Community Risk in Mackay

A multi-hazard risk assessment

by **Miriam Middelmann** and **Ken Granger** (editors)

Australian Geological Survey Organisation

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

BUREAU OF METEOROLOGY
Department of the Environment and Heritage

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

Australian Geological Survey Organisation
Executive Director: Neil Williams

ISBN: 0 642 398623

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Cities Project

Produced in conjunction with

BUREAU OF METEOROLOGY
Department of the Environment and Heritage

and in cooperation with

MACKAY CITY COUNCIL

DEPARTMENT OF Emergency SERVICES
Queensland, Australia
Emergency Services Division

CONTENTS

Figures

Tables

Plates

ACKNOWLEDGEMENTS

This multi-hazard risk study of Mackay had its origins in a chance meeting between David Ingle ('Dingle') Smith of the Australian National University (ANU) and Ian Angus (then Mackay City Engineer) at a workshop held at the Australian Emergency Management Institute (AEMI) at Mount Macedon in 1992. Dingle had expressed an interest in studying the storm tide phenomenon as an extension to his keen interest in flood impact research. Ian drew Dingle's attention to the impact of the storm tide associated with the 1918 Mackay cyclone and suggested that it would make a good point to start such research. Ian was also interested, in his capacity as Executive Officer of the Mackay Local Counter Disaster Committee, in obtaining a better understanding of the storm tide threat to Mackay.

From this fortuitous meeting emerged the study undertaken by Dingle in 1993 which was funded by the Australian Coordinating Committee for the International Decade for Natural Disaster Reduction (IDNDR). Dingle's study can be seen as being one of the key precursors to the development of the Tropical Cyclone Coastal Impacts Program (TCCIP). TCCIP activities initially built on Dingle's work on Mackay before expanding to address storm tide concerns in other Queensland centres, especially Cairns. TCCIP, in turn, had a significant influence on the development of the *Cities Project*, so, in a round about way this study (and the *Cities Project* itself), can be seen to owe its existence to that conversation around the bar at AEMI eight years ago.

This report, therefore, 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 Mackay community and Mackay City Council, in particular Mayor Julie Boyde. Of particular value was the involvement of Ian Angus and his successors as City Engineer/Director of Technical Services, John Martin and Graham Preston. Disaster Coordinator Errol Coombs and members of the Mackay State Emergency Service (SES) also provided significant support, especially during our major period of field work in 1997. We also gained significant support and assistance from Graham Smith of Council's geographical information system (GIS) Section.

At the State Government level, the project was strongly supported by the Department of Emergency Services (DES), especially the Division of Counter Disaster and Rescue Services headed by Jack Noye. Information from this study provided input to the DES *Local Government Disaster Mitigation Project* and data from that study (especially that developed on flood hazard), provided critical input to this study. This important liaison was facilitated largely by Lesley Galloway (Director of Disaster Policy and Research) and Ken Durham (Principal Policy and Project Officer). Their support and active interest is greatly appreciated. The input provided by Doug Angus (since retired from DES) during the early stages of the original Mackay work is also gratefully acknowledged.

The former Director of the Queensland Region of the Bureau of Meteorology, Rex Falls, and his staff have given outstanding support as well as direct input to this study. Bruce Harper, a consultant engineer of Systems Engineering Australia Pty Ltd., was employed by the Bureau to coordinate their input to the study. His contribution has been outstanding. He has drawn on the collective experience and knowledge of staff in the Regional Office's Hydrology Section, notably Peter Baddiley and Terry Malone, and the Severe Weather Section, especially Jeff Callaghan. The Regional Office of the Bureau has also provided invaluable support through the provision of office space and facilities for the *Cities Project* in Brisbane.

The project has also been greatly assisted and encouraged by Alan Hodges, former Director General of Emergency Management Australia (EMA) and his staff based in Canberra.

Members of the academic community have also provided great support. 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; Professor 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. Support from Andre Zerger, who was in receipt of a three year PhD scholarship from the Australian National IDNDR Committee is also appreciated. Very valuable assistance and access to research materials, especially relating to flood and storm tide, was also provided by Mike Gourlay and Jenny Hacker of the Department of Civil Engineering at the University of Queensland.

Our work was also generously supported by ERSIS 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.

Chapters 1 to 3, including the approach to the vulnerability analysis and the risk assessment process, have evolved with the *Cities Project*, especially under the Cairns case study. 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 TCCIP. It also draws heavily on the input of participants in three workshops held at AEMI 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 Dr 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 'Cairns' methodology was subsequently reviewed and subjected to a sensitivity analysis by David King, James Maloney and Colin MacGregor of James Cook University. Their greatly appreciated suggestions and advice have been taken up in this study.

Chapter 4 and Appendices E, F G and H were prepared by Trevor Jones. Ingo Hartig undertook the GIS analysis and prepared the GIS figures. Rex Bates prepared figures in the Appendices. Friedrich von Gnielinski of Queensland Department of Mines and Energy kindly provided an unpublished geological map for Mackay. Linda Foster of Queensland Department of Natural Resources (DNR) provided a comprehensive borehole database and a map of the buried surface of geological basement. George Walker from Aon Reinsurance was a valuable and cooperative source of information on building vulnerability to earthquake. Greg Reardon from the Cyclone Structural Testing Station at James Cook University provided valuable advice on the vulnerability of buildings to severe wind. John Martin, at the time from Mackay City Council, coordinated the assembly of geotechnical data. Graham Rollason from Queensland Railways provided geotechnical data. Russell Cuthbertson and Steven Jaume from QUAKES at the University of Queensland provided information from their earthquake database and information on seismograph operation. Valuable in house reviews and advice were provided by Kevin McCue, Marion Leiba and Cvetan Sinadinovski. Computer programs for processing microtremor data were written by Cvetan Sinadinovski, Vic Dent and Long Cao, who also collected microtremor data in Mackay.

Chapter 5 (compiled by Miriam Middelmann, Ken Granger, Bruce Harper, Peter Baddiley and Terry Malone) draws heavily on published material and on comments, suggestions and information provided by Mike Gourlay and Jenny Hacker of the University of Queensland. This was supplemented by recent hydrological modelling undertaken by Paul Harding of Chaseling McGriffin Pty Ltd for Hatch Associates (formerly BHP Engineering), as part of their input to the DES *Local Government Disaster Mitigation Project*. Bevan Faulkner of DNR and Noel Kidd from Ullman and Nolan Pty. Ltd. also provided valuable comment and assistance.

Chapter 6 (compiled by Ken Granger, Bruce Harper, Trevor Jones, John Stehle, Matt Hayne and Jeff Callaghan) strongly reflects input to several TCCIP workshops by many people. Particular assistance and input was received from Rex Falls and Jim Davidson of the Queensland Regional Office of the Bureau of Meteorology; David Henderson of the Cyclone Testing Station at James Cook University; and David Robinson, Michael Allen and Katrina Wilkes of the Beach Protection Authority under the Environmental Protection Agency.

Chapter 7 was prepared by Ken Granger and Trevor Jones. Dingle Smith from the ANU provided a thorough review and much valuable advice as did John Stehle and John Schneider.

The historical material in Appendices J, K, L and N were compiled by Miriam Middelmann. Appendix J captures memories of some Mackay residents of historical floods and cyclones in Mackay, and could not have been done without the willingness of the people interviewed, including those whose memories were not included in the report. Particular thanks go to John and Florence Dean, George and Bernadette Gibbs, Mick Hodge, Graham Jenner, Maude Paterson, and Lousia and John Wood, for sharing their experiences during floods and cyclones. Valuable assistance was received from the Mackay Historical Society in organising interviews, in particular, assistance was received from Enid Schmidtke, Gloria Arrow and Rose Noonen.

The historical photos (in Chapter 5 and Chapter 6 and Appendix N) draw on the collections held by the John Oxley Library and the Mackay *Daily Mercury*. The historical newspaper accounts (in Appendix K and Appendix N) draw on the collections held by the Queensland State library, Mackay *Daily Mercury*, Mackay Historical Society and the Queensland Regional Office of the Bureau of Meteorology. In particular, the willingness of the John Oxley Library and Mackay *Daily Mercury* in allowing AGSO to publish the historical material is gratefully acknowledged.

Comment on a draft version of this report was formally sought from the Mackay City Council, DES and the Bureau of Meteorology. The comments received were taken into account in the final version. An internal peer review of the report was also conducted by Marion Leiba and Kevin McCue. An external review of the report was undertaken by David Ingle Smith. All comments were valuable and greatly appreciated.

Production of the report was managed by Miriam Middelmann. GIS support was provided by Don Gordon, Ingo Hartig, Robert Lacey and Greg Scott and was managed by the *Cities Project* GIS Manager, Greg Scott.

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.

MM and KG

EXECUTIVE SUMMARY

All Australian urban communities face risks from a range of geohazards. Mitigation of these risks will improve community safety, sustainability and prosperity. However, due to the complexity of comparing the risks from different geohazards, few multi-hazard risk assessments have been attempted. This report is the second of AGSO's Cities Project multi-hazard risk assessments, and it develops further the methodology outlined in the Cairns study (Granger and others, 1999). The research assesses the risk to the Mackay community from severe winds and storm tide from tropical cyclones, flooding of the Pioneer River, and earthquakes. The report will be a valuable resource to those who are responsible for, or interested in, the management of these risks – including concerned citizens, elected officials, professional engineers, planners and emergency managers.

Approach

This study makes extensive use of AGSO's Risk-GIS method, which is a fusion of the decision support capabilities of geographical information systems (GIS) and the philosophy of risk management. The analysis of risk involves assessing the levels of hazard at Mackay, developing an understanding of the vulnerability of the elements that are at risk within the community, and synthesising a range of event scenarios. A comprehensive building database is used to generate damage assessments for the various scenarios. Each suburb is ranked for its contribution to overall community vulnerability and for its exposure to the various hazards. These two rankings determine total risk for each suburb by hazard. Finally, overall community risk from the various hazards is compared.

Results

The Mackay community has a high level of residual risk with regard to flooding of the Pioneer River. The community also has a high level of residual risk from severe wind and storm tide. Mackay has a much lesser, but significant, residual risk with regard to earthquakes.

Mackay has a moderate level of risk from hazard events that occur relatively frequently, that is, those with an average recurrence interval (ARI) of 50 years or less. Events within this range will cause some property loss and put lives at risk. However, the existing warning systems and other mitigation strategies already in place should minimise the potential loss of life and economic impact **provided the population is aware and prepared.**

Riverine flooding, cyclonic wind and storm tide events with an ARI of 100 years or more will inevitably cause significant economic harm and potentially some (possibly significant) loss of life. In these rarer and more extreme events, the loss of critical facilities and the impact on specific community functions such as business activity, especially in Central Mackay, North Mackay, Mackay Harbour, Paget and West Mackay, will add to the magnitude of the risk posed directly by the hazard event itself. These secondary risks are likely to have an effect for a considerable period of time after the initial impact and will significantly increase direct economic and social costs. Consequently, the community will be faced with a long recovery and restoration period. This is especially significant given the Mackay community's heavy reliance on disaster-sensitive industries such as agriculture and tourism.

The older areas (suburbs of South Mackay, Central Mackay, Andergrove, North Mackay, West Mackay, Slade Point and East Mackay) are most vulnerable and most at risk to the impacts of floods, cyclones and earthquakes. The suburbs of Bucasia and Beaconsfield are at significant risk from wind, storm tide and earthquake but not flooding.

Floods in the Pioneer River pose the greatest geohazard risk to Mackay. In the ARI = 100 year scenario (which sets the minimum floor level for new buildings), 18% of all buildings would have overfloor flooding, producing moderate or more severe damage and possibly structural failure.

Numerous key facilities would be exposed to inundation. The likelihood of levees being overtopped and/or breached is high. Evacuations would need to commence well before the water reached the top of the levees in order to minimise the risk to human life and property losses.

Severe wind and storm tide from tropical cyclones pose equal second in there risk to Mackay. Under an event with ARI = 1000 years (the design event for wind), almost 50% of buildings would suffer moderate or more severe damage. Modern design standards for wind-resistant buildings have provided an effective form of mitigation. However, older buildings (which comprise about two-thirds of all buildings in Mackay) are not constructed to these standards and they constitute a major source of residual risk.

As with floods in the Pioneer River, the risk of severe damage to buildings and structural failure from storm tide is high. The potential for loss of life from the rarer, more severe events is high. A storm tide scenario with a 100 year ARI (which sets the minimum floor level for new buildings) indicates that 10% of all buildings would have overfloor flooding, causing moderate or more severe damage and the possibility of structural failure.

Earthquakes also pose a significant risk to Mackay, though this threat is not well recognised. For a 475 year ARI scenario (as specified by the Australian earthquake loadings standard), about 16% of all buildings are expected to sustain damage, although about three-quarters of this damage will be slight. Electric power distribution, medical facilities and commercial businesses are especially at risk from earthquake in Mackay.

The Mackay community appears to accept a moderate level of risk for relatively frequent hazard events (ARI of 50 years or less) due to many factors including familiarity with their occurrence. **Increased community awareness regarding the possible impact of rarer, more severe hazard events could improve the public's understanding of risk, thereby making mitigation strategies easier to implement.**

CHAPTER 1: URBAN GEOHAZARD RISK ASSESSMENT

Ken Granger

This Report

This report provides details of a study of the risks faced by the Mackay community that are posed by a range of natural hazard phenomena. In this case study, the hazards addressed include earthquake, flood and severe wind and storm tide associated with tropical cyclones. It has been developed as a primary resource for those who have a responsibility and interest in the management of those risks. These span a very wide spectrum and include individual concerned citizens, elected officials, professional engineers, planners and emergency managers. The report should be seen as the first step in the process of comprehensive community risk management.

This is the second 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*. We see it as providing the foundation on which the Mackay community can build its 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 Cairns (Granger and others, 1999).

Community risk research on Mackay commenced in 1993 under an United Nations International Decade for Natural Disaster Reduction (IDNDR)-funded project, undertaken by Mr D.I. ('Dingle') Smith of the Australian National University (ANU), with a particular focus on the risks associated with storm tide inundation (Smith and Greenaway, 1994). That work was subsequently extended under the Tropical Cyclone Coastal Impacts Program (TCCIP) in 1995. This effort has provided an ideal base on which to develop the wider community risk research described in this report.

We encourage readers to view this report as a starting point, rather than an end in itself. Indeed, in June 1999, work commenced on a study of Mackay aimed at identifying and testing specific mitigation strategies to address inundation hazards in Mackay as part of a project funded by the Queensland Department of Emergency Services (DES).

The *Cities Project* case studies represent pioneering research. As such they will undoubtedly change as better information, techniques and tools develop. We are confident that this study is as accurate, scientifically sound, realistic and practical as it can be made at this stage in the evolution of 'risk science'. We welcome feedback on any aspect covered in our reports.

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 forms a significant part of Australia's contribution to the IDNDR which has run throughout the 1990's. It can also be seen as a response to the findings of the 1993 Senate Inquiry into Major Disasters and Emergencies (Senate, 1994). These findings encouraged the emergency management community to modify its doctrine from one that has 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. To provide a realistic focus to the research, and to achieve practical outcomes, the *Cities Project* is using a series of geohazard risk case studies based on Queensland centres to develop and test its science and techniques.

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

Our view of 'geohazards' is deliberately very broad and includes ***all earth processes with the potential to cause loss or harm to the community or the environment***. Whilst our focus is mainly on the potentially fatal acute geohazards such as earthquakes, landslides (not a significant issue in Mackay) and inundation, the importance of insidious geohazards such as acid sulphate soils, coastal erosion, reactive soils and dry land salinity, is also recognised. This study, however, only deals with the acute geohazards.

Such a broadly-based program of research obviously requires a multi-disciplinary approach. To enable AGSO, a traditionally-focused earth science research agency, 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, Mackay City Council, DES, Mines and Energy and Natural Resources, and researchers involved in the TCCIP, a multi-agency and multi-disciplinary research program coordinated by the Bureau of Meteorology. The risk management approaches adopted under both the *Cities Project* and TCCIP are essentially identical.

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, 1999). The generic guide provides the philosophical framework within which the *Cities Project* studies are developed. That process is outlined in Figure 1.1.

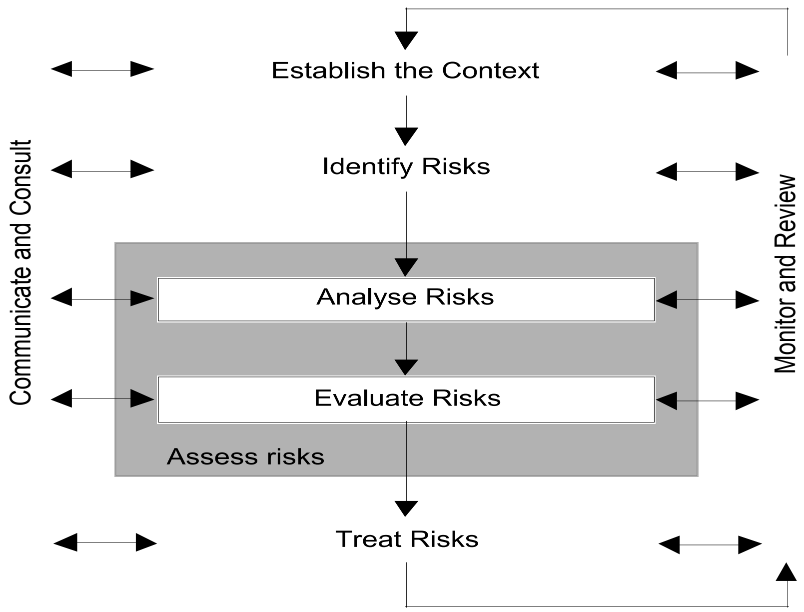


Figure 1.1: Risk management overview (Standards Australia, 1999, Figure 3.1.)

This study deals largely with the risk identification and risk assessment (i.e. risk analysis and risk evaluation) stages of the process. Whilst we provide some opinion on matters relating to risk treatment, these are the responsibility of those, such as the Mackay City Council 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 too general for our purposes, consequently we have chosen to follow the conceptual basis 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.

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 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 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.

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 maintains collections on severe weather events such as cyclones and floods, and the insurance industry maintains some data on the loss associated with such events. Throughout this report we provide details of the known history of hazard impacts in Mackay. This history is not only important in establishing levels of probability for future events, but also to illustrate that such threats are very real.

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 50 weather radar sites (including one on Mount Bassett at Mackay) and 389 automatic weather stations, and uses 1532 telemetred river height stations. The Bureau also takes data from the Japanese Geostationary Meteorological Satellite 48 times a day in addition to data taken from the polar orbiting United States National Oceanographic and Atmospheric Administration (NOAA) satellite.

Risk Analysis

Australia and New Zealand Standard *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 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 microtremor response. 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 a wide range of the elements that are at risk within the community e.g. the people, buildings and infrastructures. It involves disciplines as diverse as geography, demography, psychology, economics and engineering. It is in this aspect that the synergy between the *Cities Project* and TCCIP has been most effective, given that the elements at risk are common, regardless of the hazard involved.

A significant effort has been made to assemble very detailed data on the principal elements at risk in the built environment of Mackay, whilst comprehensive statistics of good resolution are available from the quinquennial national censuses to provide at least basic measures of human vulnerability. We have collected data for the five broad elements at risk in Mackay (which we refer to as the "five esses") including:

The Setting. Basic regional data has been accumulated from a very wide range of custodians for themes including the physical environment (climate, vegetation, geology, soils, land use, topography, elevation, etc), 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, at work and at play, vary considerably in their vulnerability to different hazards. A range of information relating to their construction is required. These building characteristics contribute to the relative degree of vulnerability associated with exposure to a range of hazards. In Table 1.1 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.

A database containing such details on some 20 700[2] individual buildings in Mackay has been developed.

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	*****	****		****	***

Table 1.1: Relative contribution of building characteristics to vulnerability

Access to shelter is also significant, so information on mobility within the community is needed. Details of the capacity and vulnerability of the road network, for example, have been acquired.

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 has been accumulated on all of these, as well as on the enterprises that wholesale, distribute and service these sectors (such as transport, material handling equipment and storage). All of the key facilities in Mackay have been identified in the *BUILDING* database (Appendix B). Apart from basic data on the key above-ground elements of the power and water supply, telecommunications and sewerage infrastructures, no detail of the lifeline networks has been available.

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, nursing homes, industries, commercial premises, agricultural land use, ambulance stations, fire stations, police stations and works such as flood detention basins and levees. Also important are socio-demographic and economic issues 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

[2] Initial collection of these data in the old Mackay city area south of the Pioneer River was undertaken by Mr D.I. 'Dingle' Smith of the ANU in 1993 under a grant from the Australian Coordinating Committee for the IDNDR. The remainder, mainly to the north of the Pioneer River, together with some update work in the area to the south, was undertaken under the *Cities Project* in 1997 and 1999.

activities and so on. Some of these may be measured in terms of the facilities that they use, such as churches 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. It is necessary, therefore, to develop appropriate models to fill the knowledge gaps. The behaviour of some hazards, such as floods, have an established body of modelling research behind them, whilst others, such as cyclones and earthquakes are, as yet, less well served.

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 most of our findings as anything more than *indications* of what the future may hold.**

The synthesis of data and the essential mapping of the spatial relationships between the hazard phenomena and the elements at risk requires the use of tools such as geographic information systems (GIS). In the work undertaken in the Mackay case study, at least 90% of the information used has some form of spatial content. Similarly, the relationships that are most significant in risk analysis and risk assessment are largely spatial. To accommodate this spatial emphasis, the *Cities Project* makes extensive use of GIS tools and technologies.

Whilst GIS have been used over the past decade as tools to address specific aspects of the risk management problem, especially in hazard mapping and the spatial modelling of phenomena such as bushfires or storm tide inundation, there are few examples of integrated risk management applications. There are obvious advantages in developing a fusion between a philosophy of risk management and the power of GIS as a decision support tool, hence *Risk-GIS*, as it has been christened in the *Cities Project*. As such, *Risk-GIS* provides the analytical 'engine' which drives the *Cities Project's* urban geohazard risk assessment process. *Risk-GIS* also provides a most potent form of risk communication through its capacity to provide a visual representation of risk situations. All of the maps and many of the diagrams and tables included in this report are output from the *Risk-GIS*. A more detailed discussion of *Risk-GIS*, the data used and the information infrastructure that supports it, is given in Granger (1998).

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 Mackay, for example, how can you realistically determine what level of risk is acceptable?

Levels of acceptability are, however, built in to such things as urban planning design constraints and the Australian Building Code, where criteria are based on design levels. 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 Mackay, for example, there is a strong spatial correlation between the areas that are most at risk from major inundation hazards (river flooding, storm tide and tsunami) and those in which sediments are most likely to maximise earthquake impact. Additionally, the impact on the Mackay 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 probable earthquake event, however, may have a greater potential for catastrophe, than the maximum probable cyclone.

The ultimate responsibility for determining what levels of risk are acceptable or tolerable rests with the Mackay community and the Mackay City Council.

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 hazards that can literally be seen coming, such as cyclones, floods and severe storms. 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 city. 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 ultimately will 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 sphere of activity of the *Cities Project*, our experience in working with emergency managers and others to date suggests that amongst 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.

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. They can also vary considerably over time. The threshold of acceptance is typically much lower immediately <u>after</u> 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 the formulation of 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.

There is little doubt, however, that the experience of the cyclone that killed at least 30 people in 1918 and the devastating flood of 1958 have both established a strong degree of risk awareness and commitment to risk reduction in Mackay. There are, nevertheless, pressures to develop areas which appear to have potentially high exposure to hazard impacts such as the East Point Spit and the area along Goosepond Creek. On the one hand the frame of reference is conservative and risk averse; on the other, the frame of reference is set more by the desire for profit/prosperity than sustainable community safety.

The key components of the *Cities Project's* understanding of the risk management process are illustrated in Figure 1.2.

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

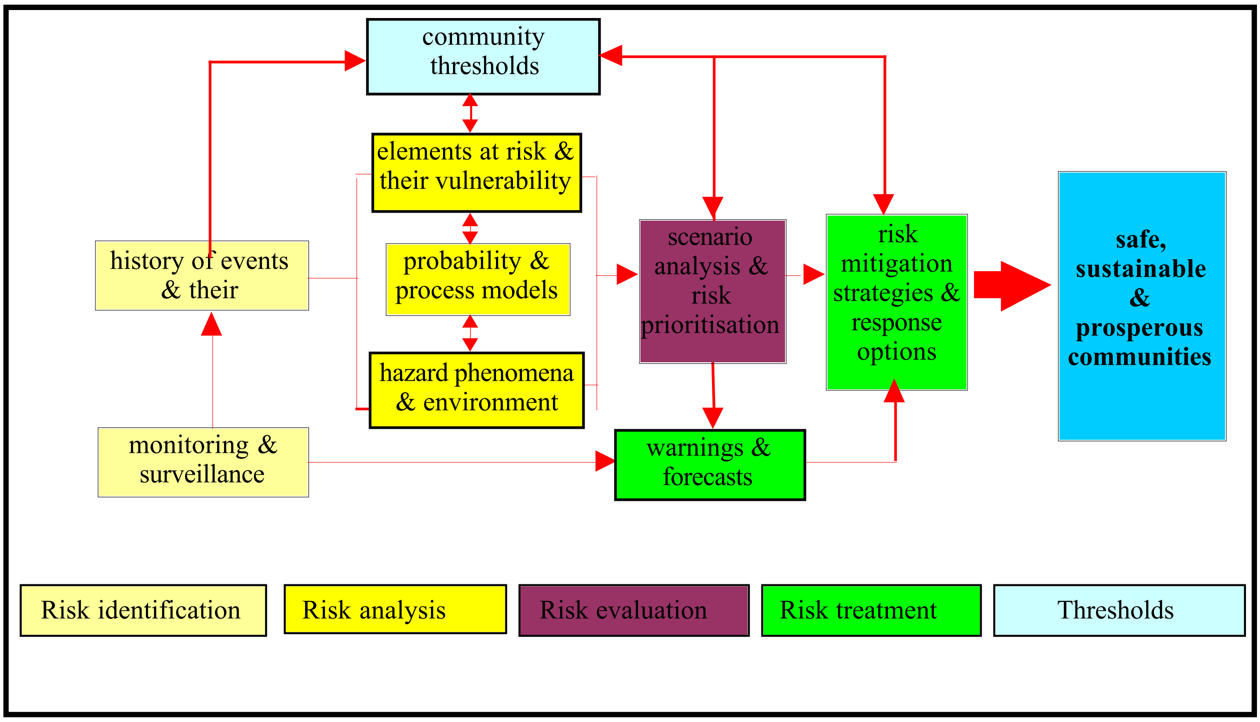


Figure 1.2: *Cities Project* interpretation of the risk management process

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 and a good number of external reviewers with appropriate local knowledge and experience.

The allocation of event probabilities is an area of particular uncertainty. A common description of event probability is the 'return period' of a particular phenomenon, for example, 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, 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 the following table (Table 1.2) to illustrate probabilities related to the chance of one or more events of a given magnitude occurring in a given time frame. In Table 1.2 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 1.2: Probability of one or more events in a specific period
(Marion Leiba, personal communication, 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)

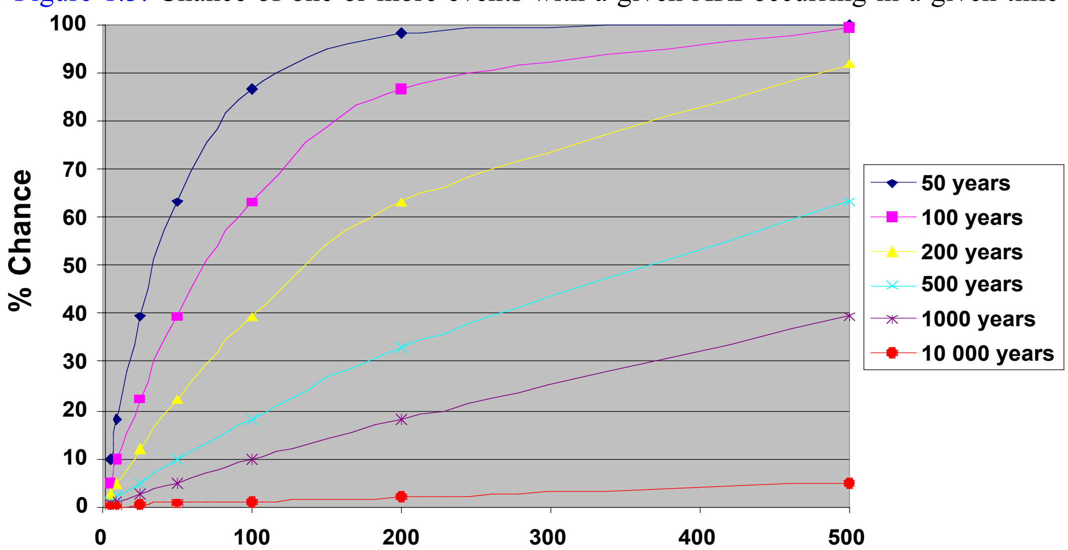
Similar information is shown graphically in Figure 1.3.

With this approach, it is much easier to see that short term risk, for example that 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 (up to 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 Mackay. The record of earthquakes, floods and cyclones extends over a little more than 100 years. For the first 75 years or so of that time there was minimal instrumental measurement except for floods. Many of the smaller or more distant earthquake events have undoubtedly gone unreported.

The absence of what might be termed 'absolute knowledge' 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.

Figure 1.3: Chance of one or more events with a given ARI occurring in a given time frame



CHAPTER 2: THE MACKAY SETTING

Ken Granger and Trevor Jones

Introduction

Mackay, in Central Queensland, is one of the State's larger regional cities. It lies, roughly mid way between Brisbane and Cairns, being some 800 km in a direct line, or 970 km by road, from Brisbane.

The 2890 km^2 area administered by Mackay City Council has a resident population of approximately 71 400. The Mackay urban area which is the focus of this study, occupies around 240 km^2 and is home to around 59 000 people. The city is predominantly a transport, education and service centre for a large sugar and grain growing district, with a major coal export terminal at Dalrymple Bay/Hay Point. Mackay is also the gateway to the tourist resorts on the southern islands of the Whitsunday Group. For the neighbouring council areas of Mirani (about 5100 people) to the west, Sarina (9400 people) to the south, and Whitsunday (18 300 people) to the north, Mackay is the major centre. These jurisdictional boundaries are shown in Figure 2.1.

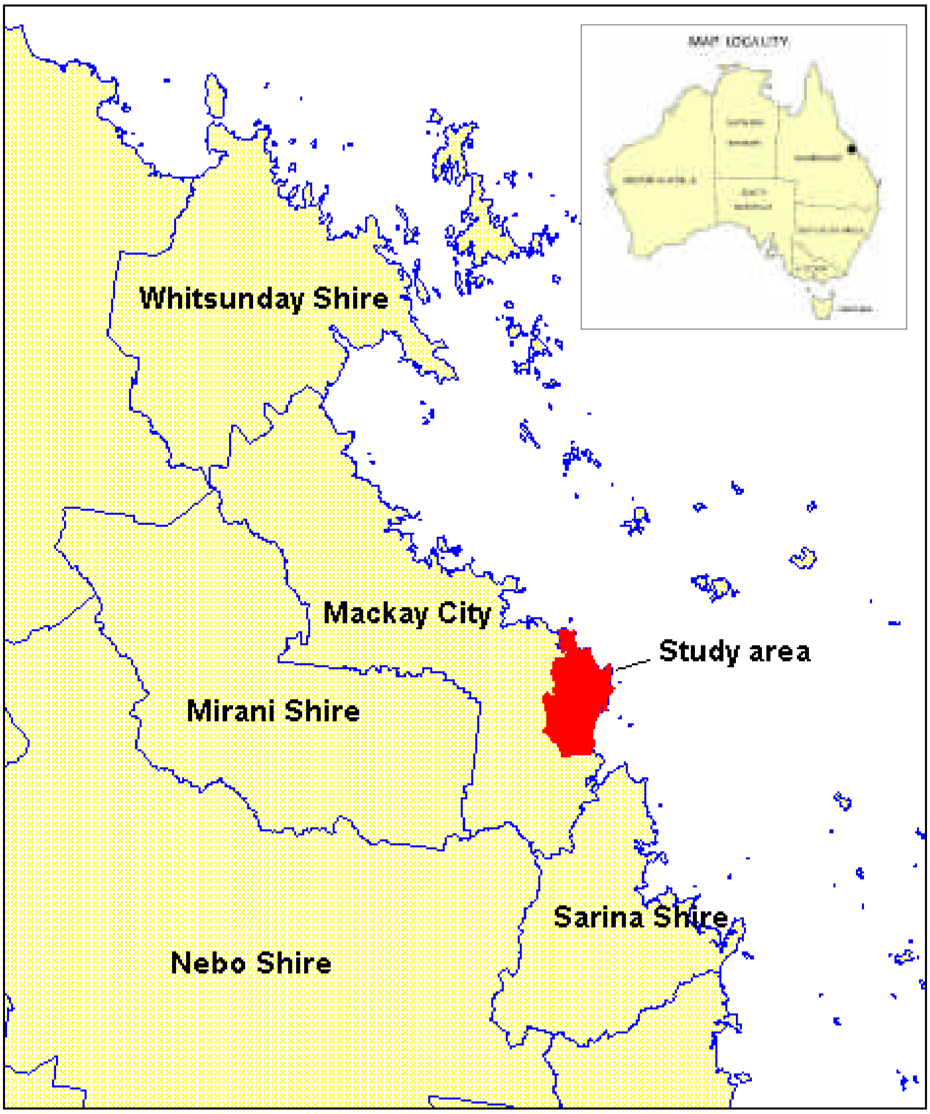


Figure 2.1: Mackay study area location

The Physical Setting

Topography: The entire study area is low-lying, with an average elevation of less than 10 m above the Australian Height Datum (AHD), with the low hills of Mount Bassett (approximately 30 m above AHD) and Mount Pleasant (about 60 m above AHD) as the main features of relief. In the original area of urban development, south of the Pioneer River, the average elevation is around 6 m above AHD and ranges from less than 4 m above AHD at the airport to a little over 11 m above AHD at the Mackay Base Hospital. A high resolution digital elevation model (DEM) of the study area, derived from large scale photogrammetric work completed by Whitsunday Surveys Ltd and enhanced by Andre Zerger as part of his PhD research at the ANU, is available.

The dominant topographic feature of the study area is the estuary of the Pioneer River. The Pioneer River, which has a catchment of about 1500 km^2, has been described by Gourlay and Hacker (1986) in the following way:

> *…the Pioneer is a most unusual river, for three main reasons:*
>
> *i. its unusually straight course;*
> *ii. the rocky nature of so much of its bed, especially in the lower reaches;*
> *iii. the irregular nature of its watershed.*
>
> *All this is best explained if the Pioneer River is considered to be a vigorous youthful river which is developing along a zone of geological weakness, the Pioneer lineament.*

The other drainage features in the study area consist of small short streams, such as McCreadys Creek, which flows into Slade Bay; Goosepond Creek, which joins the tidal Vines Creek before entering Bassett Basin near the mouth of the Pioneer; and Bakers Creek, which enters the sea to the south of the airport (see Figure 2.2).

The immediate offshore topography and tidal regime is also highly significant to an understanding of the nature of hazards in Mackay. The sand banks of the Pioneer sediment fan extend offshore almost to Flat Top Island, 2.5 km offshore, south to Bakers Creek, and well to the north in Slade Bay and Sunset Bay.

The tides in the area have the greatest range on the east coast of Australia, being a maximum of 6.7 m at Mackay, and as much as 9 m at the head of Broad Sound, 150 km to the south. High tide also occurs about two and a half hours later than high tide at Bundaberg to the south or Cairns to the north.

Various studies indicate that this phenomenon is caused by a resonant amplification of the semidiurnal lunar tide produced by a combination of the very dense nature of the Great Barrier Reef opposite Mackay, the dimensions and geometry of the lagoon between the mainland and the Reef and the spacing of gaps in the Reef. Put simply, the normal astronomic tide is retarded by the reef and concentrated through the channels including the Capricorn Channel to the south, Hydrographers Passage off Mackay and the Flinders Passage to the north. The delayed tidal flows from north and south combine in the Broad Sound-Mackay area to create the very large tidal range. Key tidal statistics are given in Table 2.1.

Table 2.1: Tidal planes at Mackay outer harbour relative to AHD (Queensland Transport, 1997)

Tidal Plane	AHD (m)
Highest astronomical tide	3.47
Mean high water springs	2.34
Mean high water neaps	1.12
Mean sea level	0.05
Mean low water neaps	-1.00
Mean low water springs	-2.22
Lowest astronomical tide	-2.94

Geology: Mackay is situated in a tectonic province of the northern New England Fold Belt called the Connors Arch. The Connors Arch largely comprises silicic volcanic rocks and granites of a Late Devonian to Early Carboniferous age originating in an Andean-type volcanic arc. The oldest Connors Arch volcanics erupted about 350 million years before present. The Connors Arch is flanked to the east by the Yarrol Province and to the West by the Bowen Basin.

Researchers from the Queensland Department of Mines and Energy (DME) and the Australian National University (ANU) have used new remote sensing technologies and traditional fieldwork to reinterpret the geology of Mackay under the South Connors-Auburn-Gogango (SCAG) Project. Their preliminary interpretations and a 1:250 000 scale preliminary geological map of the Mackay-Saint Lawrence region have been published (Hutton and others, 1999a; Hutton and others, 1999b).

In the Mackay-Saint Lawrence region, major geological units trend northwest, parallel to the coastline. Mapped lineaments and faults, including several in the Mackay study area, follow this trend or, alternatively, trend northeast at right angles to the regional trend. No major fault or lineament is mapped coincident with the Pioneer Lineament. That is, the Pioneer Lineament does not appear to be associated with a major geological or tectonic boundary.

Faults oriented 'favourably' (i.e., at right angles) to the maximum principal stress in the rocks are candidates for possible re-activation by a future earthquake. However, for Mackay, as for almost everywhere else in Australia, we have no evidence that any particular fault can be considered seismically active, nor that any one will be seismically active in the foreseeable future. Therefore, we largely discount the importance of mapped geological faults as indicators of the sites of future earthquakes affecting Mackay, and have not included them on the geological map (Figure 2.3).

The Mackay study area features several geological units. The Permian (age about 290 million years before present) Carmila Beds underlie parts of several northern suburbs including North Mackay, Nindaroo and Beaconsfield. They contain volcanic rocks at the base (up to 30 m thick), overlain by conglomerates (up to 40 m thick), sandstones, siltstones, mudstones and shales.

Rocks of the Yarrol Province are the oldest in the study area. Late Devonian to Early Carboniferous volcanic rocks of the Campwyn Beds (age about 350 million years before present) crop out in coastal headlands in northern parts of the study area such as Slade Point and Shoal Point.

Cretaceous diorite (Cretaceous Period: 65 to 141 million years before present) occurs in the western part of the study area in the largely rural suburbs of Farleigh, Richmond and Glenella.

Of more importance to earthquake hazard in Mackay are the extensive alluvial, estuarine and beach Quaternary sediments, deposited in the past 1.8 million years, that cover more than half the study area, especially in the southern and eastern suburbs. The vast Quaternary floodplain of alluvial sands, silts and clays from the Pioneer River extends under all southern suburbs. Broad sequences of Holocene (geologically recent; the past 10 000 years including the present) beach sands, fore-dune deposits, estuarine sediments and Pleistocene dunes (age between 10 000 years and 1.8 million years) are also found in the coastal suburbs. Sediment thicknesses reach 40 m South of the Pioneer River and probably about 30 m North of the Pioneer. Von Gnielinski has prepared a preliminary 1:100 000 scale geological map of Mackay, part of which is reproduced in Figure 2.3. We are grateful for permission to use this unpublished material.

Climate: Mackay lies on the coast of Queensland at approximately 21^{o} south latitude and consequently has a moist tropical climate. Rainfall is seasonal, with the heaviest rain occurring during the summer months. Extreme rainfall events are associated with tropical cyclones. Mackay comes under the influence of tropical cyclones on average at least once every two years, though 'direct hits' by severe tropical cyclones are less common.

Temperatures rarely exceed 35.0°C or go below 10.0°C for extended periods.

The main climatic statistics are summarised in Table 2.2.

Table 2.2: Selected climatic statistics for Mackay for the period 1950 to 1999 (Bureau of Meteorology 1999a)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (°C)	30.0	29.5	28.5	26.6	24.1	21.9	21.2	22.4	25.1	27.3	29.1	29.9	26.3
Mean min temp (°C)	23.5	23.3	22.2	20.0	17.2	13.7	12.8	14.0	16.5	19.5	21.7	22.9	18.9
Highest daily temp (°C)	37.2	38.7	34.7	33.8	29.2	29.1	29.7	29.3	32.3	34.9	34.9	39.4	39.4
Lowest daily temp (°C)	17.2	17.8	13.1	12.0	7.1	4.6	3.8	5.0	7.9	10.6	14.9	15.3	3.8
Av. rainfall (mm)	285	306	281	148	111	60	42	36	16	37	85	192	1598
Highest 24hr rain (mm)	286	303	389	125	178	110	170	99	32	103	165	314	389
Av. daily sunshine (hrs)	8.5	7.7	7.5	7.2	6.9	7.6	7.8	8.7	9.5	9.4	9.5	8.9	8.3

Vegetation: Within the study area there is very little natural vegetation left, other than mangroves and coastal saline marsh vegetation in the tidal creeks and flats, and pockets of *Melaleuca*-dominated wetland vegetation. The study area was originally covered by an open forest of eucalypts, palm thickets and grassland, however, this has long since been cleared for agriculture (predominantly sugar cane cultivation) and urban development.

Settlement

The present-day boundaries of Mackay City Council were established in 1995 following the amalgamation of the former local governments of Pioneer Shire and Mackay City. The area covered by this study includes all of the significant urban areas extending from the suburb of Shoal Point in the north to the settlement of Bakers Creek in the south. This area, and the suburban boundaries used throughout this report, are shown in Figure 2.4.

An excellent history of the Mackay district is provided by Kerr (1980). The following highlights are worth noting. European settlement of Mackay was established in 1862 by pastoralist John Mackay who had 'discovered' the Pioneer River in 1860 during an expedition to find good pasture land. He named the river after himself, however, it was subsequently found that Commodore Burnett of HMS *Pioneer* had already used that name on a stream near Rockhampton, so he suggested that the name be changed to 'Pioneer', even though his vessel had never entered the river. Mackay overlanded 1200 head of cattle from Rockhampton to the first property in the district at Greenmount, some 19 km from the present day city that bears his name. Mackay's cattle property was subsequently supplied by sea, using the banks of the Pioneer River estuary as the port.

The settlement grew rapidly in its early years. The first post office was opened in 1863; the first land sales were also in 1863; and sugar was introduced from Java in 1865. By 1883 there were at least 25 sugar mills operating in the district and by 1902 most of the sugar lands had already been settled.

Until the post-World War II era, urban development was largely confined to the south bank of the Pioneer River and on Slade Point. Since then, growth has steadily increased to the north of the river, especially in the Andergrove-Beaconsfield area.

Population

According to the National Census taken in September 1996, the population of the Mackay Statistical Local Area (SLA – i.e. the full local government area) was 71 894 (35 935 males and

35 959 females). Of this total, 5708 were recorded as ‘visitors’, of whom only 412 (7%) were from overseas. The study area contained 58 850 people (29 174 male and 29 678 female, including 4381 visitors).

Population density varies across the study area with the most densely populated neighbourhood (as represented by the census collectors districts - CCD - used in the 1996 census), with 3280 persons per square kilometre, in the centre of Slade Point. The lowest densities are in the rural and urban fringe areas, with the lowest density being nine persons per square kilometre in the rural neighbourhood that separates Bakers Creek from the main urban area of the city. Figure 2.5 shows the relative population densities across the study area.

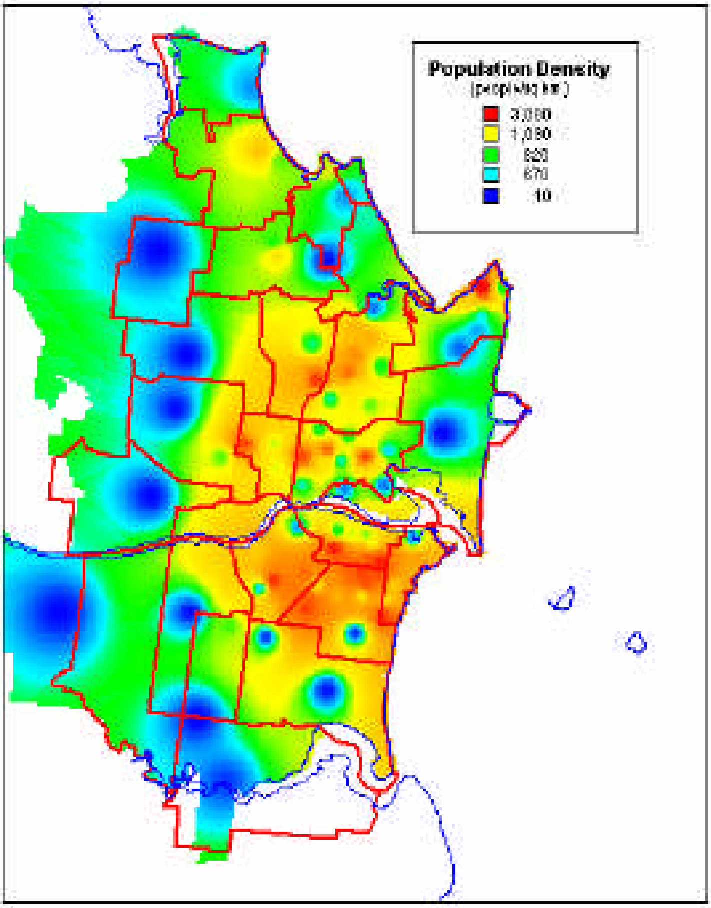


Figure 2.5: Mackay population density (people/sq km)

The gender balance also varies greatly across the study area, ranging from 73 males to every 100 females in one neighbourhood in West Mackay (dominated by a nursing home), to 156 males to every 100 females in a neighbourhood in Central Mackay (dominated by a Catholic boarding school for boys). The distribution of gender ratio is illustrated in Figure 2.6.

The age/sex structure of the Mackay City resident population is shown in Figure 2.7 compared to the makeup of the Queensland population as a whole. The similarity between the two structures indicates that Mackay is an ‘average’ Queensland community in terms of age structure.

Growth of the Mackay population is shown in Figure 2.8.

It is evident from the population data that the old Mackay City area had effectively reached its capacity by 1975 and that subsequent growth is accounted for by the redevelopment and densification of older areas. The urban area to the north of the Pioneer River (in the former Pioneer Shire area) is now the centre of growth.

Mackay is not a self sufficient community. It depends very heavily on outside sources of supply for its energy, material requirements and much of its food. Such dependence clearly imposes limits to the community's resilience to recovery from hazards.

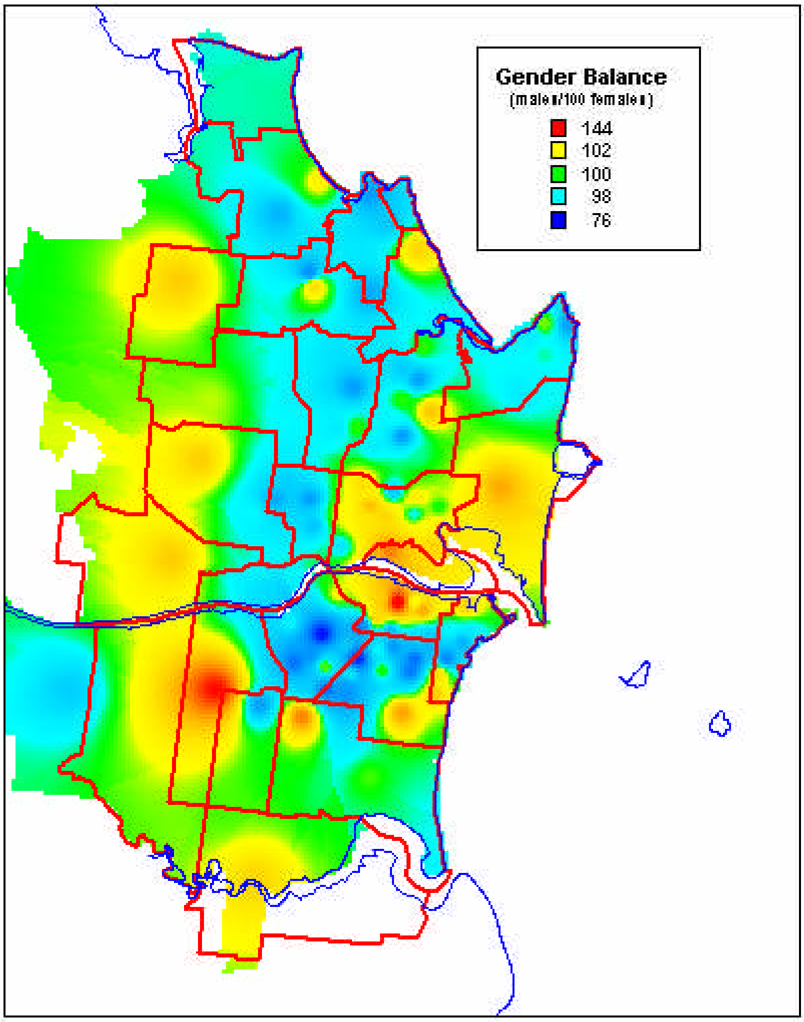


Figure 2.6: Mackay gender balance (m/f)

Mackay is heavily reliant on its transportation links to the rest of the world. They are:

- the main road links which include: to the south, the Bruce Highway to Brisbane (971 km) and beyond; north to Cairns (735 km) and beyond; and to the southwest, the Peak Downs Highway, to Clermont (274 km) and beyond;
- the main-line rail link south to Brisbane and north to Cairns provides regular passenger and freight services. The freight yards and railway station are located in Paget. A short spur line also links Mackay with the sugar centre of Marian in the lower Pioneer Valley. An extensive network of cane tram lines also exists throughout the district. A high-capacity line also links the coal fields as far west as Blair Athol (north of Clermont) with the major coal terminals at Dalrymple Bay/Hay Point (30 km south of Mackay and outside the study area);

- the airport, located just north of the mouth of Bakers Creek in South Mackay, has around 4600 domestic services per annum, making it the fifth busiest airport in Queensland after Brisbane, Cairns, Coolangatta and Townsville (ABS, 1999); and,

- the Port of Mackay provides berths for general cargo, containers, bulk grain, tankers discharging both oil and LPG and a bulk sugar terminal (Plate 2.1). A commercial fishing base and a marina catering for charter vessels and other small craft are also located within the harbour. Some fishing vessels and pleasure craft use moorings in the Pioneer River below the Forgan Bridge. In 1996-97 the Port of Mackay loaded 1.7 million mass tonnes of cargo (mainly sugar, grain and molasses) and discharged 0.6 million tonnes (dominated by petroleum products and bulk fertilisers). The Dalrymple Bay/Hay Point coal loading complex is the largest in Queensland and loaded 46.6 million tonnes in 1996-97, the greatest throughput of all Queensland ports (ABS, 1999).

Power supply for the Mackay area is drawn from the State grid. The closest base-load power stations are at Stanwell (near Rockhampton) and Gladstone, each situated around 450 km to the south of Mackay. Stanwell power station is operated by Stanwell Corporation Limited (a state-owned enterprise), whilst Gladstone power station is operated by the private company, NRG. The major transmission lines of the State grid are operated by Powerlink Queensland, whilst power distribution within the Mackay region is managed by the Mackay Division of Ergon Energy - both are state-owned enterprises.

Water supply is drawn largely from the Dumbleton Weir which was completed in 1983. This low concrete weir is located at Dumbleton Rocks and marks the limit of tidal influence on the Pioneer River, about 16 km upstream of the city.

The key terminal facilities that provide an interface between the study area and the rest of the world are shown in Table 2.3.

Table 2.3: Terminal facilities

Facility	**Suburb**	**Direction**
Ampol fuel depot	Mackay Harbour	import
Boral gas depot	Mackay Harbour	import
BP fuel depot	Mackay Harbour	import
Bulk grain terminal and loaders	Mackay Harbour	export
Bulk sugar terminal and loaders	Mackay Harbour	export
Container wharf	Mackay Harbour	import & export
Mackay airfield	South Mackay	import & export
Mackay airport terminal facilities	South Mackay	import & export
Mackay radio telephone station	Mount Pleasant	import & export
Mackay substation	West Mackay	import
Mackay telephone exchange	Mackay Central	import & export
Mobil fuel depot	Mackay Harbour	import
Rail-freight yard	Paget	import & export
Railway station	Paget	import & export
Shell fuel depot	Mackay Harbour	import
Tourist jetty	Mackay Harbour	import & export
Water treatment plant	West Mackay	import

Suburbs and Names

Suburb and locality boundaries throughout the Mackay City council area have recently been formalised. Whilst these boundaries and the suburb names are based on agreed perceptions of ‘community interest’, there is significant potential for confusion with historical or general place names. For example, the name ‘Mackay’ is used in many contexts including the urban centre, a suburb, the district, the former and present local government area.

To reduce the potential for confusion in this study, the following conventions will be followed:

- the former (pre 1995) ‘Mackay City Council area’, namely the urban area south of the Pioneer River, will be referred to as ‘Old Mackay City’;
- the urban area north of the Pioneer River that was within the former ‘Pioneer Shire Council area’ will be referred to as ‘Old Pioneer’;
- the current council area will be referred to as ‘Mackay City’;
- the suburb which has been gazetted as ‘Mackay’ will be referred to as ‘Central Mackay’; and,
- the study area covered by this report will be referred to as the ‘Mackay study area’.

Because of the significant mismatch between the CCD and suburb boundaries in the study area, it has not been possible to develop comparative statistics at the suburb level. In this study, the statistics used to measure community vulnerability in Chapter 3 have been developed at the CCD level and displayed with the suburb boundaries overlain to provide the more widely understood spatial reference. Aggregated vulnerability profiles have, however, been developed at the suburb level.

Figure 2.2: Mackay (1993 aerial photo)

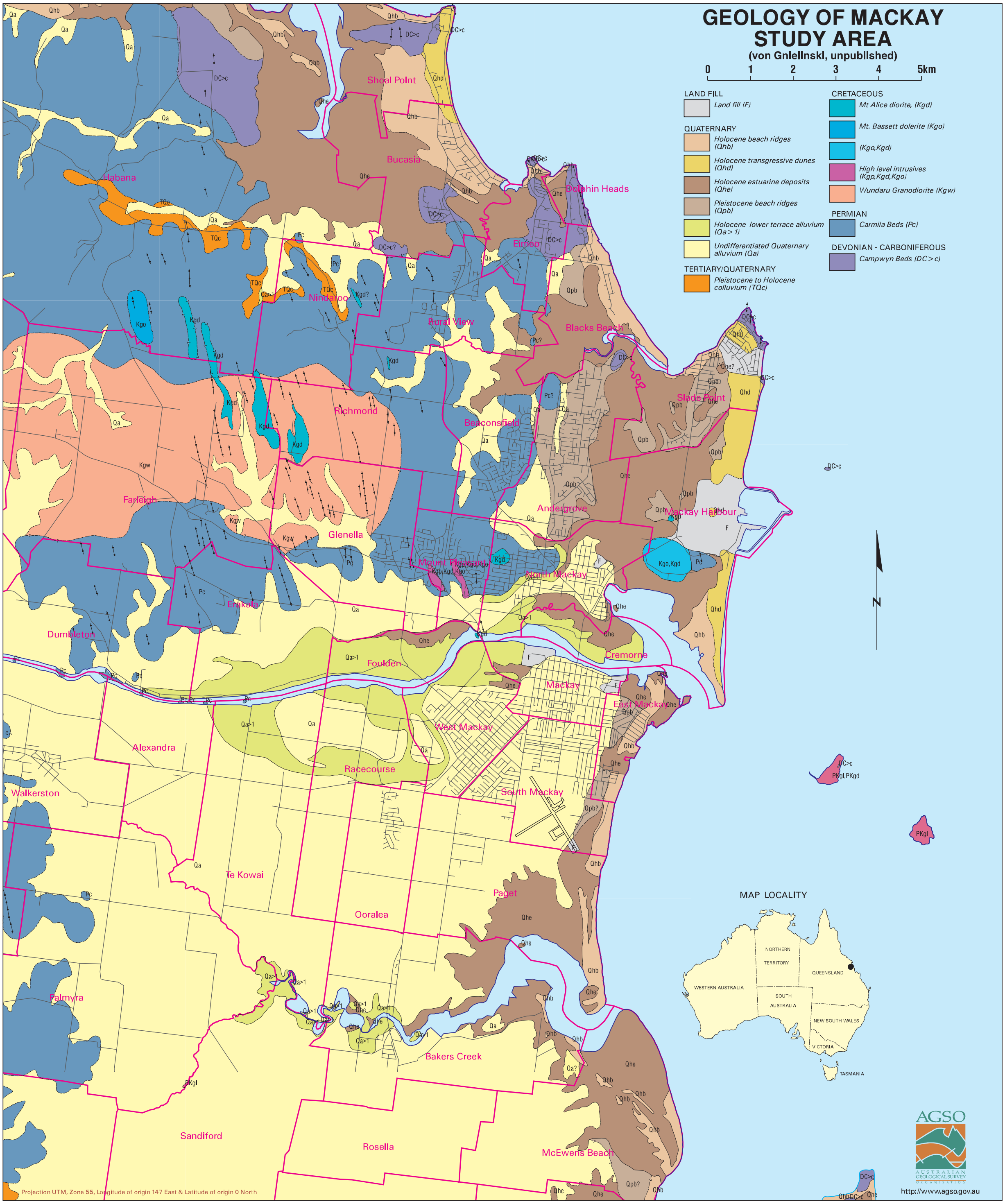


Figure 2.3: Geology of the Mackay study area

Figure 2.4: Mackay study area suburb locality map

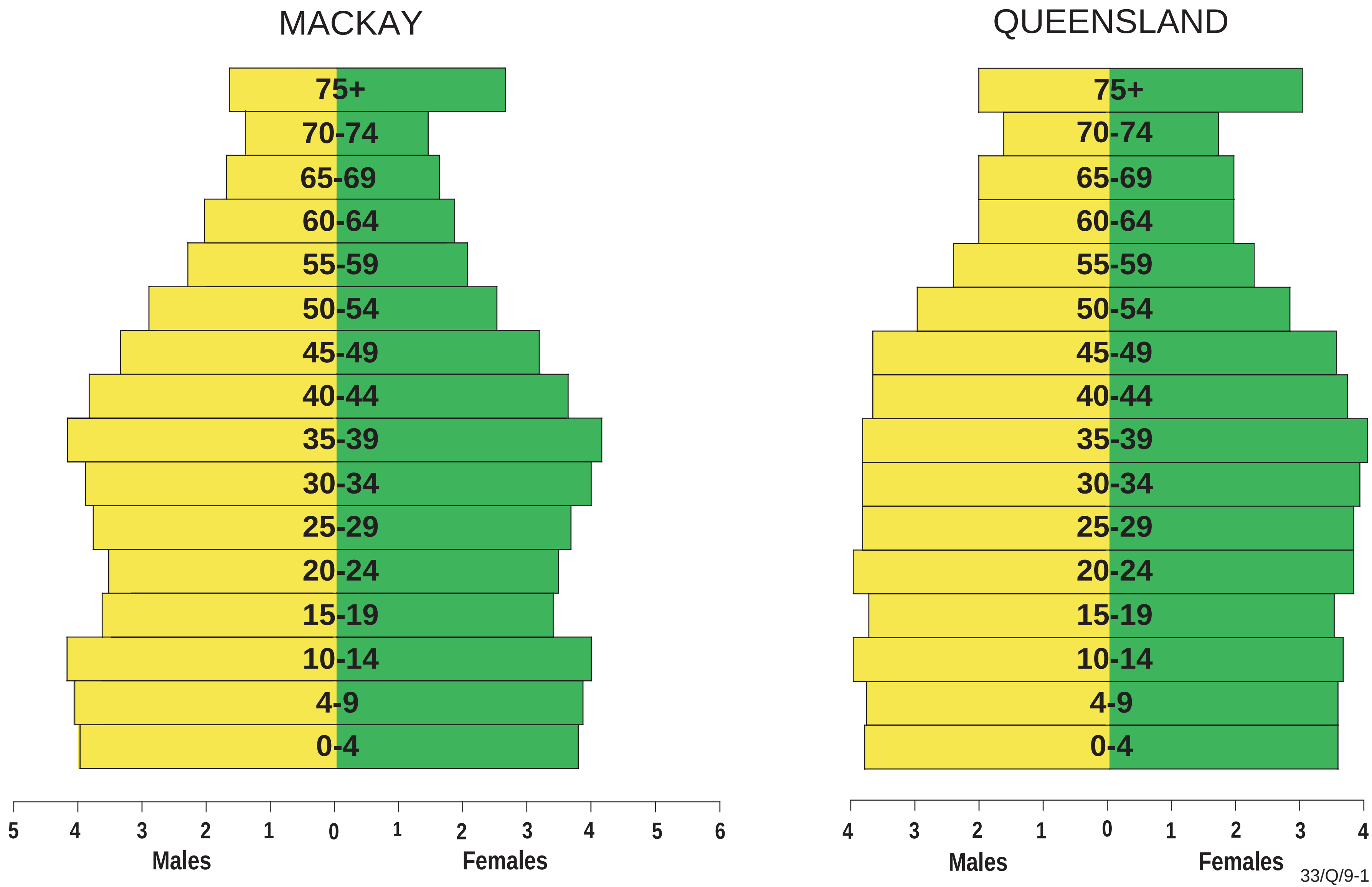


Figure 2.7: 1996 Mackay and Queensland population age/sex structure (% of total population) in five year cohorts (based on ABS, 1998a)

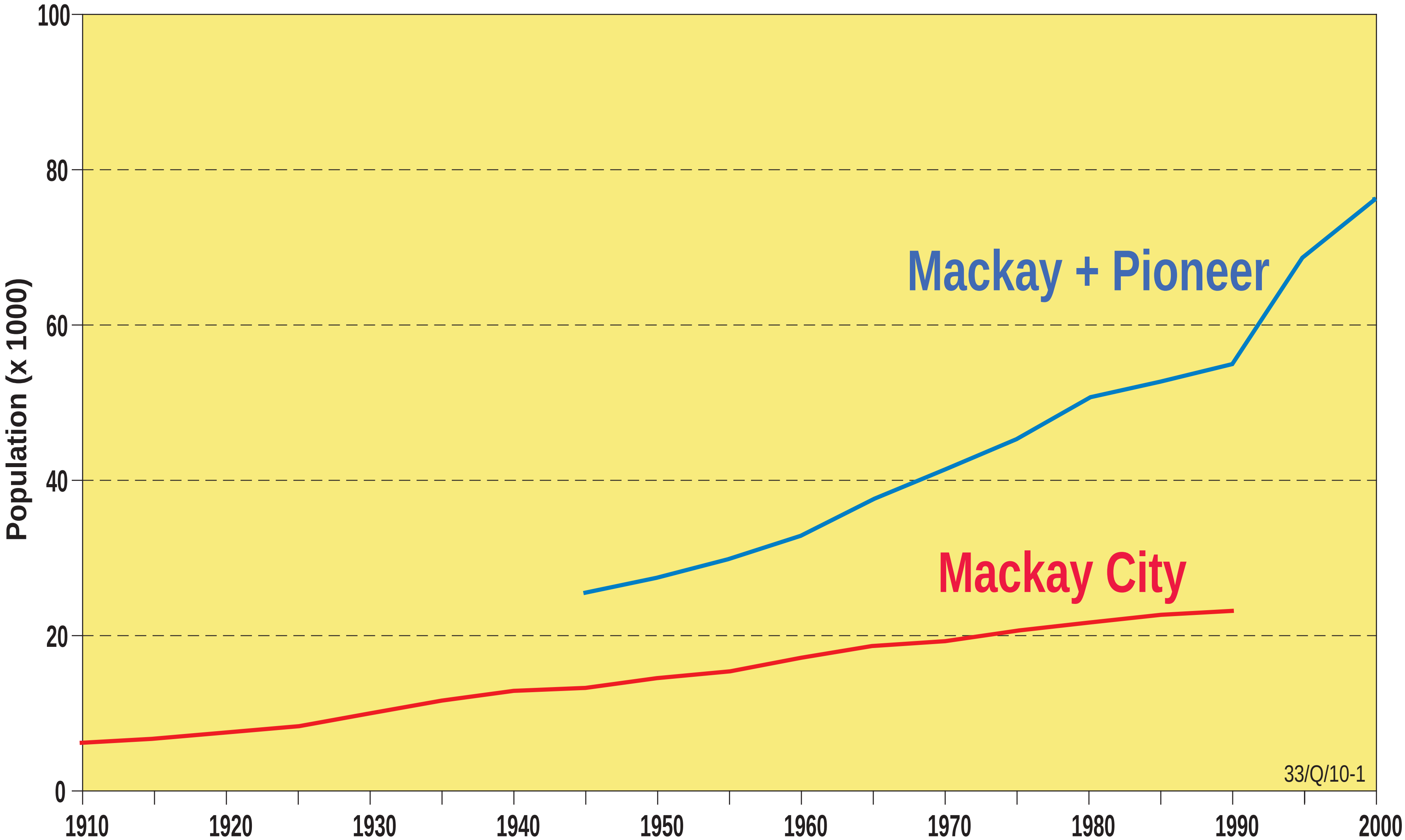


Figure 2.8: Mackay resident population growth 1910 to 2000 (source various ABS Bulletins)

Plate 2.1: Mackay Harbour - Mackay bulk sugar terminal
Collection: Miriam Middelmann

CHAPTER 3: THE ELEMENTS AT RISK AND THEIR VULNERABILITY

Ken Granger

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 Chapter 2. In this chapter we describe the key aspects of the remaining four groups.

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 database containing details of the use and structural characteristics of around 20 700 individual buildings in Mackay has been developed. For convenience, this mass of detail has been summarised down to the suburb level in the Tables 3.1 and 3.2. The format and content of the *BUILDING* database are described in Appendix B.

Table 3.1 provides the suburb-by-suburb tally of the uses to which buildings are put. It should be noted that the numbers relate to individual buildings. This differs from most published statistics. With census data, for example, the number of ‘flats’ relates to number of individual dwelling units (i.e. individual flats) rather than buildings; in industry statistics, figures typically relate to the complete enterprise or facility. Around 91% of the buildings in Mackay are residential (houses, flats and commercial accommodation), though the distribution is uneven across the study area, as shown in Figure 3.1.

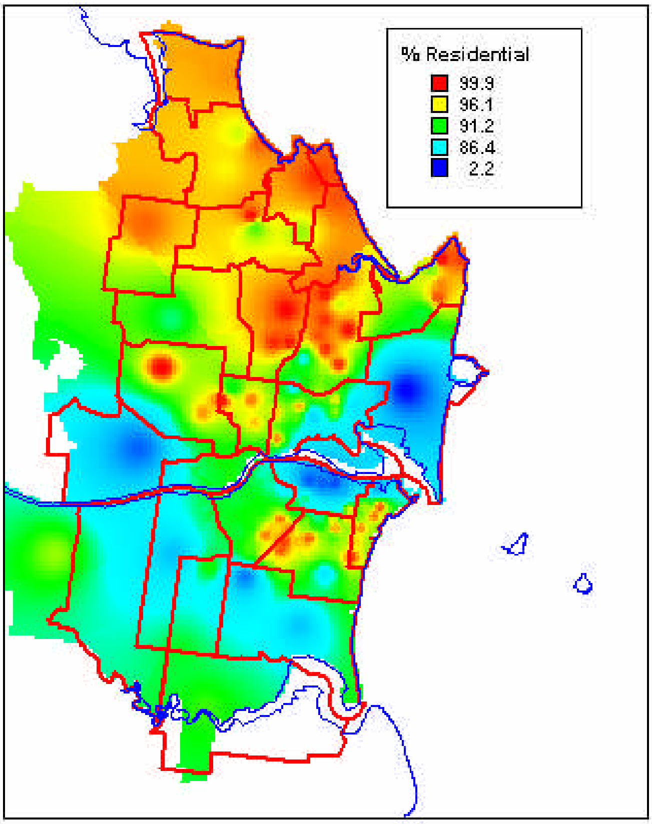


Figure 3.1: Proportion of residential buildings by CCD

Floor height is seen as a strong indicator of building vulnerability, not only for inundation hazards, but also for earthquakes. The detailed data show that some 77.4% of all buildings are built on a slab (notionally 0.3 m above ground level); 8.0% have suspended floors of less than 1.0 m above the ground; and 14.6% have suspended floors that are 1.0 m or more above ground level. The high-set 'Queenslander'-type houses are typically found in the older suburbs such as East Mackay, North Mackay, Slade Point and West Mackay. In these older suburbs, many high-set homes have had what was originally the under-floor area developed for additional living space and are now regarded as being multi-story on a slab. This type of house is referred to in Chapter 4 as 'soft story'.

The overall proportions of wall material are given in Table 3.3.

Table 3.3: Wall materials of buildings in Mackay

Material	**Houses %**	**Flats %**	**Other %**
Brick	44.8	64.2	24.5
Concrete block	3.5	8.2	27.3
Timber	21.8	8.9	5.5
Fibro	28.2	18.0	14.4
Metal	1.7	0.7	28.2

Roof material for both houses and flats is overwhelmingly metal (typically the classic corrugated iron) at 92.1%, with tile (7.0%) and fibro (0.9%) making up the remainder.

The general style of housing contained in each suburb strongly reflects the period of development of each suburb. In the older suburbs 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 (Plate 3.1 and Plate 3.2). In these older suburbs, however, there has been a significant degree of re-development with many of the original houses replaced by blocks of flats and other higher density developments.

This is in strong contrast to houses in the more recent suburbs which are almost universally on a slab, have walls of brick (or concrete block) and large areas of glass (Plate 3.3 and Plate 3.4). Roof forms are predominantly gable ended and typically have a much lower pitch than those in the older suburbs. Brick walls are most common in suburbs developed since the 1960's. The majority are likely to be of brick veneer construction, rather than 'solid' or cavity construction. Brick veneer became an accepted construction method in Queensland in the late 1950s and has been the predominant brick form since then.

Another distinct house type, probably constructed by the Housing Commission, is found mainly in the older parts of suburbs such as Andergrove and Beaconsfield. This type is high set, with fibro walls and low pitched metal clad gable roof and small windows (Plate 3.5). The lower level of these houses, which contains the garage and laundry, appear to have been enclosed by fibro-sheeted walls as standard, though the lower levels in some of these houses have subsequently been upgraded to provide living space. It is this style of house that accounts for the relatively large proportion of fibro-walled houses in Mackay.

The pattern of urban growth in Mackay over the past 80 years is reflected by the growth of the street network and can be seen in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6 and Figure 3.7. These maps have been compiled from a range of sources including historic maps and aerial photography.

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 proportions of buildings included in the Mackay *BUILDING* database, built before and after 1983, are as follows:

Pre 1983	66%	Post 1983	34%

Current residential growth in Mackay is predominantly to the north in the Andergrove and Beaconsfield areas and along the northern beaches.

Mobility: The ability of people to get to and from shelter is almost as significant as the shelter itself. Mackay has a well developed urban road network. This network is mostly bitumen sealed and apart from potential flooding of low culverts, it is an all-weather network. In the study area there are 30.2 km of highway (Bruce Highway and Peak Downs Highway); 44.9 km of urban main roads; 30.5 km of suburban access roads, and 511.3 km of suburban roads. Maintenance of the roads in the study area is largely the responsibility of Mackay City Council from its depots in West Mackay and Andergrove. The Department of Main Roads, which is responsible for the Bruce and Peak Downs Highways, has depots at Bakers Creek and West Mackay.

Passenger transport in Mackay is based largely on the family car. Mobility is, consequentially, very heavily dependant on household access to private cars, of which there are an estimated 30 000 in the study area. Households without access to a car are consequently considered to be more vulnerable than those with access. Figure 3.8 shows the distribution of households with no access to a car.

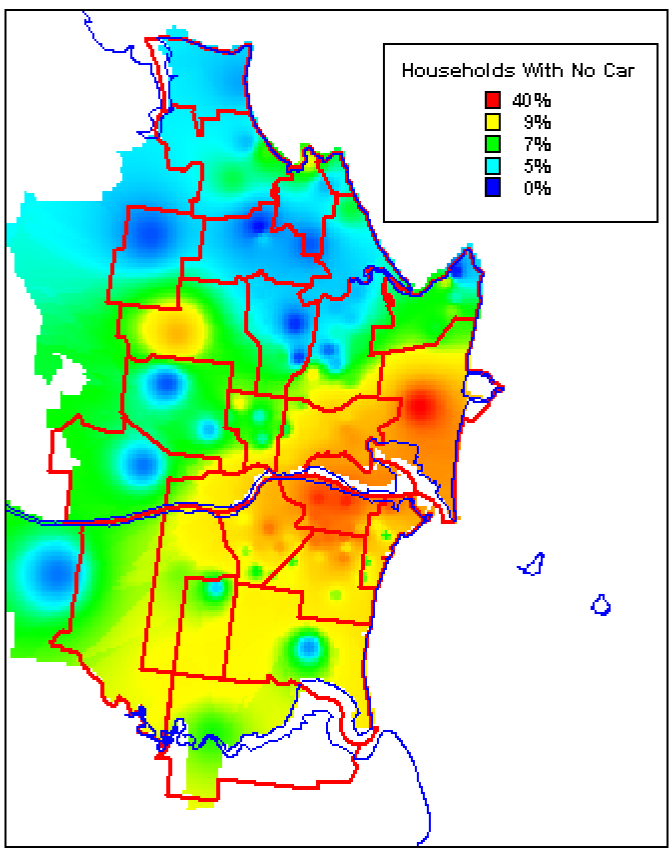


Figure 3.8: Proportion of households with no car (ABS, 1998a)

The highest proportion of car-less households is 36 out of the 91 households (40%) in the CCD that covers the suburb of Mackay Harbour, whilst the lowest proportion is three households out of 311 (1%) in one of the CCDs in Beaconsfield

This dependence on the private car is quantified in Table 3.4 which shows the proportions of travel mode used to get to work in Mackay 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.

Table 3.4: Mode of travel to work in Mackay (ABS, 1998a)

Mode	Number	Percent
Bus	133	0.5
Taxi	151	0.6
Car driver	15 716	62.2
Car passenger	2203	8.7
Motor bike	391	1.5
Bicycle	747	3.0
Walk	787	3.1
Worked at home	1127	4.5
Did not go to work	2933	11.6
Other modes (eg boat)	632	2.5
Not stated	427	1.7

Because Mackay serves as an entry point for tourists going to resorts in the Whitsunday Islands, the city has available large numbers of coaches, taxis, hire cars and other passenger vehicles. A scheduled bus service provides coverage of most suburbs.

Sustenance

The Mackay community is 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 their own right. There is, however, a very significant degree of interdependence as illustrated in Table 3.5. 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.

	Power	**Water**	**Sewer**	**Comms**	**Road**	**Rail**	**Bridge**	**AirFld**	**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**			
AirFld									
Port									

Table 3.5: Interdependence of lifeline assets (developed from Granger, 1997, Table 2)

Power supply and telecommunications 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 Mackay power supply is from the power stations near Rockhampton and Gladstone, lying some 500 km to the south of Mackay. Transmission lines operated by Powerlink bring that supply to the city via three sub stations, at Beaconsfield, Central Mackay and West Mackay.

During the crushing season, the sugar mills in the Mackay area, such as the Racecourse Mill on the western outskirts of the study area, produce surplus power from their bagasse-fuelled steam generators. This surplus power is provided to the State grid. Outside the sugar-crushing season these generators would be available, however, they would need to be fuelled by very expensive oil.

Ergon Energy manages reticulation within the Mackay urban area. The Ergon depot is located in West Mackay. No details of the power reticulation infrastructure within the Mackay study area were available at the time of writing, though observation indicates that it is overwhelmingly above ground.

Water supply: The bulk of the Mackay water supply is drawn from the Dumbleton Weir and treated at the plant on Nebo Road, West Mackay.

Distribution to consumers is by gravity feed from at least ten reservoirs and water towers throughout the study area. Details of the water reticulation network were not available for this study; however, we estimate, given the history of urban growth, that more than half of the water reticulation network is constructed of brittle material (asbestos-cement or cast iron). This type of pipe is likely to be particularly prevalent in the older areas of the city and in the larger trunk mains. The more modern segments of the network probably employ ductile material such as PVC.

Sewer: Most of the Mackay study area is connected to the reticulated sewerage network. The main sewerage treatment plant is located on the southern slopes of Mount Bassett. There are at least three sewerage pumping stations throughout the study area to cope with the low-lying terrain. Sewage is aerated at each of these pumping stations using liquid oxygen. Again, details of the reticulation network were not available, however, like the water supply network, much of it would be of brittle material such as earthenware or cast iron.

Mackay City Council, from their depots in Andergrove and West Mackay, maintain both the water supply and sewerage systems.

Telecommunications: Much of the telecommunications network infrastructure operated by Telstra in the Mackay study area (both copper wire and optical fibre) is underground, though network details were not available for this study. A major microwave relay station/terminal operated by Telstra, is located on Mount Pleasant. Details of the infrastructure operated by Optus were also unavailable.

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. The main Telstra exchange is located on River Street in Central Mackay, with a second exchange on the Bruce Highway at Paget. The Telstra service depot is located in Prospect Street, East Mackay.

Both ABC and commercial broadcast radio and TV services covering the region are provided from studios in the city.

Dedicated telecommunications networks serving both public (e.g. police, emergency services, Council, etc) and private users (e.g. taxis, couriers, fishing fleet, etc) cover the study area, many of them using the Mount Pleasant site for their transmitters.

Logistic support: The supply and distribution of goods such as food, fuel 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.

Food supply and distribution is obviously of great significance. Apart from small quantities of fruit and vegetables, meat and seafood, very little of the food consumed in Mackay is grown or processed locally. There is, consequently, a significant reliance on imported foodstuffs or raw materials such as flour. The bulk food storage, such as cold stores and grocery warehousing, and food processing facilities are concentrated in the suburbs of Central Mackay, Mackay Harbour, North Mackay and Paget. Regional shopping centres (Canelands Plaza in Central Mackay and Mount Pleasant Shopping Centre in Mount Pleasant), suburban shopping centres with smaller supermarkets or convenience stores, as well as smaller bakeries, butchers, green grocers, and so on, as well as local 'corner stores', service most suburbs. The levels of stock of basic foodstuffs held are not known.

Bulk fuel and gas storage facilities are also concentrated in Mackay Harbour (Plate 3.6), with secondary (essentially operational) storage of specialist products at facilities such as the airport (avgas and jet fuel) and some of the larger industrial and transport depot facilities (mostly diesel). Retail distribution of motor fuel is effected through more than 35 service stations, mostly located along the main access roads such as Nebo Road/Bruce Highway. There is no reticulation of gas in Mackay, so supply is provided in bottles or to bulk 'bullet' tanks. Distribution is, consequently, largely by dedicated tanker trucks. The capacity of bulk storage for most products is believed to be sufficient for approximately three weeks of normal usage. Tankers typically provide resupply by sea from Brisbane and/or Sydney.

Most other bulk storage and distribution centres for products as diverse as cement, agricultural chemicals, pharmaceuticals, raw sugar, molasses, ethanol, timber and hardware, as well as transport and handling equipment (fork lifts and cranes), are also concentrated either close to the port in Mackay Harbour, or the rail-freight facilities in Paget. Significant amounts of freight, including foodstuffs and goods such as pharmaceuticals, are also handled through the Mackay Airport in South Mackay.

Limitations: Due to the lack of adequately detailed data, it has not been possible to model lifeline vulnerability in this study. Further work is required to improve the detail on lifeline infrastructures and logistic resources to develop a better understanding of their vulnerability and their significance to the overall vulnerability of the community.

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 Mackay.

Health: The key health facilities in Mackay are the Mackay Base Hospital in West Mackay, the Mater Hospital in Central Mackay and the Pioneer Valley Hospital in Mount Pleasant. There are also four nursing homes. These include the Northern Heights Nursing Centre in Glenella, the Palliative Care Unit at the Mater Hospital in Central Mackay, Resthaven in North Mackay and the St Vincent de Paul Home in West Mackay. There are plans to relocate the Mater Hospital from its congested site in Central Mackay to a green-field site near the western end of the Ron Cam Bridge in North Mackay.

A wide range of private specialist medical practices, including pathology, surgery, and medical imaging are located within a few blocks of the Mater Hospital. Medical centres and individual general medical practices are spread throughout the city. Services such as physiotherapy, dental, podiatry, chiropractic, optometry and chemists are available throughout the study area. Community health services, such as Blue Nurses, which also operates a day respite care centre near the airport, are also available.

The age make-up of the population is a reasonable indicator of the health vulnerability of the community, with the very young (under five years) and elderly (over 65) considered to be the most vulnerable groups. The relative distribution of these age groups is shown in Figure 3.9 and Figure 3.10 respectively (see also Figure 2.7). These maps show the distribution at the CCD level.

The distribution of under five-year olds is clearly dominant in the newer suburbs such as Andergrove in the north, and Racecourse and Ooralea in the south. The CCD, which covers the suburb of Mackay Harbour, has the highest proportion of people less than five years (15.6%). The long-stay caravan park that is contained within the CCD probably accounts for this.

By contrast, the distribution of the elderly is concentrated in the central areas of East Mackay, Central Mackay, North Mackay and West Mackay, where the retirement villages and nursing homes are concentrated. The greatest proportion of elderly is 30% in the West Mackay CCD that contains the St Vincents Home.

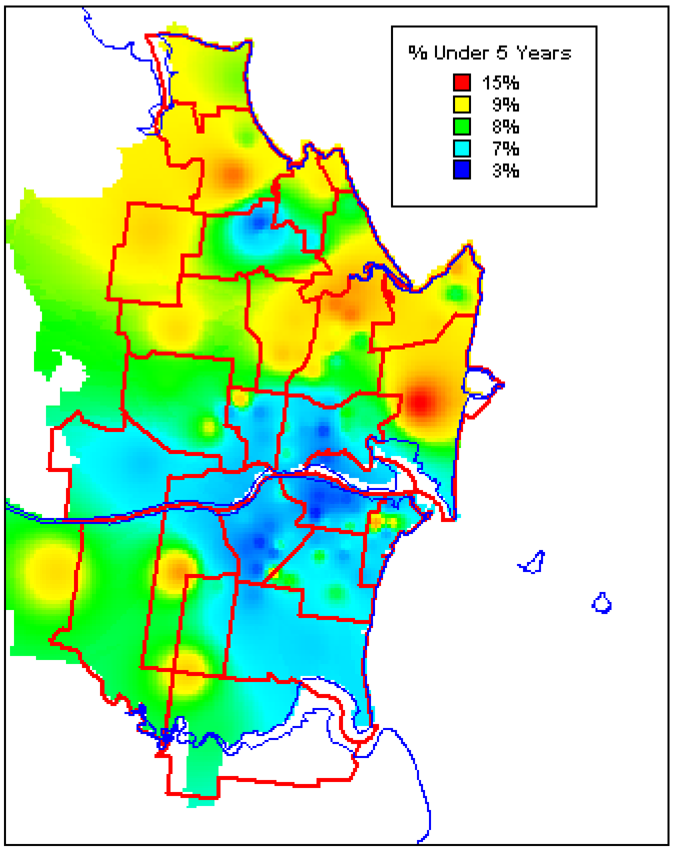


Figure 3.9: Mackay population aged under five years (ABS, 1998a)

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

Wealth: Whilst the economy of the Mackay district is undoubtedly dominated by sugar production, within the study area the service industries including retailing, manufacturing, health services and construction make the most significant contribution. The details are provided for the study area in Table 3.6. This is a clear reflection of the service centre nature of the Mackay study area.

The spatial distribution of 'wealth' within the city can 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.

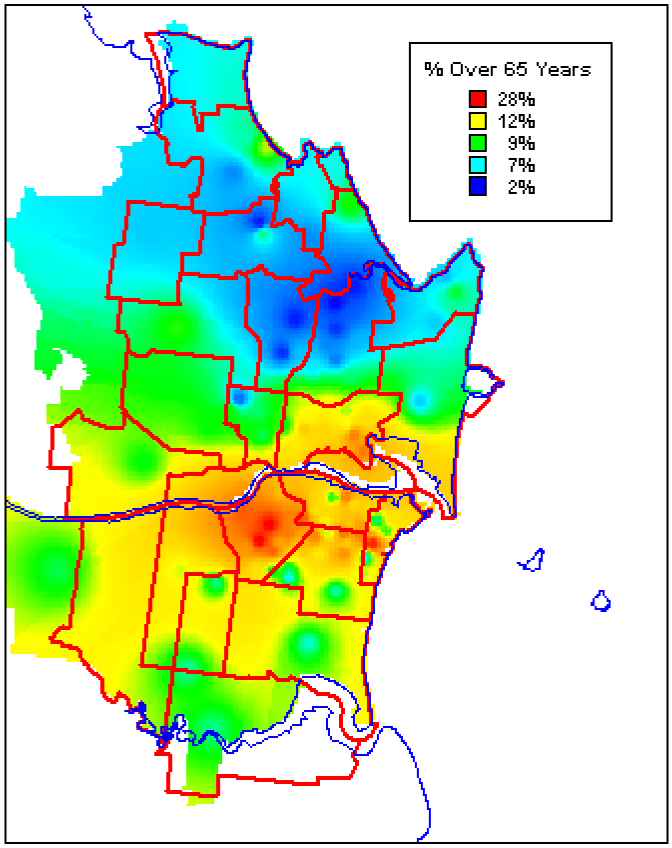


Figure 3.10: Mackay population aged over 65 years (ABS, 1998a)

Table 3.6: Mackay employment by industry (ABS, 1998a)

Industry group	**Persons employed**	**Industry percent**
Agriculture, forestry and fishing	724	2.9
Mining	457	1.8
Manufacturing	2819	11.1
Electricity, gas and water supply	299	1.2
Construction	2159	8.5
Wholesale trade	1945	7.7
Retail trade	4093	16.2
Accommodation, cafes and restaurants	1309	5.2
Transport and storage	1725	6.8
Communication services	360	1.4
Finance and insurance	758	3.0
Property and business services	2002	7.9
Government administration and defence	670	2.6
Education	1704	6.7
Health and community services	2219	8.8
Cultural and recreational services	483	1.9
Personal and other services	795	3.1
Non-classifiable economic units	355	1.4
Not stated	408	1.6
Total persons employed	25 284	

Unemployment rates of over 15%, recorded at the 1996 census, are concentrated in Central Mackay, East Mackay and Mackay Harbour, the latter having an extremely high unemployment rate of 49.3%. These are shown in Figure 3.11. The spatial distribution of unemployment rates correlates very closely with the proportion of households that are in rented accommodation, as shown in Figure 3.12. The highest proportion of households in rental accommodation (63.7% of all households) is in the north of East Mackay where there is a significant concentration of flats and units.

