyclone	Impact
26 Feb 1929	TC crossed the coast near Mossman. Low lying parts of Cairns flooded. Man drowned in Little Mitchell River near Mareeba. Cairns Harbour anemometer read 32 miles in the hour from 9.30pm to 10.30pm. Mon 25th : floods in the Herbert and man drowned in Mossman River. On 28th , another person drowned, giving a total of three deaths. By 28-29 February, this cyclone recurved towards south-east and redeveloped off the Central Coast. Bar down to 986.1hPa at Double Island Point 8pm 28th . Huge seas off the south coast. A passenger ship was disabled and just made it into Brisbane. Seas came up into the surf club at Kirra with much sand erosion and the rocks on the point moved. Buildings and roads damaged in Coolangatta. The seas broke over the jetty at Byron Bay. Farms were flooded at Southport and 100 houses vacated at Lismore.
4 Feb 1931	TC entered Coral Sea near Cooktown and moved down to Hervey Bay. Initially serious flooding in north Queensland with one drowning. Then major floods in South-East Queensland with 1300 homes inundated in Brisbane on 5 Feb with two drownings. Storm surge of 0.76m on Moreton Bay tide gauge. Most of the flooding was in Breakfast Creek where 1056 houses were flooded (396 above floor level). Around noon 5 Feb before the heavy rain in the creek catchment, high tide at the mouth of Breakfast Creek tide level was 1.1 m above ordinary high water spring. The subsequent flood levels above Bowen Bridge exceeded the 1893 flood levels. Severe beach erosion, Currumbin Creek mouth breached.
1 Feb 1934	TC tracked from the Gulf down to NSW coast. Serious flooding along Central Highlands (man drowned) and in South-East Queensland (child drowned). Considerable wind damage at Hervey Bay in northerly gales. Widespread shed and tree damage in Brisbane. Flooding from storm surges and large waves in Moreton and Hervey Bays. 1.16 m storm surge on Moreton Bay tide gauge (largest on record).
22 Mar 1936	TC recurved seawards of Fraser Island. Extensive erosion Gold Coast, the Southport Spit was breached and protective timber walls were constructed at Coolangatta, Kirra, Narrowneck and Currumbin. Ships showed a very large cyclonic circulation north-east of Fraser Island at 9am Sunday 22 March 1936. *Merkur* near 24.5S 154E bar 992 hPa wind SE 48-65 knots; *Malatta* near 21S 155E bar 992 hPa wind NW 23-40 knots. Cape Leeuwin sheltering in lee of Sandy Cape wind SE 48-55 knots. *Ormiston* near 23S 152.7E wind S 48-55 knots. Captain of the *Merkur* said it was hard to estimate wave heights but they towered 50 feet above him in the troughs. Huge sea and storm tide damage. Coolangatta: damage to old Kirra SLSC clubhouse. New club protected by bringing boulders and sandbags in. Several people seriously injured in car park when wave surged up into car park and floated a pile of logs which were to be used for a retaining wall. Storm tide kept floodwaters inland, flattening cane and maize crops. Southport: new channel cut through to sea from Broadwater just north of Jubilee Bridge (between present-day Southport SLSC and Sheraton Mirage). Channel 40 feet wide and one foot deep at high tide. On Sunday night (22nd) sea came 100 yards further inland from normal high tide mark. Moreton Bay: storm tide came over retaining walls at Cribb Island, Nudgee Beach, Shorncliffe and Flinders Parade Sandgate. Houses were wrecked at Cribb Island. At Sandgate the sea flooded along 9th Avenue, Griffith St and Murray St. At Redcliffe sea walls and beach buildings were damaged. The sea broke over the sea walls at Wynnum flooding the Esplanade and damaged boats. At Cleveland the tide flooded the road to Cleveland Point. Yeppoon: waves came over the sea wall and entered a beach cafe.
16 Mar 1937	TC tracked from Kimberleys to South-East Queensland, causing widespread major flooding and gales along east coast with ship foundering. Goods train wrecked near Bundaberg. Hotel and shop washed away at Childers.

Date of event / cyclone	Impact
19 Jan 1938	TC crossed the coast south of Bundaberg (992hPa) with gales and high seas. Damage at Hervey Bay, lower parts of Brisbane inundated at Sandgate, Cribb Island, Breakfast Creek. Severe beach erosion. Gold Coast and South Stradbroke Island inundated by sea. Floods at Casino, Kyogle. Pile Light surge 0.52 m on 2.07 m tide. Broadwater 2.41m storm tide.
27 Mar 1938	TC recurved east of Bowen. Gales, high seas and torrential rains. Harbour works damaged and bridges washed away at Mackay. Severe beach erosion Gold Coast.
6 Mar 1939	TC crossed coast near Cape Byron.
23-25 Mar 1946	TC accompanied by flood rains crossed the coast near Double Island Pt and passed over Moreton Bay and just inland of Southport at 3pm 25th. A 0.73 m storm surge recorded on Moreton Bay tide gauge (fortunately at low tide).
4 April 1946	TC passed just to the east of Fraser Island and brought heavy to flood rains to South-East Queensland.
23 Jan 1947	TC crossed the coast near Caloundra with heavy gales and high seas. Springbrook registered 706 mm of rain in 24 hours. Record floods in South-East Queensland with water up to telephone wires. Two lives were lost and widespread damage occurred from floods and high winds. 0.55 m storm surge on Moreton Bay tide gauge.
28 Jan 1948	Severe TC passed to east of Brisbane and produced a 96 knot gust at Lord Howe Island. 0.46 m storm surge on tide gauge in Moreton Bay, 1.5 m surge on foreshore.
24 Mar 1948	TC recurved over Fraser Island. Gales and high seas caused severe beach erosion over South Coast Beaches and local structural damage in adjacent areas. Tewantin reported the worst erosion ever experienced. Flooding in coastal streams.
16/19 Jan 1950	TC tracked from Gulf to Sydney. NE gales Moreton Bay and 2 metre waves. Storm surge of 0.58m on Moreton Bay gauge. Shops and houses flooded at Sandgate with houses evacuated. Sea water inundation at Wynnum with damage to boats. 7 lives lost in NSW from cyclone including girl swept by storm surge and waves off Esplanade at Cronulla. Record pressure reading of 988 hPa in Sydney.
27-28 Feb 1950	TC recurved over Gladstone and Hervey Bay. Sea water flooding at Hervey Bay. Floods South-East Queensland including north-eastern suburbs of Brisbane .
25-30 Jan 1951	TC slow moving around Fraser Island. 50 to 60 knot winds Moreton Bay. Extensive damage to boats and structural damage to buildings. Several houses undermined by sea. One life lost at Caloundra. Severe erosion Gold Coast with Southport Spit breached and had to be closed with bulldozer. Floods from rain and storm surge caused evacuation of residents on Macintosh Island, one house on the Island was blown off its stumps. Breakers were observed on the Nerang River. The road at Mermaid Beach was “feet under water”, the Burleigh skating rink and pool were smashed and great boulders were flung across the road at Currumbin.
19 Mar 1951	TC crossed the coast near Maryborough. Heavy flood rains South Coast and Darling Downs.
20 Feb 1954	TC crossed the coast at Coolangatta with a reading in the eye of 973 hPa. Some reports from the Coolangatta/Tweed Heads area had pressure readings to 962 hPa. Worst damage in that area around the Cudgen in NSW where some houses were blown apart and trees more than 1 metre in diameter were twisted out of the ground. Record reading of 982.7 hPa at Brisbane. Widespread structural damage Gold and Sunshine Coasts and around Brisbane. 0.64 m storm surge on Moreton Bay gauge however much worse on foreshore with boats in the tree tops at Beachmere. Waves at Kirra brought 2 metre of water onto highway picking up cars. 900 mm of rain were recorded at Springbrook in the 24 hour period up to landfall and floods combined with storm surge on the Nerang River caused evacuations of families and a dramatic rescue of people from Macintosh Is. The floods and cyclone then hit the Lismore district with gales whipping up large waves on the then 11.3 km wide Richmond River. 26 people tragically died from these

Date of event / cyclone	Impact
	unprecedented effects. Report from Richard Everingham 195 Newnham Rd Mt Gravatt who was working at the time at the Condong Sugar Mill. There were two barometers at the mill, one an aneroid registered 28.8 inches (975 hPa) while the other read 973 hPa. The eye took two hours to pass over the mill at around 11pm.
27 Mar 1955	TC crossed the coast at Bundaberg causing some structural damage there. TC induced tornado caused considerable damage to houses and churches at Yandina in a 300 m wide swath. A record flood occurred in the Mary River while a life was lost in Brisbane River floods.
19 Feb 1957	Long lived TC which produced 109 knot gust at Willis Island and went on to cross the NSW coast south of Pt Macquarie. Severe erosion by huge waves and high tides on South coast.
Beatrice 21 Jan 1959	TC crossed the NSW coast near Lismore. Severe beach erosion occurred in South-East Queensland and Northern NSW- buildings and equipment were damaged at Jack Evan's porpoise pool at Pt Danger - 90 m of a concrete wall was undermined at Coolum . Flooding caused damage in northern NSW. Earth dam burst at Stanthorpe causing damage to bridges livestock and machinery. Steamer *NatoneI* foundered off Double Island Point on the 24th.
Connie 16 Feb 1959	TC crossed the coast at Guthalungra where pressure in the eye was recorded at 948 hPa. Severe wind damage occurred at Ayr, Home Hill and Bowen. A man was killed at Ayr when a shop fell on him. At Ayr 33% of homes severely damaged, Buffalo Hall wrecked, schools and hotels unroofed. At Home Hill 100 persons homeless and no building escaped damage with every window broken in the main shopping area. 700 windmills destroyed in the Ayr-Home Hill area. The anemometer at Bowen recorded wind gusts up to 100 knots over a 2 hour period with forty homes totally destroyed, 190 badly damaged and 300 partly wrecked. Severe damage to powerhouse, saltworks, cokeworks and railways - dozens of boats swamped. Wind also caused considerable damage at Proserpine with 50 houses and the hospital badly damaged. There was even damage at Rockhampton as the cyclone moved south. Flood waters at Mackay caused evacuations and damage - Floods swept away the Mirani railway bridge and undermined the Forgan Bridge; Clermont had the worse floods since the 1916 cyclone; Laidley had its worst flood on record with 50 shops under 8 feet of water - 200 families were evacuated and 50 people were rescued from the roof tops. Killarney also had a record flood with 2 bridges swept away. In Allora people were evacuated from their homes. On the 18th Brisbane had wind gusts to 48 knots with minor damage and power lines down. Floods extended down to north-eastern NSW where a man was killed by fallen power lines.
Annie 1 Jan 1963	Rapidly developing TC crossed Sunshine Coast. Houses were unroofed at Buderim, Landsborough, Mt Mellum, Flaxton and Maleny and banana plantations suffered considerably. Falling trees cut power and telephone lines. Campers lost tents and caravans were capsized and small craft wrecked. Luckily it crossed at low tide as the Moreton Bay tide gauge indicated a 0.76m storm surge. Flooded streams submerged road bridges.
24 Apr 1963	TC stayed more than 500 km off the South Coast however system generated very large swells with 1000km of the easternmost Australian coast suffering varying degrees of beach erosion. American Navy vessel suffered damage off South Coast in 13 m waves. Couple were swept offshore by southerlies at Hervey Bay resulting in one death. Winds brought down power lines on Sunshine Coast.
Audrey 13- 14 Jan1964	TC tracked from the Gulf down to Coffs Harbour. There were extensive flooding and stock losses in south-western Queensland and northern NSW with wind damage in the western Darling Downs. The cyclone hit St George at 8am 14th where 52 houses lost all or part of their roofs and 22 businesses were badly damaged - 38 mm of rain was recorded in 15 min. At Goondiwindi 50 buildings were unroofed, the railway goods

Date of event / cyclone	Impact
	shed was destroyed and a church hall was flattened. Telegraph poles were snapped off. At nearby Boggabilla every building was partially or completely unroofed. Building were also badly damaged at Windorah, Quilpie, Cheepie, Charleville, Talwood, Toobeah, Pittsworth, Glen Innes and Grafton. Very heavy rain accompanied the cyclone with major flooding. Up to 294 mm of rain was recorded in South-West Queensland towns including 181 mm in 12 hours at Eulo.
Dinah 28/30 Jan 1967	*Dinah* caused severe damage at Heron Island, initially from inundation from large NE swells and a day later from winds. It recurved and passed over Sandy Cape, which recorded a central pressure of 944.8 hPa and high water 10 metres above normal. Although the cyclone was well off the coast, many trees were blown down from Rockhampton to Grafton. Houses were unroofed at Bundaberg, Maryborough and along the Sunshine and Gold Coasts. Banana and cane crops were wiped out on the Tweed Coast and a severe wind gust overturned a car at Evans Head. Huge seas and storm surge caused severe erosion at Emu Park, Yeppoon, and in the Maryborough-Bundaberg area. Storm surge inundated cane farms at Bli Bli and was knee deep in Hastings Street, Noosa. Around Sandgate, seawater 1.5 metres deep came into houses. More than one hundred homes were flooded and at Cribb Island one house was washed into the sea. Storm surge also affected the Gold Coast, with water lapping the decking of the Jubilee Bridge (which is about 1.5 metres above highest astronomical tide). A similar storm occurred on the Tweed River isolating Fingal. A section of the esplanade collapsed at Surfers Paradise.
Barbara 22 Feb 1967	TC crossed coast near Lismore. There was wind damage in the Coolangatta area with tents down and power disrupted by falling trees and flying sheets of roof iron.
Elaine 18 Mar 1967	TC moved SSE past the South Coast. Severe flooding occurred in the Brisbane creeks and in the Logan River. Further beach erosion occurred.
Glenda 2/4 Apr 1967	TC moved south 500 km east of Brisbane. Gold Coast beaches completely eroded by large waves. Six men lost their lives in two separate boat incidents in waves to 16 m off the south Queensland coast.
Dora 17 Feb 1971	TC crossed the coast north of Brisbane. There was fairly widespread structural damage at Redcliffe, the worst case being a roof removed from a block of home units. Trees and powerlines were down. Some flooding caused traffic dislocations.
Daisy 11 Feb 1972	*Daisy* made landfall on Fraser Island and the barometer at Sandy Cape dropped to 968.8 hPa. 200 homes were damaged at Pialba and more houses were unroofed in widely scattered townships. Forestry officials reported serious damage to forests near Maryborough and on Fraser Island. Flooding occurred throughout South-East Queensland with severe floods in Brisbane creeks. There was much damage to commercial stock in Brisbane. On the Gold Coast, the mouth of Tallebudgera Creek silted up, causing severe flooding upstream to commercial and domestic properties. Peak swell heights to 8.3 m were read at the South Nobby wave recording station on the Gold Coast. Severe erosion occurred down to Brunswick Heads and on the western side of Fraser Island where a 3 m storm surge was reported.
Emily 2 Apr 1972	*Emily* crossed the coast just to the SE of Gladstone while rapidly weakening. Wind damage was confined to trees and sheds. The cyclone had been very severe and generated huge seas. It claimed the lives of 8 seaman in three separate incidents off the southern and central Queensland coasts. Flooding occurred, with Kingaroy being isolated for a time and Breakfast Creek flooded some houses in Brisbane.
Wanda 24 Jan 1974	*Wanda* was a weak cyclone when it crossed the coast near Maryborough. The winds were strongest in the night after landfall when a high strengthened in the Tasman Sea. Tewantin and Caloundra then had easterlies averaging 50 knots and Cape Moreton had easterlies averaging 56 knots. Torrential rain followed and in the 5 days to 9am 29 Jan, falls reached 900 mm in the Brisbane area. Mt Glorious had 1318 mm. The Bureau in Brisbane recorded 314 mm in the 24 hours to 9am 26 Jan and the peak of the 1931

Date of event / cyclone	Impact
	flood was exceeded at 9am 27 Jan. Heavy rain in the 24 hours to 3pm 27 Jan caused the major flood. In the Brisbane-Ipswich region, 6007 houses were flooded. 56 of these were destroyed or condemned. Damage on a large scale reached $200 million (1974 value). 12 people were drowned in Brisbane and Ipswich. Additionally, several elderly people suffered fatal heart attacks while being evacuated and a 2yr old child drowned in a Brisbane creek. Major floods also affected the Gold Coast and NE NSW. 700 people were evacuated from caravan parks in the Broadbeach area. Around 1000 people were evacuated from the canal estates of Miami Keys, Moana Park, Rialto, Mermaid Waters, Florida Gardens and Burleigh Waters. Houses were swamped from water up to 1.5m deep. Evacuations also occurred along the coastal strip at Surfers (where waist deep water flooded streets near the river), Miami, Nobbys (where water came up to window sills and to the tops of caravans) and Bundall Rd Southport where floods spread over the Isle of Capri and Sorrento. Evacuations were carried out at Biggera Waters, Hollywell and Paradise Point. 200 people were stranded on Hope Island and Nerang was completely isolated. In total 2500 Gold Coast people were evacuated. The Nerang River rose to a record level of 9.91 m. Heavy swells caused severe beach erosion along the southern Queensland and NE NSW coasts. The South Nobby station recorded significant swell heights to 4.5 metres. Maximum heights were probably nearly double this. The maximum storm surge associated with *Wanda* was 1.0 m between Noosa and Double Island Pt.
Pam 6 Feb 1974	*Pam* was a very large intense cyclone which passed 500 km to the east of Brisbane. However, a 0.68m storm surge was recorded on the Moreton Bay gauge and combined with a king tide, the high tide of 7 Feb on the gauge reached 3.13 m (a record).This rise in sea level flooded Brisbane creeks at high tide and caused cancellation of some bus services. Along the open coast the beaches were already severely eroded due to earlier cyclones and this amplified the effects of run up from the large waves generated by *Pam.* At Palm Beach residents had to abandon their houses and units as seawater drove over 6.2 metre boulder walls and surged through these premises. The South Nobby Wave Station recorded long period swells (13.1 sec) with a significant wave height of 3.8 m.
Zoe 13 Mar 1974	*Zoe* crossed the coast at Coolangatta and then recurved back out to sea. There was no significant wind damage, however, flooding was extensive with major floods in Brisbane creeks cutting main roads and some houses were flooded. Major flooding occurred in northern NSW and 200 people were evacuated in Murwillumbah and 500 families were evacuated at Lismore. Landslides cut the main railway line in 4 places between Casino and Coffs Harbour. There was severe erosion along the Gold coast beaches and the significant wave height at South Nobby reached 3.8 m.
David 19 Jan 1976	*David* crossed to the north of St Lawrence. It passed over Gannet Cay AWS where a central pressure of 970 hPa was recorded. It was intensifying right up to the time of landfall. A feature was its huge size with gales extending from PNG waters down to Lord Howe Is. It generated huge swells and these combined with large tides caused extensive damage to Heron Island as it passed to the north. It crossed the coast in a sparsely populated area; however, winds unroofed 30 buildings in Yeppoon and several in Mt Morgan. Wind gusts reached 95 knots at Pine Islet and 84 knots at the Gladstone Met Office. Large seas combined with high tides caused considerable damage to breakwaters, retaining walls and other structures especially at Rosslyn Bay Harbour (Yeppoon) where the breakwater was destroyed along with yachts and trawlers. Storm tides flooded houses and shops at Urangan, Noosa and Kirra. Storm surge at Beachmere on Moreton Bay cut all roads into the town. The Port of Brisbane was closed. At wave recording stations the significant wave (peak) height reached 5.8 m (9.2 m) at Double Island Point and 3.8 m (7.6 m) at Yeppoon. Tides were up to one metre above predicted levels.