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 C1 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 CCDs in Australia (ABS, 1998b). For the Mackay study area, the mean CCD index value is 967.6, and ranges from a high (advantaged) value of 1079 in the essentially rural CCD that extends to the northwest of Andergrove, to a low (disadvantaged) value of 702 in Mackay Harbour. The spatial distribution is shown in Figure 3.13.

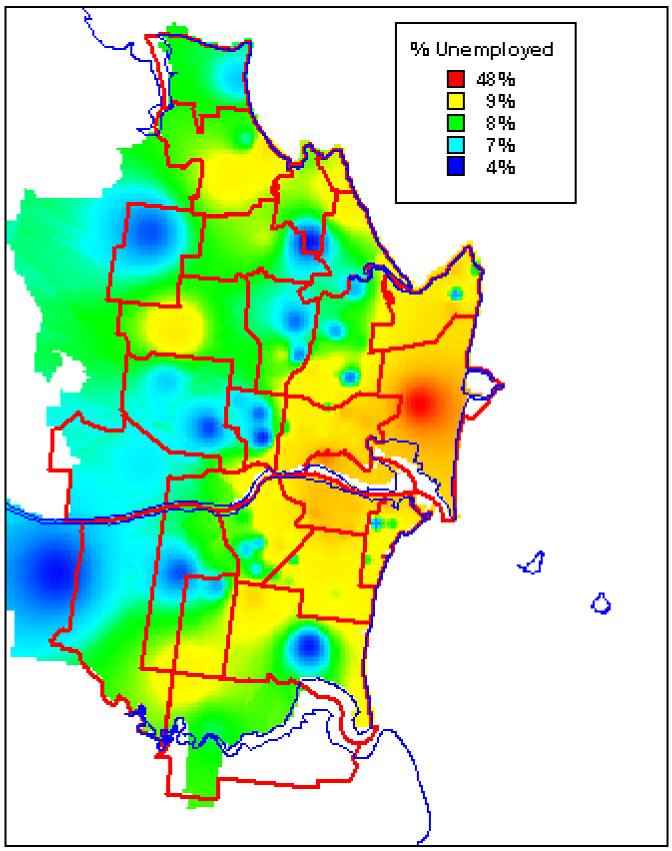


Figure 3.11: Mackay unemployment rate (ABS, 1998a)

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 C2 for a list of variables used). This index is also standardised with a national mean of 1000 and a standard deviation of 100. The Mackay study areas mean index value is 976.8. The lowest value is 787.0, more than two standard deviations below the national mean, in Mackay Harbour, whilst the highest value of 1112.5 is the rural area between Bakers Creek and Ooralea. The spatial distribution is shown in Figure 3.14.

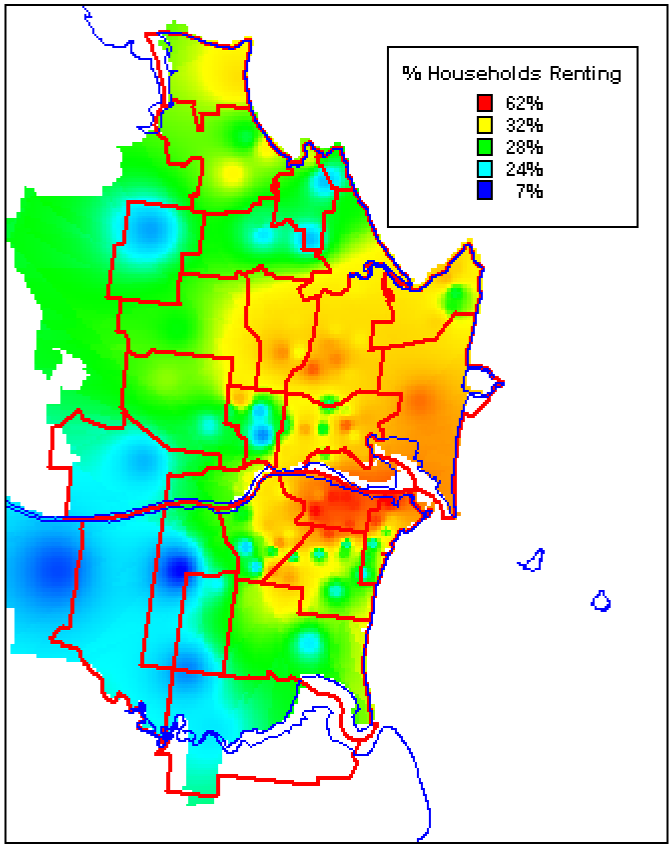


Figure 3.12: Mackay percentage of households renting (ABS, 1998a)

Protection: The full range of public safety services is provided in Mackay. The city is headquarters for the Queensland Police Service (QPS) Mackay Police District. QPS establishments are located at 59 Sydney Street in Central Mackay. The Mackay Police Station, the only police station within the study area, is co-located with the District Headquarters (HQ) with its entrance on Brisbane Street.

The Mackay District Disaster Coordination Centre, when activated, is located in the QPS District HQ building. District-level disaster control is vested in the District Police Superintendent in his (non-police) role as District Disaster Coordinator (DDC). The DDC is responsible for maintaining the district disaster plan.

There are two ambulance stations in the study area located at:

Mackay	corner of Sydney and Alfred Streets, Central Mackay
Mount Pleasant	corner of Phillip and Lauchlan Streets, Mount Pleasant

There are three fire stations in the study area located at:

Mackay	corner of Sydney and Alfred Streets, Central Mackay
North Mackay	Harbour Road, North Mackay
Northern Beaches	McHugh Street, Bucasia

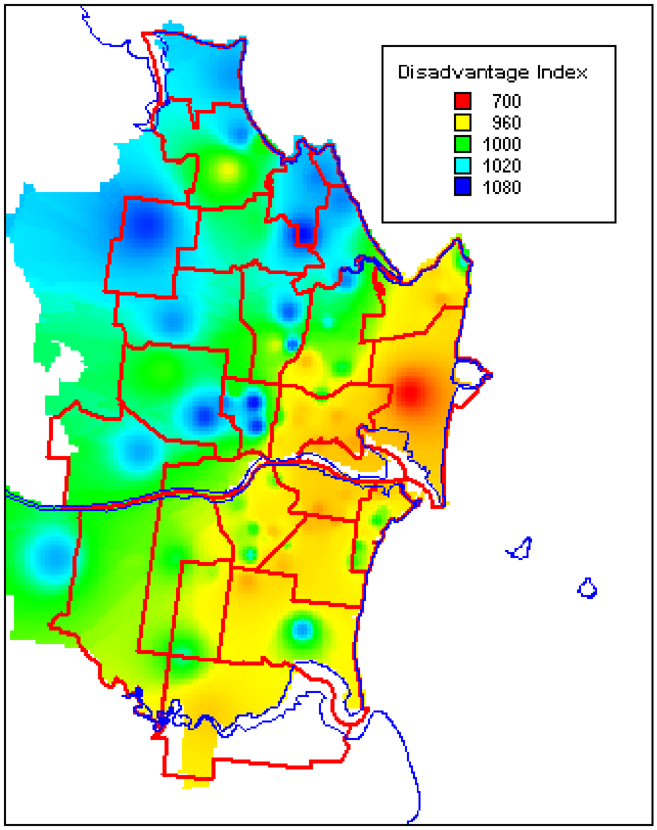


Figure 3.13: Mackay - areas of relative socio-economic disadvantage (ABS, 1998b)

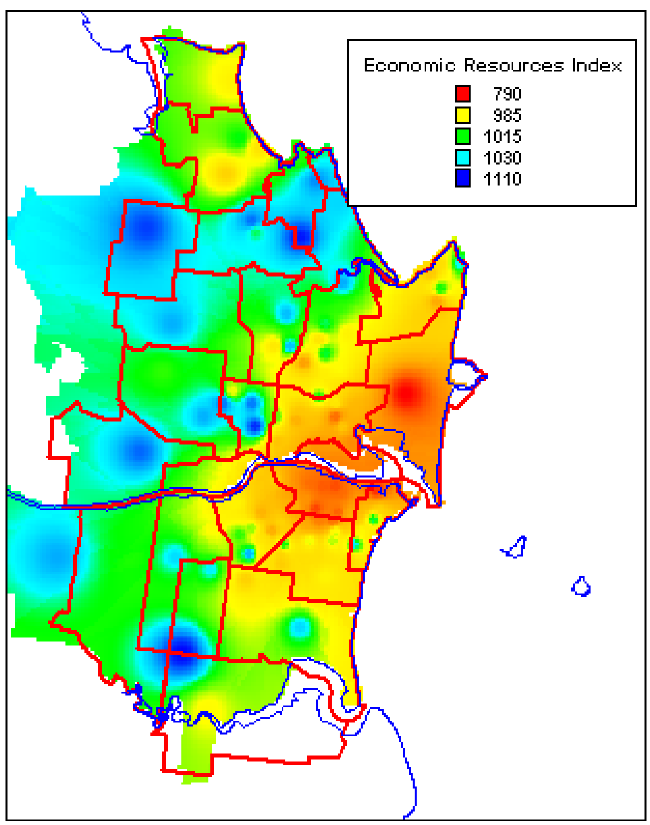


Figure 3.14: Mackay - areas of relative abundance of economic resources (ABS, 1998b)

The specialised Airport Rescue and Fire Service protects the airport. It is located on the airfield, off Milton Street, South Mackay.

Training and administration of State Emergency Service (SES) units in the Mackay District is coordinated by the DES Disaster and Rescue Services Division's District Manager, whose office is located in River Street, Central Mackay. Local SES units are the responsibility of the Mackay City Council, as is the coordination of the Local Disaster Committee (LDC). The LDC, chaired by the Mayor and supported by a full time executive officer, is responsible for the local disaster plan. Mackay City SES headquarters is located at 23 Cemetery Road, West Mackay.

The Queensland Mine Rescue Service has a base at 177 Boundary Road East in Paget, near the airport.

There are no permanent Australian Defence Force units in Mackay, though a Defence Force Reserve establishment is located at the Drill Hall at 400 Shakespeare Street, West Mackay.

The Bureau of Meteorology's weather station on Mount Bassett is a key link in the Bureau's severe weather and flood warning system and can be considered to be a key public safety facility.

The locations of the major public safety service facilities are shown on Figure 3.15.

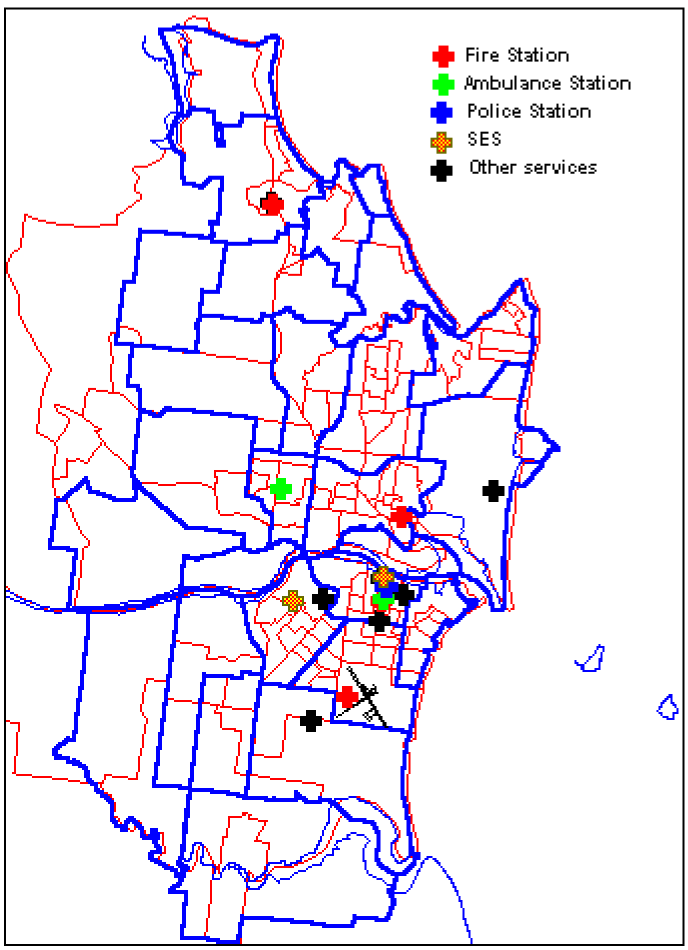


Figure 3.15: Mackay public safety services

A system of levees, training walls and bank protection works has been constructed to provide a degree of protection from flooding of the Pioneer River. These are described in Chapter 5.

The Australian Building Code, with its guidance for both earthquake and wind loads, is administered by Mackay City Council.

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 Mackay. 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 3.7 summarises the number of households in the Mackay study area according to their size and structure. There are 7412 households made up of a couple plus their children, of which almost 30% contain five or more people (i.e. notionally three or more children). There are 2217 households made up of a single parent and their children, of which 20% contain four or more people (likewise three or more children). Group or lone-person households are not included in the table.

Table 3.7: Number of households by type and size (ABS, 1998a).

	Number of people usually resident					
	2	**3**	**4**	**5**	**6+**	**Total**
Couple with children		2247	2984	1540	641	7412
One parent family	1035	744	289	92	57	2217
Totals	1035	2991	3273	1632	698	9629

The spatial distribution of large families and single parent families is shown in Figure 3.16 and Figure 3.17. 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 urban areas.

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 93.6% of the study area population over five speaking English at home. The next largest groups are Italian, Maltese, German and 'other' (each of which comprise less than 1.0% of the total). The 'other' group appears to include mainly Asian languages such as Japanese and possibly Korean.

The only significant concentration of any particular ethnic group is the proportion of Aboriginal and Torres Strait Islander people in the Mackay Harbour-Slade Point area, where between 10 and 25% of the population in each CCD is of indigenous origin.

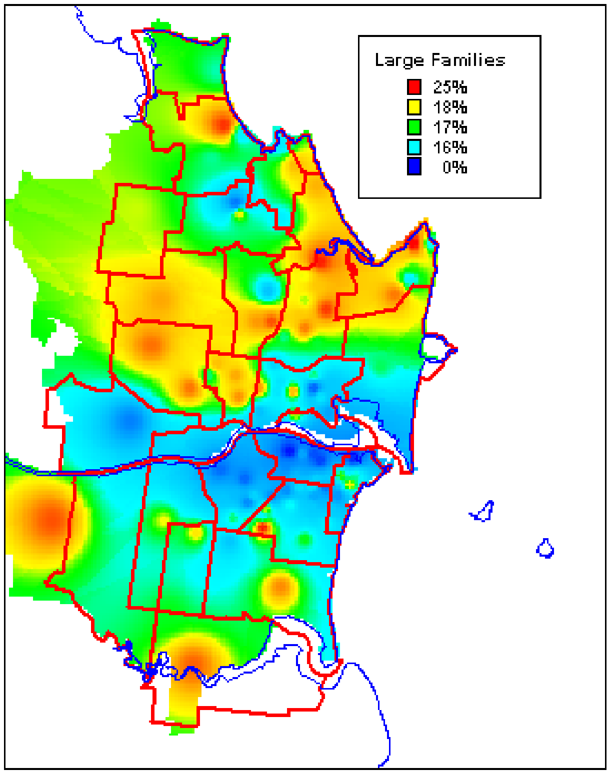


Figure 3.16: Percent of all family households with three or more children at home (ABS, 1998a)

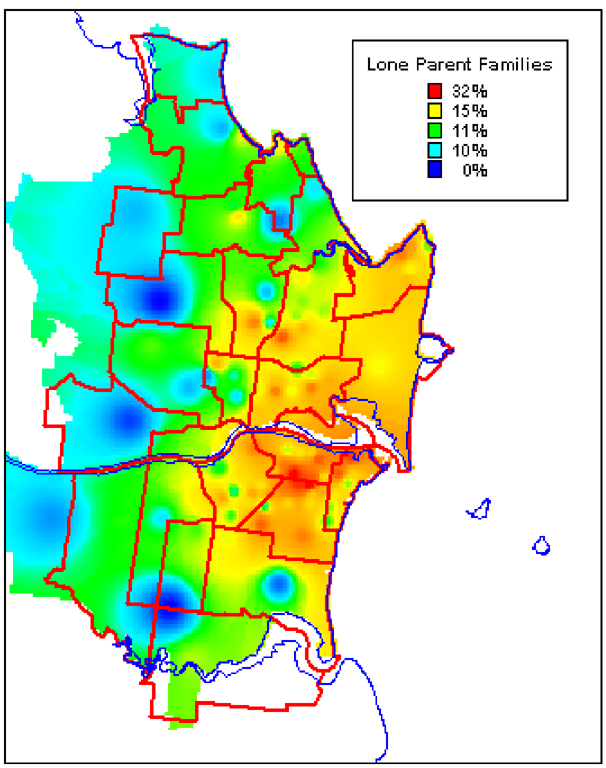


Figure 3.17: Percent of all family households with only one parent present (ABS, 1998a)

Religion: One of the more significant linkages that tend to span social cleavages such as ethnicity, is religion. In Mackay, the majority (77.4%) of people who provided answers to the questions on religion in the 1996 census were Christian. Of the remainder, 0.5% was divided between Buddhism, Islam, Hindu and Judaism (in that order), whilst 13.5% said they had no religion. Of the Christian faiths, Catholic (38.8% of all Christians), Anglican (27.5%), Uniting (16.4%) and Presbyterian (5.6%) 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 Mackay study area is clearly a mobile one, with only 40% of the population at the 1996 census living at the same address that they were living at five years previously. This change is overwhelmingly based on in-migration. Figure 3.18 shows the proportion of the total population that was living at a different address at the 1991 census and reflects the recent growth of Mackay to the north of the Pioneer River.

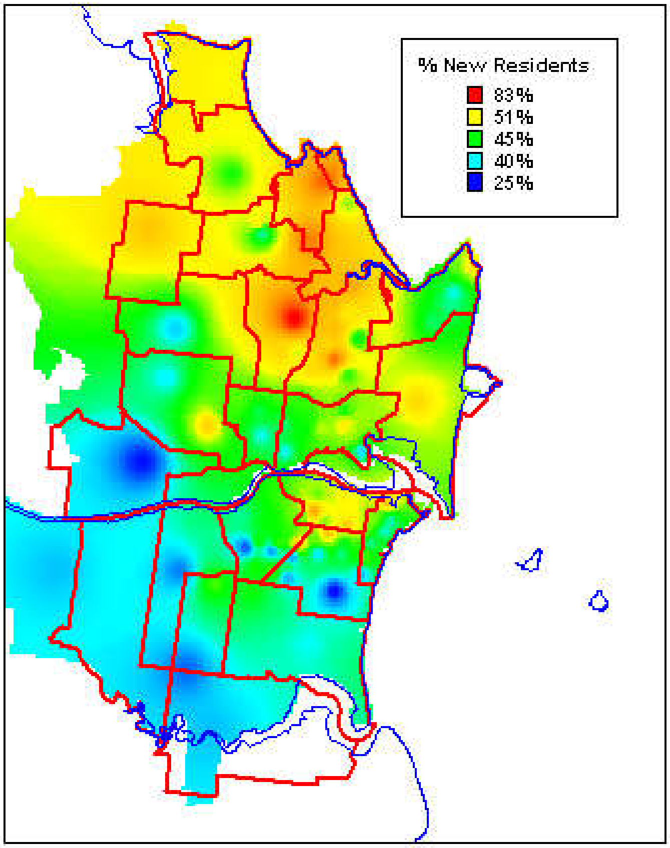


Figure 3.18: Proportion of population at census address for less than five years (ABS, 1998a)

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 Mackay, for example, some 38% of people over 15 have gained some form of post-secondary qualification. 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. Table C3 lists the locations of the 29 primary and secondary schools in Mackay. Schools are also centres in which there are concentrations of more vulnerable people for significant parts of the day. The table also includes statistics for the numbers of enrolments and teaching staff at government (State) schools where available.

A campus of the Central Queensland University (CQU) is located in Ooralea, whilst the Central Queensland Conservatorium of Music, which is also part of CQU, is located in West Mackay. These centres, together with the Mackay TAFE located in Central Mackay, provide tertiary-level education and training. Other post-secondary training institutions include Skillshare (in River Street, Central Mackay), the Indigenous Education Unit (in Wood Street, Central Mackay) and CQMS Training in Glenella.

At the other end of the educational process are at least 17 child care centres and kindergartens that serve areas of employment and the suburbs, such as Bucasia, in which young families predominate. These centres are listed in Table C4. 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 Mackay study area mean value is 943.98 and ranges from a high (high educational levels and high occupation status) of 1054.09 in Mount Pleasant to a low (low education levels and job status) of 754.37 (more than two standard deviations below the national average) in Mackay Harbour. The spatial distribution is shown in Figure 3.19. Table C5 lists the variables used to build this index.

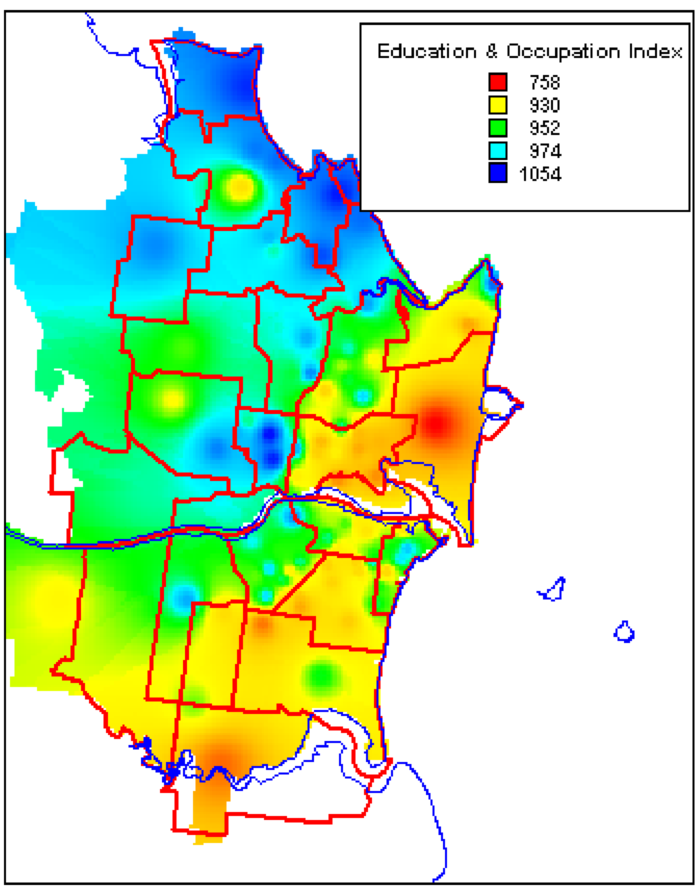


Figure 3.19: Mackay index of education and occupation (ABS, 1998b)

Community services: Community based groups provide a significant level of social resilience and effective networks for the dissemination of information. Mackay 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 significant 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.

A detailed community service guide for Mackay was published in 1999 (Mackay City Council, 1999). A summary of the types of community services available in the study area is contained in Table C6. This provides an impression of the broad extent of interests covered.

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. A total of 51 such facilities have been selected as representing those facilities which are the most critical to the overall vulnerability of the Mackay community. These are listed in Table C7.

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 would magnify the danger because of toxic contamination, fire or explosion. The facilities that are considered to contain secondary hazards are annotated in Table C7. The hazards contained at some of these facilities are not always obvious. For example, large commercial cold storage facilities would not usually be considered to be dangerous, however, they 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 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. The bulk fuel and gas depots that are concentrated in Mackay Harbour, for example, supply consumers throughout a region that extends well beyond the study area. Clearly, the loss or isolation of those facilities would have a proportionately greater impact overall than would the loss of a neighbourhood service station, for example. Likewise, the TAFE and CQU campuses attract students from a much wider catchment than does the suburban primary school. The bulk sugar and grain terminals in Mackay Harbour are significant at a national level given their importance in the export of those commodities, and consequently to the national, as well as local and State economies.

In this study we have not attempted to track the consequences beyond the study area of the loss or isolation of facilities, or to weight the significance of individual facilities.

A Composite Community Vulnerability Profile

In this chapter we have described a broad range of the elements at risk within the Mackay 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 hazard phenomena, people, buildings and infrastructure of Mackay since 1993. Whilst these data provide a detailed quantitative description of specific aspects of the city'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 city.

We consider that it is highly desirable 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. Given that most people tend to identify themselves with the suburb in which they live and/or work, we have aggregated these data, from the CCD level at which they have been compiled, to the suburb level.

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' and a composite, or combined community vulnerability assessment. We have modified that methodology slightly for Mackay, in part because of the difficulties we have experienced in linking the census data to suburb boundaries and partly because of our ongoing efforts to enhance our methods. Appendix D provides a detailed explanation of the methodology and the logic behind the selection of the variables included in this study.

It is emphasised that the values in the 'overall' column in Table 3.8 do **not** equate to a risk rating. They simply provide an indication of the **relative contribution** made to overall community risk by each suburb. A number of one indicates that a suburb contributes relatively the most individually to overall community vulnerability and a number of 27 the least. This assumes that an even and equal exposure to the impact of all hazards exists. This is clearly not the case, as will be explored in the following chapters.

The relative suburb contributions to setting (Figure 3.20 and Table 3.9), shelter (Figure 3.21 and Table 3.10), sustenance (Figure 3.22 and Table 3.11), security (Figure 3.23 and Table 3.12), social (Figure 3.24 and Table 3.13) and overall community (Figure 3.25 and Table 3.14) vulnerability are also shown below.

In the following chapters, we bring together an analysis of the earthquake (Chapter 4), flood (Chapter 5) and cyclone (Chapter 6) hazards, and their threat to the Mackay community. In Chapter 7 we draw these together into an assessment of the total multi-hazard risk faced by the Mackay community and link that assessment to a consideration of some risk mitigation strategies.

Table 3.8: Ranking of each suburb's contribution to overall community vulnerability

Suburb	Setting	Shelter	Sustain	Security	Society	Overall
Andergrove	4	1	5	14	5	3
Bakers Creek	20	19	13	12	16	16
Beaconsfield	5	6	11	16	14	10
Blacks Beach	18	12	24	19	7	19
Bucasia	12	7	10	9	10	8
Central Mackay	6	10	1	1	2	2
Cremorne	24	22	27	6	3	18
Dolphin Heads	13	16	25	26	8	20
East Mackay	7	4	16	4	9	7
Eimeo	7	11	18	23	13	15
Erakala	26	26	21	20	27	26
Foulden	27	27	26	27	26	27
Glenella	15	13	12	15	12	14
Mackay Harbour	19	21	9	2	1	9
Mount Pleasant	3	2	7	18	21	11
Nindaroo	22	18	22	25	24	23
North Mackay	11	5	3	5	6	4
Ooralea	9	14	15	11	15	12
Paget	16	20	8	7	18	13
Racecourse	25	25	19	17	25	25
Richmond	23	23	20	21	22	22
Rural View	14	17	17	22	20	21
Shoal Point	16	15	23	13	19	17
Slade Point	9	8	6	8	4	6
South Mackay	1	3	4	3	11	1
Te Kowai	21	24	14	24	23	24
West Mackay	2	9	2	10	17	5

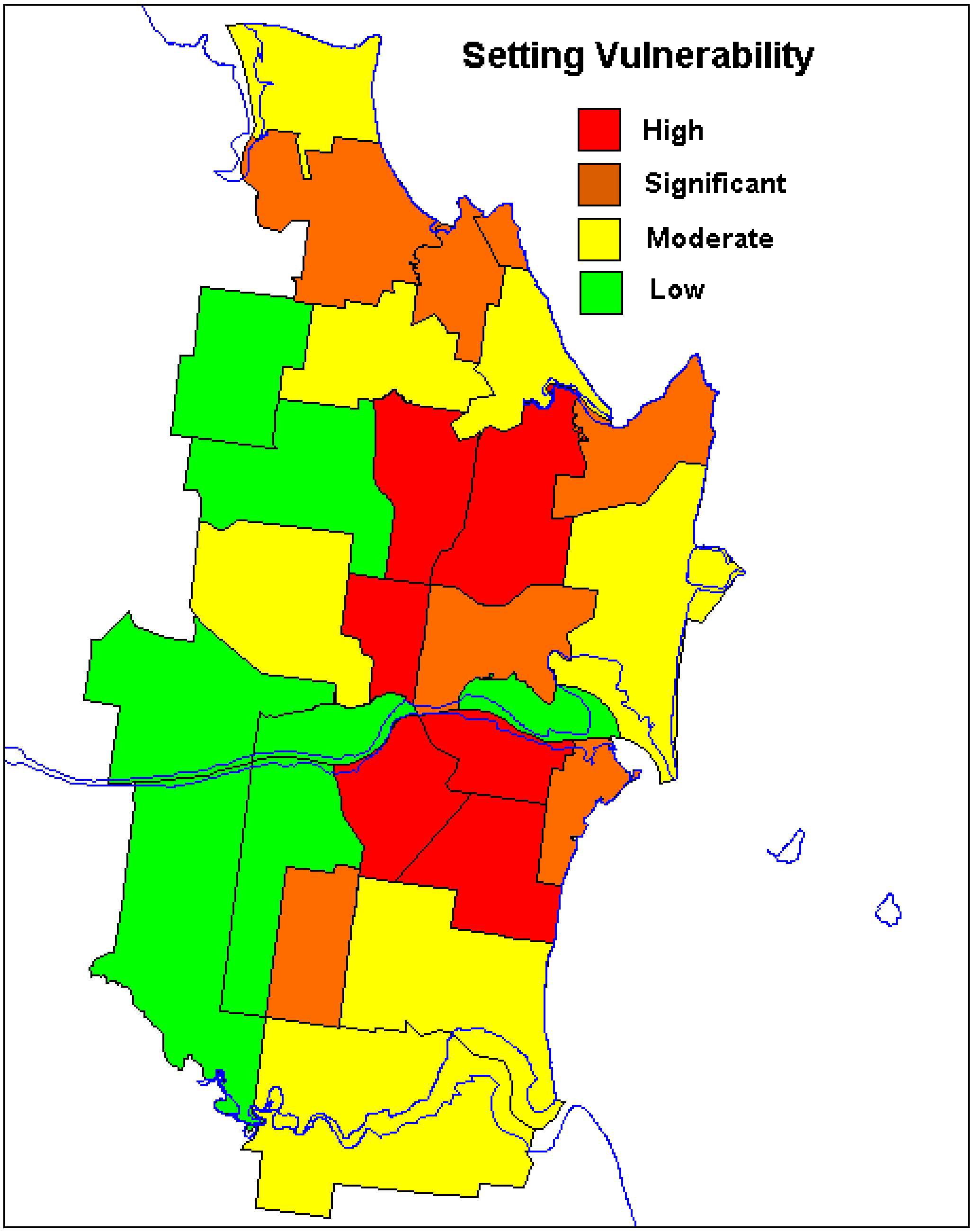


Figure 3.20: Relative suburb contribution to setting group vulnerability

Table 3.9: Relative suburb contribution to setting group vulnerability

Rank group	Suburbs (in rank order)
High	South Mackay, West Mackay, Mount Pleasant, Andergrove, Beaconsfield, Central Mackay,
Significant	East Mackay, Eimeo, Slade Point, Ooralea, North Mackay, Bucasia, Dolphin Heads
Moderate	Rural View, Glenella, Shoal Point, Paget, Blacks Beach, Mackay Harbour, Bakers Creek,
Low	Te Kowai, Nindaroo, Richmond, Cremorne, Racecourse, Erakala, Foulden

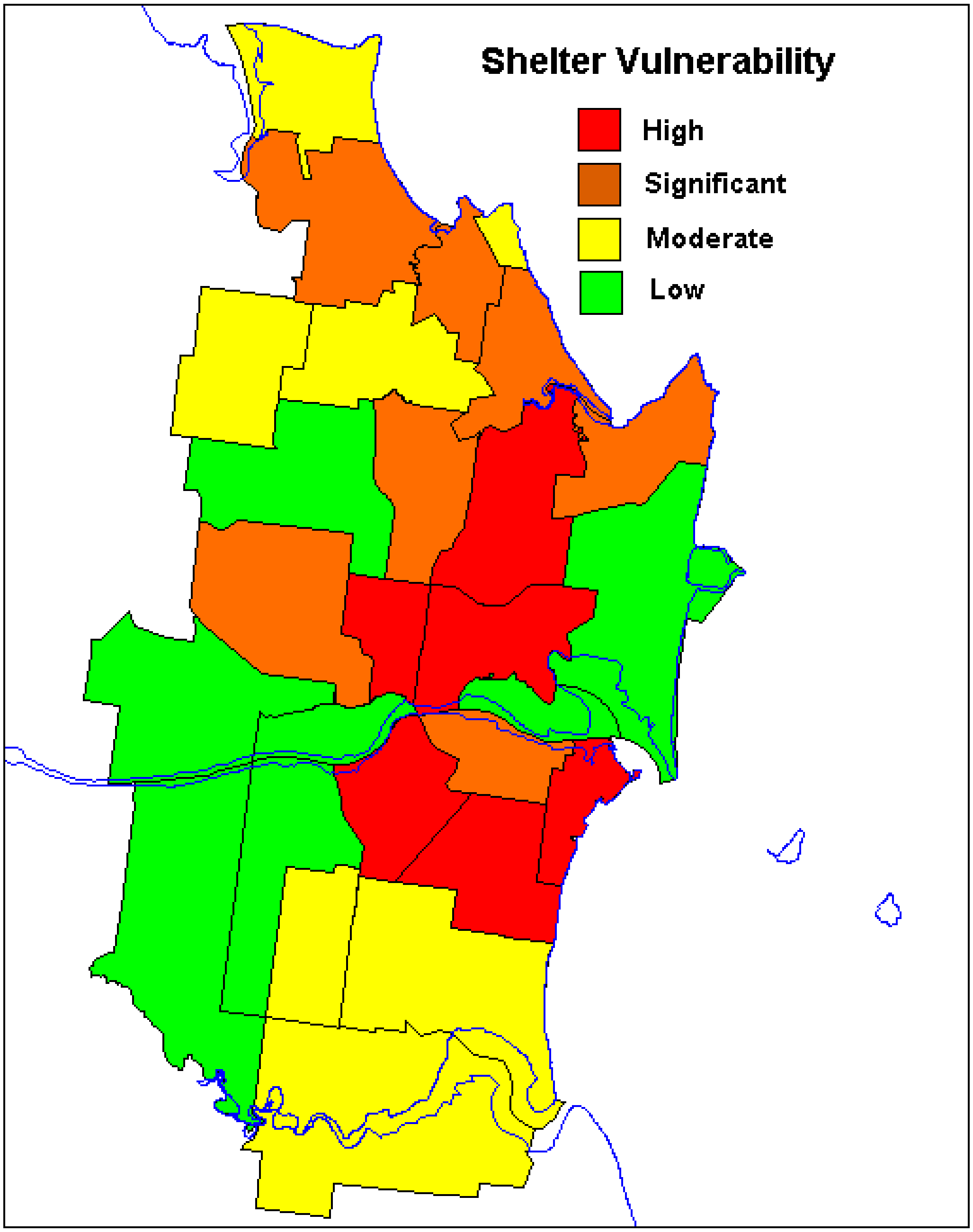


Figure 3.21: Relative suburb contribution to shelter group vulnerability

Table 3.10: Relative suburb contribution to shelter group vulnerability

Rank group	Suburbs (in rank order)
High	Andergrove, South Mackay, Mount Pleasant, East Mackay, North Mackay, West Mackay.
Significant	Beaconsfield, Bucasia, Central Mackay, Slade Point, Eimeo, Glenella, Blacks Beach.
Moderate	Ooralea, Shoal Point, Rural View, Bakers Creek, Nindaroo, Dolphin Heads, Paget.
Low	Mackay Harbour, Richmond, Te Kowai, Cremorne, Racecourse, Erakala, Foulden.

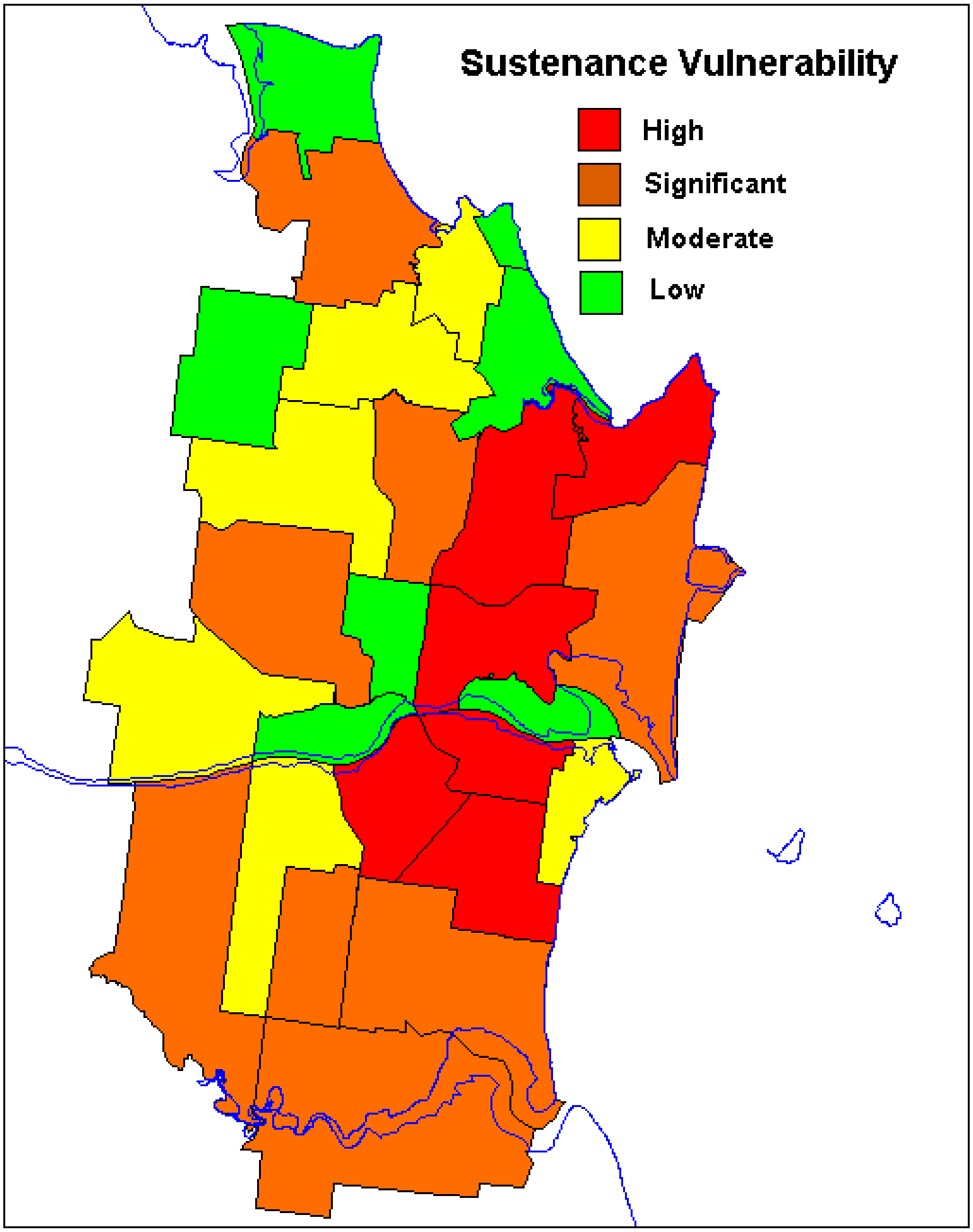


Figure 3.22: Relative suburb contribution to sustenance group vulnerability

Table 3.11: Relative suburb contribution to sustenance group vulnerability

Rank group	Suburbs (in rank order)
High	Central Mackay, West Mackay, North Mackay, South Mackay, Andergrove, Slade Point.
Significant	Paget, Mackay Harbour, Bucasia, Beaconsfield, Glenella, Bakers Creek, Ooralea, Te Kowai.
Moderate	East Mackay, Rural View, Eimeo, Racecourse, Richmond, Erakala.
Low	Nindaroo, Mount Pleasant, Shoal Point, Blacks Beach, Dolphin Heads, Foulden, Cremorne.

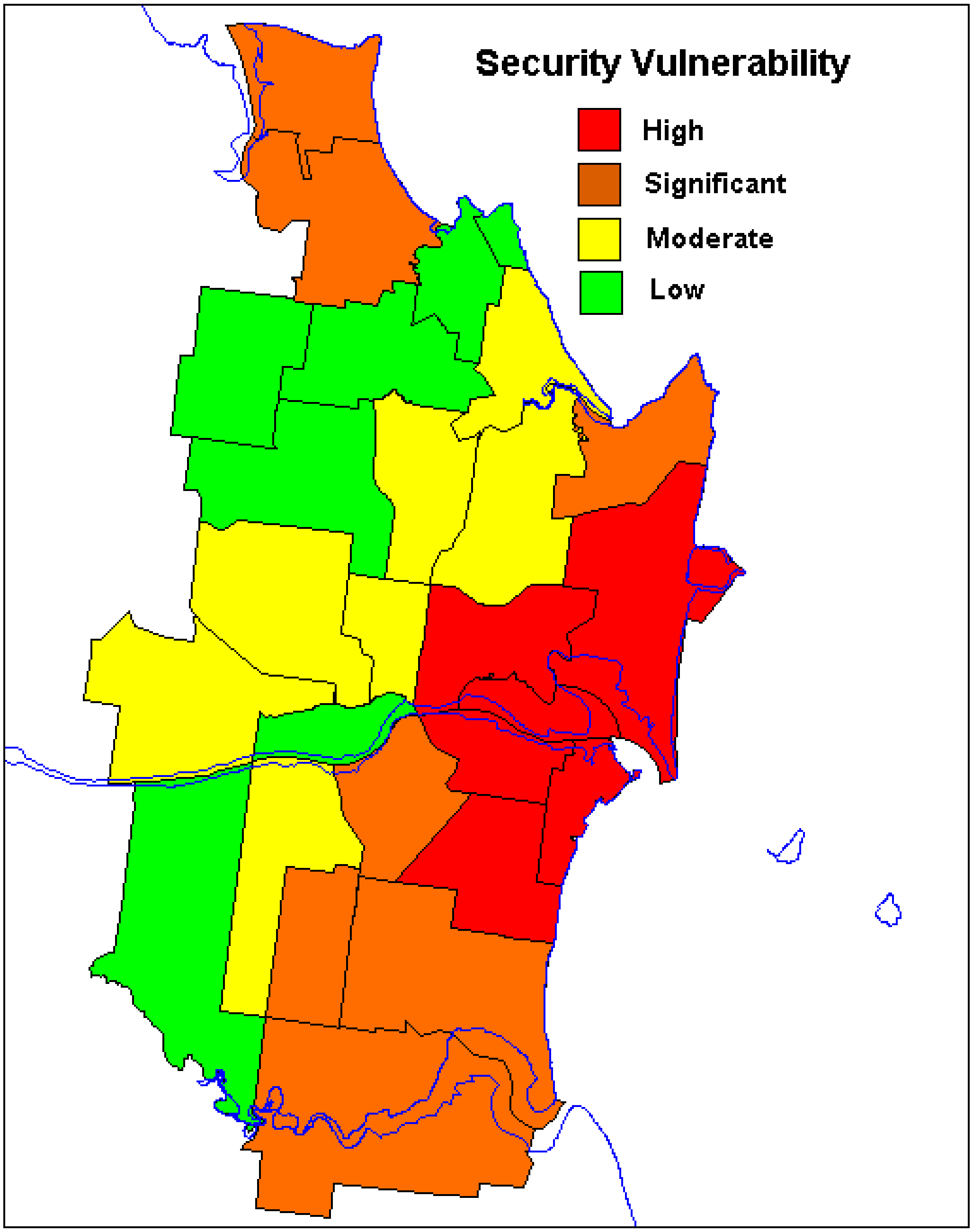


Figure 3.23: Relative suburb contribution to security group vulnerability

Table 3.12: Relative suburb contribution to security group vulnerability

Rank group	Suburbs (in rank order)
High	Central Mackay, Mackay Harbour, South Mackay, East Mackay, North Mackay, Cremorne.
Significant	Paget, Slade Point, Bucasia, West Mackay, Ooralea, Bakers Creek, Shoal Point.
Moderate	Andergrove, Glenella, Beaconsfield, Racecourse, Mount Pleasant, Blacks Beach, Erakala.
Low	Richmond, Rural View, Eimeo, Te Kowai, Nindaroo, Dolphin Heads, Foulden

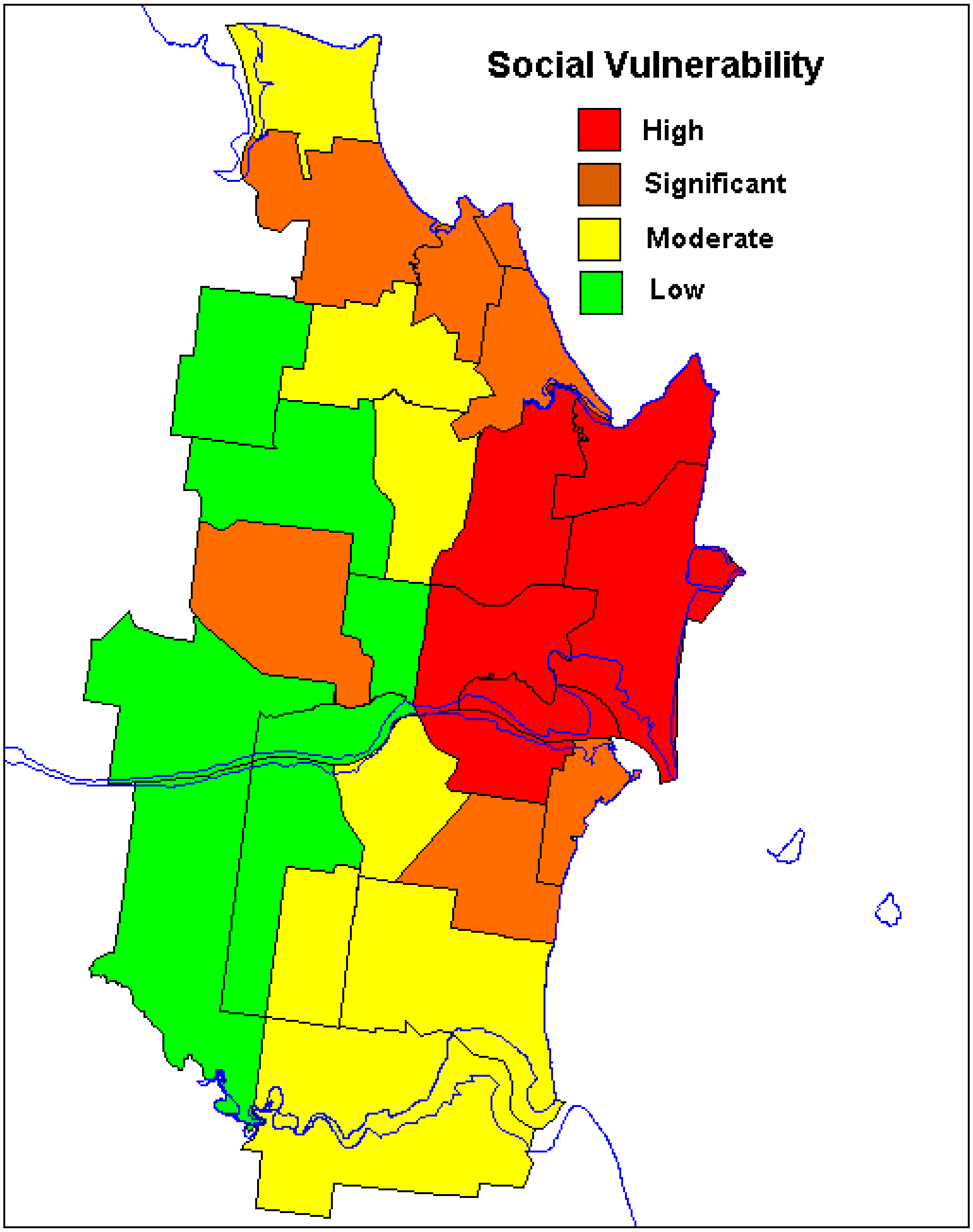


Figure 3.24: Relative suburb contribution to social group vulnerability

Table 3.13: Relative suburb contribution to social group vulnerability

Rank group	Suburbs (in rank order)
High	Mackay Harbour, Central Mackay, Cremorne, Slade Point, Andergrove, North Mackay.
Significant	Blacks Beach, Dolphin Heads, East Mackay, Bucasia, South Mackay, Glenella, Eimeo.
Moderate	Beaconsfield, Ooralea, Bakers Creek, West Mackay, Paget, Shoal Point, Rural View.
Low	Mount Pleasant, Richmond, Te Kowai, Nindaroo, Racecourse, Foulden, Erakala.

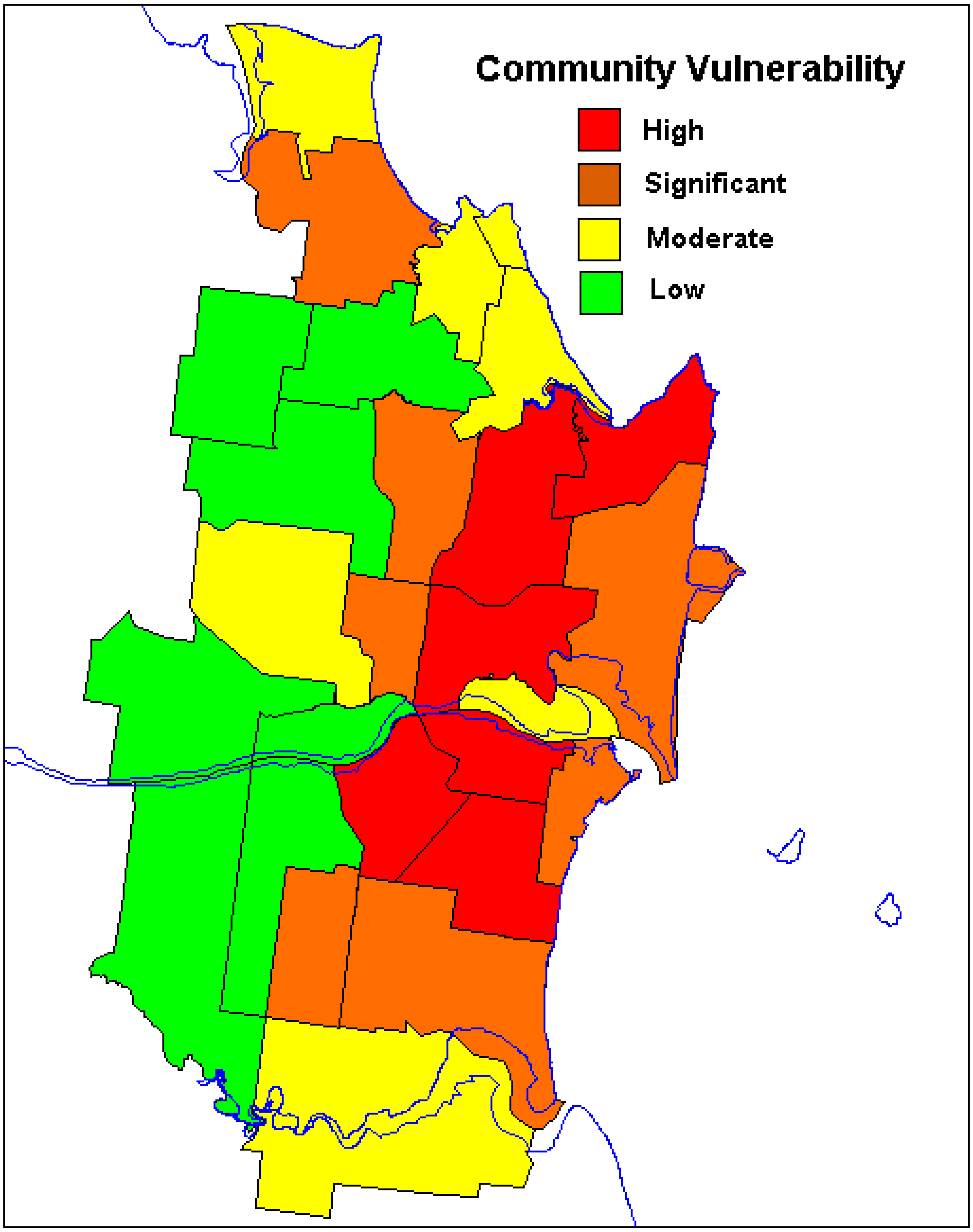


Figure 3.25: Relative suburb contribution to overall community vulnerability

Table 3.14: Relative suburb contribution to overall community vulnerability

Rank group	Suburbs (in rank order)
High	South Mackay, Central Mackay, Andergrove, North Mackay, Slade Point, West Mackay.
Significant	East Mackay, Bucasia, Mackay Harbour, Beaconsfield, Mount Pleasant, Ooralea, Paget.
Moderate	Glenella, Eimeo, Bakers Creek, Shoal Point, Cremorne, Blacks Beach, Dolphin Heads.
Low	Rural View, Richmond, Nindaroo, Te Kowai, Racecourse, Erakala, Foulden.

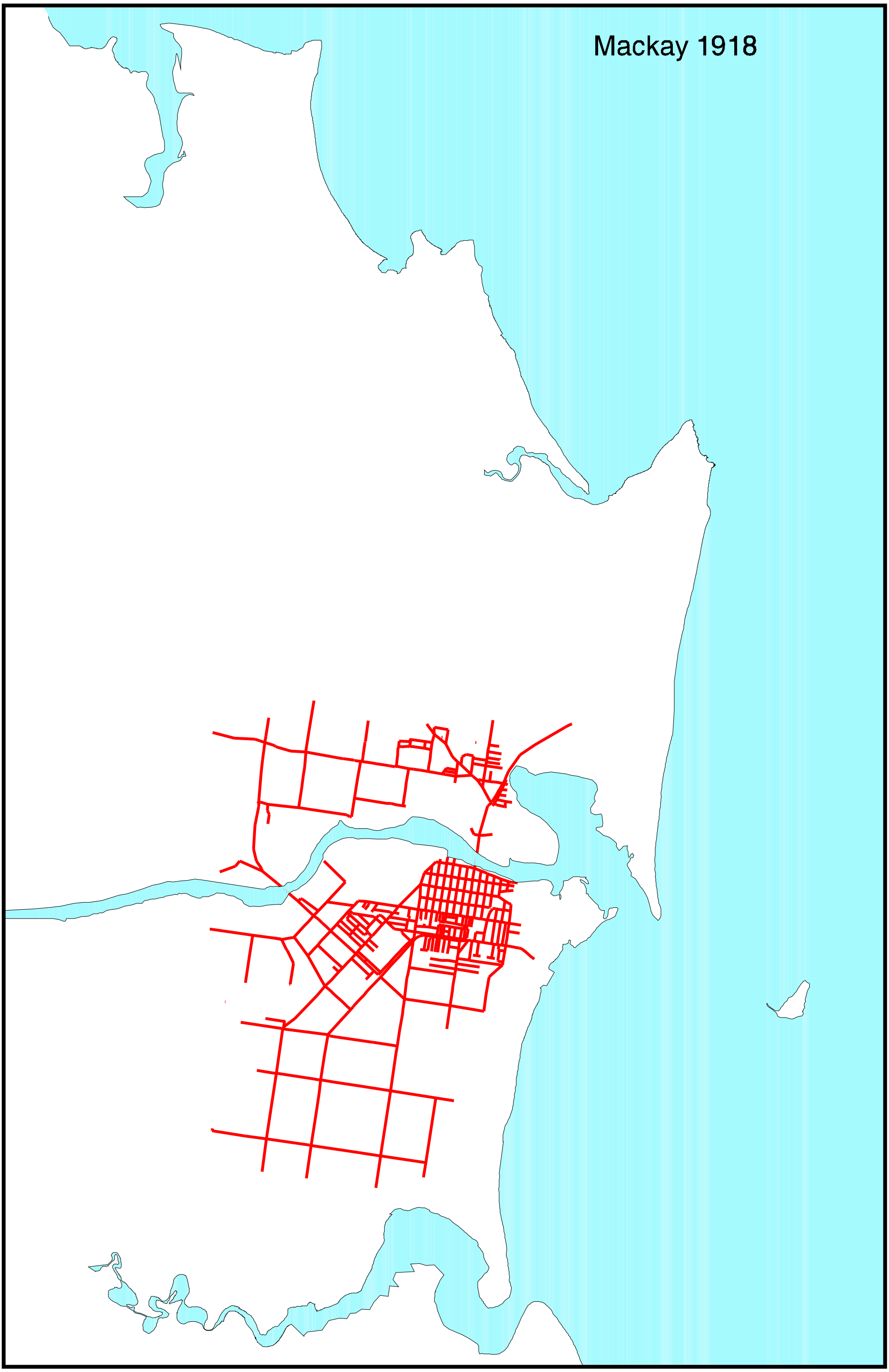


Figure 3.2: Mackay 1918

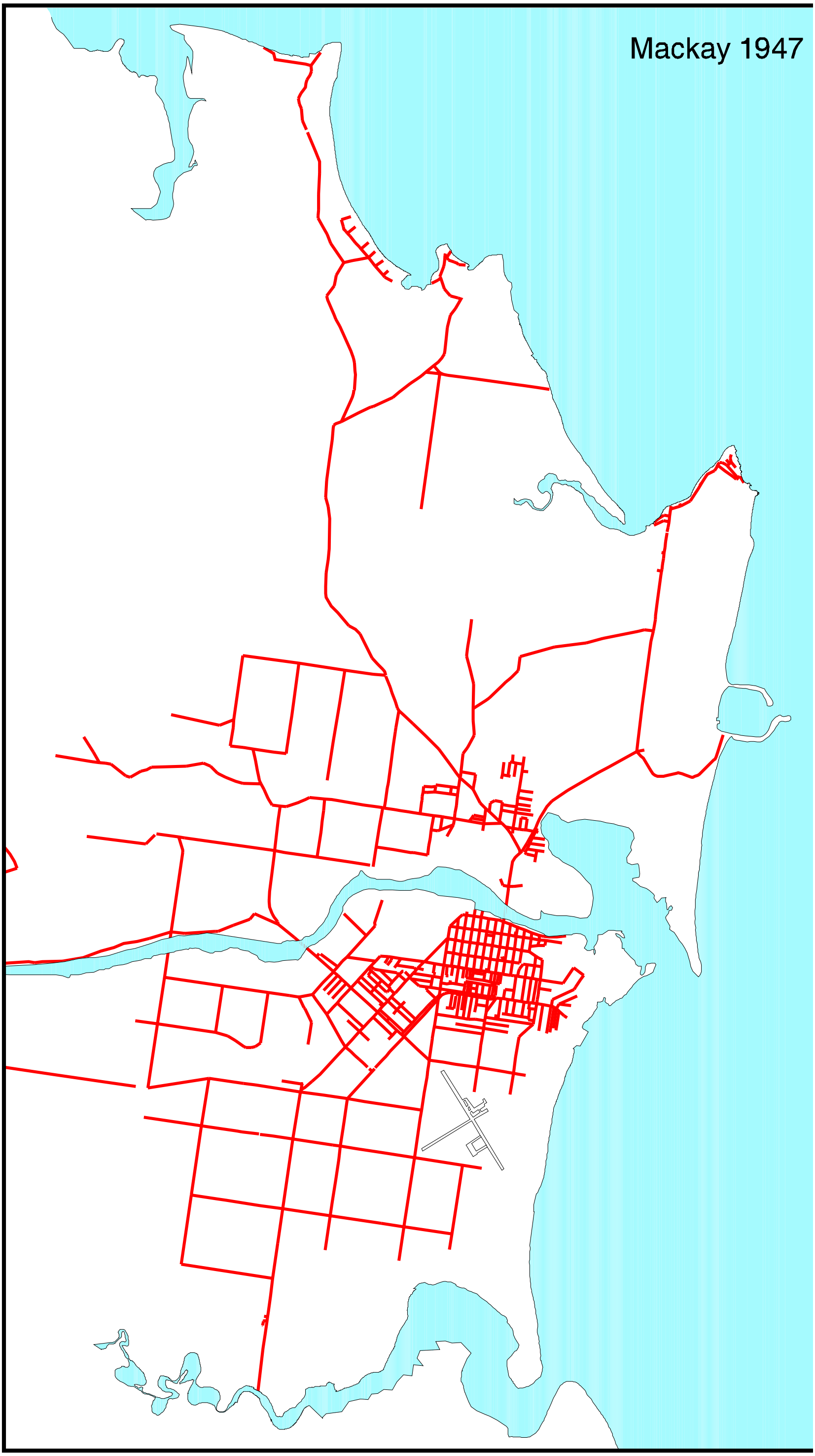


Figure 3.3: Mackay 1947

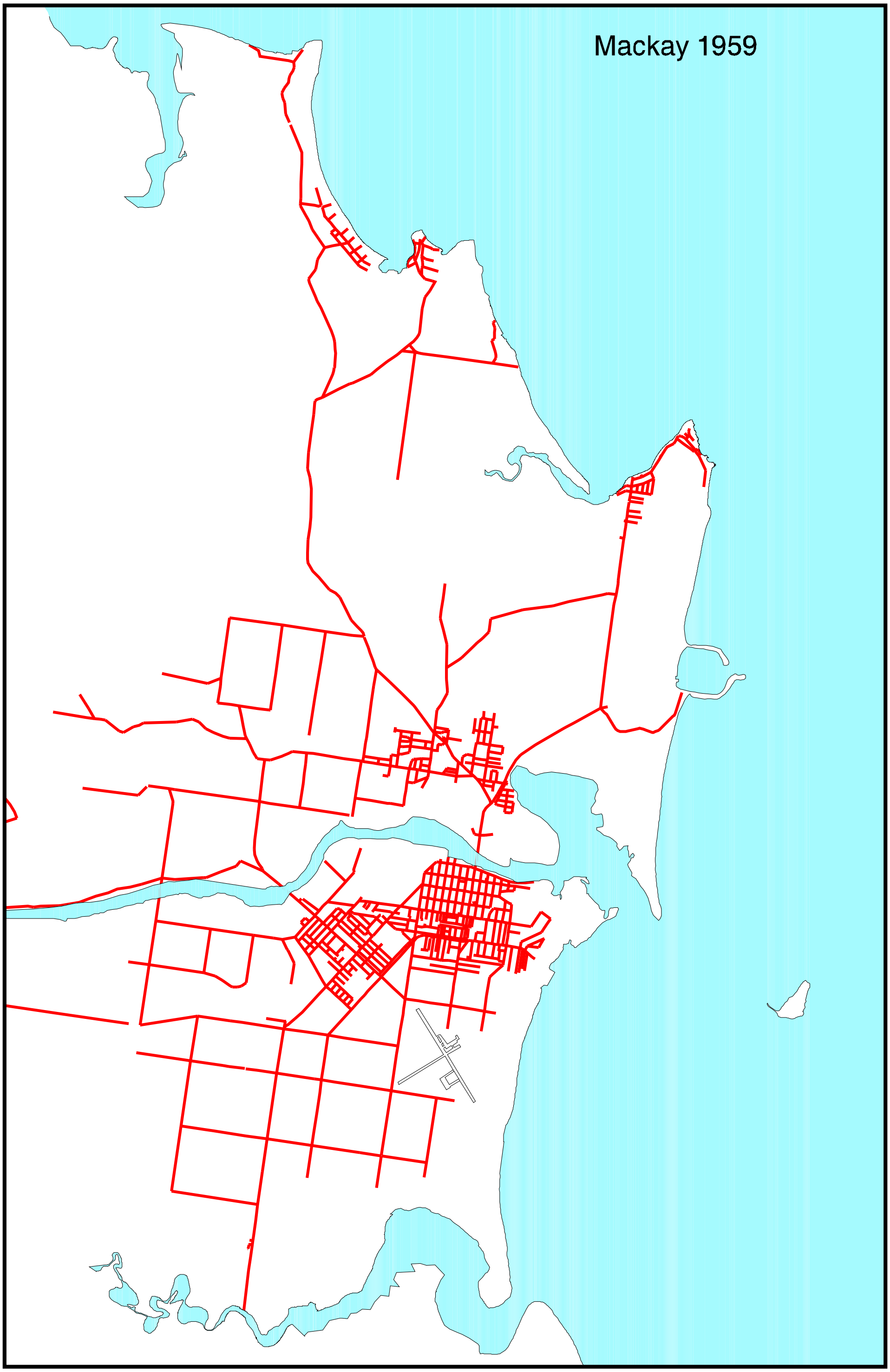


Figure 3.4: Mackay 1959

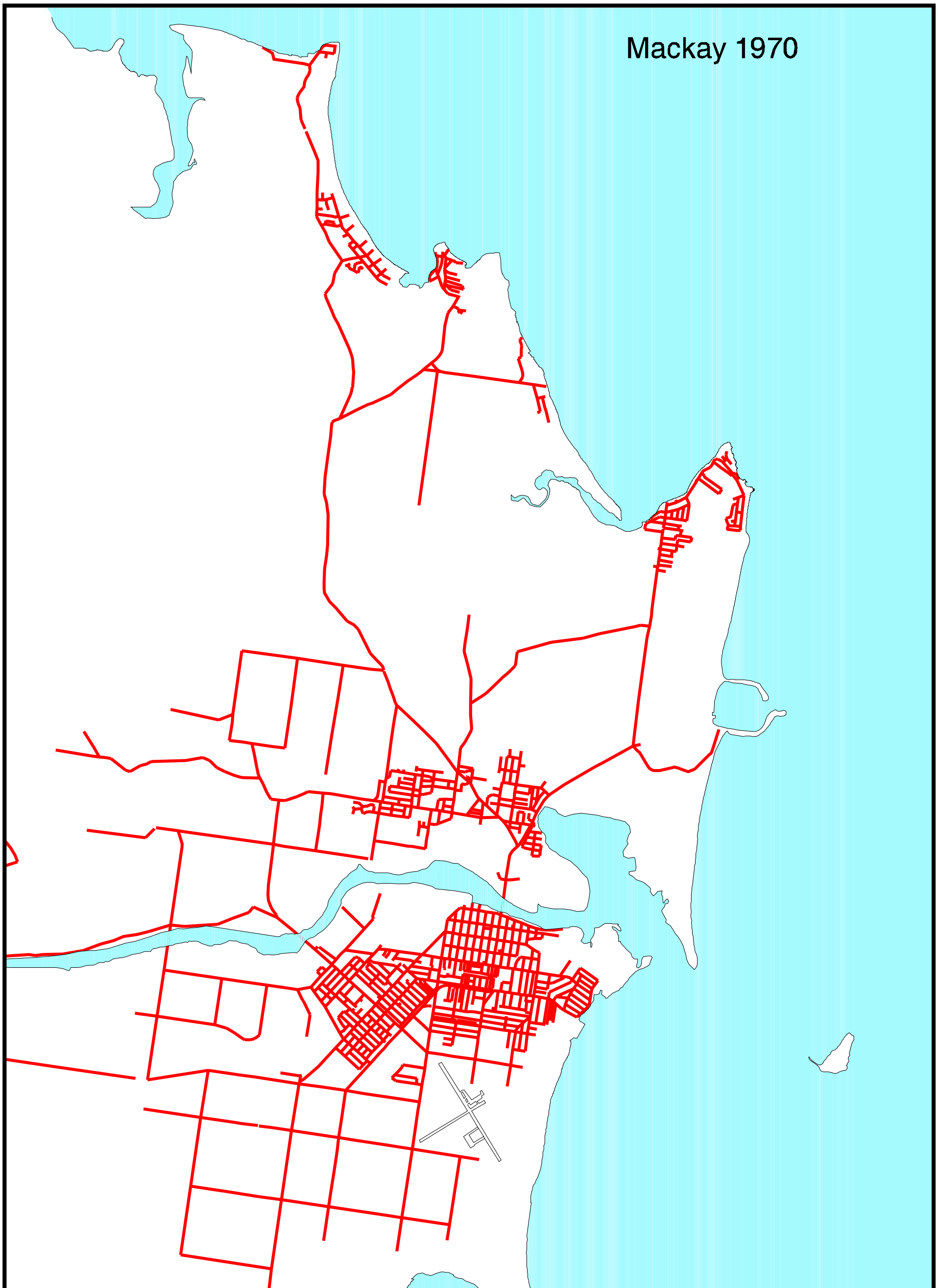


Figure 3.5: Mackay 1970

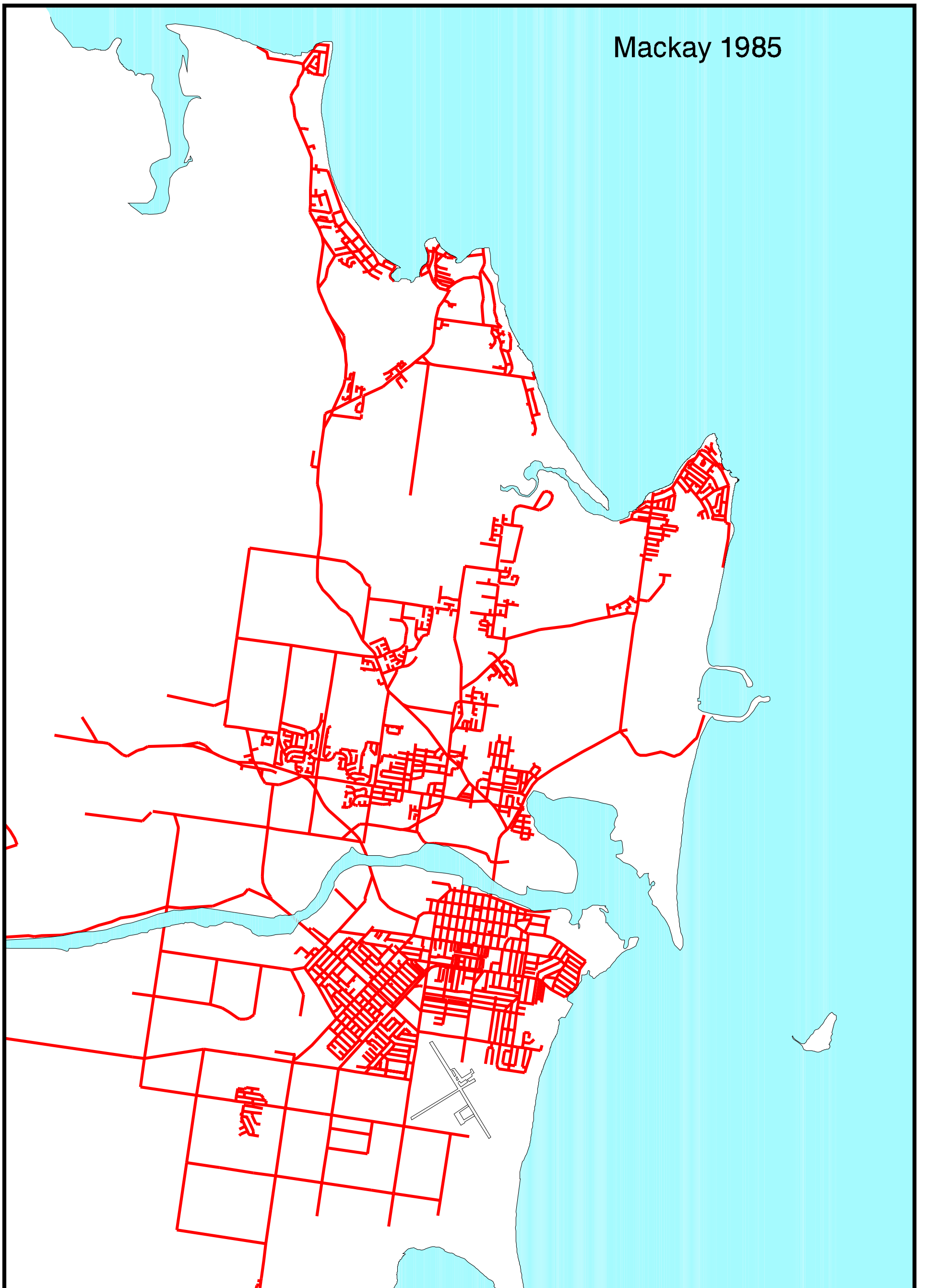


Figure 3.6: Mackay 1985

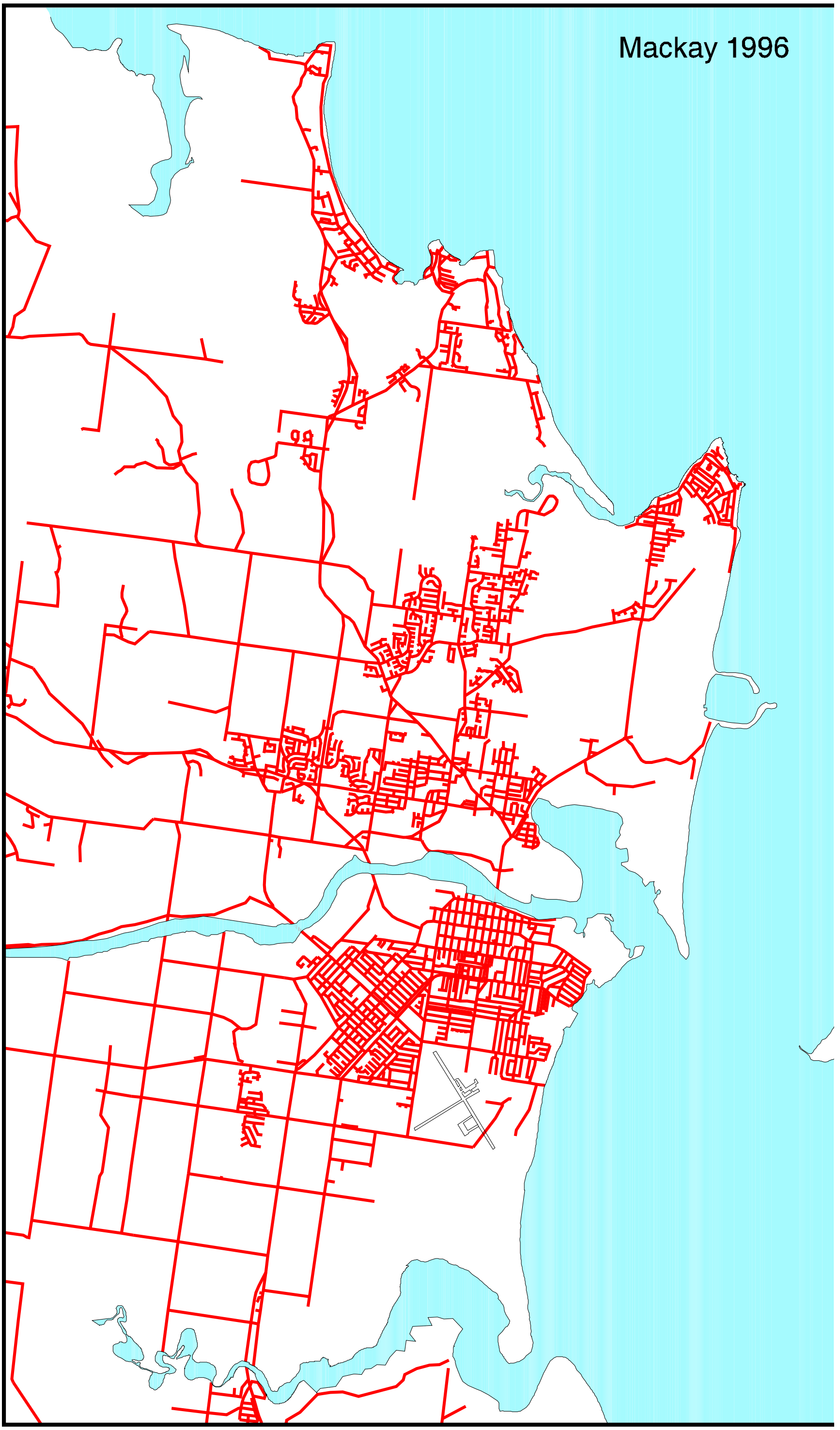


Figure 3.7: Mackay 1996

Plate 3.1: Cremorne - Old style high set house on long metal poles
Collection: Miriam Middelmann

Plate 3.2: North Mackay - Old style house set on short stumps
Collection: Miriam Middelmann

Plate 3.3: Bucasia - House under construction in new estate
Collection: Miriam Middelmann

Plate 3.4: Shoal Point - House in new subdivision
Collection: Miriam Middelmann

Plate 3.5: North Mackay - Old style high set house with an enclosed lower level
Collection: Miriam Middelmann

Plate 3.6: Mackay Harbour - Bulk fuel storage
Collection: Miriam Middelmann

CHAPTER 4: EARTHQUAKE RISKS

Trevor Jones

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. The largest earthquakes are measured by the Moment Magnitude scale or the Surface Wave magnitude scale.

Descriptions of the severity of an earthquake 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, the disruption of ground conditions, and the reactions of people and animals. A full description of the Modified Mercalli Intensity scale is provided in Appendix E.

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 not 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. Instrumental recordings usually have not been available for Australian earthquakes, although they are much preferred. Furthermore, estimations of MM intensity can be seen as part of a circular argument that omits reference to the actual ground shaking. This is because the MM intensities in the scale have been defined in part from observations of damage to different types of buildings. In turn, estimates of Modified Mercalli intensity are made by comparing field observations of building damage to the scale.

The Australian continent is distant from the narrow band of earthquake activity passing through Papua New Guinea, the South West Pacific countries and New Zealand, which delineates the boundary between the Australian and Pacific plates. Mackay 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 4.1.

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events on the community ranks has made them a costly natural hazard. Recent figures put the historical cost of earthquakes in context. The Bureau of Transport Economics (2000) has 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 reliance on power, water and telecommunications lifelines, Australian communities are becoming increasingly vulnerable to the impact of earthquakes.

Table 4.1: Most-damaging Australian earthquakes, 1950-2000

Date	Location	Magnitude	Damage	
			Contemporary	1995
03-01-1954	Adelaide SA	5.4	$8.8 M	$91 M
22-05-1961	Robertson/Bowral NSW	5.6	$0.5 M	$4.2 M
14-10-1968	Meckering WA	6.9	$5 M	$35 M
10-03-1973	Picton NSW	5.5	$0.5 M	$2.9 M
02-06-1979	Cadoux WA	6.2	$3.7 M	$10 M
22-01-1988	Tennant Creek NT (3 events)	6.2, 6.3, 6.5	$1.1 M	$1.5 M
28-12-1989	Newcastle NSW	5.6	13 killed, $862 M insured damage, est. $1500 M total damage	$1800 M
06-08-1994	Ellalong NSW	5.4	$34 M	$35 M

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 a significant earthquake (possibly of magnitude slightly less than ML 6) felt in the Noosa area of southeast Queensland in 1862. This recent discovery reinforces Rynn's observation that a significant proportion of the available earthquake data for Queensland has come from reports of felt earthquakes because of the paucity of seismograph stations.

No permanent seismographs were installed in Central Queensland before the Charters Towers seismograph, operated by the University of Queensland, was installed in 1957. This seismograph is some 300 km northwest of Mackay and, although it will detect earthquakes at this distance with magnitudes larger than about Richter magnitude 3.0, such earthquakes cannot be located accurately using the Charters Towers seismograph data alone (Russell Cuthbertson, written communication, 1998). Three seismographs, optimally placed, are usually considered the minimum number required to determine the location of earthquakes. Apart from the Charters Towers seismograph, no other seismographs were installed in Central Queensland before 1981, except for a seismograph operating at Townsville from 1956 to 1965 that was used for detecting tropical cyclones (Rynn, 1987)! This long period instrument was unsuitable for detecting local, moderate magnitude earthquake activity. In 1981 the first seismograph of the Burdekin network was installed. This network monitors the safety of dams along the Burdekin River. In 1984 the first of a similar network was installed to monitor seismicity near Awoonga dam.

Table 4.2 lists the seismographs within about 500 km of Mackay and their dates of operation. Their locations are shown on Figure 4.1. Although the Burdekin and Awoonga seismographic networks have improved the capability to locate Central Queensland earthquakes, their main purpose is to locate earthquakes immediately near the dam sites, and their clustered locations gives them a poor capability to locate earthquakes further afield.

Seismographic operation in Central Queensland has had a fragmented history. At the time of writing, the Queensland government is reviewing the state's seismic monitoring and we are uncertain of how many of the seismographs shown 'Open' in Table 4.2 are operational.

Table 4.2: Seismographs within about 500 km of Mackay

Code	Site name	Operator[1]	Type[2]	Latitude °S	Longitude °E	Opening date	Closing date
CN2	Cairns-Tunnel Hill	QLD	DA	16.911	145.7105	97-03-05	Open
CN1	Cairns-Henleys Hill	QLD	DSA	16.954	145.736	97-03-07	Open
RVH	Ravenshoe	QLD/Tully	S	17.6332	145.484	90-01-16	95-00-00
BLP	Blunder Park	QLD/Tully	DS	17.758	145.4225	90-01-19	95-00-00
HRD	H Road	QLD/Tully	DS	17.76	145.65	90-01-23	95-00-00
CCQ	Carron Ck Quarry	QLD/Tully	DS	17.8493	145.5674	90-01-20	95-00-00
SCY	Sunday Creek Yard	QLD/Tully	DS	17.878	145.337	90-01-18	95-00-00
DPT	Dingo Pocket	QLD/Tully	S	17.9127	145.8227	94-00-00	95-00-00
MNH	Munroe Hill	QLD/Tully	S	17.97	145.8	90-01-21	94-00-00
BWN	Bowen	QLD	S	20.022	148.126	95-09-22	Open
CTAO	Charters Towers	QLD	DWWSSN	20.0883	146.255	62-00-00	Open
DLB	Dalbeg	QLD	S	20.151	147.264	84-04-09	Open
DBG	Dalbeg (Removed)	QLD	S	20.275	147.299	84-03-05	84-04-02
PFD	Peter Faust Dam	QLD	S	20.3858	148.3746	91-04-18	Open
BGR	Glenroy	QLD	S	20.5492	147.1052	81-02-16	Open
MCP	Mt. Cooper	QLD	S	20.552	146.806	84-02-23	Open
DNG	Doongara	QLD	S	20.555	146.475	84-02-29	Open
CVL	Collinsville (Myuna)	QLD	S	20.59	147.609	85-04-30	Open
BGC	Glendon Crossing	QLD	S	20.614	147.1609	81-02-12	85-04-29
BMG	Mount Graham	QLD	S	20.6142	147.0608	81-02-13	85-04-30
BCS	Camp Site (temporary)	QLD	S	20.6198	147.1311	81-01-11	81-01-15
BLOB	Burdekin	QLD	DS	20.625	147.121	94-00-00	Open
BLOR	Burdekin	QLD	S	20.625	147.121	94-00-00	Open
BSL	Bruslee	QLD	DS	20.867	146.564	84-03-02	Closed
UKA	Ukalunda	QLD	S	20.899	147.127	84-03-28	Open
BNG	Bungobine	QLD	S	21.344	147.3121	85-05-05	85-08-30
MHP	Mt. Hope	QLD	S	21.396	146.802	84-04-10	Open
GVA	Glen Eva	QLD	S	21.489	147.4827	86-03-18	87-06-01
BYFQ	Byfield	CQU	DS	22.82	150.626	91-08-08	92-04-09
MRVQ	Maryvale	CQU	DS	22.9548	150.6751	92-04-09	1996
GCM2	German Ck Mine	CQU	S	22.98	148.55	90-11-01	94-06-27
UCQ3	Rockhampton	CQU	S	23.321	150.5338	90-05-20	99-04-24
RCCQ	Rockhampton Council Hall	CQU	A	23.368	150.513	93-06-17	Open
RSSQ	Rockhampton Sub-Station	CQU	A	23.387	150.5	93-10-20	Open
MTMQ	Fletchers Ck/Mt Morgan	CQU/AGSO	DS	23.7627	150.3901	90-08-27	Open
AWG	Awoonga Dam	QLD	S	24.0462	151.3157	81-09-22	87-04-14
AWD	Awoonga Dam	QLD	S	24.078	151.3157	87-07-01	Open
MNT	Monto	QLD	DSA	24.855	151.141	94-00-00	Open
MPR	Mount Perry	QLD	DSA	25.198	151.731	94-00-00	Open
CRC	Cracow	QLD	DS	25.2535	150.2799	90-07-24	1994
EDV	Eidsvold	QLD	DS	25.438	150.978	94-00-00	Closed
BGD	Biggenden	QLD	DS	25.53	152.094	94-00-00	Open
TV1	Townsville	QLD	DSA	19.258	146.81	98-07-07	Open
TV2	Townsville	QLD	DA	19.287	146.772	98-07-07	Open

NOTES:
[1] QLD = QUAKES (University of Queensland), Tully = placename, CQU = Central Queensland University, AGSO = Australian Geological Survey Organisation
[2] Types are: DWWSSN = digital worldwide seismographic network station; DS = digital 3-component seismograph; DA = digital 3-component accelerograph; DSA = digital 6-component combined seismograph and accelerograph; S = vertical-component analogue (drum recorder) seismograph

Given the instrumental coverage and low population densities of the region, many small (ML ~ 3 or less) and moderate (ML up to ~ 4_) earthquakes will almost certainly have gone undetected and consequently the earthquake catalogues for Central Queensland are incomplete. Small to moderate earthquakes (e.g. with Richter magnitudes 3_ to 4_) occurring after the installation of the Charters Towers seismograph and before the mid-1980s would have been detected by that seismograph but it may not have been possible to locate all earthquakes. Some of these pre-1980s events, however, have been documented from press and other historic records (see especially Rynn, 1987, and Rynn and others, 1987).

Since the mid-1980s, by contrast, moderate and large earthquakes occurring in Central Queensland should have been located using the Australian national network of seismographs (operated by AGSO). Further, any large Central Queensland earthquakes (~ magnitude 6 or larger) should have been located by the global network of seismographs for the past 90 years or more. The Mackay region earthquake catalogue should be complete for earthquakes of these minimum magnitudes from the onset of the times mentioned. Gaull and others (1990) stated that the catalogue was complete for their northeast Queensland Zone 30, northwest of Mackay, from 1981 for earthquakes of Richter magnitude 2 to 3 and larger, and from 1945 for earthquakes of magnitudes 4 to 5 and larger. In light of the low population densities and very sparse seismographic coverage mentioned above, we consider it to be unlikely that the earthquake catalogue was complete from these dates for these magnitudes.

The significant recorded earthquakes within 200 km of Mackay are listed in Table 4.3, and the complete listing of all recorded earthquakes in the Mackay region is listed in Appendix F. This list of approximately 70 events with Richter magnitudes greater than two was compiled from the Australian Earthquake Database, maintained by AGSO, and the database of the Queensland University Advanced Centre for Earthquake Studies (QUAKES). Large open-cut coal mine blasts from collieries in the Bowen Basin to the west of Mackay have caused problems with the earthquake catalogue for the Mackay region because they are recorded by seismographs and sometimes mistakenly included in the earthquake catalogues. Our compilation from two agencies (Appendix F) has eliminated most if not all blasts.

Most historic earthquakes in Queensland have occurred within about 200 km of the coast, either onshore or offshore. There is, however, a considerable degree of uncertainty regarding the locations of Central Queensland earthquakes that occurred up to the time of installation of the Burdekin and Awoonga seismographic networks - some epicentres may be several tens of kilometres from the true locations of the earthquakes (Figure 4.1). The proximity to the coast of historic earthquake activity is reflected in the earthquake hazard contours paralleling the coast in the Queensland earthquake hazard map published as Figure 2.3(g) in Australian Standard *AS1170.4-1993 Minimum design loads on structures, Part 4: Earthquake loads* (Standards Australia, 1993), referred to by the Australian Building Code. These contours map the expected severity of earthquake ground motion across the state, expressed as an ‘acceleration coefficient’.

The Mackay Earthquake Experience

Earthquakes have occurred near Mackay but so far none has caused significant damage. Six earthquakes are known to have been felt in Mackay with a maximum intensity of MM V (Appendix E), with minor or no resultant damage. The epicentre of the 1875 earthquake is thought to have been about 100 km southwest of Mackay. Rynn and others (1987) reported that this event was the ‘first known widely felt earthquake to be reported in Queensland', although their statement precedes recent research on the 1862 event near Noosa. The 1950 ‘Mackay’ earthquake produced the highest known ground shaking intensities in Mackay, MM V. The QUAKES database reports 'minor damage' for this event but Rynn and others (1987) reported 'no damage'. They placed its epicentre in the suburb of Mackay Harbour. The 1960 ‘Mackay’ earthquake produced ground shaking intensities in Mackay of

MM IV and the QUAKES database reports 'minor damage'. The epicentre for this event is placed about 40 km offshore, east of Mackay. An aftershock of this earthquake was recorded 35 minutes later. The 1985 'Proserpine' earthquake, offshore from the Whitsunday group, was felt MM IV in Mackay.

Table 4.3: Significant historic earthquakes within 200 km of Mackay[1]

Date	**Time (UTC[2]) hr min**	**Lat. (°S)**	**Long. (°E)**	**Place**	**ML[3]**	**I_{max}[4]**	**Comments**
11-11-1875	10 50	22.0	148.5	100 km SW Mackay	4.3	IV-V	Felt MMIV Mackay. 'Minor damage'
18-12-1913	13 54	20.0	147.0	Ravenswood	5.7(I)	V	Felt MMIV Mackay
06-06-1918	18 14	23.5	152.5	Offshore Bundaberg	6.3	VI	Damage in Rockhampton and Bundaberg. Felt from Mackay to Grafton to Charleville. Widely felt in Brisbane. Felt MMIV Mackay
06-06-1918	18 15	23.5	152.5	Offshore Bundaberg	5.1	III	Not felt Mackay
06-06-1918	18 23	23.5	152.5	Offshore Bundaberg	5.5	III-IV	Not felt Mackay
06-06-1918	19 00	23.5	152.5	Offshore Bundaberg	5.1	III	Not felt Mackay
06-06-1918	19 20	23.5	152.5	Offshore Bundaberg	5.7	III-IV	Not felt Mackay
06-06-1918	19 45	23.5	152.5	Offshore Bundaberg	5.1	III	Not felt Mackay
06-06-1918	20 15	23.5	152.5	Offshore Bundaberg	5.1	III	Not felt Mackay
07-03-1922	16 54	23.5	152.5	Rockhampton	4.5	?	
05-04-1950	19 50	21.2	149.2	Mackay	4.5	V	Felt MMV Mackay. 'Minor damage'
19-10-1960	11 37	21.1	149.5	Mackay	4.5	V	Felt MMIV Mackay. 'Minor damage'
28-11-1978		23.34	152.52	Heron Island	4.5	V	Not felt Mackay
02-08-1985	12 16	19.44	149.20	Proserpine	4.7	IV	Felt MMIV Mackay
27-09-1987	16 01	19.30	147.83	Ayr	4.6		
02-11-1998	17 09	22.81	151.15	Yeppoon	4.7		Not felt Mackay

NOTES:

1 Earthquakes ML ≥ 4 and earthquakes felt at, or near Mackay. Sources: Australian Earthquake Database (AGSO); database of the Queensland University Advanced Centre for Earthquake Studies (QUAKES); Everingham and others, 1982; Rynn, 1987; Rynn and others, 1987; McCue, 1996

2 UTC - Coordinated Universal Time = Australian Eastern Standard Time minus 10 hours

3 ML - Richter (or local) magnitude. The term (I) indicates a magnitude calculated from the radius of the felt effects of the earthquake

4 I_{max} - Maximum seismic intensity measured on the Modified Mercalli Scale (see Appendix E)

Two strong earthquakes are known to have occurred in Central Queensland. The epicentre of the Richter magnitude 5.7 Ravenswood earthquake of 18 December 1913 was about 250 km northwest of Mackay. This earthquake was felt over a large part of Central Queensland, including Mackay, although apparently without causing damage (Rynn and others, 1987). A significant earthquake sequence occurred offshore from Bundaberg on 6 June 1918. The mainshock had a Richter magnitude of 6.3 and although the event was about 700 km from Mackay it was felt in Mackay. Six aftershocks larger than Richter magnitude 5 occurred on the same day. The 1913 and 1918 earthquakes demonstrate that potentially damaging earthquakes do occur in Queensland and their occurrence near Mackay should not be discounted.

Isoseismal maps showing the distribution of seismic intensities recorded from the 1875, 1913, 1918, 1950, 1960, 1978 and 1985 earthquakes have been published (Everingham and others, 1982; Rynn and others, 1987; McCue, 1996).

Earthquake hazard in Mackay

Earthquake hazard in the Mackay region

Three estimates of earthquake hazard have been published for the region that includes Mackay. All estimates relate to a 10% probability of exceedence in 50 years at 'rock' or 'firm' sites. This probability corresponds to an Annual Exceedence Probability (AEP) of approximately 1/475, or an average recurrence interval (ARI) of 475 years. We have taken the 475-year ARI to be equivalent to a 500-year ARI for the purposes of comparison with flood and wind hazards in Chapter 5, Chapter 6 and Chapter 7.

The first estimate of hazard is found in *AS1170.4-1993* and is the one we have adopted. An 'acceleration coefficient' of 0.075 for the Mackay area was estimated from Figure 2.3 (g) of the standard. This value is equivalent to a peak horizontal ground acceleration (PGA) of 0.075 g, where 'g' is the acceleration experienced at the earth's surface under gravity.

The second estimate of hazard originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.15 g on rock, in line with their estimates of PGA for Queensland two to three times higher than previous estimates.

The third estimate is found in the work of Gaull and others (1990). The earthquake hazard maps in *AS1170.4-1993* were derived from this work. It is worth noting that Gaull and others (1990) treated the Mackay area as part of the eastern Australian area of 'background' seismicity because the area had 'sparse or no known seismic activity', although about 15 years of extra data have now become available since their analysis. A comparison of the three results is given in Appendix G.

The magnitude of the maximum probable earthquake has a moderate effect on earthquake hazard estimates. Gaull and others (1990) estimated maximum magnitude for the Mackay area to be magnitude 5.5. This value is too low and the estimate of Cuthbertson and Jaume (1996), magnitude 7, is more appropriate.

The earthquake hazard for Mackay is low to moderate by global standards (Giardini and others, 1999). 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. 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.

Urban earthquake hazard in Mackay

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 city, primarily because of local 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. Urban earthquake hazard maps attempt to quantify these differences.

An urban earthquake hazard map (or urban earthquake shaking map) for Mackay is shown in Figure 4.2. This map indicates areas of Mackay where potential earthquake shaking is expected to be relatively weaker or stronger. It was prepared using the draft 1:100 000 scale geological map for Mackay (Figure 2.3; von Gnielinski, unpublished), geological data from borehole logs, and microtremor data from recordings of low level 'background' ground vibrations. Appendix G describes the methods used to prepare the urban hazard map.

NOTE: Limitations of the earthquake hazard maps

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

The Mackay map has been divided into three site classes that determine the relative severity of earthquake shaking (Site Classes B - D in Table 4.4).

Table 4.4: Site classifications for the Mackay earthquake hazard map

Site class	Description	Mackay setting
A	Hard rock	Not identified in Mackay. Insufficient information to distinguish this site class from Site Class B
B	Rock	Extensive rock outcrop in northern suburbs including Glenella, Mount Pleasant, North Mackay, Beaconsfield, Eimeo, Dolphin Heads, Shoal Point and Rural View
C	Hard and/or stiff/very stiff soils; mostly gravels	Small areas of higher foothill slopewash gravels, sands and silts
D	Sands, silts and/or stiff/ very stiff clays, some gravels	Widespread areas of floodplain alluvium, estuarine sediments, Holocene and Pleistocene beach sand deposits south of Pioneer River and in coastal northern suburbs
E	Profile containing at least 3 m of soft /medium stiff clay	Not identified in Mackay but could exist in largely-unpopulated estuarine areas

Sites requiring special consideration (Site Class F), including sites vulnerable to potential failure or collapse under seismic loading (liquefiable sediments, quick and highly sensitive clays, etc.), peats and/or highly organic clays, very high plasticity clays, and very thick 'soft/medium stiff clays', have not been identified in the zonation maps although they may well exist in Mackay.

The relative strength of shaking is described by amplification factors for each site class. Table 4.5 lists the amplification factors that apply for Mackay (refer to Appendix G for details).

Different amplification factors apply to different periods of vibration of ground shaking and to different severities of ground shaking (Table 4.5).

The amplification factors (Table 4.5) describe the increases in the severity of earthquake shaking on Site Classes C and D in Mackay compared to rock. The least severe level of shaking, Spectral Acceleration ≤ 0.25 g, includes all of our earthquake scenarios except the ARI = 2500 year scenario.

Table 4.5: Amplification factors for Mackay site classes (modified from Building Seismic Safety Council, 1997)

Site Class B Spectral Acceleration	Site Class				
	A[1]	B	C	D	E[1]
Short-Period (T=0.3 s) (g)	**Short-period Amplification Factor**				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8
Mid-period (T=0.7 s) (g)	**Mid-period Amplification Factor**				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0

NOTE: [1] Not mapped in Mackay

Earthquake motion described in terms of spectral parameters is useful to engineers. Spectral acceleration is the maximum acceleration of an idealised 1-dimensional 'structure' relative to its 'foundations'. Similarly spectral displacement is the maximum lateral displacement of an idealised 1-dimensional 'structure' relative to its 'foundations'. The period T is the time taken to complete one cycle of vibration.

The short period amplification factors indicate a difference in hazard by a factor of up to 1.6 for different parts of Mackay. That is, the shaking on the Pioneer River floodplain and on coastal sediments would be 1.6 times stronger than the shaking on rock. Short period shaking could affect low-rise buildings (one to three storeys). The short period amplification factors are comparable to the Site Factors in *AS1170.4-1993.*

All suburbs south of the Pioneer River including Central Mackay, West Mackay and South Mackay, and most parts of the coastal northern suburbs, notably Andergrove, Mackay Harbour, Slade Point and Bucasia, will have shaking 1.6 times stronger than the shaking at suburbs on rock such as Mount Pleasant, North Mackay, Rural View and Glenella during the same earthquake. More correctly, this would be the case for a probabilistic earthquake scenario, independent of the location of the earthquake source. The outcome for any particular earthquake 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.

The factor of 1.6 mentioned above between the strength of ground shaking on rock and sediments could, in fact, be higher in Mackay. Hard bedrock will increase the relative amplification factors between sediment and rock sites to a factor of 1.6 / 0.8 = 2 (Table 4.5), and this may well be the case for Mackay. We had insufficient evidence to classify rock units in Mackay as 'Hard rock' (Site Class A) although Zammit (1995) estimated bedrock shear wave velocities consistent with Site Class A at three sites. We chose to use Site Class B for all rock outcrop in Mackay.

Earthquake hazard scenarios for Mackay

We generated six probabilistic, ground shaking scenarios, with average recurrence intervals (ARI) of 100, 200, 475 (notionally 500), 1000, 2000 and 2500 years.

The multipliers that we used to generate the ground shaking scenario with an ARI of 500 years to ground shaking for other average recurrence intervals are shown in Table 4.6. These multipliers are provisional values used in the revision of *AS1170.4-1993* (Kevin McCue, verbal communication, 2000).

Table 4.6: Provisional multiplying factors for Australian regional earthquake hazard

ARI (yr)	100	200	500	1000	2000	2500
Multiplier	0.2	0.6	1	1.4	1.75	2

The spectral values for each scenario are shown in Table 4.7. The method of preparing the earthquake hazard scenarios is described in Appendix G.

Table 4.7: Earthquake hazard scenarios for Mackay

ARI (yr)	**Site Class B**					**Site Class C**					**Site Class D**				
		T=0.3 s		**T=0.7 s**			**T=0.3 s**		**T=0.9 s**			**T=0.3 s**		**T=1.0 s**	
	PGA (g)	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**
100	0.02	0.03	0.06	0.01	0.15	0.02	0.03	0.08	0.01	0.25	0.02	0.05	0.10	0.01	0.35
200	0.05	0.09	0.19	0.04	0.44	0.05	0.10	0.23	0.04	0.75	0.07	0.14	0.31	0.04	1.06
475	0.08	0.14	0.32	0.06	0.73	0.09	0.17	0.39	0.06	1.25	0.12	0.23	0.52	0.07	1.76
1000	0.11	0.20	0.45	0.08	1.03	0.13	0.24	0.54	0.09	1.75	0.17	0.32	0.72	0.10	2.47
2000	0.13	0.25	0.56	0.11	1.29	0.16	0.30	0.68	0.11	2.19	0.21	0.40	0.90	0.12	3.09
2500	0.15	0.29	0.65	0.12	1.47	0.18	0.35	0.77	0.12	2.50	0.23	0.43	0.97	0.13	3.23

NOTE: ARI = average recurrence interval; T = Period of vibration of ground shaking in seconds; PGA = Peak Horizontal Ground Acceleration as a proportion of g, the acceleration due to gravity; SA = Spectral Acceleration; SD = Spectral Displacement.

Resonant ground shaking in Mackay sediments

The alluvial, estuarine and marine sediments underlying most of Mackay have thicknesses up to about 40 m. We are grateful to Queensland Department of Natural Resources (DNR) whose database of more than 2000 groundwater boreholes in the Mackay City area provided comprehensive information on the sediments and their thicknesses (Figure 4.3). Their database was very useful in preparing the urban earthquake hazard map for Mackay (Figure 4.2).

The earthquake response of these sediments may strongly influence building damage caused by any future earthquake, especially damage to low rise and medium rise buildings. In the simplest case, these sediments may resonate with characteristic periods of vibration when excited by seismic waves.

Underlying the Mackay sediments is geological basement with very strongly contrasting seismic properties. In general terms, the sediments form a fairly uniform veneer over basement rock. This set of conditions is strongly conducive to set the sediments resonating at their fundamental and harmonic frequencies. Amplification factors could be higher than those in Table 4.5.

Structures on top of the sediments and 'in tune' with them, i.e., vibrating with a period close to the period of a mode of vibration of the ground, can transfer significant amounts of seismic energy from the ground into larger and larger displacements of their own motions with consequent increased damage.

The map of natural resonant period of ground vibration for Mackay (Figure 4.4) supplements the urban earthquake hazard map. It provides information on the fundamental period of vibration of the ground during earthquake shaking. It also provides information on the potential for increased damage to buildings due to the increased possibility of resonance between the ground and the buildings on it during earthquakes. The natural period of vibration of the ground was measured by recording microtremors (very weak motion of the ground caused by 'background' noise from traffic, wind, surf, etc.) with portable seismographs in an AGSO field survey in 1997. About 230 point values of natural ground period recorded at nominal 500 m intervals in Mackay were contoured to produce the map.

The natural period of vibration of sediments in Mackay is remarkably uniform ($T \sim 0.3$ seconds) across large areas both north and south of the Pioneer River (Figure 4.4). Low rise buildings are likely to be affected by resonant vibrations of $T \sim 0.1$-0.3 seconds. The single value of $T = 2$ seconds recorded at Mackay airport seems high, even though the sediments there are probably the thickest in Mackay. Further measurements would give a better indication of natural period near the airport (Figure 4.3).

Mackay exposure to earthquakes

The greatest threat that earthquakes pose comes from damage to buildings. Our earthquake risk for the Mackay community is based very largely on scenario analysis of building damage in Mackay. The risk is a function of the building types, their damage states, building usage and the potential for community disruption and business interruption through building damage.

The methods of HAZUS® (FEMA, 1999) were used to derive building damage scenarios for Mackay. HAZUS® is a comprehensive earthquake loss assessment software package that can be used to estimate the probabilities of economic and social losses from earthquake.

The building damage assessment method comprises three steps, as follows.

- A building database was developed that categorises buildings into types based on their load bearing elements. This revised Mackay building database is described below.
- The response of building types to the earthquake demand loads placed on them was determined by the earthquake scenarios we set. The procedures used are based on the HAZUS® (FEMA, 1999) methods and are described in Appendix H.
- The probability of buildings being in damage states *nil*, *slight*, *moderate*, *extensive* and *complete* was determined when subjected to earthquake demand loads by the earthquake scenarios that we set.

Mackay building database

We used the Mackay building database (Appendix B) in our assessment. However, to assess building vulnerability to earthquakes, information is needed on the type of load-bearing structural frames or walls and this information is not explicit in the Mackay database. Instead, the Mackay building database, being compiled from field observations of building exteriors, provides details of wall cladding material rather than construction type.

The importance of assessing building damage using the types of load bearing elements of a building rather than simply the wall cladding is seen in the following example. In the 1989 Newcastle earthquake, cavity brick houses performed about twice as poorly as brick veneer, in terms of percentage losses of their total insured value. Houses with timber frames (brick veneer, fibro and timber cladding) all performed similarly (Blong, 1998). There is, nevertheless, a reasonably good agreement between the type of wall cladding and construction type in Mackay.

We grouped Mackay buildings into building categories based on load-bearing frames or walls. The building categories found in Mackay are described below.

Light timber frame buildings: Most Mackay buildings are of this type. These low rise buildings have timber, brick, fibro or metal exterior cladding. Most are residential buildings, or ex-residential buildings used for other purposes such as businesses. In Mackay the great majority have corrugated steel roofs.

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 tropical Australia but not elsewhere in Australia or in many other countries. Many older (pre-war) 'Queenslander' timber houses (Plate 3.1 and Plate 3.2) are found in Mackay. Most of these are in older suburbs such as North Mackay, South Mackay, Central Mackay, West Mackay, East Mackay, and Slade Point. Another distinct house type is found mainly in the older parts of suburbs such as Andergrove and Beaconsfield. This type is high set, with fibro walls and low pitched metal clad gable roof and small windows (Plate 3.5).

Together these two building types comprise about 13.7% of the Mackay stock. 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, verbal communication, 1999). It has been argued that these houses have demonstrated their resistance to cyclones, if not earthquakes, through having survived many events. 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' in the Mackay building database could include both cavity brick and brick veneer construction types. We made the assumption that all 'brick' houses and low-rise flats 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.

Metal wall cladding is found on timber frame houses, both new and old, and also covers light steel frames on low-rise factories, small businesses, warehouses, etc. We assumed that residential buildings (houses or blocks of flats) with metal cladding have timber frames and that all other metal-clad buildings have light steel frames.

Reinforced masonry buildings with reinforced concrete floors (concrete block buildings with concrete slab floor): Reinforced concrete block is the second most common type of construction in Mackay (Plate 4.1), although the total of approximately 1180 buildings is far outnumbered by buildings with timber frames. About 60% of these concrete block buildings are residential. 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. About 340 non-residential concrete block buildings were built before 1986 and some of these will not comply with wind loading provisions of the Queensland Building Act.

Light steel portal frame buildings: These buildings are used primarily for business, industry, storage and transport and logistics purposes. They are largely prefabricated and have a repetitive, moment resisting, portal frame with bracing at right angles. The rear wall is often braced. Cladding is usually steel sheet.

Reinforced concrete frame with unreinforced masonry infill panels: This type of construction has been popular for public works-related buildings such as hospitals and schools (Plate 4.2). 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. However, 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, 1990). Only one precode 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 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, verbal communication, 1999). Most unreinforced masonry buildings in Mackay are used as commercial premises.

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 marine Mackay 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.

Tilt-up concrete shear wall construction: This type of construction is becoming increasingly popular for low rise commercial and industrial facilities. Walls are massive but thin and are prefabricated to improve quality control and ease of manufacture. We have not identified any such buildings in our Mackay database but that is almost certainly a fault of our database rather than due to the fact that these buildings do not exist in Mackay.

Reinforced concrete shear walls: These structures have massive shear walls poured in situ and in Mackay have special purposes such as water reservoirs and silos at Mackay Harbour. We expect them to perform well in the non-extreme earthquake loading scenarios included in this study, and, because of their low numbers, special uses and low vulnerability, we have not included them in our damage scenarios.

The revised building database for Mackay (Table 4.8) shows that the most common construction types of buildings in Mackay are:

- timber frame buildings, domestic and non domestic (89%);
- concrete block masonry (5.8%);
- light steel frame buildings used for small business and factories, etc. (2.5%); and
- a undifferentiated group of unreinforced masonry buildings and buildings with reinforced concrete frames with unreinforced masonry infills (1.5%).

Table 4.8: Mackay building inventory by site class. See Table 4.4 for an explanation of the site classes. See text for definitions of *Post-code* and *Precode*.

Construction type and usage	**Site Class** B	C	D	**Total**
Post wind standard (*Post-code*), after 1985, residential and non residential light timber frame with fibro, timber or metal cladding	277	5	591	873
Post-code, after 1985, residential and non residential light timber frame with brick cladding (brick veneer)	2379	26	3009	5414
Pre wind standard (*Precode*), before 1986, residential and non residential light timber frame, fibro, timber, brick or metal cladding	2429	39	9748	12216
Light steel frame, non-residential; mostly commercial, logistic and industrial	19	-	501	520
Reinforced concrete frame & unreinforced masonry infill; mostly hospital and educational		-	~40	~40
Post-code reinforced masonry (concrete block) after 1985	141	10	281	432
Precode reinforced masonry (concrete block) before 1986	127	5	631	763
Unreinforced masonry (estimated)	-	-	~270	~270
Other				206
Total				20734

The remainder, comprising only 1% of the total Mackay building stock, is:

- low and medium rise concrete shear walled buildings;
- low rise concrete tilt-up buildings; and
- other types.

Building age and seismic resistance

In 1975, as a consequence of Cyclone *Tracy,* wind loading provisions were included in the Queensland Building Act. The cyclone resistance of some classes of buildings was significantly upgraded in 1982 with the introduction of Appendix 4 of the Queensland Building Act on 1 July. Improvements were made to the cyclone resistance of non-domestic buildings with light timber frames (George Walker, verbal communication, 1999). Importantly, for the first time, domestic buildings were described by the act.

The Mackay building database generally classifies buildings constructed prior to 1986 as ‘Age = C’ with no further definition. In our assessments we have considered buildings constructed prior to 1986 as *Precode* and vulnerable to earthquake shaking. This is not strictly accurate because non residential buildings constructed prior to 1986 would have been constructed in accordance with contemporary wind loading provisions of the Queensland Building Act. However, their numbers are small and we do not have specific age data for these buildings.

Buildings constructed after 1985 were considered *Post-code* and more earthquake resistant than buildings constructed earlier. *Post-code* brick veneer buildings were modelled as slightly more vulnerable than other timber frame buildings because of their massive, brittle, brick cladding.

Reinforced masonry (concrete block) buildings were all classified as *Post-code.* Again, we did not have building age data to distinguish between those built to comply with the Queensland Building Act and those not.

Buildings with light steel frames were considered as *Post-code* in that they have been 'engineered'.

Unreinforced masonry buildings were considered *Precode*. Buildings with reinforced concrete frames were considered to have some seismic resistance in that most were probably designed to resist wind loadings.

Consequence of earthquakes in Mackay

A summary of the building damage generated by earthquake shaking scenarios with likelihoods ranging from ARI = 100 years to ARI = 2500 years is shown in Figure 4.5 and Table 4.9.

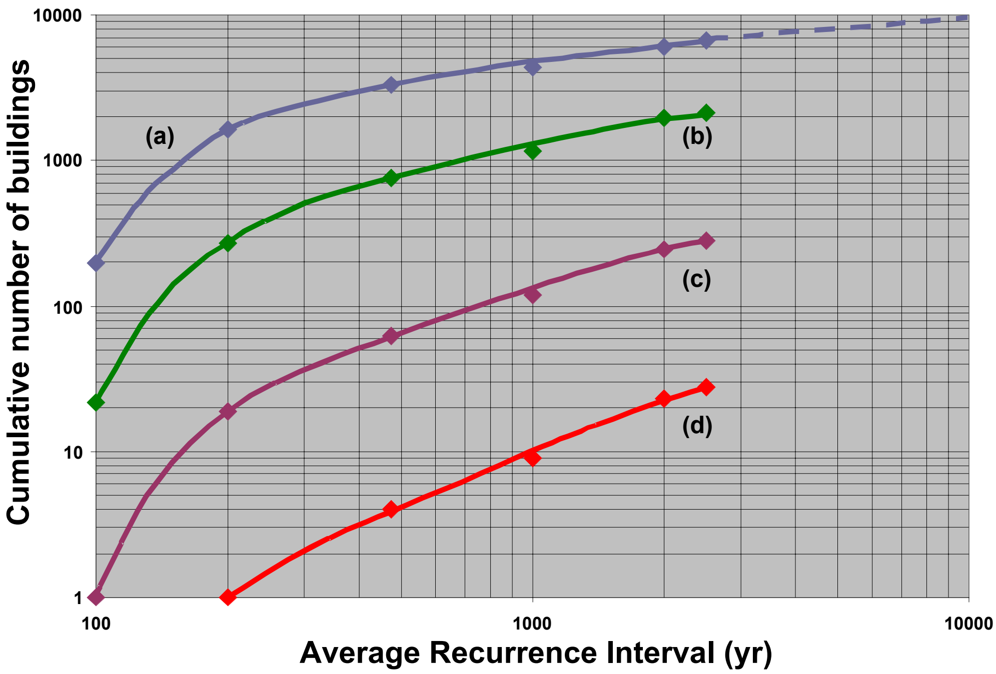


Figure 4.5: Mackay building damage scenarios with average recurrence intervals in the range 100 years to 2500 years. Damage states are (a) *slight*; (b) *moderate*; (c) *extensive*; (d) *complete*. The curves refer to the numbers of buildings in a particular damage state or a more severe state.

Earthquake scenario ARI = 100 years: The earthquake scenario in Mackay with an ARI = 100 years is mild. About 200 buildings, comprising about 1% of the building stock, are expected to sustain damage, about 90% of which will be minor. Most damaged buildings will be residential and most will be located in South Mackay, West Mackay, Central Mackay and Andergrove. Only about 22 buildings are expected to suffer *moderate* damage or more severe damage.

Earthquake scenario ARI = 200 years: In this earthquake scenario about 1600 buildings, comprising about 8% of the building stock, are expected to sustain damage, about 80% of which will be minor. Most damaged buildings will be residential and most will be located in South Mackay, West Mackay, Central Mackay and Andergrove. About 270 buildings, or about 1.3% of the building stock, are expected to suffer *moderate* damage or more severe damage.

Table 4.9: Earthquake damage scenarios for buildings in Mackay. For damaged buildings, counts refer to the numbers of buildings in the damage state or a more severe damage state.

ARI	Nil damage		Slight damage		Moderate damage		Extensive damage		Complete damage	
	No. Bldg.	% of total	No. Bldg.	% of total	No. Bldg.	% of total	No. Bldg.	% of total	No. Bldg.	% of total
100	20 321	97.9%	197	1.0%	22	0.1%	1	0.0%	0	0.0%
200	18 882	91.1%	1636	7.9%	270	1.3%	19	0.1%	1	0.0%
475	17 235	83.1%	3282	15.8%	752	3.6%	62	0.3%	4	0.0%
1000	16 159	77.0%	4359	21.0%	1153	5.5%	119	0.6%	9	0.0%
2000	14 424	69.6%	6095	29.4%	1939	9.2%	243	1.2%	23	0.1%
2500	13 875	66.9%	6645	32.1%	2127	10.1%	282	1.4%	28	0.1%

Earthquake scenario ARI = 475 years: This earthquake scenario, with an ARI = 475 years or a 10% probability of exceedence in 50 years, is the 'building code' scenario. About 3280 buildings, comprising about 16% of the building stock, are expected to sustain damage, about three quarters of which will be minor. About 750 buildings, comprising about 3.6% of Mackay building stock, will sustain *moderate* or more severe damage. Most damaged buildings will be residential and more than 100 buildings will be damaged in South Mackay, West Mackay, Central Mackay, North Mackay, Andergrove, Slade Point, Beaconsfield, Bucasia, Mount Pleasant and Ooralea.

Earthquake scenario ARI = 1000 years: In this earthquake scenario about 4360 buildings, comprising about 21% of the building stock, are expected to sustain damage, about three quarters of which will be minor. About 1150 buildings, comprising about 5.5% of Mackay building stock, will sustain *moderate* or more severe damage. Most damaged buildings will be residential. More than 100 buildings will suffer *moderate* or more severe damage in South Mackay, West Mackay, Central Mackay, Andergrove and North Mackay.

More than 100 buildings will be *extensively* damaged. About half of these will be located in Central Mackay, West Mackay and South Mackay. In Central Mackay these buildings are most likely to be business premises, constructed before 1985 of unreinforced masonry. In West Mackay and South Mackay these buildings most likely will be residential, constructed before 1985 with timber frames.

Earthquake scenario ARI = 2000 years: In this earthquake scenario about 6100 buildings, comprising about 29.4% of the building stock, are expected to sustain damage, about two thirds of which will be minor. About 1940 buildings, comprising about 9.2% of Mackay building stock, will sustain *moderate* or worse damage. Most damaged buildings will be residential. More than 200 buildings will suffer *moderate* or more severe damage in South Mackay, West Mackay, Central Mackay, Andergrove, North Mackay and Slade Point.

More than 200 buildings will be *extensively* damaged. About half of these will be located in Central Mackay, West Mackay and South Mackay. In Central Mackay these buildings most likely will be business premises, constructed before 1985 of unreinforced masonry. In West Mackay and South Mackay these buildings most likely will be residential, constructed before 1985 with timber frames.

Earthquake scenario ARI = 2500 years: In this earthquake scenario about 6650 buildings, comprising about 32.1% of the building stock, are expected to sustain damage, about two thirds of which will be minor. About 2130 buildings, comprising about 10.1% of Mackay building stock, will sustain *moderate* or more severe damage. Most damaged buildings will be residential. More than 100 buildings will suffer *moderate* or more severe damage in South Mackay, West Mackay, Central Mackay, Andergrove, North Mackay, Slade Point and East Mackay.

More than 250 buildings will be *extensively* damaged. More than half of these will be located in Central Mackay, West Mackay, South Mackay, Andergrove and North Mackay. In Central Mackay these buildings most likely will be residential, constructed before 1985 with timber frames, or business premises constructed before 1985 of unreinforced masonry. In West Mackay, South Mackay Andergrove and North Mackay these buildings most likely will be residential, constructed before 1985 with timber frames.

About 30 buildings are expected to be *completely* damaged. More than two thirds of these buildings are likely to be pre-1985 timber framed residential buildings, located in West Mackay, South Mackay, Andergrove and North Mackay, or unreinforced masonry business premises in Central Mackay.

More extreme scenarios: The consequence of earthquakes in Mackay continues to increase with increasing rarity of occurrence beyond the ARI = 2500 year scenario. For example, the ARI = 10 000 year earthquake scenario produces at least *slight* damage to an estimated 9500 buildings (about 45% of the building stock; see Figure 4.5).

A 'deterministic', or one-off, earthquake scenario could be generated that would also cause more damage than the ARI = 10 000 year probabilistic scenario. The scenario for a Richter magnitude 7 earthquake occurring within about 15 km of Mackay would be one such case.

Exposure of individual Mackay suburbs to earthquake

Our estimates of building damage were aggregated to suburban level for four scenarios: ARI = 100, 475, 1000 and 2500 years. The consequence is measured in terms of the numbers of buildings that will be *moderately* or more severely damaged (Figure 4.6). This measure may be an appropriate guide to the numbers of buildings that could need inspection by qualified personnel with regard to their safety following an earthquake. Many more buildings will suffer *slight* damage (generally minor cracking) in any given scenario but buildings in this damage state will not threaten the safety of occupants and they can continue to be occupied following the event.

The ranking of suburbs by their exposure to earthquake (Table 4.10) is entirely dependent on building numbers, building types and localised ground conditions, and is especially sensitive to the age of buildings (and in turn related to the introduction of wind and earthquake loading requirements).

There is a very strong contrast in exposure to earthquake between the most exposed quartile of suburbs (South Mackay, West Mackay, Central Mackay, Andergrove, North Mackay, Slade Point, East Mackay) and the lowest quartile of suburbs, the latter because of their low populations.

The exposure ranking of suburbs is stable across scenarios with ARIs of 475 years to 2500 years; that is, regardless of the degree of resultant damage. With increasingly extreme scenarios (beyond those we have modelled), the rank of Central Mackay would rise because of the concentration of unreinforced masonry buildings and concrete block buildings in it. This is because our modelling indicates that unreinforced masonry and concrete block buildings will suffer disproportionately heavier damage, compared with other building types, in increasingly severe earthquake shaking scenarios.

Scenario Mean Damage Ratio estimate for Mackay timber frame residences

We calculated the Scenario Mean Damage Ratio (MDR) for timber frame residential buildings in Mackay (houses and blocks of flats). These buildings comprise 87% of all buildings in Mackay. The Scenario MDR is defined as:

Scenario MDR = cost of repair or replacement / total value (total replacement cost).

The cost of repair comprises costs to repair both structural damage and non-structural damage to buildings. 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 do not include building contents.

Table 4.10: Ranking of Mackay suburbs for exposure to earthquake through building damage. Numbers of buildings estimated to be in damage state *moderate* or more severe are shown for scenarios with ARIs 100 to 2500 years

Suburb	ARI (yr)				Rank
	100	475	1000	2500	
Andergrove	2	85	130	243	4
Bakers Creek	0	14	21	37	13
Beaconsfield	0	19	24	55	11
Blacks Beach	0	9	15	28	15
Bucasia	0	29	45	85	8
Central Mackay	4	91	151	262	3
Cremorne	0	1	2	4	21
Dolphin Heads	0	1	1	3	23
East Mackay	1	51	76	136	7
Eimeo	0	10	14	30	14
Erakala	0	0	0	0	26
Foulden	0	0	0	0	27
Glenella	0	7	11	25	16
Mackay Harbour	0	6	13	24	17
Mount Pleasant	0	22	27	60	10
Nindaroo	0	0	1	2	24
North Mackay	2	73	107	203	5
Ooralea	0	23	36	66	9
Paget	0	12	25	46	12
Racecourse	0	2	3	6	20
Richmond	0	0	0	1	25
Rural View	0	3	4	11	19
Shoal Point	0	4	7	14	18
Slade Point	0	56	86	156	6
South Mackay	4	120	179	323	1
Te Kowai	0	1	2	4	22
West Mackay	3	114	174	312	2

The Scenario Mean Damage Ratio is derived from the damage states of the buildings. For both structural and non-structural damage, repair costs that contribute to the total costs were calculated as follows.

Slight damage	2% of total repair cost
Moderate damage	10% of total repair cost
Extensive damage	50% of total repair cost
Complete damage	100% of total repair cost

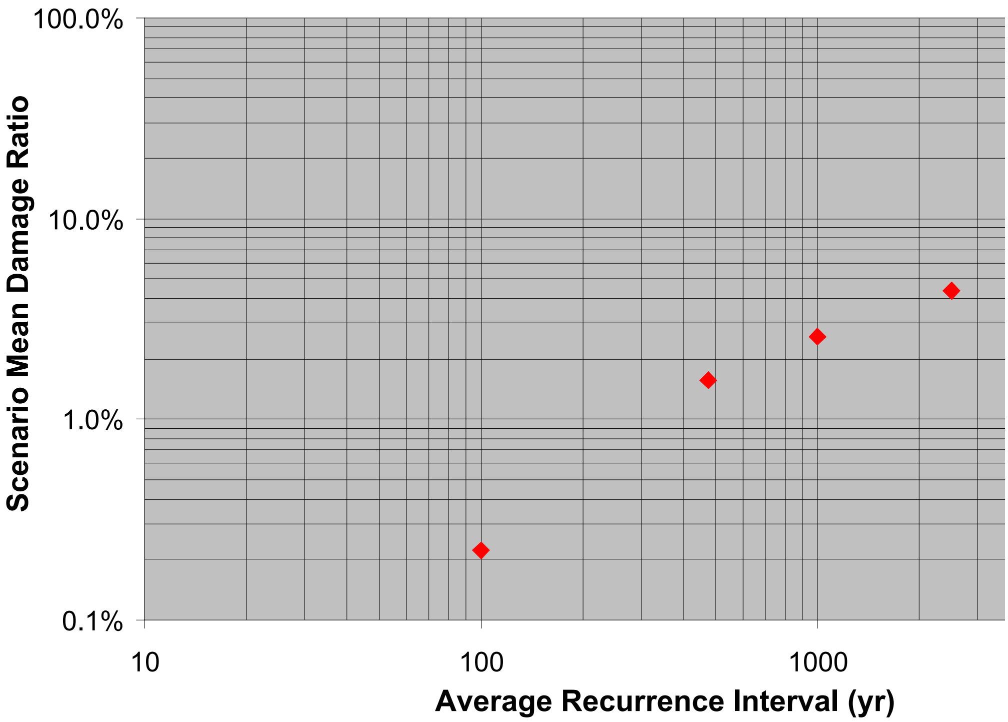
Repair costs are apportioned as follows.

Structural damage	15/64 of total cost to repair buildings

Non-structural acceleration-sensitive damage	17/64 of total cost to repair buildings
Non-structural displacement-sensitive damage	32/64 of total cost to repair buildings

These repair cost ratios are taken from HAZUS® (FEMA, 1999). The Scenario Mean Damage Ratio estimates for scenarios with ARI = 100, 475, 1000 and 2500 years are shown in Figure 4.7.

Figure 4.7: Scenario Mean Damage Ratio for timber frame residential buildings in Mackay



The estimates of Scenario Mean Damage Ratio can be converted very easily to expected direct losses by inserting replacement costs appropriate to Mackay. A surcharge for demolition, debris removal and administrative costs could be applied.

We estimate Scenario Mean Damage Ratios of 1.6% for the ARI = 475 year scenario and 4.4% for the ARI = 2500 year scenario. These values are higher than the values calculated for timber frame buildings damaged by the 1987 Edgecumbe, New Zealand, earthquake (Dowrick and Rhoades, 1990). For example, Dowrick and Rhoades (1990) calculated a Mean Damage Ratio of about 1% for Modified Mercalli Intensity VIII shaking. Intensity MM VIII approximates the Peak Ground Acceleration of 0.23 g that drives the Mackay ARI = 2500 years scenario on Site Class D.

Our Scenario Mean Damage Ratios estimates are considerably lower than the calculation of Blong (1998). He estimated a Mean Damage Ratio of about 9% for timber framed domestic buildings subject to shaking of intensity MM VIII in the 1989 Newcastle earthquake. The Newcastle repair costs may have been extraordinarily high, aggravated by poor building condition and repairs to damage not caused by the earthquake.

Earthquake risk based on building usage

Damage will occur mostly to buildings located on the sediments in Mackay. This is because the sediments increase the ground shaking severity and most of Mackay's vulnerable buildings (those predating wind and earthquake loading provisions) are built on them. Two factors, building vulnerability and location increase the risk to people occupying these buildings.

An overwhelming 96% of critical facilities including electric power substations, bulk food and fuel distributors and transport-related features are located on sediments in Mackay, compared to 73% of all Mackay buildings (Figure 4.8).

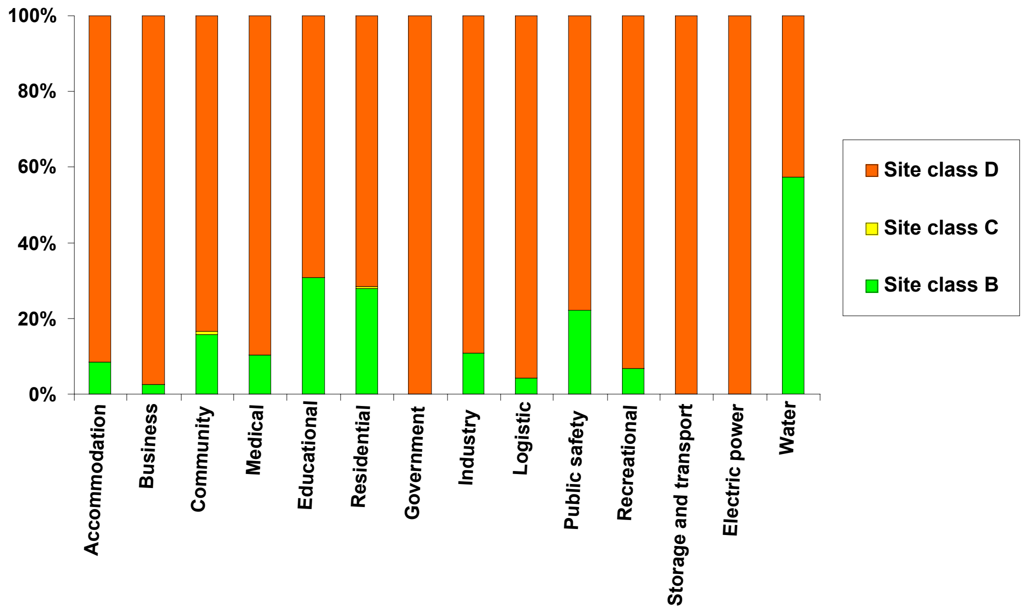


Figure 4.8: Building usage and earthquake site class relationships

Some community functions in Mackay are particularly at risk from earthquake because the structures that house them are vulnerable and the buildings are predominantly located on sediments. Usage groups predominantly housed in these structures will have a higher risk than the average for Mackay. The Mackay community may depend strongly on some of these usage groups in the event of an emergency.

All electric power distribution facilities are located on sediments including substations at West Mackay, Central Mackay, Port Mackay and Andergrove, the Mackay Electricity Board building in Central Mackay and the Ergon depot in West Mackay. Transformers, ceramic insulators and switchgear are at increased risk through the location of the facilities. About half of the buildings also may be vulnerable unreinforced masonry and *Precode* concrete block (we cannot be certain using the information in the Mackay database). Many other user groups depend on electric power to maintain their daily functions.

The capability to provide medical treatment in an emergency also may be threatened. Ninety percent of hospitals, pharmacies, old people's homes and surgeries are located on sediments. An estimated two-thirds of medical buildings predate wind and earthquake loading provisions. The seismic and wind resistance of the Mackay Base Hospital, a concrete-framed building with unreinforced masonry panels (Plate 4.2) may need to be investigated. Emergency electric power generating plant may not have seismically resistant mountings.

Business function in Mackay may be particularly at risk following a strong earthquake. About 97% of businesses are located on sediments. At least 51% of the buildings housing them are *Precode*, and about 60% of all unreinforced masonry buildings in Mackay have a business function (many of them in Central Mackay). Direct economic and social losses through business interruption following earthquake could add substantially to the total risk facing the community.

A number of key buildings with a public safety function are constructed of unreinforced masonry and are located on sediments. They include the SES headquarters, the Mackay Police Station, the Mackay Fire Station, and the Mackay Ambulance Station (all in Central Mackay). The structural integrity of these buildings, and the continued functioning of their fittings, is critical for emergency response.

All buildings with a 'government' function are located on sediments. They include local, state and federal buildings housing administrative, judiciary, port and maintenance functions. At least one third of these buildings are thought to be *Precode*. Damage to government buildings is likely to impair community recovery more than community response.

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 (*Precode*) unreinforced masonry or soft storey reinforced concrete buildings was about 3 in 10,000 for earthquake shaking of MM VIII.

Dowrick (1998) 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 much higher intensity of ground shaking (MM IX) than our most extreme scenario (ARI = 2500 years).

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 Mackay from earthquakes. The 1989 Newcastle earthquake caused deaths through collapse of non structural elements such as awnings and through partial structural collapse. Our scenarios indicate that small numbers of buildings will suffer *complete* structural damage, some with structural collapse, under the more extreme scenarios.

What is the earthquake risk to Mackay?

In this chapter we have assessed the earthquake risk to Mackay. The risk is the outcome of the interaction of the earthquake hazard, the vulnerability of the buildings, and the numbers and locations of these buildings. As described in Chapter 1:

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

In summary, Mackay faces a moderate risk from earthquakes. The level of earthquake risk in Mackay is certainly significant and earthquakes should be considered in risk management strategies for the city.

The earthquake hazard in the Mackay region (Table 4.7) is low to moderate by global standards (Giardini and others, 1999). The relatively minor historical seismicity, and its correspondingly minor impact on human activity in the Mackay 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 to moderate, it is higher in the many parts of Mackay that are built on unconsolidated sediments. These sediments are expected to amplify the ground shaking from future earthquakes.

We rate the vulnerability of Mackay buildings to earthquake as moderate. We have assumed that buildings that post-date the introduction of the wind provisions of the Queensland Building Act and the earthquake provisions of *AS1170* were constructed to those standards and that their condition has not deteriorated significantly.

About two thirds of the buildings were constructed before the enforcement of wind or earthquake loading standards and the performance of these buildings in earthquakes will be non-optimal. We consider *Precode* timber framed buildings are at least twice as likely to suffer *moderate* or more severe damage as their *Post-code* equivalents on the same type of ground.

Unfavourable ground conditions (Site Class D) increase the likelihood that buildings will suffer *moderate* or more severe damage by a factor of about 2_ compared to 'rock' foundation. In addition, about 81% of the *Precode* buildings are located on the most unfavourable ground conditions in Mackay, compared to about 73% of all Mackay buildings.

The great majority of buildings in Mackay (about 89%) have a light timber frame construction. Timber frame buildings perform well in earthquake and this is a positive factor in the earthquake risk that Mackay faces.

About three quarters of all the buildings constructed since 1985 have brick veneer cladding. This massive wall cladding will increase seismic vulnerability of buildings compared to lighter claddings such as timber or fibro, especially if combined with heavy tile roofs. However, 89% of the *Post-code* brick veneer buildings have steel roofs and only 10% have tile roofs. Brick veneer performed relatively well in the 1989 Newcastle earthquake (Institution of Engineers, 1990) and in the 1994 magnitude 5.4 Ellalong, New South Wales, earthquake (Jones and others, 1994).

Reinforced masonry (concrete block) buildings, built to resist wind in Australia, are considered the equal of any in the world (Greg Reardon, verbal communication, 2000). However, earthquake and wind loadings are different from each other, especially for massive buildings, and tropical Australian concrete block buildings have not been tested by strong earthquake shaking. In our scenario models, *Post-code* reinforced masonry buildings were about twice as likely to be in an *extensive* damage state as *Post-code* timber framed buildings although they were about equally likely to be in a *moderate* damage state.

Reinforced masonry buildings not specifically built to comply with earthquake or wind loading provisions (*Precode*) are presumed to be more vulnerable. About 420 residential buildings (houses and blocks of flats) built before 1986 are probably *Precode*. They are mostly located in West Mackay, North Mackay, Mount Pleasant, Ooralea, Slade Point and Bucasia. Some or all of the estimated 340 non residential concrete block buildings constructed before 1986 will also be *Precode*. These buildings are predominantly in Central Mackay with significant numbers also in North Mackay.

Our understanding of how reinforced masonry (concrete block) buildings in tropical Australia will perform in future earthquakes is incomplete and further research to improve this understanding would be valuable.

There is an estimated total of about 315 unreinforced masonry buildings and buildings constructed with a reinforced concrete frame and unreinforced masonry infill panels in Mackay. These are located predominantly in Central Mackay with smaller numbers in West Mackay, South Mackay and North Mackay. These buildings are typically decades old and probably have not been designed or constructed specifically to withstand lateral seismic forces. They are mainly non-residential and have the potential to contain large numbers of people at some times of the day. The Mackay Base Hospital is an example of a concrete framed building with unreinforced masonry infill (Plate 4.2). Educational buildings may also feature either of these types of construction.

Unreinforced masonry buildings are the most vulnerable buildings to earthquake shaking in Mackay. Historically and in our scenario modelling they have performed poorly. We found that they are twice as likely to suffer *extensive* damage as any other building in Mackay.

Buildings with a reinforced concrete frame and unreinforced masonry infill panels are more likely to be damaged than *Post-code* buildings or *Precode* timber frame buildings in our modelling, especially so in scenarios with more severe shaking.

Nearly all unreinforced masonry buildings and buildings with a reinforced concrete frame and unreinforced masonry infill panels are located on the most hazardous ground conditions, Site Class D. The building database for Mackay does not have the resolution to distinguish between these two types of buildings, nor to separate them from other 'brick' buildings.

Community vulnerability is also linked to building usage. Critical facilities in Mackay are more vulnerable than residential buildings because of their building types. Electric power distribution, business activity, medical treatment, and public safety activities are particularly at risk.

Suggested options for earthquake mitigation

Mackay City Council and Queensland government authorities could consider the following suggestions to mitigate earthquake risk.

Continue to use 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.

Adopt the Mackay earthquake hazard map as an aid to urban planning

The Mackay City Council could use the earthquake hazard map for Mackay (Figure 4.2) as a planning resource. The map contains better information on localised earthquake site classes than the relevant standard, *AS1170.4-1993*. The City Council could refer builders and designers to the map so that appropriate earthquake loadings will be applied to new building design and construction.

Enforce appropriate ground amplification factors for domestic buildings

The appropriate amplification factor for low rise, new domestic buildings on sediments in Mackay (Site Class D) is 1.6.

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 not appropriate for domestic structures in sediment areas in Mackay. The earthquake hazard map (Figure 4.2) provides a locality guide to apply more appropriate amplification factors.

In areas of Mackay where sediments are less than about 10 m thick, the ground could be considered as Site Class C and an amplification factor of 1.2 would apply for most low rise structures. However, we have taken the conservative decision of classifying all areas in Mackay underlain by Quaternary sediments as Site Class D. The appropriate site factor for most structures is 1.6.

We suggest that the Site Class D classification is used in all areas of Quaternary sediments. However, optionally, the Mackay City Council could place the onus of proof on the individual intending to build on sediments to prove that the mean shear wave velocity in the top 30 m of the ground is more than 360 metres per second at the site, or that the depth to moderately weathered or less weathered rock is less than 10 m, if he or she wanted to reduce the amplification factor below 1.6.

Adopt the Mackay map of natural period as an aid to urban planning

The Mackay City Council could adopt the Mackay map of natural period of ground vibration (Figure 4.4) as an aid to engineering design of new structures. The sediments beneath Mackay have thicknesses up to 40 m. The seismic properties of geological 'basement' contrast strongly with those of the sediments above. This set of conditions is strongly conducive to cause the sediments to resonate in an earthquake at their fundamental and harmonic periods of vibration. Amplification factors at resonance could be higher than the amplification factors proposed in this report.

Designers of new buildings with important functions could take these conditions into account in designing buildings to be non resonant with their foundations.

The Mackay City Council could, for example, refer structural engineers to the map of natural period in relation to building applications for General Structures of Importance II or III (*AS1170.4-1993*, Appendix A1).

Prepare a database of buildings in Mackay vulnerable to earthquake (and wind)

We estimate that about 310 older, unreinforced masonry buildings and buildings with reinforced concrete frames and unreinforced masonry infill panels are located in Mackay. They are located predominantly in Central Mackay, West Mackay and South Mackay. The current Mackay building database does not identify the location, condition, vulnerability and usage of these high-vulnerability buildings. Many of these buildings have unreinforced masonry construction and are located in Central Mackay, occupied by retail businesses. People inside and outside these buildings are at increased risk.

The Mackay City Council could compile an inventory of these buildings with the aim of assessing their function and vulnerability and, if necessary, taking mitigating action to reduce public risk.

Mitigate public risk from buildings in Mackay vulnerable to earthquake (and wind)

The Mackay City Council may want to implement schemes to improve the earthquake (and wind) resistance of seismically vulnerable buildings. Such schemes could include elements of:

- special consideration given to 'important' buildings such as those housing post disaster functions and schools;
- regulations that make seismic upgrade mandatory when any major renovation, alteration, addition or change of use is undertaken by the owner. *AS3826-1998*, *Strengthening existing buildings for earthquake* (Standards Australia, 1998) contains recommendations for retrofit of buildings;
- incentives through rating reductions for buildings that have undergone retrofitting;
- alternatively, disincentives through rating rises that increase with the time in which no mitigating action is taken;
- incentives to rebuild rather than renovate, alter or add;
- a broader state or national mitigation scheme that includes the insurance industry.

Limitations and Uncertainty

We consider the urban earthquake hazard map for Mackay, the map of natural period for Mackay and the Mackay building database to be in the most part well developed and appropriate for their usage.

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 monetary 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 Mackay; and
- the impact of secondary hazards including fire, hazardous material spills and debris.

Uncertainties in our results include the following:

Uncertainties in estimates of regional earthquake hazard

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, and the scatter of the data used to measure this attenuation;
- the definition of earthquake source zones; and
- the level of earthquake activity within these source zones.

These uncertainties are manifest in the differences of the hazard estimates made by various authors.

Uncertainties in estimates of urban earthquake hazard:

- The appropriateness of using Californian data for Australian conditions needs to be investigated further.
- The Mackay urban earthquake hazard maps were prepared by a medium-level process which included the use of limited geotechnical and geophysical data but did not employ computer waveform modelling or local recordings of earthquakes. Earthquake strong motion data were not available (there are no instruments in Mackay). The inclusion of these data and techniques would improve the results.

Uncertainties in the assessment of building performance:

- The performance of different construction types of buildings in earthquakes needs to be investigated further. This work has national significance.
- In the methodology we used, buildings are aggregated into categories and the seismic performance of these categories is generalised. Associated uncertainties in building performance are taken into account in the building damage state calculations.
- Beyond this inclusion of uncertainty, there are additional uncertainties in the appropriateness of building categories that were developed for the US being used for Australia. A specific example is the question of how the compliance of Queensland buildings to the wind loading standards of the Queensland Building Act affects seismic performance.
- A particular building category in question is the category of light steel-framed industrial and commercial buildings. There are about 520 of these in Mackay. Their modelled seismic performance in this study was poorer than we would have expected from their low-mass, ductile, response characteristics. We expect that post-standard buildings of this type in tropical Australia have been designed at least for wind loadings.
- We did not assess the effect of 'soft storeys' or asymmetries in building configuration although the Mackay building database contains information that could be used for this purpose. Dowrick and Rhoades (2000) found the effects of asymmetry or corner location to be factors of secondary importance. Buildings with a 'soft storey', which could include those

with a ground floor carpark, have partially or totally collapsed in New Zealand and Australian earthquakes (Dowrick and Rhoades, 2000; Institution of Engineers, 1990).

- There are uncertainties in the ages of buildings in Mackay. About two thirds of Mackay buildings have ages pre-1986 but no breakdown of pre-1986 age was available in most cases.
- There are uncertainties in how building condition will affect seismic performance. We have not taken into account building condition into our modelling, beyond using building age as an indicator of seismic vulnerability, and that was largely concerned with the onset of wind and seismic loading provisions. Building condition could play a major role in damage scenarios, as was indicated by heavy nonstructural damage to buildings in Newcastle from shaking in the 1989 earthquake (Institution of Engineers, 1990).

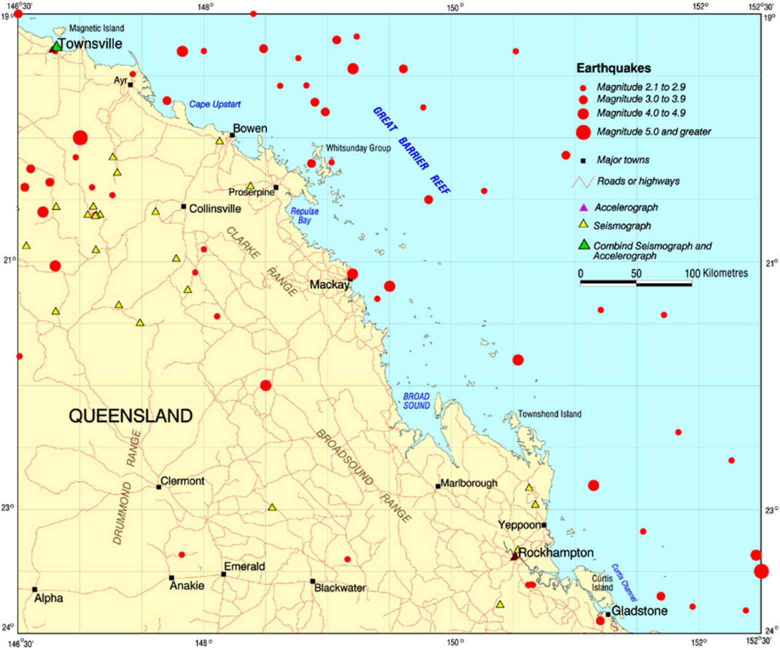


Figure 4.1: Seismicity of the Mackay region. Seismograph locations are also shown

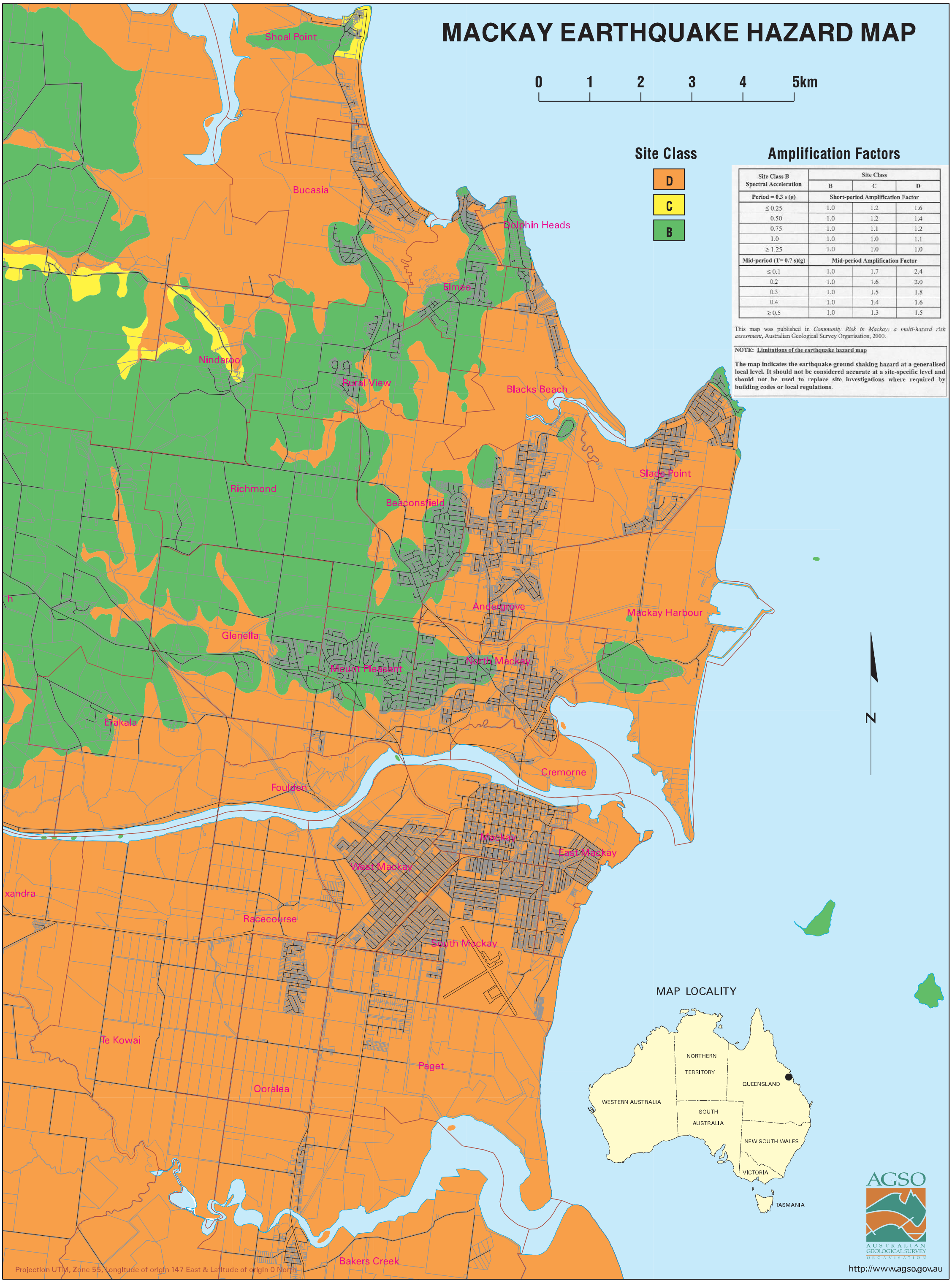


Figure 4.2: Mackay earthquake hazard map

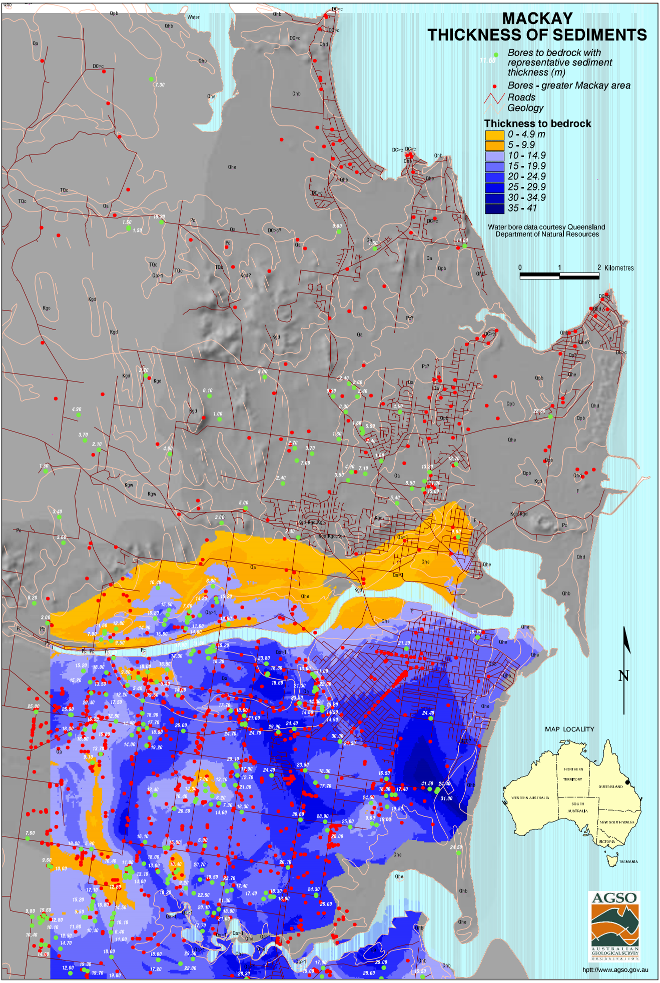


Figure 4.3: Mackay sediment thickness. Thicknesses to basement are shown in metres for boreholes with green symbol. Boreholes with red symbol do not hit basement. Outlines of geological units are shown. Water borehole data courtesy of Queensland Department of Natural Resources. Geology courtesy of Queensland Department of Mines and Energy

(F.von Gnielinski, unpublished data)

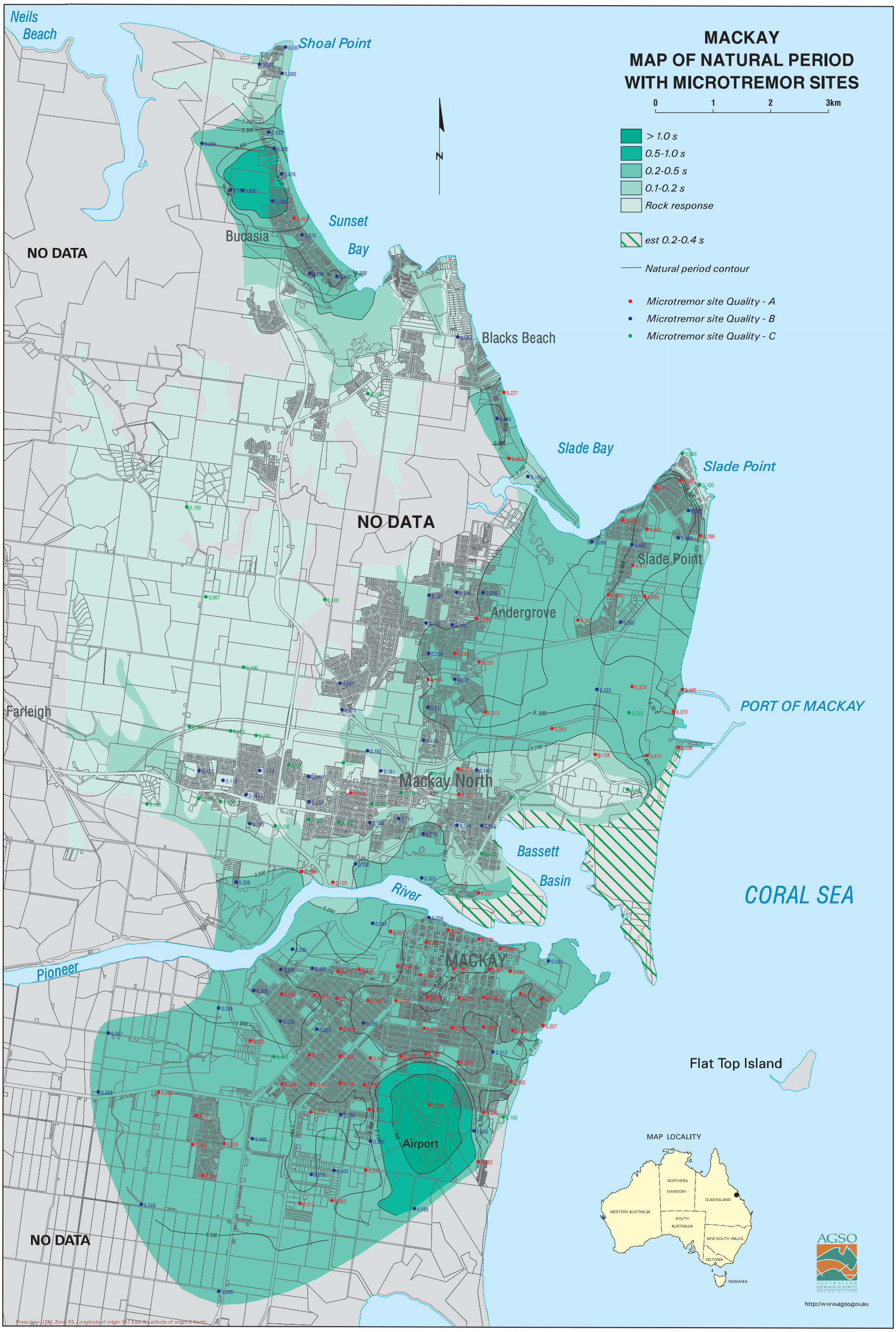
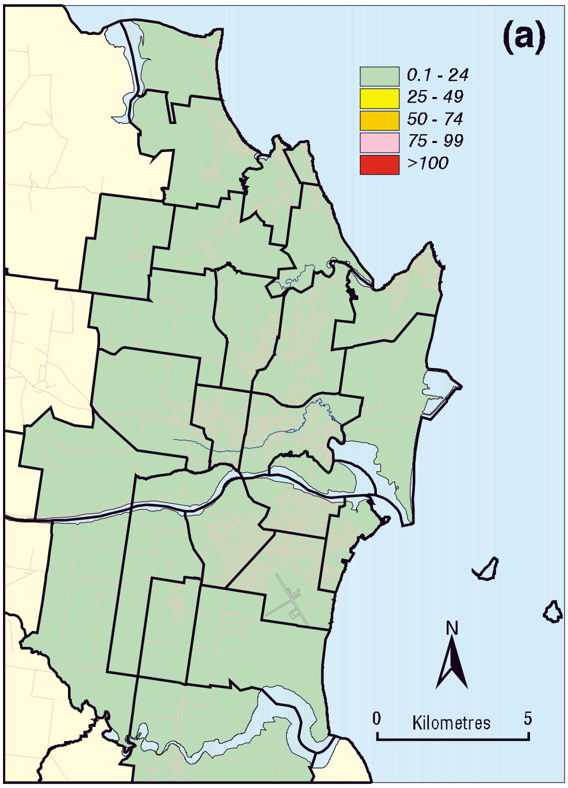


Figure 4.4: Mackay map of natural period. Microtremor sites are shown with natural period T in seconds. Quality A microtremor sites (red symbol) indicate highly tuned resonance, Quality B sites (blue symbol) less pronounced resonance, Quality C sites (green symbol) indicate resonance not observed (normal T=0.1 seconds) or resonance not reliably observed.



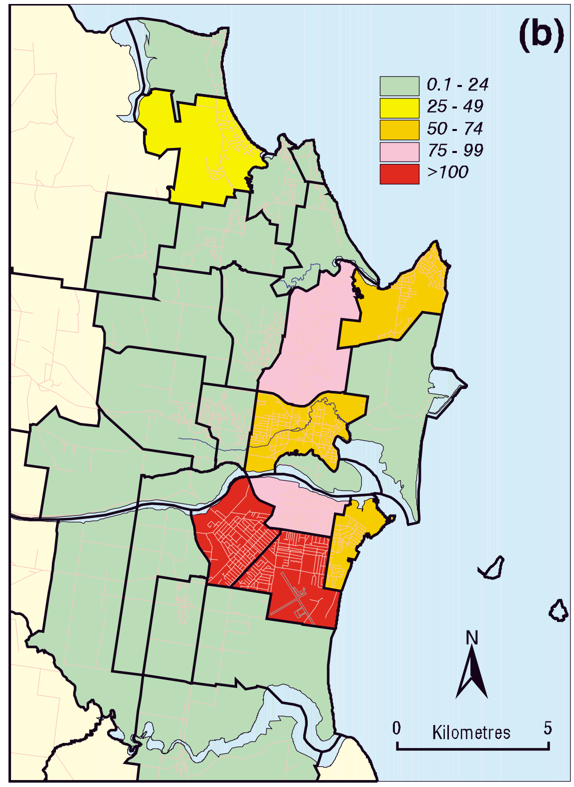
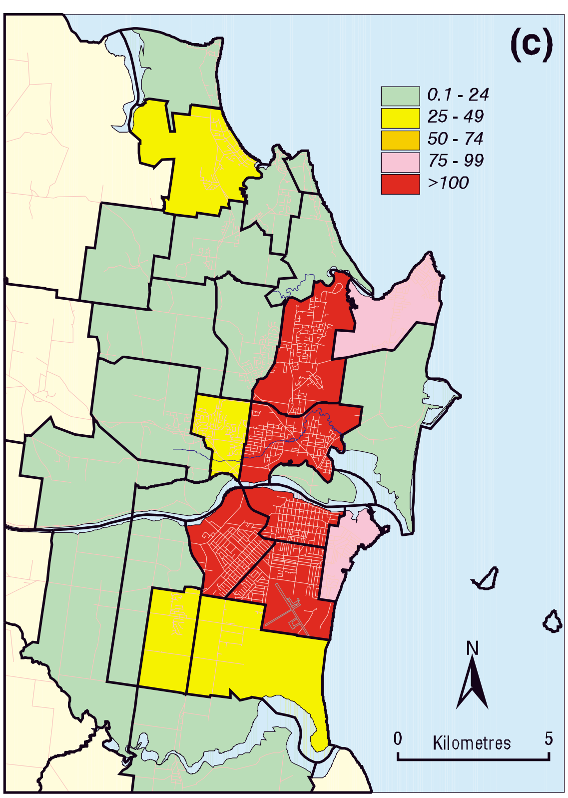


Figure 4.6: Mackay earthquake building damage scenarios for average recurrence intervals of (a) 100 years, (b) ~500 years, (c) 1000 years, (d) 2500 years. Counts indicate the numbers of buildings in a suburb suffering *moderate* or more severe damage.



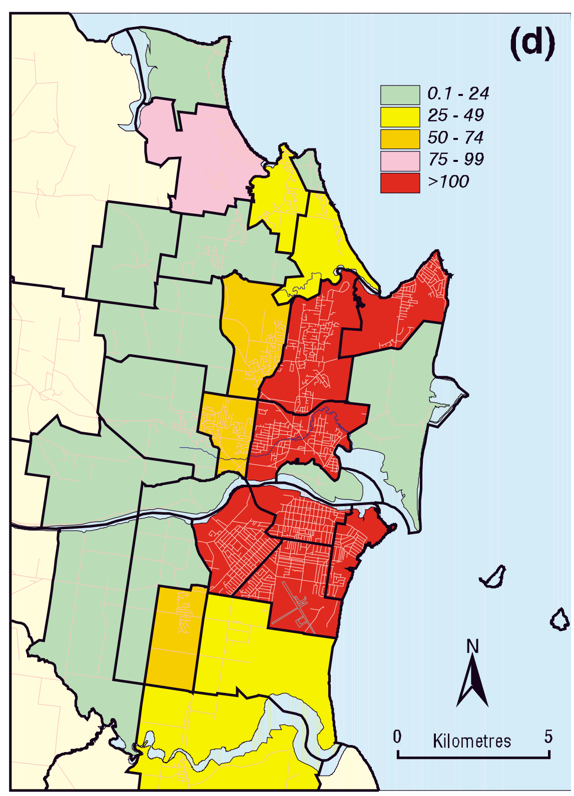


Plate 4.1: Reinforced masonry residence, tropical Queensland
Collection: Ken Granger

Plate 4.2: Mackay Base Hospital
Collection: Trevor Jones

CHAPTER 5: FLOOD RISKS

Miriam Middelmann, Ken Granger, Bruce Harper, Peter Baddiley and Terry Malone

The Flood Threat

A simple definition of flooding is *water where it is not wanted* (Chapman, 1994). Flooding occurs when the amount of water reaching the drainage network exceeds the amount of water which can be contained by the drainage channels and overflows out onto the floodplain. Several factors influence whether or not a flood occurs:

- the total amount of rainfall falling over the catchment;
- the geographical spread and concentration of rainfall over the catchment, i.e. the spatial variation;
- rainfall intensity and duration, i.e. the temporal variation;
- antecedent catchment and weather conditions;
- ground cover; and,
- the capacity of the drainage system to contain the water.

The causes of flooding are highly variable and a complex set of factors influence whether or not flooding occurs in a catchment.

Localised and/or flash flooding typically occurs where there is intense rainfall over a small sub-catchment which responds to 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 and/or non-flash flooding (lasting for more than 24 hours), occurs following rainfall of high intensity or long duration over the whole or a large proportion of the catchment. Runoff is typically low in areas where the percentage of vegetation cover 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 can cause flooding as runoff begins almost immediately. Flood levels in urban areas quickly rise where the percentage of impermeable surfaces on the floodplain, such as buildings, roads and car parks, is high. On sloping concrete and bitumen surfaces, for example, runoff is immediate.

Average recurrence interval (ARI) or annual exceedence probabilities (AEP) are statistical benchmarks used for flood comparison. ARI is the average 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.

It has been estimated by Smith (1998) that more than 80% of the buildings at risk from flooding in Australia are located in Queensland and NSW, with Queensland having the highest average annual actual damages from flooding. The key difference between NSW and Queensland is the implementation of State-wide floodplain management regulations in the former. These regulations 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 to establish. In the case of Mackay City the designated flood event adopted for planning purposes is set at the so-called Q50 (2% AEP) level (Smith ibid), which was initially estimated to be approximately the level of the 1958 flood of record. In his 1998 review of urban flooding risk in Queensland, Smith (ibid) found that, in the event of a 1% AEP flood, Mackay has the second greatest number of buildings at risk of being flooded in Queensland towns, with only the Gold Coast City Council area having more buildings at risk.

The Pioneer River poses the only significant riverine flood threat in the study area. The other significant flood threat to Mackay is urban flash flooding caused by high intensity rainfalls, similar to that which occurred in Townsville in 1998, where channel capacity was exceeded. Urban drainage surcharge could typically occur in the lead-up to flooding from the river.

Mackay is built largely on the estuary of the Pioneer River, the channel of which bisects the city. The area to the south of the River (Old Mackay) includes the Central Business District and residential areas that came under the jurisdiction of the former Mackay City Council. Old Pioneer includes the urban area north of the River that came under the former Pioneer Shire Council. The small communities of Mirani on the Pioneer River, and Finch Hatton on Cattle Creek, are also subject to flooding, but are outside the Mackay study area.

The Pioneer catchment, which covers 1489 km^2, is shown in Figure 5.1.

The Pioneer River flows from the coastal ranges in an easterly direction towards the sea and its catchment has been described in terms of the following four regions by Gourlay and Hacker (1986, p. 9):

- Cattle Creek (29%);
- Upper Pioneer River (53%);
- Lower Pioneer River (12%); and,
- Pioneer River estuary (6%).

Cattle Creek is one of the two major tributaries of the Pioneer River. Beginning in the Clarke Range, Cattle Creek rapidly loses altitude until reaching the valley floor. Its main tributaries are Cattle Creek North and Finch Hatton Creek which drain the highest parts of the catchment. Runoff tends to be more frequent in the Cattle Creek area than in the rest of the Pioneer catchment, as the area typically records the highest rainfall. Runoff is rapid, because descent from the ranges is steep. The main channel of this tributary runs very straight in a west-to-east direction.

The Upper Pioneer River drains the area north of the confluence of Cattle Creek with the lower Pioneer River. Unlike the comparative straightness of Cattle Creek, the Upper Pioneer River follows a very winding course in largely rugged terrain. Blacks Creek is the main tributary of the Upper Pioneer River, with a large number of smaller tributaries flowing into Blacks Creek. Blacks Creek flows to the east until it meets the northerly flowing tributary of Stockyard Creek. At this point, the tributaries join to become the northerly flowing Upper Pioneer River.

The Lower Pioneer River is the region downstream of the confluence of Cattle Creek with the Upper Pioneer River, near Mirani, to as far as Dumbleton Rocks. The course of this section is very straight, being confined by the distinct geological feature of the Pioneer lineament. The estuary section lies downstream of Dumbleton Rocks.

Mean annual rainfall over the catchment totals between 800 mm and 1200 mm. Typically, rainfall episodes are short and intense, especially during the summer ‘cyclone season’ between late November and April. It is during this period that the Pioneer River is particularly prone to flooding. Historically, flood-producing high rainfalls have occurred most commonly between January and March, and are associated with tropical cyclones and other tropical rain depressions. The movement of the monsoon shear line southwards during summer also influences rainfall amounts during the summer period (Gourlay and Hacker, 1986, p. 15).

A recent review of the regional hydrology by the Bureau of Meteorology shows that runoff volumes are approximately proportional to the contributing areas of each sub-catchment but do vary from event to event. Table 5.1 summarises results from the *Pioneer River URBS Model* (Bureau of Meteorology, 1995) which predicts that during large floods in Mackay, the area below Mirani Weir (18% of the catchment), contributes only about 14% of the total runoff. During smaller floods, however, the percentage runoff contributed from downstream of Mirani Weir could be significantly higher.

Table 5.1: Runoff volumes calculated from the Pioneer River URBS model (Bureau of Meteorology, 1995)

Event	Runoff Volumes							
	Upper		Cattle		Lower		Total	
	Ml x 1000	%	Ml x 1000	%	Ml x 1000	%	Ml x 1000	%
Feb 1958	334	52	236	37	67	11	637	100
Jan 1970	374	57	188	29	96	15	658	100
Feb 1979	259	50	154	30	102	20	515	100
Jan 1980	138	51	90	33	41	15	269	100
Feb 1988	279	58	128	27	75	16	482	100
Apr 1989	350	61	174	30	49	9	573	100
Mar 1990	96	54	63	36	18	10	177	100
Dec 1990	515	51	305	30	192	19	1012	100
Jan 1991	362	53	195	29	122	18	679	100
Feb 1991	348	56	187	30	83	13	618	100
Jan 1993	60	41	47	32	39	27	146	100
Feb(a) 1997	94	54	58	33	23	13	175	100
Feb(b) 1997	131	63	59	28	19	9	209	100
Feb(c) 1997	46	50	37	40	9	10	92	100
Aug 1998	105	61	48	28	18	11	171	100
Average		54		31		14		

The geomorphological evidence indicates that the Pioneer River is clearly the 'vigorous youthful' stream described by Gourlay and Hacker (1986, p. 132), the lower reaches of which have been progressively migrating north. The area to the south of the Lower Pioneer River and Pioneer River estuary forms the earlier floodplain of the Pioneer River. About 8000 years ago, during the early Holocene, the Pioneer River probably flowed through Sandy Creek to the sea, around 10 km south of its present mouth. As the region became wetter and the Pioneer River catchment enlarged, the course of the Pioneer River moved northwards, probably flowing through Bakers Creek to the sea. The present course may have been formed during an extreme flood event in the last 3000 years. Today, Sandy Creek and Bakers Creek drain their own small catchments and flow directly into the sea.

In historical times, flooding has altered the channel further. During the flood of February 1898 associated with cyclone *Eline*, the mouth of the Pioneer River moved to near its present position by breaking a course through the spit at East Point (Gourlay and Hacker, 1986, p. 49). Within two days, the old mouth immediately to the south had been filled with sediment. The Mackay *Daily Mercury* of 12 February 1898 reported that it was possible to walk across the old mouth of the estuary at low tide. Though the flood was not a particularly large one, the shape of the spit was such that, with favourable river flow, wave, tide and wind conditions, only a medium size flood was needed to alter the position of the river mouth. During floods with an ARI of 50 years or more, overflow into Bakers Creek is likely to occur (DES, 2000). During major floods with an ARI of greater than 100 years, overflow into Sandy Creek is likely to occur at Mirani, into Baker's Creek at Pleystowe (Ullman and Nolan, 1973), and to the north through North Mackay and Andergrove to Slade Bay. In the event of an extreme flood, therefore, it is possible that a new river mouth may be formed at Sandy Creek, Bakers Creek, or North Mackay, regardless of current flood mitigation works.

The Pioneer River responds extremely quickly to flood rains, with lead times of between six and nine hours between heavy rainfall in the upper catchment to a rise in flood height at Mackay (Bureau of Meteorology, 1997). It is essential, therefore, that an adequate warning system be provided.

The Bureau of Meteorology issues flood warnings for the Pioneer River in conjunction with the Pioneer River Improvement Trust using the Pioneer ALERT network. Installed in 1995, 1 mm increments in rainfall and 50 mm changes in river height are recorded and reported by radio to base station computers in Mackay and the Bureau's Flood Warning Centre (FWC) in Brisbane. The FWC uses this information to predict river heights using hydrologic models. Predictions of flood heights at Mackay are issued three hourly. Flood warnings cease when no further rainfall is anticipated and flood levels fall to that of a minor flood level at the Mackay gauge. The Bureau of Meteorology's brochure on *Flood warning for the Pioneer River* is included in Appendix I.