Date of event / cyclone	Impact
Beth 22 Feb 1976	*Beth* crossed the coast just to the north of Bundaberg. The cyclone was very asymmetric, with a band of hurricane force winds on the southern flank caused by interaction with an intensifying high to the south. Widespread damage occurred in the Maryborough-Bundaberg area with 200 homes unroofed, two aircraft damaged and rainfall up to 200 mm which caused flash flooding and cut roads for 18 hours. Heavy swell pounded the south coast and the wave recording station at Double Island Point recorded a significant wave (peak) height of 5.4 m (10.0 m).
Colin 4 Mar 1976	*Colin* moved southwards and was 220 km east of Fraser Island at one point. By far the greatest impact was from the large waves it generated. Extensive beach erosion occurred along South-East Queensland beaches. The wave recording station at Double Island Point recorded a significant wave (peak) height of 6.4 m (9.6 m). Further south, waves off Sydney Heads were estimated at 12 m in height and several launches were destroyed when 2 m waves penetrated into Botany Bay. A woman was killed at Tathra (S NSW) when swept off a cliff top by a large wave.
Paul 7 8 Jan 1980	*Paul* moved from the Gulf to enter the Coral Sea near Saint Lawrence. Heavy rain caused a record flood in the Don River, which changed its course in the lower reaches near Bowen. Two houses were washed away. Severe damage was caused to the market garden industry. Large swells affected the south coast. The Brisbane wave recording station recorded significant (peak) wave heights of 4.3m (9.8m) on 8 Jan.
Ruth 12 - 14 Feb 1980	*Ruth* remained over the ocean between Australia and New Caledonia. The highest astronomical tides for 10 years, combined with large NE swells, caused damage at Heron Island. The big tides and heavy swells caused extensive foreshore erosion along the Gold and Sunshine Coasts. The Brisbane wave recording station recorded significant (peak) wave heights of 4.0m (6.3m)
Simon 24 Feb 1980	*Simon* was rapidly intensifying and moving towards the coast when it recurved seawards over Port Clinton with a radar eye diameter of 35 km. In this remote area it caused extensive damage to vegetation. It passed slowly to the north of Heron Is which experienced wind gusts to 93 knots and a great deal of damage. Neap tides saved the Island from swell damage. Huge swells were observed but their energy was dissipated on the exposed fringing reef. A yacht ran up onto Lady Elliot Island and a rescue helicopter turned over but there were no casualties. As the cyclone passed to the east of Fraser Island a ship near Indian Head reported wind gusts greater than 100 knots. Sandy Cape Lighthouse reported winds gusting to 92 knots. Houses lost roofing iron at Hervey Bay where there was flooding. The Burnett Heads wave recording station recorded significant (peak) wave heights of 4.5m (8.9m)
Cliff 15 Feb 1981	*Cliff* crossed Fraser Island and made landfall near Bundaberg. Sugar cane crops were damaged around Bundaberg and several houses were damaged further south. A storm surge brought water into the streets at Urangan. There was a 0.7m storm surge on the Gold Coast with a large swell. A large wave train brought a surge of water into Currumbin Creek, which swept a man off the bank, drowning him. The Brisbane wave recording station recorded significant (peak) wave heights of 4.3m (7.2m)
Lance 7-9 Apr 1984	*Lance* underwent rapid extra-tropical transition near and east of Brisbane. Sustained winds reached 60 knots with damage to boats on the western side of offshore Islands in storm force westerlies. On the Gold Coast many houses lost roofing while wind drove rain into high rise buildings and there were huge seas. The Brisbane wave recording station recorded significant (peak) wave heights of 5.1m (8.8m) on 9 Apr.
Aivu 4 Apr 1989	*Aivu* crossed the coast near Ayr, with a radar eye diameter of 30 km. Just before landfall the diameter was 22 km. A pressure of 959 hPa was read in the eye at Fredericksfield, 20 km inland from the coast. Insurance pay out for buildings, cars, boats, etc was $26 million (1990 value). Total damage was about $40 million. Agricultural damage was also around $40 million and infrastructure losses were about $10 million. Wind destroyed some houses, however, mostly it caused loss of roofing

Date of event / cyclone	Impact
	iron or awnings etc. A 3 metre storm surge destroyed numerous beachfront properties in Upstart Bay and drowned one man. Major flooding occurred in the Pioneer and Proserpine Rivers. As *Aivu* approached the coast during 2 April, flood rains affected South-East Queensland and NE NSW. Seven people were lost, presumed drowned (two in Brisbane, two in the Gold Coast hinterland and three in NE NSW).
Nancy 3 Feb 1990	*Nancy* crossed the coast near Byron Bay and then moved seawards again. The strongest wind report was a mean wind of 60 knots gusting to 73 knots at Cape Moreton Lighthouse near Brisbane. The lighthouse also recorded the lowest pressure reading of 982.7 hPa while it was experiencing the strongest wind speeds. There was some structural damage to houses on the offshore islands and elevated areas near the coast, however, the major impact was from flooding. Heavy rain (up to 530mm in 24 hrs and 132mm in 3 hours) occurred between the coast and ranges south from Brisbane causing flash floods and drowning six people (5 in NSW and one in Queensland). Damage costs from flooding in Qld and NSW reached $36 million.
Betsy 13 Jan 1992	*Betsy* passed 450 km seawards of Fraser Island but, being an exceptionally large cyclone, generated very large swells which caused severe beach erosion – particularly at Noosa where all sand was washed away. Forty people were rescued at the normally safe beach at Noosa. A yacht off Fraser Island had to be rescued by the coastguard.
Fran 16 Mar 1992	*Fran* crossed the coast near the Town of 1770. The maximum anemometer wind gust recorded was 76 knots on Great Keppel Island (just off the coast from Yeppoon). In Bundaberg, 40 houses were unroofed, one was blown off its stumps. The caravan park at Bargara was evacuated. Heavy damage to fruit and vegetable crops occurred in the Bundaberg district. At Burnett Heads, the marina and 3 yachts were damaged and there was extensive damage to pontoons and yachts forced against a rock wall. Powerlines, trees, and roofs were damaged at Gympie. There was roof damage along the Sunshine Coast when *Fran* crossed Fraser Island on its way back out to sea. A storm surge inundated 20 business premises, 100 houses and 50 caravans at Hervey Bay. People were evacuated from the caravan parks. At Burrum Heads, one house had seawater through lower levels. There was major flooding in the Kolan River and moderate flooding in the Burnett River. Heavy swells caused damage on Heron Island and severe erosion on the Gold and Sunshine Coasts. In total there were 2,624 insurance claims for property damage. It has been estimated that the total damage bill (with flood damage) was 8 to 10 million 1992 dollars.
Roger 17 Mar 1993	*Roger* came within 250 km of Fraser Island before turning back out to sea. The cyclone had a very large circulation and came near the coast as a ridge built up along the NSW coast. This developed an extensive area of gale to storm force winds. Six houses sustained roof damage on the Sunshine Coast There were extensive blackouts in South-East Queensland due to fallen trees. Banana growers in South-East Queensland lost about 50 % of their crop as winds twisted and uprooted the trees. In northern NSW, fallen trees closed the 64 km Tweed Range Scenic Road. The winds and seas closed the Port of Brisbane for the first time since *David* in 1976. A man drowned in the surf at Agnes Waters. Seas were still large on 20 Jan – a man was drowned at Surfers Paradise and more than 60 people were rescued. A storm surge of 0.74m was measured on the Gold Coast Seaway gauge on 17 Mar and the peak water level reached 0.16m above highest astronomical tide (HAT). There was serious beach erosion along the Sunshine Coast. The Brisbane wave recording station recorded significant (peak) wave heights to 7.5m (13.2m) on 17 March. Ship observations off Brisbane indicated that the larger swells came from the north, north-east and east.
Rewa 20 Jan 1994	*Rewa* came within 100 km of the coast as it was recurving away from Australia. Two men were rescued from a fishing trawler near Yeppoon by an army Blackhawk helicopter. The upper trough system interacting with *Rewa* as it recurved generated severe flash flood thunderstorms over Brisbane which resulted in four deaths. Three

Date of event / cyclone	Impact
	died in traffic accidents and a boy was swept down a drain. A man was also rescued by a DES helicopter when his car was swept into a flooded creek. 100 homes were damaged by the floodwaters.
Violet 8 Mar 1995	*Violet* came close to the coast near Byron Bay while weakening below tropical cyclone intensity. Earlier it passed close to Lord Howe Island where gusts reached 68 knots with tree damage across the island. Heavy swells caused severe beach erosion near Evans Head.
Yali 26 Mar 1998	*Yali* passed 500 km east of Brisbane on a southerly track. Wind gusts to 54 knots were recorded at Cape Moreton and Double Island Point. The Brisbane wave recording station recorded significant (peak) wave heights to 6.0m (11.5m) on 26 Mar. A storm surge of 0.3m coincided with high spring tides. There was beach erosion from the Sunshine Coast to northern NSW beaches and tree damage and power blackouts on the Sunshine Coast.

APPENDIX E: IMPACTS OF EAST COAST LOWS IN SOUTH-EAST QUEENSLAND

Date of Event	Impact
19 Aug 1846	Vessel *Coolangatta* driven ashore at North Kirra Beach (just to the north of Tweed River) in easterly to north-easterly gale. Strong SW winds following day. Locality subsequently named after the vessel.
June July 1864	Tremendous gale off Queensland coast.
14-17 June 1869	Steamers unable to leave Brisbane due to tempestuous state of sea. Continuous rain in Brisbane; creeks swollen and communication with Gympie cut off; mail coach at the Durramboy Lagoon washed away and three horses drowned.
14-20 July 1876	Very heavy gales (14th), SS *City of Brisbane* attempted to enter Moreton Bay without success. Another ship narrowly escaped shipwreck in the Bay. Exceedingly furious gales on the coast between Brisbane and Sydney (18th to 20th). Heavy rain and floods (14th) Myall Creek bridge at Dalby almost destroyed and part of the railway near Gowrie swept away. High seas on the coast with heavy gales. Several lives lost in different places, also large numbers of stock and sheep. Disastrous floods and loss of life at Grafton.
3 June 1878	Unprecedented heavy gales very general on the southern coast.
15 May 1879	Very heavy gale along South-East coast of Queensland with some casualties. Very heavy rain on the coast (9th). Coffer dam at the Brisbane dry docks destroyed. Three men drowned while attempting to cross the Thomson River.
24-27 Jun 1879	Thunderstorm (24th) developed into winter cyclone (25th) with much roof damage in Brisbane. Winter cyclone in southern Queensland (27th) with great damage.
27 Aug 1879	Catholic Church at Charters Towers blown down (27th). Very severe and unprecedented floods in parts of the colony (27th), in Dalby many were forced to leave their houses. The Brisbane River was more than 8 feet above the high water mark. The floods reached their highest mark on the 30th. The Victoria baths were washed down the Brisbane River; thirty tons of Yengarie sugar were destroyed at Bundaberg Wharf.
8-11 Oct 1888	Winter cyclone moving eastward across Coral Sea. South-east gales and heavy seas in South-East Queensland and north and central coasts of NSW. Very heavy rain on the coast.
17-19 Jul 1889	Winter cyclone near Rockhampton (17th), Brisbane (18th) then moved east. Gales and heavy seas on north and central coasts of NSW.
8 Jun 1891	Hurricane at Brisbane did considerable damage. Floods Brisbane and Gympie. Gales northern NSW coast.
10-12 Jun 1893	Winter cyclone moved south-east from Central Queensland coast and then east. Gales and very heavy rain on South-East Queensland coast and north coast NSW.
26 Jul 1897	The schooner *Heroine*, a wooden vessel of 122 tons and with 130 tons of coal on board, was driven ashore at North Kirra near the mouth of Coolangatta Creek. On the 25th the schooner was at anchor off Tweed Heads and on the morning of the 26th heavy seas were breaking over her and staving in the hatches. The Captain had to slip her cables and the vessel was driven ashore. The captain and crew landed safely. Also on the 26th, the ketch *Candidate* was driven ashore at Byron Bay at the height of the gale. The captain and crew were landed by means of ropes.
23-24 Jun 1912	Very severe east to north-east gales along sub tropical coast of Queensland. Shipping delayed. Masters of vessels reported that night of 24th was the worst they had encountered.
15-16 Aug 1912	A depression off South-East coast of Queensland produced gales and high seas south of Sandy Cape.

Date of Event	Impact
24-25 Jun 1914	Winter cyclone off north coast. Gales between Mackay and Rockhampton.
21-23 Sep 1914	Winter cyclone on north coast. Gales east of Brisbane.
8-10 Oct 1914	Winter cyclone passing down off coast caused gales and torrential rains. Wrecked two ships off south coast.
23-28 Sep 1916	Winter cyclone passed from interior east-south-east out to sea producing very heavy rain and gales along south-east coast.
28 Jul 1919	Winter cyclone passed southwards between New Caledonia and Queensland. Ships driven on Barrier Reef south-east of Mackay.
22-24 July 1921	Winter cyclone from north-east struck northern NSW coast causing gales and shipping disruptions before recurving to south-east. Disastrous floods in South-East Queensland and northern NSW. Goondiwindi, Warwick and Roma flooded. Several houses washed away and 2 men drowned at Texas. A man drowned at Inglewood. Heavy stock and crop losses and damage to roads and bridges.
2-6 Oct 1921	A winter cyclone passed southwards between New Caledonia and Queensland, producing severe gales.
18-23 Jun 1925	Winter cyclone crossed central coast at Port Clinton on 19th. Some damage to buildings at Yeppoon and Taranganba Station. It recurved over Gayndah and Double Island Point.
17-20 May 1926	Cyclone passed just east of Double Island Point on 17th and moved south-east to Norfolk Island while intensifying. SS *Wanganella* adrift for a week and *Eastern Moon* in similar difficulties. Local flooding in Burnett, Dawson and Balonne Rivers.
29-30 Nov 1927	Winter cyclone off Sandy Cape moving south. Heavy weather along south coast.
15-17 Jun 1929	Winter cyclone recurved to south-east off Central Coast with gales reported. Local flooding in the Fitzroy River.
29-30 Jun 1929	Winter cyclone recurved to south-east just to north-east of Cape Moreton with gales and heavy rain. Much damage at Sandgate. Flooding in the Pine and Nerang Rivers.
7 July 1931	Winter cyclone developed South-East Queensland and moved towards the south-east. High winds in Brisbane.
10-11 Jul 1933	Winter cyclone recurved over Broadsound and Rockhampton towards the south-east. Floods in Central Queensland.
1-2 Sep 1934	Winter cyclone passed to east of Brisbane. SS *Montoro* damaged.
7-10 July 1935	Winter cyclone recurved over Shoalwater Bay and moved towards south-east. Gales. SS *Maheno* driven ashore on Fraser Island. Heavy rain in Central Queensland.
30 May 1941	Winter cyclone crossed coast near Town of 1770 and then moved back out to sea. Gales Central Coast 30th and 31st. Local heavy rain and hail.
14-16 Jun 1948	Complex cyclonic system moved from Double Island Point to Coolangatta and then seawards. Gale force winds. Flooding on South Coast and Condamine.
15-26 Jun 1950	The event began on the 15th/16th when a low developed east of Newcastle. A second low developed near Ballina on the 19th and at Rathmines Meteorology Office south-east wind gusts to 61 knots were recorded. On the 23rd, a winter cyclone moved westward towards the Gold Coast and then turned slowly back out to sea and down the NSW coast. Wind over 50 knots in Moreton Bay and northern NSW where 10 to 15 m waves reported. Houses were unroofed at Cleveland, Southport and Coolangatta. 40 launches at Southport were damaged or destroyed. 24 hour rainfall totals to 368 mm (Springbrook). Extensive damage in South-East Queensland due to flooding and 2 lives were lost. Winds to hurricane force and waves to 15 m off the NSW coast. For the 24 hours to 9am 24th Dorrigo recorded 636 mm of rain. Serious flooding in northern NSW rivers and the Clarence River forced a new path to the sea. Grafton, Kempsey and Maitland badly affected with large scale evacuations (estimated 9000) and 4 lives lost.