Detailed interpretation of forecast flood levels, in terms of suburbs and streets expected to be inundated in the Mackay area, is provided by the Mackay City Council using advice from the Pioneer River Improvement Trust.

The Mackay Flood Experience

Floods are classified by the Bureau of Meteorology (1998) depending on the local gauge height (GH) and the resulting level of community impact as follows:

1. **Minor flooding:** *This causes inconvenience such as closing of minor roads and the submergence of low level bridges.*
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.*

The Mackay gauge at Forgan Bridge (Plate 5.1), just upstream of the mouth of the Pioneer River, provides the most direct measurement of flood levels in the city reach of the estuary. At this gauge, a minor flood is deemed to commence at 6 m GH (3.06 m above the Australian Height Datum - AHD), a moderate flood at 6.9 m GH (3.96 m above AHD) and a major flood at 7.3 m GH (4.36 m above AHD).

Floods at Mackay are tidally-affected to about 7.5 or 8.0 m at the Mackay gauge (Bureau of Meteorology, 1995). Mean high water spring tide reaches 5.3 m GH at the Mackay gauge, with the highest astronomical tide (HAT) reaching about 6.4 m GH. Therefore, floods below about 6.0 m on the Mackay gauge may not be distinguishable from tidal fluctuations at the gauge and downstream.

The oldest flood gauge established on the Pioneer River was the Pleystowe Mill gauge, approximately 20 km upstream from the Pioneer River mouth. That gauge recorded flood levels from 1916 until 1978. Though the Mackay gauge only came into operation in 1968, historical peak flood heights predating 1968 have been estimated for the Mackay gauge using data gathered from gauges upstream.

Peak flood heights (either measured or estimated) for the Mackay gauge are shown in Figure 5.2. Twenty floods in the 115 year known record since 1884 are considered major floods (an average of one major flood every six years). A further ten floods are considered to be moderate flood events and ten floods are considered to be minor flood events, although there may be many more minor and moderate events which were not recorded.

The two largest recorded riverine floods occurred in February 1958 and January 1918 and were very similar in height. The flood levels used here are those from the Bureau of Meteorology records which indicate that the 1958 flood was slightly higher at Forgan Bridge. The figures in Gourlay and Hacker (1986, p. 21) suggest that the 1918 flood was slightly higher.

The estimated extent of flooding in February 1958 is shown in Figure 5.3 and is based on studies by McKay and Gourlay (1962) and Ullman and Nolan (1973). Neither source provides information with regard to flooding in 1958 in the vacant land of West Mackay or in the extended Sandfly Creek area, so the area flooded in the smaller 1946 flood was used to provide a minimum extent for the 1958 flood. The digital elevation model (DEM) was also used to estimate the extent of flooding south to the airport area and north to Slade Bay. The areas affected by flooding in 1958 are consequently, conservative estimates.

Figure 5.3: Extent of inundation during the February 1958 flood in Mackay

Peak flood height is estimated to have reached 9.14 m GH on the Mackay gauge at 8 am on the 18 February 1958. The flooding was associated with a rain depression. During the first 24 hours, 880 mm of rain was recorded at the Finch Hatton gauge on Cattle Creek, of which 530 mm fell in five hours (Gourlay and Hacker, 1986). Peak discharge is estimated at 11 000 cumecs using the rating curve from the *Pioneer River URBS model* (Bureau of Meteorology, 1995). Air, road and rail transport out of Mackay was blocked and shipping was disrupted (*Daily Mercury*, 18 February 1958). Damage to property was estimated at hundreds of thousands of pounds. Two people drowned and one was declared missing in the Cremorne area (*Daily Mercury,* 20 February 1958, Plate 5.2). The settlement of Foulden was declared a disaster area following the flood and its residents were forced to relocate permanently (Plate 5.3). The memories of one Foulden family are recorded in Appendix J and excerpts from *The Daily Mercury* of the major flood in 1958 are included in Appendix K. Memories of flooding in the Cremorne area are also included in Appendix J.

Peak flood height for the flood in January 1918 was estimated as 8.86 m GH at Mackay on 23 January 1918 and peak discharge as 9500 cumecs. The flooding was associated with the unnamed Category 4 tropical cyclone that crossed the coast on 21 January 1918, bringing with it a storm tide that inundated the Mackay settlement to a level of approximately 5.34 m AHD (see Chapter 6, Appendix J and Appendix M for more details of this event). Heavy rains followed with 610 mm of rain falling in 24 hours. Severe river flooding reached its peak on 23 January. The total damage to property in Mackay was estimated at one million pounds and at least 30 lives were lost. Most of this loss, however, was caused by the storm tide and the severe winds associated with the cyclone. There was not much left to damage when the flood eventually hit.

Other 'major' recorded floods include the floods of 1884, 1898, 1910, 1946, 1947, 1951, 1954, 1956, 1970, 1978, 1980, 1988, 1989, 1990 and 1991 (Plate 5.4). Another major flood occurred in April 1958, less than two months after the record flood. In 1979, two major floods occurred, six days apart, followed by a minor flood peak another two days later (Plate 5.5 and Plate 5.6).

The flood of January 1970 with rainfall from Cyclone *Ada* is the third highest recorded flood. Peak flood height reached 8.76 m GH (approximately 8600 cumecs) at the Mackay gauge at 7 am on 19 January. Construction of a levee in 1965/66 prevented inundation in Nebo Road and Shakespeare Street, however, parts of River Street and Carlyle Street were inundated (Gourlay and Hacker, 1986, p. 69). South Mackay was also affected, with about two feet of water in Ready Street (John Dean, verbal communication, 2000).

During the 1958, 1918 and 1970 floods, the area inundated extended into the North Mackay, Mackay Harbour, Slade Point and Andergrove areas (Ullman and Nolan, 1973).

The fourth highest recorded flood occurred on 31 January 1884. Peak flood height is estimated as 8.3 m GH at Mackay. The flooding was associated with a tropical cyclone which hit Bowen (to the north of Mackay) on the preceding day. Flooding occurred in River and Victoria Streets, the Pioneer Bridge was partly washed away and farm machinery and cane lands were damaged. Buildings were destroyed in the River Estate (Gourlay and Hacker, 1986, p. 68).

The sequence of flooding prior to the construction of the levees is described in Appendix L.

Maps of both the 1946 and 1954 floods (8.04 m and 7.45 m GH at Mackay respectively) based on McKay and Gourlay (1962) and Ullman and Nolan (1973) have been developed to illustrate the variability of the extent of 'major' flooding in Mackay prior to the construction of the levee system. These are shown in Figure 5.4 and Figure 5.5.

Historical records indicate that, prior to mitigation works, even relatively minor flood events at Mackay caused some flood damage. In March 1921 and December 1927, for example, the Bureau of Meteorology's *Results of Rainfall Observations Made in Queensland (Supplementary Volume,* 1940) states that inundation occurred in parts of Mackay. In January 1927, and again in January and February 1930, drowning deaths were associated with flooding. The widespread flooding in early 1930 was associated with a tropical cyclone which crossed the coast near Mossman (in Far North Queensland) on 20 January. This tropical cyclone recurved east of Mackay, with rainfall inundating low-lying areas of Mackay. Bridges and roads in the Mackay region were damaged, the harbour wall was severely damaged, and a bridge at Mirani was destroyed. Between 10 and 12 July 1933, heavy rainfall resulted in roads and bridges becoming submerged in the Mackay region (Bureau of Meteorology, 1940). The flooding extended over Central Queensland and was associated with a late-season cyclone, which recurved over Broad Sound and Rockhampton towards the southeast.

Severe localised flooding occurred in 1963 in North Mackay in the area of the Gooseponds. Rainfall totalling 508 mm fell in 24 hours causing short term inundation (up to 76 mm) to 150 residential properties (Ullman and Nolan, 1973).

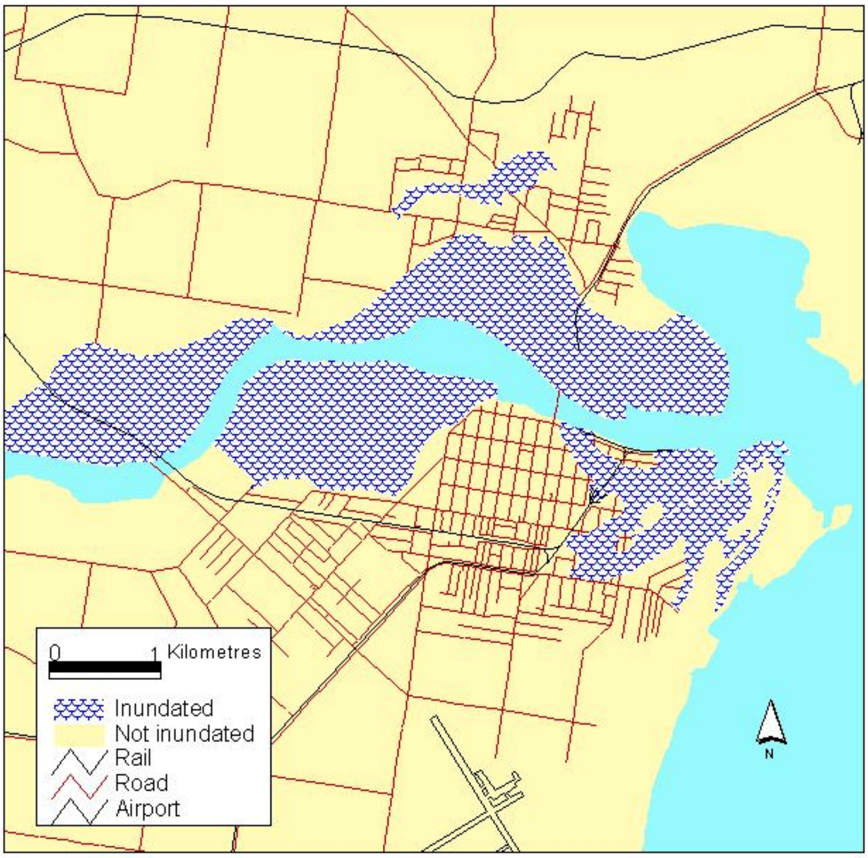


Figure 5.4: Extent of inundation during the March 1946 flood in Mackay

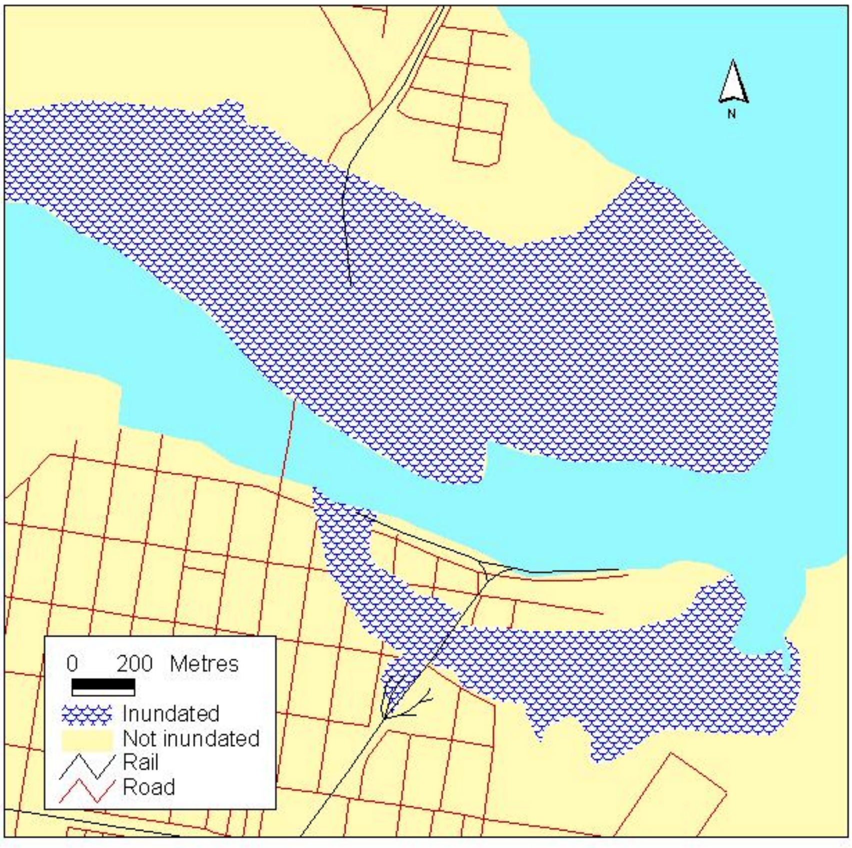


Figure 5.5: Extent of inundation during the February 1954 flood in Mackay

Flood mitigation works began in 1872 with the construction of training walls and embankments to protect the river banks being used as the town's port (Gourlay and Hacker 1986, p. 60). Most of the stone training walls on both sides of the river were constructed between 1886 and 1923 (Gourlay and Hacker, 1986, Figure 4.9). It was not until after the major floods of 1958, however, that the construction of flood mitigation levees commenced. These were initially confined to the south bank (i.e. protecting the Old Mackay area), and were designed to withstand a flood of similar magnitude to the flood of February 1958 which was thought at the time to be approximately a Q50. Further levees were built in the late seventies through to the nineties on the northern and southern sides of the Pioneer River. The impact of small to medium floods in Mackay will be further reduced following the building of a levee around Sams Road and the proposed levee stage 1B/2. The location of existing and proposed levees is shown in Figure 5.6.

A flood gate has also been constructed at the mouth of Sandfly Creek. When lowered, this gate reduces the flow of flood or storm tide water into Sandfly Creek and consequently into the urban area. It also converts the Sandfly Creek area into a flood detention basin for storm water runoff from part of Central and East Mackay. To overcome environmental concerns for the preservation of the mangrove communities along Sandfly Creek this flood gate is, under normal circumstances, left open. Council staff only close it when a flood warning is issued.

Mackay City Council (1998a) has adopted a nominal ground level for planning of Q50 (a 2% AEP flood), which is lower than many Councils. Most communities in NSW, for example, have selected the 1% AEP as the flood planning level. Mackay City Council has, however, adopted minimum building floor levels for new buildings. This must be whichever is the higher of the estimated level of the 1 in 100 year flood event or the 1 in 100 year storm tide event plus allowance for a factor of safety and stormwater drainage freeboard (Mackay City Council 1998a). The amount of residual risk in Mackay is however high. Furthermore, as discussed later, these flood levels have recently been reviewed. What was previous believed to be an ARI of 50, for example, is actually closer to a 40 year ARI, so the protection afforded by the planning controls are not as effective as previously believed.

Pioneer River Flood Risk Scenarios

The statistically reliable flood record for Mackay spans about 90 years and there are isolated data which extend the information for very severe floods back to 1884. During this time various mitigation works have altered the floodplain's response to flooding and this has necessitated re-appraisal of the stage-discharge relationships. Also, rainfall records have been extended over time and space and the regional hydrology has been reassessed. Accordingly, estimates of flood recurrence intervals have changed over the years and several physical and numerical flood modelling studies have been undertaken (e.g. Cameron, McNamara and Partners, 1976; McKay, 1979; and Bureau of Meteorology, 1995). A 'quasi two-dimensional' hydraulic model of the Pioneer River has recently been developed by Hatch Associates (ex BHP Engineering) under a consultancy to the Department of Emergency Services (DES, 2000). That study provides updated estimates of the 2% and 1% AEP flood flows (50 and 100 year ARI) and also the PMF (probable maximum flood). The resulting modelled flood levels for Mackay are used here. However, we have extensively modified the flood extents (in consultation with Hatch Associates) to remove anomalies. The PMF is the statistically largest possible flood which can occur and is usually perceived as having an AEP of between 0.001 and 0.0001%. This is equivalent to an ARI of between 100 000 and one million years. The predicted levels of these floods at Forgan Bridge gauge are shown in Table 5.2 below.

Table 5.2: Predicted Flood Levels at Forgan Bridge (DES 2000)

AEP	**ARI**	**Flood Level**
(%)	(years)	(m AHD)
2	50	7.12
1	100	7.49
PMF		8.33

Levee Overtopping

The Mackay levees have been built to an average height of about the level of the 1958 flood which at the time was judged to be a Q50. However, the DES (2000) modelling study suggests an ARI of about 38 years for this event and concluded that the present levee may only provide protection for floods up to an ARI of approximately 30 years. This represents a levee crest elevation of about 6.7 m AHD near Canelands. Higher floods will then lead to overtopping of the levee and potentially to scouring which, depending on the magnitude of the event, may result in failure and breaching of parts of the system. In the overtopping scenario there will be localised areas of high flow velocity over or through the levee that will cause local scouring and erosion, significant damage to property and hazardous conditions for residents, making movement very difficult. The overflowing floodwaters would then seek alternative paths to the sea through natural creek systems and major drains, causing ponding and inundation in some areas as the flow increases. If the levee fails to retain a significant proportion of the flood then ultimately the inundation levels might be similar to those which would have occurred without the levee system in place.

The DES (2000) study indicates that during a flood with a 2% AEP the levee would be overtopped initially at Canelands near Alligator Creek by about 0.6 m for several hundred metres. The levee in the vicinity of Forgan Bridge would then be overtopped by about 0.5 m and then the levee at Sandfly Creek by about 0.3 m. **This assumes that the levee would remain intact during overtopping, while in reality the levee would be likely to suffer severe damage and could fail completely.** The sudden influx of water as the levee is scoured and/or breached would raise water levels in the city significantly and could catch remaining people in the area unprepared. Movement of remaining people could be severely inhibited because of the high velocities, depending on location. A severe wind and/or storm tide event concurrently, or within 24 hours of riverine flooding would further increase community vulnerability.

No studies have yet been done which fully assess the likely progression of such an event, however, the combination of such low level levees and rapid rise time of the Pioneer River make it likely that evacuations would need to commence well before the water reached the top of the levees in order to minimise the risk to human life and property damage or loss.

Flood risk scenarios

The total number of properties in the study area (see Figure 2.1) is 20 750. For the purposes of assessing the risk of inundation to buildings in Mackay during the 2% AEP, 1% AEP and PMF scenarios, those properties classified with a feature use of type "O" (open space) and type "Z" (miscellaneous features, e.g. car parks) are excluded in this assessment. Therefore, the actual total number of buildings in the Mackay study area is 20 672. References to the number of buildings affected by flooding refers to the number of properties which would be exposed to inundation and does not necessarily mean that there would be overfloor flooding unless specifically indicated.

Depth of inundation, greater than one metre, has been modelled for the developed areas of North Mackay, Central Mackay, East Mackay and South Mackay for each of the scenarios. For the PMF scenario, depth of inundation greater than one metre has also been modelled for the Lagoons area around West Mackay and the Gooseponds. Depth of inundation greater than two metres has been modelled for these areas during the PMF scenario except for the Gooseponds and the Lagoons area. Outside of these areas, the horizontal extent of inundation only is indicated. It is likely, therefore, that the area covered by water deeper than one metre, and the number of buildings affected by overfloor flooding is greater than indicated in these scenarios, particularly in the area of the Gooseponds and in the Lagoons area.

Figure 5.7 shows the cumulative exposure to flood inundation in Mackay. Figure 5.8 shows the distribution of buildings with water overground by suburb for the three scenarios. Figure 5.9 shows overground flooding by suburb as a percent of the number of buildings in the suburb. Each scenario is described in more detail below.

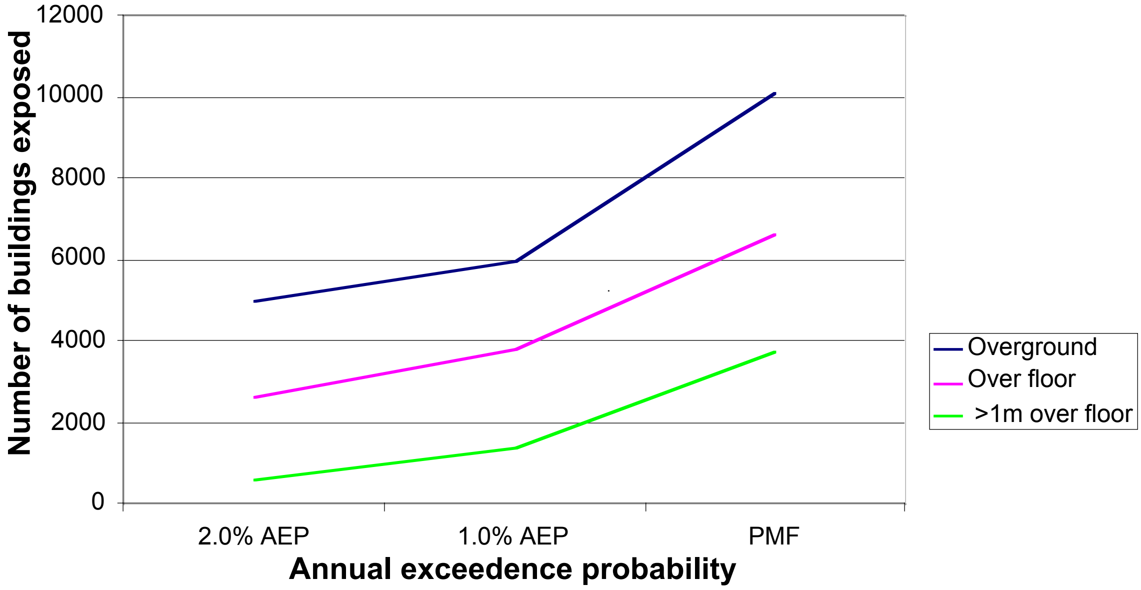


Figure 5.7: Cumulative exposure to flood inundation in Mackay

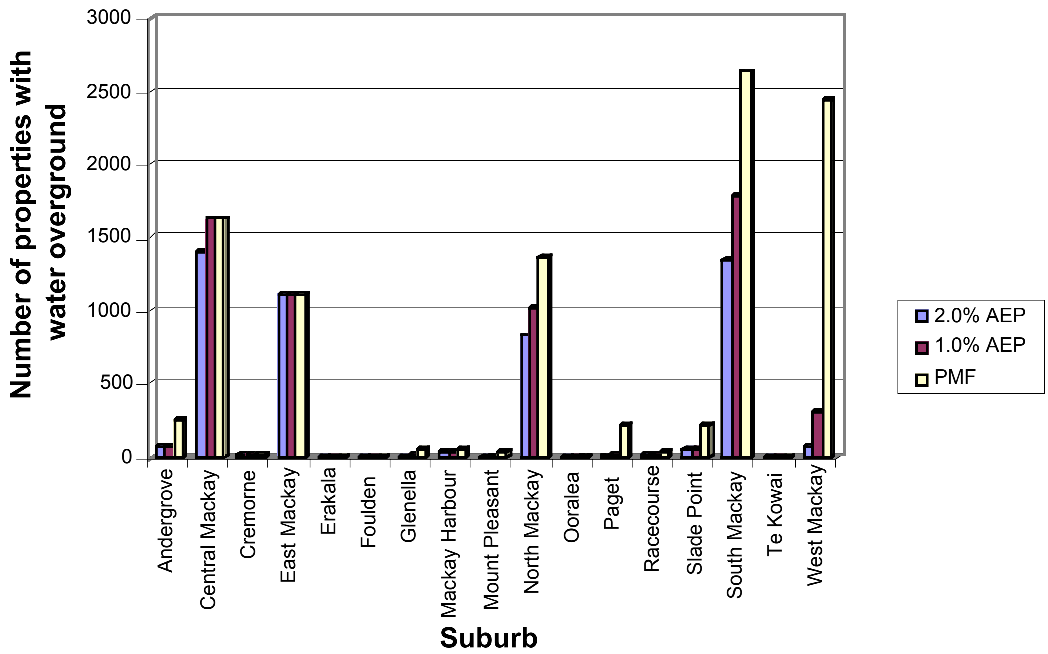


Figure 5.8: Distribution of buildings with water overground by suburb for 2% AEP, 1% AEP and PMF scenarios

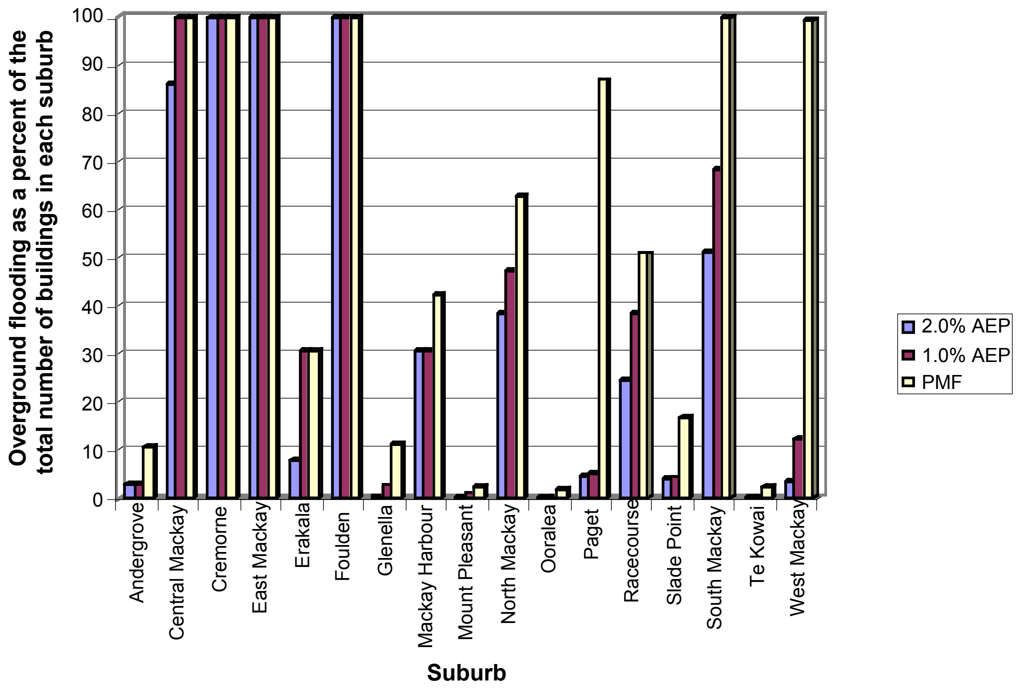


Figure 5.9: Overground flooding by suburb as a percent of buildings in the suburb for 2% AEP, 1% AEP and PMF scenarios

A summary of building damage generated by the 2% (ARI = 50) and 1% AEP (ARI = 100) and PMF flood scenarios is shown in Table 5.3. The damage levels are assigned assuming that slight damage occurs when a property is inundated, moderate damage occurs when flood waters rise up to one metre above floor level and extensive damage occurs when flood waters rise over one metre above floor level. This is intended to be indicative only. Slight damage may include damage to items stored below floor level (e.g. lawnmowers and tools) and fences. The damage level increases as soon as overfloor flooding occurs with damage to carpets, floor boards, chipboard, plasterboard etc. As water depth over floor increases, so does the risk of extensive damage and structural failure. Black (1975), for example, showed that building failure of weatherboard houses can occur when flood depth over floor level 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.

The flood damage scenarios in Table 5.3 also assume that severe wind or storm tide associated with tropical cyclones does not precede flooding as in 1918 when many of the buildings were already damaged by the time the riverine flood occurred.

Table 5.3: Flood damage scenarios for buildings in Mackay

ARI (yr)	Nil damage		Slight damage		Moderate damage		Extensive damage	
	No. Bldg.	% of total	No. Bldg	% of total	No. Bldg	% of total	No. Bldg	% of total
50	13065	75.8%	2395	11.6%	1980	9.6%	626	3.0%
100	10748	70.5%	2276	11.0%	2452	11.9%	1372	6.6%
PMF	3923	51.1%	3451	16.7%	2875	13.9%	3774	18.3%

Q50 (2% AEP) flood:

Spatial distribution of buildings affected by flooding: Figure 5.10 indicates the extent of inundation in Mackay during a flood with an estimated 2% AEP. Under this scenario, the levees would be overtopped by about 0.5 m and approximately 5000 (24%) of the buildings in Mackay would have water on the property and 176 km of road would be affected. Of the 29 suburbs in the Mackay study area, 12 suburbs (41%) would have buildings free from inundation.

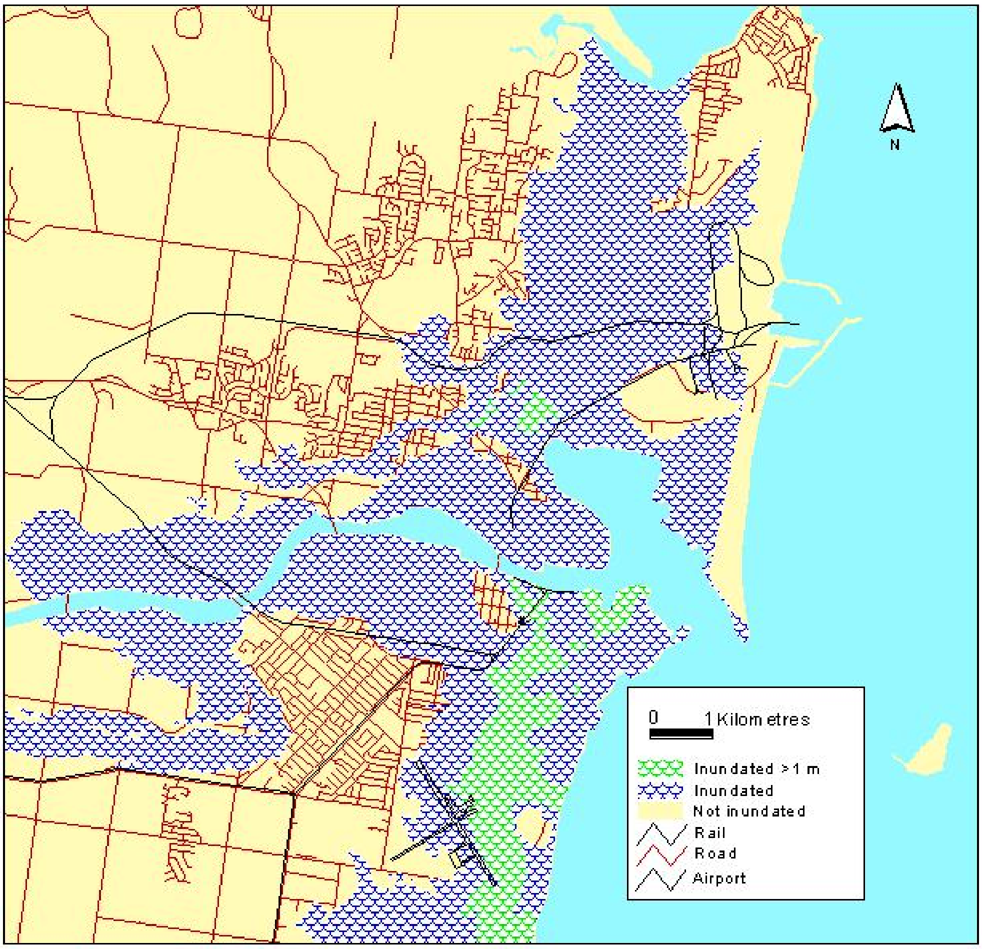


Figure 5.10: Modelled extent of inundation for Mackay for a flood with a 2% AEP. Modified from DES (2000)

All of the buildings in the suburbs of Cremorne, East Mackay and Foulden would be affected, however, Foulden has only one building and Cremorne only 23 buildings respectively. On the other hand, South Mackay has approximately 1350 buildings affected, however, only 51% of the suburb is affected by flooding (see Figure 5.8 and Figure 5.9). Fifty percent of the suburbs affected by inundation would have less than ten percent of the buildings in the suburb affected. The greatest number of buildings affected lie in the suburbs of Central Mackay, South Mackay and East Mackay (28%, 27% and 22% respectively of the total number of buildings affected by inundation) (see Figure 5.8). Whilst the actual areal extent of inundation is slightly less on the southern side of the river (19.6 km^2 compared to 23.1 km^2), 80% of the buildings and 63% of the roads affected are on the southern side.

Feature use distribution of buildings affected by inundation: Of the approximately 5000 or so buildings that would be affected, 76% would be houses, 8% would be blocks of flats and 10% would be buildings related to business. Only about 6% of properties affected would be buildings related to public safety, storage and transport, logistics, health services, power, water supply and sewerage utilities, telecommunications, accommodation, education, recreation, industry, community and government. These, however, form many of the key facilities.

Key facilities affected: A number of key facilities would be affected. Those that would include:

- the North Mackay fire station;
- the Mackay City Council building (from which the local disaster coordination committee would operate); the Mackay fire station; the SES district headquarters; the ABC studios, the Tennyson Street substation, the Mackay electricity board, and the major food warehousing and cold store facilities in Central Mackay;
- water treatment plant in West Mackay;
- the Central Queensland helicopter rescue service, and the Mackay airport and aviation depots in South Mackay; and,
- the BP fuel depot and transport terminals in Mackay Harbour.

Depth of inundation and overfloor flooding: Approximately half of the 5001 properties inundated would have water over floor level (see Figure 5.7). Ten percent (1980 buildings) of the total number of buildings in Mackay (20 672) would have overfloor flooding of less than one metre. Three percent (626 buildings) of the total would have overfloor flooding of greater than one metre and are likely to suffer severe damage and/or structural failure. At least two key facilities would be affected by overfloor flooding. These would include the Central Queensland helicopter rescue service and the Mackay airport depot, both situated in South Mackay.

Thirty-eight percent of houses, 45% of flats and 47% of businesses with properties affected by inundation would have overfloor flooding of less than one metre. Thirteen percent of houses, 13% of flats and 8% of businesses with properties affected by inundation would have overfloor flooding of greater than one metre. No account has been taken of the additional damage likely to be caused by localised high velocities as the levee is overtopped.

Isolated properties: Approximately a further 1970 (10%) buildings would be isolated for a period by flooded and/or damaged roads. Of these, parts of Central Mackay, North Mackay and Mackay Harbour would be entirely isolated. Part of South Mackay would also be surrounded by floodwaters but is not developed. Parts of Slade Point would be isolated by floodwaters and ocean. Other suburbs would not be completely isolated by water, lying on the fringes of flooded areas, but could be isolated due to flooding of access roads. Of the buildings isolated by flooding there would be:

- 204 in Central Mackay including the Mackay ambulance station, the district police headquarters, the Mater hospital and many buildings related to business;
- 2 in Erakala, both residential;
- 1 business in Glenella;
- 82 in Mackay Harbour including the Mt Bassett weather station, the bulk fuel and gas storage depots; the bulk ethanol and chemical storage tanks; the major sewage treatment plant; the grain silos, the sugar terminals, and other port and industrial facilities;
- 9 in Mount Pleasant, largely buildings related to business;
- 362 in North Mackay, predominantly residential;
- 1 house in Paget;
- 12 in Racecourse, all residential;
- 1249 in Slade Point, most of them residential;
- 35 in South Mackay, predominantly residential but including the Mackay airport fire station and the airport terminal; and,
- 10 in West Mackay, all residential.

Q100 (1% AEP) flood:

Spatial distribution of buildings affected by flooding: Figure 5.11 indicates the extent of inundation in Mackay during a flood with an estimated 1% AEP. Under this scenario, the levees would be overtopped by about 1 m and approximately 6100 (30%) of the buildings in Mackay would have water on the property and 201 km of road would be affected. No additional suburbs would be affected compared to a 2% scenario.

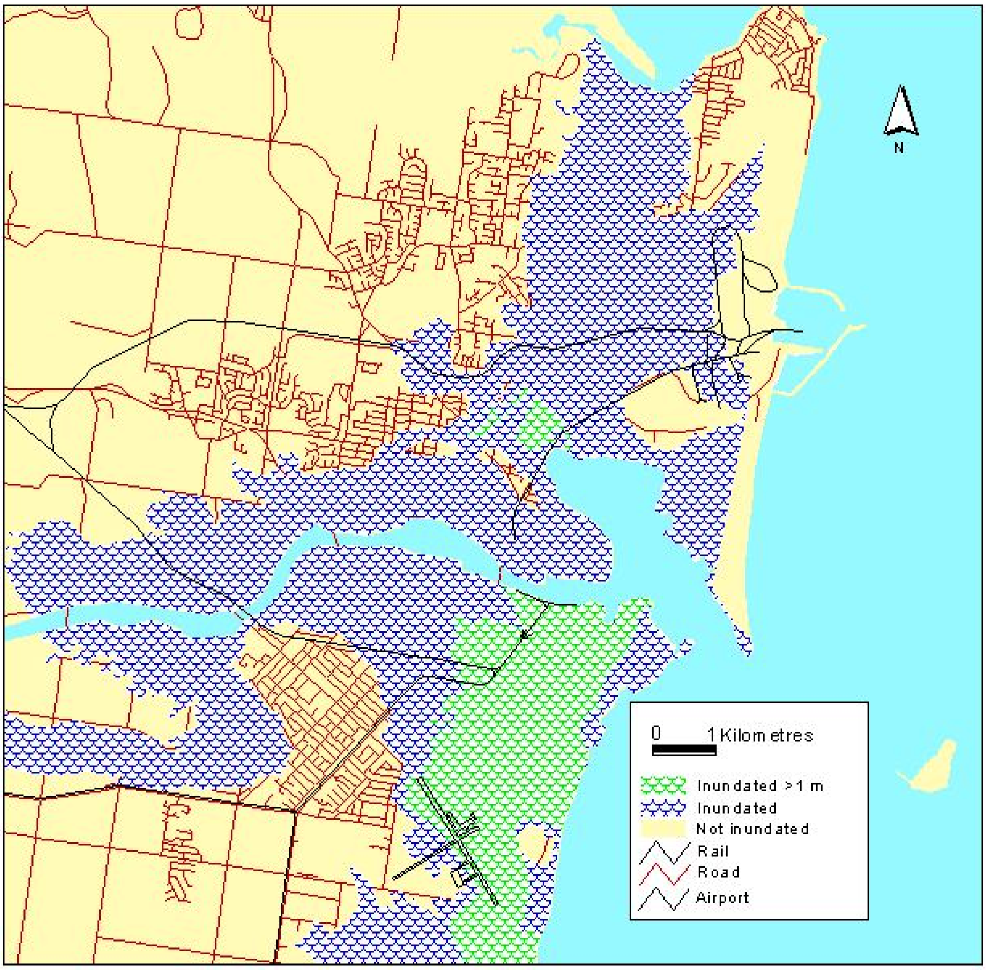


Figure 5.11: Modelled extent of inundation for Mackay for a flood with a 1% AEP
Modified from DES (2000)

In addition to all the buildings in Cremorne, East Mackay and Foulden being affected (as in a 2% scenario), all the buildings in Central Mackay would also be exposed to inundation (see Figure 5.9). Only thirty-eight percent of the suburbs affected by inundation would have less than ten percent of the buildings in the suburb affected. The greatest number of buildings affected lie in the suburbs of South Mackay, Central Mackay, East Mackay and North Mackay (29%, 27%, 18% and 17% respectively of the total number of buildings exposed to inundation) (see Figure 5.8). Eighty percent of the buildings and 63% of the roads affected would be on the southern side of the river, though inundation would be slightly less on the southern side (21.7 km^2 compared to 24.6 km^2).

Feature use distribution of buildings affected by inundation: Of the approximately 6100 or so buildings that would be affected, 76% would be houses, 7% would be blocks of flats and 10% would be buildings related to business. Only about 7% of properties affected would have buildings related to other feature uses.

Key facilities affected: The key facilities affected during a 2% AEP flood would be affected to a greater depth during a 1% AEP flood.

However, a small number of additional key facilities would be affected including:

- the ambulance station; the district police headquarters; the Mackay telephone exchange; and, the Mater hospital, all in Central Mackay; and,
- the Mackay airport fire station in South Mackay.

Depth of inundation and overfloor flooding: Approximately 3820 buildings (62% of buildings affected) would have water over floor level (see Figure 5.7). Twelve percent (2452 buildings) of the total buildings in Mackay would have overfloor flooding of less than one metre. Seven percent (1372 buildings) of the total would have overfloor flooding of greater than one metre. At least eight key facilities would have water over floor level. These would include the fire station, ambulance station, the ABC studios, the Mater hospital and cold storage, all in Central Mackay; and, the Mackay airport and aviation depots and the Central Queensland helicopter service in South Mackay.

Thirty-eight percent of houses, 45% of flats and 47% of businesses with properties affected by inundation would have overfloor flooding of less than one metre. Twenty-two percent of houses, 26% of flats and 21% of businesses with properties affected by inundation would have overfloor flooding of greater than one metre. No account has been taken of the additional damage likely to be caused by localised high velocities as the levee is overtopped.

Isolated properties: Approximately a further 1590 (8%) buildings would be isolated for a period by flooded and/or damaged roads. Of these, parts of North Mackay and Mackay Harbour would be entirely isolated. A small part of South Mackay would also be surrounded by floodwaters but is undeveloped. Parts of Slade Point would be isolated by floodwaters and ocean. Other suburbs would not be entirely isolated by flooding as they lay on the fringes of flooded areas, but could be isolated by flooded access roads. Of the buildings isolated by flooding there would be:

- 13 in Andergrove, all residential;
- 2 in Glenella, for business and storage;
- 82 in Mackay Harbour including the Mt Bassett weather station, the bulk fuel and gas storage depots; the bulk ethanol and chemical storage tanks; the major sewage treatment plant; the sugar terminals and grain silos and other port and industrial facilities;
- 188 in North Mackay, most of them residential;
- 4 in Paget, predominantly business;
- 9 in Racecourse, all residential;
- 1247 in Slade Point, largely residential;
- 5 in South Mackay including the Mackay airport terminal;
- 1 house in Te Kowai; and,
- 35 in West Mackay, residential but including the Mackay Base hospital.

The PMF Scenario:

Spatial distribution of buildings affected by flooding: Figure 5.12 indicates the extent of inundation in Mackay during an estimated PMF. The extent to which the levees would be overtopped would vary along the city reach. Under this scenario, the levee would be overtopped by about 2 m near the intersection of Shakespeare Street and Nebo Road, by nearly 2 m at Milton Street near Canelands, by 0.6 m at River Street near Canelands, by 1.4 m in the city reach upstream of the Forgan Bridge and by 1 m in the city reach downstream of the Forgan Bridge. Approximately 10 100 buildings (49%) of the buildings in Mackay would have water on the property and 275 km of road would be affected.

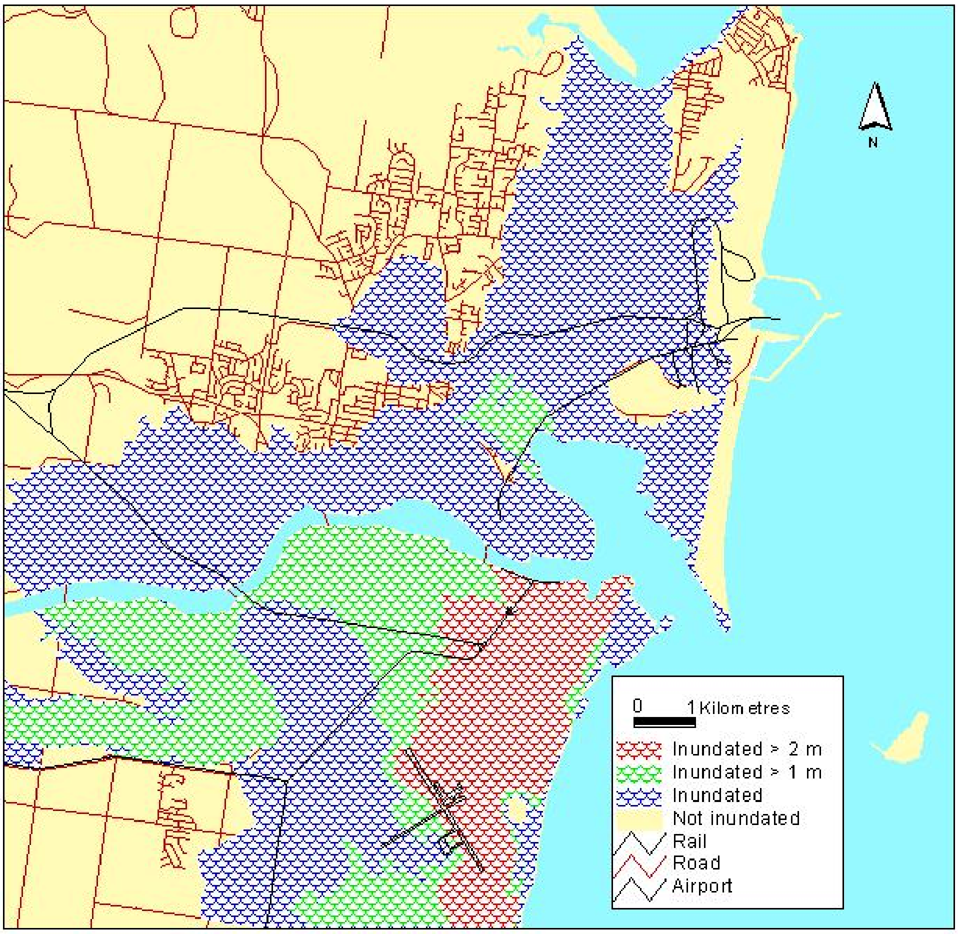


Figure 5.12: Modelled extent of inundation for Mackay for a PMF
Modified from DES (2000)

The suburbs affected during a 1% AEP equivalent scenario would again be affected (and to a greater depth) during a PMF scenario, however, the suburb of Te Kowai would also be affected. During a PMF scenario, all the buildings in Central Mackay, Cremorne, East Mackay, Foulden and South Mackay would be affected. Ninety-nine percent (2444 buildings) would also be affected in West Mackay. North Mackay would have a large number of buildings affected (1360), though only 63% of the buildings in the suburb would be affected (see Figure 5.8 and Figure 5.9). Whilst the actual areal extent of inundation is very similar on the northern and southern sides of the Pioneer River (29.7 km^2 on the north compared to 31.8 km^2 on the south), 80% of the buildings and 65% of the roads affected would be on the southern side.

Feature use distribution of buildings affected by inundation: Of the approximately 10 100 or so buildings that would be affected, 80% would be houses. That is, 45% of houses in Mackay would be exposed to inundation. Sixty-four percent of the blocks of flats in Mackay would be affected, and 87% of businesses. This would have a large impact on the local community, through permanent or temporary displacement, through disruption of supplies, and through temporary or permanent closure of local shops.

Though all the buildings other than residential and business only comprise 6% of the buildings affected, the number of people affected would extend to a much wider area than that directly affected by flooding. The worst affected (as a percentage of the total number of buildings in each type of feature use) are buildings associated with power utilities (92%), with only the Port substation unaffected. This could potentially cause power outage throughout the entire city. Eight-eight percent of buildings associated with doctors and health services would be affected. Only one of three hospitals would be flood free and nearly all nursing homes would be affected.

This would have special implications for evacuations and place a large strain on the few unaffected services.

Eighty-four percent of buildings associated with industry in Mackay would be affected. Seventy-eight percent of buildings associated with public safety would be affected. This would disrupt industry operations in Mackay and reduce the ability and speed with which the relevant services could provide emergency response.

Key facilities affected: The key facilities affected during a 1% AEP flood would also be affected (and to a greater depth) during a PMF flood. However, additional key facilities would be affected including:

- the substation in Andergrove;
- the Mackay Base hospital; the substation and Ergon depot buildings in West Mackay;
- the railway station in Paget; and,
- the Mackay airport terminal and airport control tower in South Mackay.

Depth of inundation and overfloor flooding: Approximately 6650 buildings (65% of the number of buildings affected) would have water over floor level (see Figure 5.7). Fourteen percent (2875 buildings) of the total number of buildings in Mackay would have overfloor flooding of less than one metre. Eighteen percent (3774 buildings) would have overfloor flooding of greater than one metre and are likely to suffer severe damage or structural failure. At least fifteen key facilities would have water over floor level. These would include:

- the North Mackay fire station;
- the Mater hospital, the Mackay ambulance station, the Mackay fire station, the SES district headquarters, the district police headquarters, the Mackay City Council, the Mackay telephone exchange, the Mackay electricity board and the Tennyson Street substation, all in Central Mackay;
- the Mackay Base hospital and water treatment plant in West Mackay; and,
- the Mackay airport and aviation depots, the Central Queensland helicopter rescue service, and the Mackay airport fire station, all in South Mackay.

Of these, at least nine key facilities would have water greater than 1.5 m over floor level and are likely to suffer severe damage or structural failure. These would include:

- the Mater Hospital, the Mackay fire station, the Mackay ambulance station, the ABC studios, and the Mackay electricity board and Tennyson Street substation, all in Central Mackay; and,
- the Mackay airport, the aviation depots, and the Central Queensland helicopter rescue service, all in South Mackay.

Twenty-eight percent of houses, 26% of flats and 35% of businesses with properties affected by inundation would have overfloor flooding of less than one metre. Thirty-five percent of houses, 54% of flats and 47% of businesses with properties affected by inundation would have overfloor flooding of greater than one metre.

No account has been taken of the additional damage likely to be caused by localised high velocities as the levee is overtopped.

Isolated properties: Approximately a further 1540 buildings (7%) would be isolated for a period by flooded and/or damaged roads. Parts of North Mackay, Mackay Harbour and West Mackay would be entirely surrounded by water. Floodwaters and ocean would isolate parts of Slade Point. The small part of South Mackay that would be isolated, however, is as undeveloped. Other suburbs would not be entirely isolated by water as they lay on the fringes of flooded areas, but could be isolated by flooded access roads. Of the buildings isolated by flooding there would be:

- 228 in Andergrove, nearly all residential;

- 1 business in Erakala;
- 14 houses in Glenella;
- 68 in Mackay Harbour, including the Mt Bassett weather station; the bulk fuel and gas storage depots; the bulk ethanol and chemical storage tanks, the major sewage treatment plant; the grain silos, the sugar terminals, and other port and industrial facilities;
- 30 in Mount Pleasant, all residential;
- 80 in North Mackay, residential and business;
- 12 in Ooralea, including buildings used for business, residential and logistics;
- 3 houses in Paget;
- 4 houses in Racecourse;
- 1086 in Slade Point, most of them residential;
- 2 houses in Te Kowai; and,
- 14 in West Mackay, largely business.

Scenario Uncertainty

The extents of the 2% and 1% AEP floods and the PMF are derived from DES (2000). Information on depth of inundation is limited to the developed areas of North Mackay, Central Mackay, East Mackay, South Mackay and West Mackay, and until more detailed water depth information is available, the number of buildings affected by overfloor flooding (and the depth of overfloor flooding where it occurs) will be uncertain. The absence of detailed velocity information also makes estimates of structural damage and danger to human life difficult to assess.

Dam or weir failure

There are no major dams in the Pioneer River catchment. The largest dam is the Teemburra Dam, with a catchment area of 66 km^2 in the Upper Pioneer catchment. Dam Break Analysis (DBA) undertaken by the Department of Natural Resources (DNR, 1998) indicates that embankment failure caused by a PMF would not have a significant impact on Mackay, though would inundate parts of the townships of Mirani and Marian and Pleystowe Mill. This analysis, however, does not include any inflow from creeks below the dam to the junction with the Pioneer River itself. Therefore Mirani township, Marian township and Pleystowe Mill may be flooded to a greater depth than indicated by the DBA. PMF with dam failure is only 1.3 m below the rail bridge in Mackay and may be influenced by the tide. Unexpected dam failure not associated with flooding (for example caused by piping failure or an earthquake), would cause inundation only in Marian.

Three weirs exist in the catchment, Mirani Weir, Marian Weir and Dumbleton Weir. Weir failure would not greatly affect Mackay, subject of course to tidal influence, though no DBA has, as yet, been undertaken by DNR (Bevan Faulkner, verbal communication, 2000).

Interpretation

The number of buildings at risk from small to medium floods in Mackay has decreased through levee construction. Ongoing urbanisation on the flood plain, however, has increased the number of buildings vulnerable to flooding in an event that exceeds the current level of protection afforded by the levee system. Though such mitigation works can greatly reduce the risk to a community in one sense, they can also produce a misleading sense of security. Consequently, in the event of a large flood overtopping or breaching the levees (i.e. a flood with an ARI of 50 or higher), flood impact will be severely damaging.

An effective flood warning system (as operated by the Bureau of Meteorology in conjunction with the City Council and Pioneer River Improvement Trust in Mackay) is therefore crucial to the provision of an adequate warning period for flood preparations and/or evacuation in flood prone areas, especially when a flood that is likely to exceed the height of the levees is predicted. Given the very limited warning time available for Mackay, considerable attention needs to be given by Council to detailed planning for the overtopping and possible failure of the levees. To be effective, this will require the involvement of the Mackay communities at risk.

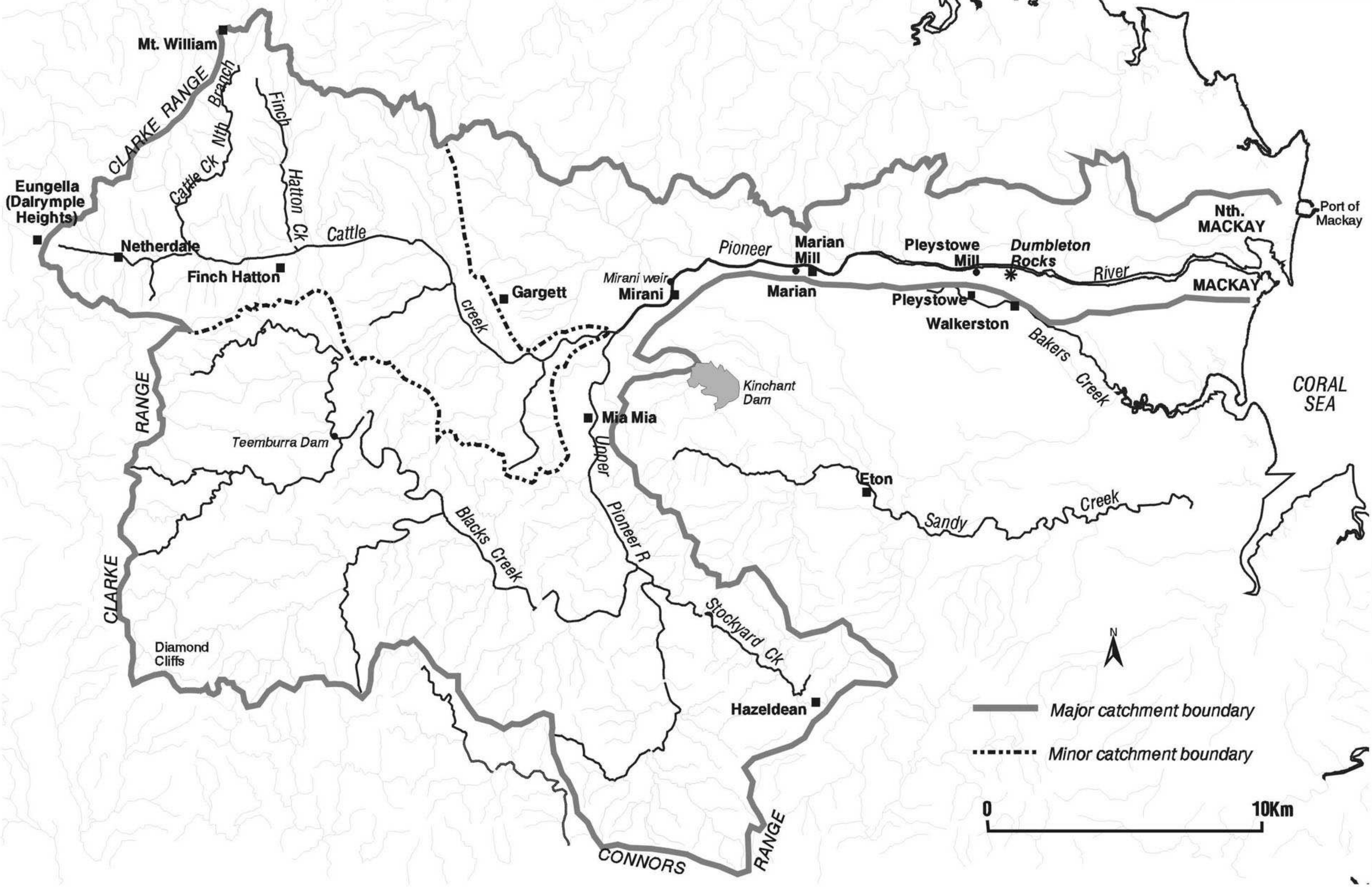


Figure 5.1: Pioneer River catchment locality map

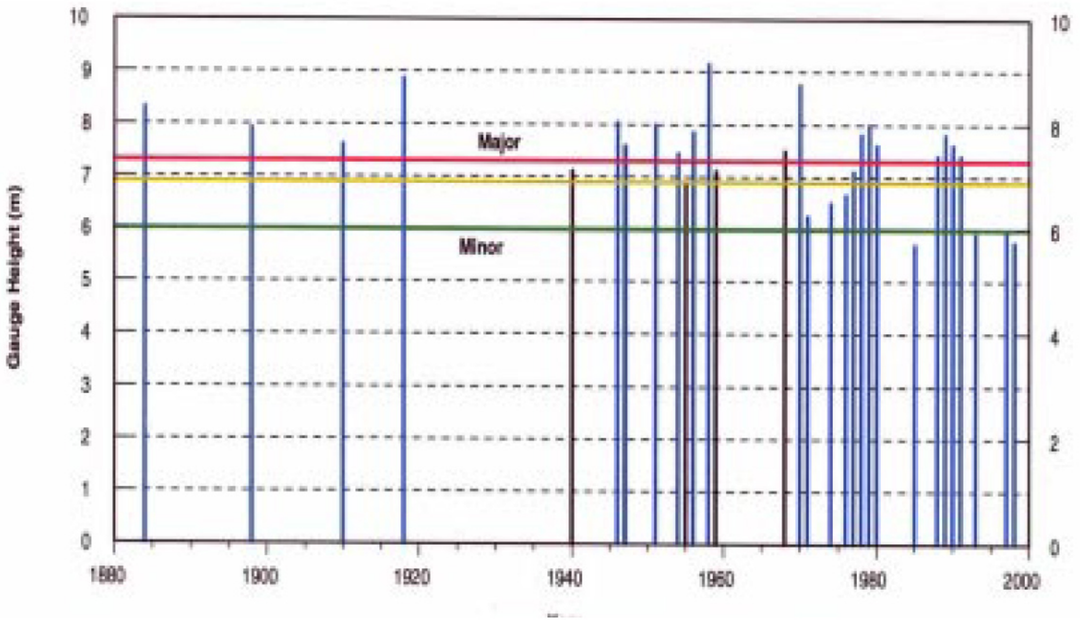


Figure 5.2: Peak flood heights for Mackay Station at Forgan Bridge (Bureau of Meteorology)

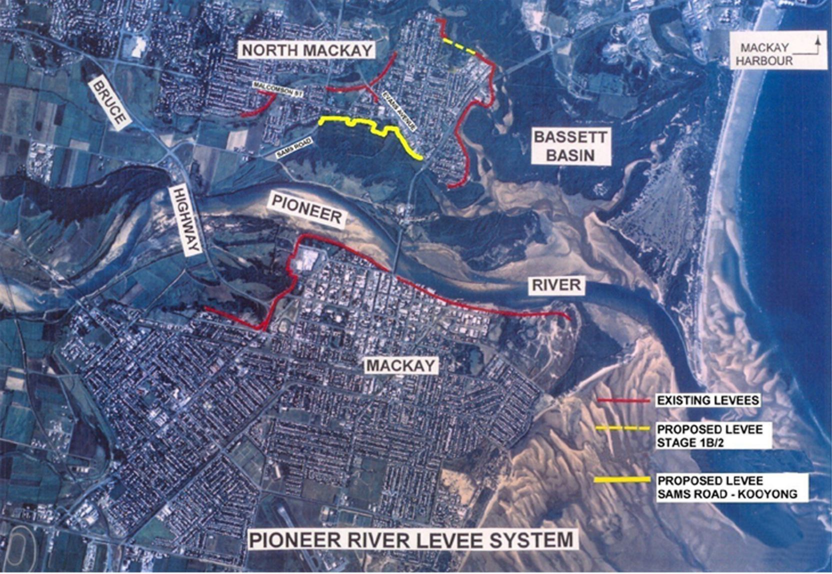


Figure 5.6: Pioneer River levee system (Ullman and Nolan Pty Ltd.)

Plate 5.1: The Forgan Bridge, looking northwest
Collection: Miriam Middelmann

Plate 5.2: Cremorne February 1958 - Rescuers at work
Collection: Mackay *Daily Mercury*

Plate 5.3: Foulden February 1958 - Devastation following a major flood
Collection: *Mackay Daily Mercury*

Plate 5.4: Mackay early 1991 - Flooded Hospital Bridge
Collection: Mackay *Daily Mercury*

Plate 5.5: Mackay February 1979 - River Street deluged by floodwaters
Collection: Mackay *Daily Mercury*

Plate 5.6: Mackay 1979 - Michelmores threatened by floodwaters
Collection: Mackay *Daily Mercury*

CHAPTER 6: CYCLONE RISKS

Ken Granger, Bruce Harper, Trevor Jones, John Stehle, Matt Hayne and Jeff Callaghan

The Cyclone Threat

There is little doubt that tropical cyclones pose a significant overall threat to Mackay. Since the settlement was founded in 1862 there have been at least 77 cyclones that have had an impact on the city. The greatest impact was caused by the cyclone of 21 January 1918, in which the combined effects of strong winds, storm tide and flood destroyed or damaged around 75% of the buildings in the town and took at least 30 lives. The inventory of cyclones affecting Mackay (Appendix M) is based largely on a listing of historical events compiled from many sources by the Bureau of Meteorology's Queensland Regional Office in Brisbane.

Of the 77 cyclones or ex-cyclones included in Appendix M, 19 have either crossed, or approached, the coast within 75 km of Mackay. A further 29 cyclones have approached to between 75 and 150 km of the city, with the remaining 29 being more distant than 150 km. An approach to within 75 km would bring Mackay within the radius of destructive winds of most cyclones of Category 2 or above.

There are three components of a 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, whilst the storm surge is linked closely to the combination of surface wind speed, 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 (1999b) uses the five-category system shown in Table 6.1 for cyclones in Australia. Severe cyclones are those of Category 3 and above.

Table 6.1: 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 storm tide inundation hazards and the risks that they pose. The consequences of intense rainfall have been addressed to varying degrees in Chapter 5 (Flood Risks). Because of the generally flat terrain of the Mackay urban area, with the slight exception of the houses built around the flanks of Mount Pleasant, landslides generated by intense rainfall are not considered to be a significant hazard and consequently, no landslide assessment is included in this study.

The Cyclone Phenomenon

The strict 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, the 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 (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.

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 northeast and northwest of Australia; and in the Gulf of Carpentaria. Cyclones in the Australian region occur predominantly between 15° and 20°S, 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, 1998). The period of recorded observations of cyclone occurrences, however, is only a little more than 100 years. In sparsely settled regions or regions remote from the coast, the records are accurate only since the advent of satellite observation from the early 1960s.

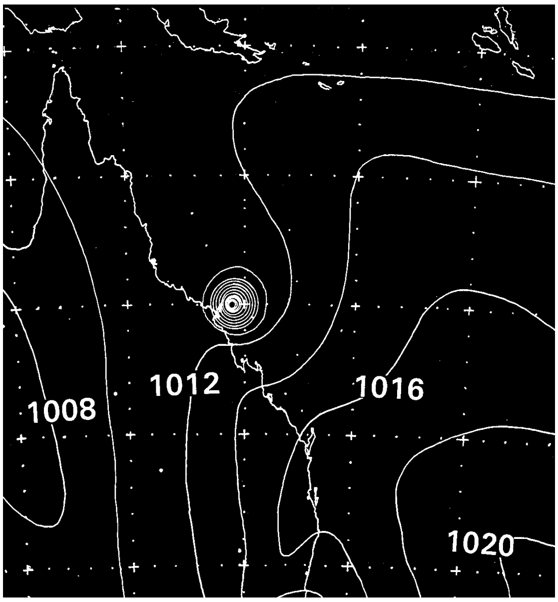
Once formed, cyclones in the Southern Hemisphere tend to move westwards and polewards under combined easterly steering currents and dynamic effects, although individual tracks can be erratic. Cyclonic movement along the Queensland coast between 10° and 15°S latitude is mostly southwest to westward and south to southeastward. South of latitude 15°S, the major direction of movement is southeastward (Coleman, 1971) due to interaction with predominantly westerly flows. Continental east coast effects also tend to cause blocking and steering such that many cyclones tend to track southwards parallel to the coast.

The main structural features of a severe tropical cyclone are the eye, the eye wall and the spiral rainbands. 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. Studies by Black and Marks (1991) and 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 in association with the eye wall and outer rain bands. Tornadoes on the outskirts of tropical cyclones have been experienced in Mackay on at least three occasions. 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.

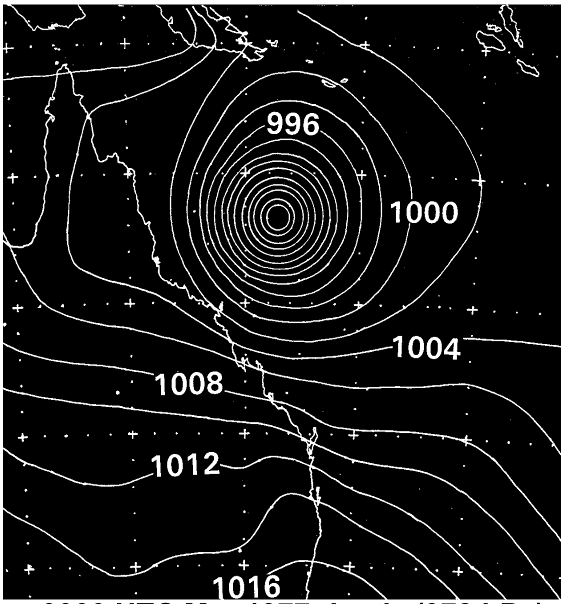
Given specifically favourable conditions, tropical cyclones can continue to intensify until they are efficiently utilising all of the available energy from the immediate atmospheric and oceanic sources. This maximum potential intensity (MPI) is a function of the climatology of regional sea surface temperature (SST) and atmospheric temperature and humidity profiles. Applying a thermodynamic MPI model (Holland, 1997) for the Mackay region, the MPI is thought to represent a central pressure of about 895 hPa. This is considerably more intense than any cyclone to date recorded in the region but not as low as has been experienced worldwide. Thankfully, it is rare for any cyclone to reach its MPI because environmental conditions often act to limit intensities in the Queensland region.

The windfield within a moving cyclone 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 the direction of cyclone movement and circulation on the left-hand side of the cyclone 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.

For any given central pressure, the lateral extent of individual tropical cyclones can vary enormously. Examples of the surface pressure (isobar) fields of two very different tropical cyclones that have affected Mackay are shown in Figure 6.1. The first is that of *Ada* in 1970, which devastated the Whitsunday Islands region 80 km to the north. This was a particularly small cyclone with modest central pressure, but it was embedded in a relatively high pressure zone and produced extreme winds. It was so small that the zone of destructive winds fitted between the coast and the Great Barrier Reef. The alternative example is *Justin* in 1997. *Justin* was a very large cyclone centred more than 500 km north of Mackay. This storm, again with modest central pressure at the time, generated extreme waves and a persistent storm surge over many days causing extensive coastal damage. Coastal damage was due to the alignment of the outer winds with the exposed eastsoutheast fetch near Mackay, which is not protected by the Great Barrier Reef.



1200 UTC Jan 1970 *Ada* (963 hPa)



0000 UTC Mar 1977 *Justin* (978 hPa)

Figure 6.1: Examples of tropical cyclones affecting the Mackay region (surface isobars shown in 2 hPa intervals)

The Mackay Cyclone Experience

The cyclone season in Mackay is typical of the Southern Hemisphere, extending from late November to April, with the occasional event occurring in May. The greatest incidence of cyclones occurs during January, February and March. Figure 6.2 shows February to be the month in which, historically, more of the close cyclones occur; January, February and March have more of the mid-distance cyclones; and January has more of the distant cyclones.

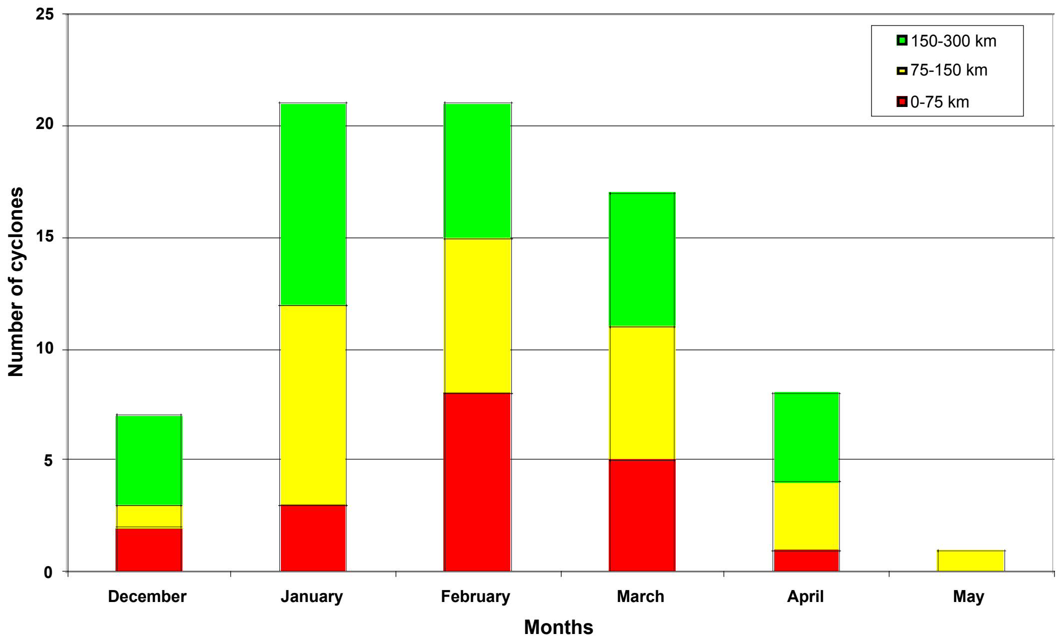


Figure 6.2: Frequency of cyclones in the Mackay area 1867-1997.

Of the 77 cyclones that have had some effect on Mackay (listed in Appendix M), at least ten have inflicted substantial damage other than flooding (covered in Chapter 5) or caused significant dislocation. A brief outline of these events and their impact will provide some level of appreciation. It is difficult, however, to make direct comparisons of damage between individual cyclones because the Mackay township has changed greatly over time. The ten most notable cyclones were:

- 17 February 1888 – an unnamed severe cyclone recurved near Mackay with severe winds destroying several buildings. One ship was lost and another dismasted;
- 4 February 1898 – Cyclone *Eline* recurved very close to Mackay causing extensive destruction and flooding. The court house and two churches were destroyed and many other buildings were damaged;
- 10 December 1915 – winds from an unnamed low category cyclone, tracking from the north, bent telegraph poles and damaged roofs in the town;
- 21 January 1918 – an unnamed, at least Category 4 cyclone, scored a bulls eye hit on Mackay bringing with it a 3.6 m storm surge that inundated much of the town to a level of 5.4 m above AHD. The storm tide and the winds destroyed around 1200 buildings and damaged most of the rest. At least 30 people lost their lives;
- 7 March 1955 – an unnamed Category 3 cyclone crossed the coast at Sarina to the south. Widespread wind damage was experienced in Mackay;
- 17 January 1970 - small Category 3 Cyclone *Ada* passed through the Whitsunday Group and within 80 km from the city at its closest point. Severe damage was experienced in the area close to the track and the Pioneer River reached major flood levels.

- 5 March 1976 – Category 1 Cyclone *Dawn* crossed the coast within 30 km of Mackay. Two houses were unroofed in North Mackay;
- 1 March 1979 – Category 1 Cyclone *Kerry* crossed the coast at Proserpine, 80 km to the north. Significant wind damage was suffered by at least 26 houses in Mackay and many boats were destroyed by huge seas inside the outer harbour;
- 26 December 1990 – Category 4 Cyclone *Joy*, which had weakened to Category 2 level by the time it reached Mackay, caused extensive damage. A tornado demolished two houses and damaged at least 40 others. A seaside caravan park was extensively damaged by high seas and one person drowned in the surf;
- 9 March 1997 – Category 4 Cyclone *Justin* had not reached its full strength when it generated massive seas that caused significant coastal erosion on all of Mackay's beaches.

The full text of the description of the 1918 cyclone, published in the *Mackay Daily Mercury* on 26 January 1918 (five days after the disaster), is contained in Appendix N, along with other contemporary reports of the cyclone. Some of the key observations include:

> *The destructive period of the cyclone was about ten hours and it was almost incredible the amount of damage that was done in that short period* [Plate 6.1]. *Some of the residents are able to report that not a pane of glass was damaged in their homes, but they are very few. Of the 1200 or 1400 houses within the Municipality of Mackay, not more than one quarter escaped damage of some kind, and in a great many cases the buildings were levelled to the ground. The town on Monday afternoon presented an appalling spectacle. The damage in most cases consisted of the houses being unroofed, and this particularly applied to the larger buildings such as hotels, churches, public halls and two-storied buildings* [Plate 6.2 and Plate 6.3]. *As with other classes of buildings some of them collapsed entirely and some sustained partial damage only. The residential area suffered severely. A great many of the residences were thrown down and completely destroyed, while others were unroofed or otherwise damaged. No particular part of the town suffered more than any other part. The damage was general in town and country and confirms the opinion that the centre of the cyclone traversed the district.....*
>
> *While the cyclone was at its height another terror, in the shape of a tidal wave, swept the town and caused consternation amongst the fear wracked householders. It struck the coast about five o'clock when the cyclone was raging and it is alleged a wall of water 25 ft* [7.6 m] *high swept over the beaches; and taking a southwesterly direction submerged the town to varying depths as far out as Nebo Road. It was 5 or 6 ft deep on Beach Road and about 2 ft deep at the Ambulance corner. The water flowed inland in waves, carrying debris of a substantial character with it. In the river the wave played havoc with the shipping, wharves, stores and houses, while a large section of the Sydney Street bridge, which is the main avenue between Mackay and North Side, was washed away....*
>
> *The heavy rain, combined with the big tide, caused a record flood in the river on Tuesday. There is no authentic record as to the height the river rose, as the gauges were all washed away, but the Harbour Master (Captain Greenfield) states that the water rose at least 20 ft. The lower portion of the town was inundated to a depth of* [unreadable]. *The river broke across below Devil's Elbow into Barnes Creek and relieved the pressure in the main outlet, and on Thursday morning the back water in the land near the cemetery overflowed and crossing Nebo Road, rushed down Shakespeare Street and a parallel street to a depth of 3 ft. It is the opinion of experienced men that had this second diversion not occurred the loss of life would have been enormous. The flood commenced to subside on Thursday afternoon and is already back to normal....*
>
> *Mr J. Shanks and his brother Mr Frank Shanks, also had a terrible experience. They resided in the old butter factory and when the tidal waters entered the building took refuge in what they considered the strongest room in the house and put their wives and families on a table. The water rose above the level of the table and another one was placed on top and as the waters still continued to rise chairs were provided. When everything seemed secure, the*

kitchen from the house adjoining collapsed and partly demolished the building where the people were. Mr Frank Shanks was rendered insensible through being struck by falling timber and all were thrown into the water. Mr J. Shanks then heroically secured rafts and ultimately, after a fierce battle with the elements, and a most perilous journey, during which his wife and children and his brother's baby disappeared, he reached the Waterside Workers Hall and gained entrance through a window. Mr Frank Shanks afterwards reached Tennyson Street and upon his information a rescue party was organised and a number of people, including Mr. and Mrs. Weir and several who had sought refuge in their residence, together with those who were in the hall, were rescued. The force of the rain was terrible, Mr Shanks remarking that he was bruised all over with the driving rain and had every stitch of clothing ripped off his body.

Parkinson and others (1950) mapped the extent of storm tide inundation produced by the 1918 cyclone. This, together with the location of known fatalities in the Mackay urban area, is shown in Figure 6.3. In all, at least 30 people died in the cyclone of which 13 drowned in the storm tide and two died due to buildings collapsing. The numbers of dead at each location is shown in the figure. It is little wonder that the Mackay community still takes the threat of cyclones more seriously than most other communities in Queensland.

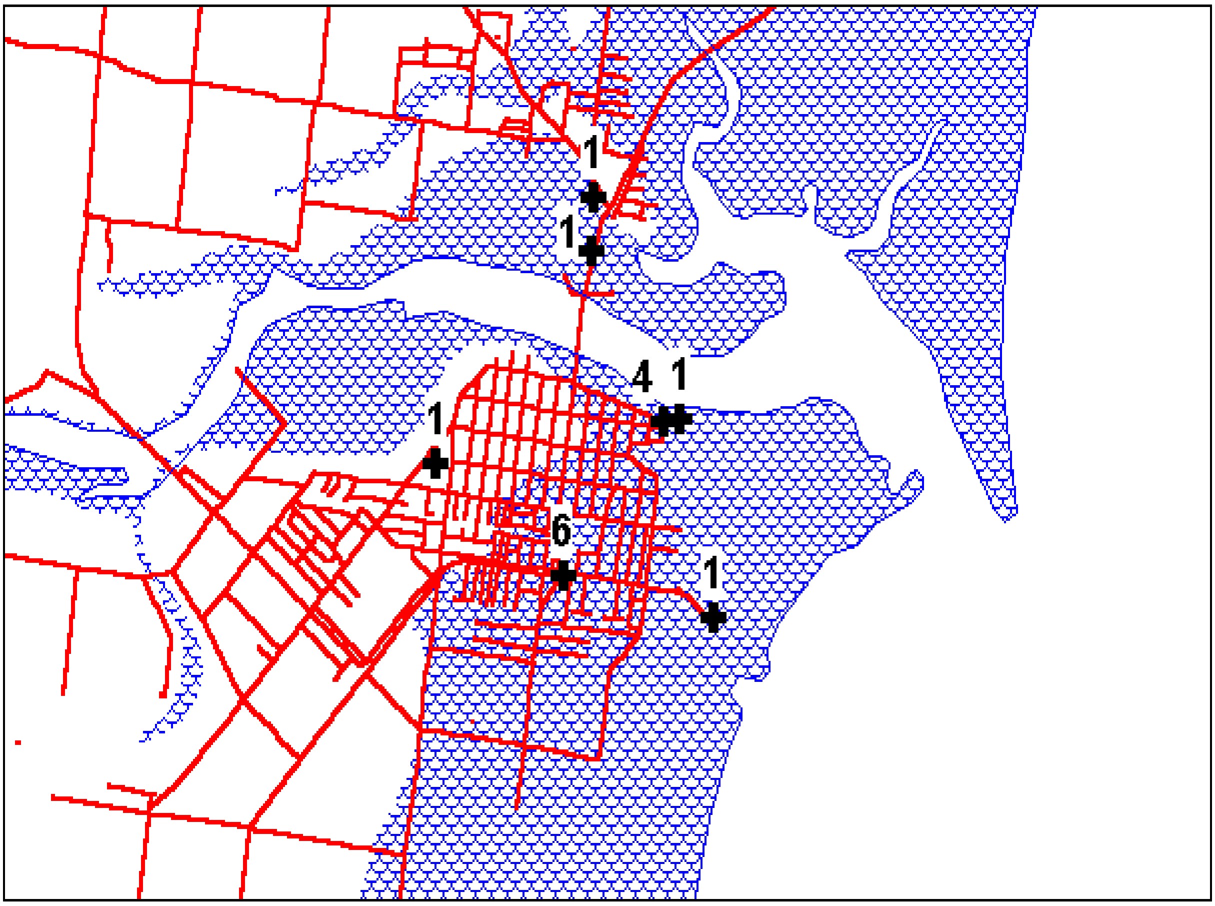


Figure 6.3: Mackay 1918 storm tide inundation and number of fatalities

Cyclone Variability

Observational record: Holland (1981), observed that *tropical cyclone data are only as good as their concomitant observing systems and analysis techniques*. The most common flaw in tropical cyclone records is missing data. In Australia, for example, the number of recordings increased from 1909 to 1959, parallel with an increase in population and trade in the north of the continent (Holland, 1981). It was not until 1966, with the launching of ESSA satellites, that cyclones could be investigated systematically.

Based purely on observational records, Ryan (1993) noted that cyclonic frequency varied considerably in the Australian region between 1959 and 1989, from five cyclones in 1988-1989 to a maximum of 19 in 1963-1964, however, no trend is apparent.

Yearly cyclonic frequency near Mackay has been calculated using cyclones which track within 300 km of the site and for which an impact has been recorded (Figure 6.4). Cyclonic frequency shows considerable variability and although there is a trend suggesting an increase in frequency towards the present this is thought to be due to incomplete data sets as mentioned above. For the reliable portion of the recorded period from 1966 to present, the record shows considerable variability with three cyclones occurring in 1976.

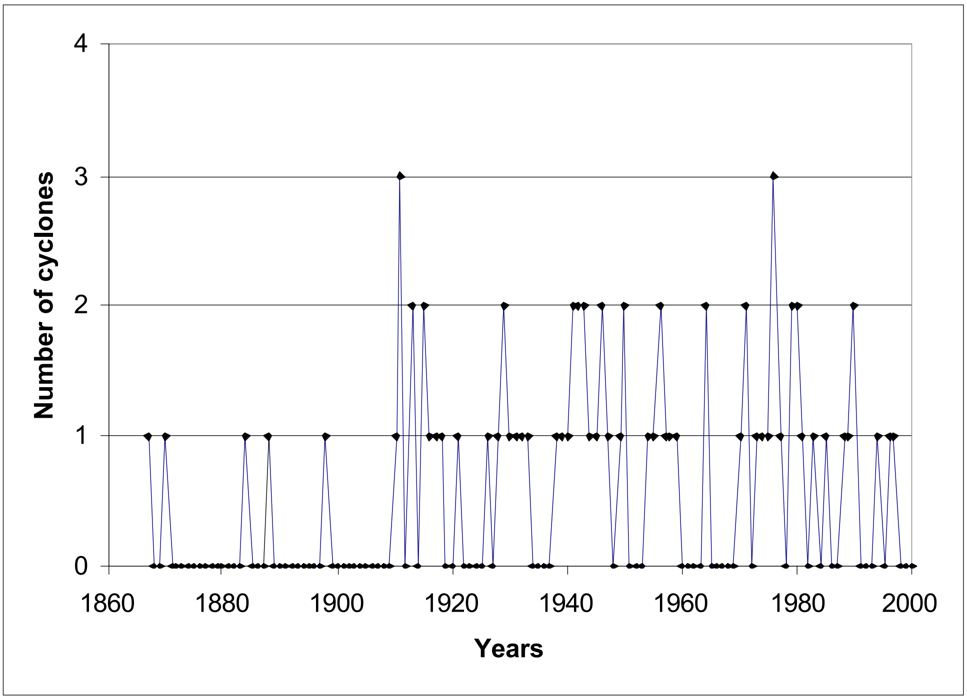


Figure 6.4. Yearly occurrences of tropical cyclones within 300 km and impacting on Mackay

Climatic Variability: Figure 6.4 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 (WMO 1995). For many years one of the principal indicators of seasonal cyclonic activity has been the so-called El Niño - Southern Oscillation (ENSO) phenomenon. This is the name given to a quasi-biennial (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 Mackay are typically above average. Ocean temperature is not the only factor causing cyclone variability but it is a prime contributor, and, 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 to move further towards the east (El Niño) or west (La Niña) during ENSO events.

Several techniques are used to determine 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 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 SSTs from various zones in the Pacific. These data have become routinely available from satellite as well as 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 6.5 shows that when the historical record is separated into El Niño and La Niña periods, there is a 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 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 three since the mid-1970s. This has been reflected along much of the east coast of Queensland by a corresponding reduction in frequency of cyclone occurrence and Figure 6.4 indicates this effect from about 1980 onwards within 300 km of Mackay. 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 in the next section, or even global climate change. From 1998 to early 2000 there has been a return to mild La Niña and near-neutral conditions.

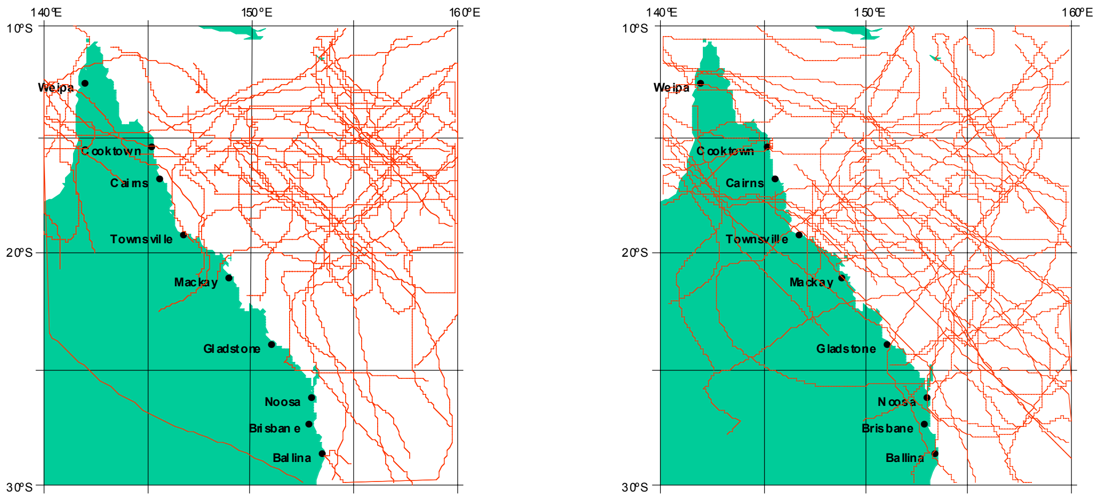


Figure 6.5. Differences in tropical cyclone tracks between El Niño (left) and La Niña (right) years.