Date of Event	Impact
	Navy ship *Fair Wind* lost with crew of 17. 648 ton freighter *Bangalow* driven ashore at Coffs Harbour. Tornado at Cudgen wrecked 4 homes and damaged others. At Grafton 3000 people were made homeless with 6 houses washed away. At Maitland 3200 were made homeless. Aerial surveys from Newcastle to Queensland revealed hundreds of blocks swept clear of homes. Millions of pounds (1950) damage to NSW train and tram tracks. Cronulla surf club collapsed into sea and extensive damage to other foreshore installations along the NSW coast. When rain cleared southward from the Maitland area, westerly gales caused wave damage to submerged houses in an inland sea south and east of Maitland. Several houses and flats collapsed in the Sydney area by foundations being undermined by heavy rain. 300 families were evacuated in the Hunter Region. Similar evacuations in the Woy Woy-Tuggerah area. Main roads out of Sydney were cut by landslides and flooded bridges. Five lives were lost.
16 Nov 1950	Low crossed coast near Brisbane and caused considerable structural damage with one life lost.
8-9 Jun 1951	Winter cyclone crossed coast Coffs Harbour and then moved over Darling Downs. Heavy rain.
29 Aug 1953	Winter cyclone made landfall at Rockhampton and then moved back out to sea. Gusts to 50 knots recorded at Rockhampton.
11-13 Jul 1954	Complex cyclonic system crossed coast near Bundaberg and then recurved towards south-east. Winds to hurricane force left a trail of damage along the coast south from Bundaberg. Woman killed at Nambour when shed was lifted by wind and hurled into her. Houses, shops, jetties and boats were badly damaged. 200 people were left homeless, hundreds of small craft were wrecked. Many houses unroofed including 50 at Caloundra. Hurricane force winds in Moreton Bay with widespread property and boat damage at Redcliffe, Sandgate and Wynnum. The Dutch naval sloop *Snellius* reported waves to 21 m off the South Coast.
8-12 Jun 1958	Large intense winter cyclone passed to east of South Coast. Waves over 10m were reported off the South Coast out to a distance of 640 km. The schooner *Venturer* was wrecked near Lady Musgrave Island. Other ships sustained damage. Floods cut roads in South-East Queensland. There was severe beach erosion along the coast.
24-26 May 1960	Small deep low developed off the South Coast on the 25th north of a vigorous high in the Tasman Sea- 457 mm of rain fell in 3.5 hours at Cawarral (near Rockhampton)- Flash flood damage to crops and communications - extensive sea damage to Gold Coast Beaches and interruptions to shipping.
5-7 Jun 1961	Deep complex low developed with centre east of Brisbane and another near Lord Howe Island. Gales and large seas along south coast caused the harbours to be closed.
6- 7 October 1961	1040 hPa high near Tasmania and an upper low forced a deep trough or small low to move off the Central Coast. A house was blown down at Rosedale. Heavy flooding in the Curtis River. And heavy damage to roads. Crop and stock losses. 356 mm of rain was recorded in 9 hours at Wonbah (near Mt Perry.)
9-11 Jul 1962	Winter cyclone developed north-east of Fraser Island and moved past Gold Coast. 60 to 70 knot winds reported from Tweed Heads to Yamba in the 24 hours to 9am 11th. Local flash floods Brisbane to Gold Coast. Fruit trees damaged buildings flattened at Sunnybank. Small boats wrecked, buildings flattened, extensive beach erosion and roads damaged Gold Coast. Radio mast wrecked at Lytton. Widespread flooding in Nerang, Albert and Logan Rivers. In NSW small craft lost or damaged at North Coast harbours. Bad floods in Murwillumbah, Lismore, Bellingen and Grafton with many evacuations and people drowned. At 1am on the 9th, 2 waterspouts came ashore at Port Macquarie and left a trail of destruction. 3 men were killed when a two-story building they were erecting was wrecked. 30 house were damaged. Largest 24 hour rain totals 265mm in Springbrook and 227mm in Lismore.
7-8 May 1963	Small winter cyclone developed near Tewantin and then moved south-eastwards out to sea. Gales brought down trees and power lines. Big tides and heavy rain caused severe

Date of Event	Impact
	local flooding at Redcliffe, Wynnum, the Sunshine Coast and the Gold Coast. There was waist deep water in Sutton Street, Redcliffe and other streets were under 5 feet of water. Families were evacuated at Lota. A landslide cut the Pacific Highway at Kirra. The Casino-to-Tenterfield road was washed away west of Casino, leaving a 1000 foot sheer drop. Lismore had a major flood with water entering the city. Grafton then flooded with 700 families evacuated from their homes.
25-28 June 1965	Winter cyclone developed off Sunshine Coast and moved out to New Caledonia. Maximum average winds 44 knots at Double Island Point. Ship reported southerly winds averaging 60 knots east of Fraser Island as winter cyclone intensified while moving seawards. Heavy-to-flood falls in Mary River catchment and in Moreton Bay. Maximum 24 hour rainfall registration of 242 mm at Tewantin.
18-21 Jul 1965	Winter cyclone developed east of Brisbane, moved up to Fraser Island, turned southwards over Brisbane, down to Yamba and then seawards. Wind gusts to 60 knots recorded at the Bureau in Brisbane. There was much damage to small structures in the metropolitan area and 3 houses were unroofed. Trees were uprooted, plate glass windows smashed and telephone and power lines downed. Along the Bay, many small craft were damaged. There was much crop damage in surrounding areas. Fallen trees and floods blocked roads. 24 hour rain totals in Brisbane were up to 236mm on the 20th. 510mm fell in 24 hrs at Springbrook. The upper trough associated with the development of the winter cyclone brought snow into the tropics for the first time on record. Scattered falls were reported on the 19th from the Central Highlands through the northern Warrego to the Darling Downs and Maranoa. Further north, snow fell west of Mackay at Dalrymple Heights and Blue Mountain. Sleet was observed at Nebo and Clermont and on the 20th Thangool reported snow.
9-13 Jun 1966	Winter cyclone developed near Fraser Island and then moved south and passed to the east of Brisbane and the Gold Coast. Average winds to fifty knots along the southern Queensland coast. 24 hour rainfall totals:- 388mm Springbrook; 213mm Caboolture; 197mm Beenleigh and 163mm Brisbane Airport.
8-13 Jun 1967	Winter cyclone developed near Willis Island and moved down to Bundaberg on the 10th, passed over Fraser Island and then moved into Moreton Bay on the 11th before moving over Gold Coast and then out to sea on the 13th. Cape Moreton reported gales from 9am on the 9th to 9am on the 11th, with the strongest winds (gusts to 80 knots) at 6pm on the 10th. Very heavy rain fell on the 11th to 12th. Bureau in Brisbane recorded 282mm in 24 hours to 9am on the 12th. 140mm fell in the 3 hours to 10pm on the 11th. Springbrook recorded 636 mm in 24 hours to 9am on the 12th, including 276mm in 6 hours to 3am on the 12th. A woman was killed when her car overturned into Mary River at Gympie. A youth was killed in an intersection crash in blinding rain at Clayfield. Two men were rescued from flooded vehicles at Doboy Creek and Wickham Street in Fortitude Valley. Five hundred people were evacuated from flooded homes, fourteen people were rescued by boat. Fifteen cars were swept into Enoggera Creek and the occupants either escaped or were rescued. A car plunged into a washout at Chapel Hill. Hundreds of homes and shops in Fortitude Valley, Ashgrove, Moorooka, Hemmant, Breakfast Creek, Newstead, New Farm, Woolloongabba, Stones Corner, Greenslopes, Coorparoo, Fairfield, Annerley, Milton, Toowong, Newmarket, Windsor and Albion had water pouring through them. The floods wrecked three yachts in Breakfast Creek. Caravans were washed away from the Newmarket Caravan Park. Landslides cut Brisbane rail services and there was much damage to roads and bridges. On the Gold Coast, water entered the ground floors of structures in Cavill Avenue. The worst hit areas were the canal estates west of Broadbeach, where hundreds of houses were isolated. Fifty families were evacuated from homes on the Gold Coast. At Southport, houses were washed away or undermined. Many boats were set adrift by the gales and were badly damaged. Huge seas added to the severe beach erosion left over from the

Date of Event	Impact
	summer cyclones. Over the border in NSW, there were two deaths. 400 people were evacuated from their homes in Grafton and sixty families were evacuated from homes in the Kyogle region.
21-22 Jun 1967	Winter cyclone moved from Willis Island down to Fraser Island and then turned towards the south-east and passed over Lord Howe Island. Average winds to 40 knots along the southern Queensland coast. Rainfall in Brisbane to 60mm produced minor flooding.
26-28 Jun 1967	Winter cyclone developed just to the east of Brisbane (26th) and moved slowly north to the east of Double Island Point (27th) and then turned slowly towards the south-east. Hurricane force winds were reported from Cape Moreton from 9am 26th to 3pm 27th. A man was killed when his car crashed into a creek at Nerang in bad weather on the night of the 26th. Some houses and buildings were unroofed at Burleigh and Surfers Paradise. At Mudgeeraba, a building was blown off its stumps and wrecked. Boats were swept from their moorings. Two houses at Mermaid Beach were lost to the sea (26th). Large sections of the Esplanade at Surfers Paradise were lost to the sea and lanes and streets collapsed at Palm Beach (26th). The swimming pool from the Beach Lodge resort was lost to the sea at Surfers Paradise. By the 28th, the Esplanade at Main Beach fell into the sea and 5 houses were wrecked at Nobby's and Palm Beach. Many houses were badly damaged by the sea along the Gold Coast, however a volunteer army of 5000 people placed around 100,000 sandbags along the foreshore, helping to prevent many houses being lost to the sea. Wreckage of the prawn trawler *Sydney J* was found at Tewantin with no trace of the owner-skipper who was believed to have drowned.
5-8 Jul 1973	Winter cyclone developed east of Mackay (5th) and moved down just seawards of the Sunshine Coast by the 7th. It then moved back up north to the east of Yeppoon. Four people drowned on the evening of the 7th; two near Nambour when the car went into a creek and two near Yandina after their car became stranded. Average winds of 40 to 55 knots were reported along the South Coast from 8 am 5th until 10pm 8th. A ship reported average winds of 60 knots off Stradbroke Island at 3pm 6th while another ship reported winds of 74 knots off the Gold Coast at 3pm 7th. Trees and power line were brought down throughout South-East Queensland causing widespread blackouts. Some houses were unroofed at Kingaroy and near Warwick. The South Nobby wave recording station on the Gold Coast reported significant wave heights to 5.2 m and maximum wave heights to 8.7 metres. The 1600 ton cargo ship *Cherry Venture* was driven ashore 1.5 km south of Double Island Point on the afternoon of the 8th, after foundering in 'forty foot waves'. Twenty four hour rainfall totals recorded 9am 6th included: 384mm Nambour; 349mm Woodford; 340mm Mapleton; 335mm Maleny and 328mm Springbrook. Many roads in South-East Queensland were cut by floods. and in Gympie, 6 feet of water was over Mary Street on the night of the 6th. The Mary River at Gympie peaked at 19.6 m at 2am on the 9th with houses, shops and factories under 2 m of water.
29-30 Jul 1979	Winter cyclone developed to the north-east of Fraser Island, moved down just to the east of Brisbane and then turned eastwards out to sea. Gales along the Gold Coast. The Brisbane wave recording station (7 km east of Point Lookout) recorded significant (peak) wave heights of 4.7m (8.7m) on the 30th of July.
6-9 May 1980	Winter cyclone developed near Fraser Island, moved east and then turned back and crossed the coast to the north of Brisbane. Average winds along the south coast to 45 knots. The Brisbane wave recording station recorded significant (peak) wave heights of 5.2m (8.1m) on the 8th of May. Six houses at Labrador (Gold Coast) were flooded by 1 m of water (6th). Floods cut roads in Brisbane and power lines were brought down causing blackouts in some suburbs (6th). Vehicle swept off road by floods in the Gold Coast hinterland, though the driver escaped injury (8th). Roads flooded in the Waterford-Marsden area (9th).

Date of Event	Impact
21-22 May 1981	Major low pressure system developed near Mount Isa and moved down to north-western NSW. Small secondary winter cyclone developed on the coast near Cairns and ran right down the east coast with gale force winds. Extensive sugar cane damage Cairns to Home Hill. 16 homes damaged at Darling Heights (Toowoomba). Two small yachts wrecked. Local flooding from Rockhampton to Proserpine. Two boys drowned at Rockhampton and one near fatality at Proserpine when motor vehicles were washed off creek crossings. The Brisbane wave recording station recorded significant (peak) wave heights of 3.8m (5.2m) on the 22nd of May.
3-5 Jun 1983	Small low formed north-east of Cape Moreton while major low developed near New Caledonia with a central pressure of 1000 hPa (4th) and north of a large 1040 hPa high. Storm force winds South Coast 3pm 3rd to 9pm 4th with gusts to 70 knots at Cape Byron. The Brisbane wave recording station recorded significant (peak) wave heights of 5.3m (10.0m) on the 8th of May.
20-23 Jun 1983	A winter cyclone developed in the Coral Sea and moved down through Hervey Bay across the Sunshine Coast and back out to sea. Maximum sustained winds of 60 knots were reported from a ship east-north-east of Noosa. Gusts to 56 knots were recorded at the Brisbane City Bureau (22nd). 350 mm of rain was recorded in the 24 hours to 9am 22nd at Nambour including 229mm in 4 hours. A boy was drowned at Pomona after being sucked into a flooded drain. A man was killed at Gatton when a tree fell on him. In Brisbane, winds brought down trees and powerlines and landslides closed the Southeast Freeway and Settlement Road. Brisbane creeks were flooded. On the Sunshine Coast, many centres were isolated as floods and landslides cut roads. Trees and power lines were down and 15 yachts were damaged at Mooloolaba . Eleven caravans were washed away and destroyed by floodwaters at Yandina Caravan Park. In Nambour, shops were flooded including a Mercedes dealership where cars were washed away. Floodwaters inundated houses and shops in the lower parts of Mary Street , Gympie. On the Gold Coast trees and power lines were blown down and tiles were lifted off roofs. A boat was sunk in one of the canals and many roads were blocked by floods, downed trees and landslides. There was widespread crop damage in South-East Queensland. Eleven houses were evacuated at Roma. Major flooding occurred at Dalby with 13 houses evacuated. There was severe beach erosion along the South Coast and the Brisbane wave recording station recorded significant (peak) wave heights of 5.1m (7.1m) on the 22nd of Jun.
8-10 Jul 1985	A 1009 hPa low developed on the Sunshine Coast by 3pm 8th and moved south while intensifying to a 1001 hPa low over southern suburbs of Brisbane at 3am 9th. Maximum sustained 38 knots north-east winds at Cape Moreton and 50 knots east-north-east winds with gusts to 65 knots at Cape Byron. Caloundra recorded 239 mm of rain in 24 hours. At 9am 9th the low was 1001 hPa and just to the north of Yamba, after which it deepened and moved to the south-east. Lord Howe Island at 3pm 9th had 40 knot winds from east-south-east with gusts to 54 knots.
7-9 Apr 1984	Tropical cyclone *Lance* underwent rapid extra-tropical transition near and east of Brisbane. Sustained winds reached 60 knots with damage to boats on the western side of offshore Islands in storm force westerlies. On the Gold Coast many houses lost roofing while wind drove rain into high rise buildings and there were huge seas. The Brisbane wave recording station recorded significant (peak) wave heights of 5.1m (8.8m) on 9 Apr.
2-3 Sep 1985	A large low pressure area developed in the Tasman Sea with the main 990 hPa centre east of Sydney on the 2nd. It then moved south-east and deepened below 988 hPa. On the 2nd, westerly wind gusts uprooted trees, damaged buildings and crops and blacked out 9000 homes in Brisbane. The maximum wind gust recorded in Brisbane was 97 km/h (52 knots) at 11.12 am on the 2nd. Waves to 3 m high were reported on Moreton Bay.

Date of Event	Impact
9-10 May 1987	Small low on the Gold Coast with large 1037 hPa high in the Tasman Sea. 345mm of rain in the 24 hours to 9am 10th at Springbrook with flash flooding on the Gold Coast. Road collapsed at Bundall. A woman was drowned when the motor cycle she was a pillion passenger on ran into a metre of water at Nerang. A man was drowned when swept away by floodwaters at Tallebudgera Caravan Park. A man was missing believed drowned by a flash flood on his Mullumbimby property. There was one other death (source Lucinda Coates, BoM Melbourne). Many other people were rescued from floodwaters and hundreds of houses were flooded. Three boats sank at Southport.
4-7 Apr 1988	Small low moved out to sea from Sunshine Coast, then up to Fraser Island, back to Gympie, out to sea again and then back overland west of Brisbane. In Springbrook, the measured rainfall was: 24 hours to 9am 4th, 228mm; to 9am 5th, 246mm; to 9am 6th, 302mm. 161 mm at Dayboro in 24 hr to 9am 6th, causing flash floods. In South-East Queensland flooding closed schools, swept people off bridges, uprooted trees, caused landslides and closed roads and highways. Landslides blocked the Western Freeway and roads at Samford. Floods isolated people at Cecil Plains for a week. Ipswich SES had more than 200 calls for help. 400 residents were stranded in their homes at Kholo. Sandbagging was required to save homes at Tarragindi and Logan. The crop damage in the Lockyer Valley and Darling Downs reached $20 million (1988$). Floods also cut roads and isolated communities in north-east NSW. Gold Coast wave recording station recorded significant wave heights to 4.28 m on 5 Apr.
10-11 Apr 1988	Small low developed south-east of Fraser Island and moved onto Sunshine Coast. 24 hour rainfalls :- Springbrook 215mm to 9am 11th and 337mm to 9am 12th; Cooroy 239mm to 9am 11th; Eumundi 203mm to 9am 11th. Gales were reported from Double Island Point to Yamba. Wind gusts to 50 knots at the Gold Coast uprooted trees, flipped small craft, and ripped bigger boats from their moorings. SES repaired roofs, cleared trees from houses and sandbagged houses on Gold Coast. Crop damage expected to reach $100 million in South-East Queensland from the series of lows. Communities continued to be isolated by floods in South-East Queensland. Huge seas on Gold Coast with 1 m waves on Broadwater. Brisbane wave recording station recorded significant wave heights to 4.1 m on 11 Apr.
14-16 Sep 1988	A low developed 100 km east of Cape Moreton and then moved slowly out to sea. Gales affected the Gold and Sunshine Coasts and the North Coast of NSW. Large swells hit the Gold Coast and northern NSW. Brisbane wave recording station recorded significant wave heights to 4.62m on 15 Sept.
14-18 Dec 1988	A tropical low developed near Willis Island and initially moved towards the south-south-east before turning south and then south-west before crossing the coast south of Gladstone. Gales were reported from near the low and along the Sunshine Coast. Central business area of Gladstone badly flooded. One metre of water swept through shops in Goondoon Street on the 18th. There were four deaths from road accidents over South-East Queensland in bad weather on the 18th. Brisbane wave recording station recorded significant wave heights to 4.98m on the 18th of December.
24-26 Apr 1989	Tropical low developed near Yeppoon on the 24th,moved down the coast over the Sunshine Coast on the evening of the 25th and east of the Gold Coast on the morning of the 26th. Gale to storm force winds on the Sunshine Coast with 15 houses suffering roof damage and 5 houses damaged by falling trees. One person was drowned at a creek crossing on the Gold Coast and another was electrocuted on the Sunshine Coast. Heavy rains caused widespread flooding. At the high tide early on the 26th, some roads in Brisbane were under a metre of water. Landslides blocked city streets, walls collapsed and power lines were brought down. Flooding occurred at Gympie and several houses on the Sunshine coast were flooded. Large seas caused severe beach erosion along the Sunshine and Gold Coasts. The Brisbane wave recording station recorded significant wave heights to 6.11 m on the 25th of April.