Power and others (1999) recently highlighted the potential importance for the 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 (under review) 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. Again, 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.

Climate Change: The potential impact of global warming arising from the so-called "enhanced Greenhouse effect" has become a major scientific and social issue since the 1980's. Greenhouse warming occurs when solar radiation absorbed by the earth is re-emitted as heat energy back into the atmosphere where it is partly trapped by “greenhouse” gases. These gases then re-emit the radiation in all directions, further warming the atmosphere and the earth’s surface. The process is a natural one; without these gases the earth’s surface would be approximately 33^{o}C cooler. However, human activities are believed to have markedly increased the level of greenhouse gases such as CO_2 and CFC’s in the atmosphere. This is expected to raise global temperatures over time, potentially leading to changed climates. One of the consequences of these changes could be a change in the incidence, severity and southern movement of tropical cyclones.

A global “consensus” report on climate change is provided by the Intergovernmental Panel on Climate Change (IPCC) of the World Meteorological Organisation (WMO) and United Nations Environment Program (UNEP). It is updated at approximately five-year intervals, following an intensive review by some hundreds of scientists. According to the IPCC Second Assessment Report in 1995 (IPCC, 1996):

- the climate has changed over the past century;
- the balance of evidence suggests a discernible human influence on global climate;
- the climate is expected to continue to change in the future;
- there are still many uncertainties, including the rates and regional patterns of climate change;
- there is a possibility for more extreme rainfall events;
- there could be enhanced precipitation variability associated with ENSO;
- under the “business as usual” emissions scenario, sea level is expected to rise by between 20 cm and 86 cm, with a best estimate of about 50 cm, by 2100; and,
- global mean surface air temperature is expected to rise between 1^{o}C and 3.5^{o}C, with a best estimate of 2^{o}C, by 2100. Substantial regional variations in these estimates are to be expected.

IPCC (1996) highlights the uncertainties in past data records of tropical cyclones and the difficulties in discerning any long-term trends, but suggests that there may be an increase in cyclone frequency and intensity. More recently, Henderson-Sellers and others (1998) presented an expert consensus that concedes the possibility of a modest increase in the maximum potential intensities of tropical cyclones but with little likelihood of increased frequency or coverage.

Given the possible implications of future climate change scenarios, it could be prudent in Mackay to plan for a possible increase in the intensity of cyclones as compared with the last 25 year period.

Interpreted record: A different approach to the interpretation of cyclonic frequency uses evidence from storm surge deposits. This method can produce frequency records dating back 6500 years, highlighting longer period variability as well as bypassing the problems associated with observational records.

Hopley (1968) was one of the first to interpret storm ridge patterns in northern Australia. Hopley inferred a mid to late Holocene change of storm intensity and direction from the morphology of early versus late shingle deposits at Curacoa Island (350 km northwest of Mackay). Hopley, suggested that at the time of initial spit formation (about 6000 radiocarbon years B.P.), the dominant waves had a greater northerly or northeasterly component and that stormier conditions prevailed. Later, Rhodes (1980) established a radiocarbon dated record of Holocene storm ridges at western Cape York Peninsula. According to Rhodes, there were four periods of ridge development, the earliest between 5900 and 4700 years B.P., the second between 3500 and 2500 years B.P., the third around 1400 years B.P. and the last from 400 B.P. to the present. Rhodes also analysed 25 radiocarbon ages collected by Smart (1976) from Cape Keer Weer on western Cape York Peninsula and considered that they showed ridge formation during approximately the same four periods.

Chappell and others (1983) suggested that patterns of cyclone frequency could be deduced from storm ridge sequences in north Queensland, on the basis of data from Curacoa Island (northeast of Townsville) and other sites. Radiocarbon dates from the past 4000 years were grouped into 500 year intervals and the assumption that cyclone frequency has not changed was tested statistically. Further in-depth analysis by Hayne and Chappell (in press) at Curacoa Island and Princess Charlotte Bay beach ridge sequences, found no significant variation of cyclone frequency at either site for the past 6000 years and 2500 years respectively.

A similar study is reported by Chivas and others (1986) from Lady Elliot Island in the southern Great Barrier Reef. Dates from beach ridge samples appear to show that there has been no significant variation of ridge-building event frequency during the past 4000 years (Chappell and Thom, 1986; Chivas and others, 1986).

Cyclone Warning Systems

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 (Bureau of Meteorology 1999c). This encompasses an area essentially between 138°E (Gulf of Carpentaria) and 160°E (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 array of informational and computational resources used by its staff. These include an extensive network of automatic weather stations (AWS), 15 of which are located along or offshore of the Great Barrier Reef between 15°S and 25°S providing a very effective observational system. Additionally, weather radars provide coverage within about 300 km of the entire east coast south of 15°S. A variety of satellite derived products are also available (visible and infra-red imagery, radar and water vapour), and guidance is provided from a number of numerical weather models, both global and for the local area.

Ranges of warning products are produced depending on the situation. *Tropical Cyclone Outlooks* are disseminated daily to advise the potential for cyclonic activity within 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 48 hours. This is upgraded to a *Cyclone Warning* if gales are expected within 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.

Storm tide warnings are issued by the Bureau of Meteorology in conjunction with the State Counter Disaster Organisation (SCDO, 1994) which interfaces with a number of key State Government organisations. Department of Emergency Services (DES) provides the executive role for the SCDO. The Beach Protection Authority (BPA), now a part of the Environmental Protection Agency (EPA), provides specialist advice and data in respect of wave and storm surge readings from its real-time network of waverider 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.

Severe Wind Risks

Most of the structural damage caused by tropical cyclones is inflicted by the strong winds that reach their peak in the eye wall. This damage can be caused directly by the wind and/or by the debris that it propels, frequently with great force.

Wind damage tends to increase disproportionately to the wind speed. According to Meyer (1997), winds of 70 m/sec (250 km/h) cause, on average, 70 times the damage of winds of 35 m/sec (125 km/h). Damage tends to start where sustained wind speeds begin to exceed 20 m/sec (about 75 km/h). In addition to the high wind speeds, the turbulence of the winds caused by terrain features and large buildings is also a decisive factor. Turbulence is often a particular problem on the lee slope of hills, such as Mount Bassett and Mount Pleasant. However, for the vast majority of the Mackay urban area, local terrain effects will be minimal.

Buildings: The construction, design, age and location of buildings each have an influence on the risk of building damage. Advances made in cyclone resistant construction since the 1970s have resulted in improved building performance under wind loads. Generally, however, metal roofs are more susceptible to wind damage than are tile roofs, though the latter are more susceptible to damage by wind-driven debris; reinforced brick and concrete block walls are resilient, while fibro, metal cladding and even timber walls are susceptible to being penetrated by debris. Large areas of unprotected glass are even more susceptible to both wind and debris damage.

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. The fastening of roofing material to trusses and the fastening of roof members to walls and foundations are also important.

Some of the key forces on buildings are illustrated in Figure 6.6 and Figure 6.7. These are based on Meyer (op. cit. p.18). 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.

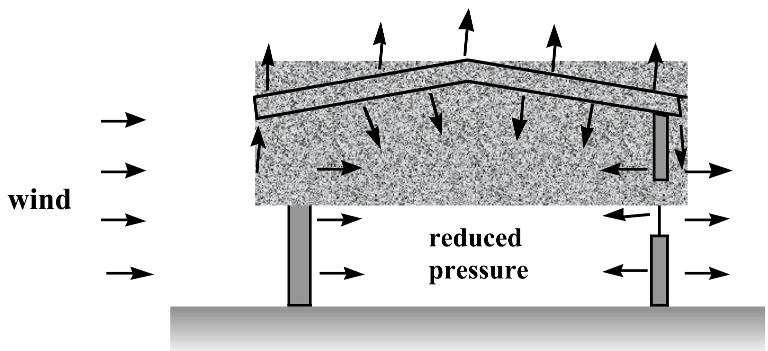


Figure 6.6: Wind forces working on a building with external integrity

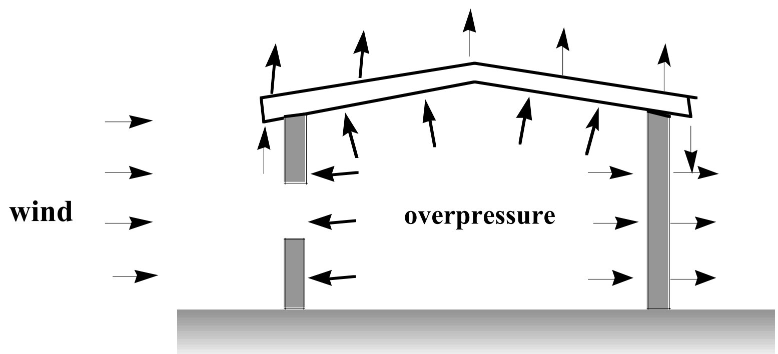


Figure 6.7: Wind forces working on a building where its external integrity is lost

Wind loading standards in Australia were first implemented by structural engineers in 1952. It was not until the experience of the severe destruction wrought by Cyclones *Althea* (Townsville) in 1971 and *Tracy* (Darwin) in 1974 that efforts were made to strengthen building standards in Queensland and elsewhere in Australia, especially for domestic structures termed "non-engineered 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 1981, and had already become widely applied for domestic structures in Queensland by that time. *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).

The wind loading code makes some allowance for the site on which the building stands. Buildings on ridge crests, for example, are more exposed than are buildings on flat ground; buildings close to the coast or on open country are more exposed than buildings further inland or grouped in suburban settings. By-and-large, ridge crest terrain exposure is not a significant issue for wind hazards in the Mackay study area, however, some 7630 buildings (37% of the total) lie within one kilometre of the shoreline and the open land of the airfield.

Building age is highly significant because it reflects both the degree of conformance to the Building Code, 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 cyclonic 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.

To model the likely impact of severe wind across the study area from a range of scenarios we have used damage estimate values developed by Harper (1999a) for domestic buildings in three broad zones in Mackay that are consistent with the wind loading code. They are:

- foreshore – terrain category 2;
- town – terrain category 2.5 with shielding; and
- inland- terrain category 2.5.

Two age classes have also been established, that is, nominally pre and post 1980. The tallies for all Mackay buildings and for just domestic buildings in each of the resulting six categories are given in Table 6.2.

Table 6.2: Mackay buildings by wind-risk category (domestic buildings in parenthesis)

	Foreshore	**Town**	**Inland**	**Total**
Pre 1980	5550 (4995)	8090 (7250)	30 (25)	13670(12270)
Post 1980	2080 (1845)	4770 (4440)	230 (170)	7080 (6455)
Totals	7630 (6840)	12860(11691)	260 (195)	20750 (18725)

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 (Harper and Holland 1998, Walker 1994) which are also deemed consistent with US experience in Hurricane 'Andrew' (Sparkes 1993).*

By assigning recurrence probabilities to the peak wind gusts it is possible to establish estimates of the percentage of damage likely to be experienced by domestic buildings under a range of scenarios.

The 'damage curves' for Mackay, shown in Figure 6.8, clearly illustrate the significance of the introduction of building code standards in the 1980s. This point was clearly evident in the experience of the impact of Cyclone *Winifred* near Innisfail in 1986 and most recently with Cyclone *Vance* at Onslow in Western Australia in 1999 (Reardon, Henderson and Ginger, 1999). The "% damage" values shown are relative to the nominal replacement cost of a dwelling and associated assets or, when aggregated, a total residential community. Industrial and commercial buildings, where individual engineering design and inspection have been applied, are expected to suffer significantly less damage than dwellings in similar conditions (Bruce Harper, personal communication, 2000). It is therefore expected that the total community loss under extreme wind conditions will be dominated by damage to dwellings.

The 'damage curves' in Figure 6.8 were derived using the probabilistic wind speeds for Mackay in Harper (1999b).

The proportions of damage to domestic buildings, across the entire community, are given for pre-1980 buildings in Table 6.3 and for post-1980 buildings in Table 6.4. The expected total levels of damage in Mackay under five scenarios are summarised in Table 6.5.

As a general rule of thumb, community damage levels in excess of around 20% would probably render many individual buildings uninhabitable until repairs were effected.

Table 6.3: Expected level of damage to pre-1980 domestic buildings

	FORESHORE (% damage)	**TOWN** (% damage)	**INLAND** (% damage)
50 year ARI	0.7%	0.1%	0.1%
100 year ARI	2.7%	0.1%	1.2%
500 year ARI	19.7%	2.0%	11.0%
1000 year ARI	36.0%	4.1%	18.4%
10000 year ARI	100.0%	19.1%	77.5%

Table 6.4: Expected level of damage to post-1980 domestic buildings

	FORESHORE (% damage)	**TOWN** (% damage)	**INLAND** (% damage)
50 year ARI	0.1%	0.1%	0.1%
100 year ARI	0.1%	0.1%	0.1%
500 year ARI	2.9%	0.1%	1.0%
1000 year ARI	6.4%	0.1%	2.7%
10000 year ARI	25.7%	2.8%	15.0%

Table 6.5: Total expected level of damage to domestic buildings with respect to replacement/repair costs, with equivalent numbers of completely damaged buildings

	FORESHORE (% damage)	**TOWN** (% damage)	**INLAND** (% damage)	**TOTAL** (% damage)
50 year ARI	1% 39	0% 12	0% 0	0.3% 51
100 year ARI	2% 136	0% 12	0% 0	0.8% 148
500 year ARI	15% 1036	1% 148	2% 4	6.4% 1188
1000 year ARI	28% 1918	3% 304	5% 9	11.9% 2232
10000 year ARI	80% 5469	13% 1513	23% 45	37.5% 7027

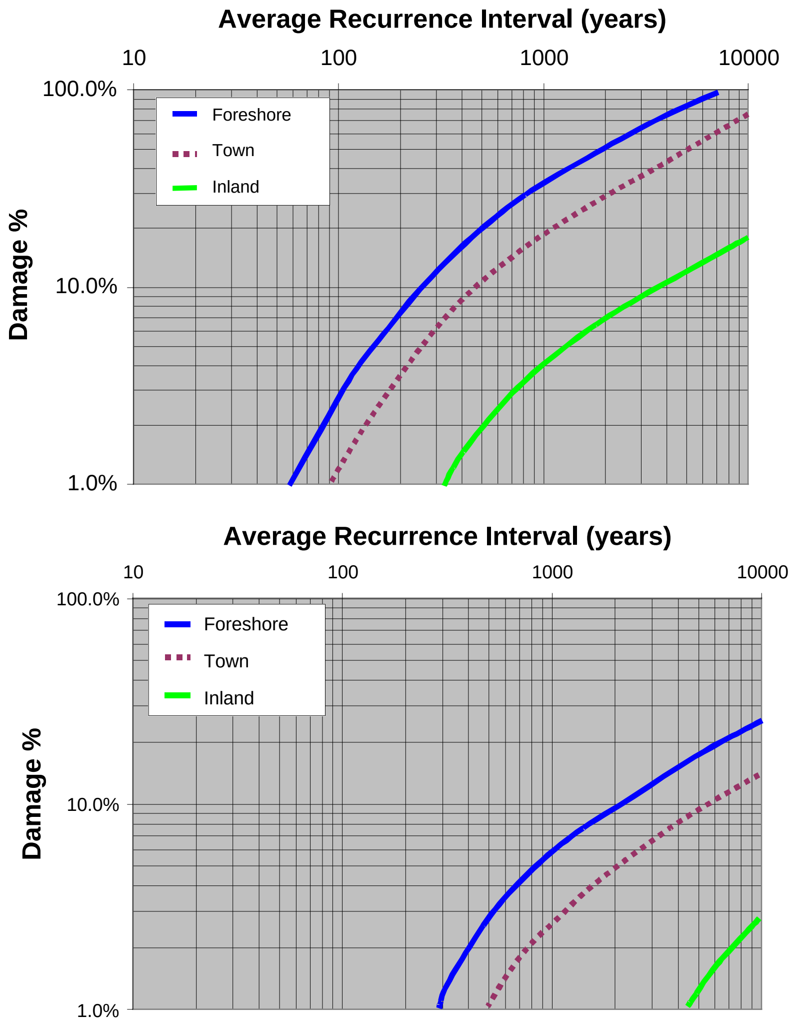


Figure 6.8: Expected level of wind damage to domestic buildings in Mackay as a function of age of construction and type of exposure for various return periods. Top, pre-1980 dwellings; bottom, post-1980 dwellings

A summary of the building damage generated by wind scenarios with likelihoods ranging from ARI = 50 years to ARI = 10 000 years is shown in Figure 6.9 and Table 6.6. Damage categories 'slight', 'moderate' and 'extensive' have been developed to allow comparisons of building damage from severe wind, flood, storm tide and earthquake in Chapter 7. The categories of damage are derived using the indicative 'damage curves' presented in Figure 6.8. These curves are assumed to be mean damage curves, with a log-normal standard deviation of 1.0. 'Reasonable' variations of the log-normal standard deviation were found not to influence the results drastically. The damage ratios used in HAZUS (FEMA, 1999) are assumed to be indicative of the damage level (refer to Chapter 4). The discrete damage ratios of HAZUS have been converted to the continuous ranges: slight, 1%-5%; moderate, 5%-25%; and extensive, 25%-100%.

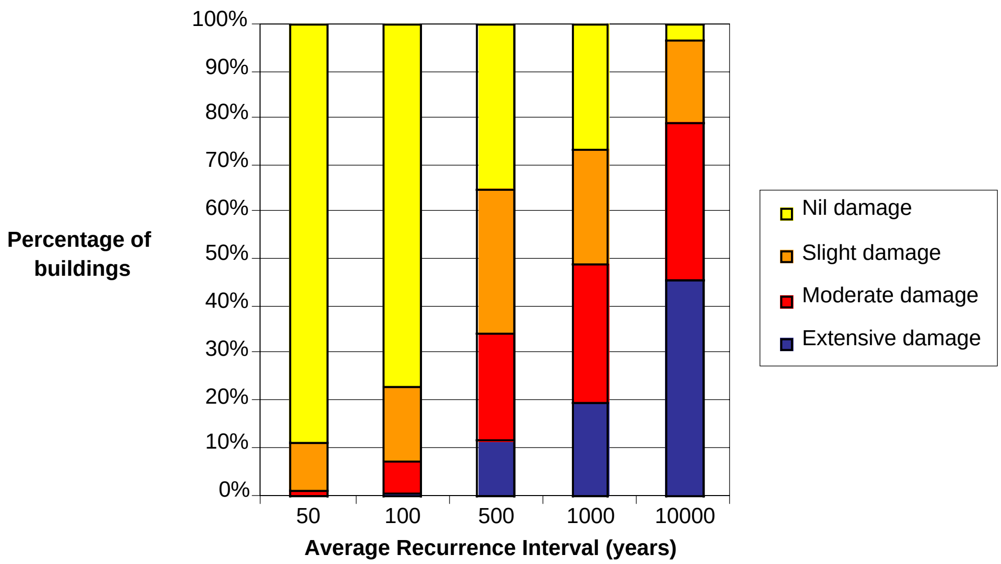


Figure 6.9: Estimated wind damage states of Mackay residential buildings for various scenarios

Table 6.6: Estimated wind damage states of residential buildings in Mackay

ARI	Nil damage		Slight damage		Moderate damage		Extensive damage	
	No.	% of total	No.	% of total	No.	% of total	No.	% of total
50	16650	89.0%	1921	10.3%	142	0.8%	1	0.0%
100	14371	76.8%	3010	16.1%	1269	6.8%	64	0.3%
500	6541	35.0%	5754	30.7%	4321	23.1%	2098	11.2%
1000	5041	26.9%	4552	24.3%	5480	29.3%	3641	19.5%
10000	680	3.6%	3275	17.5%	6240	33.3%	8519	45.5%

Wind damage estimates were also developed for Mackay, for a similar range of scenarios, using a different wind speed model that is based on wind speeds in *AS1170.2-1989*. This was done because local government and developers are required to apply the standard to the design and construction of new structures under the Australian Building Code. It is also of interest to estimate the potential damage in Mackay from design wind speeds.

The wind speed model of Harper (1999b) for Mackay is preferred over the approach contained in *AS1170.2-1989*. Although we have not evaluated Harper's (1999b) model fully, its methodology has a better scientific basis, and his assessment was developed specifically from the Mackay regional tropical cyclone climatology, thus enabling the improved prediction of rare cyclonic events. Harper also had access to a longer historical record. The hazard model in *AS1170.2-1989*, in contrast, is a broad model applicable to all of Australia Region C. Region C extends along the entire northern coastline of Australia, from the Pilbara in Western Australia (with a southern segment also at latitudes 25-27 degrees S), through the Northern Territory, and through northern and Central Queensland to 25 degrees S. It was developed from research and data available until about 1987. A revision of *AS1170.2* is due to be released in 2001.

The same terrain parameters were applied to this second wind speed model. The peak mean gust speeds are significantly higher than those in the Harper (1999b) model, and the marked sensitivity of domestic building damage to increasing wind speeds leads to considerably higher predicted damage levels. Harper (1999a) stated (p.28):

> *The wind speed estimates used herein are based on AS1170.2, Region C and as such represent a smoothed and likely conservative interpretation of the actual wind speeds due to tropical cyclones in the region. This particularly applies in the extrapolation of speeds to the MPE level of a 10,000 year return period. More specific and detailed studies (e.g. Harper* 1999 [b]*) show significant reductions in predicted return period speeds for this area …*
>
> *The wind speed damage relationships applied in this study should be regarded as indicative only …*

The results of this second damage assessment based on *AS1170.2-1989* wind speed parameters are similar to those presented by Harper (1999a) but we have had the benefit of direct access to the latest GIS building datasets.

Figure 6.10 compares the damage to residential buildings in Mackay predicted by the two assessment methods: the preferred method in this study that uses wind speeds from Harper (1999b), and the method based on the wind speeds described by *AS1170.2-1989*. The wind risk estimated in this study is much lower than the risk estimated by the method based on *AS1170.2-1989*. The key indicator of this lower risk is the level of building damage at ARI ≤ 100 years.

The expected damage from rare wind events (ARI = 500 years and ARI = 1000 years) is also much less under the scenarios in this report than under scenarios generated by the Region C wind speeds of *AS1170.2-1989*.

For the extreme scenario (ARI = 10 000 years), there is little variation in the damage estimated by either method. This result is a consequence of the pronounced sensitivity of the building damage relations to very high wind speeds.

We have already observed that *AS1170.2-1989* may be conservative, and damage estimates based on Region C wind speeds are not fully in agreement with the historical record (Appendix M).

The apparently conservative nature of damage estimated from *AS1170.2-1989* wind speeds is not necessarily undesirable. Proper application of the code results in new structures built to withstand severe winds. Under *AS1170.2-1989*, these winds are nominally at the 1000-year ARI level but, under Harper's model (1999b), the wind speeds are those of an extreme event (ARI = 10 000 years). The outcome for Mackay is that the risk of damage to modern structures from severe wind is reduced compared to the risk that would exist if the standard was relaxed.

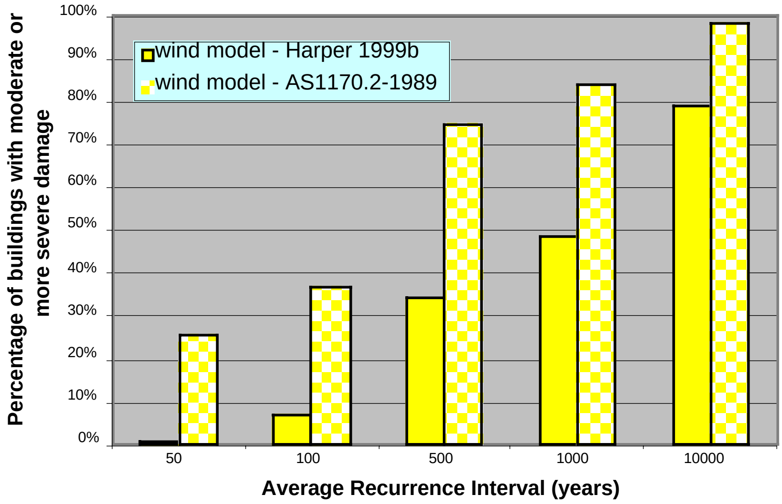


Figure 6.10: Comparison of building damage resulting from wind gust speed models of Harper, 1999b, (solid bars) and *AS1170.2-1989* (cross-hatched bars). Predicted levels of moderate or more severe damage to residential buildings are shown

Table 6.7 lists the levels of expected damage to domestic structures by suburb under each scenario both as a percentage and as equivalent numbers of houses, and Figure 6.11, Figure 6.12, Figure 6.13 and Figure 6.14 show the spatial distribution for the 100 year, 500 year, 1000 year and 10 000 year scenarios respectively.

It should be noted that building damage may occur from both severe wind and storm tide during the same cyclone event. Hence, a building may be extensively damaged by severe wind prior to a storm tide. The damage scenarios presented in Table 6.6 and Table 6.11 assume that a building will be damaged only by severe wind **or** by storm tide. As a result, estimates of damage from tropical cyclone that are simple additions of the individual building damage from severe wind and storm tide will be conservatively high.

Lifelines and other assets: With most cyclones that approach to within the radius of maximum 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. Whilst it is unusual for power poles and pylons to be brought down by high winds, it certainly has happened. In the Brisbane Valley in 1999, for example, several transmission line pylons were brought down in extreme wind gusts associated with a local storm (in the type of micro-burst conditions that could be experienced in the tornadic outbreaks experienced in cyclones). Also in Cyclone *Steve* in Cairns (late February 2000), several poles were pushed out of the vertical because the ground they were in had been saturated by up to four weeks of continual heavy rainfall before the severe winds were experienced.

Tree-fall also represents a significant threat to buildings, life and assets such as cars. Trees 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 ahead of severe wind will increase the likelihood of trees being brought down. The disposal of debris produced by wind damage to trees in cyclones inevitably presents the Council's 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, the large transmission or relay towers may even be brought down.

Table 6.7: Relative levels of wind damage by suburb

Suburb	**50 year ARI** % damage (equivalent no. dwellings)	**100 year ARI** % damage (equivalent no. dwellings)	**500 year ARI** % damage (equivalent no. dwellings)	**1000 year ARI** % damage (equivalent no. dwellings)	**10 000 year ARI** % damage (equivalent no. dwellings)
ANDERGROVE	0.1 (3)	0.3 (6)	2.3 (53)	4.4 (102)	16.9 (393)
BAKERS CREEK	0.5 (1)	1.6 (4)	12.1 (30)	22.4 (55)	65.4 (162)
BEACONSFIELD	0.1 (1)	0.1 (1)	0.8 (10)	1.6 (21)	8.8 (117)
BLACKS BEACH	0.4 (1)	1.5 (4)	11.8 (29)	22.1 (55)	64.9 (161)
BUCASIA	0.4 (4)	1.4 (12)	10.8 (92)	20.1 (172)	58.9 (505)
CENTRAL MACKAY	0.2 (2)	0.5 (5)	4.7 (45)	9 (85)	30.9 (293)
CREMORNE	0.7 (0)	2.7 (0)	19.7 (3)	36 (5)	100 (15)
DOLPHIN HEADS	0.1 (0)	0.3 (0)	4.2 (3)	8.6 (6)	31.2 (21)
EAST MACKAY	0.6 (7)	2.2 (23)	16.3 (176)	30.1 (325)	85.2 (919)
EIMEO	0.2 (1)	0.6 (4)	5.1 (31)	9.8 (60)	31.2 (190)
ERAKALA	0.1 (0)	0.1 (0)	1 (0)	2.7 (0)	15 (2)
FARLEIGH	0.1 (0)	0.1 (0)	1 (0)	2.7 (0)	15 (2)
FOULDEN	0.1 (0)	0.1 (0)	1 (0)	2.7 (0)	15 (0)
GLENELLA	0.1 (0)	0.1 (0)	0.5 (2)	0.9 (4)	6.2 (28)
HABANA	0.1 (0)	0.1 (0)	1 (0)	2.7 (0)	15 (1)
MACKAY HARBOUR	0.1 (0)	0.1 (0)	2.9 (0)	6.4 (0)	25.7 (0)
MOUNT PLEASANT	0.1 (1)	0.1 (1)	1.4 (17)	2.9 (34)	14.2 (167)
NINDAROO	0.1 (0)	0.1 (0)	0.4 (0)	0.9 (0)	6.7 (4)
NORTH MACKAY	0.3 (6)	0.9 (17)	7.3 (142)	13.8 (267)	43.1 (838)
OORALEA	0.1 (1)	0.1 (1)	1.2 (7)	2.5 (14)	12.7 (69)
PAGET	0.1 (0)	0.3 (0)	2.6 (2)	5.1 (4)	20.1 (17)
RACECOURSE	0.1 (0)	0.6 (0)	5.5 (2)	9.4 (4)	41.2 (18)
RICHMOND	0.1 (0)	0.1 (0)	1.3 (0)	3.1 (1)	16.6 (5)
RURAL VIEW	0.1 (0)	0.1 (0)	0.1 (0)	0.1 (0)	2.9 (11)
SHOAL POINT	0.4 (1)	1.4 (3)	11.7 (21)	21.9 (39)	64.5 (116)
SLADE POINT	0.5 (7)	1.8 (23)	13.9 (174)	25.8 (322)	74.2 (925)
SOUTH MACKAY	0.4 (11)	1.5 (38)	11.6 (294)	21.5 (546)	62.9 (1599)
TE KOWAI	0.1 (0)	0.1 (0)	1.2 (1)	3 (1)	16.5 (7)
WEST MACKAY	0.1 (3)	0.2 (4)	2.3 (52)	4.7 (104)	19.5 (437)

The substantial commercial and pleasure boat fleets in Mackay are also at risk in strong winds and waves. During Cyclone *Kerry* in 1971, for example, many pleasure craft and small boats were damaged or destroyed inside the protection of the outer harbour. During cyclone alerts, many small craft take shelter in, or close to the mangroves that fringe Bassett Basin, though the recent completion of a major marina immediately south of the outer harbour may provide greater protection for such craft.

Strong winds also carry salt spray from the surf 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 Risks

In terms of loss of life, the impact of the 1918 Mackay storm tide, where at least 13 people drowned, ranks behind Cyclone *Mahina* (where close to 400 pearling fleet crew drowned in Bathurst Bay in 1899), and the March 1918 Innisfail cyclone (where as many as 100 died). The 1918 Mackay storm tide is, however, the most destructive storm tide event to have impacted an urban area in Australia.

A *storm tide* is created by the combined action of the *storm surge* produced by the cyclone, and the normal sea level produced by the *astronomical tide*. Storm surges are generated by a combination of the inverted barometer effect and wind stress. The actual height of the surge at the coastline is strongly influenced by these characteristics including the angle at which the cyclone crosses the coast. The influence of each is affected by conditions near the site where the cyclone makes landfall, including coastal geometry and tides. Each of these influences will be considered below.

The lowering of atmospheric pressure is the factor that has the greatest influence on surge height in the open sea. This so-called “inverse barometer” effect generates a hydrostatic rise of sea level of approximately 1 cm for each hectopascal (hPa) drop in pressure. During the most severe storms, a pressure drop of up to 100 hPa is possible; hence, it is unlikely that the inverse barometer effect could produce an open water sea level rise much greater than 1 m. In deep water this is the only factor contributing to changes in still-water levels (Simpson and Riehl, 1981).

The other factor directly responsible for a storm surge is severe wind stress applied to the ocean surface that results in a gradual acceleration of the near-surface layer. In deep water there is no net significant wind-driven transport of water because countercurrents established at depth compensate for the surface transport. As the wind-driven surface flow enters shallow water, however, seabed friction retards the counter currents, leading to an increase in water level (setup) which reaches a maximum at the shoreline. Wind-driven surface flow can also cause a depression of the water surface when winds blow offshore leading to a decrease in the water level (setdown).

The storm surge is thus caused by the combined influence of the inverted barometer effect along with wind-driven currents that are controlled by wind velocities and the fetch or distance over which the wind blows. The intense circulating surface winds of tropical cyclones also generate short period surface waves (sea and swell) which propagate out from the storm centre. These waves ride upon the elevated long period storm surge and may attack beaches and coastal margins at higher than normal elevations.

Nearshore breaking wave setup also adds to the overall quantum of sea level increase produced in a storm tide. Wave setup is defined as the super-elevation of the mean water level caused by wave action alone, and occurs largely in the inshore zone where waves break and impart a shoreward flux of momentum (Komar, 1976).

Where the water depth shoals rapidly towards the shoreline, wave setup may constitute a significant proportion of the total surge (Simpson and Riehl, 1981). It follows that for islands in deep water the wave setup component may exceed both the wind stress and inverted barometer surge components. As a wave moves shoreward on a sloping bottom, the process of shoaling causes the amplitude to increase until the wave breaks when the ratio of wave height to still water depth is about 0.78. Wave setup occurs because breaking waves transport water shorewards, causing the water surface to rise from the breaker zone to the shoreline. It follows then, that larger waves transport more water shoreward when they break and produce a larger setup. Simpson and Riehl (1981), studying the storm surge associated with Cyclone *Eloise* (1975), deduced that wave setup contributed 1.4 m to the surge height, which reached 4.9 m above still water level.

Overall storm tide height is therefore, determined by the combination of the storm surge, wave setup and height of the astronomical tide at the time the cyclone crosses the coast. In general, areas with a high tidal range have a lower probability of extensive surge flooding than areas with a small tidal range, because tidal channels and intertidal flats are extensively exposed and the mean water level is substantially below low-lying land areas for most of the tidal cycle. It has become standard practice for emergency managers to relate storm tide inundation levels to the Highest Astronomical Tide (HAT). In Mackay, HAT is approximately 3.66 m above mean sea level (or AHD), whilst lowest astronomical tide (LAT) is 3.04 m below AHD. A storm surge of 3 m, therefore, would be entirely absorbed by the tidal range were it to arrive at half tide or less, but would inundate land up to 3 m above the highest tide level if it coincided with the HAT. It is probable that storm tide inundation would tend to last for six hours or less. The various elements of the storm tide are illustrated in Figure 6.15.

Cyclonic storm surges in the Southern Hemisphere are greatest in the left forward quadrant of the cyclone where surface wind effects are greatest. Storm speed and track in relation to the coastline configuration and bathymetric profile may modify this effect. Surge developed in the left forward quadrant of southern hemisphere cyclones appears to reach a peak when a cyclone, viewed from the land, crosses the coast moving from left to right at an angle of about 60^o (Hopley and Harvey, 1979). The height is reduced by up to 40 percent as crossing angles approach 0^o and 180^o.

Surge heights can also be dramatically affected by the rate of cyclonic advance, which often changes as cyclones proceed along their track. Maximum possible storm surge heights may be achieved by fast moving cyclones (As-Salek and Yasuda, 1994), while surge heights from slower moving storms may be only half those of rapidly moving storms (Nickerson, 1971). Typical forward speeds in the Mackay region average 20 km/h, but range up to about 35 km/h.

As the cyclone approaches shore, the natural slope of the sea bed (bathymetry) influences the amount of wave setup contributing to overall storm tide levels. Generally, the more shallow and wide the near-shore and offshore profile the greater the potential wave setup component. The general configuration of the coastline is also important. Amplification of a storm tide may also occur where the surge is funnelled into a bay or estuary, but responses may be complex, owing to seiches and resonances, and surge behaviour at such sites may vary considerably from one cyclone to the next.

In summary, the height of the storm tide is influenced by:

- the inverted barometer effect;
- surface wind stress;
- nearshore breaking wave setup;
- storm characteristics including, speed and track;
- wave height and period;
- the state of the astronomical tide in relation to the cyclone; and
- morphological conditions including bathymetry and coastal configuration.

The threat posed by the storm tide is then the sum of these influences in relation to the community at risk.

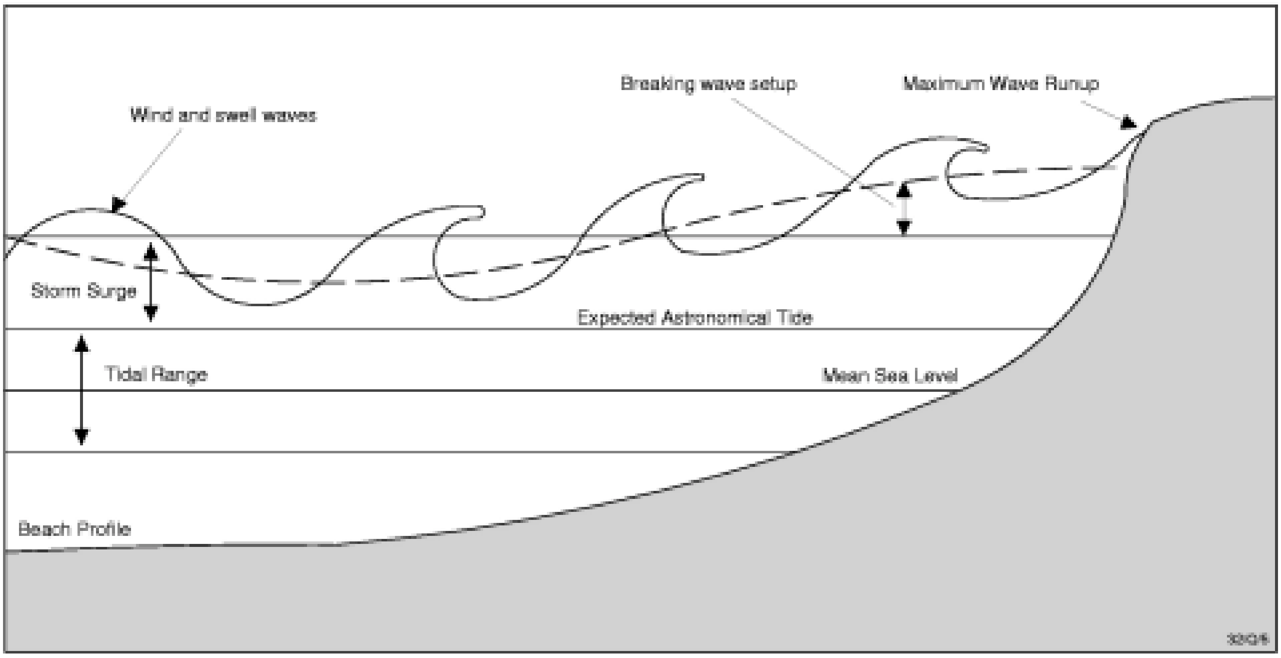


Figure 6.15: Components of a storm tide (adapted from Stark, 1988)

The location of crossing is important given that the maximum surge height on the Queensland coast will be to the left of the storm's track near the forward left quadrant of the cyclone in the band of maximum onshore winds (i.e. close to the eye wall). A cyclone crossing the coast 25 to 50 km to the north of Mackay, therefore, will produce a greater storm tide than a cyclone crossing directly over, or to the south of the city. Areas to the north of the crossing point may experience reduced surge levels or even setdown.

Inundation by storm tide can last up to around six to eight hours and largely subsides with the next low tide. The outward run of this water, combined with flooding from intense cyclonic rainfall not only raises the level of the storm surge but also presents a hazard as it has its own velocity seaward which can increase as the storm tide recedes. This 'back wash' is often associated with scouring around structures and the mobilisation of large volumes of debris.

Vulnerability to Storm Tide

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. Figure 6.16 is an example of a 'still water' storm tide hazard map of Mackay. It has been taken from the *Action Guide* produced by Mackay City Council (1998b) to educate the community on a range of risks, including storm tide. It shows the area that would be inundated by a storm tide 4 m above HAT, and shows therefore, the area that would need to be evacuated in advance of a storm tide. It was developed by simply taking the contour that represents the level that is 4 m above HAT. 'Still water' mapping, similar to this example, but employing up to five zones in increments of one metre above HAT, is now the Queensland standard.

The 'still water' model does not take account of any wave setup or wave runup (the height to which the momentum of broken waves can carry them up the shore face). Sea wave height and power, however, 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, 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. For coastal locations in the USA, the portion of the coastal 100 year flood plain that would be inundated by tidal storm surges with velocity wave action is identified, this zone is termed the V-zone. Generally, the V-zone is defined by the inland extent of a three foot breaking wave where the still water depth during the 100 year flood decreases to less than four feet. 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 a 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 large parts of Mackay.

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 and in buildings prone to failure. 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.

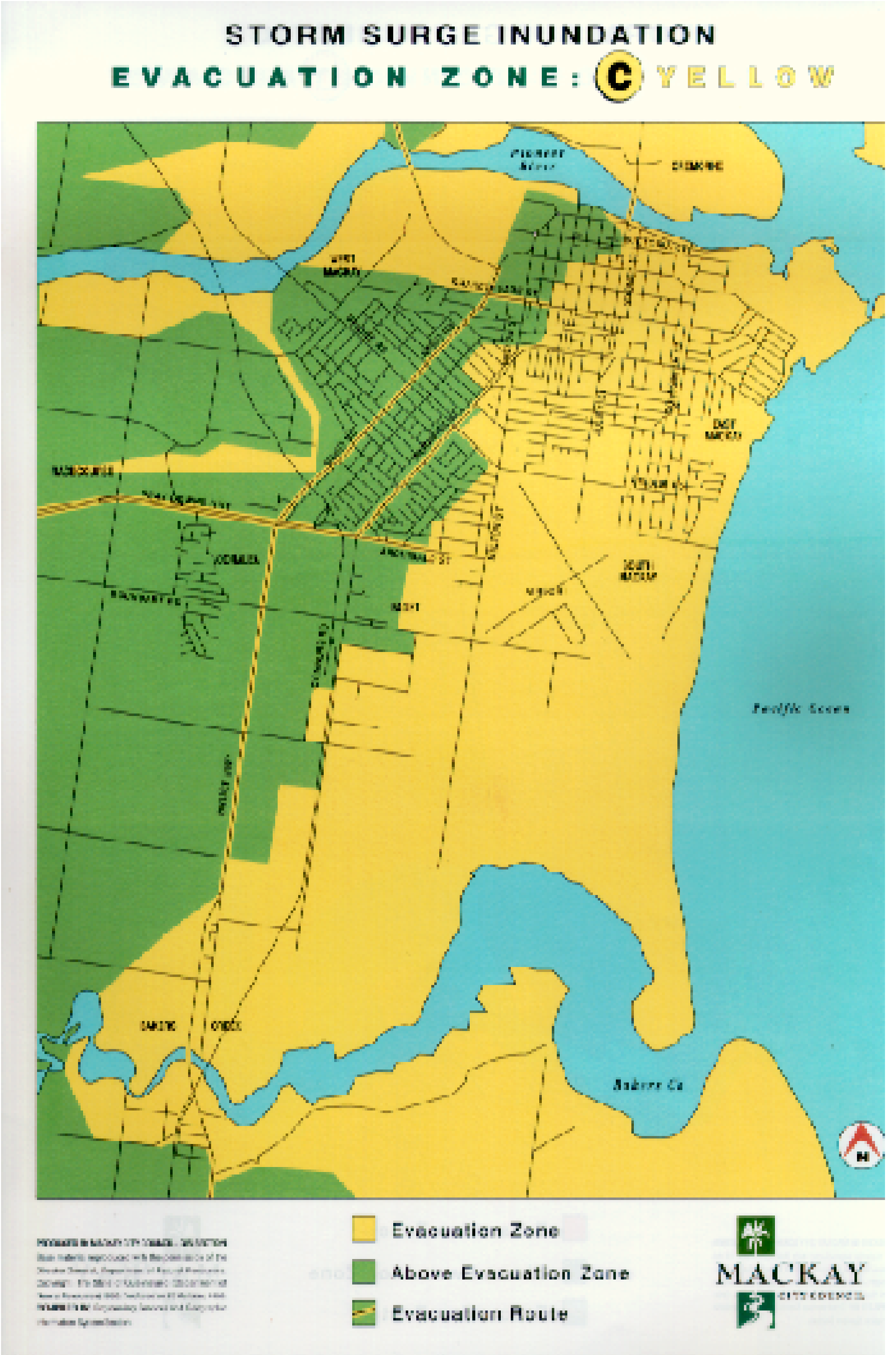


Figure 6.16: Mackay ‘still water’ storm tide hazard zonation map (Mackay City Council, 1998b)

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 over floor level. They do not, however, estimate 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, including sugar cane. 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 Risk Scenarios

The storm tide height (above AHD) annual exceedence probabilities (AEP) cited in Appendix 2 in Harper (1998), which are based on published estimates by the same author in 1985, are given in Table 6.8. The difference between the northern beach suburbs and the city area are explained in terms of off-shore bathymetry.

Table 6.8: Comparison of published forecast storm tide height (above AHD) for various AEP

Locality	2% AEP	1% AEP	0.2% AEP	0.1%AEP	0.01% AEP
Shoal Point	3.7 m	4.0 m	4.8 m	5.0 m	6.0 m
Slade Point	3.7 m	4.1 m	4.8 m	5.1 m	6.1 m
Mackay City	3.8 m	4.1 m	4.9 m	5.2 m	6.2 m

From Harper (1998), based on Harper (1985)

The storm tide estimates given in Table 6.8 do not include an allowance for wave setup. The BPA recommendation for wave setup presented in Harper (1998) suggests that for Mackay, an additional 0.5 m be allowed in all scenarios. The wave setup addition is assumed here to be sustained inland for a considerable distance and is therefore added to the storm tide height. Harper suggests (personal communication, 2000) that the 0.5 m figure for wave setup at Mackay is uncertain and that more empirical evidence and research is needed before this estimate can be improved beyond the realms of an 'educated guess'.

The storm tide estimates do, however, take into account the tide range at Mackay, as Harper (1998, p. 9) observes:

> *Since the storm tide level is strongly influenced by the state of the tide, it follows that locations with a large tidal range will provide a degree of statistical variability, which can serve to reduce the likelihood of a severe storm tide inundation.*

To model the likely impact of storm tides of 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 buildings and the road network, the 'still water' inundation values offered by Harper were used. The modelling is aimed at identifying:

- buildings that would be inundated to more than 1 m over floor;
- buildings that would have water over the floor but less than 1 m in depth;
- buildings that would have water on the property but not over floor level;
- properties that would be free of inundation;
- road segments with more than 0.5 m of water over its lowest point (not trafficable by any vehicle);
- road segments with between 0.25 and 0.5 m of water over its lowest point (trafficable by high clearance vehicles only);
- road segments with up to 0.25 m over the lowest point (trafficable by most vehicles); and,
- road segments that are unaffected.

To take account of the wave setup and wind driven shallow water wave components, the following adjustments were made:

- the wave setup allowance of 0.5 m recommended by the BPA was added to the storm tide height;
- an allowance of 30% of the mean depth of over ground level inundation of still water surge plus wave setup 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 over-land water depth.

Buildings that are within 150 m of the shoreline which have over-floor inundation were further identified because of the 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 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 surge 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. 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 building database described in Chapter 3 and Appendix B. Floor heights were estimated in the field for most buildings and are, for at least 90% of buildings observed in the field, accurate to within 0.25 m. Where buildings were not observed in the field by us, but were surveyed by Smith in 1993, floor heights were generalised into three categories – on slab (0.3 m), suspended floor (0.5 m) and high set (2.0 m). The values collected by Smith are only marginally less accurate than those collected by the *Cities Project*. Where buildings were not surveyed, a default value of 0.3 m (i.e. slab-on-ground construction), was used.

The ground height for each building and road segment was interpolated in the geographical information system (GIS) from the digital elevation model (DEM) developed by Andre Zerger. Given the large scale topographic mapping and photogrammetric sources used for this elevation model, inherent uncertainties exist for the interpolated elevation data. Zerger (1998) reports that 90% of the elevation values in the DEM are accurate to at least 0.3 m. 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 DEM produced by Zerger are substantially less than those published for the original topographic data and are the very best available. Few other areas in Australia of elsewhere have contour data of this quality.

There are also uncertainties associated with the inundation models used. For example, the uniform 0.5 m 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 buildings subject to inundation at various depths under the five scenarios were identified using the following models for:

- inundation over ground level only: $Gd\_ht < std + wsu + sww$;
- inundation over floor level: $Fl\_ht + Gd\_ht < std + wsu + sww$; *and*,
- inundation > 1.0 m over floor level: $Fl\_ht + 1 + Gd\_ht < std + wsu + sww$.

where:

Gd_ht	is the height of the ground above AHD;
std	is storm tide height;
Fl_ht	is the height of the building floor above ground level;
wsu	is the wave setup value of 0.5 m; and
sww	is the height allowance for shallow water wind waves calculated as 30% of the mean depth of over-ground inundation.

The extent of storm tide inundation for the various AEP scenarios are presented in Figures 6.17 to 6.26 and in Figure 6.28. For each of these scenarios the following key applies:

- buildings that are likely to have more than 1 m of water over floor level are shown in red;
- buildings with water over floor level but less than 1 m in depth are shown in yellow;
- buildings with water on the surrounding property but not over floor level are shown in green; and,
- properties not affected by inundation are shown in grey.

A similar process was used for the road network.

No allowance has been made for the frictional effect on the storm tide of buildings, vegetation and micro-relief; nor has the channelling effect of the roads that are perpendicular to the shore been taken into account.

The modelling results are summarised in the following discussions of each of the five scenarios. A comparison of the outcomes for the five scenarios is also provided to illustrate the incremental growth of risk as the probability decreases.

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. For example, the flood which was associated with the 1918 cyclone peaked two days after the passage of the cyclone and the storm tide impact (Gourlay & Hacker, 1986, pp. 193-4).

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 4), where a range of population distribution scenarios (e.g. day, night, weekend, holiday period, etc.) needs to be considered.

The 2% AEP scenario: Under this scenario, inundation to a depth of up to 3.8 m of surge plus 0.5 m of wave setup could occur. Such a situation could be caused by a storm surge of as little as 0.8 m above HAT arriving at close to a high tide.

By applying this inundation level our model indicates that some 2580 buildings could be affected as follows (rounded numbers):

- a small number of buildings could have water over floor level to a depth of >1 m;
- up to 1580 buildings could have water over floor level to a depth of less than 1 m;
- up to 1020 buildings could have water on the property, but not over floor level;
- the remaining 18 120, or so, buildings would be free of inundation;

- 72.9 km of road would not be trafficable (i.e. more than 0.5 m of water over the pavement);
- 21.5 km of road would only be trafficable by high clearance vehicles (0.25 to 0.5 m of water over the pavement); and,
- 13.9 km of road would have less than 0.25 m of water over the pavement and would be trafficable by most vehicles.

Overall, the impact of a 2% AEP (ARI of 50 years) storm tide event would certainly cause significant damage to buildings and short-term dislocation would be significant. Greatest impact will be felt in the low lying areas of East Mackay and South Mackay. These areas are further defined by Juliet Street in the west and Hague Street in the east and along the coastal fringe of Slade Point to the north of Seagull Street and west of Slade Point Road, and on the northern side of Ocean Avenue. In that area as many as 3000 cars could be at risk of salt water damage if not moved to higher ground before the impact of the storm tide. The northwestern end of the airport runway would also be inundated. The modelled impact of the study area is shown in Figure 6.17 and a more detailed view of the city area is shown in Figure 6.18.

The 1% AEP scenario: The minimum storm surge required to create a storm tide of 4.1 m above AHD (0.6 m above HAT) would be a little over 1 m, arriving at, or close to a very high tide.

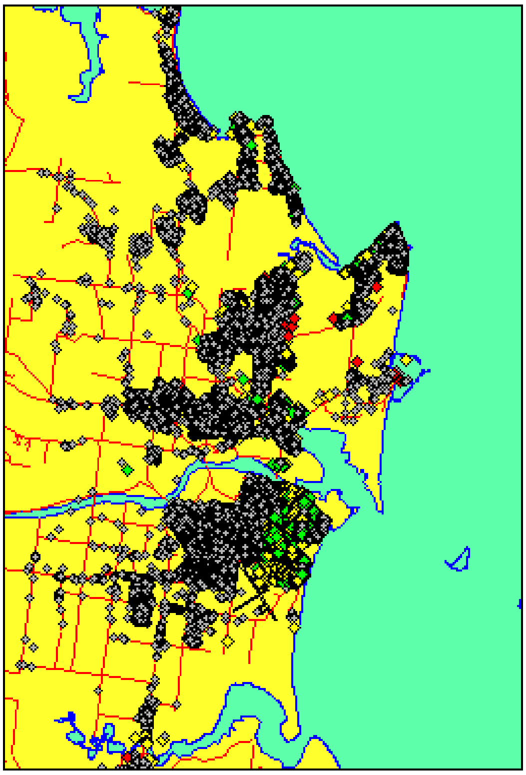


Figure 6.17: Modelled impact of a 2% AEP storm tide scenario

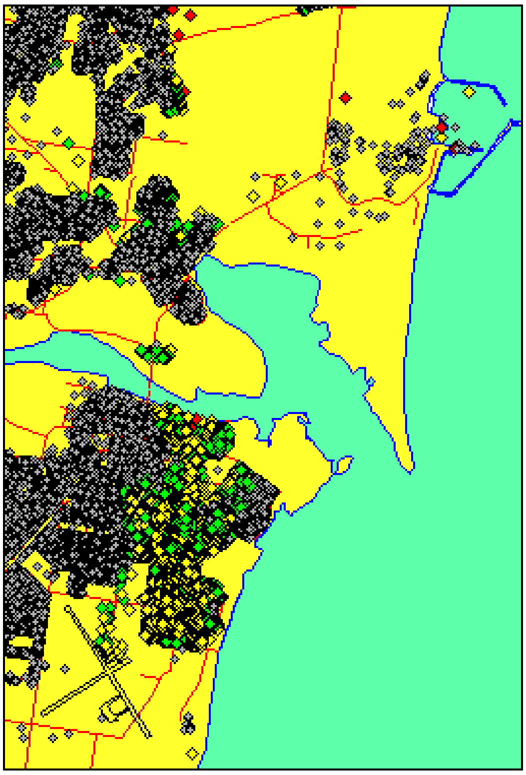


Figure 6.18: Modelled impact of a 2% AEP storm tide scenario (detail)

By applying our model for a storm tide of 4.1 m above AHD and a 0.5 m wave setup figure, around 3410 buildings could be affected as follows (figures rounded):

- up to 60 buildings and other structures would likely fail having more than 1 m of water over floor level;
- up to 2110 buildings could have water over floor level of less than 1 m;
- up to 1250 buildings could have water on the property, but not over the floor;
- the remaining 17 270 or so buildings would be free of inundation;

- 107.6 km of road would not be trafficable (i.e. more than 0.5 m of water over the pavement);
- 15.1 km of road would only be trafficable by high clearance vehicles (0.25 to 0.5 m of water over the pavement); and,
- 17.2 km of road would have less than 0.25 m of water over the pavement and would be trafficable by most vehicles.

The spatial extent of inundation would be little different from that for the 2% AEP scenario as shown in Figure 6.19 and Figure 6.20.

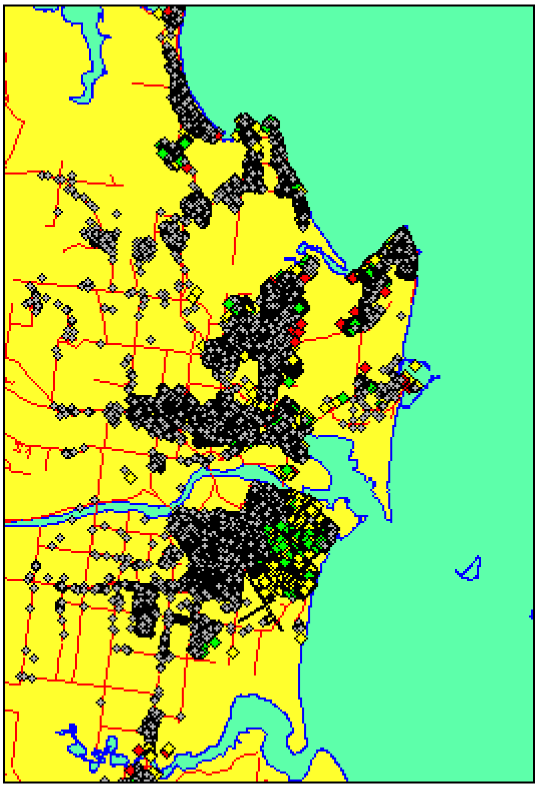


Figure 6.19: Modelled impact of a 1% AEP storm tide scenario

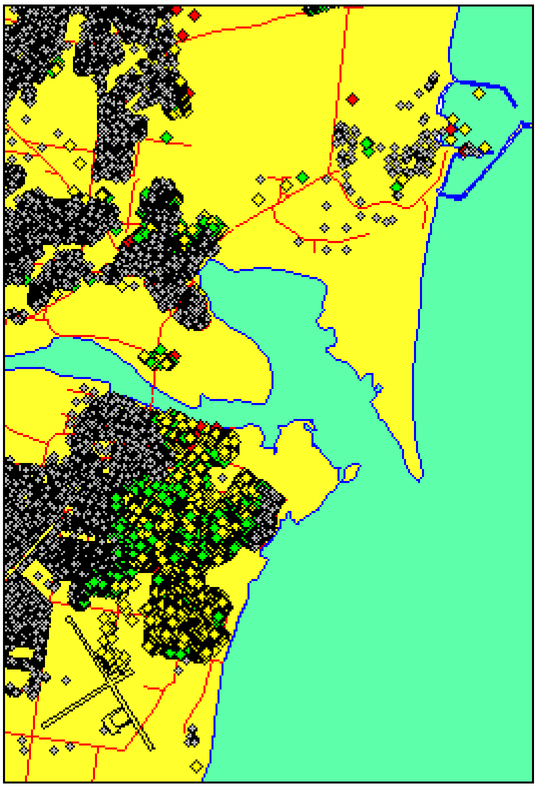


Figure 6.20: Modelled impact of a 1% AEP storm tide scenario (detail)

Of the 60 buildings and structures at greatest risk:

- 37 are houses;
- 7 are business or industrial buildings, mainly in Central Mackay; and,
- 3 are logistic support and transport related buildings in Central Mackay, including wharf facilities along the Pioneer River.

The pattern of inundation clearly reflects the drainage and micro-topography of the inner city area. The main entry points for this inundation would be along Sandfly Creek from the Pioneer River and into the creek at the eastern end of the airport runway. To the north of the River, the main ingress is over the coast in Slade Point and Eimeo and along the drainage systems around the fringes of Andergrove.

As many as 120 people would probably need, or want, to be evacuated from the houses and flats with more than 1 m of surge over floor level. Most of these people would be in coastal Slade Point and the low-lying fringe areas of Andergrove. It is also likely that a significant number of people in the rest of the storm tide affected areas would evacuate.

The impact of a 1% AEP storm tide event would undoubtedly be significant, though fewer than 200 people would probably be at risk of serious harm. Perhaps as many as 60 buildings and other structures could be at risk of destruction or significant damage, with as many as 2100 further buildings likely to suffer substantial contents damage. Some 4100 cars would also be at risk of salt water damage unless they were moved to higher ground in advance of the storm tide impact, and the airport runway would be inundated.

The 0.2% AEP scenario: A storm tide inundation level of 4.8 m above AHD (1.3 m above HAT) is essentially identical to that experienced in the 1918 cyclone if allowance for wave setup is also included.

By applying our model for a storm tide of 4.8 m above AHD and a 0.5 m wave setup figure, around 5860 buildings and other structures would be affected as follows (numbers rounded):

- as many as 2040 buildings and other structures could have more than 1 m of water over floor level - of these about 175 buildings are within the first 150 m of the shore line, mostly in Eimeo and Slade Point, and along the Pioneer River downstream of the Forgan Bridge. These 175 buildings would have a heightened risk of being destroyed because of sea wave velocities and runup;
- up to 2090 buildings could have water over floor level of less than 1 m depth;
- a further 1730 buildings could have water on the property;
- the remaining 14 820 or so buildings would be free of inundation;
- 162.4 km of road would not be trafficable (i.e. more than 0.5 m of water over the pavement);
- 18.7 km of road would only be trafficable by high clearance vehicles (0.25 to 0.5 m of water over the pavement); and,
- 18.1 km of road would have less than 0.25 m of water over the pavement and would be trafficable by most vehicles.

The spatial distribution of these buildings is shown in Figure 6.21 with closer detail in Figure 6.22.

Of the 2040 buildings at greatest risk:

- 1620 are houses and 170 are blocks of flats;
- 4 are commercial accommodation buildings;
- 140 are business or industrial buildings, mostly in Central Mackay;
- 31 are logistic support and transport related buildings, again mostly in Central Mackay;
- 4 are buildings related to public safety; and,
- 53 are buildings providing community facilities including schools.

Under this scenario, inundation will extend to around 2.7 km inland from the shore, as far as Paradise Street in South Mackay. The model shows the buildings close to Binnington Esplanade between Moody Street and Nott Street (i.e. on the foreshore 'front row') as being above inundation level. This area was filled in the late 1960s to be above the level of the 1918 storm tide. Even though the model does not show the buildings as suffering inundation, it is likely that they would suffer significant damage from wave runup and wind-driven spray – even if the land on which they stand was not eroded by wave action.

Approximately 5200 people could be at great risk of harm if not evacuated in advance of the storm tide impact from the houses and flats where water exceeds 1 m over floor level. A further 5850 or so people in dwellings with less than 1 m of water over floor level would probably also need to be evacuated to less exposed shelter, though, in reality, their lives would not be at great risk were they to remain in their homes. That would mean the evacuation of most of East Mackay, South Mackay, the northeast corner of North Mackay and coastal areas of Slade Point and Eimeo, to areas including West Mackay, Mount Pleasant and Beaconsfield. Activation of designated evacuation shelters across the city would be required to cope with the numbers of evacuees that were unable to take refuge with friends or relatives elsewhere in the city.

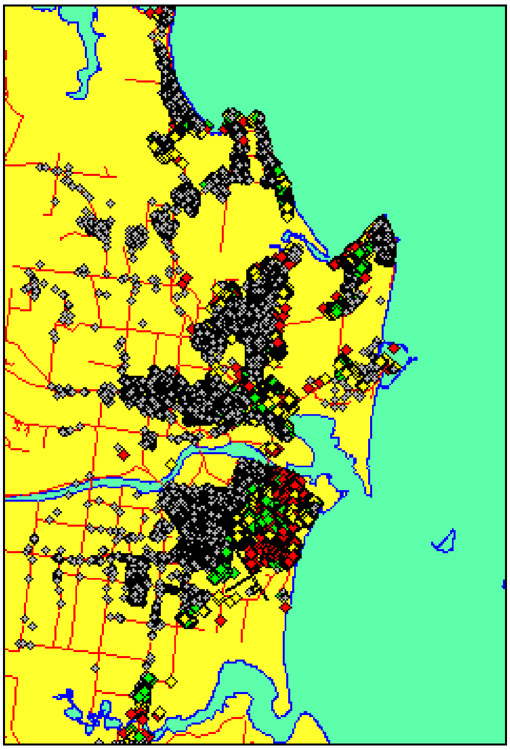


Figure 6.21: Modelled impact of a 0.2% AEP storm tide scenario

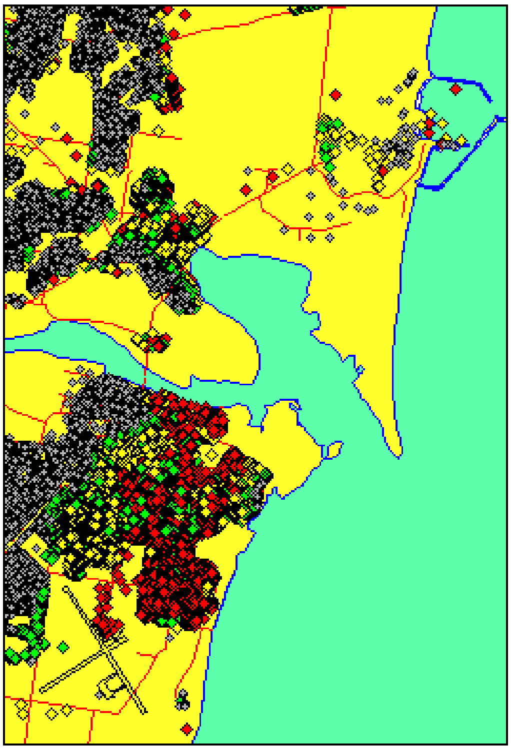


Figure 6.22: Modelled impact of a 0.2% AEP storm tide scenario (detail)

The impact of a 0.2% AEP storm tide event would be potentially catastrophic. The prospect of having as many as 11 000 people, or 20% of the total study area population, requiring or desiring evacuation from their homes, is indeed stark. In 1918, 13 people out of a total population of around 5000 (2.6%), were drowned in the storm tide. Significant development has, however, taken place towards the shore line in both East Mackay and South Mackay (as well as in the northern beach suburbs) since the 1918 storm surge, placing a significantly greater number of people and properties at risk. The potential for substantial loss of life under the 0.2% AEP scenario is high. Given a similar ratio of fatalities as that experienced in 1918, the death toll under this scenario today could be at least 140. At least 6000 cars would be at risk of damage ranging from minor to complete emersion by salt water if not moved to high ground in advance of the storm tide impact.

A comparison of the 0.2% AEP scenario model results and the actuality of the 1918 storm tide is provided at the end of this chapter.

The 0.1% AEP scenario: The minimum storm surge required to create a storm tide of 5.1 m above AHD (1.6 m above HAT) would be around 2.0 m arriving at, or close to a very high tide, though in reality a much greater surge would be required given Mackay's large tidal range.

Our model for a storm tide of 5.1 m above AHD and a 0.5 m of wave setup indicates an impact on around 6800 buildings as follows (numbers rounded):

- as many as 2670 buildings could have more than 1 m of water over floor level - of these about 235 are within 150 m of the shore line and have a very high risk of being destroyed. These are mainly in coastal areas extending from Shoal Point to the outer harbour, and in the Pioneer River downstream from the Forgan Bridge;
- up to 2490 buildings would have less than 1 m of water over floor level;
- up to 1650 buildings would have water on the property, but not over the floor;
- the remaining 13 880, or so, buildings would be free of inundation;

- 188.5 km of road would not be trafficable (i.e. more than 0.5 m of water over the pavement);
- 21.5 km of road would only be trafficable by high clearance vehicles (0.25 to 0.5 m of water over the pavement); and,
- 18.7 km of road would have less than 0.25 m of water over the pavement and would be trafficable by most vehicles.

The spatial extent of this modelled inundation is shown in Figure 6.23 with detail in Figure 6.24.

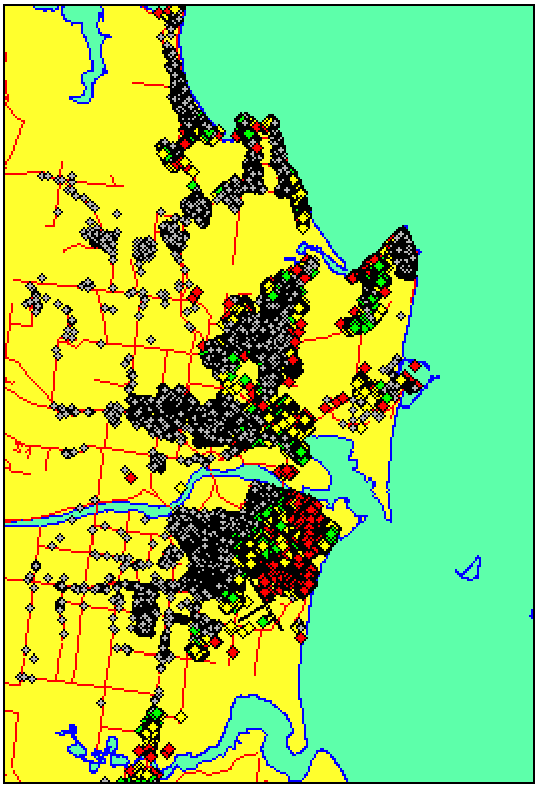


Figure 6.23: Modelled impact of a 0.1% AEP storm tide scenario

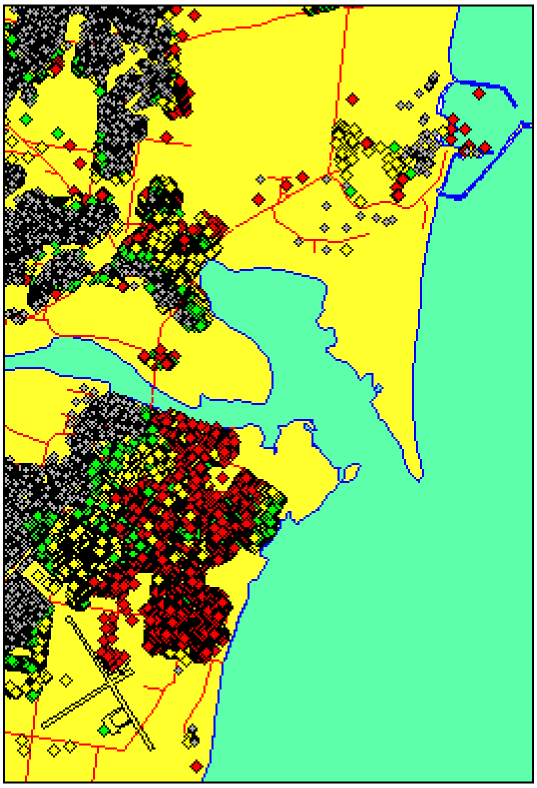


Figure 6.24: Modelled impact of a 0.1% AEP storm tide scenario (detail)

Of the 2670 buildings at greatest risk:

- 2090 are houses and 207 are blocks of flats;
- 7 are commercial accommodation including caravan parks;
- 210 are business or industrial buildings;
- 47 are logistic support and transport related, including most of the facilities at both the airport and the outer harbour;
- 5 are buildings related to public safety and health services; and,
- 70 are buildings providing community facilities including government, recreation and education.

Inundation would extend for about 3.0 km inland, almost as far as the Paulette Street/Field Street intersection in West Mackay. Approximately 6680 people would need to be evacuated from the houses and flats at very great risk of substantial inundation. A further 6970 people would probably need to be evacuated from the houses and flats with less than 1 m of water over the floor. Activation of designated evacuation shelters across the city would be required to cope with the numbers of evacuees that were unable to take refuge with friends or relatives elsewhere in the city.

The impact of a 0.1% AEP storm tide event would be catastrophic. The prospect of having as many as 13 650 people, or 25% of the total study area population, at risk of drowning if they were to remain in their homes, is indeed an awesome outlook. The potential for substantial loss of life under this scenario is very high. At least 8750 cars would be at risk of damage or total loss if not moved to high ground before the impact of the storm tide.

The 0.01% AEP scenario: This is close to the maximum probable storm tide event. Its outcome would be as extreme as its probability of happening is low.

The minimum storm surge required to produce a storm tide of 6.2 m above AHD (2.7 m above HAT) would be around 3.0 to 3.5 m, arriving at, or close to a very high tide. Obviously, Mackay has not yet experienced a storm tide impact of this magnitude, however, Category 5, Category 4 and potentially some high Category 3 cyclones crossing the coast within 25 to 50 km to the north of the city could produce such an impact.

Our model for a storm tide of 6.2 m above AHD and a 0.5 m wave setup indicates that at least 10 360 buildings (approximately 50% of the total building inventory in the study area) would be affected as follows (numbers rounded):

- up to 5580 buildings could have more than 1 m of water over floor level - of these about 460 are within the first 150 m of the shore line and would be at extreme risk of being destroyed;
- around 3160 buildings could have water less than 1 m deep over floor level;
- around 1610 buildings could have water on the property, but not over the floor;
- the remaining 10 300, or so, buildings would be free of inundation;
- 282.4 km of road would not be trafficable (i.e. more than 0.5 m of water over the pavement);
- 21.5 km of road would only be trafficable by high clearance vehicles (0.25 to 0.5 m of water over the pavement); and,
- 18.7 km of road would have less than 0.25 m of water over the pavement and would be trafficable by most vehicles.

Of the 5580 buildings at greatest risk (i.e. with more than 1 m of water over floor level):

- 4430 are houses and 350 are blocks of flats;
- 50 are commercial accommodation;
- 420 are business or industrial buildings, mainly in Central Mackay, North Mackay, South Mackay and Slade Point;
- 90 are logistic support and transport related buildings, mostly in Bakers Creek, Central Mackay and the port area;
- 26 are related to public safety (including the Mater Hospital, both fire stations and the ambulance station); and,
- 160 are community facilities including government, recreation and educational facilities.

The extent of inundation under the 0.01% scenario would reach as far as 3.5 km from the shoreline in the area south of the Pioneer River, reaching the intersection of Shakespeare and Gardiner Streets in West Mackay. The spatial extent is shown in Figure 6.25 and in detail in Figure 6.26.

Approximately 13 800 people would be at extreme risk of drowning unless evacuated from the houses and flats at greatest risk in advance of the storm tide impact. A further 8860 people from the houses and flats with less than 1 m of water over floor level would also want, or expect, to evacuate. Activation of designated evacuation shelters across the city would be required to cope with the numbers of evacuees that were unable to take refuge with friends or relatives elsewhere in the city.

The impact of a 0.01% AEP storm tide event would be catastrophic. The prospect of having as many as 22 600 people, or 42% of the study area total, at risk of drowning if they remained in their homes, is alarming at best. The potential for substantial loss of life under this very low very low probability scenario is extremely high. As many as 11 000 cars would suffer extensive salt water emersion damage if not moved to higher ground.

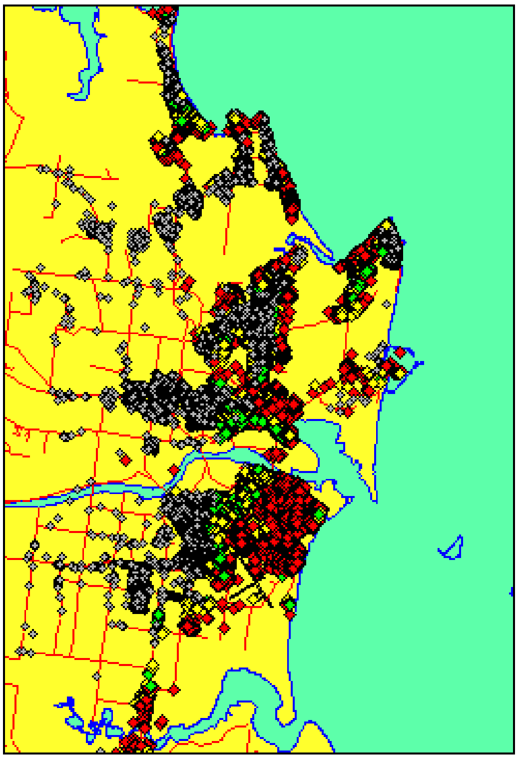


Figure 6.25: Modelled impact of a 0.01% AEP storm tide scenario

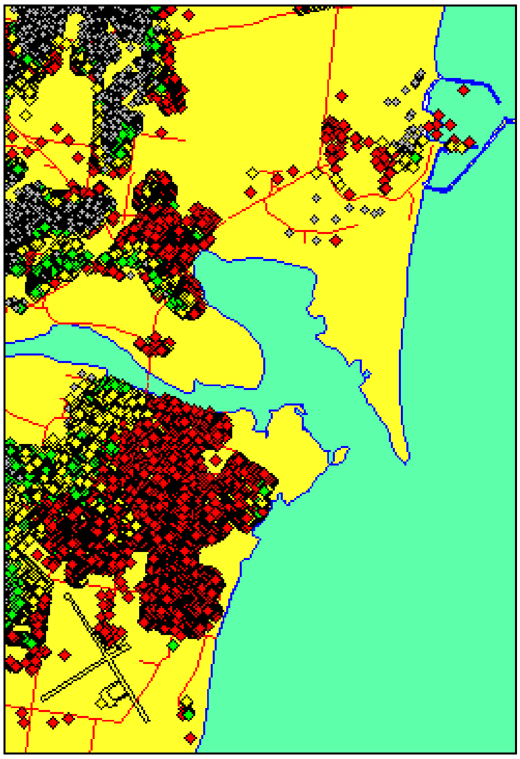


Figure 6.26: Modelled impact of a 0.01% AEP storm tide scenario (detail)

Comparative Storm Tide Risk

It is clear that the potential impact of storm tide on Mackay is considerable, as was demonstrated in 1918. The spatial extent is obviously dictated by topography, with the Pioneer River and low lying coastal lands providing the main ingress routes for the inundation. The suburbs least exposed to storm tide risks (and the suburbs that would need to accept evacuees from at-risk areas) are Andergrove (except the lower-lying fringes), Beaconsfield, Glenella, Mount Pleasant, North Mackay, Ooralea and the higher areas of West Mackay.

An analysis of the function of buildings affected under each scenario reveals that the utilities (i.e. water supply, sewerage and power supply) and the commercial sector (the combined 'business and industrial' properties and the 'logistic, storage and transport' properties) would suffer the greatest proportional impact. Commercial accommodation would suffer the lowest impact, largely because of its main concentration along Nebo Road – one of the highest areas in the southern part of the city. The figures provided in Table 6.9 for each class of function are the percentages of all buildings in the Mackay study area, within each functional class, that would have water of any depth over floor level. A number of conclusions regarding community risk in Mackay may be drawn from these figures.

For **houses** which are the dominant form of shelter in the community the analysis indicates that:

- for the events of most frequent occurrence (2% and 1%) a relatively small proportion of houses are located in storm tide-prone areas; for events with a lower probability the impact on housing will be considerable;
- in the higher probability events, for the majority of the population, shelter in their own home is clearly the preferred option; for the less common events, however, significant evacuations are likely to be required in advance of the cyclone's impact. For those people whose homes would be at risk of hazardous levels of inundation, the most abundant form of alternative shelter would be with friends, relatives, colleagues or others in their homes in safer areas.

Table 6.9: Percent of buildings, 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	7.1	9.6	18.1	22.8	38.9
Flats	13.9	20.5	35.0	38.8	61.0
Commercial accommodation	2.5	2.5	14.7	27.6	46.6
Business & industry	8.3	15.1	33.2	40.4	73.3
Logistic, transport & storage	10.9	17.4	35.3	42.3	60.7
Public safety & health	5.3	5.3	24.0	33.3	52.0
Community, education & sport	7.5	11.6	27.9	32.8	54.7
Utilities	21.4	35.7	39.3	46.4	57.1

For **flats**, the second major form of accommodation, the analysis suggest that:

- there is a degree of concentration of flats in storm tide-prone areas;
- for the lowest magnitude scenario (2% AEP) flats will provide shelter for substantial numbers, however, for the scenarios of 1% AEP, or lower probability, significant numbers of people who live in flats could need to be relocated; and,
- many blocks of flats are two-storey and where those blocks are not at risk of being destroyed, vertical evacuation within the same block could be an option.

For **commercial accommodation**, the major source of shelter for tourists and other visitors, the figures suggest that:

- there is a low to moderate concentration of these facilities in storm tide-prone areas given that the majority are located on the higher ground along Nebo Road;
- for scenarios of 0.1% AEP or greater rarity, significant relocation of residents of commercial accommodation could be required. Most of these would need to be provided with shelter in public centres because there would be inadequate alternative commercial accommodation available in 'safe' areas;
- for the lower intensity scenarios there should be sufficient alternative commercial accommodation to house those who would need to be relocated; and,
- caravan parks (of which there are nine) would need to be evacuated or adequately secured for all but the lowest intensity cyclones because of the strong wind hazard threat to caravans.

For **business and industrial** properties the figures suggest that:

- these facilities are concentrated in several areas, some of which are storm tide-prone; and,
- the potential for economic loss is relatively small in the lowest magnitude scenario, however, for the higher intensity events, the economic loss to both buildings and stock will be substantial. In events of 1% AEP or greater rarity, many smaller businesses may suffer economic losses that would see them fail, with a consequent severe impact on employment and general community well being.

For **logistic, storage and transport** properties the figures suggest that:

- these facilities are reasonably dispersed, with relatively limited concentration in storm tide-prone areas, other than at the airport and the outer harbour;
- it would take a storm tide event with an AEP of 0.2%, or lower probability, to have a profound effect on the sustainability of Mackay; and,
- damage and loss of these facilities, under all scenarios, however, would be greatly exacerbated by the likely dislocation of power, water and telecommunications lifelines as a result of the strong winds.

For **public safety and health** properties the figures suggest that:

- these facilities are reasonably well dispersed throughout the community, with a relatively low proportion located in areas susceptible to storm tide inundation in scenarios up to, and including, a 1% AEP;
- the capacity of public safety and health authorities to support the community during and after a storm tide impact will, nevertheless, be significantly diminished, especially with the higher intensity events; and,
- alternate facilities in areas that would not be affected by storm tide inundation are generally available to provide a level of service after the event, albeit with reduced resources and capacity.

For **community, education, recreation and government** facilities the figures suggest that:

- these facilities are also well dispersed throughout the community; and,
- the high proportion of these (mostly) public facilities that would suffer minimal storm tide impact would be available for use as emergency shelter for short periods after the event. A survey of buildings which could potentially be used for shelter, undertaken by Q-Build in 1998, however, indicates that very few, if any, buildings, such as school classrooms, would be suitable as safe havens from storm tide during a cyclone impact. Their suitability is limited because of factors such as large and unprotected windows and marginal engineering integrity - even if they are outside the area at risk of inundation (Mullins and others, 1998).

For **utility** facilities (i.e. water, power, sewerage and telecommunications) the figures suggest that:

- these facilities are well dispersed. This, in part, reflects the use of hill tops for key services such as water reservoirs and for telecommunications towers;
- loss of some of the more sensitive facilities, especially one or more of the power substations and the telephone exchange, which are located in storm tide-prone areas, may render the whole utility sector inoperable; and,
- for the above-ground utilities, strong winds and wind-blown debris will pose the greatest threats during cyclones. Underground utilities other than telecommunications should not suffer damage unless there is significant scouring by the storm tide. Underground telecommunications and power supply infrastructure that is exposed to storm tide inundation may, however, suffer significant damage.

Exposure index: In the absence of empirical data on loss and damage caused by storm tide inundation, we have used the following simple weights to indicate the relative impact of a 0.2% AEP event. This scenario (effectively a repeat of the 1918 cyclone impact), has been chosen as a significant and known level of storm tide impact. The assumption is that the deeper the inundation and the closer to the 'front row', the greater the degree of damage incurred. The weights are applied as follows:

- the tally of buildings with >1 m of water over floor level and less than 150 m from the shoreline are multiplied by 3;
- the tally of buildings with >1 m of water over floor level and further than 150 m from the shoreline are multiplied by 2.5;
- the tally of buildings with <1 m of water over floor level and less than 150 m from the shoreline are multiplied by 2.5;
- the tally of buildings with <1 m of water over floor level and further than 150 m from the shoreline are multiplied by 2;
- the tally of buildings with water on the property only and less than 150 m from the shoreline are multiplied by 1.5; and,
- the tally of buildings with water on the property only and further than 150 m from the shoreline are multiplied by 1.

The index values and suburb rank based on that index is shown in Table 6.10 where a rank of one indicates the suburb which has incurred the greatest degree of damage.

Table 6.10: Mackay suburbs index of storm tide exposure

Suburb	Index	Rank	Suburb	Index	Rank
Andergrove	382	6	Eimeo	309	7
Bakers Creek	186	10	Foulden	5	17
Beaconsfield	297	8	Mackay Harbour	95	12
Blacks Beach	132	11	North Mackay	1062	4
Bucasia	211	9	Paget	77	13
Central Mackay	1854	3	Shoal Point	42	15
Cremorne	54	14	Slade Point	821	5
Dolphin Heads	40	16	South Mackay	3328	1
East Mackay	2281	2	the remainder	0	18

Cumulative storm tide risk exposure: The relative exposure of the Mackay community to the storm tide hazard from each scenario is illustrated in Figure 6.27.

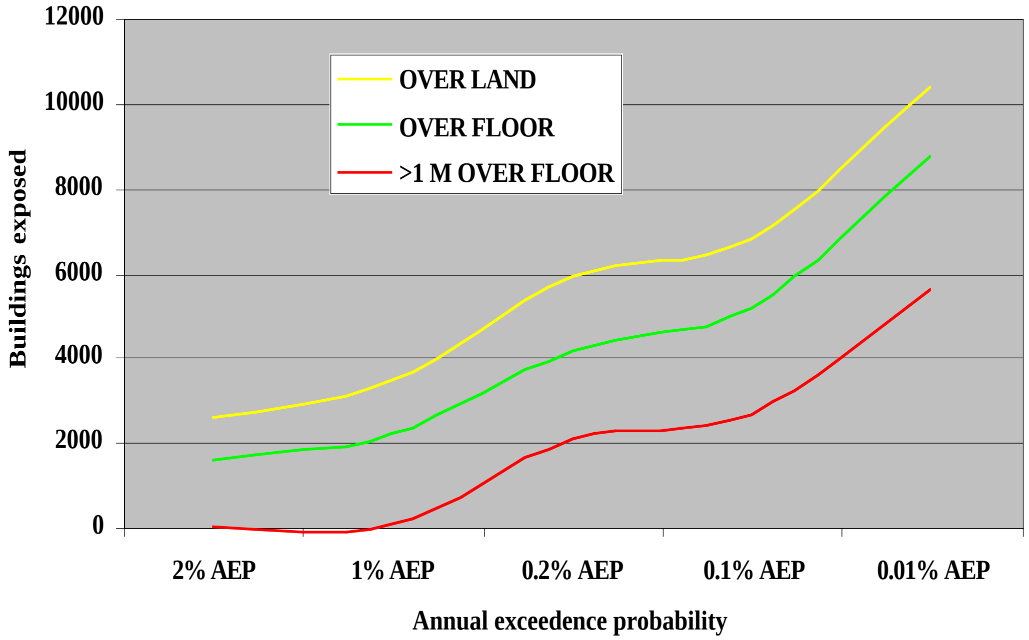


Figure 6.27: Cumulative exposure to storm tide inundation in Mackay

A summary of the building damage generated by storm tide scenarios with likelihoods ranging from ARI = 50 years to ARI = 10 000 years is shown in Table 6.11. As noted earlier, storm tide may occur in conjunction with severe wind and therefore adding the individual estimates of building damage is likely to give conservatively high estimates of damage. The method used in Chapter 5 for determining damage levels was also used here for storm tide.