Date of Event	Impact
21 -22 Feb 1992	Monsoon low crossed the coast near Rockhampton as it formed a secondary centre near Maryborough. Very heavy flood rains South-East Queensland. A motorist lost his life when he attempted to cross a barricaded crossing on the Stanley River. 225 homes were inundated by depths up to 800 mm in the Maroochy system. There was a flash flood component to this flooding. 30 to 40 houses and 110 business premises were flooded at Gympie. There was flash flooding at Bundaberg and on the Cherwell River near Howard where 60 houses and caravans were inundated and around 20 people evacuated.
14-16 Feb 1995	Low developed off the central coast and deepened to 997 hPa early on the 15th before making landfall on the Sunshine Coast. Winds to storm force south of the centre. Flash floods occurred at Hervey Bay though fortunately at low tide. The Brisbane wave recording station recorded significant wave heights to 6.42 m on the 15th.
14-17 Feb 1996	A tropical low developed near New Caledonia and moved past Brisbane and brought storm force southerly winds to waters off the Gold Coast. A storm surge brought some flooding up the Brisbane River at Newstead. A storm surge of 0.59m was measured at the Gold Coast Seaway. The luxury vessel *Queen Elizabeth II*, travelling from Brisbane to Sydney, was battered by average winds of 26 ms^{-1} and very short and very steep 10 m waves just off the northern New South Wales coastal town of Yamba around 1900 UTC 15 February 1996, resulting in injuries to passengers. The Brisbane wave recording station recorded significant wave heights to 6.19 m on the 15th.
1-5 May 1996	Low developed east of Townsville and intensified as it moved down to waters just off Brisbane. Wind, sea and flood damage South-East Queensland - 3 drowned in small craft and in rivers. Boy swept down drain - 1 traffic accident death - 16 houses were damaged by wind at Tamborine and there was wind damage on the Gold Coast. Landslides blocked roads and fallen trees brought down power lines. The maximum wind gust of 65 knots was recorded at Cape Moreton AWS. Storm tides flooded the Sandgate foreshore at Flinders Parade. The Gold Coast Seaway was 0.51m above the predicted high tide on the 2nd, which was 0.18 m above HAT. The Brisbane wave recording station recorded significant wave heights to 6.9 m on the 2nd.
4-5 Feb 1999	A low developed east of Fraser Island and moved south. Highest peak and highest significant waves on the Southport wave rider buoy on the 4th were 6.7 m and 3.5 m. Two men were lost when a 8.1 m fishing boat was wrecked by a large wave on Breaksea Spit north Fraser Island early on the 6th.
8-10 February 1999	Small low developed near Double Island Point. In the lead up rains, a girl drowned at Samford on the 6th. A man and a woman in a campervan were swept into creek at Kennilworth when bank collapsed on afternoon of the 8th; the man drowned. On the 8th at the Sunshine Coast, flooding and landslides closed dozens of roads. Wind blew power lines down causing blackouts and several houses had roof damage. SES sandbagged homes against flash flooding in Nambour, Palmwoods, Coolum, Mudjimba and Pacific Paradise. Landslides affected the Obi Range Road between Mapleton and Kennilworth, Jimna Creek Road, Cedar Pocket Road and Tin Can Bay Road. Kilcoy was isolated by floodwaters. At Brookfield a schoolgirl was rescued from Mogill Creek. In Fortitude Valley a landslide closed off Ivory Street. The road to Bribie Island was cut. SES volunteers attended wind and flood damage operations in the Laidley and Gatton area. Fallen trees cut several roads. Double Island Point automatic weather station (AWS) recorded a gust of 63 knots at 0047 UTC 8th, while the AWS at Cape Moreton registered a gust of 56 knots at 0119 UTC 8th. A peak wave height of 8 m was measured on the waverider buoy off Main Beach Southport at 1300 UTC 8th. On the 9th, top 24 hour rainfall totals to 9am were Maleny 404 mm, Mary Cairncross 370mm, Nambour 332 mm. In Brisbane, Strathpine recorded 182 mm. A boy was drowned when he was swept into a stormwater drain at Palmwoods. Another boy was rescued after being swept from a park in Nambour. A man was drowned when he was swept over a weir while boogie-boarding in the Caboolture River and a man was trapped by

Date of Event	Impact
	the rapidly rising South Pine River at Albany Creek and drowned. North of Brisbane 160 roads were cut, with the Bruce Highway being the worse affected by cuts in several key locations. 17 800 houses were without power in South-East Queensland. A man drowned in a creek on the Gold Coast. On the 10th, the body of a man was found in a creek just outside Conondale. The Mary River at Gympie peaked at 21.95 m (The highest level this century). 150 business and 20 houses were inundated.
20 May 1999	A disturbed area formed well off the Queensland coast during the third week of May. By 1800 UTC 20 May 1999 the low was about 225 nautical miles north-west of the northern tip of New Caledonia. The system moved on a fairly straight southerly track for the next five days, passing about 300 nautical miles west of Noumea, New Caledonia. The system continued slowly southward until the 25th, when it accelerated rapidly south-south-eastward, passing west of the southern tip of New Zealand's South Island and near Auckland Island around 0600 UTC on 26 May. During 25 May the storm had intensified, had central convection and extensive peripheral cloud banding, and looked more like a tropical cyclone than at any previous time. On 23 May the storm also exhibited an eye-like feature. The storm had a significant impact on the Australian coast between 25°S and 32°S although its closest approach was about 400 nautical miles off the coast. There were two helicopter rescues to stricken yachts just off Brisbane and two more near Port Macquarie. Swells with wave heights to 10 m were reported. Numerous ships reported winds well above gale force, and there were a couple reporting winds in excess of 50 knots: ELMQ 23/0600Z 150/50 knots near 26.3° S, 159.6°E ---- 23/1200Z 140/54 knots near 26.3°S, 154.0°E The storm passed about 50 nautical miles east of Lord Howe Island around 1200 UTC on 24 May. That station reported peak winds of 41 knots with a gust to 57 knots at 24/1355 UTC. However the anemometer is obstructed for south-west winds. An anemometer on runway 10 recorded a maximum gust of 81 knots from the south-west during the afternoon of the 24th. The mean wind was 62 knots. Boats in the Lagoon with anemometers recorded gusts to 85 knots. Boats in the Lagoon were washed ashore. Three lodges were damaged and one was unroofed. There was widespread tree damage. 24 hour rainfall to 9am 25th at Lord Howe was 150.0mm. Secretary Island (located in the south-west of South Island) experienced gusts to 78 knots as the storm brushed by New Zealand. Invercargill reported 60 knot winds at 2100 m and 84 knots at 3050 m. Finally, as the system moved rapidly south-south-eastward on 26 May, it passed over a drifting buoy near 52.5°S,169.0°E which reported a minimum pressure of 975.2 hPa at 1249 UTC.

APPENDIX F: IMPACTS OF SEVERE STORMS ON SOUTH-EAST QUEENSLAND

Date of event	Impact
February 1871	Capt C.B Whish diary 'the soil (at Caboolture) which is being plowed up looks beautiful, friable and moist and the oldest canes are growing away well since the hail storm'. (Caboolture Historical Society, 1973)
10 August 1916	Extensive hail storms in the Sunshine Coast hinterland from Melany to Palmwoods. Bald Knob (near Melany) 'left like a snow capped mountain for three days'. (Caboolture Historical Society, 1977)
17 April 1956	Hail and wind damaged crops and buildings in Brisbane. Many people in Brisbane injured by flying glass and large hailstones associated with wind gusts to 56 knots.
10 December 1956	30 houses were unroofed and a cottage blown off its stumps at Redcliffe –100 000 pounds (1956 value) damage -3000 poultry killed by hail. Crops damaged at Strathpine. 20 houses were unroofed at Booval and 5 people were injured by hail.
3 February 1957	73 knot gust at Amberley. Radio station 4IP's radio transmitter damaged. Power disrupted in Ipswich. Lightning struck a house at Oxley causing a small fire, fireballs were reported.
14 March 1957	Thunderstorm hit Brisbane between 4pm and 5pm. Church, golf clubhouse and ten houses unroofed in north and north-west suburbs- trees uprooted and power lines down causing protracted blackouts. The centre of the storm passed over Enoggera, Windsor and Nundah. 57 knot wind gusts were recorded by the Bureau of Meteorology.
12 December 1958	Storm damaged houses and gardens in Brisbane. Hail 6.3 cm in diameter shattered many windows and ruined gardens. Power lines down with prolonged blackouts. Lightning damaged a house at Oxford Park. Rainfall of 13.4 mm in 5 minutes was recorded, causing flooding in the city area. Water entered business premises in Fortitude Valley with considerable damage to stock. Roads were also flooded. 3.8 cm hail at Kallangur smashed fibro roofs, destroyed crops and killed poultry.
17 December 1958	Hail storm hit Brisbane. Houses were unroofed, roads and bridges flooded and power lines brought down. Wind tore the roof off a house at Chelmer and hurled it 65 m. Other roofs were shattered by flying debris at Indooroopilly. Water several feet deep swept through a flat at Paddington. Two houses were unroofed at Windsor with interiors ruined. Another two houses at Ashgrove lost their roofs. Two houses were struck by lightning. Flash flooding caused much damage through the city and suburbs. 17 mm of rain in 5 minutes and then 44 mm in 30 minutes were recorded at the Bureau's observation site in the City, while 69 mm in 45 minutes was recorded at Bardon.
28 December 1958	Storm over the southern suburbs of Brisbane unroofed 15 homes, a factory, school, prison block and Rocklea show buildings. Gusts to 61 knots were recorded at Archerfield, 50 knots in the city and 48 knots at Eagle Farm. 25 m wood and steel roofs were hurled 100 m and awnings were torn from many shops. Lightning strikes were reported in 10 suburbs. Roads were flooded and Bureau of Meteorology recorded 15 mm in 5 minutes. Widespread power blackouts resulted.
3 January 1959	Storms in Brisbane produced local flooding in Northern suburbs. 14 homes were flooded at Booval.
3 February 1960	Lightning struck and burnt down a house at Indooroopilly. Wind damage was reported at Coorparoo, Loamside and Fordlane. South side suburbs were blacked out and trunk-line circuits were out. 115 mm of rain in 1 hour was recorded at Deagon.
27 November 1960	Storms in Brisbane. Houses unroofed at Rosalie and Auchenflower, trees were uprooted along Coronation Drive blocking the road. Many windows were broken by hail, especially in northern and western suburbs. Flash floods occurred in City streets.

Date of event	Impact
25 February 1961	Storms with flash floods in the Bundamba Creek. A car was swept off culvert with 2 people killed. A man was struck by lightning. Lightning shattered a 12 m tree at Bald Hills.
17 November 1961	127 mm of rainfall in 75 minutes was recorded in Upper Brookfield. Roads and bridges were washed away and farmland damaged.
21 November 1961	75 mm of rainfall in 45 minutes was recorded at Redland Bay. Crops were damaged and more than 15 cm of topsoil was washed away. Rainfall caused local flooding.
18 December 1961	Storm in Brisbane. Flash flood across the northern suburbs with Kedron Brook 1.8 m over Sandgate Road. Widespread power blackouts.
October 1962	Storm produced 81 knot wind gusts at Amberley, causing power blackouts and structural damage to buildings at Brisbane and Ipswich.
17 November 1962	Two men drowned in Moreton Bay when a trawler capsized off Redcliffe during a storm. The roof was blown off the new school at Scarborough. In Brisbane, buildings were damaged by 60 knot winds, unroofing some in the Windsor and Redbank areas.
7 December 1962	Winds caused extensive damage to houses and buildings at Brisbane. Power and telephone lines were brought down. Heavy hail and rain resulted in flash floods. The worst affected suburbs included Wynnum, Manly, Hawthorne and Morningside. The Manly Baths were wrecked and the Manly Memorial Hall unroofed. At least 50 homes were seriously damaged at Morningside and Hawthorne. A waterspout sank a small craft in the Brisbane River.
11 December 1962	Wind damage to houses in Kenmore, Indooroopilly, Corinda, Sherwood, Oxley, Inala, Acacia Ridge, and Eight Mile Plains. Hail at Oxley was as large as 4 cm in diameter. A funnel cloud was sighted. Fallen trees blocked the Pacific Highway at Slacks Creek.
31 October 1963	Very heavy hail recorded in Brisbane. Hail drifts 1.2 m deep were observed at Woolloongabba. Hail blocked drains and caused water damage to property and household belongings. Severe winds caused roof damage to buildings in East Brisbane and Highgate Hill, and widespread power blackouts.
2 January 1964	Wind gusts to 66 knots recorded at Amberley. Houses were unroofed, buildings damaged and power lines down in Ipswich.
3 January 1964	Storm with severe winds and hail caused property damage at Ipswich. Maximum wind gusts of 62 knots were recorded at Amberley.
29 December 1964	Very large hail (to 185 grams in weight) caused widespread damage to buildings, windows, gardens and crops at Petrie, Kallangur and Lawnton. Hail and rain caused local flooding in eastern parts of Brisbane.
26 January 1965	Storms with hail caused serious wind and water damage to properties in the Brisbane area. The heaviest rain fell in a narrow swathe from Kenmore through South Brisbane and the City and across to Nundah. Severe wind damage was reported from West End to Eagle Farm including Hawthorne and Morningside. Houses and buildings were unroofed or damaged, trees uprooted or snapped and power lines downed. Water from hail-blocked drains entered houses and buildings. Rail traffic halted when water caused signals to fail. Extensive power losses occurred across the area. Details: in Hamilton, sheds and buildings damaged, 2 ships torn from moorings, full 200 litre drums and 1 tonne gangway blown along by the wind. Around Hawthorne and Morningside, 20 houses unroofed and buildings damaged. At Wooloongabba Cricket Ground buildings damaged, homes and buildings damaged at New Farm, West End, Hendra, Newstead and Fortitude Valley. Wind gusts to 59 knots were recorded.
18 December 1965	Thunderstorm caused severe damage to properties at Kenmore, Toowong, Ashgrove, Bardon, and Enoggera. 20 houses were unroofed, trees were uprooted or snapped off, power lines were brought down. Gusts to 44 knots were recorded.
19 December 1967	Storms cut a swathe several kilometres wide from Coopers Plains to Chermside. Around 3000 insurance claims (mostly hail) were made. Hail to cricket ball size was reported. One house had 123 holes in its roof and some cars were penetrated by hail.