Table 6.11: Storm tide damage scenarios for buildings in Mackay

ARI (yr)	Nil damage		Slight damage		Moderate damage		Extensive damage	
	No. Bldg.	% of total	No. Bldg	% of total	No. Bldg	% of total	No. Bldg	% of total
50	18 069	87.4%	1020	4.9%	1580	7.6%	3	0.0%
100	17 252	83.5%	1250	6.0%	2110	10.2%	60	0.3%
500	14 812	71.7%	1730	8.4%	2090	10.1%	2040	9.8%
1000	13 862	67.1%	1650	8.0%	2490	12.0%	2670	12.9%
10 000	10 322	49.9%	1610	7.8%	3160	15.3%	5580	26.9%

Interpretation

Tropical cyclones bring with them the multiple threats of strong winds, heavy rain, storm tide inundation and high seas. They consequently pose a considerable threat to Mackay. In the 136 years since the settlement was established, there have been 77 cyclones that have had some effect on the town - that is an average of a cyclone every two years, though a direct 'hit' by a severe cyclone is substantially less common.

The conventional response to an impending cyclone impact is for people to take shelter in their own homes. This is an appropriate and proven strategy except in those areas that would be subject to storm tide inundation. In those areas many people would be exposed to building collapse and a significant risk of drowning, especially were the level of inundation to exceed 1 m over floor level, unless evacuation of people occurred ahead of the cyclone crossing the coast.

Evacuation of those people at risk must be completed before the winds reach 75 km/h (typically six hours before the cyclone's eye reaches the coast), the strength at which it ceases to be safe for anyone to be out of doors. For storm tide events with annual exceedence probabilities up to, and including 1%, the numbers of people involved are relatively small and could be easily managed with appropriate warning, planning and community awareness. Beyond that level, however, a considerable effort would be required to undertake and manage the numbers of evacuees that would be involved, unless the vast majority were prepared to manage and undertake their own evacuations beginning at least 24 hours before the forecast cyclone impact time. Delay in commencing a major evacuation process increases the risk of people being caught in the open or in their transport when the cyclone hits, because of gridlock on the roads leading out of the danger area.

Whilst the direct impact of a severe cyclone on Mackay will have a major immediate impact with potentially significant loss of life and massive damage, the long term impact could also be catastrophic. In an extreme event, a major proportion of the survivors could need to be evacuated to centres as far away as Brisbane and Sydney (as was the experience of Darwin following the impact of Cyclone *Tracy* in 1974). The loss of facilities on which the community relies could be such that it could be difficult to sustain the population of the city and its dependent hinterland for an extended period without substantial external assistance.

Limitations and Uncertainties

We have already discussed at some length the key concerns we have with data and model limitations and uncertainties. Given the generalised assessment that we have undertaken, however, we are confident that the results present a range of reasonable, potential consequences.

The differences in wind damage estimated by the method employed in this study and a method based on wind speeds from *AS1170.2-1989* are considerable and they highlight the need for improved hazard and vulnerability models to reduce the uncertainties in risk assessment.

It is also important here to test the sensitivity of the storm tide impact model that we have employed. Three models, ranging from the simplistic 'still water' model (used by Smith and Greenaway, 1994) that projects the level of inundation to the same contour value as the height of the storm tide above AHD, to the more complex, but complete, model used in this study are compared in Table 6.12. For each scenario, the total of dwellings for each of the three water depth indicators is tallied to give the total buildings affected. The statistics for each model, against each scenario, are provided.

From the figures in Table 6.12 it is clear that the 'still water' model significantly underestimates the number of buildings at risk and should not be used. Although a number of caveats have previously been outlined, the significance of including the wave setup, as well as the shallow water wind wave components is considered justified.

It is also possible to compare the modelling results with the spatial extent of the 1918 storm tide. The 1918 storm tide inundated Mackay to a level of approximately 5.4 m above AHD. This was caused by a storm surge of 3.7 m arriving close to the top of a 1.95 m above AHD high tide (Gourlay & Hacker, 1986, p.51). That level puts it within 0.2 m of our modelled 0.2% AEP scenario based on:

- Harper's 0.2% AEP storm tide scenario of 4.8 m above AHD (1.2 m above HAT);
- a 0.5 m wave setup; and,
- an allowance of 0.3 m for shallow water waves.

The extent of the 1918 storm tide inundation was mapped by Parkinson and others (1950). Figure 6.28 shows their inundation boundary in the main Central, East and South Mackay areas compared with the modelling for a 0.2% AEP storm tide described above (blue dots are all properties with water above ground level). The 'fit' is extremely good – only 3.2% of buildings inside the 1918 inundation zone were missed by the model.

Table 6.12: Comparison of buildings affected under five storm tide impact models in Mackay

Scenario	**Level**	**Model 1** (buildings)	**Model 2** (buildings)	**Model 3** (buildings)
2% AEP	>1m over floor			
	<1m over floor	60	111	1548
	not over floor*	825	1071	1015
1% AEP	>1m over floor	7	16	58
	<1m over floor	699	1150	2108
	not over floor	1243	1116	1248
0.2% AEP	>1m over floor	105	904	2040
	<1m over floor	2300	2100	2090
	not over floor	1307	1560	1734
0.1% AEP	>1m over floor	904	1728	2668
	<1m over floor	2100	2018	2488
	not over floor	1560	1654	1651
0.01% AEP	>1m over floor	3004	4028	5585
	<1m over floor	2689	3071	3164
	not over floor	1640	1791	1615

NOTES:

* Water on the property but not over floor level
Model 1 = the 'still water' model.
Model 2 = the 'still water' model plus an allowance for shallow water wind waves.
Model 3 = the '0.5 m wave setup model + shallow water wind wave' model.

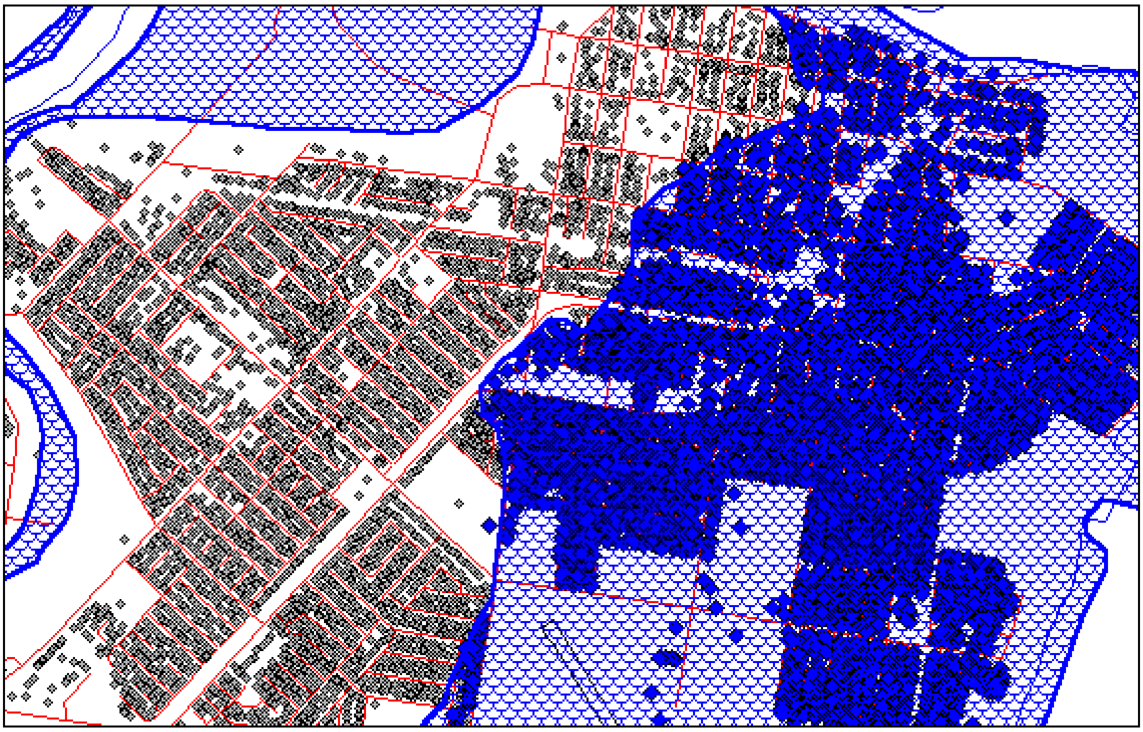


Figure 6.28: Comparison with 1918 Mackay inundation and 0.2% AEP modelled inundation.

Plate 6.1: Mackay 1918 cyclone - Mackay lies in ruins. Taken from the corner of the River and Argyle Streets
Collection: Mackay *Daily Mercury*

Plate 6.2: Mackay 1918 cyclone - Destroyed Masonic Hall, Wood Street. Unroofed Star Theatre in background
Collection: John Oxley Library, Brisbane

Plate 6.3: Mackay 1918 cyclone - Geohamilton's Bakery, situated on the north side of the Pioneer River
Collection: John Oxley Library, Brisbane

CHAPTER 7: A MULTI-HAZARD RISK ASSESSMENT

Ken Granger and Trevor Jones

Overview

Our approach in developing this multi-hazard risk assessment of Mackay has been consistent with the general risk management process outlined in *AS/NZS 4360:1999 Risk management* (see Figure 1.1 and Figure 1.2) 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 Mackay 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 Mackay community.

Our methods have also been shaped by the definition of **total risk** adopted in this study, namely:

> ***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…*
>
> (Fournier d'Albe, 1986)

Thus total risk depends on both hazard exposure and community vulnerability. Our studies have emphasised the vulnerability of the community whereas the definition of Fournier d'Albe (1986) does not.

To assess overall community risk, therefore, it is necessary to bring together the assessment of hazard impact and community vulnerability to reach an assessment of total risk and then to measure that risk against established risk criteria.

Risk Criteria

It is difficult, if not impossible, to be categorical about levels of acceptable or tolerable risk. Such risk criteria vary wildly 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 does 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 cyclone. There is clearly 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 Mackay the following thresholds are either explicitly or implicitly accepted, albeit with minimal community input:

- 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';
- for flood - Council Guidelines require ground fill levels of new urban subdivision development to be above the level of the ARI = 50 years flood, and new building floor levels to lie above the level of the ARI = 100 years flood;
- 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 - Council Guidelines require ground fill levels of new urban subdivision development to be above the level of the ARI = 50 years storm tide event (plus allowance for other factors), and new building floor levels to lie above the level of the ARI = 100 years storm tide (plus allowance for other factors).

This approach would seem to set inconsistent standards of 'risk acceptance' and is certainly not unique to Mackay. The thresholds for earthquake and severe wind have largely been set by agencies outside Mackay, 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 acceptability standards play a larger part in setting thresholds.

These thresholds do not generally address the risks to structures (and consequently people) built before the introduction of the various standards or planning constraints. 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.

In spite of the limitations, these thresholds do provide us with a benchmark against which to assess community risk in Mackay.

Total Risk Assessments for Mackay Suburbs

In Table 7.1 we have brought together the rank values of Mackay suburbs for their contribution to overall community vulnerability (from Table 3.8) and their rank values for exposure (based on the number of domestic buildings) to 'code design' level events including earthquake (from Table 4.10), flood (from Table 5.3), strong winds (1000 year ARI from Table 6.6), storm tide (from Table 6.10) and overall cyclone (by taking the highest rank achieved for flood, wind and storm tide). Each of the exposure rankings is based on scenarios that match the notional 'acceptability' threshold values described above.

By plotting each suburb's rank of contribution to overall community vulnerability against its rank of exposure to each hazard, it is possible to classify suburbs according to their **total risk** as follows:

A. high total risk (high exposure and high contribution to vulnerability)
B. significant total risk (high exposure and low contribution to vulnerability)
C. moderate total risk (low exposure and high contribution to vulnerability)
D. low total risk (low exposure and low contribution to vulnerability)

In this classification 'high' rank is taken to be the top 50% of ranks and 'low' is the bottom 50% of ranks as follows:

high contribution ranks 1 to 13 | low contribution ranks 14 to 27
high earthquake exposure ranks 1 to 13 | low earthquake exposure ranks 14 to 27
high flood exposure ranks 1 to 8 | low flood exposure ranks 9 to 16
high wind exposure ranks 1 to 13 | low wind exposure ranks 14 to 27
high storm tide exposure ranks 1 to 8 | low storm tide exposure ranks 9 to 17
high cyclone exposure ranks 1 to 13 | low cyclone exposure ranks 14 to 27

Suburbs with no exposure to a particular hazard have been left unranked.

Table 7.1: Ranking of Mackay suburbs according to vulnerability and hazard exposure

Suburb	Vulnerability	Earthquake	Flood	Wind	Storm Tide	Cyclone
Andergrove	3	4	6	7	6	6
Bakers Creek	16	13		10	10	10
Beaconsfield	10	11		14	8	8
Blacks Beach	19	15		11	14	11
Bucasia	8	8		5	9	5
Central Mackay	2	3	1	8	3	1
Cremorne	18	21	9	17	11	9
Dolphin Heads	20	23		16	16	16
East Mackay	7	7	3	2	2	2
Eimeo	15	14		9	7	7
Erakala	26	26	16	23		16
Foulden	27	27	12	24	17	12
Glenella	14	16	12	18		12
Mackay Harbour	9	17	8	25	12	8
Mount Pleasant	11	10	12	13		12
Nindaroo	23	24		26		26
North Mackay	4	5	4	4	5	4
Ooralea	12	9	12	15		12
Paget	13	12	11	19	15	11
Racecourse	25	20	10	20		10
Richmond	22	25		21		21
Rural View	21	19		27		27
Shoal Point	17	18		12	13	12
Slade Point	6	6	7	3	4	3
South Mackay	1	1	2	1	1	1
Te Kowai	24	22		22		22
West Mackay	5	2	5	6		5

Total earthquake risk: Any earthquake strong enough to cause damage in Mackay will have an effect across all suburbs. All suburbs, therefore, have some degree of exposure. Damage increases disproportionately with increasingly severe ground shaking scenarios. The consequences of earthquakes in Mackay are low for frequently occurring events (e.g. ARI = 100 years or less) but they are high for rare events (e.g. ARI = 2500 years) and they continue to increase for increasingly rare events, at least up to ARI = 10 000 years.

The relationship between each suburb's vulnerability contribution (i.e. the relative contribution made to overall community risk by the elements at risk in each suburb as detailed in Chapter 3) and its exposure to earthquake is shown in Figure 7.1 and the spatial distribution in Figure 7.2. Suburbs are listed according to their earthquake exposure rating in Table 7.1 and their total risk rating in Table 7.2.

For example, Andergrove is ranked as having the fourth highest exposure to earthquake and the third highest contribution to community vulnerability in Table 7.1. Therefore Andergrove has a high total risk from earthquake (high exposure and high contribution to vulnerability).

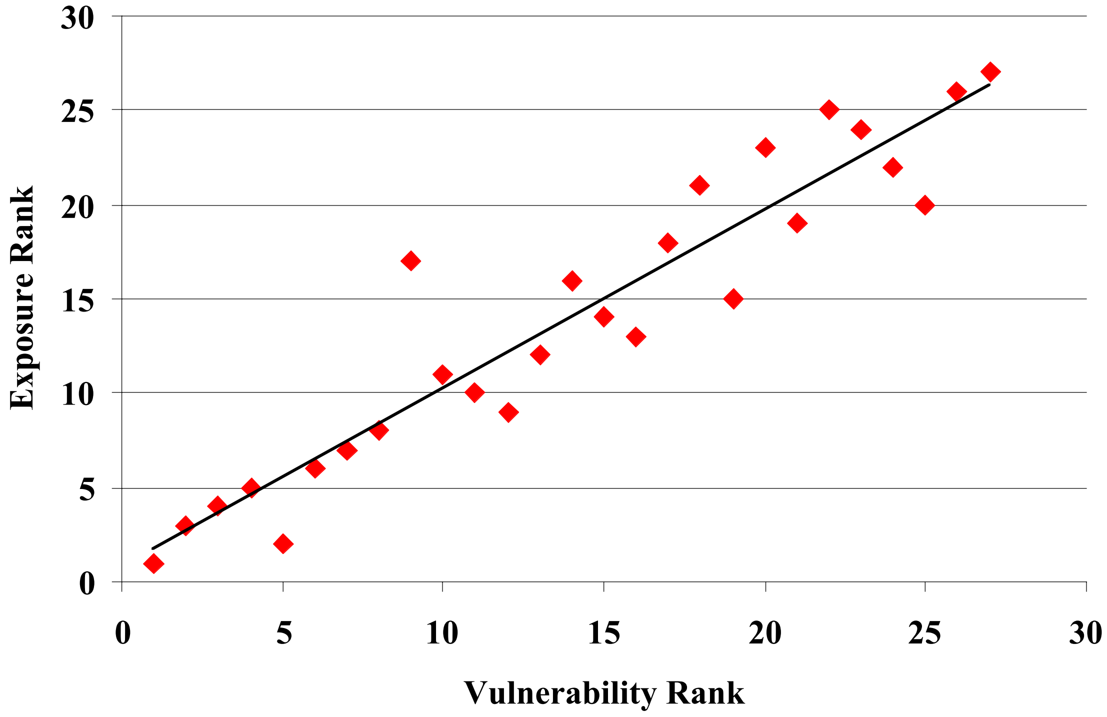


Figure 7.1: Mackay earthquake total risk relationship

There is a strong association at the suburb level between earthquake exposure and community vulnerability, especially for the ten or so suburbs that contribute most to the overall vulnerability of the Mackay community. The most notable exception is Mackay Harbour. It has a low number of buildings and the potential impact of earthquake on the Mackay region through interruptions to port operations is not fully described by our assessment of exposure.

The close relationship between earthquake exposure and overall community vulnerability is to be expected given that earthquake exposure is dependent on the number of buildings in a suburb, and a suburb's contribution to overall community vulnerability is dependent on the number of elements at risk (including buildings) in it. However, two factors that figure strongly in determining earthquake exposure - the performances of buildings during earthquakes and the ground conditions on which the buildings are located - do not figure in assessing overall community vulnerability, and so earthquake exposure and contribution to community vulnerability are not fully dependent on each other.

Rather, the strong association between community vulnerability and exposure to earthquake can be traced to the history of development of the city. The port and nearby suburbs were developed first and these are situated on flat, alluvial ground. Early development of the city continued largely on the floodplain to the south of the Pioneer River and community infrastructure and facilities to sustain the community also developed there. Most of Mackay's most vulnerable, older buildings are found in these areas. Vulnerable groups of the community, for example, the old, those renting and those unemployed, are also found in the first-developed suburbs.

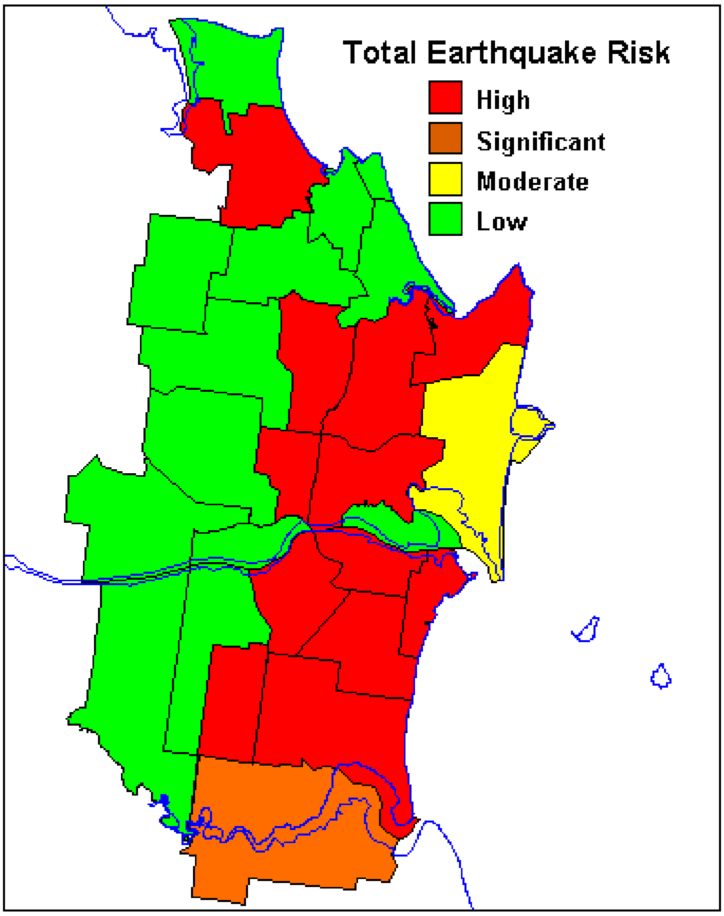


Figure 7.2: Distribution of total earthquake risk

Table 7.2: Mackay suburb rating for total earthquake risk (alphabetic order)

RISK LEVEL	SUBURBS
High total risk	Andergrove, Beaconsfield, Bucasia, Central Mackay, East Mackay, Mount Pleasant, North Mackay, Ooralea, Paget, Slade Point, South Mackay, West Mackay
Significant total risk	Bakers Creek
Moderate total risk	Mackay Harbour
Low total risk	Blacks Beach, Cremorne, Dolphin Heads, Eimeo, Erakala, Foulden, Glenella, Nindaroo, Racecourse, Richmond, Rural View, Shoal Point, Te Kowai
No discernible risk	nil

Under the 'code' scenario, with a 10% probability of exceedence in 50 years, or an ARI of approximately 500 years, about 3280 buildings, comprising about 16% of the building stock, are expected to sustain damage, about three quarters of which will be minor. About 750 buildings, comprising about 3.6% of Mackay building stock, will sustain moderate or more severe damage. Most damaged buildings will be residential and more than 100 buildings will probably be damaged in South Mackay, West Mackay, Central Mackay, North Mackay, Andergrove, Slade Point, Beaconsfield, Bucasia, Mount Pleasant and Ooralea.

Total Pioneer River flood risk: The computation of the total flood risk has been based on the Pioneer River Q50 model described in Chapter 5.

Under this scenario approximately 5000 buildings would be exposed to inundation and would consequently suffer moderate damage. The scattergram (Figure 7.3) shows the close positive correlation between the flood exposure ranks (based on the numbers of buildings likely to be affected) and the ranking of suburbs according to their contribution to community vulnerability. Suburbs not affected by the Q50 flood scenario have been excluded from the scattergram. Suburbs are listed according to their total risk rating in Table 7.3. Figure 7.4 shows the distribution of total flood risk.

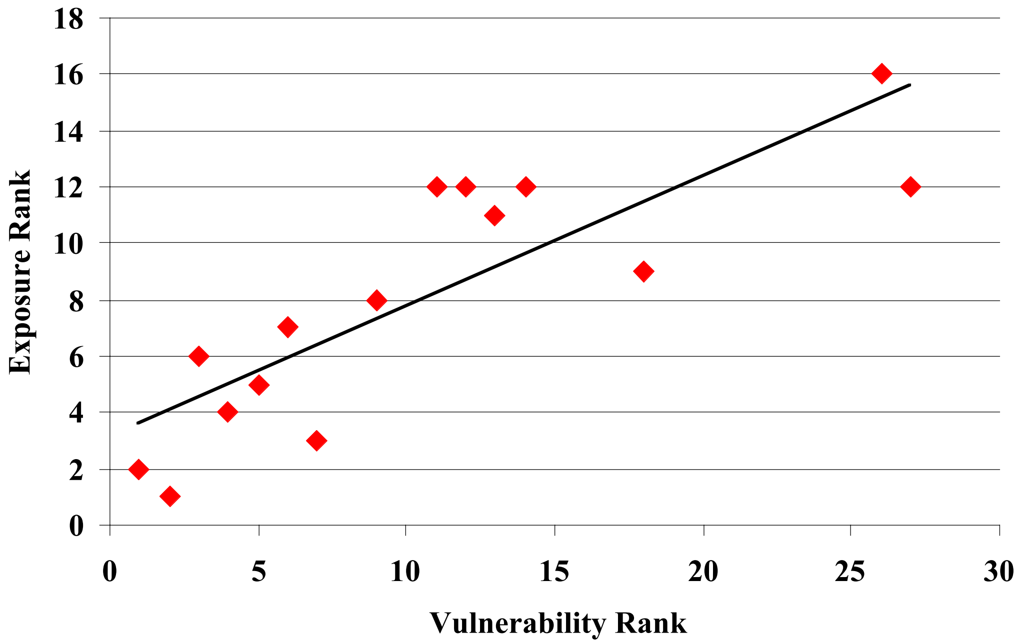


Figure 7.3: Mackay flood total risk relationship

Table 7.3: Mackay suburb rating for total flood risk

RISK LEVEL	SUBURBS
High total risk	Andergrove, Central Mackay, East Mackay, Mackay Harbour, North Mackay, Slade Point, South Mackay, West Mackay.
Significant total risk	
Moderate total risk	Mount Pleasant, Ooralea, Paget.
Low total risk	Cremorne, Erakala, Foulden, Glenella.
No discernible risk	Bakers Creek, Beaconsfield, Blacks Beach, Bucasia, Dolphin Heads, Eimeo, Nindaroo, Racecourse, Richmond, Rural View, Shoal Point, Te Kowai.

This relationship is hardly surprising given the development history of Mackay. Mackay was established as a river port, it has grown as a river town and remains a river town. The Pioneer River is the dominant feature in the Mackay landscape. The suburbs which contain the more significant concentrations of residential and commercial development are located adjacent to the river, in spite of the city's history of flood disasters.

Whilst Cremorne and Foulden are clearly the most flood prone of all suburbs (100% of the buildings in both suburbs are likely to be affected), they rank as only 'low risk'. This is because they contribute only a minor amount to overall community vulnerability and produce only a minor exposure expressed in terms of the total numbers of buildings potentially affected – 23 and one buildings respectively out of the total of 5000. The significance of this specific risk issue is dealt with when we consider mitigation strategies below.

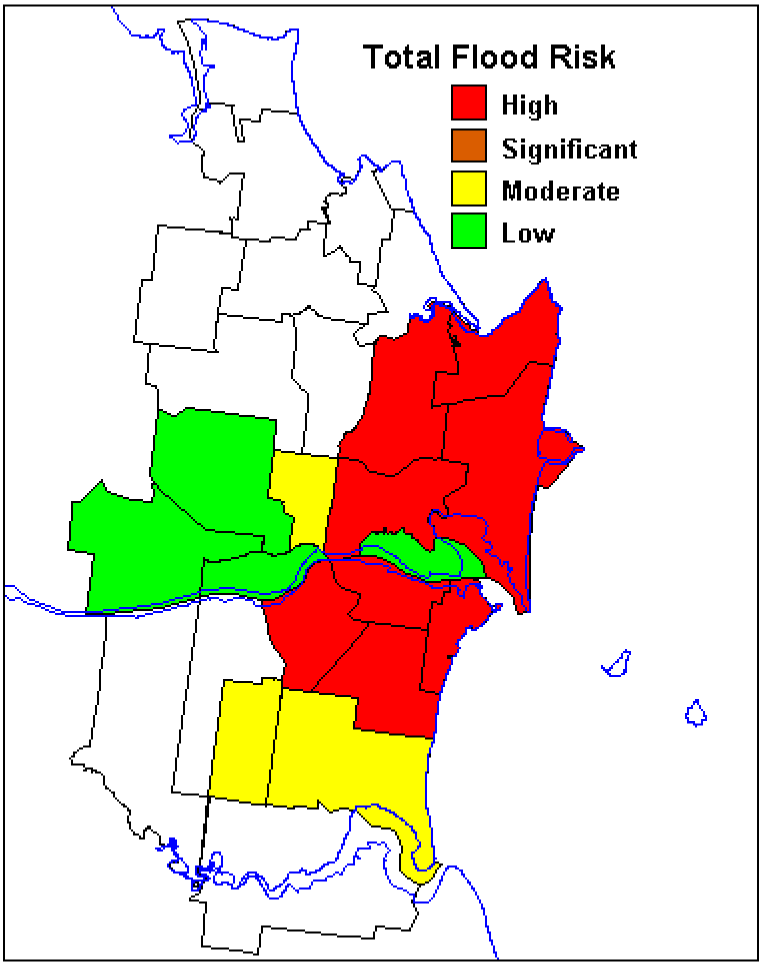


Figure 7.4: Distribution of total flood risk

Destructive wind total risk: There is again a strong association between exposure to strong winds and vulnerability contribution shown in the scattergram (Figure 7.5), especially for those suburbs ranked in the top ten. The most significant outrider value is Mackay Harbour (which ranks 25th in terms of severe wind exposure but 9th in vulnerability). This can be explained by the fact that the exposure assessment is based on the impact of a code design level event (i.e. a wind with a 1000 year ARI) on domestic structures. Whilst non-residential buildings will also receive damage in such an event, the data on which to base a realistic risk assessment for non-residential buildings are not available. The majority of non-residential buildings, especially in Mackay Harbour, are, however, likely to have been constructed to higher engineering standards than the average house. The spatial distribution is shown in Figure 7.6 and the suburbs are listed by total risk in Table 7.4.

Proximity to the coast and age of settlement are clearly the key determinants in wind risk.

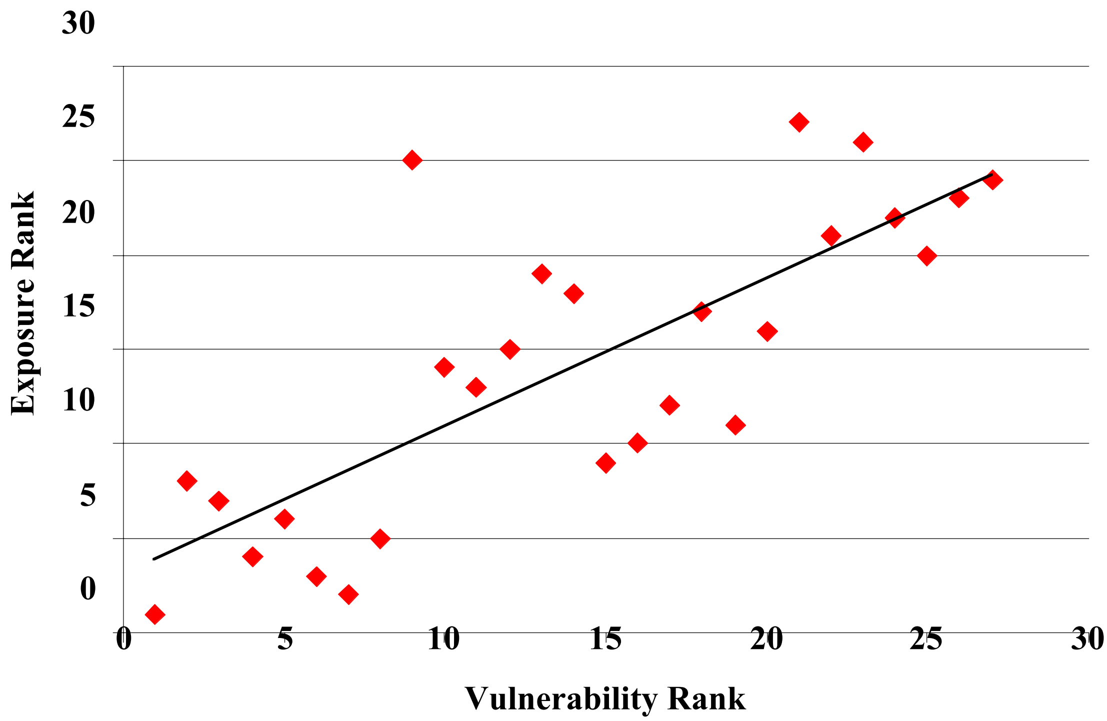


Figure 7.5: Mackay total severe wind risk relationship

Table 7.4: Mackay suburb rating for total severe wind risk (alphabetic order)

RISK LEVEL	SUBURBS
High total risk	Andergrove, Bucasia, Central Mackay, East Mackay, Mount Pleasant, North Mackay, Slade Point, South Mackay, West Mackay
Significant total risk	Bakers Creek, Blacks Beach, Eimeo, Shoal Point
Moderate total risk	Beaconsfield, Mackay Harbour, Ooralea, Paget
Low total risk	Cremorne, Dolphin Heads, Erakala, Foulden, Glenella, Nindaroo, Racecourse, Richmond, Rural View, Te Kowai
No discernible risk	nil

Total storm tide risk: The relationship between exposure to storm tide risk, based on an event with an AEP of 1% (ARI of 100 years), and vulnerability contribution is shown in Figure 7.7. Again, it displays a strong positive correlation reflecting the fact that the suburbs that contribute most to the overall vulnerability of Mackay also have the greatest exposure to a significant storm tide impact. As with the earthquake and flood risk, this is a strong reflection of the city's historic evolution. The same specific risk/total risk anomaly in both Cremorne and Foulden is also evident.

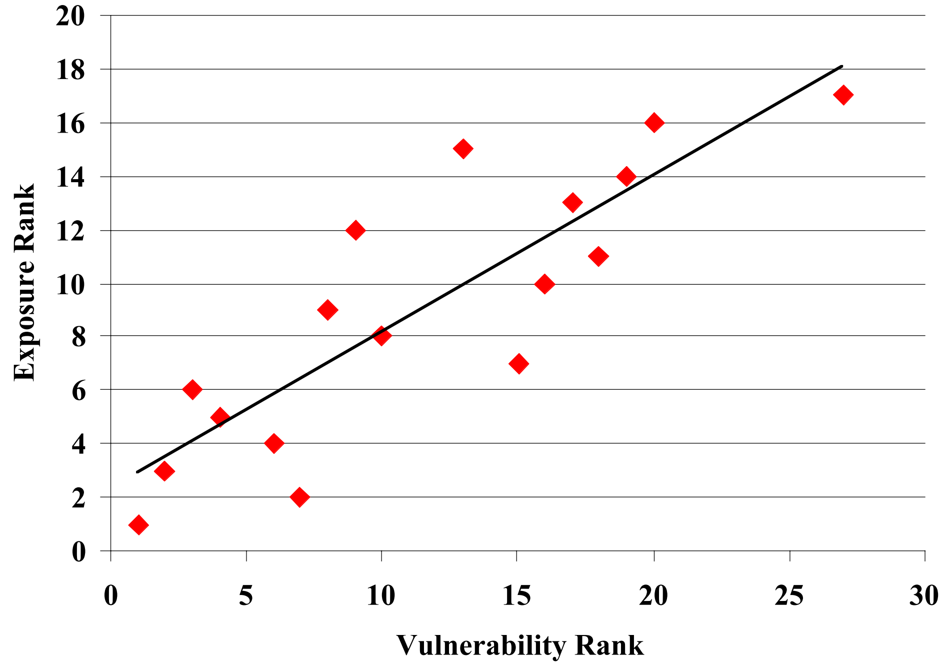


Figure 7.7: Mackay storm tide total risk relationship

The suburbs are listed by total risk in Table 7.5 and the spatial distribution is shown in Figure 7.8.

Table 7.5: Mackay suburb rating for total storm tide risk (alphabetic order)

RISK LEVEL	SUBURBS
High total risk	Andergrove, Beaconsfield, Central Mackay, East Mackay, North Mackay, Slade Point, South Mackay.
Significant total risk	Eimeo.
Moderate total risk	Bucasia, Mackay Harbour, Paget.
Low total risk	Bakers Creek, Blacks Beach, Cremorne, Dolphin Heads, Foulden, Shoal Point.
No discernible risk	Erakala, Glenella, Mount Pleasant, Nindaroo, Ooralea, Racecourse, Richmond, Rural View, Te Kowai, West Mackay.

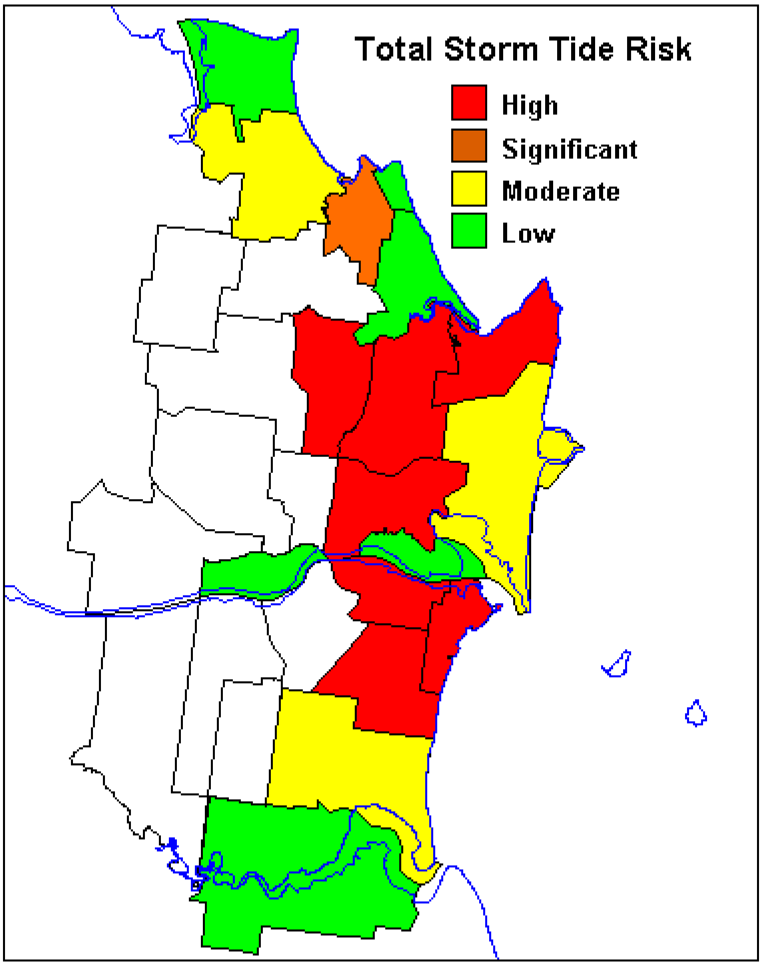


Figure 7.8: Distribution of storm tide total risk

Total cyclone risk: Given that cyclones are compound hazards which bring with them (in severe cases) destructive winds, storm tide and flood, it is appropriate to consider the cumulative total risk represented by a severe cyclone impact. To do this, we have simply taken the highest exposure rank for the individual hazards identified in Table 7.1 for each suburb. Again, as shown in Figure 7.9, there is a strong positive correlation between exposure to the hazard and the contribution made to overall community vulnerability. The scatter at the right hand side of the graph is explained by the fact that not all suburbs are exposed to all of the cyclone's components, so suburbs such as Foulden (with only two buildings) have a pseudo-high ranking for flood that boosts their overall rank.

Table 7.6: Mackay suburb rating for total cyclone risk (alphabetic order)

RISK LEVEL	SUBURBS
High total risk	Andergrove, Beaconsfield, Bucasia, Central Mackay, East Mackay, Mackay Harbour, Mount Pleasant, North Mackay, Ooralea, Paget, Slade Point, South Mackay, West Mackay.
Significant total risk	Bakers Creek, Blacks Beach, Cremorne, Eimeo, Foulden, Glenella, Racecourse, Shoal Point
Moderate total risk	nil
Low total risk	Dolphin Heads, Erakala, Nindaroo, Richmond, Rural View, Te Kowai.
No discernible risk	nil

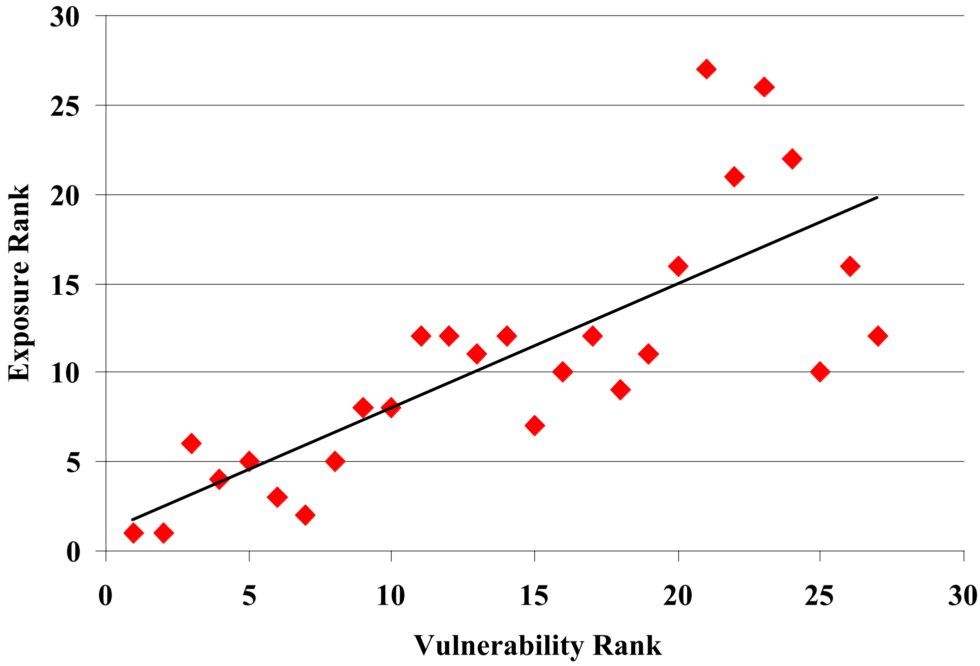


Figure 7.9: Mackay cyclone (combined) total risk relationship

The suburbs are listed by total risk in Table 7.6 and the spatial distribution is shown in Figure 7.10.

Risk Evaluation and Prioritisation

Several methodologies have been described in the literature for evaluating and prioritising risk as the first step towards establishing treatment strategies and priorities. 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).

Whilst both of these approaches provide a useful method for reaching a qualitative evaluation of risk, especially for a single hazard, they provided rather a limited, subjective rating for total risk and are cumbersome in their application to multi-hazard risk evaluation and prioritisation. The semi-quantitative approach that we have adopted in this study, by contrast, provides a more objective means of identifying the risks that pose the greatest threat to the total community. It also provides a means by which to identify the risks that pose the greatest threat to individual suburbs within the community.

At the community level the relative level of risk posed by each of the hazards considered can be assessed from the numbers of buildings likely to be damaged, and the severity of that damage, under the hazard scenarios. Figure 7.11, Figure 7.12 and Figure 7.13 compare the likely building damage from floods, severe winds, storm tides and earthquakes.

This multi-hazard risk assessment is probably the first attempted in Australia and one of very few in the world. Clearly, the damage comparisons in Figure 7.11, Figure 7.12 and Figure 7.13 contain considerable limitations and uncertainties, and the results must be taken as indicative. We refer the reader to Chapter 4, Chapter 5 and Chapter 6 for discussions of some of these limitations and uncertainties.

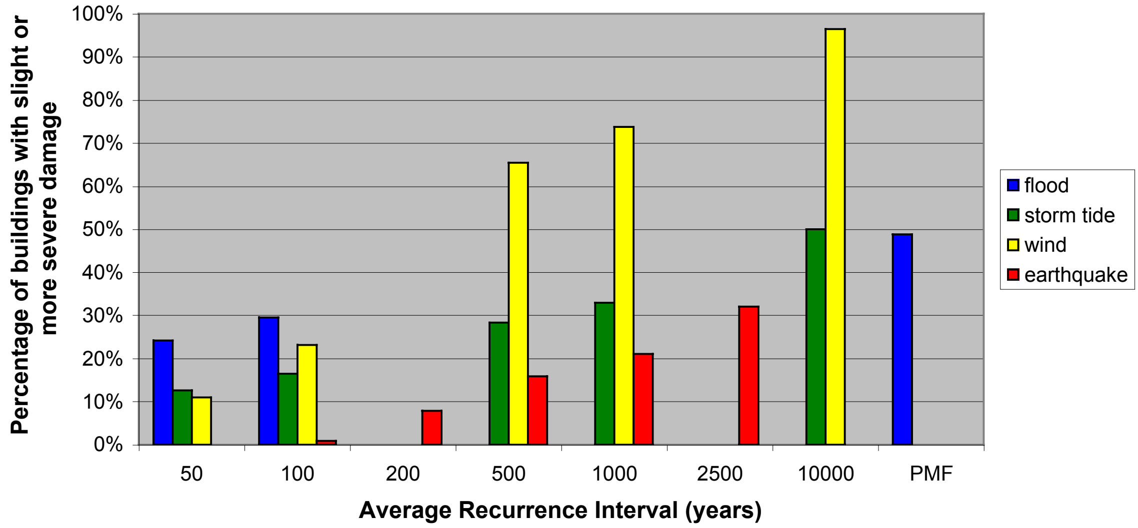


Figure 7.11: Slight or more severe damage for all hazard scenarios considered

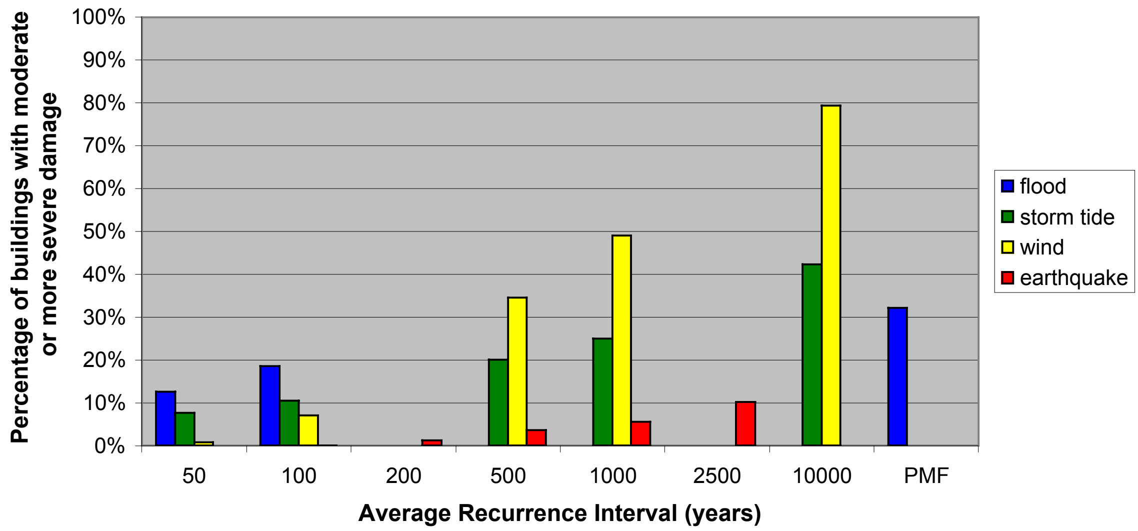


Figure 7.12: Moderate or more severe damage for all hazard scenarios considered

Although the absolute levels of predicted damage may have bias or significant associated uncertainty, the relative risks are, we believe, more robust.

Although we have attempted to compare damage from the different hazards as closely as possible, there are some differences in the assessments. For earthquakes and severe winds, residential buildings only were considered, whereas for storm tide and floods all buildings were considered. For storm tide, floods and severe wind, damage to buildings and building contents was included whereas for earthquakes, building damage only was considered. These differences are considered relatively minor in comparison to other uncertainties in the risk evaluation.

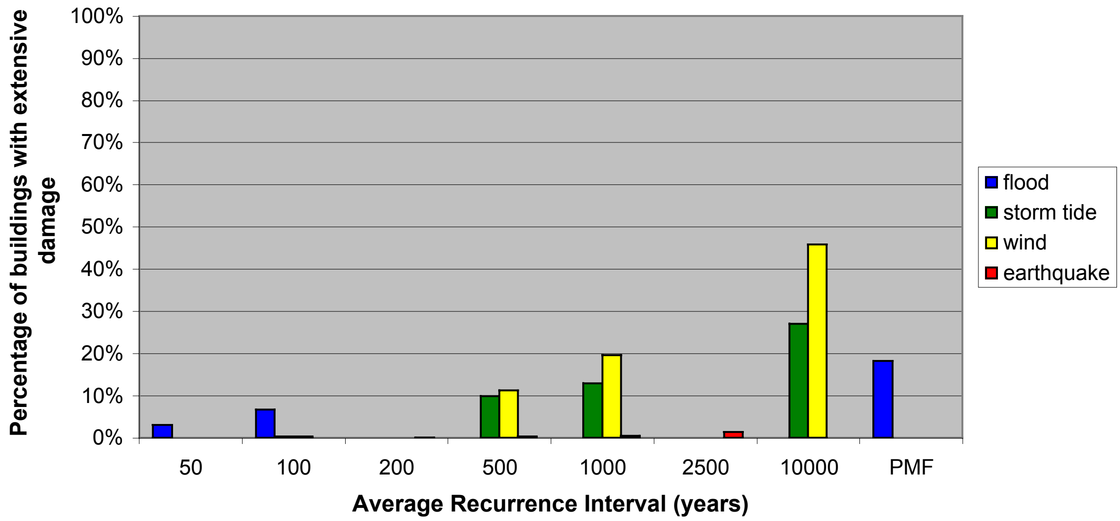


Figure 7.13: Extensive damage for all hazard scenarios considered

Notwithstanding the many uncertainties inherent in the risk evaluation, the results indicate that the single geohazard **Floods in the Pioneer River pose the greatest risk to Mackay.** Major flood levels in the Pioneer River have been reached 20 times since 1884. If the risks associated with local storm water surcharge from the same rainfall episode that caused the riverine flooding were added (a very significant issue for Gooseponds Creek), the potential damage from floods would be greater than indicated.

The relatively frequent major flooding events make floods the greatest risk to Mackay. In scenarios with ARIs of 50 years and 100 years, more than 10% of Mackay buildings will be moderately or more severely damaged (Figure 7.12). However, extreme floods will not affect all parts of Mackay, unlike extreme earthquakes and winds from tropical cyclones, which could cause damage across all suburbs.

A major flood, beyond the 50 year ARI level, has not been experienced in Mackay since settlement. Given that the flood structural mitigation works in place in Mackay have been set at what was thought to be the 50 year ARI level, but in fact may be the level for events with an ARI of less than 50 years, is likely that events with an ARI of 100 years or more will cause major loss. Under such a major flood scenario (ARI ≥ 100 years), Mackay would be isolated for some time, given that all road and rail links would be cut and the Mackay airport would also be closed by flood waters. The isolation would be, in part due to flooding of creeks and rivers to the north and south of the Pioneer. Such an event could also pose significant environmental risks, including the potential for the mouth and course of the Pioneer River to change significantly. It is estimated that the Probable Maximum Flood will cause moderate or more severe damage to about 30% of Mackay buildings.

A program of levee construction began in the 1960s and is nearing completion. Planning constraints for development in the flood-prone areas of the estuary were not introduced until the early 1990s, though much of the urban area at risk had already been established by that time. Flooding is, however, generally of short duration and the warning systems operated by the Bureau of Meteorology provide sufficient time for residents to take steps to protect their property and for emergency services to conduct precautionary evacuations if that course of action is indicated.

The risk of fatalities in any flood event is significant, especially where people ignore warnings to evacuate, or indulge in irresponsible behaviour such as ‘surfing’ in the floodwaters or attempting to negotiate flooded roads. Drownings through this kind of behaviour and building failure have been demonstrated by the 1958 flood.

The geohazards **severe wind from tropical cyclone and storm tide are equal second in the threats they pose to Mackay**. In relatively frequent events (e.g., ARI = 50 or 100 years), wind will cause less damage than floods and possibly less than storm tide also. However, wind has the potential to inflict damage over a large geographical area, whereas the impact of storm tide and flood is restricted to low lying and coastal areas. In events that are unlikely to occur (e.g, ARI = 500 or 1000 years), wind will damage more Mackay buildings than any other geohazard (Figure 7.12).

It should be noted, also, that predictions of wind damage from the wind speeds in *AS1170.2-1989* are higher than the levels predicted in this study, for events with any probability of occurrence. In fact, the wind model based on *AS1170.2-1989* leads to the result that wind is the geohazard that causes the greatest risk to Mackay. We have compared the damage from the two wind models in Chapter 6.

Design practice aimed at making buildings more resilient to strong winds came into use in the 1950s. The cyclone resistance of major buildings was formalised in 1975 through the Queensland Building Act. The resistance of some classes of buildings was significantly upgraded in 1982 with the introduction of Appendix 4 of the Act which also introduced requirements for domestic structures. These appear to provide an effective form of mitigation. However, older buildings in Mackay (about two-thirds of all buildings) were not constructed in accordance with these standards.

Given the capacity of the cyclone monitoring and warning system operated by the Bureau of Meteorology, it is now highly unlikely that the Mackay community will be caught by surprise by tropical cyclone. Thanks to the annual community awareness campaign mounted jointly by the Bureau, the DES and Mackay City Council, there is a high level of community awareness of the risk and how to cope with it. The level of awareness has been reinforced by the community’s experience of Cyclone *Justin* in 1997. The risk to life from destructive cyclone winds, therefore, should be low and confined to the foolhardy who ignore the warnings and advice, or those who do not hear or understand the warnings.

Mackay holds the dubious distinction of being the only significant urban population in Australia to have suffered a significant **storm tide** impact. That 1918 experience has clearly remained strong in the community’s consciousness.

For the more frequently occurring events (ARI ≤ 100 years), storm tides have a lesser potential for loss than floods and this is the reason why storm tide risk is less than flood risk. Storm tides and floods will cause moderate damage to similar numbers of buildings, but floods will also cause extensive damage to significant numbers of buildings (Figure 7.13).

For rarer, more extreme events, the situation is reversed and storm tide has the potential for greater destruction than floods in these rare events (Figure 7.12).

The potential for destruction by storm tide is derived not only from the large numbers of people, buildings and critical facilities that are located within the area in which storm tide impact would be greatest but also from the extremely limited options available in Mackay for safe evacuation ahead of a storm tide impact. A significant storm tide also carries with it the threat of major environmental impacts. These include major levels of coastal erosion and/or deposition that would, in turn, pose a threat to beachside suburbs. A small sampling of the damage potential of storm tide and associated high seas in Mackay was provided by Cyclone Justin in 1997.

Although earthquakes are not widely recognised as a significant threat to Mackay, our research leads us to conclude that **earthquakes pose the fourth geohazard risk to the Mackay community**. **The level of earthquake risk in Mackay is certainly significant and earthquakes should be considered in risk management strategies for the city.** For more frequently occurring events, damage will be low. However, like severe winds, earthquakes have the potential to impact upon the entire Mackay community, and strong but rare events (e.g., ARI ≥ 1000 years) will cause damage to many buildings (Figure 7.12).

The probability of death is low in any of the earthquake scenarios considered. However, the possibility of casualties or deaths in Mackay from earthquakes cannot be excluded.

The economic risk posed by earthquake in Mackay is substantial, especially in the older parts of the city. In addition to losses from building damage, old and brittle underground utilities such as water and sewerage networks will be especially susceptible to damage.

Risk Mitigation Options

The development and implementation of risk mitigation strategies for Mackay lies outside the remit of the *Cities Project*. Our experience in working with emergency managers and others, in Mackay and elsewhere, has, however, given us some insight into key aspects of risk mitigation that are offered here as observations, rather than as suggestions, let alone recommendations.

Risk management culture: At a philosophical level at least, one of the most potent forms of risk mitigation 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 is Mackay City Council. The compartmentation and isolation of emergency risk management from the mainstream of community governance can best be attributed to the lack of a broad culture of risk management.

Unlike many other local governments in Queensland, risk management has clearly taken root in Mackay City Council, though it is still at an early and fragile stage of development. This commitment can be largely attributed to the pioneering efforts of successive city engineers since the early 1990s and most recently through the Council's active involvement in the Queensland *Local Government Disaster Mitigation Project* sponsored by the DES. Indeed Mackay Mayor Julie Boyde has been actively involved in that project. The lead shown by Mackay City Council is clearly underpinned by the development and promotion, by the 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 mitigation 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 Mackay City Council 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 our Mackay 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 the Historical Society and the *Mackay Mercury* each maintain collections on the community experience of disaster, there is no consolidated index or coordination of information about the Mackay history of disasters and their impact on the community, other than for the 1918 cyclone and, perhaps, the 1958 flood;

- modern event experience: Mackay 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, 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.

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. Whilst there is some scope to improve their timeliness and accuracy, 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.

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)

Nonetheless, warning systems will be much more effective if the community is aware of their existence and of the implications of warnings.

Community awareness: 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. An effective strategy of risk communication is, therefore, essential. For example, a typical public flood warning will be expressed in terms of a height on the reference flood gauge (e.g. the Forgan Bridge gauge). Few people could translate that level to their own property in terms of how high the water would reach, with any certainty, consequently the value of the warning is diminished because few individuals would 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.

Building and planning codes: Building codes and planning regulations are rightly seen as being very effective strategies for risk reduction. The simplest way to reduce risk is obviously to prevent development in areas that are prone to regular and/or significant hazard impact such as floods. Such an approach has already been adopted in Mackay with the Council's inundation policy for new development. It requires immunity to the 50 year ARI flood and storm tide event for fill levels for buildings, and floor levels for all habitable rooms above the 100 year ARI flood and storm tide levels.

If planning constraints are not a viable option (as is the case with earthquakes and destructive winds), the best option is to ensure that the buildings and infrastructure that provide the community with shelter, sustenance, security and social viability are built to withstand reasonable degrees of hazard impact.

Mackay City Council enforces the provisions of the Australian Building Code, which established minimum standards for construction to safely withstand established levels of earthquake and wind risk. 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. 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.

However, by no means is all geohazard risk in Mackay treated by building and planning regulations. The rarer, more severe geohazard events make a secondary but substantial contribution to the total geohazard risks in Mackay. In the case of flood and storm tide, for example, this means that new buildings complying with the Council's Guidelines are protected from most of the flood and storm tide risk in Mackay, but they still face the risk of inundation from more severe events than those addressed by the Guidelines.

In contrast, the design event for the wind loading standard *AS1170.2-1989* has an ARI of 1000 years such that the adoption of the wind standard is a conservative measure in comparison with the flood and storm tide risk criteria. The standard may be even more conservative than it appears, and the community additionally protected, because recent research suggests that wind gust speeds for Mackay may not be as high as described by the standard.

This study has provided new earthquake hazard information. Mackay City Council could use the information to ensure that development does not introduce unnecessary risk. The Council could, for example, adopt the Mackay earthquake hazard map to inform developers and their engineers of ground conditions with regard to earthquake.

Many existing buildings in Mackay are susceptible to wind, in particular, and earthquake. The Mackay City Council could compile a database 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 the 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.

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 a policy was implemented in Foulden following the 1958 flood when several houses were lost and roads and land was buried under deep deposits of sand and gravel. Consideration has also been periodically given by Council to buying out the properties in Cremorne. Such programs are usually expensive and marked by controversy, however, they are clearly effective in reducing risk.

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 enables 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 the historical centre as the community expands.

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 (see especially Zamecka and Buchanan, 1999), 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 planning phases. Most mitigation 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 developed in 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, <u>before</u> 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 Mackay and other real urban centres.

<u>Critical facility protection</u>: The loss or isolation of critical facilities such as the hospitals, the airport, cold stores, fuel depots 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 uninterruptable 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.

<u>Engineered defences for flood</u>: The classic response to risk mitigation has been to turn to structural defences such as levees, dams, flood detention basins and fill. 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.

There is an increasing tendency to emphasise non-structural mitigation measures (such as those discussed above) and to regard structural defences as the mitigation 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 mitigation strategies to be modelled and their effects tested against the risk reduction criteria that they aim to meet.

Conclusion: Is Mackay a Risky Place?

The Mackay study area has a relatively high level of risk exposure to most geohazards above the 2% AEP range (i.e. an ARI of 50 years or less). Events within this range will cause some loss **and put lives at risk** however the warning systems and other mitigation strategies already in place should keep loss of life to virtually zero and economic loss to nuisance, or at least tolerable levels. This will only be possible if the local community **is aware and prepared**. There are, however, a few suggestions to reduce the current level of risk in a more pro active way.

Despite this being a period of sustained population growth, there have been no fatalities directly attributable to the impact of a natural hazard in the Mackay community in the past two decades. This is due to the fact that there have been no significant earthquakes and very few major cyclone or flood impacts during that time. It can also be attributed to the Council's program to implement hazard-based planning constraints, to introduce and enforce building codes and maintain an effective local emergency management capability.

These risk mitigation strategies have greatly reduced the exposure of new developments to hazards and maximised resilience of structures to the more common hazard impacts. This study and other recent studies have provided the Mackay City Council with new information on the level of this risk which may lead to a reappraisal of mitigation measures. **Overall, we would assess Mackay as having a moderate level of risk exposure to the more frequently occurring hazard events.** It should also be recognised that the climate of the region, that is the source of these hazards, is also the source of the community's wealth in agriculture**.** A tolerably low level of risk, in exchange for community wealth, is perhaps not such a bad deal!

The Mackay community has a high level of residual risk exposure to flood, severe wind and storm tide. Mackay has a much less, but significant, residual risk exposure to earthquakes. Flood and cyclonic wind and storm tide events with an AEP of 1.0% or less (an ARI of 100 years or more) will inevitably cause significant economic harm and potentially some (and possibly significant) loss of life. In these rarer and more extreme events, the loss of critical facilities and the impact on specific community functions such as business activity, especially in Central Mackay, North Mackay, Mackay Harbour, Paget and West Mackay, will add to the magnitude of the risk posed directly by the hazard event itself. These secondary risks are likely to have an effect for a considerable period of time after the initial impact and will significantly increase the direct economic and social costs. Consequently, the community will be faced with a long recovery and restoration period. This is especially significant given the Mackay community's heavy reliance on disaster-sensitive industries such as agriculture, the provision of services such as education, and tourism.

It is clearly not possible, economic, or rational to attempt to eliminate all risk. It is, however, feasible and economic to reduce the residual risk by implementing long-term planning strategies (such as the relocation of critical facilities, the 'retrofit' of key buildings and the 'flood proofing' of roads) and by maintaining a vigorous campaign of community awareness and involvement in the community risk management process. The sooner that process is started, the sooner the risk will be reduced to an even more acceptable level.

It is also important to recognise that Mackay is a growing community and that the planning of future urban development should be done in such a way to not increase the community's exposure to risk. Table 7.7 shows the population projections for the period 1996 to 2016 produced by the Department of Communications, Local Government and Planning. The Mackay (Part A) statistical area is the urban area that is essentially the same as our study area, whilst the Mackay (Part B) statistical area is the rural area not included in this study.

Table 7.7: Mackay population projections 1996 to 2016

AREA	1996	2001	2006	2011	2016
Mackay (Part A)	61 080	65 950	70 650	74 870	78 410
Mackay (Part B)	10 370	11 430	12 590	13 830	15 230
Mackay City (total)	71 450	77 380	83 240	88 700	93 640

Much of the new development is likely to be in the 'safer' areas more distant from the coast, the Pioneer River and the softer sediments, such as Rural View.

Where to From Here?

At the beginning of this multi-hazard risk assessment of Mackay 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 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 it does, this study should be updated and its assessments re-evaluated.

Turning the information and the risk assessments provided here into risk mitigation strategies is a task for others, particularly Mackay City Council and the Mackay community. This process will be significantly enhanced by the work being undertaken in parallel with this study under the DES *Local Government Disaster Mitigation Project*. It is also up to them to keep the information base we have established up to date. If it is not kept current it will rapidly move from being an asset to being a liability.

We are greatly encouraged by the action that has already become evident in the city and elsewhere. A strong level of commitment to risk management is beginning to emerge. We are confident that Mackay is well on the way to becoming a much safer, more sustainable and prosperous community.

REFERENCES

ABS (1999) *Queensland Year Book 1999.* Australian Bureau of Statistics, Canberra.

ABS (1998a) *CData 96 (Final release).* CD-ROM databases from the 1996 National census, Australian Bureau of Statistics, Canberra.

ABS (1998b) *1996 Census of population and housing: socio-economic indexes for areas.* Information paper 2039.0, Australian Bureau of Statistics, Canberra.

As-Salek, J. A. and Yasuda, T. (1994) 'Effects of characteristics of the cyclones hitting Noakhali-Cox's-Bazar coast of Bangladesh on surges and negative-surges in Meghna estuary', in preparation.

Basher, R.E. and Zheng, X. (1995) 'Tropical cyclones in the southwest Pacific: spatial patterns and relationships to southern oscillation and sea surface temperature.' *Journal of Climate,* 8(5), 1249-1260.

Berry, B.J.L. & Horton, F.E. (1970) *Geographic perspectives on urban systems.* Prentice-Hall Inc, Englewood Cliffs, New Jersey.

Black, R.D. (1975) 'Floodproofing rural residences'. *Report to the US Dep't of Commerce, Economic Development Administration, Washington DC.*

Black, P.G. and Marks, F.D. (1991) 'The structure of an eyewall meso-vortex in Hurricane Hugo' (1989). *19th Conference on Hurricane and Tropical Meteorolog.* AMS, May 6-10, Miami, FL, pp. 579-582.

Blong R.J. (1998) 'Damage - the truth but not the whole truth', in David King and Linda Berry (eds) *Disaster Management: Crisis and Opportunity*, conference proceedings (Cairns 1-4 November), Centre for Disaster Studies, James Cook University, Cairns.

Bretschneider, C. L., Collins, J. R. and Pick, G. S (1966) *Storm surges: theory, measurements, and data collection: state of the art.* Company Technical Report.

Building Seismic Safety Council (1997) *National Earthquake Hazards Reduction Program Recommended Provisions for seismic regulations for new buildings and other structures* (FEMA 302 and 303), Building Seismic Safety Council, Washington DC.

Bureau of Meteorology (1999a) *Climatological summary for Mackay MO using data from 1950 to 1999*. Database extract, Bureau of Meteorology, Queensland Regional Office, Brisbane.

Bureau of Meteorology (1999b) *Database of cyclone tracks in the Queensland Region*. Severe Weather Section, Bureau of Meteorology, Brisbane, unpublished.

Bureau of Meteorology (1999c) *Tropical cyclone warning directive (eastern region) 1999-2000.* Queensland Regional Office.

Bureau of Meteorology (1997) *Flood forecasting and warning directive Pioneer.* Bureau of Meteorology, Queensland.

Bureau of Meteorology (1995) *Pioneer River URBS model.* Hydrology Section, Bureau of Meteorology, Queensland.

Bureau of Meteorology (1992) *Understanding cyclones: Queensland.* Australian Government Publishing Service for the Bureau of Meteorology, Canberra.

Bureau of Meteorology (1940) *Results of rainfall observations made in Queensland (supplementary volume).* Commonwealth of Australia.

Bureau of Meteorology (1914) *Results of rainfall observations made in Queensland.* Meteorology of Australia.

Bureau of Transport Economics (2000). 'The cost of natural disasters, preliminary results 25 August 2000'. *Module 1 of the Disaster Mitigation Research Project*, Canberra.

Callaghan, J. (1999) *Tropical cyclone impacts along the Australian east coast from November to April 1867 to 1999.* Bureau of Meteorology working document, Brisbane, unpublished.

Callaghan, J. and Power, S. (under review) *Long term changes in the occurrence of damaging cyclonic storms in tropical and sub tropical eastern Australia*. Submitted Australian Meteorological Magazine 1999.

Cameron, McNamara & Partners (1976) *Pioneer River model study – Report on hydrology*. Cameron, McNamara & Partners, Brisbane.

Chan, J.C.L. (1985) 'Tropical cyclone activity in the northwest Pacific in relation to El Nino/Southern Oscillation phenomenon.' *Monthly Weather Review* 113**,** 599-606.

Chapman, D. (1994) *Natural hazard.,* Oxford University Press, Melbourne.

Chappell, J. and Thom, B.G. (1986) 'Coastal morphodynamics in north Australia: review and prospect.' *Australian Geography Studies* 24, 110-127.

Chappell, J., Chivas, A., Wallensky, E., Polach, H. and Aharon, P. (1983) 'Holocene palaeo-environmental changes, central to north Great Barrier Reef inner zone.' *Journal of Australian Geology and Geophysics* 8, 223-235.

Chivas, A., Chappell, J., Polach, H., Pillans, B., and Flood, P. (1986) 'Radiocarbon evidence for the timing and rate of island development, beach-rock formation, and phosphatisation at Lady Elliot Island Queensland.' *Marine Geology* 69, 273-287.

Chowdhury, J.U. (1994) *Determination of shelter height in storm surge flood risk area of Bangladesh coast*, unpublished report.

Cline, I.M. (1926) *Tropical cyclones*. MacMillan Company, New York.

Coleman, F. (1971). *Frequencies, tracks and intensities of tropical cyclones in the Australian region - November 1909 to June 1969.* Bureau of Meteorology, Melbourne.

Crouse, C.B. and McGuire, J.W. (1996) 'Site response studies for purpose of revising NEHRP Seismic Provisions'. *Earthquake Spectra* 12(3).

Cuthbertson, R.J. and Jaume, S.C. (1996) 'Earthquake hazard in Queensland', in *Queensland University Advanced Centre for Earthquake Studies (QUAKES) Report 1*, pp. 13-39, The University of Queensland, Brisbane.

Davidson, R. (1997) *An urban earthquake disaster risk index.* John A. Blume Earthquake Engineering Center, Report No. 12, Stanford University, Stanford, California.

Davidson, R. and Shah, H.C. (1998) 'Evaluation and use of the earthquake disaster risk index'. *Understanding urban seismic risk around the world project document.* Stanford University, Stanford, California.

DES (2000) *Local government disaster mitigation project. Mackay – Technical reports, mitigation options, working papers and mapping*, in press. Department of Emergency Services.

DNR (1998) *Teemburra dam, Teemburra Creek AMTD 20.5 km. Dam break analysis,* unpublished, Department of Natural Resources.

Dong, K. (1988) 'El Niño and tropical cyclone frequency in the Australian region and the northwest Pacific.' *Australian Meteorological Magazine* 36, 219-225.

Dowrick, D.J. (1998) 'Earthquake risk for property and people in New Zealand', *NZ National Society for Earthquake Engineering Conference,* Wairakei, Taupo, March 1998.

Dowrick, D.J. (1996) 'The Modified Mercalli Intensity Scale – revisions arising from recent studies of New Zealand earthquakes', *Bulletin of the New Zealand National Society for Earthquake Engineering* 29 (2), 92-106.

Dowrick, D.J., and Rhoades, D.A. (2000) 'Earthquake damage and risk experience and modelling in New Zealand'. *Twelfth World Conference on Earthquake Engineering, Paper 0403,* Auckland, 2000.

Dowrick, D.J., and Rhoades, D.A. (1997) 'Comparative vulnerability of different classes of building in the 1987 Edgecumbe, New Zealand, earthquake'. *New Zealand National Society for Earthquake Engineering Conference.* Wairakei, Taupo, March 1997.

Dowrick, D.J., and Rhoades, D.A. (1990) 'Damage ratios for domestic buildings in the 1987 Edgecumbe earthquake'. *Bulletin of the New Zealand National Society for Earthquake Engineering* 23 (2), 137-149.

Dunn, G. E. and Miller, B. I. (1960) *Atlantic hurricanes.* Louisiana State University Press.

EMA (1993) *Commonwealth counter disaster concepts and principles*. Australian Counter Disaster Handbook, Vol. 1, Emergency Management Australia, Canberra.

EPA (1988) *Seven cardinal rules of risk communication*. Pamphlet, US Environmental Protection Agency, Washington.

Evans, J.L. and Allen, R.J. (1992) 'El Nino/Southern Oscillation modification to the structure of the monsoon and tropical cyclone activity in the Australasian region.' *International Journal of Climatology* 12, 611-623.

Everingham I.B., McEwin A.J. and Denham D. (1982) *Atlas of Isoseismal Maps of Australian Earthquakes.* Bulletin 214, Bureau of Mineral Resources, Canberra.

FEMA (1999) *HAZUS99,* Federal Emergency Management Agency, Washington, D.C.

FEMA (1992) *Learning from Hurricane Hugo: Implications for public policy - an annotated bibliography*. Federal Emergency Management Agency, Washington DC.

Field, E.H., and Jacob, K.H. (1995) A comparison and test of various site response estimation techniques, including three that are not reference site dependent, *Bulletin Seismological Society America* 85 (4), 1127-1143.

Fournier d'Albe, E.M. (1986) 'Introduction: reducing vulnerability to nature's violent forces: cooperation between scientist and citizen.' In Maybury, R.H. (ed.) *Violent Forces of Nature,* pp. 1-6, Lomond Publications, Maryland.

Gaull, B.A., Michael-Leiba M.O. and Rynn J.M.W. (1990) 'Probabilistic earthquake risk maps of Australia'. *Australian Journal of Earth Sciences* 37, 169-187.

Giardini, D., Grunthal, G., Shedlock, K., Zhang, P. (compilers) (1999) *Global Seismic Hazard Map,* produced by the Global Seismic Hazard Program, conducted by the International Lithosphere Program.

Gourlay, M.R. and Hacker, J.L.F. (1986) *Pioneer River estuary sedimentation studies.* Department of Civil Engineering, University of Queensland, St Lucia.

Granger, K.J. (1998) *ASDI from the ground up: A public safety perspective*. Australia New Zealand Land Information Council and AGSO, Canberra.

Granger, K.J. (1997) 'Lifelines and the AGSO Cities Project.' *The Australian Journal of Emergency Management* 12 (1), 16-18, Emergency Management Australia, Canberra.

Granger, K.J (1993) 'Submission by the Australasian urban and regional information systems association inc to the Senate inquiry into major disasters and emergencies' in *Senate Hansard report Friday, 8 October 1993,* pp. 728-759, Standing Committee on Industry, Science, Technology, Transport, Communications and Infrastructure (Reference: Disaster management), Canberra.

Granger, K.J. (1988) *The Rabaul volcanoes: an application of geographical information systems to crisis management.* Unpublished MA Thesis, Australian National University, Canberra.

Granger, K., Jones, T., Leiba, M. and Scott, G. (1999) *Community risk in Cairns: a multi-hazard risk assessment*. Australian Geological Survey Organisation, Canberra.

Gray, W.M. (1979) 'Hurricanes: their formation, structure and likely role in the tropical circulation.' In D. B. Shaw (ed.), *Meteorology over the tropical oceans*. London, Royal Meteorological Society**:** pp. 155-218.

Gray, W.M. (1975) *Tropical cyclone genesis.* Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado.

Gray, W.M. (1968) 'Global view of the origin of tropical disturbances and storms.' *Monthly Weather Review* 96, 669-700.

Harper, B.A. (1999a) *Tropical Cyclone Winds and Storm Tide - Mackay*, Systems Engineering Australia P/L, Brisbane.

Harper, B.A. (1999b) 'Numerical modelling of extreme tropical cyclone winds'. APSWE Special Edition, *Journal of Wind Engineering and Industrial Aerodynamics* 83, pp. 35-47.

Harper, B. (1998) *Storm tide threat in Queensland: history, prediction and relative risks.* Conservation Technical Paper No. 10, Department of Environment and Heritage, Brisbane.

Harper, B. (1985) *Storm tide statistics – Parts 1 to 8.* Report for the Beach Protection Authority, Blain Bremner and Williams Pty Ltd.

Harper, B.A. & Holland, G.J. (1999) 'An updated parametric model of tropical cyclone.' *Proceedings 23rd Conference on Hurricanes and Tropical Meteorology*, American Meteorological Society, Dallas, Texas, USA.

Hayne, M. and Chappell, J. (2000) 'Cyclonic frequency during the last 5000 years at Curacoa Island, north Queensland, Australia*'. Palaeogeography, Palaeoclimatology and Palaeoecology,* in press.

Hayne, M. and Chappell, J. (2000) 'Cyclonic frequency during the last 2500 years at Princess Charlotte Bay, far north Queensland, Australia,' in preparation.

Henderson-Sellers, A., Zhang, H., Bertz, G., Emanuel, K., Gray, W., Landsea, C., Holland, G., Lighthill, J., Shieh, S. L., Webster, P. and McGuffie, K. (1998) 'Tropical cyclones and global climate change: a post-IPCC assessment.' *Bulletin of the American Meteorological Society* 79 (1), 19-38.

Holland, G.J. (1997) 'The maximum potential intensity of tropical cyclones.' *Journal of Atmospheric Sciences* 54(11), 2519-2541.

Holland, G.J. (1981) 'On the quality of the Australian tropical cyclone data base.' *Australian Meteorological Magazine* 29**,** 169-181.

Hoover, R. A. (1957) 'Empirical relationships of the central pressures in hurricanes to the maximum storm surge and storm tide.' *Monthly Weather Review* 85, 167-174.

Hopley, D. (1968) 'Morphology of Curacoa Island spit, north Queensland'. *Australian Journal of Science* 31 (3), 122-123.

Hopley, D. and Harvey, N (1979) 'Regional variations in storm surge characteristics around the Australian coast: a preliminary investigation'. In R. L. Heathcote and B. G. Thom (eds.), *Natural hazards in Australia,* pp. 164-188, Australian Academy of Science**,** Canberra.

Hutton, L.J., Withnall, I.W., Bultitude, R.J., von Gnielinski, F.E., Lam, J.S. (1999a) 'South Connors-Auburn-Gogango Project: Report on Investigations during 1998', *Queensland Government Mining Journal* 100 (1173) 40-50.

Hutton, L.J., Withnall, I.W., Bultitude, R.J., von Gnielinski, F.E., Lam, J.S. (1999b) 'South Connors-Auburn-Gogano Project: Progress Report on Investigations during 1998'. *Queensland Geological Record* 1999/7. Department of Mines and Energy, Queensland.

Hwang H.M., Jun-Rong Huo and Huijie Lin (1997) 'Estimation of ground shaking by census tracts', Chapter 3b in D.P. Abrams and M. Shinozuka (Editors) *Loss assessment for Memphis buildings*, pp 55-70, National Centre for Earthquake Engineering Research Technical Report NCEER-97-0018.

Institution of Engineers (1993) *At what price data?* National Committee on Coastal and Ocean Engineering, Institution of Engineers Australia, Canberra.

Institution of Engineers (1990) *Newcastle earthquake study.* Institution of Engineers Australia, Canberra.

IPCC (1998) *The regional impacts of climate change – an assessment of vulnerability*. A special report of Working Group II, Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0 521-632560-0.

IPCC (1996) *Climate change 1995 – the science of climate change*. Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0 521-56436-0.

Jelenianski, C. P. (1989) *Storm surge and sea-state*. Workshop on tropical cyclones, Geneva.

Jones, O.A. (1959) 'Queensland earthquakes and their relation to structural features'. *Journal & Proceedings of the Royal Society of New South Wales* 92, 176-181.

Jones, T.D., Wesson, V., McCue, K.F., Gibson, G., Bricker, C., Peck, W., and Pascale, A., (1994) 'The Ellalong, New South Wales, earthquake of 6 August 1994', in *Survival of lifelines in earthquakes,* Proceedings of a seminar of the Australian Earthquake Engineering Society, Canberra, 1994, 55-70.

Kepner, C. and Tregoe, B. (1981) *The new rational manager.* Kepner-Tregoe Inc., Princeton, NJ.

Kerr, J.D. (1980) *Pioneer Pagent – a History of Pioneer Shire.* Pioneer Shire Council, Mackay.

Komar, P. D. (1976) *Beach processes and sedimentation*. Prentice-Hall, New Jersey.

Lachet, C., and Bard, P-Y. (1994) Numerical and theoretical investigations on the possibilities and limitations of Nakamura's technique, J*ournal Physical Earth,* 42, 377-397.

Landsea, C.W., Gray, W.M., Mielke, P.W. (Jr) and Berry, K.J (1994) Seasonal forecasting of Atlantic hurricane activity. *Weather,* 49 (8), 273-284.

Lourensz, R. S (1981) *Tropical cyclones in the Australian region July 1909 to June 1980.* Canberra, Australian Government Publishing Service.

Mackay City Council (1999) *Community Information Guide*. Mackay City Council, Mackay.

Mackay City Council (1998a) *Development Manual* Vol. 2 - Engineering, Mackay City Council, Mackay.

Mackay City Council (1998b) *Action Guide for Survival of Natural Disasters – Pioneer River South to Bakers Creek*. Mackay City Council, Mackay.

Mahaney, J.A., Paret, T.F., Kehoe, B.E. and Freeman, S.A. (1993) The Capacity Spectrum Method for Evaluating Structural Response during the Loma Prieta Earthquake. *Proceedings of the 1993 United States National Earthquake Conference,* Memphis, Tennessee. 2, 501-510.

Mahendran, M. (1995) 'Cyclone intensity categories.' In proceedings of a workshop *Atmospheric hazards: process, awareness and response.* University of Queensland, Brisbane.

Marra, F.J. (1998) 'Crisis communication plans: poor predictors of successful crisis management'. In D. King and L. Berry (eds.) *Disaster management: crisis and opportunity*, pp. 296-306, conference proceedings (Cairns 1-4 November), Centre for Disaster Studies, James Cook University, Cairns.

McCue, K.F. (1996) (Compiler), *Atlas of isoseismal maps of Australian earthquake.* Part 3, AGSO Record 1995/44, Australian Geological Survey Organisation, Canberra, 1996.

McInnes, K., Walsh, K. and Pittock, G. (1999) *Impact of sea level rise and storm surges on coastal resorts.* CSIRO Division of Atmospheric Research, Melbourne.

McKay, G.R. (1979) *Development of the Pioneer River – the hydraulic model study*. University of Queensland, Department of Civil Engineering, Report CH21.

McKay, G.R. and Gourlay, M.R. (1962) *Report on Pioneer River model investigation for Pioneer River Improvement Trust.* Department of Civil Engineering, University of Queensland, Brisbane.

Meyer, P. (1997) *Tropical cyclones.* Swiss Reinsurance Co, Zurich.

Morrow, B.H. (1999) 'Identifying and mapping community vulnerability.' *Disasters*, 23 (1), 1-18, Overseas Development Institute, Oxford.

Mullins, P., Rossitier, J. and Mollee, F. (1998) 'Shelter buildings – cyclone'. In D. King and L. Berry (eds.) *Disaster management: crisis and opportunity*, conference proceedings (Cairns 1-4 November), Centre for Disaster Studies, James Cook University, Cairns.

Murty, T.S and Flather, R.A. (1994) 'Impact of storm surges in the Bay of Bengal,' in preparation.

Nakamura. Y. (2000) 'Clear identification of fundamental idea of Nakamura's technique and its applications'. *Twelfth World Conference on Earthquake Engineering, Paper 265.* Auckland, 2000.

Nakamura. Y. (1989) 'A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface'. *Quarterly Review of Railway Tech. Res. Inst.,* 30 (1): 25-32.

National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meterological Laboratory, Hurricane Research Division. (1999), web site.

Newmark, N.M. and Hall, W.J. (1982) *Earthquake Spectra and Design,* Earthquake Engineering Research Institute, Oakland, California.

Nicholls, N. (1992) 'Historical El Nino / Southern Oscillation variability in the Australian region.' In Diaz, H.F. and Margraf, V. (eds.), *El Nino, historical and paleoclimate aspects of the Southern Oscillation,* Cambridge University Press, Cambridge, UK, pp. 151-174.

Nicholls, N. (1979) 'A possible method for predicting seasonal tropical cyclone activity in the Australian region.' *Monthly Weather Review,* 107**,** 1221-1224.

Nickerson, J.M. (1971) 'Storm surge forecasting'. *NAVYWEARSCHFAC,* Technical Report, pp. 10-71.

Palmen, E. (1948) 'On the formation and structure of tropical hurricanes.' *Geophysica*, 3, 26-38.

Parkinson, C.E., Fison, E.C., Leach, R.A. and Wilmoth, G.R. (1950) *Flooding in the Pioneer River and its effect on the Mackay city area.* Report of a Committee of Enquiry to the Coordinator General of Public Works, Brisbane.

Pielke, R.A. (Jr) and Landsea, C.W. (1999) 'La Niña, El Niño, and Atlantic hurricane damages in the United States.' *Bulletin of American Meteorological Society* 80, 2027-2033.

Pilgrim, D.H. (1993) *Barron River design flood for development at Kamerunga.* Unpublished report to Mulgrave Shire Council, D.H. Pilgrim & Associates, Kyle Bay, NSW.

Power, S., Casey, T., Folland, C., Colman, A. and Mehta, V. (1999) 'Inter-decadal modulation of the impact of ENSO on Australia'. *Climate Dynamics,* 15, 319-324.

Qin Z. and Duan Y. (1992) 'Climatological study of the main meteorological and marine disasters in Shanghai.' *Natural Hazards,* 6, 161-179.

Queensland Transport (1997) *The Official Tide Tables and Boating Safety Guide 1998.* Queensland Department of Transport, Brisbane.

Reardon, G., Henderson, D. and Ginger, J. (1999) *A structural assessment of the effects of Cyclone Vance on houses in Exmouth EA Technical Report No 48,* Cyclone Structural Testing Station, School of Engineering, James Cook University, Townsville.

Rhodes, E. (1980) *Modes of Holocene coastal progradation, Gulf of Carpentaria.* Unpublished PhD thesis, Department of Biogeography and Geomorphology, Australian National University, Canberra.

Riehl, H. (1979) *Climate and weather in the Tropics.* Academic Press Inc, London.

Ryan, C.J. (1993) 'Costs and benefits of tropical cyclones, severe thunderstorms and bushfires in Australia.' *Climatic Change* 25, 252-267.

Rynn, J.M.W. (1987) *Queensland Seismic Risk Study*, Final Report to the State Government of Queensland, Queensland Department of Mines, Brisbane.

Rynn, J.M.W., Denham, D., Greenhalgh, S., Jones, T., Gregson, P.J., McCue, K. and Smith, R.S (1987) *Atlas of Isoseismal Maps of Australian Earthquakes*, Bulletin 222, Bureau of Mineral Resources, Canberra.

Salter, J (1997) 'Risk management in the emergency management context.' *Australian Journal of Emergency Management*. 12 (4), 22-28, Emergency Management Australia, Canberra.

SCDO (1994). *Storm tide warning-response system.* Jointly issued by the State Counter Disaster Organisation and the Bureau of Meteorology (Qld), November.

Senate (1994) *Disaster management*. Senate Standing Committee on Industry, Science, Technology, Transport, Communications and Infrastructure, Canberra.

Simpson, R.H. and Riehl, H. (1981) *The hurricane and its impact*. Blackwell, Oxford.

Smart, J. (1976) 'The nature and origin of beach ridges, western Cape York Peninsula, Queensland.' *Journal of Australian Geology and Geophysics*, pp. 211-218.

Smith, D.I. (1998) *Urban flooding in Queensland – a review.* Queensland Department of Natural Resources, Brisbane.

Smith, D.I. (1990) 'The worthwhileness of dam failure mitigation: an Australian example.' *Applied Geography,* 10, 5-19.

Smith, D.I and Greenaway, M.A. (1994) *Tropical storm surge, damage assessment and emergency planning: a pilot study for Mackay, Queensland.* Resource and Environmental Studies No. 8, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Somerville, M., McCue, K.F. and Sinadinovski, C. (1998) 'Response spectra recommended for Australia'. *Proceedings*, *Australasian Structural Engineering Conference.* Auckland, pp 439-494.

Sparkes, P.R. & Bhinderwala, S.A (1993) 'Relationship between residential insurance losses and wind conditions in Hurricane Andrew.' *Conference on Hurricanes of 1992*, ASCE, Miami.

Standards Australia (1999) *Australia New Zealand Standard AS/NZS 4360:1999 Risk management.* Standards Australia, Homebush, and Standards New Zealand, Wellington.

Standards Australia (1998) *Strengthening existing buildings for earthquake (AS3826-1998),* Homebush, NSW.

Standards Australia (1993) *Minimum design loads on structures part 4: earthquake loads AS 1170.4-1993.* Standards Australia, Homebush.

Standards Australia (1989) *SAA Loading Code Part 2: Wind loads AS 1170.2-1989.* Standards Australia, Homebush.

Standards Australia & ICA (1999a) *SAA HB132.1 Structural upgrading of older houses part 1: non-cyclone areas.* Standards Australia and Insurance Council of Australia, Sydney.

Standards Australia & ICA (1999b) *SAA HB132.2 Structural upgrading of older houses part 2: cyclone areas*. Standards Australia and Insurance Council of Australia, Sydney.

Ullman and Nolan (1973) *A plan of development for the Pioneer river and tributaries*. Report to Joint Committee of Pioneer and Upper Pioneer River Improvement Trusts.

Von Gnielinski, F. *Geology of Mackay Study Area,* 1:100 000 scale map (unpublished)

Wakimoto, W. and Black, P.G. (1994) 'Damage survey of Hurricane Andrew and its relationship to the eyewall'. *Bulletin of the American Meteorological Society*, 75 (2) 189-200.

Walker, G.R (1994) CSIRO Division of Building, Construction and Engineering, personal communication to Dr B.A. Harper cited in Harper (1999).

WMO (1997) *Tropical cyclone operational plan for the South Pacific and south-east Indian Ocean*. World Meteorological Organisation TD-No. 292, Tropical Cyclone Programme Report No. TCP-24, Geneva.

WMO (1995) *Global perspectives on tropical cyclones*. World Meteorological Organisation TD-No. 693, Tropical Cyclone Programme Report No. TCP-38, Geneva.

Zamecka, A. and Buchanan, G. (1999) *Disaster Risk Management*. Department of Emergency Services, Brisbane.

Zammit, R. (1995) *Seismic hazard of City of Mackay,* Honours Project, Department of Applied Physics, Central Queensland University, Mackay campus.

Zerger, A.Z. (1998) *Cyclone inundation risk mapping*. Unpublished PhD Thesis, Centre for Resource and Environmental Studies, Australian National University, Canberra.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
AEMI	Australian Emergency Management Institute
AEP	annual exceedence probability
AFLD	air field
AGSO	Australian Geological Survey Organisation
AHD	Australian height datum
ANU	Australian National University
ARI	average recurrence interval
ASDI	Australian spatial data infrastructure
AWS	automatic weather stations
B.P.	before present
BPA	Beach Protection Authority
C	Celsius
CBD	central business district
CCD	census collection district
Comms	telecommunications
CQU	Central Queensland University
cumec	cubic metres per second
DDC	disaster district coordinator
DEM	digital elevation model
DES	(Queensland) Department of Emergency Services
DME	(Queensland) Department of Mines and Energy
DNR	(Queensland) Department of Natural Resources
EDRI	earthquake disaster risk index
e.g.	for example
EMA	Emergency Management Australia
ENSO	El Niño / Southern Oscillation
EPA	Environmental Protection Agency
FEMA	(US) Federal Emergency Management Agency
ft	feet
FWC	flood warning centre
GH	gauge height
GIS	geographic information system
GMS	global meteorological satellite
ha	hectares
HAT	highest astronomical tide
hPa	hecto-pascals
HQ	headquarters
hr(s)	hour(s)
IDNDR	International Decade for Natural Disaster Reduction
in	inches
IPA	Integrated Planning Act
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
km	kilometres
km/h	kilometres per hour
LAT	lowest astronomical tide
LDC	local disaster committee
LPG	liquid petroleum gas
m	metres
max	maximum
MDR	mean damage ratio
min	minimum
mm	millimetres
MPI	maximum potential intensity

m/sec	metres per second
MEOW	maximum envelope of water
NOAA	(US) National Oceanographic and Atmospheric Administration
PGA	peak horizontal ground acceleration
QPS	Queensland police service
RACQ	Royal Automobile Club of Queensland
SCAG	South Connors-Auburn-Gogano Project
SCDO	State Counter Disaster Organisation
SEIFA	socio-economic indexes for areas
SES	State Emergency Service
SLA	statistical local area
SOI	Southern Oscillation Index
SST	sea surface temperature
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
UPS	uninteruptable power supply
VHF	very high frequency
WMO	World Meteorological Organisation

APPENDIX B: MACKAY *BUILDING* DATABASE FORMAT

The following list provides details of the table structure employed for the *BUILDING* database.

UFI	Integer	
Feature	Character	35
Address	Character	35
Suburb	Character	25
Type	Character	2
Fl_ht	Decimal	3,1
Gd_ht	Decimal	6,2
Storeys	Decimal	2,0
Walls	Character	2
Roof	Character	2
Ro_shape	Character	2
Ro_pitch	Character	2
Windows	Character	2
Plan_reg	Character	2
Vert_reg	Character	2
Age	Character	2
Units1	Decimal	2,0
Units2	Decimal	2,0
Units3	Decimal	3,0
Status	Character	2
Comments	Character	35
Lot_plan	Character	15
Longitude	Decimal	9,4
Latitude	Decimal	9,4
Std50	Character	2
Std100	Character	2
Std500	Character	2
Std1000	Character	2
Std10000	Character	2
V_zone	Decimal	4,2
Site_class	Character	2

NOTE: in the following description, attributes in **bold** need to be collected in the field; attributes *underlined* and in italics are typically derived from council data but need to be verified in the field; attributes in plain text are derived from other sources.

A brief explanation of the thresholds adopted is also provided where appropriate.

The first group of fields provide for unique identification and description of the feature.

UFI Unique Feature Identifier - unique number for each record. Computer generated.

Feature Name of the feature or its occupant or use as indicated by signs on or at the feature.

Address Street address of the feature including number and street name.

Suburb Suburb, town or locality name.

Type Major activity conducted at feature as identified from field observation. The following broad activity groups have been used and features displayed with the symbols indicated in the following table:

Table B1: Classification of feature use for Mackay

CODE	CLASSIFICATION	SYMBOL	COMMENTS
P	**P**ublic safety - police, fire, ambulance, SES, defence, etc.	12pt solid cross, black	*Sensitive facilities* related to the provision of emergency response
S	**S**torage and transport - features that support road, rail, air and sea transport and storage (eg warehouses)	12pt solid dot, orange	*Sensitive facilities* that contribute significantly to community sustainability
L	**L**ogistics - bulk supplies of fuel, gas & food including supermarkets and service stations	12pt solid dot, yellow; 18pt solid dot yellow is used for major complexes	*Sensitive facilities* that contribute significantly to community sustainability
D	**D**octors and other health services - hospitals, nursing homes, clinics, dentists, etc.	12pt solid cross, green	*Sensitive facilities* that provide all forms of health service
U	power **U**tilities - generation, distribution and service facilities	12pt solid star, black	*Sensitive facilities* that provide, manage, or service power supplies
W	**W**ater supply and sewerage utilities - above ground storage, treatment, pumping, etc.	12pt solid dot, light blue	*Sensitive facilities* that store, treat, or reticulate water and sewerage services, or manage and service those utilities
T	**T**elecommunications - radio, telephone, TV, etc.	12pt asterisk, black	*Sensitive facilities* that provide, manage, or service communications services
A	**A**ccommodation - commercial (non private) accommodation such as hotels, motels & resorts	10pt solid square, red	*Special risks* associated with commercial accommodation where concentrations of people are found - typically short term accommodation
B	**B**usiness - commercial and professional facilities such as shops, offices, etc.	10pt solid square, yellow	*Special risks* associated with shopping centres and other places of business
E	**E**ducation - schools, TAFE, convents, child care centres, etc.	12pt 'flagged building', red	*Special risks* associated with concentrations of children
R	**R**ecreation facility - sporting clubs, grandstands, etc.	10pt solid square, green	*Special risks* associated with periodic concentrations of people
I	**I**ndustry - manufacturing and processing industries such as sawmills, sugar mills, cement plants, ship building, etc.	12pt solid triangle, yellow	*Special risks* associated with either processes and materials used and/or concentrations of people
H	**H**ouses - private, detached houses only	9pt solid diamond, black	Detached houses only

F	**F**lats - includes all multi-occupant private dwellings including units, town houses and apartments	9pt solid diamond, red	All forms of private accommodation other than detached houses - includes self contained holiday units, or apartments typically used for longer stays than motels, resorts, etc.
C	**C**ommunity facilities - churches, halls, public toilets, libraries, scout huts, monuments, etc.	12pt solid dot, purple	Mainly non-government facilities providing direct service to the community
G	**G**overnment facilities - offices, depots, etc. of all levels of government	12pt solid dot, dark blue	Facilities from which government services are provided or administered
Z	Miscellaneous features – eg. sheds, car parking structures, etc.	10pt open square, black	Generally minor or low use features
O	**O**pen space - features such as parks, reserves, etc.	10pt open green square	Land without buildings used for parks, reserves, etc.
V	**V**acant land	9pt solid circle, pale green	Used only for land that is intended for buildings.

The next group of attributes describe aspects of the building that contribute to its vulnerability to a range of hazards.

Fl_ht Height of the floor above ground level. Estimated to the nearest 10 cm. A value of 0.3 indicates a slab construction. A default value of 0.3 is also used where field observed data are not available

Gd_ht Height of the ground (above the Australian Height Datum - AHD) at the centre of the feature. Derived from DEM.

Storeys The number of storeys above ground.

Walls Construction material used for the walls of a feature. The following codes are used:

B brick, masonry or stone
C concrete block
P precast concrete slab
R reinforced concrete frame
T timber
F fibro
M metal

Roof Construction material used for the roof. The following codes are used:

T tiles
F fibro
M metal
C concrete

Ro_shape Predominant roof shape with the following codes:

H hip ended
G gable ended

Flat roofs are automatically gable ended.

Ro_pitch Roof pitch with the following codes:

H	high (>1:4 slope)
L	low (< 1:4 slope)
F	Flat

Tiled roofs are automatically high pitch. The thresholds were recommended by Mr Greg Reardon of the James Cook University Cyclone Testing Station to differentiate slopes that will have greater (low slope) or lesser (high slope) 'lift' from strong winds.

Windows The relative size of individual windows with the following codes:

L	large windows or glass doors (i.e. greater than 75% of wall height occupied by glass in a given window or door)
S	small windows
N	no windows
O	open walls

Plan_reg Plan regularity - an observation of the plan configuration geometry regularity of the building based on Figure A1 of AS1170.4-1993 (Earthquake loads) with the

following codes:

R	regular (essentially square or rectangular)
I	irregular ('T', 'L', 'U' or other irregular shape)
U	unknown, not observed

If collateral evidence exists of plan irregularity other than geometric (eg. mass resistance eccentricity or discontinuity of diaphragm stiffness) then the appropriate code should be used with details placed in the *Comments* field.

Vert_reg regularity Vertical regularity - an observation of the vertical configuration geometry

and stiffness ratio (e.g 'soft storey' construction) based on Figure A2 of AS1170.4-1993 (*Earthquake loads*) with the following codes:

R	regular
I	irregular
U	unknown, not observed

'Queenslander' style houses or 'six pack' blocks of flats in which the main mass of the building is elevated on posts or piles and the open under-space occupied by garages etc. should be coded as *Irregular*. If collateral evidence exists of other forms of vertical irregularity (e.g. in mass ratio irregularity caused by a roof-top swimming pool) then the appropriate code should be used with details placed in the *Comments* field.

Age Estimated date of construction with the following codes:

A	built since 1995
B	built between 1985 and 1994
C	built between 1975 and 1984
D	built between 1965 and 1974
E	built between 1955 and 1964

F built before 1955

Note: most buildings coded 'C' are simply those built before 1985

In general terms these dates reflect significant changes in building regulations and/or practice (e.g. first wind loading code introduced in 1975, upgraded in 1984-85; earthquake loading code for domestic structures effective by 1995; brick veneer construction techniques became popular after 1955).

The following fields describe the number of dwelling units contained in multi-resident features such as flats, apartments and units, or businesses in commercial complexes.

Units1 The number of separate occupiable dwelling units (discrete flats, apartments, town houses, motel/motel suites, etc.) with the lowest dwelling space (not including laundries, garage, etc.) located on the ground floor (level 1). Estimated to be at least 95% accurate where recorded. Typically based on a count of letterboxes; some data for commercial accommodation taken from material provided by the operator of the feature or from the RACQ accommodation guide.

Units2 The number of separate occupiable dwelling units with the lowest dwelling space located on the second level. Other parameters as for *U1*.

Units3 The number of separate occupiable dwelling units with the lowest dwelling space located on the third or higher levels. Other parameters as for *U1*.

The following fields provide for additional data and for an assessment of the general data quality.

Status An indication of the source of the detailed data with the following codes:

O observed - field collected
E estimated - based on sample or cursory observation
P interpreted from aerial photos
D data taken from the work of 'Dingle' Smith in 1993
U unknown - yet to be collected

Comments Note field for added information on the feature derived from field notes.

The following fields provide linkage to other databases such as rates or the DCDB.

Lot_plan The lot-on-plan description of the parcel of land on which the feature object is located. Derived by computer from the DCDB and/or council data.

Longitude Decimal longitude derived by computer from the feature object location using AGD84 as the datum.

Latitude Decimal latitude derived by computer from the feature object location using AGD84 as the datum.

The following fields provide information related to hazard exposure. They have been derived from other data including the DEM and floor height.

Std50 Exposure of building to a 2% AEP storm tide where:

A more than 1 m over floor level
B water over floor level but less than 1 m
C water on property but not over floor level

Std100	Exposure of building to 1% AEP storm tide with coding as for *Std50*
Std500	Exposure of building to 0.2% AEP storm tide with coding as for *Std50*
Std1000	Exposure of building to 0.1% AEP storm tide with coding as for *Std50*
Std10000	Exposure of building to 0.01% AEP storm tide with coding as for *Std50*
V zone	Distances from the shoreline in 150 m increments. Values are 0.8 = 0 to 150 m, 0.4 = 150 to 300 m; and, 0.2 = 300 to 450 m.

APPENDIX C: ELEMENTS AT RISK DETAILS

Table C1: Variables used in the SEIFA *Index of Socio-Economic Disadvantage* (ABS, 1998b)

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 (%); and,
- 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 (%); and,
- lacking fluency in English (%).

Table C2: Variables used in the SEIFA *Index of Economic Resources* (ABS, 1998b)

Variables with weights between 0.2 and 0.4:

- households owning or purchasing dwelling (%);
- dwellings with four 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 $1300 per month (%); and,
- rent greater than $249 per week (%).

Variables with weights between 0 and 0.2:

- households purchasing dwelling (%);
- households owning dwellings (%);
- dwellings with three or more motor cars (%); and,
- 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 one or no bedrooms (%);
- rent less than $74 per week (%); and,
- 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 (%); and,
- dwellings with no motor cars (%).

Table C3: Mackay Schools

SCHOOL	ADDRESS	LOCALITY	STUDENT NUMBERS			STAFF NUMBERS
			PRE[1]	PRI[2]	SEC[3]	
Andergrove State	Fernleigh Avenue	Andergrove	94	674		38
Beaconsfield State	Nadina Street	Beaconsfield				
Bucasia State Primary	Kemp Street	Bucasia	27	238		14
Dundula State	Main Street	Bakers Creek	36	107		5
Eimeo Road Primary	Eimeo Road	Rural View	30	278		13
Fitzgerald State	Norris Road	North Mackay	82	640		33
Glenella Primary	Hill End Road	Glenella	48	141		6
Holy Spirit College	Baxter Drive	Mt Pleasant				
Kewarra Special	Mansfield Drive	Beaconsfield		25		6
MacKillop Catholic	Nadarmi Drive	Andergrove				
Mackay Central State	Alfred Street	Cent Mackay	41	220		12
Mackay Christian College	Quarry Street	North Mackay				
Mackay North State High	Burgess Street	North Mackay			1131	77
Mackay North State Primary	Evens Avenue	North Mackay		365		26
Mackay 7th Day Adventist	Milton Street	Cent Mackay				
Mackay Special	Goldsmith Street	East Mackay				4
Mackay State High	Milton Street	South Mackay			932	69
Mackay West Primary	Brooks Street	West Mackay	86	713		42
Northview Primary	Pioneer Street	Mt Pleasant	41	309		19
OLMC High	Penn Street	South Mackay				
OLMC Primary	Penn Street	South Mackay				
Pioneer State High	Bedford Street	Andergrove			705	56
St Francis Xavior Primary	Bridge Road	West Mackay				
St Josephs Primary	Canberra Street	North Mackay				
St Patrick's College	Gregory Street	Cent Mackay				
Slade Point Primary	Slade Point Road	Slade Point	50	358		19
Victoria Park State	Goldsmith Street	East Mackay	116	573		31
Victoria Park Special	Shakespeare Street	Cent Mackay				
Whitsunday Anglican	Celeber Drive	Andergrove				

Where 1 = preschool, 2 = primary school, and 3 = secondary school.

NOTE: The enrolment and teacher statistics for state schools were derived from Department of Education data for 1996. No comparable data are available for non-government schools. State preschools are typically (but not exclusively) co-located with their respective primary school.

Table C4: Mackay Child Care Centres

CENTRE	ADDRESS	SUBURB
Beach Kidz Ch ild Care & Education Centre	Eimeo Road	Eimeo
Billabong Kindyland	Hamilton Street	North Mackay
Billabong Kindytown	Shakespeare Street	East Mackay
Birralee Child Care Centre	Pompey Street	South Mackay
Bucasia Kindergarten Association	Fisher Street	Bucasia
Busy Kids Childrens Education Centre	Celeber Drive	Andergrove
Hot Tots Education Centre	Paget Street	West Mackay
Kookaburra Child Care	Bedford Road	Andergrove
Koolyangarra Childcare Centre	River Street	Central Mackay
Mackay Child Care Centre	River Street	Central Mackay
Mackay Cubbie House Childcare	Beaconsfield Road	Beaconsfield
Mackay Family Day Care	Wellington Street	Central Mackay
Mackay Kindergarten	Shakespeare Street	West Mackay
Pioneer Pre School	High Street	North Mackay
St Francis Xavior Day Care Centre	Holland Street	West Mackay
Snugglepot Kindeland	Grendon Street	North Mackay
YMCA Playmates Childcare Centre	Macalister Street	Central Mackay

Table C5: 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’ (%); and,
- persons aged 15 and over at a college of advanced education 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’ (%); and,
- 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’ (%); and,
- 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 (%); and,
- person aged 15 years and over with no qualifications (%).

Table C6: Mackay Community Organisations

SPORTS AND HOBBIES REPRESENTED	SERVICES REPRESENTED
Archery	Aboriginal and Torres Strait communities
Athletics	Aged care services
Baseball	Apex
Basketball	Boy Scouts and Girl Guides
Bicycle racing	Chamber of Commerce and Industry
Bird fanciers	Conservation and environmental groups
Bowling	Country Women's Association
Boxing	Drug and alcohol support groups
Bridge	Eisteddfod
Bush walking	Endeavour Foundation
Cars and motor racing	Genealogical groups
Chess	Guide dogs for the blind
Cricket	Historical Society
Croquet	Hospital auxiliaries
Dance	Independent retirees
Dog coursing and kennel	Jaycees International
Fishing	Legacy
Flying and gliding	Lifeline
Football (all codes)	Lions International
Gem and lapidary	Marriage guidance
Golf	Masonic and other lodges
Gymnastics	Meals on wheels
Hockey	Neighbourhood and community associations
Lawn Bowls	Paraplegic and quadriplegic association
Life saving and surfing	Police and Citizens Youth Club
Martial arts	Probus
Netball	Professional and business groups
Photography	Queensland keep fit
Pottery	Quota
Racing, hunting and pony	Red Cross
Roller skating and roller hockey	Returned Services League
Scuba diving	Rotary
Shooting	Rotaract
Softball	RSPCA
Squash	St Johns Ambulance
Swimming	SES
Table tennis	Sexual assault service
Tennis	Soroptimists International
Tenpin bowling	South Sea Islanders Association
Vigaro	Toastmasters
Volleyball	U3A
Wheelies and disabled sport	Women's Information and Referral
Wood turning	YMCA
Yachting and boating	YWCA
Yoga	Zonta International

Table C7: **Mackay Critical Facilities**

FACILITY	STREET	SUBURB	HAZARDOUS
ABC Studios	River Street	Central Mackay	
ABC Radio Transmitters (4QA)	Slade Point Road	Mackay Harbour	
Airport runways	Milton Street	South Mackay	
Airport Control Tower	Milton Street	South Mackay	
Airport Rescue and Fire Service	Milton Street	South Mackay	
Alcorn's Bakery	Bedford Street	Andergrove	
Ambulance Station Mackay	Alfred Street	Central Mackay	
Ambulance Station Mt Pleasant	Lauchlan Street	Mount Pleasant	
Ampol Fuel Depot	Harbour Road	Mackay Harbour	major
Boral Gas Depot	Harbour Road	Mackay Harbour	major
BP Fuel Depot	Graeme Heggie Road	Mackay Harbour	major
Campbells Cash & Carry	Victoria Street	Central Mackay	yes
Canelands Shopping Town	Mangrove Road	Central Mackay	yes
Caltex Fuel Depot	Harbour Road	Mackay Harbour	major
Country Bake Bakery	Bridge Road	West Mackay	
CSR Bulk Sugar Terminal	George Bell Drive	Mackay Harbour	yes
District Police HQ Mackay	Sydney Street	Central Mackay	
Fire Station Mackay	Alfred Street	Central Mackay	
Fire Station North Mackay	Harbour Road	North Mackay	
Fire Station Northern Beaches	McHugh Street	Bucasia	
Grain Silos	George Bell Drive	Mackay Harbour	yes
INCITEC	Harbour Road	Mackay Harbour	major
James Borthwick & Sons	Connors Road	Bakers Creek	yes
Mackay Base Hospital	Bridge Street	West Mackay	yes
Mackay City Council Centre	Gordon Street	Central Mackay	
Mackay City Council Works Depot	Bedford Road	Andergrove	major
Mackay Port Facilities	Harbour Road	Mackay Harbour	yes
Mackay Railway Yards	Boundary Road	Paget	yes
Mackay SES District HQ	River Street	Central Mackay	
Mackay SES Local HQ	Cemetery Road	West Mackay	
Mata Hospital	Gordon Street	Central Mackay	yes
Mobil Fuel Depot	Graeme Heggie Road	Mackay Harbour	major
Mount Bassett Weather Station	Mount Bassett Drive	Mackay Harbour	minor
Mount Pleasant Shopping Centre	Philip Street	Mount Pleasant	yes
Northern Food Wholesalers	Heidi Street	Paget	yes
Pauls Ltd	Evans Avenue	North Mackay	yes
Pioneer Valley Hospital	Raymond Crocker Av	Mount Pleasant	yes
Police Station Mackay	Brisbane Street	Central Mackay	
Racecourse Mill	Peak Downs Highway	Racecourse	yes
Radio 4CRM Studio	Victoria Street	Central Mackay	
Radio 4MK Studio	Sydney Street	Central Mackay	
Radio 4MK Transmitter	Mt Bassett Cemetery Rd	Mackay Harbour	
Seafresh Products	River Street	Central Mackay	yes
Searaker	River Street	Central Mackay	yes
Sewerage Treatment Plant	Mt Bassett Cemetery Rd	Mackay Harbour	yes
Shell Fuel Depot	Harbour Road	Mackay Harbour	major
Telephone Exchange Mackay	River Street	Central Mackay	yes
Telephone Exchange Paget	Bruce Highway	Paget	minor
TEN TV Studio	Wellington Street	Central Mackay	
Water Treatment Plant	Nebo Road	West Mackay	yes
WIN TV Studio	Gregory Street	Central Mackay	

Notes:

major = nature and quantity of hazardous materials poses a major potential threat
yes = nature and quantity of hazardous materials poses a moderate threat
minor = nature and quantity of hazardous materials poses a minor threat

APPENDIX D: METHODOLOGY FOR ASSESSING RELATIVE COMMUNITY VULNERABILITY

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 described individual aspects of the community and the contribution they make to community vulnerability. We also presented an assessment of their relative contribution to the overall community vulnerability of Mackay. In this Appendix we describe the methodology we have developed to produce that relative assessment and the philosophy that underpins it.

The Challenge

Over the past four or five years a large amount of high resolution data has been accumulated on the hazard phenomena, buildings, infrastructure and the people of Mackay. Whilst those data provide a detailed quantitative description of specific aspects of the city'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 city. We considered it to be highly desirable, however, to be able to identify those parts of the city 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 suburbs 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 is being used 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 rely on 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 posed by 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 multi-variate statistical techniques in that it was undertaken using MapInfo and Microsoft Excel rather than specialised statistical analysis software. This computationally less demanding approach was felt to be important given that it is intended for use by local governments and others responsible for undertaking risk assessments at the local level.

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 the 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 Mackay, however, we have adopted a different strategy, namely constructing the analysis at the level of the CCDs used in the 1996 national census. These units typically contain approximately 200 households. We have chosen this approach for two reasons. First, the suburb boundaries for Mackay do not match with CCD boundaries so it was difficult to translate the census-derived statistics to the suburban level. Second, we wished to test and demonstrate the utility of using a much higher resolution of risk assessment than provided by the suburban-level approach. In the Mackay study area there are 27 suburbs and 96 CCDs.

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.

We have not, as yet, conducted a systematic sensitivity analysis, though our observations during the development of the techniques with the Cairns study, and subsequently with this Mackay study, suggest that whilst relatively minor changes to the inclusion of variables may cause some variation to individual ranks, the overall results remain largely consistent. A detailed sensitivity analysis and comparison of the Cairns and Mackay methods has been commissioned as part of our ongoing methodology development process.

The Setting

Given that the variables within the 'setting' group of elements at risk (see Chapter 1 and Chapter 2) relate 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. the key power substations and the fuel depots), export of goods from the study area (e.g. the bulk sugar and grain terminals) and bi-directional facilities (e.g. the airfield and rail-freight terminal). The facilities identified as terminals are listed in Table 2.3. In determining suburb ranks, those facilities that have both an import and export function (e.g. the airport) were weighted by a value of two, whilst those with either import (e.g. fuel depot) or export functions (e.g. sugar terminal) were given a weighting only of one.

Population: Clearly the most significant element at risk is the population of the community. CCDs were ranked on the basis of their total population. The absolute population totals ranged from a high of 1560, to a low of 90 and a mean of 613 persons. CCDs were ranked from highest value to lowest value.

Population density: To balance the absolute population figures, which are sensitive to CCD boundary design, we have also included population density taken as the number of people per square kilometre. This is sensitive to CCD area (a function of boundary design). The density ranges from a high (rank 1) of 3280, to a low (rank 96) of nine, with a mean of 1244.

Masculinity: 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 to be sensitive to identifying institutions such as nursing homes and boarding schools where highly skewed gender ratios can be expected. The values range from 76 males per hundred females to 156 males per hundred females with a mean of 99.7. 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 variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.20 and listed in Table 3.9.

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 Mackay *BUILDING* database (Appendix B), that were within their boundary. This source was chosen over the house totals contained in the 1996 census data provided in ABS (1998a) because it was considered to be more current by three years. The totals ranged from a high of 507 (rank 1) to a low of one (rank 96), with a mean of 185.

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. Values ranged from 3.55 people down to 2.31 persons, with a mean of 2.88. CCDs were ranked from highest value to lowest value.

Flats: Flats are the second most significant form of shelter. The total number of multi-occupant buildings classified as flats in the Mackay *BUILDING* database contained in each CCD was used rather than the number of flats and other similar forms of accommodation contained in the census data. The census data provides tallies of the number of individual dwelling units rather than buildings, so for consistency and currency the building data was used in preference. Totals ranged from 60 (rank 1) to 0 (rank 85), with a mean of 9. CCDs were ranked from highest value to lowest value.

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 rather than the occupancy of buildings. For the CCDs with flats, values ranged from an average of 3.43 persons per flat (rank 1) to a low of 1.0 person per flat (rank 76). CCDs were ranked from highest value to lowest value.

Residential ratio: The proportion of buildings used for residential purposes to the total number of buildings provides a measure of relative residential land use. Residential buildings were taken to include houses, flats and commercial accommodation (hotels, motels, resorts and caravan parks). Ratios ranged from 99.99% residential to 2.25% residential with a mean of 89.55%. CCDs were again ranked from highest value to lowest value.

Road network density: The road network provides the means for people to move to and from shelter, with the denser the network, the greater the urban mobility. Nodes (i.e road intersections) were extracted from the road network data used in the GIS and the ratio of nodes to road length total number in each CCD was tallied to give a measure of network density. This was chosen as a better measure of network density over road length alone because the ranking of the larger, rural CCDs can be high because of the longer lengths of road involved. Values ranged from a high of 9.7 nodes/km (rank 1) to a low of 1.0 nodes/km (rank 96), with a mean of 5.4 nodes/km.

Cars: Private cars are clearly the most important form of transport (and thus mobility) within Mackay. CCDs were ranked on the estimated number of cars to which households had access. This figure was derived from the figures 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. Values ranged from 809 to 51 with a mean of 311.8. CCDs were ranked from highest value to lowest value.

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. Values ranged from 39.56% of households (rank 1) to zero car-less households (rank 95). The mean for all CCDs was 11.0%.

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.21 and listed in Table 3.10.

Sustenance

Three variables were used to represent 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 buildings classified as having a logistic or transport and storage function within the Mackay *BUILDING* database were tallied for each CCD. Some 52 CCDs had no such facilities whilst the greatest number was 70. CCDs were ranked from highest value to lowest value.

Lifeline facilities: The proportion of above-ground facilities supporting both power and water supply, such as power sub-stations and water reservoirs, and telecommunications, such as telephone exchanges and broadcast studios, contained in the Mackay *BUILDING* database, have been used to rank CCDs for this utility lifeline variable. Only 21 CCDs contain such facilities, with the greatest number being six in the one CCD. Again, CCDs were ranked from highest value to lowest value.

Lifeline length: Ideally we would have liked to be able to include the lengths of power supply reticulation and water reticulation infrastructure, however, such data were not available for Mackay. As a surrogate we have used the length of road in each CCD. We feel that this is a reasonable surrogate because lifelines such as water supply, sewerage, power supply and telephone cabling are closely related spatially to the road network. The values range from a high of 51.27 km (rank 1) to a low of 1.03 km (rank 96), with a mean of 6.63 km.

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.22 and listed in Table 3.11.

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 SEIFA *Socio-Economic Indexes for Areas* produced by the ABS 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 and SES 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 buildings in the Mackay *BUILDING* database located in each CCD was used. Only 24 CCDs contained safety facilities, with the greatest number being 24. CCDs were ranked from highest value to lowest value.

Business premises: These facilities make a significant contribution to the overall economy and employment situation, as well as facilitating the distribution of goods and services. Again, the tally of buildings classified as having a business or industrial function, in the Mackay BUILDING database, contained in each CCD was used. In all, 69 CCDs contained such buildings, with the greatest number being 140. Again, CCDs were ranked from highest value to lowest value.

Relative Socio-Economic Disadvantage: The SEIFA *Index of Socio-Economic Disadvantage* (ABS, 1998b) 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.

For Mackay, the socio-economic disadvantage index ranges from a low of 702.39, three standard deviations below the national mean, whilst the highest index is 1078.34. The study area mean is 967.70. CCDs were ranked from lowest value (most disadvantaged) to highest (least disadvantaged).

Economic Resources: SEIFA also provides an *Index of Economic Resources* (ABS, 1998b). 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. For Mackay CCDs, values range from a low of 787.51 to a high of 1112.25. Again CCDs were ranked from lowest to highest value.

People under five years of age: The very young are felt to be 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. Percentages range from a high of 15.61% (rank 1) to a low of 2.51% (rank 96) with a mean of 7.72%.

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. Percentages range from a high of 30.24% (rank 1) to a low of 1.59% (rank 96) with a mean of 10.90%.

Households renting: The proportion of households that were renting their accommodation is also seen as an indicator of economic resilience. Percentages calculated from the 1996 census data range from 64.62% (rank 1) to a low of 6.82% (rank 96).

Unemployment: A widely used indicator of economic vulnerability is the rate of unemployment. The rate for each CCD included in the 1996 census data 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. Values range from a high of 49.23% (rank 1) to a low of 3.55% (rank 96).

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.23 and listed in Table 3.12.

Society

Seven variables were used to reflect the social elements at risk.

Community facilities: A wide range of practical, social and cultural services supports 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 buildings, in the Mackay *BUILDING* database, contained in each CCD was tallied. In all, 69 CCDs contained community buildings with the greatest number being 35 (rank 1).

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 percentage of such families of the total number of families in each CCD was calculated from the 1996 census data. Values ranged from 25.70% (rank 1) to no large families in one CCD (rank 96). The community mean was 15.51%.

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. The percentage of all families which have only a single parent was calculated with the highest (rank 1) being 36.92%, whilst a single CCD had no single parent families (rank 96). The community mean was 15.47%.

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, though we have no clear data for international tourists for Mackay. The percentage of visitors (both overseas and domestic) in the total CCD population in the 1996 census was used. The highest percentage of visitors was 32.68% (rank 1). Only one CCD had no visitors. The overall mean was 7.03% .

Education and Occupation: The third SEIFA index included in this study is the *Index of Education and Occupation* (ABS, 1998b). This index is based on an analysis of 18 weighted variables selected to reflect the educational and occupation structures of communities (see Table C5). 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. Values range from 754.38 (rank 1) to a high of 1054.09 (rank 96) with a community mean of 943.61.

New residents: People who have lived at their census address for less than five years have been included because they can indicate vulnerability through a lack of awareness of the local disaster environment and lack of strong community links. These 'new residents' include longer-term residents who have simply moved residence within the area, though the great majority have moved from other statistical local areas (SLA). CCDs were ranked on the proportion of people over five years of age that were living at a different address to that at the 1991 census to the total CCD population over five years. Values range from 85.26% (rank 1) to a low of 25.94% (rank 96). The community mean was 47.42%.

No religious adherence: Lack of strong social links, such as adherence to a religion, is seen as an indicator of 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'. Percentages range from a high of 25.5% (rank 1) to a low of 5.63% (rank 96) and a mean of 13.79%.

Suburb-level composite: A composite view of the societal group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.24 and listed in Table 3.13.

Composite Ranking

To provide a composite rating of the **relative contribution of each suburb to overall community vulnerability**, the ranks for the 30 variables for each CCD that fell completely or partly within each suburb boundary were summed and that sum ranked. The resulting values were used to produce Figure 3.25 and Table 3.14.

Further Development

It is clear that this methodology is still at an early stage of its development and that it requires further work. We have already identified a number of aspects that demand further research and development to be addressed in a separate research project to be undertaken by external consultants. We would also welcome any suggestions, comments and/or advice, that readers may have to improve it.

Weighting: 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.

The method used in this study for reaching the composite vulnerability profile values is a departure from the method used for the Cairns study (see Appendix E in Granger and others, 1999). In that study, we multiplied the ranks for each of the 'five esses' to achieve the composite community value. In our ongoing review and development of this methodology we have recognised that the approach used for the Cairns study implicitly weights each individual variable depending on the number of variables contained in each group. 'Total Population', for example, because it was the sole variable used in the setting group for Cairns, carried a significantly greater weight than did say 'Logistic Facilities' which was one of eight variables in the security group. In the methodology employed in this study the ranks for each of the 30 variables were summed to achieve an overall community vulnerability profile rank. A comparison of the outcomes of applying the 'Cairns method' and the method used in this study is made with Figure D.1 and Figure D.2. The actual ranks produced by the two methods are listed in Table D.1.

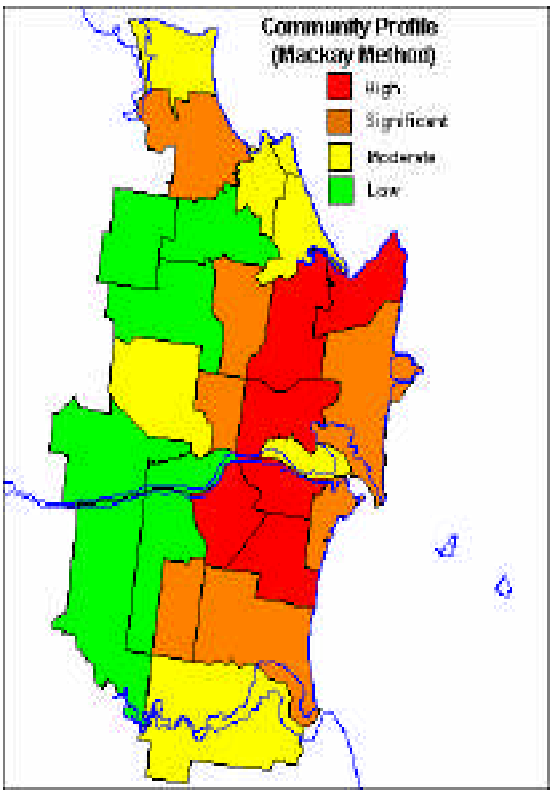


Figure D.1: Total risk ranks using 'Mackay' method

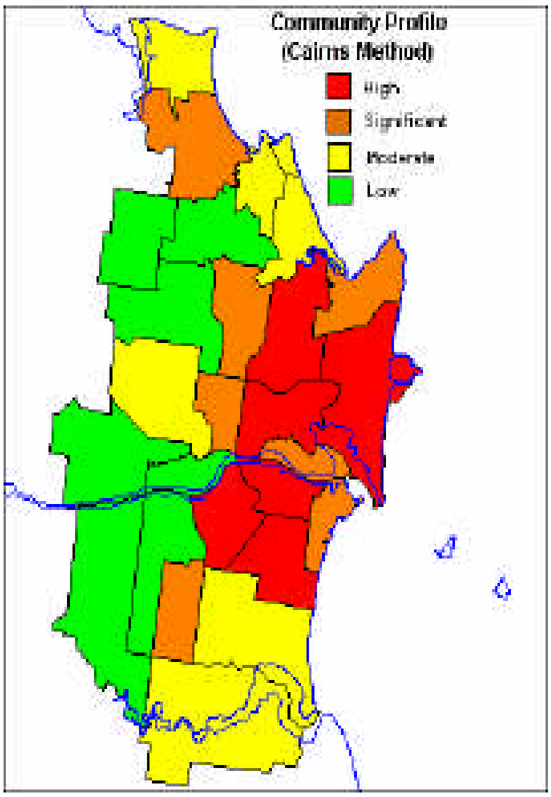


Figure D.2: Total risk ranks using 'Cairns'method

Table D.1: Comparison of total risk ranks using 'Mackay' and 'Cairns' methods

SUBURB	MACKAY	CAIRNS	SUBURB	MACKAY	CAIRNS
Andergrove	3	3	Mount Pleasant	11	9
Bakers Creek	16	18	Nindaroo	23	25
Beaconsfield	10	11	North Mackay	4	5
Blacks Beach	19	17	Ooralea	12	12
Bucasia	8	10	Paget	13	14
Central Mackay	2	1	Racecourse	25	24
Cremorne	18	13	Richmond	22	23
Dolphin Heads	20	19	Rural View	21	21
East Mackay	7	7	Shoal Point	17	20
Eimeo	15	16	Slade Point	6	8
Erakala	26	26	South Mackay	1	2
Foulden	27	27	Te Kowai	24	22
Glenella	14	15	West Mackay	5	4
Mackay Harbour	9	6			

The most significant difference is in the results for Cremorne which is five ranks higher using the 'Cairns' method. All other results are within three ranks. We believe, however, that the 'Mackay' method is likely to prove to be preferable to the 'Cairns' method because of the latter's implicit, if unintended, weighting.

Facility importance: By contrast, the importance of individual facilities such as the airport, hospitals, rail terminal, port and police headquarters to overall community vulnerability are probably under-stated because they are simply dealt with as one of a number of buildings. This is particularly an issue for those facilities, such as the airport and police stations, that have only limited distribution, but service a wider area. Further research is needed to incorporate their catchment suburbs in addition to the suburbs 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 buildings that have dual or multiple functions - should they be counted in more than one attribute? For example, the control tower at the airport has only been counted as a logistic support facility. However, in addition to its role in the operation of the airport, it is also a major aeronautical telecommunications hub - equivalent in many ways to the regional telephone exchange. It was not, however, counted in the telecommunications attribute.

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 typically 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. The bulk sugar loading facilities in the port, by contrast, have at least national significance, given their role in the shipping of a major export commodity. The loss of those facilities would cause a significant dislocation to the local, state and national economies, especially if an alternate port (e.g. the closest being Townsville to the north or Bundaberg to the south) did not have the capacity to easily handle the extra demand. The sugar facilities have a high order of functional significance and a low degree of redundancy.

Whilst there is clearly scope for further research and refinement, we feel that it is appropriate, given the community-level focus of this study, to ignore the functional significance and redundancy issue in terms of weighting the facilities in the community vulnerability profile. The focus is on the risk to the community under study. For risk assessments covering broader and more complex regions (e.g. South-East Queensland), or for communities that host a concentration of high order facilities (e.g. Gladstone) such issues will, however, need to be addressed.

Facilities versus buildings: In the analysis undertaken here, the total number of buildings in a given category has been used rather than the number of facilities. This has probably produced a bias where a facility is made up of a large number of individual buildings. That facility makes a greater contribution than an equivalent facility that consisted of a single large building. This is most notably the case with nursing homes and schools. A sensitivity analysis needs to be conducted on this aspect.

Conclusion

Regardless of the obvious limitations in the methodology employed here to provide a measure of the relative contribution each suburb 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, including Gladstone, South-East Queensland, Newcastle and Sydney, will undoubtedly produce further refinements.

This is another step on what will hopefully continue to be a fruitful journey.

APPENDIX E: 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.

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 F: EARTHQUAKES IN THE MACKAY REGION

AGSO World Earthquake Database and QUAKES Database (University of Queensland) 21-Mar-2000

Date: 01 January 1840 to 21 March 2000
Latitude: 19°S to 24°S
Longitude: 146.5°E to 152.5°E
Depth: 0 km to 100 km
Magnitude: greater than 2

Table F.1: Earthquakes in the Mackay region

Source	Date	Time	Lat	Long	Depth	Local magnitude	Authority
QUNI	18751111	105000	-22.000	148.5	30	4.5	QUNI
QUNI	19000509	0	-19.300	146.8	0	2.2	QUNI
RYNN	19121206	170000	-23.900	151.2		3.5	E/M
QUNI	19131218	135400	-20.000	147.0	33	5.7	RYNN
QUNI	19180606	181500	-23.500	152.5	10	5.1	QUNI
QUNI	19180606	181424	-23.500	152.5	15	6.3	QUNI
RYNN	19180606	182300	-23.500	152.5	0	5.5	RYNN
QUNI	19180606	190000	-23.500	152.5	10	5.1	QUNI
RYNN	19180606	192000	-23.500	152.5	0	5.7	RYNN
QUNI	19180606	194500	-23.500	152.5	10	5.1	QUNI
QUNI	19180606	201500	-23.500	152.5	10	5.1	QUNI
QUNI	19220307	165450	-23.500	152.5	10	4.5	QUNI
JONES	19500405	195052	-21.100	149.2	33	4.5	ISO
QUNI	19591125	43102.6	-19.700	147.7	0	3.3	QUNI
QUNI	19601019	113706.3	-21.200	149.5	5	4.5	QUNI
QUNI	19601019	121204	-21.300	149.4	5	2.8	QUNI
QUNI	19621228	125022.6	-19.300	148.0	10	2.4	QUNI
QUNI	19630212	160251.2	-20.250	146.6	10	3.0	QUNI
QUNI	19670318	203922	-19.000	148.4	10	2.5	QUNI
QUNI	19690111	210517	-20.900	148.0	10	2.4	E/M
RYNN	19720505	133250	-19.000	146.5		3.0	E/M
RYNN	19780524	173759.5	-20.600	146.7	10	4.0	CTA
AUST	19781128	184455.5	-23.370	152.46	31	4.5	BRS
QUNI	19800208	44207.3	-21.794	150.537	9	4.3	ML
QUNI	19810913	155824.6	-19.184	149.235	9	2.1	ML
QUNI	19811021	202156	-19.577	148.828	5	2.1	ML
QUNI	19811113	191942	-21.442	148.107	6	2.3	ML
RYNN	19820615	132124.7	-19.302	150.52	0	2.7	MD
RYNN	19821116	153421.4	-19.581	148.615	2	2.3	MD
RYNN	19821231	91945.5	-20.464	147.262	0	2.1	MD
GSQLD	19831113	64212.2	-21.035	146.799	5	4.5	MD
GSQLD	19840419	65018	-21.764	146.512	13	2.8	GSQL
QUNI	19850607	221335.3	-20.200	149.033	4	2.3	QUNI
AUST	19850727	164346.7	-19.281	148.48	5	3.5	AUST
GSQLD	19850802	121658.4	-19.443	149.203	10	4.7	GSQL
AUST	19870927	160126.3	-19.304	147.825	9	4.6	AUST
QUNI	19880226	134619.2	-19.210	149.071	4	3.3	QUNI
AUST	19880521	22319.8	-23.700	151.69	9	3.4	AUST
QUNI	19890210	150906.7	-23.784	151.947	10	2.4	QUNI
QUNI	19890326	141843.7	-21.390	151.205	19	2.4	QUNI
QUNI	19891119	120046.1	-19.358	148.763	10	2.9	QUNI
QUNI	19891119	123750	-19.790	148.99	4	2.9	QUNI

QUNI	19900312	11729.6	-20.142	150.923	5	3.0	QUNI
QUNI	19900609	40610.3	-23.364	147.822	19	2.9	QUNI
QUNI	19901103	194907.1	-23.402	149.16	8	2.7	QUNI
QUNI	19901211	161029.6	-23.610	150.619	6	2.3	QUNI
QUNI	19910315	42900.6	-23.816	152.378	8	2.4	QUNI
QUNI	19910406	14445.4	-20.499	149.814	8	3.2	QUNI
QUNI	19910413	32829	-20.429	150.264	8	2.7	QUNI
QUNI	19910610	120023.2	-23.609	150.658	0	2.9	QUNI
QUNI	19910610	130044	-23.607	150.644	10	2.9	QUNI
QUNI	19910911	53608.4	-19.712	148.895	9	3.2	QUNI
QUNI	19910911	71337	-19.792	148.979	11	3.0	QUNI
QUNI	19911112	40842	-22.605	152.263	8	2.2	QUNI
QUNI	19911214	134612	-22.378	151.833	8	2.6	QUNI
QUNI	19920521	14515.4	-21.087	147.93	3	2.2	QUNI
QUNI	19920730	82351.9	-19.444	149.609	5	3.1	QUNI
QUNI	19920804	95353.6	-21.429	151.716	8	2.6	QUNI
QUNI	19930223	211236.1	-19.755	149.773	8	2.6	QUNI
QUNI	19940617	115233.8	-20.208	148.867	4	3.4	QUNI
QUNI	19950827	20700	-20.625	147.121	0	2.3	QUNI
QUNI	19951030	171842.2	-19.487	147.426	10	2.4	QUNI
QUNI	19961005	34104.7	-23.177	151.547	10	2.8	QUNI
QUNI	19970215	132850.6	-20.400	146.553	10	3.5	QUNI
QUNI	19971024	183112.6	-20.400	147.098	19	2.6	QUNI
AUST	19981102	170938.1	-22.808	151.146	0	4.7	AUST
ASC	19990325	122608.8	-20.359	146.755	0	3.4	ASC
ASC	19990424	214848.7	-20.159	146.966	0	2.7	ASC

Source

ASC	AGSO Seismological Centre
AUST	AGSO Seismological Centre
GSQLD	Geological Survey of Queensland
JONES	Jones, 1959 (see References)
QUNI	University of Queensland
RYNN	Rynn, 1987 (see References)

Authority for magnitude

ASC	AGSO Seismological Centre
AUST	AGSO Seismological Centre
BRS	Brisbane seismograph
CTA	Charters Towers seismograph
E/M	Estimated magnitude
GSQL	Geological Survey of Queensland
GSQLD	Geological Survey of Queensland
ISO	Isoseismal map
JONES	Jones, 1959 (see References)
MD	Duration magnitude
ML	Local (Richter) magnitude
QUNI	University of Queensland
RYNN	Rynn, 1987 (see References)

APPENDIX G: PREPARATION OF MAP OF NATURAL PERIOD, EARTHQUAKE HAZARD MAP, AND EARTHQUAKE SHAKING SCENARIOS FOR MACKAY

This appendix contains three Parts:

- **PART A**: Preparation of Mackay map of natural period
- **PART B**: Preparation of Mackay earthquake hazard map
- **PART C**: Generation of earthquake shaking scenarios for Mackay.

PART A: Preparation of map of natural period for Mackay

The map of natural period for Mackay (Figure 4.4) shows point values and contours of measured natural period *T* of the ground, in the period range of interest with regard to structures *T* = 0.07 s to *T* = 2.0 s.

NOTE: Limitations of the earthquake hazard maps

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

Method used

The single site, H/V, or 'Nakamura' method was used. In this method the horizontal, spectral, ground shaking is divided by the vertical, spectral, ground shaking to produce H/V spectral ratio plots. A resonant peak may be observed in the spectral ratio plot for a site, and that peak is interpreted to occur at the fundamental period of vibration of the sediment column. A large body of theoretical and empirical research from the past decade has analysed the H/V method and compared its prediction of the fundamental ground period with, for example, assessments made from earthquake recordings (e.g., Nakamura, 1989; Lachet and Bard, 1994; Field and Jacob, 1995; Nakamura, 2000). The results generally indicate that the method is robust in revealing the natural period of sediment vibration excited by vertically incident seismic shear waves.

We recorded very weak, ambient, ground vibrations, or 'microtremors', created by wind, surf action, traffic, etc., with portable seismographs to reveal resonances in the sediments. *In situ* recordings of local earthquake shaking are the best method to determine the response of sediments but none is available in Mackay and are not likely to be for a significant time, even were instruments to be installed (there are no monitoring instruments in Mackay).

Field recording

AGSO seismologists used portable, digital seismographs to record microtremors at about 230 sites in Mackay in 1997 (Figure 4.4). Sensors were triaxial, passive type with a natural period of 1 s, and sampling rate was 100 Hz. The sites had a nominal 500 m spacing and were located primarily on sediments. Two recordings, each of 200 s duration, were made at each site.

Data processing

The recordings were divided into time series of 40 s duration each with 1 s overlap and the Fourier spectra of these were averaged. Median horizontal spectra divided by median vertical spectra, with attendant $\pm\sigma$ deviations, were used to produce the spectral ratio plots. The FFT computer programs written by Cvetan Sinadinovski and other programs written by Vic Dent and Long Cao, all of AGSO, were used to process the data.

Resonant period *T*, where observed, was interpreted for each microtremor site. Point values of *T* are shown on the map of natural period (Figure 4.4). These values were contoured using ArcInfo V7.2.1 *tincontour* programs to produce the final contour map.

Quality factors (of microtremor resonance) were assigned to the sites as follows:

- Quality A - pronounced, narrow, resonant peak observed in the spectral ratio plot;
- Quality B - broader-based resonant peak observed; the resonant period is more difficult to assess accurately than for Quality A sites;
- Quality C - resonance not observed or resonance not reliably observed. Sites where resonance was not observed appear on the map with a nominal period $T = 0.1$ s.

PART B: Preparation of Mackay earthquake hazard map

The Mackay earthquake hazard map is shown in Figure 4.2.

NOTE: Limitations of the earthquake hazard maps

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

We used a two-stage method to prepare the Mackay earthquake hazard map. The stages are:

- **Stage 1 -** Subdivide the city into zones of differing earthquake hazard according to defined site classes
- **Stage 2 -** Assign amplification factors to the site classes and hence to the zones of differing earthquake hazard.

Stage 1 - Subdivide the city into zones of different earthquake hazard according to defined site classes

Our site classifications are based on those published in the 1997 Provisions of the US National Earthquake Hazards Reduction Program (NEHRP), published by the US Building Seismic Safety Council (1997). Their site classes are described in Table G.1 and we have included extra lithological descriptions in the table from Crouse and McGuire (1996) and Hwang and others (1997).

We used the preliminary 1:100 000 scale geological map of Mackay (Figure 2.3; von Gnielinski, in preparation), a large database of groundwater borehole logs provided by Queensland Department of Natural Resources, geotechnical information provided by Queensland Rail, and the outputs of AGSO's Mackay microtremor survey to determine the earthquake hazard zones defined by site class.

All areas of rock outcrop in Mackay were included in the earthquake hazard map as Site Class B. Seismic shear wave velocities in some Mesozoic and older geological units may in fact be greater than 1500 ms^{-1} and, if so, the accurate classification of these units would be Site Class A, but we have no information to distinguish between Site Class A and Site Class B. No direct measurements of shear wave velocities were available for Mackay, as is commonly the case for Australian cities.

We classified small areas of Mackay as Site Class C. These are areas of Tertiary/Quaternary colluvium comprising material transported, largely by gravity, from the adjacent Carmila Beds in suburbs Nindaroo and Habana (see the Mackay geological map, Figure 2.3).

The rest of onshore Mackay we have classified as Site Class D (stiff clays, medium dense to dense sands), including areas where landfill has been placed over sediments (Table G.1).

To arrive at the Site Class D classification, we estimated mean seismic shear wave velocity to a depth of 30 m below the earth's surface (Vs). Shear wave velocity in the top 30 m is the key determinant for site class (Table G.1).

Table G.1: Site classes for earthquake hazard maps (based on Building Seismic Safety Council, 1997)

Site Class	Site Class definition
A	**HARD ROCK** Vs > 1500 ms^{-1}
B	**ROCK** 760 ms^{-1} < Vs ≤ 1500 ms^{-1}
C	**VERY DENSE SEDIMENTS AND SOFT ROCK** Hard and/or very stiff sediments, very dense soils, mostly gravels, and soft rock with 360 ms^{-1} < Vs ≤ 760 ms^{-1} or with either N > 50 or s_u ≥ 100 kPa
D	**STIFF SEDIMENTS** Sands, silts and/or stiff clays, some gravels, with 180 ms^{-1} ≤ Vs ≤ 360 ms^{-1} or with either 15 ≤ N ≤ 50 or 50 kPa ≤ s_u ≤ 100 kPa
E	**SOFT SEDIMENTS** A sediment profile with Vs < 180 ms^{-1} or with either N < 15 or s_u < 50 kPa or any profile with more than 3 m of soft clay defined as sediment with PI > 20, w ≥ 40%, and s_u < 25 kPa
F	**SEDIMENTS REQUIRING SITE-SPECIFIC EVALUATION** · sediments vulnerable to potential failure or collapse under seismic loading such as liquefiable sediments, quick and highly sensitive clays, collapsible weakly-cemented sediments · peats and/or highly organic clays (thickness > 3 m) · very high plasticity clays (thickness > 8 m with PI > 75) · very thick soft/medium stiff clays (thickness > 36 m)

NOTES:
Vs = Mean shear wave velocity to a depth of 30 m
N = Mean Standard Penetration Test blow count to a depth of 30 m
s_u = Mean Undrained Shear Strength to a depth of 30 m
PI = Plasticity Index
w = Moisture content

The natural period of ground vibration, *T*, measured in the microtremor survey and the thickness of Mackay sediments, *H*, determined from the DNR borehole database, yields estimates of Vs. Where 'soft' sediments overlie 'hard' rock, resonant vibration in the sediments occurs for shear waves with a wavelength of four times the sediment thickness. In that case:

$$Vs = \frac{4H}{T}$$

where *Vs* is seismic shear wave velocity in metres per second, *T* is resonant period of the fundamental mode of vibration in seconds and *H* is sediment thickness in metres. We assume:

- the interface between the sediments and the underlying bedrock is subhorizontal and planar. This is not true at a site-specific scale and many channels are cut into the bedrock (Linda Foster, verbal communication, 1999). However, our assumption is reasonable on a more general scale demonstrated by the remarkable consistency of natural period values across large areas of Mackay;
- we are observing the fundamental period of ground vibration in the spectral ratio plots;
- the microtremor technique is sampling the sediment column and not the bedrock below. This will be so if there is a significant contrast in seismic impedance between sediments and bedrock. In Mackay this is the case except perhaps where bedrock is highly weathered to significant thicknesses. Weathered bedrock in Mackay may be several metres thick (up to about 20 m but generally about 0 - 10 m from DNR borehole records).

We abstracted Quality A and B microtremor sites within about 500 m of boreholes listed in the DNR database and formed a set of pairs of microtremor sites and nearest borehole. The site pairs are located on all of the main Quaternary geological units found in Mackay. Most of the pairs are located south of the Pioneer River on undifferentiated Quaternary sediments (unit Qa). Site pairs are also located north of the Pioneer, sampling three other sediment units: Qhe, Qpb and Qhb. Our results cannot distinguish differences in seismic velocities among the different geological units. The mean distance between the 17 Quality A microtremor sites and their respective paired borehole was 326 m with a standard deviation of 133 m.

Seismic shear wave velocities Vs in sediments in Mackay of thicknesses from about 12 metres to 30 metres lie in the range 180 ms^{-1} to about 340 ms^{-1} (Figure G.1). Figure G.1 indicates that these velocities are in the upper ranges where sediments are thicker, and that velocities in the lower ranges where sediments are thinner, as may be expected if consolidation has occurred that is related to thickness of overburden. Sparse microtremor Quality B data suggest that shear wave velocities may be between 100 ms^{-1} and 200 ms^{-1} in sediments less than about 10 m thick.

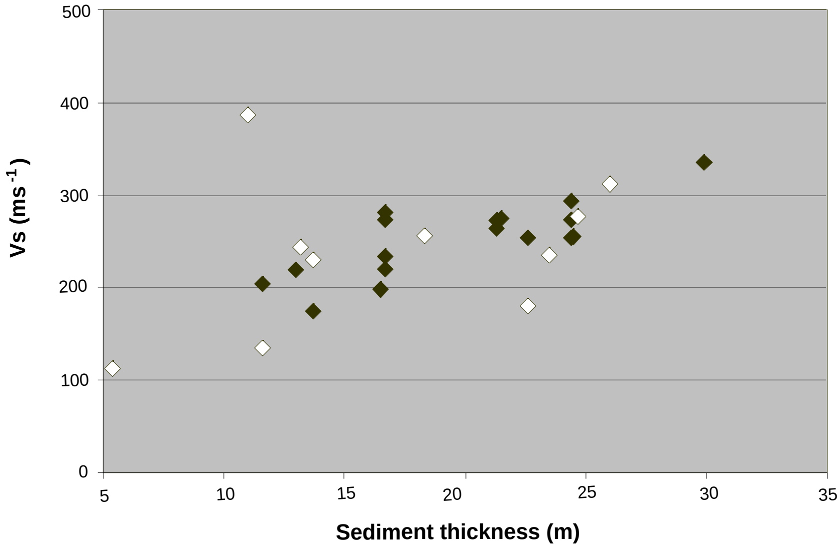


Figure G.1: Relationship between seismic shear wave velocity (Vs) and sediment thickness in Mackay. Dark symbols indicate Quality A microtremor sites, light symbols indicate Quality B microtremor sites.

These seismic shear wave velocities in the Mackay sediments alone place them clearly in Site Class D (Table G.1). However, our method classifies the mean shear wave velocity in the top 30 m of the ground and so bedrock shear wave velocities must be taken into account where sediments are less than 30 m thick. For reasonable values of bedrock shear wave velocities, areas in Mackay where sediment are thicker than about 10 - 15 m clearly match the Site Class D velocity criteria. Where sediments are thinner than 10 m mean shear wave velocities in the top 30 m could be more than 360 ms^{-1} and the resultant site class is Site Class C. In the absence of shear wave velocity measurements in rocks found in Mackay, we have taken the conservative action of classifying all areas in Mackay underlain by Quaternary sediments as Site Class D. The borehole depths to bedrock (Figure 4.3) indicate where sediments may be less than 10 m thick.

Table G.2: Relationship between site class and geological unit for Mackay

Site class	Geological unit[1]	Lithological Description
B	D-Cc, Pc, Kgw, Kgp, Kgo, Kgd	Extensive rock outcrop in northern suburbs of Devonian-Carboniferous Campwyn beds, Permian Carmila Beds, Cretaceous diorites, granodiorites and dolerites
C	TQc	Small areas of Pleistocene-Holocene colluvium
D	Qa, Qa1, Qhe, Qhb, Qhd[2], Qpb, F	Widespread areas of Quaternary floodplain alluvium, Holocene estuarine sediments, Holocene and Pleistocene beach sand deposits south of Pioneer River and in coastal northern suburbs. Areas of landfill over sediments

NOTES:
[1] von Gnielinski, in preparation
[2] Parts of Qhd in Shoal Point are zoned Site Class C

In this study we did not find evidence of clays that would indicate Site Class E and we did not search specifically for geological conditions that would indicate special sites (Site Class F in Table G.1).

Stage 2 - Assign amplification factors to the site classes

The amplification factors describe the relative severity of earthquake shaking. The amplification factor for Site Class B, 'rock', is unity and the severity of ground shaking on other site classes is expected to vary in proportion to the amplification factors. The amplification factors are period-dependent and intensity-dependent. Note that spectral values are used. These describe the motion of an idealised oscillator relative to its 'foundations', which are themselves moving due to earthquake ground motion.

In the absence of sufficient recordings of Australian earthquakes, our amplification factors are taken from the US NEHRP provisions (Building Seismic Safety Council, 1997). Table 4.5, reproduced from Chapter 4, presents the amplification factors for short period vibration (T = 0.3 s) and medium period vibration (T =1.0 s in the NEHRP Provisions, $T \geq 0.7$ s for the Australian response spectra described in Part C of this appendix).

The short-period amplification factors are comparable with but not identical to those in *AS1170.4-1993*. The short-period amplification factors will match closely those in the revision of *AS1170.4-1993* for the lowest level of ground shaking in Table 4.5. Table 4.5 additionally contains amplification factors for stronger shaking that will not be included in the revision of *AS1170.4-1993*.

Table 4.5: Amplification factors for site classes (modified from Building Seismic Safety Council, 1997)

Site Class B Spectral Acceleration	**Site Class**				
	A	**B**	**C**	**D**	**E**
Short-Period (T=0.3 s) (g)	**Short-period Amplification Factor**				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8*
Mid-period (T=0.7 s) (g)	**Mid-period Amplification Factor**				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0*

NOTE: Values shown with an asterisk are based on judgment.

The mid period amplifications ($T \geq 0.7$ s) apply to ground shaking affecting high rise buildings (none in Mackay at present) and other structures with similar natural periods of vibration. The mid period amplification factors for Site Classes C and D are significantly higher (around 50%) than the Site Factors in *AS1170.4-1993*.

The mid-period amplification factors are similar to those in the revision of *AS1170.4-1993* for the lowest level of ground shaking in Table 4.5. Table 4.5 additionally contains amplification factors for stronger shaking that will not be included in the revision of *AS1170.4-1993*.

The short-period amplification factors for Mackay could be higher than the those in Table 4.5, because of conditions strongly conducive to resonance in the sediments, as we mentioned in Part A. Specific periods of vibration at which the amplification factors could be higher would include the fundamental period and the lower periods (higher frequencies) of the harmonics. Amplifications at non-resonant, longer periods (periods T greater than about 1 s) may be muted compared to the factors in Table 4.5 because there is insufficient sediment thickness to generate resonant vibrations at these periods.

However, we recommend that the amplification factors in Table 4.5 are adopted for Mackay. More research is needed to develop appropriate Australian amplification factors and to improve our understanding of this potentially catastrophic resonance phenomenon involving tuned vibration between buildings and sediments in Australian conditions. The published amplification factors are largely derived from empirical data from California where basement geology is quite different from most parts of Australia.

PART C: Generation of earthquake shaking scenarios for Mackay

Earthquake shaking scenarios on rock (Site Class B)

Three estimates of earthquake hazard have been published for the region that includes Mackay (Table G.3). All estimates relate to a 10% probability of exceedence in 50 years at 'rock' or 'firm' (Site Class B) sites. This probability corresponds to an Annual Exceedence Probability (AEP) of approximately 1/475, or an Average Recurrence Interval (ARI) of 475 years. We have taken the 475-year ARI to be equivalent to a 500-year ARI for the purposes of comparison with flood and wind hazards in Chapter 5, Chapter 6 and Chapter 7.

The first estimate of hazard is found in *AS1170.4-1993* and is the one we have adopted. An 'acceleration coefficient' of 0.075 for the Mackay area was estimated from Figure 2.3 (g) of the standard. This value is equivalent to a peak horizontal ground acceleration, or PGA, of 0.075 g, where 'g' is the acceleration of a falling object under gravity. The earthquake hazard map (Figure 4.2) in *AS1170.4-1993* was compiled by an Australian Standards Committee and was a development of the work of Gaull and others (1990).

The second estimate is found in the probabilistic work of Gaull and others (1990). It is worth noting that Gaull and others (1990) treated the Mackay area as part of the eastern Australian area of 'background' seismicity because the area had 'sparse or no known seismic activity', although there is now an additional 15 years of data.

The third estimate of hazard originates from the probabilistic work of QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.15 g on rock, in line with their estimates of PGA for Queensland 2-3 times higher than previous estimates. Their estimate of MM VI for the 'code' scenario also indicates ground shaking at least twice as strong as the MMI estimate of Gaull and others (1990). Their value of peak ground velocity (PGV) is an order of magnitude higher than the estimate of Gaull and others.

Table G.3: Earthquake hazard for Mackay with a 10% probability of exceedence in 50 years

PGA (g)	**PGV (mm s^{-1})**	**MMI**	**Source**
≤ 0.02	≤ 20	≤ V	Gaull and others, 1990
~0.075	-	-	*AS1170.4-1993*
~0.15	~250	VI	Cuthbertson and Jaume, 1996

We generated six probabilistic, ground shaking scenarios, with average recurrence intervals of 100, 200, 475 (notionally 500), 1000, 2000 and 2500 years.

The multipliers that we used to generate the ground shaking scenario with an average recurrence interval of 500 years to ground shaking for other average recurrence intervals are shown in Table 4.6. These multipliers are provisional values used in the revision of *AS1170.4-1993* (Kevin McCue, personal communication, 2000).

The basis for our regional, probabilistic earthquake hazard estimates on rock (Site Class B) in Mackay is the response spectrum in Figure G.2 (Somerville and others, 1998). It was derived from ground motion recordings of reverse faulting earthquakes of magnitude 6.0 ± 0.6. This spectrum will appear in the revision of *AS1170.4-1993*. The spectrum describes elastic, horizontal, 5% critically damped motion of an idealised oscillator and is normalised to a peak ground acceleration of 100 cms^{-2} (approx. 0.1 g). However, for Mackay, the value of PGA with an ARI = 475 years is 0.075 g. The spectrum was therefore scaled down by a factor of 0.75 to generate our ARI = 475 year 'rock' scenario for Mackay.

Table 4.6: Provisional multiplying factors for Australian regional earthquake hazard

Average Recurrence Interval (yr)	100	200	500	1000	2000	2500
Multiplier	0.2	0.6	1	1.4	1.75	2

The spectrum was scaled up or down by the factors in Table 4.6 to generate 'rock' spectra (Site Class B) for scenarios other than ARI = 475 years.

Earthquake shaking scenarios on Site Classes C and D

Additional spectra for very dense sediments and stiff sediments (Site Classes C and D respectively) were produced by modifying the Site Class B (rock) response spectra for the scenarios with ARI = 100, 200, 475, 1000, 2000 and 2500 years with the amplification factors in Table 4.5. Figure G.3 shows the response spectra for Site Classes B, C and D in Mackay, normalised to a PGA on rock of 100 cms^{-2}.

Table 4.7 provides the PGA and spectral values for each probabilistic earthquake shaking scenario developed for Mackay.

Table 4.7: Earthquake hazard scenarios for Mackay

ARI (yr)	**Site Class B**					**Site Class C**					**Site Class D**				
		T=0.3 s		**T=0.7 s**			**T=0.3 s**		**T=0.9 s**			**T=0.3 s**		**T=1.0 s**	
	PGA (g)	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**
100	0.02	0.03	0.06	0.01	0.15	0.02	0.03	0.08	0.01	0.25	0.02	0.05	0.10	0.01	0.35
200	0.05	0.09	0.19	0.04	0.44	0.05	0.10	0.23	0.04	0.75	0.07	0.14	0.31	0.04	1.06
475	0.08	0.14	0.32	0.06	0.73	0.09	0.17	0.39	0.06	1.25	0.12	0.23	0.52	0.07	1.76
1000	0.11	0.20	0.45	0.08	1.03	0.13	0.24	0.54	0.09	1.75	0.17	0.32	0.72	0.10	2.47
2000	0.13	0.25	0.56	0.11	1.29	0.16	0.30	0.68	0.11	2.19	0.21	0.40	0.90	0.12	3.09
2500	0.15	0.29	0.65	0.12	1.47	0.18	0.35	0.77	0.12	2.50	0.23	0.43	0.97	0.13	3.23

NOTE: ARI = Average Recurrence Interval; T = Period of vibration of ground shaking in seconds; PGA = Peak Horizontal Ground Acceleration as a proportion of g, the acceleration due gravity; SA = Spectral Acceleration; SD = Spectral Displacement.

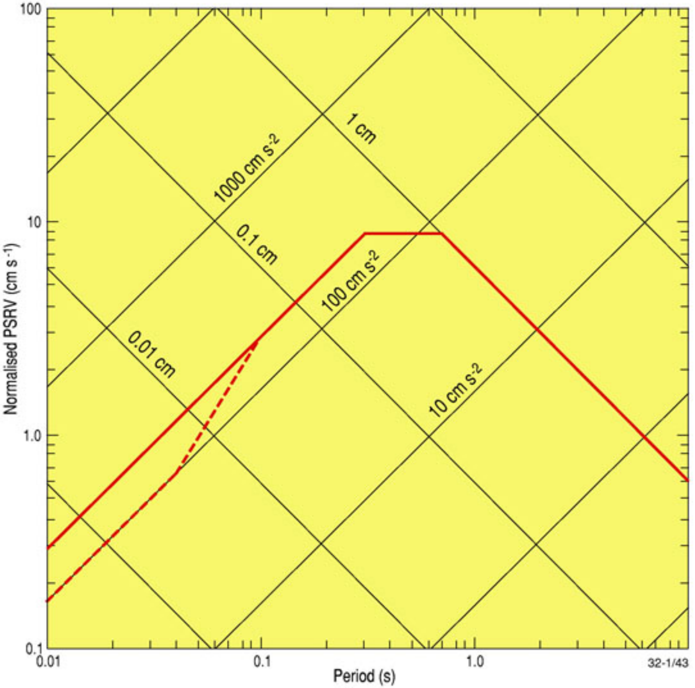


Plate G.2: Responce spectrum for earthquake shaking on Rock (Site Class B), normalised to a PGA of 100cm s^{-2} (after Somerville and others, 1998). Spectrum is for elastic, horizontal, 5% critically damped motion. Spectral acceleration equals PGA for periods less than 0.04 s (dashed line). Extension of spectral acceleration to periods less than 0.1 s (solid line) will be included in the revision of *AS1170.4-1993*.

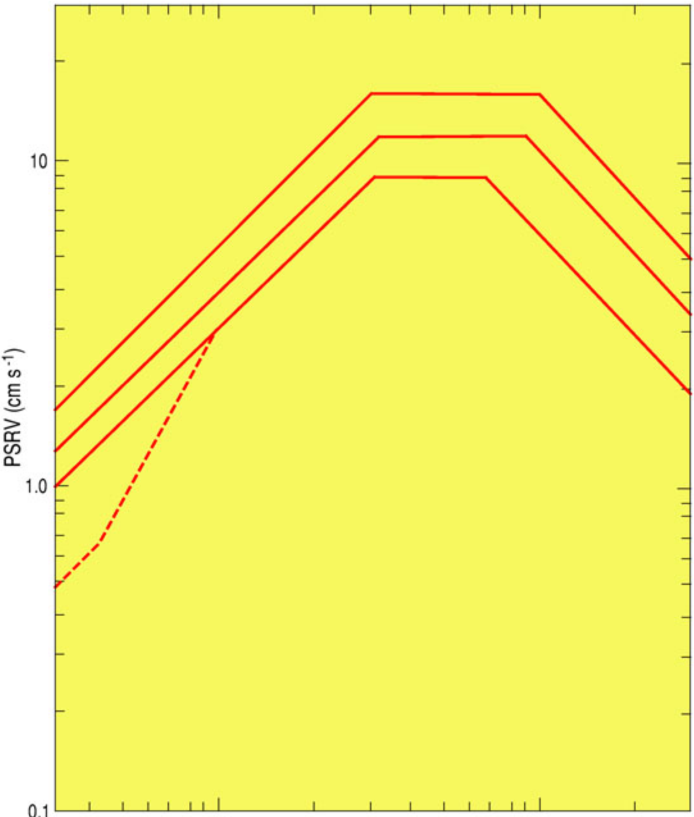


Figure G.3: Responce spectra for earthquake shaking on Site Classes B (lowest), C (centre) and D (topmost), normalised to a PGA of 100cm s^{-2} . Spectra are for elastic, horizontal, 5% crtically damped motion. Spectral acceleration equals PGA for periods less than 0.04 s (dashed line for Site Class B only is shown). Extension of spectral accelerations to periods less than 0.1 s (solid lines) is shown.

APPENDIX H: METHOD OF ESTIMATING EARTHQUAKE BUILDING DAMAGE IN MACKAY

Our building damage assessment method comprises three steps:

- We developed a building database categorising buildings into types based on their load bearing elements. These building types and the revised Mackay building database are described in Chapter 4;
- We determined the response of these building types to earthquake demand loads generated by the earthquake scenarios. Our techniques of determining building response are based on the HAZUS® (FEMA, 1999) methods and are described below. HAZUS® is earthquake loss and mitigation assessment software developed by the US Federal Emergency Management Agency (FEMA, 1999). We used the HAZUS® methods but not the HAZUS® software routines;
- We determined the probability of the various building types falling into damage states *nil*, *slight*, *moderate*, *extensive* and *complete* when subjected to the earthquake demand loads generated by the earthquake scenarios. The definitions of these damage states, and our techniques of determining the probabilities of their occurrence, are also based on the HAZUS® methods.

Building types

The building types included in damage scenarios for Mackay are:

- low-rise light timber frame;
- low-rise light steel frame;
- low-rise reinforced concrete frame & unreinforced masonry infill;
- low-rise reinforced masonry (concrete block); and
- low-rise unreinforced masonry.

Descriptions of the building types are given in Chapter 4. The building types are designed to be compatible with the building categories of HAZUS®.

Building response to earthquake demand loads

The performance of building types is described by building capacity curves. These ‘push-over’ curves describe the nonlinear deformation of buildings in response to lateral earthquake forces. An example building capacity curve is shown by the red solid curve in Figure H.1. The intersection of the building’s capacity curve with an applied earthquake demand response spectrum yields the peak building response in terms of spectral displacement for a particular ground shaking (demand) scenario. The HAZUS® method is similar to the static, building capacity spectrum technique of Mahaney and others (1993).

Figure H.1 demonstrates the technique using the example of light timber frame residential buildings. The response spectra that generate earthquake shaking scenarios for Mackay have been converted to the same format as the building capacity curves (spectral acceleration against spectral displacement) to enable their intersection with the building capacity curves. Preparation of the demand response spectra is described in Appendix G. The demand spectra in Figure H.1 refer to earthquake spectral shaking on Site Class D with average recurrence intervals of (a) 100 years; (b) 475 years; (c) 1000 years; and (d) 2500 years. Damping has been increased from 5% of critical to levels appropriate for light timber frame buildings undergoing the intensities of shaking generated by the scenarios. In this example they are 10% of critical for cases (a) - (c) and 15% of critical for case (d).

More generally, appropriate damping values for each building type are drawn from Newmark and Hall (1982) by the HAZUS® methodology. We used most of the damping values provided in HAZUS® to produce appropriate demand response spectra for each building type.

The capacity curve for *Precode* timber frame residences is shown in Figure H.1 (solid red curve). The capacity curve is nonlinear. It exhibits elastic behaviour for low demands (the straight line portion of the curve). Design loads will normally occur on the elastic part of the curve. For demand loads beyond the elastic yield limit (beyond the straight line portion of the curve), building response is ductile and the building undergoes permanent deformation under earthquake loading.

In HAZUS®, building capacity is modelled to be lognormally distributed. An indication of the dispersion associated with the median capacity curve for *Precode* timber frame residences associated with building capacity is shown by the red dashed curves in Figure H.1.

The capacity curve for *Post-code* timber frame residences is shown in Figure H.1 by the dashed blue curve. Both *Precode* and *Post-code* capacity curves for light timber frame residences are adopted from HAZUS®.

The intersections of the demand curves and capacity curves for each building type found in Mackay, on each site class, and for each of the six earthquake shaking scenarios, yielded values of spectral displacement that drove the building damage scenarios. An example is shown in Figure H.1. A spectral displacement of about 0.8 cm is indicated for *Precode* timber frame residences under the ARI = 2500 year, Site Class D shaking scenario.

Building damage states

The damage states for the various building types found in Mackay are described below. The descriptions of damage states are taken directly from HAZUS®. 'Small' cracks are assumed throughout to be visible cracks with a maximum width of less than 3 mm. Cracks wider than 3 mm are referred to as 'large' cracks.

Light timber frame buildings:

Slight Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate Structural Damage: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundations cracks.

Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 5% of the total area of buildings with *complete* damage is expected to be collapsed.

Light steel frame buildings:

Slight Structural Damage: Few steel rod braces have yielded which may be indicated by minor sagging of rod braces. Minor cracking at welded connections or minor deformations at bolted connections of moment frames may be observed.

Moderate Structural Damage: Most steel braces have yielded exhibiting observable significantly sagging rod braces; few brace connections may be broken. Some weld cracking may be observed in the moment frame connections.

Extensive Structural Damage: Significant permanent lateral deformation of the structure due to broken brace rods, stretched anchor bolts and permanent deformations at moment frame members. Some screw or welded attachments of roof and wall siding to steel framing may be broken. Some purlin and girt connections may be broken.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to broken rod bracing, failed anchor bolts or failed structural members or connections. Approximately 25% of the total area of buildings with *complete* damage is expected to be collapsed.

Reinforced concrete frame buildings with unreinforced masonry infill walls:

Slight Structural Damage: Diagonal (sometimes horizontal) hairline cracks on most infill walls; cracks at frame-infill interfaces.

Moderate Structural Damage: Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks may be observed in concrete beams or columns.

Extensive Structural Damage: Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to a combination of total failure of the infill walls and nonductile failure of the concrete beams and columns. Approximately 25%(low-rise), 20%(mid-rise) or 15%(high-rise) of the total area of buildings with *complete* damage is expected to be collapsed.

Reinforced masonry buildings with concrete floors:

Slight Structural Damage: Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the shear walls have exceeded their yield capacities indicated by larger cracks.

Extensive Structural Damage: In buildings with relatively large area of wall openings most shear walls have exceeded their yield capacities and some of the walls have exceeded their ultimate capacities exhibited by large, through-the wall diagonal cracks and visibly buckled wall reinforcement. The diaphragms may also exhibit cracking.

Complete Structural Damage: Structure is collapsed or is in imminent danger of collapse due to failure of the walls. Approximately 20%(low-rise), 15%(mid-rise) or 10%(high-rise) of the total area of buildings with *complete* damage is expected to be collapsed.

Unreinforced masonry buildings:

Slight Structural Damage: Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.

Extensive Structural Damage: In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls. Approximately 25% of the total area of buildings with *complete* damage is expected to be collapsed.

Probability of building damage states

Building damage is described probabilistically for each building type by the HAZUS® methodology. Given a spectral displacement of the building type under a certain earthquake demand scenario, there is a discrete probability that buildings of that type will be in each damage state *nil*, *slight*, *moderate*, *extensive* and *complete*.

The probability of being in or exceeding a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the spectral displacement, S_d*, the probability of being in or exceeding a damage state, ds, is modeled as:*

$$P[ds|S_d] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \qquad (5\text{-}3)$$

where:

	$\bar{S}_{d,ds}$	*is the median value of spectral displacement at which the building reaches the threshold of the damage state, ds,*
	β_{ds}	*is the standard deviation of the natural logarithm of spectral displacement of damage state, ds, and*
	Φ	*is the standard normal cumulative distribution function.*

(HAZUS® Technical Manual, p. 5-35; FEMA, 1999)

Example fragility curves are shown in Figure H.2. The damage functions for each building type in Mackay were taken from HAZUS®.

We reproduce a cautionary note from the HAZUS® Technical Manual, p.5.3 (FEMA, 1999):

While the fragility and capacity curves are applicable, in theory, to a single building as well as to all buildings of given type, they are more reliable as predictors of damage for large, rather *than small, population groups. They should not be considered reliable for prediction of damage to a specific facility without confirmation by a seismic/structural engineering expert.*

Figure H.2 shows typical fragility curves for damage states. From the figure, for a spectral displacement of 10 cm, the probability of the building type being in damage state *slight* or a more severe state is 1 (certain), the probability of the building type being in damage state *moderate* or a more severe state is about 0.5, the probability of the building type being in damage state *extensive* or a more severe state is about 0.05, and so on. The probability of being in the discrete damage state *moderate* is 0.5-0.05 = 0.45 approximately.