Date of event	Impact
20 January 1970	A 27 km wide front of hail and wind damage passed through the southern suburbs. Almost all houses in the Slacks Creek-Rochedale area were damaged with 70 badly damaged. 60 houses were damaged at Wynnum, many unroofed. Widespread damage occurred across the city. SES reports indicate 5 houses were unroofed, 2000 houses damaged and 100 houses were declared structurally unsafe.
20 February 1970	Insurance records show a significant loss this day with a 75 knot gust recorded at Brisbane Airport.
27 December 1972	Wind damage occurred from Oxley through to Sunnybank. Tents were flattened on North Stradbroke Island. 5000 houses damaged throughout southeast Queensland.
14 January 1973	Wind and rain damage occurred from Redbank through Darra to Tingalpa and Gumdale. 15 houses were unroofed and 1000 damaged.
4 November 1973	Severe thunderstorm with a tornado moved from Brookfield to Eight Mile Plains, causing extensive damage along its path. The tornado track was 51 km long and 100 m to 230 m wide. 500 houses were unroofed, 1390 damaged and 500 declared structurally unsafe.
30 November 1976	Thirty buildings were damaged by wind in Brisbane’s northern suburbs. Twelve houses were unroofed at Ipswich. Wind gusts to 49 knots were recorded in the city and to 62 knots at the Airport.
16 December 1977	Damaging storm path from Yeronga to Nundah with severe wind gusts. 150 houses were damaged with 50 declared structurally unsafe.
26 March 1978	A severe hailstorm with up to orange and cricket ball size affected the Mudgeeraba region inland from the Gold Coast, destroying a poultry farm. Hail lay up to 0.5 m deep on the ground. Damage was also reported at the Sunshine Coast, where 4 houses were unroofed at Bli Bli and one at Nambour.
7 November 1978	Egg-size hail damage and some wind damage from Wacol across to Sunnybank. 16 houses were unroofed and 1000 damaged.
13 December 1978	25 homes damaged in Ipswich and the western suburbs.
14 December 1978	Extensive hail damage (egg size) from Albany Creek to Brackenridge and Bald Hills. 40 houses were damaged.
23 March 1979	Wind and hail damage occurred in the Ipswich area. A 60 knot wind gust was recorded at Amberley. Caravans and 22 homes were damaged.
27 April 1979	Extensive hail damage Alderley, Dorrington, Enoggera and Newmarket with egg-size hail. Thirty-six houses suffered roof damage caused by severe winds. Damage also occurred at Stafford, Grange, Bardon and Northgate.
20 November 1979	Thunderstorm with severe winds and large hail caused major property damage. 700 insurance claims were made. 10 houses were unroofed, 500 suffered damage and 5 were declared structurally unsafe. The major suburbs affected included Woodridge, Mount Gravatt, New Farm, Camp Hill, Carina, Wynnum, Capalaba, and Beenleigh.
21 November 1979	One house was destroyed and 30 damaged at Kallangur, Lawnton , Petrie and Brackenridge.
20 December 1979	Wind gusts of 64 knots were recorded at Amberley. Hail and wind damage occurred in Ipswich and 36 homes were damaged at Peak Crossing.
20 January 1980	Hail to golf ball size occurred over a wide area from Tennyson through to Sandgate. 63 knot wind gusts were recorded at Brisbane airport. Homes at Saint Lucia, Alderley, Chermside, Geebung, Strathpine and Sandgate were damaged.
28 February 1980	36 homes suffered roof damage at Beenleigh.
22 November 1980	Widespread wind and hail damage with 67 knot wind gusts reported at Brisbane Airport. Area affected was from Sunnybank to Wynnum. Most damage to housing was at Murarrie where 46 homes were unroofed. Other wind damage at Cannon Hill and Nudgee and flashfloods at Greenslopes and Browns Plains.

Date of event	Impact
16 December 1980	900 homes were seriously damaged by hail at Brighton. A tornado was sighted at Hayes Inlet. 4000 tarpaulins were needed to secure damaged homes. 860 homes were unroofed, 1600 damaged and 100 declared structurally unsafe. Another supercell passed from Ipswich to Coopers Plains unroofing 70 homes and damaging another 150. 25 light aircraft were destroyed at Archerfield.
29 November 1981	A severe Z6 cell passed over Beaudesert causing considerable wind and hail damage. Golf ball sized hail caused a dozen injuries and 70 homes were unroofed or suffered major damage. The cell continued northwards across the city and reformed but passed out to sea without further severe effects.
7 December 1982	Severe wind and hail damage at Beenleigh with 180 houses damaged and one death. 53 knot wind gust recorded at Wickham Terrace.
8 September 1983	A tornado was suspected of causing damage in the Lamington National Park area and associated storms caused damage along the south coast region. Sections of walking track south of O'Reilly's took four months to clear of felled 2000 year-old Antarctic Beech and cedars.
6 October 1983	Severe damage occurred in the Cotton Tree caravan park in Maroochydore causing seven injuries and one death. A tornado was suspected of clearing a 50 m wide strip that destroyed 13 caravans and damaged six others.
3 November 1983	On a day of considerable regional thunderstorm activity, one severe storm affected the Gold Coast region and damaged 16 houses at Ashmore.
4 January 1984	Severe wind and hail damage was reported in the Laidley-Gatton area to farm buildings and also crops.
6 January 1985	Severe wind and hail in the Manly area with 2 deaths. 10 houses were unroofed and 200 damaged.
18 January 1985	Major Brisbane hailstorm (south-west and north-east suburbs) with wind gusts to 101 knots recorded at Brisbane Airport and hail up to cricket ball size. 2000 houses were unroofed, another 20 000 suffered damaged and 12 were declared structurally unsafe. The damage path was 8 to 12 km wide from Jamboree Heights to Banyo. Major damage occurred at Jamboree Heights, Corinda, Sherwood, Graceville area and a region bounded by Windsor, Chermside, Banyo, Eagle Farm and Hamilton.
13 October 1985	Hail to the size of oranges damaged 40 houses in the northwest Brisbane suburbs.
9 March 1985	Tornado reported at Daisy Hill. Extensive property damage occurred at Ipswich and through the southern suburbs of Brisbane. 1000 homes suffered damage.
13 October 1985	Hail from a Z5 (50 dBZ reflectivity) cell ranging up to orange and tennis ball size caused damage to 40 houses in the north western suburbs.
19 October 1987	Hail damage occurred in the Ipswich area and wind damage occurred in the Clayfield-Kedron-Stafford area. 40 houses were unroofed, 220 others were damaged and 2 were declared structurally unsafe.
24 November 1987	Hail and wind damage with wind gusts to 87 knots recorded at the Tennyson Power House (40 m elevation). Damage occurred in the Ipswich and Goodna areas. 270 houses were unroofed with 820 others damaged.
24 December 1989	A tornado was sighted at Redcliffe. Wind damage also occurred in the Brisbane area. A yacht at the Newport Marina recorded wind gusts in excess of 100 knots. 500 homes were unroofed, another 1000 were damaged and 12 were declared structurally unsafe.
2 November 1990	Hail damaged 27 homes in the Booval area and 12 homes were damaged by hail and wind at Albany Creek.
30 November 1991	Hail and wind caused damage to areas in the southern suburbs of Brisbane. A possible tornado sighting at Sunnybank. 5 houses were unroofed and 20 others damaged.
29 November 1992	This was a day of quite considerable thunderstorm activity in South-East Queensland with five major severe storm cells affecting the regions south from Bundaberg to the Gold Coast. Brisbane experienced golf ball sized hail across the SE suburbs from a Z4 cell but no severe winds, with damage mainly to motor vehicles. This storm notably interrupted the Australia - West Indies Test Match at Woolloongabba and was

Date of event	Impact
	nationally telecast. Maroochydore had severe winds and hail up to cricket ball size from a Z5 supercell that caused significant property and vehicle damage. Numerous light aircraft were damaged. West of Maryborough, near Oakhurst, an estimated F3 tornado from a Z6 supercell cut a path 30 km long and between 150 to 250 m wide through mainly forest country. Accompanying hail was at least golf ball size. Further north at Bucca near Gin Gin, another Z6 supercell spawned an estimated F4 tornado with a 10 km path. It destroyed nine homes and lead to about twenty cattle having to be destroyed because of their injuries. The width of this tornado was estimated as between 20 to 60 m on the ground. The owner of one of the demolished houses reported that, together with most items, “the fridge is still missing...”. Hail ranged from cricket ball to grapefruit size.
26 December 1992	Roofs were torn off houses in the Brighton, Brackenridge area. At least 50 houses were also damaged at Albany Creek, Sandgate and Redcliffe.
6 January 1993	A storm swept through Ipswich and the western suburbs of Brisbane and damaged 29 houses, four of them extensively. SES received 100 calls for assistance.
4 November 1994	Areas from Mount Tamborine through Helensvale were affected by golf ball sized hail that damaged every car in the Movie World car park.
29 January 1995	Storm hit Brisbane late at night and damaged 100 homes (most properties suffered roof damage, broken windows or fallen trees on houses). The Rialto theatre lost its roof. Wind gusts to 55 knots were recorded at Brisbane Airport.
5 November 1995	Wind storm in Brisbane with SES responding to 60 calls for help throughout the Brisbane suburbs.
6 November 1995	Thunderstorms caused extensive hail damage at Bellbowrie with hail to softball size observed. 30 houses were unroofed and 300 others damaged. Approx $60 million losses.
19 November 1995	Severe but very localised wind damage in Caboolture resulted in several homes being destroyed and many more damaged.
16 December 1995	A line of thunderstorms moved rapidly through the Gold Coast and southern suburbs of Brisbane ahead of a surface trough. The storms, moving at about 90 km/h, produced severe wind gusts between Beaudesert, Beenleigh and then out through Redland Bay and over Moreton Bay.
18 December 1995	A phenomenal day of severe thunderstorm activity with three lines of severe storms through the South-East region alone. Severe storms also occurred in the Wide Bay - Burnett and Capricornia districts. The first line of storms passed through Brisbane, followed by a second line in which a severe cell affected Maroochydore producing wind and hail. The third line produced a severe cell over the Caboolture-Morayfield area
10 December 1996	Thunderstorm caused widespread wind and hail damage. SES Brisbane responded to 51 tasks at Mansfield, Mt Gravatt, Inala, Woolloongabba, Nathan, Forest Lake, Durack, Holland Park, Salisbury Tarragindi, Pinkenba, mainly for hail damage and water intrusion. 9 other tasks were also attended to in Pine Rivers, Redcliffe and Caboolture. Wind gusts to 69 knots were recorded at Brisbane Airport and 56 knots at Archerfield. 10 aircraft were damaged by hail at Archerfield.
31 March 1997	Thunderstorm caused hail damage in the Chermside area. The Chermside shopping centre suffered severe hail damage. 40 houses in the Brisbane suburbs sustained roof damage. There was also widespread damage in the Caboolture shire. Approx $10 million insurance losses.
28 January 1998	Thunderstorms with intense rainfalls caused flashfloods in the Sunnybank and Rocklea areas. 20 homes were flooded. Calamvale recorded 154mm.
10 April 1998	Severe wind and hail storm at Ipswich with SES responding to 132 calls for help. Wind gusts to 63 knots were recorded at Amberley. 3 people were killed when they came in contact with fallen power lines. The Beenleigh Ambulance received 50 calls due to injuries from slamming doors and windows in the wind.

Date of event	Impact
13 October 1998	Wind damage in Fortitude Valley, Bowen Hills, Breakfast Creek, Albion, Clayfield, Ascot, Nundah, Toombul, Greenslopes and Coorparoo. A school was unroofed at Wynnum and many large trees were uprooted along the Wynnum-Manly foreshore. Wind gusts to 64 knots were recorded at the Brisbane Airport and an anemometer was held at 70 knots maximum deflection for 3 minutes at the Manly Coast Guard. A yacht at Manly recorded a wind gust of 85 knots. Department of Civil Engineering (University of Queensland) study indicated winds of 90 knots damaged house at Hendra. Hail to 5 cm in diameter was observed at Cannon Hill. Insurance claims $23 million.
18 November 1998	Wind partially unroofed 6 houses at Toowoomba, with the Toowoomba Airport anemometer recording a gust of 60 knots. Approximately 37 000 houses lost power, chiefly in the towns of Laidley, Gatton and Esk. Houses in the Brisbane suburbs of Chapel Hill and Kenmore had roofs damaged by falling branches. Brisbane airport recorded a maximum wind gust of 49 knots.
24 November 1998	Widespread storms across South-East Queensland with power supply company Energex stating that almost 100 000 homes lost power. Ipswich SES controller reported that they attended about 50 homes and businesses damaged by storms, with rain causing additional damage. Hail to golf ball size was reported at Rosewood and Marburg. A brick duplex was destroyed at Caloundra, where a tornado was reported. Eight other houses were also damaged in the Caloundra area.
5 December 1998	Hail larger than golf ball-size was reported from the Ivory Rock conference centre near Peak Crossing (south of Ipswich). Roofs and 30 cars suffered hail damage. Hail to golf ball size was also reported from Manly West and Algester.
16 December 1998	Thunderstorm with large hail moved north across the Brisbane city area and eastern suburbs. A Toyota dealership reported 600 vehicles sustaining damage between $2,000 and $8,000 each. Suncorp, Queensland’s major insurer, reported more than 1500 vehicle claims, with total damage estimated as between $10 million and $12 million. The Insurance Council of Australia named the worst hit suburbs as Clayfield, Windsor, Wilston, Albion, Northgate and Wavell Heights with an estimated total damage bill of $76 million. There were many reports of hail, the largest reported diameter was 10 cm at Bracken Ridge. Additional storms caused damage in the Ipswich area and in the Gold Coast hinterland.
11 January 1999	Ipswich SES controller about 9.00 pm reported 75 callouts to businesses and homes damaged by thunderstorm gusts during the evening. Sixty homes and the Brisbane Court House and Tivoli Sewage works were damaged. Approximately 12 000 homes lost power. Maximum wind gusts of 37 knots were reported at Amberley RAAF base. Damage to caravans at North Ipswich
4 October 1999	Power lines brought down in the suburbs of Booval and Bundamba about 5.15 pm, disrupting traffic. Energex representative reported that about 3100 homes lost power, chiefly in the Bundamba and Booval area. Bundamba creek rose 1.5 m in 30 minutes, flooding also at River View. Fallen tree damaged house in Pine Mountain. Severe flooding occurred in Durack and Inala. Roads also flooded near Helensvale at about 7pm.
14 October 1999	Two early morning storms (occurring at 7.30am and 8.15am) 8 km south-east of Nanango, with rainfall recordings of 65mm and 105mm during that timespan. Also some light to medium hail.
20 October 1999	Heavy rain recorded at Brisbane airport. 47mm between 12.25 am and 1.00 am , and approximately 24mm between 3.15 am and 4.00 am. Wind at Brisbane Airport 12:30 am recorded gusts of 37 knots. Anecdotal reports of hail and fallen trees in suburbs south of the airport.
7 November 1999	Between 4:00 and 8:00 am golf ball size hail at Chapel Hill and Zillmere. 2cm and golf ball size hail reported from Caboolture. 2cm hail reported from Indooroopilly. 1cm size hail reported from Samford, The Gap, Banyo, Wavell Heights and Northgate.

Date of event	Impact
23 November 1999	Broad rotation under cell in the Beenleigh area, at about 5.30 pm reported by David Bernard (meteorologist). Report from G McNutt (meteorologist) of 'violent' winds at Woolloongabba, with 'building shaking'.
10 December 1999	Storm chasers reported a swathe of property and tree damage stretching from just south of Boonah to Redland Bay, due to strong winds associated with a thunderstorm. Storm spotter and newspaper reports of large hail - 5 cm at Brunswick Heads (NSW); 2-3 cm at Stephens (Gold Coast); golf ball size at Park Ridge, Shailer Park and other areas south of Brisbane in 2 separate cells.
30 December 1999	The towns of Palmwoods, Chevallum, Forest Glen and Nambour (the Sunshine Coast hinterland) experienced building, crop and tree damage; mostly wind damage, but some hail damage to fruit. Energex representative stated 20 000 homes lost power due to fallen power lines.
5 January 2000	Pea to marble size hail; 'very strong wind gusts'; minor flooding; reported by storm spotter at Wellington Point. Courier Mail newspaper report of 7 houses damaged in the suburb of Capalaba, and 2 houses damaged in Birkdale, and 2 houses damaged in Wellington Point. Damage to trees was also reported. A funnel cloud was reported from Annerley at 5:15 pm, looking towards Cleveland.

APPENDIX G: MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY (after Dowrick, 1996)

MM I *People*
Not felt except by a very few people under exceptionally favourable circumstances.

MM II *People*
Felt by persons at rest, on upper floors or favourably placed.

MM III *People*
Felt indoors; hanging objects may swing, vibrations may be similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM IV *People*
Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings
Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures
Walls and frame of building are heard to creak, and partitions and suspended ceilings in commercial buildings may be heard to creak.

MM V *People*
Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings
Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start, or change rate.

Structures
Some windows Type I cracked. A few earthenware toilet fixtures cracked.

MM VI *People*
Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily.

Fittings
Objects fall from shelves. Pictures fall from walls. Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved. Glassware and crockery broken. Very unstable furniture overturned. Small church and school bells ring. Appliances move on bench or table tops. Filing cabinets or “easy glide” drawers may open (or shut).

Structures
Slight damage to Buildings Type I. Some stucco or cement plaster falls. Windows Type I broken. Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM VII *People*
General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars who may stop.

Fittings
Large bells ring. Furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile contents of buildings.

Structures
Unreinforced stone and brick walls cracked. Buildings Type I cracked with some minor masonry falls. A few instances of damage to Buildings Type II. Unbraced parapets, unbraced brick gables, and architectural ornaments fall. Roofing tiles, especially ridge tiles, may be dislodged. Many unreinforced chimneys damaged, often falling from roof-line. Water tanks Type I burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II) may move and leak. Some windows Type II cracked. Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM VIII *People*
Alarm may approach panic. Steering of motor cars greatly affected.

Structures
Buildings Type I, heavily damaged, some collapse. Buildings Type II damaged, some with partial collapse. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down. Some pre-1965 infill masonry panels damaged. A few post-1980 brick veneers damaged. Decayed timber piles of houses damaged. Houses not secured to foundation may move. Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM IX *Structures*
Many buildings Type I destroyed. Buildings Type II heavily damaged, some collapse. Buildings Type III damaged, some with partial collapse. Structures Type IV damaged in some cases, some with

flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V. Houses not secured to foundations shifted off. Brick veneers fall and expose frames.

Environment
Cracking of the ground conspicuous. Landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM X *Structures*
Most Buildings Type I destroyed. Many Buildings Type II destroyed. Buildings Type III heavily damaged, some collapse. Structures Type IV damaged, some with partial collapse. Structures Type V moderately damaged, but few partial collapses. A few instances of damage to Structures Type VI. Some well-built timber buildings moderately damaged (excluding damage from falling chimneys). Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves.

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe.

MM XI *Structures*
Most Buildings Type II destroyed. Many Buildings Type III destroyed. Structures Type IV heavily damaged, some collapse. Structures Type V damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.

MM XII *Structures*
Most Buildings Type III destroyed. Many Structures Type IV destroyed. Structures Type V heavily damaged, some with partial collapse. Structures Type VI moderately damaged.

Construction types

Buildings Type I Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Type I–III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed in detail to resist earthquake forces.

Structures Type IV Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid 1930s to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI Structures dating from c. 1980 with well defined foundation behaviour, which have been especially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high (value) contents, or new generation low damage structures.

Windows
Type I – Large display windows, especially shop windows.
Type II – Ordinary sash or casement windows.

Water tanks
Type I – External, stand mounted, corrugated iron water tanks.
Type II – domestic hot-water cylinders unrestrained except by supply and delivery pipes.

APPENDIX H: IMPACT OF FLOODING IN SOUTH-EAST QUEENSLAND

Given in the following pages are details of known floods in the Brisbane River Basin, including Ipswich and the surrounding districts, extracted from:

- *The Romance of the Bremer*, Margery Brier-Mills, Historical Society of Ipswich, 1982. (Ref 1)
- *The early floods of the Brisbane-Bremer River system, 1823-1867*, Murdoch Wales (in association with Geoffrey Cossins and Robert Broughton), Brisbane City Council, 1976 (Ref 2).
- *Caboolture country*, Caboolture Historical Society, 1973 (Ref 3).
- *By many campfires*, Caboolture Historical Society, 1977 (Ref 4).
- *From spear and musket: 1879-1979*, Caboolture Shire Council, 1979 (Ref 5).
- *Results of rainfall observations made in Queensland*, Bureau of Meteorology, 1940.
- Monthly Weather Reviews & various data, Bureau of Meteorology.

Date of event	Impact
Early 1820's	John Oxley, early explorer, mentioned evidence of an inundation which he discovered on 19 September 1824 in an area north of the junction of the Bremer with the Brisbane: "the starboard bank an elevated flat of rich land, declining to a point where had evidently by its sandy shore and pebbly surface, been at some time washed by an inundation; a flood would be too weak an expression to use for a collection of water rising to the full height (full fifty feet) which the appearance of the shore here renders possible." (Ref 2)
1825	Major Edmund Lockyer mentioned the evidence of a large flood while in the area of today's Mount Crosby pumping station - "marks of drift grass and pieces of wood washed up on the sides of the banks and up into the branches of the trees, marked the flood to rise here of one hundred feet". Lockyer's descendant, Nicholas Lockyer, in 1919 made the following remarks: "the official record of the flood level of the river on the 4th February 1893 at the Pumping Station, the site of which is within a mile of Lockyer's camp, was 94 feet 10.5 inches. His remarks would seem to suggest that between Oxley's visit in September 1824 and his [Major Edmund Lockyer] own in September 1825, the river had experienced a flood as great as that subsequently experienced in February 1893." (Ref 2) Note that the early records refer to heights taken at the Ipswich Pumping Station. This was on the Brisbane River (not the Bremer river) near Kholo.
March 1836	Brisbane: Commandant of the Moreton Bay Settlement, Captain Foster Fyans, wrote that "we had constant rain from the 8th to the 12th March, and I am happy to say, notwithstanding the river rose about 12 feet, we sustained no injury or consequence, and those many parts of the cornfields were flooded". Murdoch Wales comments that this was in fact only three feet lower in the central city area than the 1974 flood. (Ref 2.)
1839	As reported by the *Moreton Bay Courier*, 30 May 1857, Ref.2, regarding the 1857 flood: "the river began to rise on Tuesday morning (at Ipswich) more rapidly than usual, and on Thursday afternoon it had attained the maximum height of between 35 and 40 feet above the level, being 14 feet less, we believe, than when it rose in the great flood of 1839 when, according to the statement of one who resided here at the time (probably one of the Thorn household), the river overflowed its banks to the extent of 54 feet completely filling all the gullies leading from the Bremer to what are today the main streets of the town, and inundating the country to the eastward of the Main Range for many miles." Ref 2 also refers to a letter by McConnel of "Cressbrook" near Toogoolawah in which it was said that the 1839 flood was three feet four inches higher than the 1864 flood of twelve feet six inches. Cossins suggests that with a major flood at both Cressbrook and Ipswich, Brisbane must have experienced a flood also. (Ref 2.)
1841	Ipswich flood "55 feet above the ordinary height of the Bremer". (From *Queensland*

Date of event	Impact
	Times, Ref 1) "The water rose 70 feet at Ipswich and no such flood again seen until the 1893 trouble. In the floods of 1857, 1863, 1864, 1870 the water rose 45 feet to 50 feet in Ipswich. The 1887 flood is said to have risen 50 feet in Ipswich which is 5 feet above 1864 and 1870. The flood of May 1857 was the outcome of 6 weeks long continued rather than heavy rain. That of 1863 was February autumn one 15.14 inches of rain fell in 16 days. In March 1864 an equinoctial gale brought the floods. The night of the 18th was terrific. A hurricane blew. The river rose 50 feet in 12 hours at Ipswich. The deluge of March 1870 consisted of 24.25 inches of rain in a little over 4 days; 8.20 inches being the maximum fall in 12 hours." (From *Australian Pioneers and Reminiscence*, Nehemiah Bartley, Ref 1.)
14/1/1841	Brisbane: Highest flood in Brisbane’s recorded history (to 2000). In 1896, JB Henderson, the Government Hydraulics Engineer in an address to Parliament reported that he found by examination of earlier plans that the 1841 flood was [7 centimetres] higher than the flood of 5th February 1893. (Ref 2)
9/6/1843	Brisbane: A flood of 2.76 metres AHD. (Ref 2)
10/1/1844	Heavy floods experienced at Ipswich on 10th January 1844 (HA Hunt, 1913).(Ref 2) Flood peak at Brisbane about 4 feet less than the record 1841 flood.
17/12/1845	Heavy floods experienced at Ipswich on 17th December 1845 (HA Hunt, 1913). (Ref 2)
11-14/4/1852	Heavy floods at Brisbane and Ipswich. Ipswich: "We are informed by a person of credit that the Bremer roses 24 or 25 foot." (From *Moreton Bay Courier*, Ref 1.) Possibly peaked Tuesday 13 April of Wednesday 14 April following the Easter weekend.
19-20/5/1857	Great floods at Ipswich and Brisbane; river at Ipswich rose 45 feet, and at Brisbane 12 feet.
May 1857	Ipswich: "In the inundation in the autumn of 1857 the Bremer rose about 40 feet." (From *Queensland Times*, Ref 1.) "At Mr Flemings extensive establishments, it appears that the water rose 51 feet above its usual level, reaching to the second pane of the window of his new flour mill." (From *Moreton Bay Courier*, Ref 1.) Ipswich: As reported by the *Moreton Bay Courier*, 30 May 1857, (Ref.2), regarding the 1857 flood : "the river began to rise on Tuesday morning (at Ipswich) more rapidly than usual, and on Thursday afternoon it had attained the maximum height of between 35 and 40 feet above the level, being 14 feet less, we believe, than when it rose in the great flood of 1839 when, according to the statement of one who resided here at the time (probably one of the Thorn household), the river overflowed its banks to the extent of 54 feet completely filling all the gullies leading from the Bremer to what are today the main streets of the town, and inundating the country to the eastward of the Main Range for many miles." Brisbane: "The following morning the wharves were completely inundated with the water rising over the banks to flood the lower portions of both North and South Brisbane. Frogs' Hollow [along a stream, beginning near the corner of Albert and Elizabeth Street and extending northwards to the St Stephen's Cathedral site before making its way to the river near Edward Street] was badly affected and the residents of between twenty and thirty houses had to be evacuated." (Ref 2) From a correspondent of the *Brisbane Courier*, 29th June 1907: "The flood of 1857 was the result of eight weeks' continuous, but not heavy, rain. There had been a strong fresh in the river for several weeks, and during a portion of this time all vehicular traffic between North and South Brisbane was suspended as the horse-punt at Russell Street was unable to cross on account of the strong current. At Ipswich the river rose 45 feet, and waterside stores were submerged to the roof; in the Brisbane reaches, however, the flood waters did not rise more than 7 feet above ordinary springs. Rowing

Date of event	Impact
	boats were plying in Margaret, Mary, and Charlotte streets, but except near Edward and George streets there were few house in the streets named. There were only a couple of houses in Albert Street between Charlotte and Alice Streets, and the whole of the low-lying ground from Elizabeth Street to the river was a muddy lake. At South Brisbane one could stand on a hill at Cordelia Street near Boundary Street and see an unbroken sheet of water stretching from Melbourne Street to Tribune Street. Stanley Street was submerged from Walmsley Street to within 1000 yards of the present dry dock. A good deal of the land at Hill-end was submerged, as was also the land on the opposite side of the river, now known as St. Lucia, and which was then a dense vine scrub. Most of the scrub lands at Oxley were also under water, as was Montague-road from the Stanley-street to the present West-end Reserve".
7/10/1858	Flood at Ipswich.
12/10/1858	Ipswich: "Nothing but the absence of a fresh in the Brisbane River prevented the most calamitous consequences in Ipswich, as the water rose even opposite Woodend some six feet higher than during the flood of May 1857." (From the *North Australian*, Ref 1.)
26/1/1863	Ipswich: Brisbane River bank high, Bremer River rose 4 or 5 feet, Brisbane Road almost impassable.
30/1/1863	Ipswich: Bremer River still rising and the Brisbane River a banker.
2/2/1863	Ipswich: Bremer River rapidly failing. At the height of the flood a shed on the river bank was about 15 feet under water.
15 & 16/2/1863	Severe floods at Brisbane, Ipswich and places elsewhere.
17/2/1863	Brisbane: Great deal of damage done by floods; road to Ipswich impassable; Oxley Creek residents flooded out; hundreds of acres of land under water; machinery at the mill affected, work stopped; Frog's Hollow under water; telegraphic communication with Sydney interrupted. River 40 feet above ordinary level.
18-20/2/1863	Ipswich: Heavy rain fell incessantly from the 12th to the 15th, and caused the highest flood, except that of 1841, on record. Stores along the wharves swept away; roads and creeks impassable; ferry house and several small buildings on the banks of gullies and other low lying positions inundated; creek at One-Mile Bridge a roaring torrent, telegraph posts submerged; Rosewood township partly under water; Nelson Plains one sheet of water. "The 1863 flood was 12 ft. lower than the 1841 flood, as on the Sunday night, when the water was at its highest, it was estimated to be 43 feet above the usual level of the river." (From *Queensland Times*, Ref 1.)
20 & 21/2/1863	The greater portion of the lowlands between Laidley and Ipswich one sea of water.
17-18/3/1863	Flood in Queen Street Brisbane from Wheat Creek; very heavy fall of rain; shops and dwellings flooded. The *Courier* reported "all Queen Street was in a state of consternation last evening consequent upon a sudden flood which deluged the back premises, yards, and basement stories of nearly all the houses on the west side of Queen Street from Albert Street to Edward Street. It would appear that the current was so strong that it smashed windows, burst in bolted doors, and carried gates from their hinges."
23/4/1863	Brisbane: The late rain caused floods over the low-lying ground at Milton and in Fortitude Valley.
25/4/1863	Ipswich: Bremer River rose 15 feet; water within a few inches of the One-Mile bridge; rain ceased; no further rise.
3/12/1863	Ipswich: Continuous rain; flood at Three Mile Bridge; western road impassable.
5/2/1864	Ipswich: Owing to heavy rains communication with the interior cut off and the Warwick mailman forced to return to Ipswich; creek at Fassifern bank to bank; Bremer River rising rapidly.

Date of event	Impact
8/2/1864	From *Courier* files 8-13/2/1864: "The weather has been very tempestuous and rainy during the early part of the week, and the Bremer and Brisbane Rivers rose above their usual flood-tide levels. Very slight inconvenience was felt in Brisbane from the overflow, the proprietors of warehouses on the waterside having taken timely precautions to prevent damage to property by removing their goods. At Ipswich, however, the ferry house was submerged, and the gauging shed was considerably damaged and several of the wharves were flooded. Stream traffic between the two towns was temporarily suspended. Man drowned whilst attempting to cross the river at Ipswich."
17-19/3/1864	Flood and gale at Brisbane and Ipswich (from the *Courier* files 19-22/3/1 864). On Saturday night (19th March) the river began to rise, and it was evident that a flood was impending. The telegraph posts at the One-Mile Creek Bridge, Ipswich, which had been raised 20 feet higher than they were at the flood of 1863, were swept away, although they had been let into the ground to a depth of 9 feet and supported by struts. The water at Brisbane rose throughout the whole of Sunday, and at 4 o'clock in the afternoon Albert Street, from Alice Street to Charlotte Street was impassable, and many of the residents of Frog's Hollow had to abandon their tenements. Raff’s Wharf was 5 feet under water, as also were Harris’s, Forrest’s and Town’s. The water went up Russell Street as far as Mr Kincheial’s store. At the 3 Miles Scrub the water rose 25 feet above the ordinary level. At Milton much damage was done, and the whole of the cemeteries were under water.
21/3/1864	The flood was at its highest at Ipswich at 1am on Monday, the 21st March, when it was flush with the stone wall at the end of East Street. At this point, the water remained stationery for two hours, when it began to fall slowly. (from *Queensland Times*, 16 Apr 1864, Ref 1.)
23-30/3/1864	From the *Courier* files: Flood damage at Oxley Creek. A large amount of property has been destroyed at Oxley Creek by the late floods. All the farmers on the Brisbane side of the Creek were compelled to leave their houses, and camp on the high ground in the neighbourhood of Cooper’s Plains. On the opposite side very few were driven out. McDonald’s Hotel was submerged to the eaves, and a sheet of water extended from the new sawmills, situated near the junction of the creek with the river, to the high land at the back of Cooper’s Plains, a distance of nearly 7 miles. River rose 18 feet above the level reached during the flood that occurred about a fortnight ago, and 10 feet above that of the flood of March 1863.
23/3/1864	Brisbane: The greatest amount of damage by recent floods occurred at South Brisbane, Frog's Hollow, and Fortitude Valley. For many miles along the banks of the river farmers were flooded out, and crops, furniture and in some cases their habitations swept away. Stone jetty at Cleveland completely swept away during a gale on the 18th. Ipswich: Ipswich surrounded by impassable rivers and creeks immense damage caused. At Gatton the creek rose 1 5 feet higher than ever known before.
2/4/1864	Brisbane: Two hundred teams stuck up on the road between Ipswich and Toowoomba. Highways throughout interior in impassable state after heavy rains; distressing accounts of destruction received from the northern and interior districts; several lives lost.
5-10/8/1864	Ipswich: Heavy and almost continuous rain; river rose; wharfs many feet under water; One-Mile bridge impassable rifle butts under water.
22/9/1865	Brisbane: Some damage done to the dam in course of erection at the Enoggera Creek waterworks by a heavy fall of rain.
27/10/1866	A terrific storm occurred at Brisbane; town flooded and some buildings unroofed.

Date of event	Impact
10-12/12/1866	Brisbane: Almost incessant rain since 2 am on the 10th inst.; creeks and watercourses overflowed; lower parts of South Brisbane flooded to a considerable extent. A.S.N.Co's wharf covered; a foot of water in the shed. Total rainfall from 2 a.m. Sunday 9th to 9 pm Wednesday 12th, 5.75 inches. At 9 am on l1th inst. the water was within 3 feet of the by-wash at Enoggera Reservoir and rising at the rate of 4 inches per hour. At 1.30 am 12th the depth of the overflow was 9 inches. By 5 pm the 11th all the wharfs at Ipswich on the southern bank were several feet under water, while there were 3 or 4 feet of water in the sheds; water almost level with the top of the Railway Wharf at North Ipswich, and 10 feet above its ordinary level at high water.
1/2/1867	Brisbane: The recent heavy rain caused floods on low and excavated land and basement floors of buildings in several portions of the town. Ipswich: At about 12.30 pm the Bremer River had risen 20 feet at the Ipswich wharfs and was still rising; the One-Mile Creek Bridge at Little Ipswich was submerged the railway at Walloon flooded and traffic suspended. The embankments upon the line, 4 miles from Gatton, were washed away. A man and a team of horses were drowned while trying to cross the creek at Helidon.
2/2/1867	Serious floods at Brisbane, Ipswich and in parts of the country.
21/4/1867	Severe flood and gale at Brisbane and Ipswich; loss of life occurred; houses unroofed; damage done to new Victoria Bridge works.
26-28/4/1867	Brisbane: During most of the week ending 27th April, the weather was very unsettled, and on Friday the 26th rain commenced to fall steadily and continued with but little intermission all day on Saturday. Soon after midnight on Saturday the rain which had been falling in heavy showers accompanied by squalls of wind, commenced to descend in torrents. The rain continued to fall incessantly until daylight. In consequence of this heavy rain the river rose, and never within the last twenty years have the indications of a flood shown themselves within so short a period. The river at high water on Sunday was on a level with the highest spring tides, although the present are dead neaps. Between 8 and 9 o'clock at night, which would have been about half ebb, the water had fallen 2 feet. The two lowest wharfs in the town were covered. A strong current was running down the river all Sunday, carrying with it large quantities of drift timber in single logs and rafts as well as other debris evidently washed off the bank. The temporary bridge linking north and south Brisbane acted as a dam and collapsed on the evening of 29 April as a result of the debris piling up against it.
22/1/1868	Floods throughout the country especially the southern parts. Bremer River rose 9 feet, wharves submerged; flood anticipated.
23/1/1868	Ipswich floods subsiding, weather clearing up.
27/4/1868	Ipswich: Heavy rains. Slight fresh in the Bremer last week and on the 27th the river continued to rise with great rapidity. Shortly after noon it was flush with the wharves and towards evening there were several feet of water in the sheds. The railway line was also damaged.
31/1/1870	Brisbane: Creeks between Brisbane and Gympie swollen; after the Glass House mountain stage was reached the driver of the Gympie coach found it necessary to swim across the creeks with the mails.
7-11/3/1870	Great rains. On the 7th there was a fresh in the river; the Upper Brisbane showed signs of flood, the water being within a foot of top of breakwater. Much of low-lying country at Eagle Farm Flats was flooded and Breakfast Creek Road below the Waterloo Inn was covered to a depth of several inches. On the 8th the river rose considerably, at 2 pm it was 6 feet above high water mark. At Enoggera Reservoir the water was 1'7" below bywash on the 5th, 9" above on the 6th and 4'10" above bywash on 1lth. All creeks in district flooded. The water covered Bowen Bridge and extended as far as foot of the hill beyond the hospital. At Caboolture on 8th the river rose 15 feet above ordinary high water level. On the 9th the river at Ipswich was 20 feet above high water level and at Brisbane on the same date from 3 to 4 feet deep on wharf and in wool

Date of event	Impact
	pressing and produce stores. In Stanley Street, Town's Wharf was completely hidden by water which appeared to be half-way up posts on the wharf sheds. The Bremer at Ipswich subsided after reaching within a few feet of last great flood.
10/3/1870	Goodna: Flood waters surrounding the post office and still rising; wires submerged at the creek. Glengallan Creek very much flooded.
12/3/1870	Oxley: Fields along the banks of Oxley Creek partially devastated by floods. Ipswich: "The flood of 1864 was fully five feet higher than the present one which reached its greatest altitude during Wednesday night." (from *Queensland Times*, 12 Mar 1870, Ref 1.)
14/3/1870	Ipswich: Incessant rain; river again rose considerably.
9/4/1870	Brisbane: Heavy rains. On the 15th the Bremer rose at Ipswich until the water was 2 feet above the wharves. On the 16th the Bremer was 20 feet above the ordinary level and still rising; only the roofs of the wharf sheds visible. On the 18th rain ceased; the Brisbane River was swollen considerably.
14-18/7/1870	Heavy rains. On the 15th the Bremer rose at Ipswich until the water was 2 feet above the wharves. On the 16th the Bremer was 20 feet above ordinary level and still rising; only the roofs of the wharf sheds visible. On the 18th rain ceased; the Brisbane River was swollen considerably.
17/11/1870	Ipswich: Perfect deluge of rain in the evening and during the greater part of the night; the Bremer rose almost to the top of the sheds at the company's wharf; One-Mile Creek high. Brisbane: Heavy rain on evening of 17th over the whole of southern portion of the colony; lower parts of the town flooded; creek overflowed its banks and flooded cellars of the houses in Queen Street. Rainfall for 24 hours ending 9 am on 18th 3.66 inches; heaviest fall since floods in early part of the year.
24/2/1871	Oxley: Heaviest thunderstorm of year; creeks and roads flooded.
22/12/1872	Bremer River rose rapidly; 3 feet of water in the A.S.N. Co's sheds at Ipswich in a few hours time.
30/12/1872	Several of the cellars in Queen Street, Brisbane flooded through stoppage of the creek. Almost all rivers up country flooded during last week by heavy rains.
28/2/1873	The Bremer and other rivers much swollen owing to the continued rains; overflow at Enoggera reservoir about 14 inches above the by-wash.
1/3/1873	The Bremer rose to within a few inches of the A.S.N.Co's receiving shed at Ipswich.
17-19/6/1873	Heavy flood at Brisbane. At Ipswich one of the greatest floods experienced since 1864 occurred, and the Bremer rose 40 feet above ordinary level; eight persons and over 6,000 sheep drowned at Cecil Plains. Floods also general up country; great damage at places.
24/6/1873	The highest point reached by the flood at the Port Office in Brisbane was 3 feet 10 inches above the highest spring tides and 5 feet lower than the flood in 1864.
31/12/1873	Flood at Ipswich.
16-23/2/1875	Floods in the Kenilworth district required stock to be rescued (Ref 3).
30/8/1879	The floods reached the highest mark. Victoria Baths washed down the Brisbane River.
20/10/1882	Enoggera Reservoir in flood.
11/1882	C.B. Whish reported that 'the late floods in the Caboolture River' had washed away the northern approaches to the Caboolture bridge (Ref 3).
19-22/1/1887	Very heavy rain over Moreton and East Darling Downs divisions. Creeks in flood and low-lying ground submerged at Cryna (Beaudesert) and Fassifern. Goodna township flooded; houses under water. "The rain commenced on Wednesday January 19. During the 24 hours to 9am on Friday 21st, 2.63 inches was recorded. Between 9am and 4.30pm on the same day 6.83 inches was recorded." (from *Queensland Times*, 22 Jan 1887, Ref 1).

Date of event	Impact
	'James Hipwood, Mayor of Brisbane, requested the (Caboolture Divisional) board to advise immediate information as to the urgent wants for food and clothing through floods in the division.' (Ref 5)
22/1/1887	Railway traffic on the Southern and Western Railway suspended on account of floods. Bowen Bridge, Brisbane 5 feet under water at 5 pm, washed away at 6.30 pm.
23/1/1887	Very high flood at Brisbane. Several lives lost by drowning and a great deal of property damaged.
25/1/1887	The steamer *Barrabool* ran aground in Brisbane River and two sailors were drowned by the flood waters.
13/8/1887	Heavy rains flooded the low-lying ground in neighbourhood of Brisbane.
17/7/1889	Low lying suburbs of Brisbane flooded owing to the heavy rains; river rose to within a few inches of the flood mark of January 1887.
19/7/1889	Floods in most of the Queensland rivers south of Bundaberg. Five vessels adrift in Brisbane River. The Brisbane wharves and part of Ipswich submerged.
25/1/1890	Brisbane: Water in the river 3'4" above the height reached by the King tides; several of the wharves flooded.
10/3/1890	Floods in the Brisbane River.
11/3/1890	Owing to floods all telegraphic and postal business interrupted. Brisbane River 18' above the level of the 1887 flood.
12/3/1890	Ipswich: Height of flood above spring tides 58.48 feet; measured at high water at Bremer railway bridge.
13/3/1890	Floods subsided.
28/3/1890	Ipswich: Height of flood above spring tides 35.85 feet; measured at high water at Bremer railway bridge.
11/6/1891	Traffic on Indooroopilly ferry interrupted owing to strong fresh in the Brisbane River.
3/2/1893	Lower part of Brisbane submerged, and water still on the rise; the *Elamang* and the gunboat *Paluma* were carried by the flood into the Botanical Gardens, and the *Natone* on to the Eagle Farm flats.
4/2/1893	Disastrous floods in the Brisbane River; 8 feet of water in Edward Street at the *Courier* building. Numbers of houses at Ipswich and Brisbane washed down the rivers. Seven men drowned through the flooding of the Eclipse Colliery at North Ipswich. Telegraphic and railway communication in the north and west interrupted.
5/2/1893	The Indooroopilly railway bridge washed away by the flood. Heaviest floods known in Brisbane and suburbs.
6/2/1893	The lower part of South Brisbane completely submerged. The flood rose 23'9" above the mean spring tides and 10 feet above flood mark of 1890; north end of the Victoria Bridge destroyed.
7/2/1893	Flood waters subsiding. Sydney mail train flood bound at Goodna, unable to either proceed or return.
13/2/1893	Second flood for the year in the Brisbane River.
16/2/1893	More rain in the south east districts; another rise in the Brisbane; further floods predicted.
17/2/1893	A third flood occurred in the Brisbane River for the year.
18/2/1893	The *Elamang* floated off from the Botanical Gardens. Business at a standstill in Brisbane. Ipswich and other towns. Several deaths by drowning reported.
19/2/1893	The gunboat *Paluma* safely floated off the Gardens, and the *Natone* off Eagle Farm flats. Another span of the Indooroopilly railway bridge carried away. The third flood reached its maximum height at 12 noon, viz. 10 inches below the first flood.
21/2/1893	Flood waters subsiding.
11/6/1893	Flood waters of the Brisbane River still rising.
10/6/1893	A fresh in the Brisbane River.

Date of event	Impact
12/6/1893	Flood at Brisbane reached a height of 10 feet 10 inches above low water or 1'4" above the level of the flood of 1887; water stationary at 10 am.
(nd) 1898	'Mr Inigo Jones reported flood damage to a culvert at Coochin Bridge' (Ref 5).
28/2/1907	Brisbane: Considerable rise in the Brisbane after the recent heavy rains; immense quantities of water hyacinth washed down to the city reaches of the river.
15/3/1908	At Brisbane the river rose to 14'8 1/2" above low water springs. Serious flood at Rosewood.
March 1908	Esk: Heaviest rain and floods since 1903. All traffic practically suspended for many days. Extraordinary season. Goodna: River Height at 2 pm 15th 38'4". Harrisville creeks all bankers 13th to 17th and all low lying lands flooded. Ipswich: Bremer River in flood rose to 48'. Laidley: Excessive rains throughout district from 14th to 17th cause local floods and washaways and some damage to crops. Pinkenba floods in river, and half of Pinkenba under flood for three days. Redbank: Flood covering all low lying lands. Rocklea: Owing to heavy rains on 14th and 15th, flood prevailed in this district but did not reach quite as high as 1903 flood.
March 1910	Crohamhurst River constantly in flood. Esk: River 12' over normal. Goodna: Slight fresh during month. Cedar Pocket: Creek in a continual fresh. Harrisville: Warrill Creek in flood twice.
13/1/1911	Floods at Rosewood.
2/1913	Stanley River and creeks in the Woodford area in flood (Ref 4).
3/1914	Mary river in flood below Conondale (Ref 4).
5-10/2/1915	Two men drowned in Stanley River at Woodford.
1-4/2/1916	Local heavy flooding in Brisbane district.
11/4/1916	Stanley River flooded.
1-10/2/1922	A heavy fresh in Brisbane River.
4/2/1924	Low-lying areas of Brisbane submerged; boy drowned at Zillmere.
11/2/1924	Flooding in Lockyer district.
16-18/3/1925	The Stanley, Caboolture, Pine, Logan and Albert Rivers flooded.
18-22/6/1925	Most south coast rivers and creeks rose considerably. Flood in Stanley River. Railway line washaways and damage to bridges and roads.
1-8/1/1926	Local heavy flooding coastal districts south from Mackay and in sub-tropical interior. Numerous line washaways and several bridges damaged. Boy drowned at Ipswich.
16-31/12/1926	Flood in Stanley River disorganized traffic between Woodford and Kilcoy. Loss of stock in Brisbane River Valley.
January 1927	Local flooding during first half of month notably in Brisbane on 4th when low-lying parts under water.
15-31/1/1927	Stanley and Upper Brisbane Rivers flooded; strong fresh only in lower reaches of Brisbane but many metropolitan suburban districts submerged. Low-lying parts of Ipswich under water.
5-14/3/1927	Stanley flooded and railway line damaged between Woodford and Kilcoy.
& 24-26/3/1927	The Murrumba and Wivenhoe Bridges (Upper Brisbane) covered. Crops damaged.
1-2/4/1927	Minor flooding in several south-eastern rivers, chiefly the Stanley, Burnett, and Mary. Numerous bridges submerged; dislocation of traffic and damage to roads and railway tracks.
1-4/10/1927	Heavy local flooding in south-eastern districts, including low-lying parts of metropolis. Many bridges submerged and some damaged.

Date of event	Impact
13-22/2/1928	Floods in Stanley and Upper Brisbane very high but in metropolitan reaches of latter only moderate fresh experienced.
18-21/4/1928	Only a big fresh in lower reaches of Brisbane River, but many of the low-lying parts of the metropolitan suburbs were inundated and the damage to city streets, bridges etc. was estimated at £50,000. Lad was drowned at Graceville.
18-21/4/1929	Stanley and Upper Brisbane Rivers flooded but a strong fresh only in city reaches of the Brisbane.
2-10/2/1930	Some bridges over Stanley River submerged.
2-8/2/1931	Brisbane experienced its first flood for 23 years. Most city wharves submerged and water reached almost to Stanley Street, South Brisbane. More serious inundations in parts of suburbs, notably the Milton, Oxley, Rocklea, Fairfield and Sherwood districts. Bridges and roads in Greater Brisbane area damaged to extent of about £25,000. TC entered the Coral Sea near Cooktown and moved southward to Hervey Bay. Initially serious flooding occurred in north Queensland with one drowning. As the system moved south towards Hervey Bay, major floods developed over south-east Queensland with 1300 homes inundated in Brisbane on the 5th February. Two people drowned. A storm surge of 0.76 m was recorded on the Moreton Bay tide gauge. Most of the flooding in Brisbane was in Breakfast Creek where 1056 houses were flooded (396 above floor level). Around midday on the 5th February, before the heavy rain in the creek catchment, high tide level at the mouth of Breakfast Creek was 1.1 m above ordinary high water spring levels. The subsequent flood levels above Bowen Bridge exceeded the February 1893 flood levels. Ipswich: "From a maximum height of 47ft 6 ins about 3 o'clock on Saturday morning (February 7) the Bremer early this morning had dropped to 16ft 6 ins." (from *Queensland Times*, Mon 9 Feb 1931, Ref 1)
6/3/1931	Low lying parts of Brisbane inundated.
2/1931	The Caboolture Shire territory suffered the biggest flood ever recorded. The Waraba Creek bridge was washed away and extensive flood damage was suffered in many placed (Ref 5)
9/12/1931	Low lying suburbs of the metropolitan area were submerged. Much damage to roads and bridges, cost of repairs to latter estimated at between £2,000 and £3,000.
15-31/1/1935	Laidley Creek reached its highest level for 40 years.
4/4/1933	Man drowned in Stanley River. Low lying part of metropolis inundated and some damage to property particularly in Nundah district where several fences washed away.
11/12/1933	Some flooding of creeks in the metropolitan area; a lad drowned in Ekibin Creek.
30 & 31/1/1934	Disorganization of traffic in coastal districts south from Maryborough.
20-23/2/1934	Low-lying suburbs of Brisbane again submerged.
1-4/4/1934	Flooding in many streams between Brisbane and Gympie, submerging bridges and roads, and seriously dislocating transport services.
12/4/1934	Further flooding between Gympie and Brisbane.
21/12/1934	Some flooding of creeks and inundations of low-lying parts in the metropolitan area.
17/10/1935	Low-lying parts of Brisbane suburbs flooded, especially in Wynnum district where roads damaged to extent of about £10,000.
10/3/1937	Local flooding between Brisbane and Coolangatta.
15-20/3/1937	Low-lying parts of Brisbane and Ipswich inundated. Floods at Harrisville highest since 1911.
19-21/1/1938	Local flooding in Moreton section of South Coast division, chiefly Stanley River. Low-lying parts of Brisbane inundated.
31/1/1938	Low-lying suburbs of Brisbane submerged.
23-27/5/1938	Kilcoy isolated for few days; low-lying parts of Brisbane submerged on two occasions.
11-17/3/1939	Extensive flooding of low-lying suburbs of Brisbane.
April 1939	Local flooding in Esk district.

Date of event	Impact
5/7/1939	Some flooding in Stanley River and the adjacent reaches of the Brisbane River.
Dec 1943	At 0900 on the 30th a small cyclonic centre was indicated a little to the north of Cape Moreton. The formation of this depression was responsible for flood rains from 28th to 30th. The rain spell lasted approximately 36 hours, but fortunately eased by Monday 31st when the centre, filling in, was located 250 kilometres to the north-east of Lismore. Much flooding of low lying areas in South Moreton districts with rapid rises in creeks and main streams on 29th and 30th, but no excessive heights were reached on the Brisbane River. Local reports for 30th included Stanley River at Villeneuve - over railway bridge, Caboolture River at Caboolture Post Office — traffic bridge submerged, Pine River at Dayboro — main street under water.
January 1946	On 23rd rain stations west and south of Brisbane reported 75 to 125mm and up to 165mm (Kalbar and Laidley). These falls caused local flooding, mainly in Lockyer Creek, but main streams in the Moreton and Port Curtis districts were not affected.
April 1946	The rainfall accompanying the offshore cyclonic depression from 2nd to 5th caused moderate rises in the Mary and Stanley rivers where local flooding occurred. At Murrumba, where the Brisbane River rose over the traffic bridge on 6th, conditions were indicative of the temporary traffic dislocation which occurred in these areas.
January 1947	Flooding was particularly heavy in the Logan and Albert river basins, the highest since 1887 and 1893. At Slacks Creek, floodwaters reached telephone wires. On 25th the Logan River peaked at Dulbolla and Beaudesert and the Albert River peaked at Bromfleet and Lumeah. The following peaks were reported from the lower tributaries of the Brisbane River. Warrill Creek at Harrisville on 25th, highest since 1893, and Bremer River at Ipswich on 26th, highest since 1931.
26/1/1947	Ipswich: Bremer River in major flood, highest since 1931.
January 1951	Flooding was most severe over the South Coast Moreton where 500 to 750mm seven day rainfall totals caused strong rises in the Mary and Brisbane river systems and in other smaller coastal streams. All transport services were disrupted and low level flooding caused considerable property damage and covered all roads from Brisbane to a depth of a metre or more. Many houses were evacuated particularly in the Maroochy River districts where flooding was very severe. One life was lost at Currumundi Lake near Caloundra.
31/1/1951	Ipswich: Bremer River peaked just below major flood height, two households evacuated, widespread disruptions to traffic. Brisbane-Ipswich road closed at Woogaroo Creek. Brisbane: Brisbane River in flood, severe disruptions to road traffic, most roads out of Brisbane closed due to inundation from flooding caused by metropolitan and adjacent stream.
1/2/1951	Brisbane: Brisbane River in flood between Brisbane and Ipswich backing up creeks, flooding of low lying areas extensive. Oxley Creek 5' over Oxley road.
2/2/1951	Brisbane River flood threat did not eventuate; rain and flooding easing.
March 1955	Serious flooding was also reported in the upper Brisbane River, as well as the small coastal streams north of Brisbane, namely the Pine and Maroochy rivers, as a result of 125 to 375mm rains on 27th. Flood heights in the Brisbane River were generally the highest since 1931, resulting in moderate flooding in the lower Brisbane catchment on 29th and 30th. One life was lost. The Port Office gauge at Brisbane peaked at 3am on 30th, resulting in flooding of some low lying suburbs.
29/3/1955	Ipswich: Bremer River in major flood, severe disruption to traffic, widespread inundation of low lying areas; highest flood since 1947.
30/3/1955	Brisbane: Brisbane River in minor flood, some inundation of low lying areas. Great quantities of debris in river.
18/2/1959	Brisbane River in flood Brisbane Valley Highway cut at Wivenhoe.

Date of event	Impact
Nov 1959	Laidley: Local severe flooding resulted in 1 metre of water in some streets of Laidley, flooding business premises. Hundreds of acres of small crops were inundated in the Lockyer Valley with damage proving very costly. Marburg: Heavy flood run-off damaged three bridges, destroyed a garage and covered the western highway to in excess of 1 metre of water.
May 1960	Further heavy rain, 125 to 150mm in 48 hours, brought about flash flooding in the upper Stanley River on 26th.
February 1961	Flash flooding in the Bundamba Creek at Booval on 25th swept a car off a culvert, killing two people.
November 1961	On 17th intense one hour 75 to 125 rains in the Upper Brookfield area led to flash floods which caused destruction of roads and bridges. In the Brisbane Metropolitan area heavy rains on the 20th caused local flash flooding in many suburbs, the worst hit areas being Mount Gravatt and Sandgate. The Brisbane Valley Highway was cut between Esk and Toogoolawah, due to flash flooding of Gallanani Creek, and rail traffic was slowed because of erosion. Heavy rain in the Bremer catchment on 17th, followed by further falls in the next few days, caused a rise in the river, submerging the bridge at Rosewood for some days. Freshes in other tributaries of the Brisbane River resulted in a slight rise in the main river in its lower reaches.
March 1963	From 13th to 18th heavy rain in south-east districts produced 250mm totals with some totals up to 500mm. Local flooding and traffic disabilities were reported in the Mary and Brisbane rivers as well as the shorter Moreton streams. The Stanley River at Peachester reported peak flows as did the Brisbane River at Murrumba and Wivenhoe Bridge.
March 1967	On 18th falls of up to 150mm associated with Cyclone *Elaine* were recorded in the south-eastern corner of the State. Minor flooding and traffic disabilities occurred as a small flood moved down the Brisbane River, while the Logan River peaked at Macleans Bridge on 19th.
12/6/1967	Ipswich: Bremer River, in major flood but below 1955 levels. Brisbane: No flooding from Brisbane River itself but widespread severe local flooding from metropolitan creeks with damage estimated in the excess of $1million. Traffic at a standstill; rail traffic halted on some suburban lines. 500 people evacuated from low lying areas. Rainfalls averaging 200 to 250mm in the South Coast Moreton district during the week ending 14th resulted in moderate flooding in the Brisbane and Mary rivers and adjacent coastal streams. The Brisbane River peaked at Vernor on 12th, the highest recorded since 1955, and the Mary River peaked at Gympie on 11th, the highest since 1963. Worst flooding was in the Nerang River, which peaked at Numinbah Valley early on 12th, highest since 1954, and flooded some residential areas on the Gold Coast. Traffic disabilities occurred throughout the Moreton district, but were worst in coastal areas south of Brisbane. Serious local flooding in Brisbane itself on the night of 11th.
January 1968	Seven day totals of over 750mm were common in the headwaters of the Mary River, while slightly lower totals were recorded in the headwaters of neighbouring coastal streams and in the headwaters of the Stanley River. The Mary River peaked at Gympie on 10th, and all coastal roads from Brisbane to the north of Bundaberg were impassable to traffic for a few days as the flood peak moved downstream. Many people in Gympie and other centres downstream were forced to evacuate their homes as flood waters approached, and at least one life was lost. Slightly lower rainfalls in the Brisbane River sub-catchments other than the Stanley were sufficient to cause minor to moderate flooding in parts of the Brisbane Valley, while moderate falls on the border ranges produced only minor flooding in coastal streams south of Brisbane.

Date of event	Impact
14/1/1968	Ipswich: Bremer River in moderate flood; Moogerah Dam spills for the first time since construction, widespread traffic disabilities throughout catchment, most roads cut in low areas or by washouts.
15/1/1968	Brisbane: Brisbane River in minor flood causing some inundation of low river front reaches in the metropolitan area in conjunction with high tides and heavy local runoff.
October 1970	On Saturday 24th there was flash flooding in the Brisbane City metropolitan area in Kedron Brook and Enoggera Creek resulting in damage to furniture and fittings in private homes. Several people were drowned.
4/2/1971	Moderate to major flooding in the Bremer caused inundation of low lying parts of Ipswich. Widespread disruptions to traffic throughout the catchment area considerable damage to roads and bridges.
February 1972	During the second and third weeks of the month, major flooding occurred in the upper and middle reaches of the Mary, upper Brisbane and Stanley rivers in association with heavy rainfall from Cyclone *Daisy*. Flooding, with traffic disabilities, also occurred in Sunshine Coast streams and the Pine and Nerang rivers. Severe local flooding occurred in Brisbane City metropolitan creeks on the morning of Saturday 12th, following general falls of 175mm to 225mm in the 24 hour period.
April 1972	During the first week of the month heavy rains in south-east Queensland, associated with Cyclone *Emily*, caused moderate flooding in the Mary, Stanley and upper Brisbane rivers. Flooding also occurred in the Kolan and Curtis Coast streams, the Burnett, Albert, Logan, Nerang and Pine Rivers, and Sunshine Coast streams. There was widespread traffic disruptions in the above catchments as Easter holiday traffic returned to Brisbane. On the night of Sunday 2nd to Monday 3rd, heavy rain in Brisbane City metropolitan creek catchments caused major flooding in suburban areas, resulting in much damage to property and household furniture.
July 1973	During the period 6th to 10th, heavy rain in south-east Queensland caused moderate to major flooding to the coastal strip between Brisbane and Bundaberg. Several lives were lost. Minor flooding occurred in the Brisbane City metropolitan creeks, in particular Enoggera-Breakfast creeks and Kedron Brook, and also in the Nerang River. Major flooding also occurred in the upper Brisbane River and Stanley River, but flooding was not significant in the lower reaches.
27 & 28/1/1974	Ipswich: Bremer River reached the highest levels this century and the highest since 1893. Flood damage through the Ipswich City area was devastating, some 2,000 homes and properties were affected, many being totally destroyed, countless others were affected, many beyond repair and business, property and damage to services running into millions of dollars. Two people were drowned or killed as a result of the flooding during this period.
25-29/1/1974	Brisbane: The Brisbane River also reached the highest level this century and the highest level since 1893. Similarly to Ipswich, the lower flood prone areas suffered extreme damage; 14 lives were lost, some 8,000 householders were affected, many totally destroyed, others damaged to the tune of thousands of dollars as a result of inundation and battering from both strong currents and water borne debris. Business houses and industry generally suffered countless millions of dollars in losses due to damage to premises, stock and loss of business. Estimated damage approximately $200 million in 1974 money values.
November 1974	On 27th moderate flooding downstream from Harrisville and Rosewood in the Bremer River.
January1976	Between 20th and 23rd, stream rises and some flooding occurred in the south-east quarter, including the Brisbane and Mary rivers, from heavy rain associated with Cyclone *David*. Laidley Creek recorded a major flood in this period with flood waters entering the town of Laidley.

Date of event	Impact
February 1976	By mid month, major flooding was occurring in most streams in the Brisbane Valley, the Albert and Logan Rivers, the Macintyre, Moonie and Weir Rivers, the Condamine, Balonne, Bulloo and Paroo rivers, the Warrego, Thomson and Barcoo rivers, and Cooper Creek, plus Diamantina and Georgina rivers and Eyre Creek . Major flooding in these rivers was caused by the low pressure system formally Cyclone *Alan*.
May 1980	Most streams in the Nerang, Albert and Logan Rivers and Brisbane City metropolitan creeks reached minor flood levels on 7th and 8th. Traffic disabilities occurred through the area, especially along Oxley Creek. No damage reports were received.
November 1981	Local to minor flooding occurred in the Bremer River from 2nd to 4th and local flooding with traffic disabilities for Brisbane City metropolitan creeks on 3rd.
January 1982	Widespread moderate to heavy rainfall in the Moreton South Coast district caused local flooding in the Brisbane City metropolitan area on 21st. Minor to moderate flooding occurred in the Mary River from 21st to 25th, the coastal streams from Brisbane to Noosa on 21st, the Bremer and Warrill creeks on 21st and 22nd and the Stanley River and upper Brisbane River from 21st to 23rd.
May 1982	Moderate to heavy early morning rain in the Brisbane City metropolitan area on 30th, caused local flooding and traffic disabilities in some flood prone suburbs.
May 1983	On the afternoon of 28th moderate flooding occurred in the Bremer River with minor flooding at Ipswich the next day.
April 1984	Stream rises and local flooding were reported from Brisbane metropolitan area and the Macintyre and Dumaresq river systems on 8th due to heavy rainfall in the southeast corner. Gale force winds and heavy rainfall on 8th caused widespread electrical failures, local flooding and traffic disabilities and property damage in the Brisbane metropolitan area and the Gold Coast. Twelve people were rescued from disabled yachts in Moreton Bay and coastal waters of the Moreton Coast.
August 1985	During the evening of the 17th, thunderstorms in the Brisbane metropolitan area caused local flash flooding.
October 1985	Flooding in low lying areas of metropolitan Brisbane due to heavy rain during the morning of the 27th.
February 1988	A severe thunderstorm over Cooyar Creek catchment on the evening of Friday 12th caused the highest flood since European settlement in the township of Cooyar. Several houses and buildings were washed away and two lives were lost.
June 1988	Widespread moderate with local heavy rain on the 3rd and 4th in the South Coast districts caused moderate flooding in Warrill Creek near Amberley on the 5th
July 1988	A man drowned when his car was swept away in a flooded creek in one of the southern Brisbane suburbs.
April 1989	During the first few days of the month, the Albert and Logan rivers experienced moderate flooding, and local to minor flooding occurred in creeks in the greater Brisbane area during the same period. A renewed heavy rain period commenced in southeast Queensland on 25th causing major flooding to re-occur at Gympie on the Mary River, and in the upper Brisbane River, the Albert and Logan rivers to the south of Brisbane and other coastal streams between Maryborough and the New South Wales border. Severe local flooding also occurred in the Brisbane metropolitan area overnight on Tuesday 25th.
May 1989	Very heavy rain re-developed in the south-eastern districts during the 16th and 17th. Minor to moderate flooding was recorded in the Albert and Logan rivers, and also in the Bremer River and Warrill Creek.
February 1990	Moderate to heavy rainfall in the Brisbane Metropolitan /Sunshine Coast area on the 24th produced flooding in low lying areas of Brisbane and parts of the southern Sunshine Coast. Flooding became more extensive the next day, causing traffic disabilities.

Date of event	Impact
February 1991	On the night of Thursday 7th very heavy rain of around 200mm fell over areas of the Logan system and Warrill Creek catchments to the south of Brisbane. Three people drowned at flooded road crossings during the flash flooding that followed. Extensive damage occurred to rural properties, fencing and crops in the Boonah, Rathdowney and Kalbar areas and a school at Kooralbyn was destroyed. Flooding subsequently developed in the Logan River and record flood levels were recorded at several locations. Flooding of low lying properties, roads and bridges accompanied the flood peak. Several houses were flooded in the suburbs of Logan City in the Waterford area during the weekend of 9th and 10th.
December 1991	Severe flooding of some coastal streams occurred in south east Queensland from Thursday 12th to Saturday 14th. Areas of major flooding along the Bremer River, Bundamba and Warrill Creeks caused significant property loss and damage. In the Bundamba Creek area, forty two people were rescued from flooded homes.
February 1992	Major flooding in the upper reaches of the Stanley River occurred during Saturday 22nd and one motorist was drowned attempting to drive across a flooded river crossing.
March 1992	Major flooding occurred in the upper reaches of the Brisbane and Stanley rivers. No reports of damage were received. Minor flooding occurred in some of the Brisbane Metropolitan Creeks causing minor traffic problems.
February 1995	Rainfall around the Sunshine Coast during the middle of February caused moderate flooding in the Mary and Upper Stanley rivers to 17th.
November 1995	Moderate flooding occurred in the upper reaches of the Bremer River and Warrill Creek from the 20th to 21st but only small rises resulted in the lower reaches of the Bremer.
May 1996	Brisbane River basin: Heavy rainfalls and flooding were reported throughout the Brisbane catchment during the first week of May with widespread 7 day rainfall totals of up to 600mm. A tidal surge caused by the low pressure system and gale force winds caused higher than normal tides in the Brisbane River which also contributed to flooding in low lying areas. Runoff from the first peak in the Bremer River combined with the tidal surge and local runoff in the Brisbane City reaches caused higher than normal tides at the Port Office during Saturday 4th and Sunday 5th. The observed high tide at the Port Office on Saturday 4th at 2255 was 1.99 metres AHD (0.61 metres above the predicted tide). On Sunday 5th the high tide at 2338 was 1.94 metres AHD (0.57 metres above the predicted tide). Minor flood level at the Port Office is 1.70 metres. At Lowood the Brisbane River started to rise as floodwaters from Lockyer Creek moved downstream causing a minor flood peak of 12.26 metres at about 2100 on Sunday 5th. Downstream at the Mt Crosby Weir the flood peaked at 14.10 metres at 1200 on Sunday 5th. These floodwaters combined with runoff from the Bremer River produced a Moggill peak of about 7.10 metres AHD at about 0300 on Monday 6th. The effect at the Port Office was a height of 1.60 metres AHD (0.79 metres above predicted tide) at 1200 on Monday 6th and 1.74 metres AHD (0.40 metres above predicted tide) at the next high tide just after midnight. Flood levels at gauges on the Brisbane River downstream of Lowood during this event were the highest recorded since January 1974. They were, however, well under flood levels recorded during January 1974. For example in 1974 the height at Mt Crosby was 26.74 metres, the height at Moggill was 19.93 metres and the Port Office reached 5.45 metres AHD. During this event, inflow from the Stanley River and tributaries caused the storage level in Somerset Dam to rise from about 54% to just over Full Supply Level. Moderate flooding in the Upper Brisbane River caused the storage level in Wivenhoe Dam to rise from 57% to nearly 90%of Full Supply Level. During this flood event there were no releases from Wivenhoe Dam or Somerset Dam. Laidley Creek suffered major flooding with a major flood peak of 9.00 metres at Mulgowie on Friday 3rd. At the Showground Weir site a major flood peak of 8.25 metres was also reached on Friday 3rd. Further rainfalls in the catchment during Saturday 4th caused a second major flood peak of 9.09 metres at

Date of event	Impact
	Mulgowie on Sunday 5th. The Showground Weir peak reached 8.25 metres. Combined runoff from the Lockyer Creek and tributaries as well as runoff from Laidley Creek caused river rises on Lockyer Creek at Glenore Grove during Thursday 2nd with major flooding commencing on Friday 3rd. A peak of 13.62 metres was recorded at Glenore Grove at 0900 on Friday 3rd. Flood levels started to recede slowly at Glenore Grove during Friday afternoon and Saturday morning but started to rise again as further rainfall fell upstream and a second major flood peak of 14.30 metres was reached at 0900 on Sunday the 5th. The flood level at Glenore Grove remained above major flood height from early Friday morning till late on Sunday night. The peak of 14.30 metres is the highest flood peak at Glenore Grove since January 1974 when it reached 14.94 metres. Downstream at Lyons Bridge the flood peaked at 16.44 metres at 0900 on Sunday 5th. This was 0.10 metres below the peak of the January 1974 flood. Flooding in the Lockyer Creek catchment caused extensive crop damage. Evacuations were carried out around Laidley and in the Glenore Grove area. The Warrego Highway was cut near Glenore Grove. Numerous other roads were cut during this flood event isolating farm communities. Bremer River and Warrill Creek: With the onset of the heavier rainfall on the 1st and 2nd, runoff started in the Bremer River and Warrill Creek in the early morning of Thursday 2nd. The Bremer River at Rosewood and Walloon continued to rise during Thursday and peaked at a moderate flood height on Thursday afternoon. Renewed heavy rainfall in the area that night and during Friday the 3rd caused renewed rises in the Rosewood and Walloon areas and a major flood peak of 6.20 metres was recorded at Rosewood at noon on Friday 3rd. Downstream at Walloon a major flood peak of 8.20 metres was also recorded at noon. This peak is the highest recorded at Walloon since the floods of January 1974 when the peak at Walloon was 8.70 metres. On Warrill Creek a major flood peak of 6.75 metres was reported at Amberley at about 2100 on Friday 3rd . This peak was about 3.4 metres below the January 1974 peak. Upstream at Harrisville and Kalbar major flooding was also occurring during Friday. The combined runoff from Walloon and Amberley as well as Purga Creek runoff caused a moderate flood peak of 11.31 metres at the David Trumpy Bridge in Ipswich at 2100 on Friday 3rd. This is well below the January 1974 flood level in Ipswich of 20.70 metres. It is also below the last significant flood event during December 1991 when there was a flood peak of 13.10 metres at Ipswich. Further rainfall was reported in the catchment on the afternoon of Saturday 4th and morning of Sunday 5th with the heaviest falls in the Rosewood to Walloon area. The subsequent moderate flood peak at Ipswich was 9.85 metres at 2300 on Sunday 5th. The floodwaters in the Ipswich area during this second peak were significantly affected by backwater flooding in the Brisbane River.
February 1999	Significant river rises in the Stanley and Brisbane rivers and tributaries above Wivenhoe Dam resulted from heavy rainfall on 8th. Moderate flooding developed in the Stanley River and major flooding in the Brisbane River above Wivenhoe Dam. Releases from Wivenhoe Dam commenced on the 9th causing closures of low level crossings along the Brisbane River downstream of Wivenhoe Dam, with minor flooding between Wivenhoe Dam and Mount Crosby. The same rainfall system caused rapid rises with moderate flooding in Lockyer Creek, Warrill Creek and the Bremer River. The Bremer River at Ipswich peaked just below the minor flood height on the evening of the 9th.