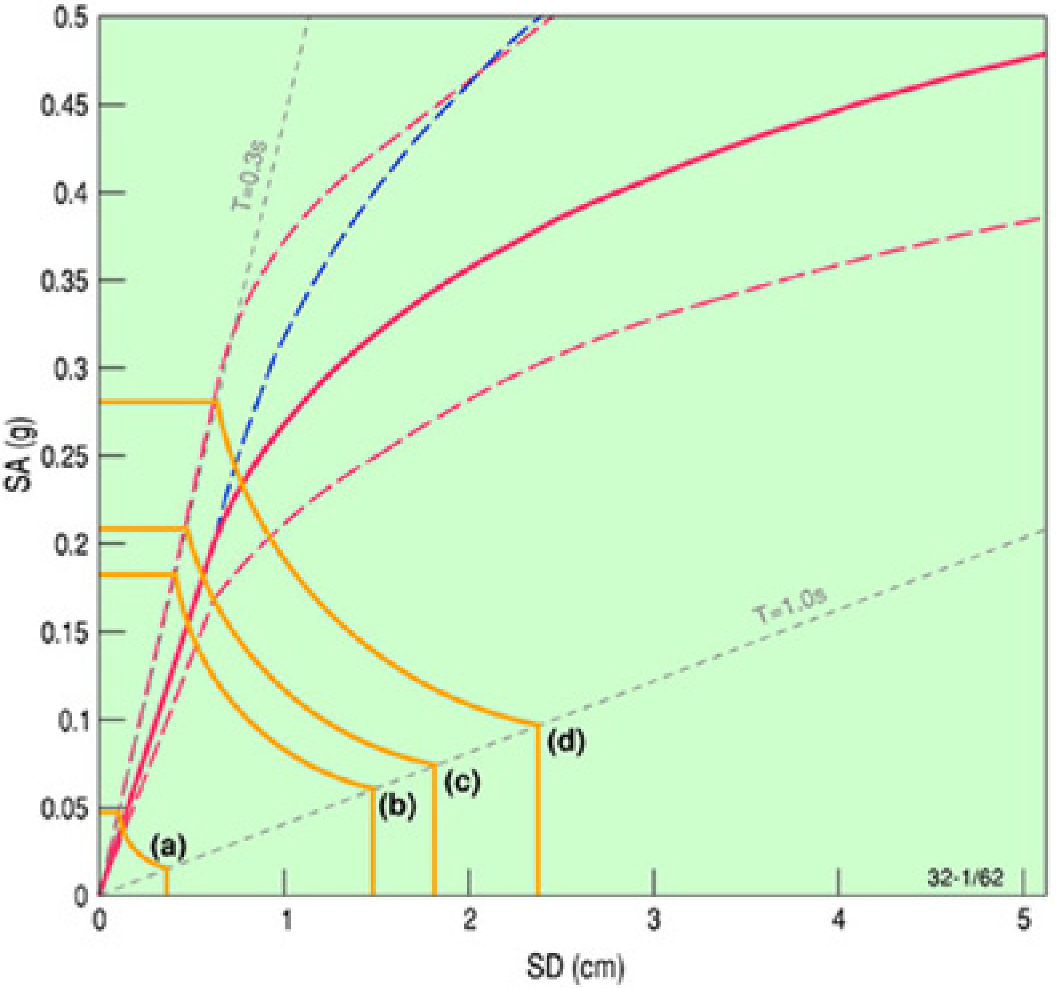


Figure H.1: Earthquake capacity and demand curves for timber framed buildings, Mackay. Demand curves refer to earthquake spectral shaking on Site class D with ARIs of (a) 100yr; (b) 475yr; (c) 1000yr; and (d) 2500yr. Capacity curves are shown for *Precode* (solid red) and *Post-code* (dashed blue) timber framed residences. Red dashed curves indicate dispersion associated with *Precode* median curve. (Capacity curves adopted from FEMA, 1999). SA = spectral acceleration; SD = spectral displacement

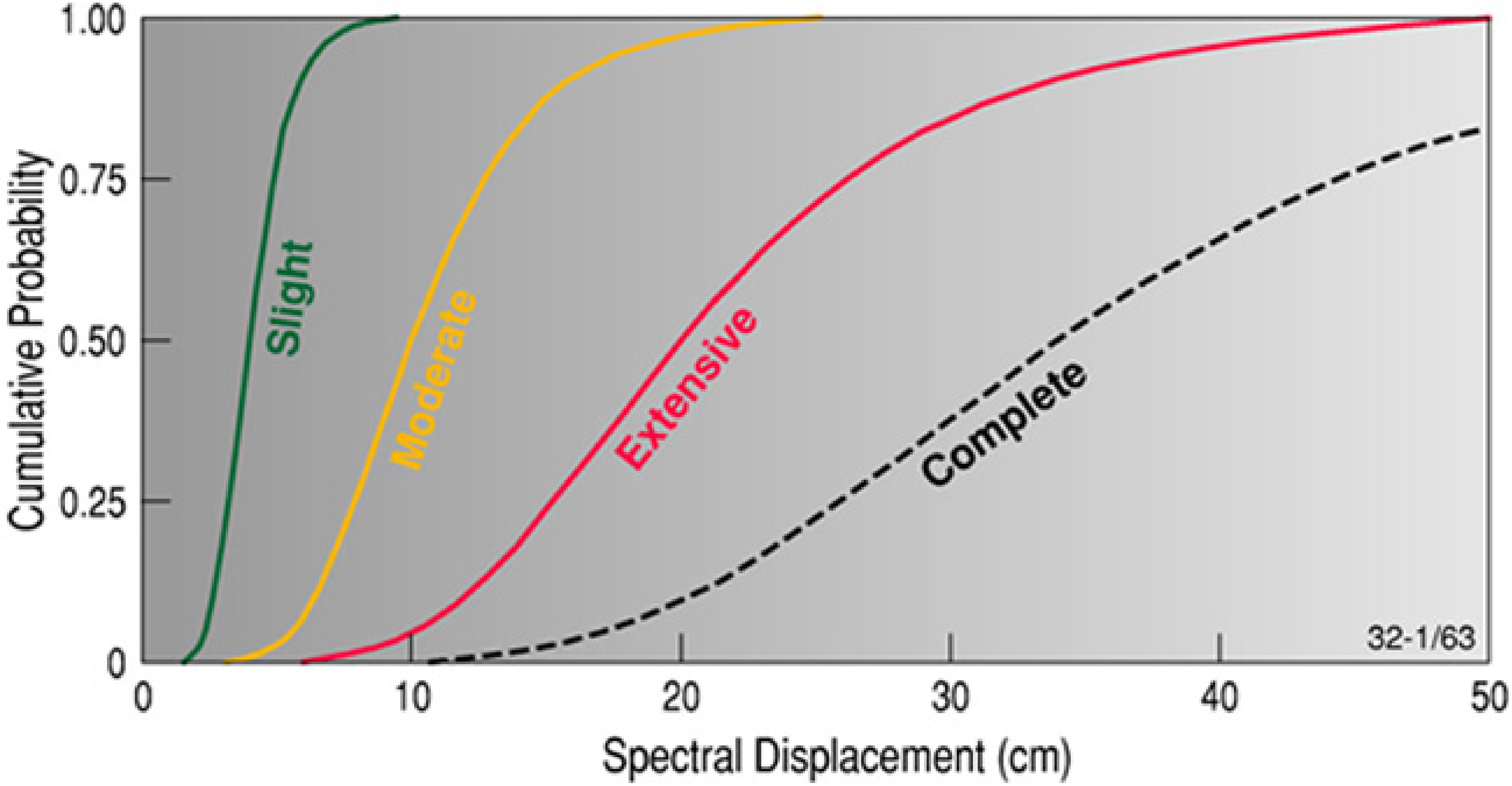


Figure H.2: Typical fragility curve for earthquake damage to buildings (Adopted from FEMA, 1999)

BUREAU OF METEOROLOGY
Queensland Regional Office
February 2000

FLOOD WARNING for the PIONEER RIVER

This brochure describes the flood warning system for the Pioneer River basin. It is intended to provide reference information which will be useful for understanding Flood Warnings and River Height Bulletins issued by the Bureau of Meteorology during periods of high rainfall and flooding.

The Flood Risk

The Pioneer River Basin has a catchment area of about 1500 square kilometres and lies between the head waters of the Fitzroy and Burdekin Rivers. The river flows in an easterly direction from the Clarke Range and Connors Range to the sea. Very high rainfalls can occur along the ranges which causes very fast stream rises in Blacks and Cattle Creeks which feed into the Pioneer River. In most cases a river rise will occur at Mackay within ten hours of heavy rainfall in the upper areas of the catchment.

The City of Mackay can be subject to major flooding with low lying areas, especially the Cremorne area, being susceptible. No major flood problems occur until the river at Mackay reaches about 7.2 metres on the Forgan Smith Bridge gauge. The introduction of an extensive levee system offers some protection for small to medium floods but large floods will still cause extensive flooding in Mackay.

Previous Flooding

The Pioneer River has a quite well recorded flood history with documented evidence of flooding as far back as 1884. Since that time many devastating floods have occurred, with the highest occurring in February 1958 which peaked at a height of 9.14 metres on the Mackay flood warning gauge at the Forgan Bridge.

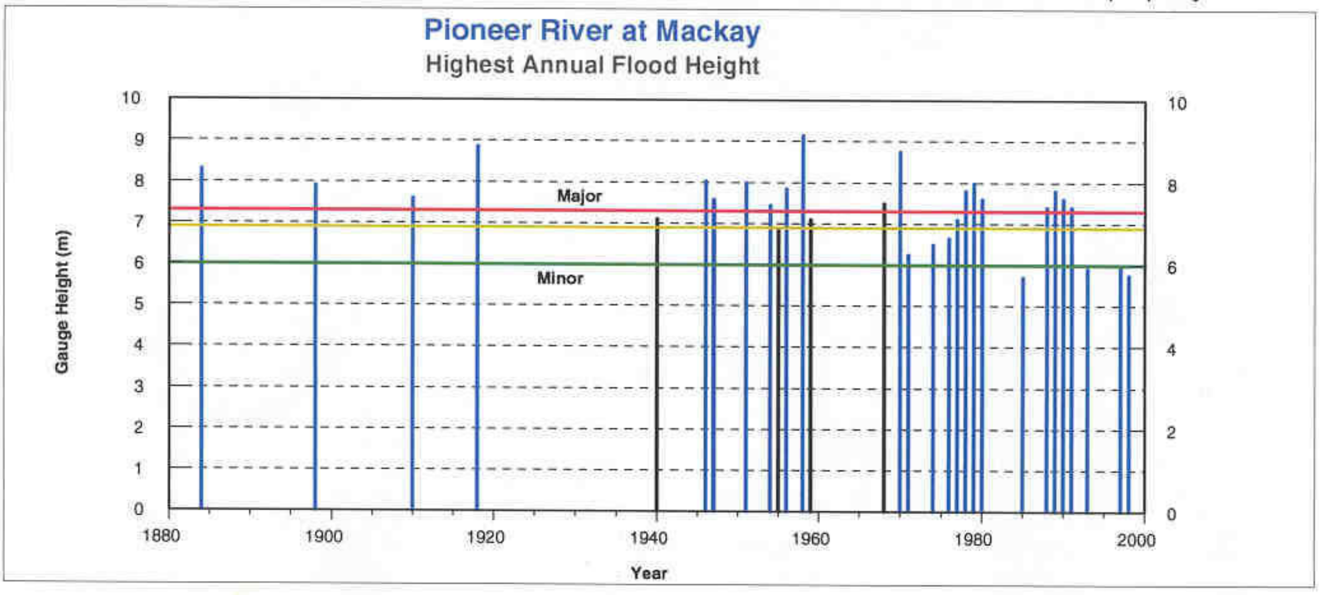
Flood Forecasting

The Bureau of Meteorology, in association with the Pioneer River Improvement Trust and Mackay City Council, operates a flood warning system for the Pioneer River based on a rainfall and river height observations network shown on the map on Page 4. In consultation with the Pioneer River Improvement Trust, the Bureau issues predictions of flood heights for the Pioneer River at Mackay whenever it is expected to exceed 7 metres at the Forgan Bridge gauge. The objective is to provide at least three to nine hours warning of heights above 7 metres. These forecasts are updated every three hours while the river is rising.

The real time ALERT flood reporting network enables predictions to be made earlier and with more accuracy.

Local Information

The responsibility for providing information about flood problem areas in Mackay rests with both the Mackay City Council and with the Pioneer River Improvement Trust through its Consulting Engineers, Ullman and Nolan. The detailed local information interprets Bureau river height predictions into depths and areas of flooding for Mackay. This enables flood threatened residents to take appropriate action before the floodwaters reach their property.



PIONEER ALERT SYSTEM

The Pioneer ALERT system was installed in 1995 as a cooperative project between the Bureau of Meteorology and the Pioneer River Improvement Trust. The system is based on a network of rainfall and river height field stations which report via VHF radio to base station computers in Mackay. The field stations send reports for every one millimetre of rainfall and every 50 millimetre change in river height. The Pioneer network has over 15 field stations, some of which measure rainfall and river height, some measure rainfall only and one monitors the tide at Mackay Outer Harbour. The base station computer collects the data and has software that displays it in graphical and tabular form. The data is on forwarded to the Bureau's Flood Warning Centre where it is used in hydrologic models to produce river height predictions.

FLOOD WARNINGS AND BULLETINS

The Bureau of Meteorology issues Flood Warnings and River Height Bulletins for the Pioneer River basin regularly during floods. They are sent to radio stations for broadcast, and to Local Councils, emergency services and a large number of other agencies involved in managing flood response activities. Flood Warnings and River Height Bulletins are available via:

Radio: Radio stations, particularly the local ABC and local commercial stations, broadcast Warnings and Bulletins soon after issue.

Local response organisations: These include the Council, Police, and State Emergency Service in the local area.

Internet/World Wide Web Access: Warnings, Bulletins and other weather related data may be found on the Bureau's Home Page at:
www.bom.gov.au

The Queensland Flood Warning Centre page is at :

www.bom.gov.au/weather/qld/inside/flood/flood.shtml

Weather by Fax : Flood Warnings and River Height Bulletins are also available through a facsimile information retrieval system, along with a wide range of other weather and climate information.

Main Directory: (Freepoll)	1800 630 100
Flood Warnings:	1902 935 065
River Height Bulletins:	1902 935 056

INTERPRETING FLOOD WARNINGS AND RIVER HEIGHT BULLETINS

Flood Warnings and River Height Bulletins contain observed river heights for a selection of the river height monitoring locations. The time at which the river reading has been taken is given together with its tendency (e.g. rising, falling, steady or at its peak). The Flood Warnings may also contain predicted river heights for some time, hours or days, in the future. River Height Bulletins also give the height above or below the road bridge or causeway for each river station located near a road crossing.

One of the simplest ways of understanding what the actual or predicted river height means is to compare the height given in the Warning or Bulletin with the height of previous floods at that location.

The table below summarises the flood history of the Pioneer basin - it contains the flood gauge height of the highest flood recorded at selected river height locations, together with the heights of recent floods.

River Height	Highest Recorded Flood		1970	1978	1979	1980	1988	1990
Finch Hatton	May 1989	6.50	-	-	-	-	3.60	5.85
Gargett	Dec 1990	9.31	7.99	7.52	7.68	8.41	-	9.31
Sarich's	Jan 1970	14.78	14.78	-	11.82	10.73	-	10.86
Mia Mia	Apr 1989	12.50	-	-	11.40	10.00	-	11.00
Mirani Weir	Mar 1988	13.70	-	11.66	9.83	12.74	-	12.37
Mirani	Feb 1958	16.46	14.02	10.60	10.85	11.00	10.90	10.90
Mackay	Feb 1958	9.14	8.76	7.80	8.00	7.60	7.40	7.60

Historical flood heights for all river stations in the flood warning network, as shown on the Pioneer River basin map on the back page, are available from the Bureau of Meteorology.

FLOOD CLASSIFICATIONS

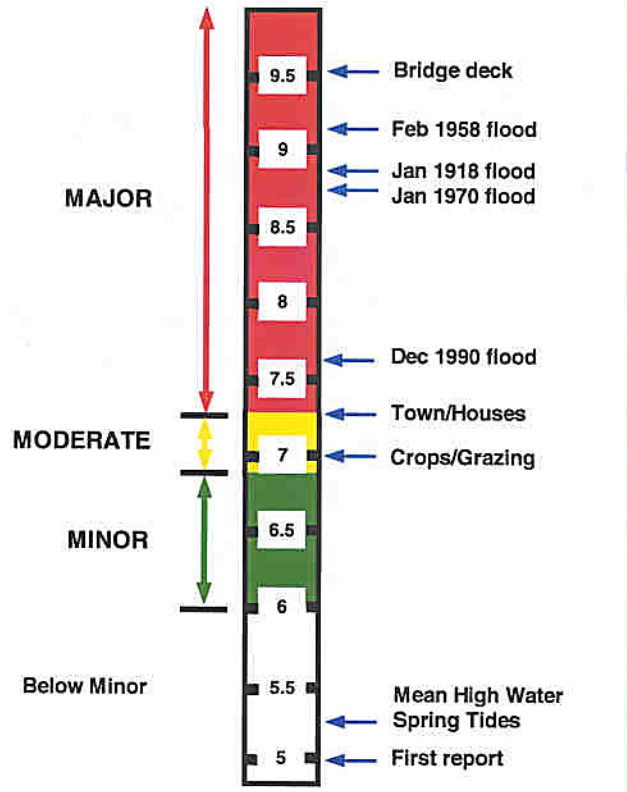
At each flood warning river height station, the severity of flooding is described as minor, moderate or major according to the effects caused in the local area or in nearby downstream areas. Terms used in Flood Warnings are based on the following definitions.

Minor Flooding: This causes inconvenience such as closing of minor roads and the submergence of low level bridges and makes the removal of pumps located adjacent to the river necessary.

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.

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.

Each river height station has a pre-determined flood classification which details heights on gauges at which minor, moderate and major flooding commences. Other flood heights may also be defined which indicate at what height the local road crossing or town becomes affected by floodwaters.



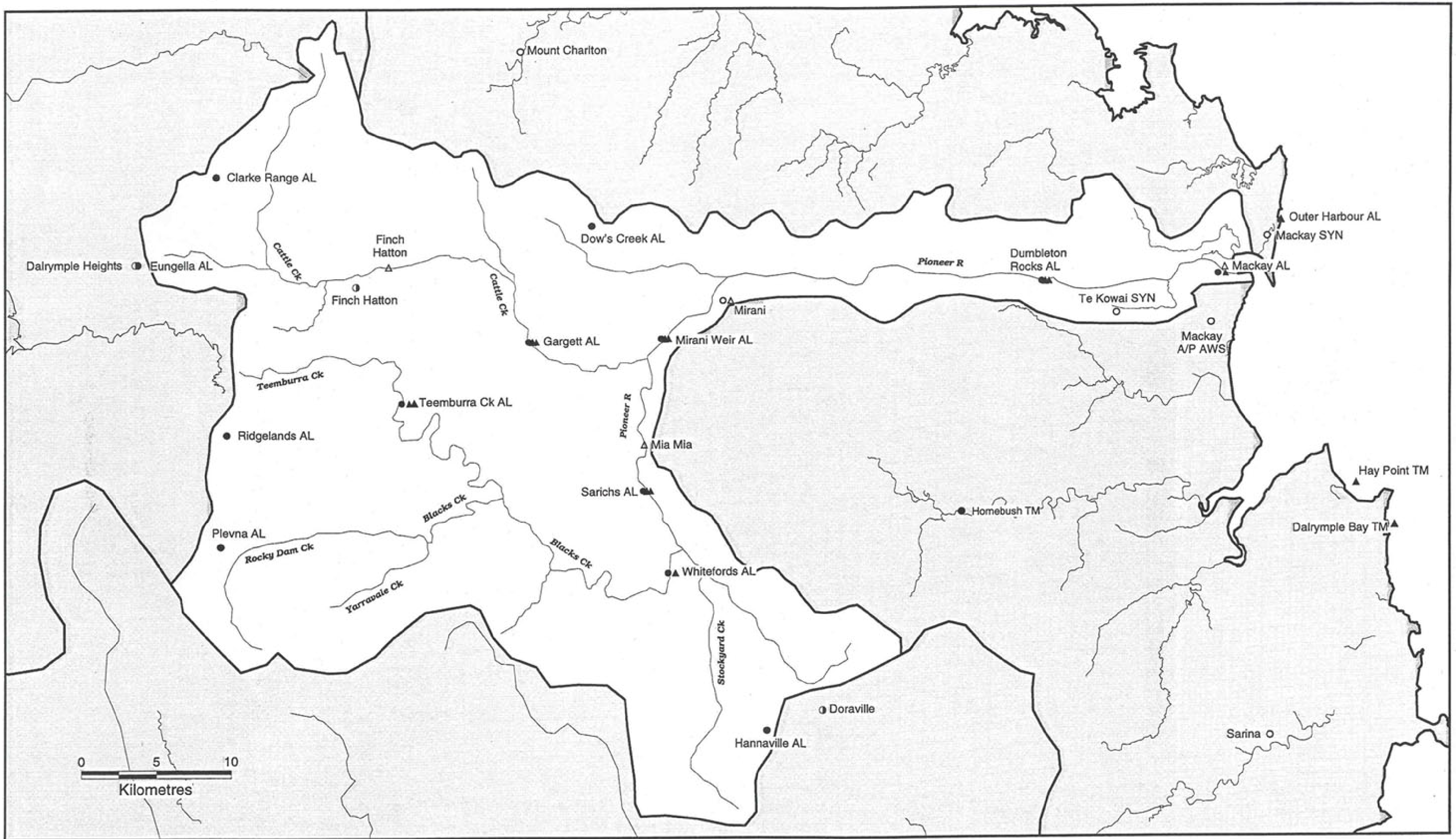
Forgan Bridge, Mackay Flood Classification

The table below provides the flood classifications for selected river height stations in the Pioneer River basin.

River Height Station	Crossing Height	Minor Flood	Moderate Flood	Major Flood
Mia Mia		5.0	7.0	9.0 d/s
Finch Hatton	10.00 (B)	3.0	4.0	5.0
Mirani Weir		7.0	9.0	10.0
Mirani	15.8 (B)	6.0	8.0	9.0 d/s
Dumbleton Rocks	14.00 (C)			
Mackay	9.58 (B)	6.0	6.9	7.3

All heights in metres on flood gauges.
(B) = Bridge (C) = Crossing d/s = Downstream

For further information, contact: Regional Director, Bureau of Meteorology, GPO Box 413, Brisbane 4001



◑ Manual Heavy Rainfall Station
○ Daily Reporting Rainfall Station
△ Manual River Station
● Telemetry Rainfall Station
▲ Telemetry River Station

PIONEER RIVER

FLOOD WARNING NETWORK

Rainfall Period ....

Ending at ....

Revised: Dec 1999

APPENDIX J: CONTEMPORY EYEWITNESS ACCOUNTS OF FLOODING IN MACKAY

Miriam Middelmann

Below are three eyewitness accounts of flooding in Mackay. Interviews were conducted by AGSO in February 2000 with the assistance of the Mackay Historical Society, and are not transcribed in their entirety here. Where indicated, a fictitious name has been used to maintain privacy. The first account is the memories of a girl who was twelve during the 1918 cyclone and storm surge. The second account is the memories of a mother and her son who experienced first hand the disastrous flooding in Foulden in February 1958. The third account is from an engineer whose home and business were in the Cremorne area for many years. He gives his opinion as to the causes of flooding, particularly in the Cremorne area and describes their effects.

1918 cyclone
Mrs Alice Smith (alias used)

Mrs Alice Smith was twelve years old during the 1918 cyclone. At the time of the 1918 cyclone she and her family lived in 45 Evan St, South Mackay. Her family's house survived the 1918 cyclone but was burnt down at a later date. Since then, flats have been built on the block and it has been renamed 145 Evan St. Though her family wasn't evacuated, she noted that people in Cremorne and East Mackay were evacuated.

We didn't wake up through the night. We woke up early in the morning. When we got up there was the water racing past. And I can remember as plain as anything a tank came washing down and seeing it jump up over the railway line and jump the other railway line.

There were all sorts of stuff getting washed past. We only had a sheet of iron from another place hit in the corner of our bathroom. But it was a bathroom/storeroom in those days. The kerosene and sugar were side by side in the corner of the storeroom. This sheet of iron pierced the roof and down came the water into the kerosene. And the kerosene flowed over into the sugar. That was all the damage that we had. But the water came up level with the verandah - we were just five steps up. We were watching to see if it came up any higher. If it had we were going to come up to the empty trucks. A lot of houses were just washed off their blocks.

When we got outside and saw what happened, it was really terrible. Then we had to line up for bread and everything else, organised by the Local Council.

The further towards the beach the worse off the flooding. East Mackay copped it. Houses were washed off their blocks because of the tidal wave.

1918 was the worst flood, worse than 1958, because of the big tidal wave where the river broke its banks. Out near the Toyota corner [corner of Shakespeare Street and Nebo Road, where the Commercial Hotel was], *near the showgrounds…but by the time it came to where we were it* [the water] *wasn't very deep, but it was over the counter of the Commercial Hotel.*

I remember a piano getting washed down the road, probably wouldn't have been much good afterwards…..also animals…up past our place there were chooks and dogs and lots of things [being washed down the road]. *Nothing big like a horse* [near where our house was, but horses and cattle were swept along with the water elsewhere].

One family was practically washed out. Welch was their name. Son and his father I think was all that was left out of about five of them. Drowned. Lived down Evan Street, however a long way from where *we were. In those days there weren't the houses that there are now. Not big and flash as they are now…the woman got caught in the barbed wire fence by her hair…she drowned.*

The street was lined with clothes [which had been damaged by the flooding. The clothes hung on lines tied between the trees]. *Socks drying. Then they* [the shop keepers] *had sales* [to sell the clothes affected by the flooding].

The evacuated I think went to the schools, and then they had to be fed and looked after. When their whole house was destroyed then there was nothing to go back to.

[Our family] *never left our home during the cyclone. They said it was going to come again so we got ready to go up into these trucks, but it didn't happen. Everything was wet. We had the chooks up on the verandah. Dad and Jim went and got them out and put them up onto the side verandah. Everybody stayed home together. You could go out the next day or so I think. But everything was wet and soggy and that but you could go out. Of course everybody was going out to see what damage was done and that.*

The winds blew houses off their blocks and then the surge on top of that …just blown to pieces. And right the way out from here people still felt the wind. Winds and storm surge pretty much at same time. Or pretty close anyway.

The war was on then and the soldiers got word that Mackay was wiped out.

February 1958 flood, Foulden
Mrs Louisa Jenner and Mr Graham Jenner

Mrs Louisa Jenner (L) and Mr Graham Jenner (G) lived in Foulden at the time of the 1958 flood. Foulden was considered to be a disaster area following the 1958 flood so nobody was allowed to move back. Now the area is used for farming and grows sugar cane. Though the road used to follow the river up to Foulden, there is no longer a road going out there.

L: *There was about twenty houses there* [in Foulden]. *About four houses were completely washed away up the top. The river really moved over its width and took everything in front of it. There was Mrs Deseeme, down there. She was only left with what she stood up in. She was left with nothing. All* [of us] *out there, we had windmills or spears for our water. Their spears are now in the middle of the Pioneer River. The river changed its course. The flood started on the 17 Feburary 1958 at about 6 pm.*

G: *This was a high blocked house then. Dad had the dog and chooks all under the house and the dog started hitting its head on the floorboards at about two o'clock in the morning* [18/2/1958]. *So Dad walked under there at about two o'clock in the morning and there was still silt on the cement. When we were rescued at six in the morning, between our place and the house next door there was a 6 ft fence and we sort of got tangled up with this boat and this 6 ft fence and this young fella jumped out the back and gave us a shove and off we went and Dad said, "What did you push off?" "The ground," and Dad said "You couldn't push off the ground there was 6 ft of water there," but there wasn't. Later that afternoon there was only 3 ft of water.*

At two o'clock in the morning the river hadn't changed its course, then from two o'clock to six o'clock that was when all that silt built up and this place ended up a low blocked house, you couldn't even crawl under it. From 2 am to 6 am the river changed its course. That's when all the people had all the drama up the road….. The majority of the rain fell up at Mia Mia, in about eight hours, four inches in an hour or so…. This old fella up near Mia Mia kept emptying his gauge.

L: *The water at its peak just came over the floor under the front door into the loung*e [of our house]. *That's when I started to panic and put things up to the ceiling.*
G: *The worse thing was that we didn't know how much further the flood was to come up. But Mackay's like that. As soon as it stops raining its gone.*
L: *It* [the house] *was very well built.*
G: *The house was on 6 ft blocks*.
L: *The water would have been 6.6 ft deep, counting the timber underneath.*

L: *A lot of places did not have the phone on. We had the phone on. The phone went out very early in the morning. We packed up our things. But we only took our purse and whatever we could.*

G: *Where we lived* [in Foulden] *we were a bit low, so Dad used to drive the car up to Mrs Wall's house and put it up on the footpath whenever the river came up. But this time it got washed away*.

L: *It was a big disaster* [1958 flood]. *We thought that we were bad but a lot of others had it much worse. The water just came down in a wall and took everything in front of it…….These people* [a family] *in Foulden sat up in the fruit trees till help came to them.*

G: *Billy Patens house had debris up against the house, then the water started chewing the foundations and the house fell into a hole*.
L: *The water hit them* [the houses], *eroded* [the soil around the foundations], *and the houses fell into a hole. The terrific force of the water makes these huge holes. Then it churns…..It started about 6 o'clock at night…. There was a little house next door to us and the water was above its windows*.
G: *It fell into a hole*.
L: *It was right on the ground really*. *And those people were in with us. There was a house up the road and when all this happened the river come in and that. They were lucky. They took a sheet of iron off the roof and scrambled up there and sat on the roof. And did it rain, it just poured*.

G: *Paten's house fell off the blocks and they wrapped their baby up in a shower curtain and they were trying to get up onto the roof so they smashed a hole through the ceiling because the house was moving. Trying to get up through the roof they dropped the baby. She was bobbing along, but she was in the shower curtain, so she was buoyant, so she shot outside through the window. Someone grabbed her. It was pretty lucky that no one did drown up there.*

L: *McDonald was washed off and there was a banana tree floating so he grabbed it and then got to a big tree and he sat up in that. Then the Proctors threw a rope out to him and pulled him into their lounge room and they had a two storey house. The water was about 6 or 8 ft deep…..It was just a sea of water. All I could think, was would I see anybody again? Whichever way you looked out the window there was water everywhere. It is very low there*.

G: *It* [the river] *started to break its banks at the International Motors Corner*. *They done rockwork up past Foulden, but after the floodwaters dropped the water got in behind the wall and pulled it down…. I remember when dawn came and all the water was tearing down…. and the boats came up through the back….*
L: *And you know how high cane is, they just floated right over the top of that.*
G: *Then two boats came round and put Mum, Mrs* [Betty] *Collard, Morris, Rhonda and Daryl and took them over to Proctor's farm house. And then* [the men] *we got into the boat and they took us straight to Thursdan Creek. Then Betty panicked as she thought Frank had gone missing.*
L: *See, when you split up families it's hard. They took the woman and children first…. See we climbed out that corner window. And we just dropped into the boat. You couldn't get the boat up the steps here*.

G: *All these snakes and rats came up on the back steps, coming down the river, plenty of vermin.*

L: *We were evacuated to Glenella, to the big dance hall. It's still there. They have just repaired it.*

G: *Went to Glenella in boats. We were taken in big Council trucks to the hotel where we were all checked out.*
L: *Had doctors at the hotel. If you needed help, these doctors would help you. Robert Amos got his leg gashed. Dr Chenoworth was doing all the first aid there. This chap said "that will be alright till I get my leg checked by the doctor…" He didn't realise that he was being tended by a doctor.*
G: *Most of cane farmers had boats, and the army. They all helped.*

L: [Immediately after the 1958 flood] *we stayed with friends in Glenella. Then our friends gave us a house on Cemetery Road to live in. Then we moved into our house* [in North Mackay] *in May.*

L: *In the beginning of 1946 we had a flood, and they took us out by boat. The water only came up about 2 or 3 ft, and being up on high blocks it didn't worry us. Then we were taken by boats to the Glenella Hotel. I always reckoned that we should have never built there. When the tide came in the river used to break its banks.*

The Government declared Foulden a disaster area and made everybody move. My neighbours built a new house. I felt so sorry for them. They were not long married,… they had beautiful furniture…… and it just went overnight. They had nothing……They managed to salvage a few things, but once the flood goes through, you never seem to be able to get rid of that smell. You can clean it but…. You never get back what you've lost [from disasters].

We did have our furniture because the water only came over our floor. The government gave blocks of land, we balloted for them. My late husband went in and they just drew lots as to which block of land they got. Land was given all around this area. These houses were mostly housing commission houses. The people in Meadow Street, they bought their own. They got so much money to buy that ground. We just got the piece of ground plus a little bit of money. People moved to North Mackay, Bucasia, Glenella...

We were very lucky. My brother-in-law from Ilbilbie had a cane truck and he came up with his two cousins and they helped my husband pull the house down…. One weekend we had fifteen carpenters and it just went up like a mushroom. I couldn't get over it. It is exactly the same except that we had louvres along the side and we changed them over the years to windows (Plate J.1)*.*
G: *We cut it down between the studs. Dropped all the walls. Cut the floor up.*
L: *Took the roof off, dropped it and stacked it up. Like a jigsaw. We had to get another set of blocks under the house and that was ninety pounds.*
G: *It had a fibro roof and I remember Dad unscrewing the brace and bit and all the roof and only grabbed two bits of fibro.*
L: W*e had a fibro roof and ply ceilings. We still have ply ceilings in the house, but not fibro, we put an iron roof on.*
L: *There would be only three houses moved from Foulden…. These walls* [of the house] *are 5 ft high. You can't get a lot of them over the bridges….. House pieces brought over Glenella way I think, up Sugarshed Road.*

G: *My Dad used to say that a lot of women had a couple of houses built for them. My wife had the same house built twice. Three out of twenty* [houses] *moved. The rest weren't worth doing much with. The rest fell to bits, fell into a hole or that sort of thing.*

L: *If the river was up it would come up over the Hospital Bridge, as it does still now. They had a big railway bridge beside it but they have pulled that down.*
G: *Tommy Pitts* [shop keeper], *he was opposite the Mackay Base Hospital* [in West Mackay]. *But when we ended up moving here* [to North Mackay], *he used to deliver the tucker over here to. He looked after us, the local store…..*
L: *He took your order the day before and they delivered the next day. And sometime you only used to get paid once a fortnight but you used to pay when you could.*

L: *Nobody killed in Foulden. Cremorne there were a couple* [deaths].
G: *They are not really sure who they lost in the Cremorne. There were people moving in and out all the time.*
L: *Along the river there were shacks, I suppose you'd call them squatters. Those shacks were all washed away* [in Cremorne].

L: [The flooding] *started 6 pm on 17 February and it was all over on the 18 February. It was just on dark, and the river was just running….. You were just standing there. It was up to your ankles then up to your knees, it was so swift ….*
G*: …….We went back and had a look at Foulden. It was about three or four in the afternoon* [on the 18/2] *and all the water had gone.*
L: *It didn't last for two or three days. It was just overnight.*
G: *Mackay always drains quickly. We didn't stay there, just looking. We couldn't drive in there, it was all sand and silt, just walked.*
L: *When I went back the morning I didn't know the place, it had changed so much. It was a shambles. What water can do…… I couldn't believe Foulden had changed so much. It was just a heap of rubbish.*

Cremorne flooding
Mr Mick Hodge

Mick Hodge, an engineer, owned a business and home in the Cremorne and experienced a number of floods.

If you look at the problems in Mackay, most of them are man made with poor engineering and with people who do projects for that day, people without a vision. In the olden days, the first thing that we did when we interfered with the river was we built the director wall down the middle of the river. The idea of that was good at the time as it was designed to direct the current to the southern bank and cut off a third of the river. It done two things, it scoured the river up nicely and kept the southern bank navigable for the transport we had at the time, and it also built Cullen Island, the big sand bank, and blocked the river again.

The director wall when it was originally built was only a stone wall. It had a height equivalent to about a 21 ft tide or 22 ft tide. From that level we blocked off a third of the flow. Since then the water has steadied on the downstream side, it's filled up all the mud flats and now all the mangroves have filled up. Now a third of the river is effectively blocked off altogether for flood, hence we are getting a bigger afflux upstream until the director wall is moved. The director wall healed all water to the southern bank and caused huge damage to East Mackay. And it flooded all the public utilities, all the City Council's utilities, all the workshops, all the main roads and the powerhouse. So it shows you that something changed [in the river] *and it was the effect of the director wall. While it was doing one good thing, and still does a good thing, it stops the river from meandering around, and that's sacred now, no-one can move it, it's owned by Mackay Harbour Board* [it has caused inundation of buildings]*. While it is a monstrosity now it was a good idea. It would be silly to move the director wall completely, because you only need to drop it down, because it still stops the river from meandering.*

They then built a railway bridge across the river. They planned to trellis it from bank to bank [across the floodplain] *but they decided that they had to build it cheaper, so they used cheap landfill* [instead of piles], *which formed an embankment and therefore dammed the water, flooding everybody upstream and scouring everything downstream. See, as this low level bridge was built and as the Pioneer River is full of debris, the bridge was packed with debris as soon as it was submerged. So you couldn't get a drink of water on the other side of it. So we had a complete dam built right across the river. So we objected to it for years, but because it was built by the officials it didn't dam the water!*

The first flood which gave any damage to us in the Cremorne was in 1940. It was most damaging to us. It was only a small flood. It banked right up against the railway line. A lot of people had their houses on the ground. All of our chickens were on the ground and nine horses were tied up on the flat and the flood drowned all of the horses and chickens. The flood came unexpectedly at 2.30 am in the morning. One of my friends had a humpy there. Most of the houses were humpies then, and he heard a strange noise and he put his foot out of bed and he was up to his knees in water. It came right into his house at 2.30 am in the morning. It was unexpected then.

At that time we objected [to the damming and flooding]. *But the war was on. So we had a meeting about it with the Mackay Harbour Board, the State Government and the Railway Department and they admitted liability, but there was a war on. So they got away with it.*

Then '42' flood, then '44' flood, then '46' flood was a bigger flood, but we were building our houses up higher so there was less damage. So that time we had another big pow wow at the railway station. The railway and the Mackay Harbour Board was represented. I am the last living person in that delegation. The building of a river model was promised. However, we didn't get anything. In 1951 we got a higher flood. Cullen Island was building up. So we put up with the '51' flood. They then commissioned the Queensland University Professor [then Dr] *Gordan McKay. He built the river model and he wrote a report. And that report was damming. The director wall, the railway embankment and the Forgan Street Bridge are singularly not causing the full damage. But collectively they are a monstrosity.*

The director wall caused another problem. In the olden days every old engineer made cylindrical piles. Nowhat the angle the water hits it [the bridge] *from, you get flow. In the 30s we streamlined all our piles. It was a wonderful idea so long as the current remained constant from that angle. But they had built a director wall at an angle. So when they designed the piles on the Forgan Street Bridge the director wall was already there. But they didn't take it* [the director wall] *into account. So the piles are at a different angle to the flow. Therefore it acts like a aircraft wing. The water hits it* [the piles] *at an angle and transfers force and digs out from the back. Hence in the '58' flood we dug out the piles of the Forgan Street Bridge and part of the bridge fell down. It was an error. And that's causing an afflux. The current hitting it and changing direction causes another afflux. The hydraulic mistake that the Forgan Bridge represents. It's a prize for the idiots. But you can't blame the bloke who designed it, because he was given a plan of the river without the director wall in it. So the combined effect of the railway bridge, the director wall and the Forgan Bridge give us terrific high floods. So we put up with that until the 1970s, when they moved the railway bridge. Since the railway bridge was moved the floods in Cremorne should have been lowered by at least a metre.*

Now if you want to ask me about the floods. We had two effects of the floods in the Cremorne area: we had the ponding effect on the upstream side, and the increase in current velocity that dug all the houses out on the eastern side as it did in the Foulden flood. I think it dug three to five houses out [in Cremorne]. *The speed of the current as it went over the railway line was so high that it dug those houses out. They didn't get washed away, they got scoured out. Where we were we had steady water. So when you get an obstruction like the director wall, like the railway embankment or road embankment, you get a steadying effect on the upstream side and a scouring effect on the downstream side. So the unfortunate people are on the downstream side. They don't get as high water but the speed of the water is faster and it digs out everything around them.*

Fortunately we never had those two main creeks [of the Pioneer catchment, Cattle Creek and the Pioneer River] *hit maximum flood together. We have never yet had the Gooseponds* (Plate J.2) *and Pioneer River flood* [at the same time]. *The danger to Mackay is the Gooseponds. Have a look at what happened when we duplicated the Ron Cam bridge. We lifted the carrageway up feet and left the unfortunate business people there and we have a little bridge across Gooseponds, that's Jane's Creek. Fortunately in the Cremorne, the old timers in the twenties we either built our bridges high and trellised it, or built it low and let the floods go over it. But in the 30s something happened to our intelligence and we built the bridges halfway and the bridges blocked up. In the older days we had* *three culverts through it and we were smart and we then started building the roads above the flood height.*

The '58' flood in the Pioneer River ran about 260 000 cusecs. That's their figures. And they said that it is possible for the Pioneer River to run 500 000 cusecs. And I challenged Professor McKay on that saying " that it's impossible, because every tributary to it would run backwards. All the creeks would run backwards up to Walkerston and what would be Homebush would disappear". Imagine the volume of the water you would have to have to do that. Once you get it [the Pioneer River] *up to around 300 000 cusecs all the water would run backwards, because that is the capacity of the banks. Our banks couldn't carry more.*

I had freehold property in the Cremorne – engineering business (Plate J.3). *We lived next door to the business and a lot of our staff lived around us. But we had a lot of unfortunate people there. See, we had the poor people of Mackay in the Cremorne. Cremorne had a very big population in the 30s. My Dad was good to them. We used to look after them. They were all our people. They all had little humpies or tin sheds under the mangroves. The population in the Cremorne then was about 500. We had a bakery, two corner stores, a hotel and a poultry business and naturally it was all washed away.*

My house was high set, about 10 ft above the ground level. During the '58' flood the water was about 0.8 m below the floor. A cow went under the house and its' horns raked the floor. There was 7 or 8 ft of water over the carriage way of the road. Our place was a refuge [during flood]. W*e used to take the people in because the houses around were low. See, only about three houses were high set. Our place used to look like a League of Nations in all the floods. By the '58' flood the humpies were already gone – lost during the earlier floods. In the 1958 flood we lost about fifty houses in total. A few dozen little houses and humpies were lost, plus a corner store, dance hall, an upholstery shop, and the Cremorne Hotel.*

I put a deputation to the Pioneer Shire asking them for support on the floods. The deputation said that we've got to do something. We've got to build up [our buildings] *or you've got to drop the man-made structures. I rang the Mackay Harbour Board up and ordered 2500 cubic yards of overburden and hired five trucks* [to lift my business up higher by filling underneath]. *We jacked the business up higher and higher. It was an achievement. We lifted the business up 5 ft and maintained production all the time. Put a new roof over the top and kept working. But it cost thousands and thousands of dollars to fill. Incidentally the Council wouldn't give me a permit so I built it without a permit anyway, though they threatened to prosecute me all the time. Built* [the ground up] *about 1.8 m – higher than the road. One of the 1970s floods flooded the business because of the railway bridge. The water covered our floor but gave us no damage. But it won't be flooded anymore because the floods are lower by 1.5 m* [because of the removal of the railway bridge].

Incidentally I led the Cremorne people and we didn't pay our rates because we didn't get any service so we didn't pay. This went on for two years and then I got a call from the Shire Clerk one day and he said "Mick, the Council is going to sell up all the Cremorne". I said "That was interesting. I don't know anybody who would want to buy in the Cremorne". And I told the Council that "Until you give us some service and grade our roads we won't pay our rates". The road was all scoured up by floods, 4 ft holes. Nobody had touched the road for years. Yes, we had town water, but incidentally when we went to the Cremorne they wouldn't give us town electricity as some of the Council didn't want us to move there. So we only had three horsepower. We got town power in about 1939. Then I got a call from the Council saying "you'll have a grader in the morning by 9 o'clock". And I said, "Mr Chairman, when the grader comes at 9 o'clock we will pay our rates by 10 o'clock". And from then on we had no problem. Every year they'd grade our road and we would pay our rates.

But we got another problem. Everytime they build a road up the water going over the road is effectively cut off. They haven't woke up to themselves yet. The Mayor has spent millions of dollars raising the streets, so the people camp on the street as the people's houses are lower than the street. In 1962 I tried to plan to help Mackay. We had a big argument in town about draining the river. In *the 1958 flood all the low areas were flooded. There was a great argument in town. The Mayor I said to him "Until we get enough brains to drain the river south, you are going to have this problem". I wanted them to make the network of roads flat, lower than the people, draining the water south. You need wide streets, you need to put a wide based drain and let the water run down the streets so it won't do any damage. But they lift the streets every year and the town is getting flooded out.*

If they moved the director wall, then the river would drench itself, because it is currently blocked by the effect of the director wall, sand and mangroves. The Mackay Chamber of Commerce tried for years to let the sand people move Cullen Island but it didn't work because of the engineers receiving a percentage of cost.

The bottom of Barnes Creek is solid rock. The Pioneer River has drifted as far north as it can. Over the centuries the river has moved up from Homebush. See, in the '94' flood the river used to go around the bottom end of Gordon Street but in the flood it moved north. The river has come right over and hit against a rock wall, Rockleigh. In the eastern Cremorne it is all rock. They had three acres of land down there and they had a swimming pool, toilets and all the recreation for Mackay. Big rock pools. In 1936 the Showmans Guide and the Show Association had a disagreement, and the whole of the side shows went over to the Cremorne. But that all went with the scour of the water, we lost all that.

The Councils after the '58' flood swapped land in various places around Mackay. So people moved from the floodplain, especially from Cremorne [and Foulden], *mostly to North Mackay around Quarry Hill. Swapped land* [north of the river] *for their land* [on the floodplain]. *They couldn't swap their land for land south of the river. About three big houses moved. Some of the others demolished their houses, wanted to go the other way. People sold their blocks of land or just left them. Cremorne just deteriorated then, but it is growing again now. In 1970 flood, Hodge was about the only business house left in Cremorne.*

I reckon that when you see unfortunate people as in the Cremorne, people invested their whole life's savings in a piece of dirt and a house and to see them lose it. And you've got to remember that it doesn't hurt the rich much. And as I said in a public letter "I couldn't worry about Hodges', because we could afford to live in the Cremorne. We have never put in any flood claim. We could afford to live there, but what about the poor unfortunate people that can't afford to get out".

Plate J.1: North Mackay - House moved from Foulden following the 1958 flood
Collection: Miriam Middelmann

Plate J.2: The Gooseponds
Collection: Miriam Middelmann

Plate J.3: Cremorne - House and business owned by Hodge
Collection: Miriam Middelmann

APPENDIX K : CONTEMPORARY REPORTS OF THE FEBRUARY 1958 FLOOD

The following material of the major flood in Mackay in February 1958 is taken from the Mackay *Daily Mercury*.

The Daily Mercury, Monday, February 17, 1958

HEAVY FLOODING IN CITY

Wet season starts with more than foot of rain

MAIN ROADS CUT

Large sections of Mackay city and suburbs were under a foot or more of water at noon yesterday.

Coastal areas to the north were blocked by the Gooseponds which was 2 ft over the bridge at Evans Avenue and about a foot over in Malcomson Street at 2 p.m. yesterday. At 9.45 a.m. the flooded Pioneer River cut off traffic over the hospital bridge. By 4 p.m. the level had risen to more than a foot and rising. At 6 p.m. it rose sharply to 4 ft and was maintaining that level at 10.30 p.m. At the Gooseponds late yesterday, a P.M.G. truck was stranded in shallow water with a wet engine at the Malcomson Street Bridge while attempting to get three poles which had been knocked over by a landslide on the road to Glenella…..In the centre of the city at the Victoria-Wood Street intersection pedestrians were walking knee deep across Victoria Street. At the Victoria Street – Wellington Street intersection water was lapping a car door packed near the kerb, and was 7 or 8 in deep in Crawford's corner store. In Goldsmith Street, East Mackay at 6 p.m. water was about 3 in above floor level on the front door of a low blocked home. In West Mackay Bridge Road near the Fourways intersection many streets were flooded from fence to fence. Water was lapping entrances in the Fourways shopping centre and goods on floor level at the rear of the premises were moved to higher positions.

DEATH IN FLOOD

Tail lights burning under water led Mackay police to a drowned man in a small sedan car submerged in the Gooseponds on Saturday night.

The man was Denis Laurence Matthews (23), fitter, of Forsyth Street. He went off the approaches to the Malcomson Street bridge over the Gooseponds at approximately 9.45 p.m. No one saw the accident. The car, which went off the left hand side of the bridge outbound, was completely covered by 8 ft of water which was lapping the decking of the bridge at the time. At 10.40 p.m. Douglas Miller, of Malcomson Street, was driving across the bridge when he saw the tail lights of the submerged sedan.

Second car in

As he backed up to investigate, another sedan travelling outbound left the approaches to the bridge and plunged into the Gooseponds. Its nearside wheels lodged on the top of the submerged car. The five men in the second car, which was driven by Bruce Graham, of Farleigh, escaped injury. They reported the accident to the Mackay police and requested a crane to lift their car out. When the crane had dragged out Graham's car it "fished" for the still glowing tail lights of Matthew's sedan. Diving was impossible because of the muddy water. A rope finally was hooked under the offside rear springs of the submerged car and at 12.15 a.m. the crane hauled it to the surface. Matthew's body was found over the rear of the driver's seat facing the back. Police said last night rain could have obscured visibility on the bridge which had no handrails.

The Daily Mercury, Tuesday, February 18, 1958

POLICE EVACUATE AT CREMORNE
River breaks into city:
Mirani bridge collapsed:
Finch Hatton awash
CRITICAL TODAY?

About 50 people were evacuated by police last night from the Cremorne and Harbour Landing areas, as the Pioneer River broke its banks.

Others evacuated privately following police radio warnings, which began at 9.30 p.m., of flood danger in the low-lying areas adjacent to the river in the city reach.

Into City

After 11 o'clock the river broke its bank on the city side of River Street. By 11.40 it had flooded Carlyle Street to 8 in over the crown of the road and had entered a store on the Victorian-Carlyle Street corner. Late last night City Council engineers predicted that to 3 a.m. the river would maintain its level of 24 ft at Forgan Bridge with possibly slight rises. At 1 a.m. it was maintaining 24 ft in spite of a falling tide. They predicted a critical period at 11.40 a.m. at the top of the 18 ft 2 in tide on the river today. Two families were evacuated from Town Beach and picked up in Rae Street by an army lorry and taken to private accommodation for the night. Residents in the Marajou area on the Farleigh side of the Hospital Bridge were evacuated for safety to Glenella and Farleigh last night. Water was over the main road at Foulden. The flood in the river was slapping the under section of the floor at Michelmore's over the river………………… About 11 o'clock at the top of a 16 ft 6 in tide in the river, the flood water submerged Barnes Creek Road at Cremorne between the Buffalo Hall and the Hotel. At 11.30 p.m., when a press car left the area, the water was about 6 in over the road and running fast.

Army truck

At 11.30 p.m. the river was lapping under the railway bridge but had not broken the River Street bank. Police used an Army lorry to transport pensioners and families to an emergency refuge at the Wood Street Salvation Army Hall. Salvation Army officers said the emergency centre would remain open throughout the night for the people flooded from their homes. Captain V. Brown, of the Salvation Army, remained with a police crew in the Army lorry ready for further evacuations. At the hall, evacuated families and old people were settling down for the night with blankets. Salvation Army members were arranging to supplement food the evacuees took with them when they left their homes. A police radio truck which had been on standby in the Cremorne area withdrew at 11.30 p.m. to Forgan Bridge. Police roped off danger areas at Cremorne. Residents had left low-lying homes to sleep in the Cremorne Hotel. They stacked furniture and belongings above flood level in their homes before leaving. Residents were expecting the worst flood in nearly 20 years.

"Looks bad"

Cremorne shopkeeper Mr. D. Wells said as he and his family prepared to leave their home for the Cremorne Hotel "It looks really bad tonight. I've been here for 18 years and I've never seen it look like this. The water tonight is coming at us from the south. All other times it has come from the west". Police borrowed Mackay Surf Lifesavers' rescue boat and left it ready for any emergency at the hotel.

LATE NEWS

At 1.45 a.m. today, the Pioneer River was running 26 ft high at the Forgan Bridge gauge, and rising. Water was racing down Brisbane, River, Carlyle, and Tennyson Streets. Police were patrolling the lower reaches of the flooded streets in boats.

City registers 28.95 inches of rain in four days
TRANSPORT OUT OF CITY BLOCKED
Sharp rise in Pioneer River
Rainfall in Mackay had totalled 28.95 inches in the four days to 9 o'clock last night since the wet season started on Thursday.

The official recording at the Mackay aerodrome was well under a private reading of 32 in on a city gauge for the same period. The drome figure put Mackay's rainfall at 15.20 in in the 24 hours to 9 a.m. yesterday followed by a further fall of 4.65 in in the next 12 hours.

River rise

Yesterday's rain was sufficient to maintain local flooding in the city area, but heavy falls in the upper reaches were followed by a sharp rise in the Pioneer River early last night. At the aerodrome the official registration for the 48 hours ended 9 a.m. yesterday was 21 in 55 points (pts). Of this, 15 in 20 pts fell in the 24 hours to 9 a.m. and in the next 12 hours to 9 p.m. a further 4 in 65 pts were recorded. In the 24 hours ending 9 a.m. yesterday a private gauge showed a reading of 18 in 69 pts From 9 a.m. to 8 p.m. a further 3 in were registered.

Flooding yesterday had caused a complete blockage of air, road and rail transport out of Mackay and shipping schedules were disrupted. The aerodrome which was closed at 3.30 a.m. on Sunday remained closed all day yesterday. Classes in many schools were cut by more than half. One of the worst affected schools in the flood area was North Mackay, which had an attendance of 90 out of 450. The lowest attendance for one class was four. There was a full roll up of teachers. The Eimeo road section of the school near the Gooseponds was under water. Many schools in the district were shut. Wind direction changed from east, southeast to east and later in the afternoon to south, southeast. Velocity varied from 12 to 25 knots.

Filled yards

It was a repetition of Sunday in the suburbs and city as water from flooded storm water drains filled back yards, gutters and streets inches deep. The heavy rain eased off at 6 p.m. and late afternoon sun tried to break through the heavy overcast but by 7 p.m. it was raining heavily again At the Mackay bulk handling terminal, manager (Mr. H. W. Burkitt) reported leakage in the main shed was "nothing to speak of". In the shed was 89 200 tons of sugar and the bulk vessel Ninny Figari (bound for the United Kingdom), which has been berthed in Mackay since Saturday, could not be loaded until the weather cleared.

All roads out of Mackay were blocked by flood waters during the day and the R.A.C.Q. advised motorists not to travel.

North of Mackay the roads were blocked at the Gooseponds, both in Malcomson Street and Evans Avenue. The Evans Avenue route was impassable, but heavy trucks negotiated the Malcomson Street Bridge. The swift wash prevented cars from crossing until about 6 p.m. when the water was falling…

The Daily Mercury, Wednesday, February 19, 1958

FLOOD RECORD
Beat 1918 level
SIX HOMES, HALL LOST
Worst floods in the history of Mackay which exceeded the 1918 cyclone levels were receding slowly last night.

About 180 people evacuated by police parties from their floodbound homes on Monday night and yesterday spent the night in dry areas of the city. At least six homes and the Buffalo Hall at the northern approach of the Forgan Bridge are known to have been swept away. City business houses entered by the flood water have suffered heavy stock and plant losses. Thousands of acres of rich *canelands along the Pioneer River flats were inundated. Erosion losses are expected to be heavy. In the city area, the Pioneer river broke its banks before 8 a.m. to flow down Nebo Road and through business and residential areas, leaving the immediate city area a virtual island.*

Rescued

First contact with North Mackay was made after 5 p.m., when crossing of flooded sections could be made on foot and by boat. Flooding in the area was reported to be relatively light. At Foulden Mr. A. E. Zunker crossed the racing river current in a rowboat to rescue an elderly couple marooned on the roof of a dangerously tilting house. Three houses were washed from their sites in the Foulden area and three in the Cremorne area. Rail, road and air communications in and out of Mackay were cut and about 1000 telephone subscribers were cut off.

Record level

Crisis period for Mackay yesterday was between 9 a.m. and 11 a.m. At 9.30 a.m. flood level at the Forgan Bridge was at a record 30 ft…Heavy flooding in south and east Mackay yesterday was mainly caused by the river breaking its banks between the western end of Victoria Street and the Commercial Hotel. About 6 a.m. a sheet of water rushed down Shakespeare Street and to a lesser extent down Gordon and Alfred Streets, flooding the railway station area and areas further south. In the south Sydney, east Shakespeare and Keats Streets areas water rose about 3 ft in half an hour. It covered fences in South Sydney Street and Keats Street. Late last night streets in the area were still covered by about 2.5 ft to 3 ft of water and was dropping very slowly, Sewerage systems were out of order but temporary arrangements had been made by the City Council on Monday.

RIVER ROSE A FOOT OVER 1918 LEVEL

The Pioneer River yesterday rose above the recorded levels of the 1918 cyclone.

Peak level of 30 ft at the Forgan Smith Bridge yesterday morning was about one foot above flood level recorded at the bridge site in 1918. Working from flood survey maps, consulting engineer Mr. C. N. Barton last night put the general level of yesterday's flood in residential areas as one foot above the 1918 level. According to the plans yesterday's flood was a foot higher at the Commercial Hotel corner. It was also a foot higher at the lower (western) ends of Victoria and Gordon Streets. In 1918 the flood is not recorded as having broken over Milton and Peel Streets. In 1918 the river broke its bank and crossed Nebo Road at the northern end of the Showgrounds. There was conflicting evidence about water at the southern end of the showgrounds. But yesterday the showgrounds were completely flooded to knee depth and portion of the fence along Nebo Road was tilted by the force of the water. Mr A. Grant who was in Mackay during the 1918 flood, said from his observations the level of water today was much the same as in 1918….

Station off air

Normal services of Mackay's commercial radio station, 4MK, was disrupted because of a failure through water at the Mt Bassett transmitting station.

The gas main in North Mackay was severed in six places by floodwaters in the Pioneer River for the first time in history. Workmen were unable to begin repairing the damage until the water level had subsided sufficiently at 6 p.m.

RESCUERS EVACUATE ALL CREMORNE AREA

Rescue teams yesterday evacuated 120 people from the Cremorne area.

They had stayed overnight in their homes and in the Cremorne Hotel during the areas most severe flood battering to date. Floodwaters washed away three homes and the Buffalo Hall. Sixty people had been evacuated by the police to the city area on Monday night. Yesterday they were forced to wait *until floodwaters had dropped sufficiently before starting the second evacuation operation at 3.45 p.m. <u>Police and civilians led by the officer in charge of the Mackay Police District (Inspector R. V. Woodbury) brought women and children from the verandah of the Cremorne Hotel by boat, and guided men along a rope chain to the end of the Forgan Bridge.</u>*

Eight men led by Mr. R. Wormald, radio mechanic of West Mackay, had fought their way with a rope through the river, still dangerously high, to a power pole 50 yards away. The rope was then anchored to the pole and carried through fast flowing water to the next anchor point – the service station. From there the rope was taken over the road to the hotel. The last boatload from Cremorne was safely on the Forgan Smith Bridge at 6.20 p.m. Approach road to the bridge was completely washed away with big slabs of bitumen torn up by the force of the water. The fast flowing river had demolished the Buffalo Hall at 7.30 a.m. yesterday. All that was left was a piece of buckled dance floor just above the surface. A wooden barrier around a service station nearby was smashed and buckled.

Poles over

Along the length of the Harbour Road from the service station, power and telegraph poles leaned with their lines hanging in the water. Cremorne Hotel, which sheltered thirty men and women at the height of flood was covered in debris and its sagging front verandah showed signs it had been damaged by the flood. Along the riverbank adjacent to the hotel were gaps from which houses had been carried or damaged by the force of the flood. Many of those rescued told pathetic stories of the loss of not only their homes but everything they possessed. Mrs E. Morrow, of Palm Street, her two daughters and husband spent the night in the hotel and watched their house swept away at 6 a.m. Mrs Morrow said: "We have lost everything apart from a portmanteau of clothes. We lost our furniture, house and even my daughter Lynette's glory box. She is due to get married next month. We have lived in Cremorne for twelve years and have survived other floods. But we never want to settle in Cremorne again".

Lost _2000

Mrs A. Wells, who, with her husband, owns a small shop opposite the Cremorne Hotel said: "It was a night of terror. It was not only our losses but those of the other poor people in the Cremorne, too. We (herself, husband, son, daughter-in-law and two children) have only the clothes we stand up in Mr. Wells said he estimated his loss of stock, house, furniture, refrigeration and such at over _2000. Some were more fortunate. Mr. and Mrs. L. Herman, with their 18 months old daughter, said after the rescue the water had only lapped the floorboards of their high blocked house and there had been no loss of furniture. However, an outhouse had been lost and fowls drowned. The 30 people who stayed in the hotel told a tale of hunger and fear. The kitchen was flooded and locked and many had not eaten since lunchtime on Monday. Apprentice fitter R. Malone, of Shakespeare Street, who went to help and remained to be stranded on Monday night, gave his description of the end of the Buffalo Hall: "At 6 a.m. the outhouses at the side of the hall went. An hour later, the back of the hall started to collapse, then the right side, and finally it collapsed completely. As the wreckage drifted downstream it hit a section of the approach to the railway bridge, lifted the line and twisted it over." Of the night in the floodbound hotel, Mr. Malone said, "throughout the hotel it did not look as if the building would go, but the water rose 4 ft up the wall. Everybody evacuated the ground floor and moved to the upstairs section. There was no food and all we had were a few lollies, some cake and prunes. Asked why people did not take advantage of the evacuation on Monday night, Mr. Malone said they thought they would be safe in the hotel.

POWER FAILED

North Mackay was without electric power during most of the flood ordeal yesterday.

Power to the North Side failed at 5.15 a.m., and had not been restored last night. A Regional Board spokesman said it was thought the failure was because a pole had been washed out…..

The Daily Mercury, Wednesday, February 19, 1958

TWENTY FORCED OUT OF FLOODWATERS

Pensioners were forced to leave their cottages in East Mackay yesterday.

Working from three out-board motor dinghies, two policemen and a number of civilians successfully evacuated 20 aged pensioners from their cottages in MacArthur Street between 8 a.m. and 10 a.m. as floodwaters 3 and 4 ft deep swept through the area…..The evacuees were taken to a high blocked house in Ready Street. The water here was just as deep but the house was well above its level. After the evacuation was completed a five-ton Army transport truck, which was being used in rescue operations, churned through flooded streets with food supplies for the pensioners. Manned by Constable G. A. Williamson and civilians, the truck made its way along flooded Shakespeare Street into Prospect Street, which was under 3 ft 6 in of water, and Evan Street, which was a raging torrent….There was heavy general flooding in South and East Mackay areas. Parts of Hucker, Wentford, Prospect, Goldsmith, Gold, Evan, Shakespeare, Byron Park, Porter, Moore and Ready Streets were 5 ft under. By late afternoon the water level had dropped to about 4 ft

---

AS WE SAW IT

Things got into some funny places during the flood crisis hours. Among them was the pushbike left hanging over a signpost at the Shakespeare-Goldsmith street corner.

A bicycle rack in the middle of Carlyle Street yesterday afternoon looked out of place – the road was only open to swimmers and boats.

Jack O'Brien, waterside worker, of Shakespeare Street, received lacerated wounds and abrasions to the right shin when he stepped into a manhole which had been uncovered by water.

The Daily Mercury, Thursday, February 20, 1958

BIG FLOOD LOSS
SEVENTEEN HOUSES DEVASTED AT FOULDEN

At least three houses were swept away and 14 wrecked or badly damaged when the full force of the flooded Pioneer River hit the settlement of Foulden on Tuesday.

Foulden, on the northern bank of the Pioneer River was completely isolated by road, rail and telephone until yesterday morning. Dozens of people in the area were homeless yesterday and more than 12 modern vehicles were upturned and buried in the sand. Acres of sugar land were flattened, part of the Foulden road was washed away and parts of the main northern railway line were feet deep in sand.

Clothes only

Residents who had been rescued by boat returned to their mud, silt and sand covered homes when flood waters receded yesterday in an attempt to rescue property. Many had lost all their belongings except the clothes they were wearing at the time of the flood. Last night all had been accommodated at hotels or at the homes of friends. Foulden felt the full force of the flood when the river burst its banks and smashed into the road about 5 a.m. on Tuesday.

During the peak of the flood,

- ***People were rescued from drowning.***
- ***Houses with people inside or on the roofs were swept yards by the current.***
- ***People scrambled into the high branches of trees to safety and livestock were drowned.***

Motor transport was unable to get to the settlement yesterday because of the sand covered road on the northern approach to the Pioneer Bridge. Residents rescued were taken to the Glenella Hall from where they obtained other accommodation. They paid tribute to the energies and generosity of police and civilian helpers.

CLUNG TO TREE

During the Tuesday flood a man, his wife and three sons spent nine hours clinging to the branches of an orange tree with only one orange which was growing on the tree for food. They were Mr G.A. Nielson and his family who yesterday were trying to salvage property from their wreaked home. In driving rain yesterday morning, Mr Nielson said he expected to suffer a complete loss from the floods. At 10.30 on Monday night water first entered his low blocked house, so he swung two wire mattresses from the cross beams of the roof, inside the house, and placed his wife and children on them.

Bashed hole

When flood waters continued to rise he bashed a hole in the side of his house and struggled with his family to an orange tree in the backyard of next door neighbour Mr. Clarence Reeves. When trying to get to the tree, a three-year-old son, Paul, was washed away and almost drowned. Mr. Nielson said he managed to get his son to the tree. Other members of the family had been temporarily pinned inside the house by swirling furniture and timber. They sat in the orange tree from 6 a.m. Tuesday until they were rescued at 8 p.m. Included in his flood losses was a wallet containing fifty or sixty pounds, he added. When the water receded his house was a smashed wreck of timber, furniture and mud. About 5.30 a.m. a fibro house belonging to Mr. Colin Macdonald with about 16 people inside was swept from its 8 ft high blocks and carried about 100 yards by the current. The occupants tore a strip of iron from the roof and clambered outside where they were safe from the water. Miss Margaret Lemberg (18) was knocked off the house and spent 1.5 hours clinging to the branches of a fig tree. Mr. MacDonald also took refuge in the tree.

Baby fell in

A three-weeks-old baby, Kathleen Paton, daughter of Mr. and Mrs. Paton fell in the water swirling outside the house but was rescued by Mr. Royce Atherton. She was revived with artificial respiration. The six roomed house of Mr. Clarence Reeves, his wife and five children, was smashed when flood waters hit it and tilted it on a dangerous angle into a crater scoured out at the side of the house. Mr Reeves said, as he was carrying possessions from the house yesterday, that he had broken a hole in the ceiling of his house and placed his wife and family on the roof about 2 a.m. Tuesday. His car was buried in sand in the backyard of the house. He estimated his total loss was about _4000.

TWO DEAD, ONE MISSING AFTER CREMORNE FLOOD

Two men were found drowned in the Cremorne area early yesterday morning and a woman is missing, presumed drowned.

The men were: Edward Lee McCarthy (40), labourer, of Cremorne, and Michael Francis Piggott (36), labourer, also of Cremorne. The missing woman is Lilly Peters (or Peterson), aged about 65, also of Cremorne. To late yesterday no other fatalities had been reported to police. Extensive inquires had been made in the worst of flooded areas and no further persons were reported missing.

Found bodies

Bodies of the drowned men were found by Mr. Vernon Chilly, of Mt. Bassett, at 7 a.m., about half a mile from the northwest end of Palm Street. The bodies were about 50 yards apart and about 150 yards from a small house which collapsed late on Monday night or early Tuesday morning. Police presume that the two men had taken refuge in the house. It is believed the missing woman was also in the house when it collapsed. Police inquires and searches yesterday found no trace of the missing woman……..

LIMIT ON WATER SUPPLY REMAINS

City water pumping stations will not be back in full operation for 'some days'.

Mackay is still being restricted to a maximum water consumption of one million gallons a day, following the flooding of pumping stations on Tuesday. Yesterday both pumping stations at Nebo Road, flooded on Tuesday, were pumped dry. The City Council was endeavouring to dry the motors and switch apparatus. The Regional Board transformer, which was also put out of commission, due to flooding, was still unable to be fixed yesterday.….The Council has not had to restrict the use of the sewerage system in spite of floodings of some pumping stations.

OVER BOWSERS

…Men yesterday were clearing mud and silt from the Pioneer Service Station at the northern approaches to the Pioneer Bridge. Manager (Mr. W. Jocumsen) said the floodwaters had swept over the top of the 6 ft petrol bowsers. About 6 a.m. there was a sea of water as far as the eye could see to the north. The bitumen had disappeared and there was from 2 ft to 5 ft of sand across the road for about a mile. During the flood at least one car had been hurled against a tree and buried….

SURFMEN HELPED

Mackay lifesavers worked an 18-hour stretch during the critical stages of the flood at Cremorne on Tuesday. The surfmen were asked to assist in the flood rescue by Mackay police chief (Inspector R. V. Woodbury).

APPENDIX L: SEQUENCE OF FLOODING IN MACKAY, PRIOR TO LEVEE CONSTRUCTION

The following material is taken from a report for the Pioneer River Improvement Trust (McKay and Gourlay, 1962) and describes the sequence of flooding in Mackay, prior to levee construction.

The first areas flooded were the cane fields and swamps of West Mackay, the swamps in the Cremorne-Barnes Creek area and the Foulden farming area. Flooding then occurred in the low-lying residential and commercial areas of Mackay, particularly in the vicinity of River Street, Shakespeare Street, Cremorne and low-lying areas of North Mackay. Extracts from McKay and Gourlay (1962) follow:

1. River Street flooding

Floodwaters first spill over bank into River Street between Michelmore's store and the Railway Bridge when the Forgan Bridge gauge reads 13.5 ft. This represents a discharge of 100 000 to 130 000 cusecs at Pleystowe depending on the tide. This water flows in a southeasterly direction across Carlyle, Victoria and Tennyson Streets to Lawson Street, where it flows through culverts in the railway embankment to the Sandfly Creek area. This is what occurred during the flood on 8 February 1954 [7.45 m GH at Mackay].

As the flood rises further, spilling into River Street occurs downstream of the Railway Bridge and River Street is inundated from just downstream of the Forgan Bridge to Tennyson Street. Since the culverts through the railway embankment are of small size and the area to the east of the embankment is filled with water entering from the river via Sandfly Creek, the floodwaters now back up behind the railway embankment. When the water exceeds that of the river bank between Tennyson and Byron Streets, water flows back into the river. This was observed during the floods on 11 January 1951 [8 m GH at Mackay] *and on 31 March 1956* [7.85 m GH at Mackay]*…*

For still higher floods such as on 18 February 1958 [9.14 m GH at Mackay] *the river overflows upstream of Forgan Bridge between the bridge and the Harbour Board office and water flows across the Sydney Street intersection down River Street towards Lawson Street. Floodwaters now overtop the railway embankment from a point near Alfred Street to the river and spill into the Sandfly Creek area. It is not absolutely certain whether water returns to the river between Tennyson and Byron Streets as before, as it appears that the general flow here is parallel to the river across the railway embankment with some flow in a southerly direction into Sandfly Creek in the vicinity of the Butter Factory. Under these conditions, the flood level in the city to the west of the railway embankment becomes relatively constant while that in the Sandfly Creek area increases with the size of the flood. Flood levels in River Street where the initial flooding occurs also increase with flood magnitude. No water entered the area to the west of the embankment from the Shakespeare Street breakthrough during the February 1958 flood owing to the higher level between Shakespeare and Alfred Streets near the railway goods yard.*

The period of inundation of the city is difficult to determine as it depends very much on the drainage characteristics of the area, as well as on the tide and the rate of fall of the flood. However, the period that the river is actually spilling at River Street, ie Forgan Bridge level is greater than 13.5 can be determined. It varies from four hours on 8 February 1954 to 18 hours on 18 February 1958.

The river level at Fisherman's Wharf is not known accurately but it appears that it was 4 to 5 ft. lower than that at Forgan Bridge at the peak of the February 1958 flood and about 2 ft. lower for January 1951 and March 1956 floods.

The general behaviour of the 1946 flood is different to the above in the following respects:

1. *No overflow occurred upstream of Forgan Bridge even though the gauge reading was 18.18 and the ground level here is 17.1.*
2. *No return flow into the river appears to have occurred until some distance downstream of the Butter Factory, the bank between Tennyson Street and the present Fisherman's Wharf being above flood level.*

The first of these discrepancies could be accounted for by an error in the Forgan Bridge flood level. A value of 16.18 would be more consistent with other flood data. The second is probably due to the fact that on this occasion there was a bridge in the railway embankment with a considerably larger waterway area than the culverts, and the water did not bank up behind the embankment.

2. Sandfly Creek flooding

Floodwaters in the Sandfly Creek area come from three sources:

1. *Backwater from the river downstream of Fisherman's Wharf; this includes the effect of the tide.*
2. *Water from River Street flowing through or over the railway embankment.*
3. *Water from Shakespeare Street breakthrough flowing down Shakespeare Street and crossing the railway line between Shakespeare Street and Stevenson Street.*

Flood levels in the area will be influenced by the tide height (the area is extensively flooded during high spring tides) and the magnitude and duration of the flood, the latter factors having a predominant effect.

3. Shakespeare Street flooding

Both during the 1918 [8.86 m GH at Mackay] *and February 1958 floods, water spilled over the high bank in the vicinity of the intersection of Shakespeare Street and Nebo Road in West Mackay. Little is known of what happened in 1918 as the issue is confused by the flooding the day before from the storm surge. However, in 1958 it is known that large areas on either side of Shakespeare Street were flooded. The general movement of floodwaters was east through the city along Shakespeare Street, vearing south after crossing Wood Street to cross the railway line between Shakespeare Street and Stevenson Street. The floodwaters then merged in the Sandfly Creek area with water from other sources. The depth of the floodwaters ranged from about 1 to 3 ft.* [31 cm to 92 cm].

From the above descriptions it can be seen that the general movement of floodwaters, and the areas inundated, in Mackay are quite clear. However, information is inadequate on the flood level of the river in the vicinity of the Butter factory (Fisherman's Wharf) which makes the design of protective works for the River Street area difficult. Also the problem arises as to which area suffers the most from a flood. For instance, the River Street area has been flooded eight times since 1918, and there have been some close shaves. The Shakespeare Street area has been flooded only twice during this period. During the February 1958 flood the depth of flooding was generally greater in the River Street area while a greater area and many more people were affected by flooding in the Shakespeare Street area.

4. Flooding in Cremorne and North Mackay

Relative little specific information is available concerning flooding in this area. General movement of floodwaters appears to be that water overflows the director wall upstream of Cremorne and then divides, one current flowing towards Barnes Creek, the other flowing between Cremorne and the director wall under the Forgan Bridge. When the capacity of the

Barnes Creek Bridge waterway is exceeded, water banks up behind the road embankment and then overtops it (February 1954 flood). Higher floods (1946, 1951, 1956 and February 1958 floods) overtop the railway embankment, which then acts as an overflow weir. This embankment was washed out during both the 1946 [8.04 m GH at Mackay] *and 1951 floods. While the railway embankment is overtopped, it is not certain whether the Barnes Creek Railway Bridge is overtopped also. Levels for the 1956 flood indicate that it was not on that occasion, but it seems that it* [the Barnes Creek Railway Bridge] *was overtopped during the February 1958 flood.*

A comparison of flood levels for the February 1958 flood and ground levels in the North Mackay area indicates that floodwaters must have flowed from the Cremorne-Barnes Creek area across Malcolmson Street and Evans Avenue into the Gooseponds and Vines Creek. The depth of water would have to be no more than one foot [30.5 cm], *probably less…*

APPENDIX M : MACKAY CYCLONE HISTORY

This list has been compiled from several sources, most notably an unpublished list compiled by Jeff Callaghan of the Bureau of Meteorology (Callaghan, 1999), a database of cyclone tracks developed by the Bureau's Severe Weather Section in Brisbane (BoM, 1999) and Appendix 1 in Harper (1998).

Cyclones which passed within 75 km of Mackay are shown with their date in **bold**; those which passed between 75 and 150 km of Mackay are shown with their dates underlined. More distant cyclone for which tracks within 300 km or for which an impact on Mackay has been recorded are also included.

2 March 1867

An unnamed but severe cyclone brought gales and did much damage to Bowen, 160 km to the northwest. Whilst we have found no reported impact from Mackay, the 5-year old settlement almost certainly suffered some impact.

30 January 1870

An unnamed cyclone of unknown strength probably crossed the coast between Mackay and Bowen. Given the damage in Bowen and subsequent flooding in Peak Downs and Clermont inland off Mackay, it is likely that damage was caused in Mackay.

30 January 1884

An unnamed but severe cyclone (Category 3?) crossed the coast near Bowen (160 km north-west). Severe flooding was reported from Mackay and a 3 m storm surge was recorded at Poole Island in Edgecumbe Bay south-east of Bowen.

17 February 1888

An unnamed cyclone (Category 3?) recurved just east of Mackay with severe winds demolishing several houses. The *Geelong* ran aground with the loss of two crew and the *Youyang* was dismasted.

4 February 1898

Cyclone *Eline* (Category 3?) recurved over Mackay causing extensive destruction and flooding. Many buildings including the Court House and two churches, were destroyed whilst many others were damaged. The major flood caused the Pioneer River to shorten its course by 4.8 km (its present course). The lowest barometer reading was 984 hPa.

28 January 1910

An unnamed cyclone (Category 2-3?) which had originally crossed the coast around Cape Tribulation north of Cairns before re-crossing the coast near Townsville and degenerating into rain depression. Major flooding was experienced in Mackay.

10 January 1911

An unnamed cyclone, which had originated in the Gulf, had degenerated to a rain depression before it passed about 400 km to the west of Mackay bringing heavy rain and some flooding.

11 February 1911

An unnamed (Category 1-2?) cyclone paralleled the coast from the Cape to Mackay bringing heavy rain and flooding. The rain depression finally crossed the coast near Mackay.

23 March 1911

An unnamed (Category 1-2?) cyclone recurved to the east of Townsville before paralleling the coast to the southeast. By the time it reached the Mackay area it had degenerated into a rain depression centred about 200 km off shore.

16 January 1913

An unnamed low category cyclone (Category 1-2?) recurved to within 200 km to the east of Mackay. No reports of damage have been identified.

4 April 1913

An unnamed low category cyclone (Category 1-2?) paralleled the coast within 250 km to the east of Mackay. No reports of damage have been identified.

8 February 1915

An unnamed, but low category (Category 1-2) cyclone paralleled the coast passing within about 70 km of Mackay. No reports of damage for Mackay have been identified, however, considerable damage was experienced in Bowen.

10 December 1915

An unnamed cyclone (possibly Category 3) which approached from the north, probably within 75 km, hit Mackay. Winds bent iron telegraph poles double and damaged roofs in the town.

27 December 1916

An unnamed severe (Category 3?) cyclone crossed the coast near the Whitsunday Group about 110 km to the north. The lighthouse on Flat Top Island off Mackay was severely damaged. After moving inland this cyclone brought disastrous flooding to the Clermont area with the loss of 62 lives.

14 December 1917

An unnamed (Category 1-2?) cyclone crossed the coast perhaps less than 50 km to the north of Mackay, bringing gales and heavy rain. No reports of damage in Mackay have been identified.

21 January 1918

An unnamed severe cyclone (Category 4) crossed the coast just to the north of Mackay. The central pressure was less than 933 hPa. An estimated 1 200 houses were destroyed and very few surviving buildings escaped damage. The cyclone crossed the coast at close to (a relatively small) high tide and the 3.6 m surge that accompanied the cyclone caused great damage and accounted for at least 13 of the 30 people who lost their lives. Heavy rains which followed the cyclone gave rise to the second highest flood on record for the Pioneer River two days after the storm tide.

5 April 1921

An unnamed severe (Category 3) cyclone crossed the coast in Broad Sound having passed about 140 km off Mackay. No reports of damage in the town have been identified.

8 February 1926

An unnamed (Category 1-2?) cyclone recurved off the coast from Townsville. It approached to within 230 km of Mackay. No reports of damage in the town have been identified.

21 April 1928

An unnamed (Category 1) cyclone recurved near Mackay and Broad Sound. No reports of damage in Mackay have been identified.

20 February 1929

An unnamed (Category 1) cyclone recurved off Townsville and approached to within 250 km of Mackay. No reports of damage in the town have been identified.

26 February 1929

An unnamed low category cyclone which had originally crossed the coast at Mossman (north of Cairns) recrossed the coast near Mackay before re-intensifying. No reports of damage in Mackay have been identified.

28 January 1930

An unnamed (Category 1) cyclone recurved to the east of Mackay. Minor flooding occurred in the town.

1 February 1931

An unnamed (Category 1?) cyclone which paralleled the coast from the north-west approached to within 230 km of Mackay. No reports of damage in Mackay have been identified; however, this cyclone eventually caused serious flooding in Brisbane.

19 January 1932

An unnamed (Category 1?) cyclone which tracked from the Gulf to the east of Townsville caused serious flooding between Mackay and Cairns.

27 December 1933

An unnamed (Category 1?) cyclone in the Coral Sea recurved to within 250 km to the east of Mackay. No reports of damage in Mackay have been identified.

27 March 1938

An unnamed (Category 1-2?) cyclone recurved to within 150 km of Mackay. Gales, high seas and torrential rain were experienced. The outer harbour, which was at an early stage of construction, was damaged and some bridges were washed away.

27 January 1939

An unnamed (Category 1?) cyclone crossed the coast about 100 km to the south of Mackay. No reports of damage in Mackay have been identified.

17 March 1940

An unnamed cyclone (Category 1-2?) crossed the coast at Mackay from the north. Storm force winds were recorded at Mackay but no reports of damage have yet been identified.

3 April 1941

An unnamed Category 1 cyclone paralleled the coast from the north within 140 km of Mackay. No reports of damage in Mackay have been identified.

30 May 1941

An unnamed Category 1-2 cyclone, tracked from the north to within less than 100 km from Mackay. No reports of damage in Mackay have been identified.

8 February 1942

An unnamed Category 1-2 cyclone crossed the coast from the east about 100 km south of Mackay. No reports of damage in Mackay have been identified.

16 February 1942

An unnamed Category 1-2 cyclone which had crossed the coast near Cardwell moved out to sea north of Mackay. No reports of damage in Mackay have been identified.

30 January 1943

An unnamed Category 1 cyclone crossed the coast near Broad Sound, about 190 km to the southeast of Mackay. Coastal flooding was experienced between Mackay and Maryborough.

12 February 1943

An unnamed Category 1 cyclone crossed the coast from the north at Mackay. No reports of damage in Mackay have been identified.

7 March 1944

An unnamed Category 1 cyclone recurved about 260 km to the east of Mackay. No reports of damage in Mackay have been identified.

5 March 1945

An unnamed category 2 cyclone which had formed in the Gulf recrossed the coast at Bowen, 160 km to the north-west. No reports of damage in Mackay have been identified.

18 January 1946

An unnamed low category cyclone (Category 1-2?) crossed the coast in Broad Sound, around 110 km to the south after having tracked from the north and passing within 90 km of Mackay. This cyclone produced a major flood in the Pioneer River.

4 March 1946

A Category 1 cyclone, which had first touched the coast near Innisfail on the 2nd , tracked along the coast within 80 km of Mackay. No reports of damage in Mackay have been identified.

10 February 1947

A Category 1 cyclone crossed the coast in Broad Sound after having tracked within 100 km to the east of Mackay. A major flood in the Pioneer River was experienced.

15 February 1949

An unnamed Category 1-2 cyclone crossed the coast north of Cooktown and then recurved to recross the coast at Mackay. Significant flooding was experienced in the north of the State, however, no reports of damage in Mackay have been identified.

15 January 1950

An unnamed Category 1 cyclone that first recurved near Cooktown in Far North Queensland subsequently tracked southeast parallelling the coast. It passed within 160 km to the east of Mackay. No reports of damage in Mackay have been identified.

11 March 1950

An unnamed Category 1 cyclone crossed the coast at Camilla, about 90 km south of Mackay. This cyclone had tracked within 75 km to the east of Mackay. No reports of damage in Mackay have been identified.

8 February 1954

An unnamed Category 1 cyclone crossed the coast near Townsville before tracking within 150 km inland of Mackay. Widespread major flooding was caused.

7 March 1955

An unnamed Category 3 cyclone passed directly over Sarina, 60 km to the south of Mackay. Widespread structural damage and heavy rain was experienced. A storm surge of 0.5 m above the predicted astronomical tide has been reported.

20 January 1956

An unnamed Category 1 cyclone crossed the coast near Airley Beach, 140 km to the north before degenerating to a rain depression inland of Mackay. No reports of damage in Mackay have been identified.

6 March 1956

Category 3 cyclone *Agnes* tracked along the coastline from Townsville to the Whitsunday Group before moving to the east. It brought strong winds and torrential rain to coastal areas. The rains produced a major flood in the Pioneer River and a storm surge of 1.4 m above the predicted astronomical tide has been reported.

10 January 1957

An unnamed Category 1 cyclone crossed the coast just to the north of Mackay. No reports of damage in Mackay have been identified.

1 April 1958

A small, but intense, unnamed Category 3 cyclone crossed the coast to the south of Bowen. Tornadic outbursts and major flooding were experienced in Mackay. A storm surge of 0.5 m at Mackay has been reported.

16 February 1959

Severe Category 3 cyclone *Connie* crossed the coast near Guthalungra near Ayre before tracking south. It was still at Category 2 level when it passed around 80 km to the west of Mackay. Floodwaters caused damage to several bridges including undermining of the Forgan Bridge. A storm surge of 0.5 m at Mackay has been reported.

16 April 1964

Category 3 cyclone *Gertie* recurved to the north-east of the Whitsunday Group bringing it within 250 km of Mackay. Extensive coastal flooding was experienced.

6 December 1964

Cyclone Flora (Category 1?) formed in the Gulf and crossed into the Coral Sea near Innisfail before tracking down the coast. By the time it reached the Mackay region it was heading to the east and was about 240 km north-east of the town. No reports of damage in Mackay have been identified.

17 January 1970

Small Category 3 Cyclone *Ada* passed through the Whitsunday Group. Severe damage was experienced in the area close to the track and the Pioneer River reached major flood levels. The track passed within 80 km of the city at its closest point.

16 February 1971

Category 2 cyclone *Gertie* passed within 80 km of Mackay on a north-westerly track before crossing the coast near Cardwell. Only minor damage appears to have resulted, though a storm surge of 0.3 m above the predicted astronomical tide at Mackay has been reported.

20 February 1971

Category 1 Cyclone *Fiona* tracked from the Gulf to cross the coast near Rockhampton, passing about 100 km to the west of Mackay. Apart from bringing heavy rain, a tornado destroyed a house near Sarina.

18 December 1973

Category 1 Cyclone *Una* crossed the coast near Townsville before tracking south. It passed within 210 km to the west of Mackay and caused major flooding in the Pioneer River and a storm surge of 0.4 m above the predicted astronomical tide was recorded at Mackay.

18 January 1974

Category 1 Cyclone *Vera* recurved in the vicinity of Townsville, passing close to the Whitsunday Group and within 110 km to the north of Mackay. No reports of damage in Mackay have been identified.

16 January 1975

Category 2 Cyclone *Gloria* which formed close to the coast near Cairns, tracked southeast taking it within 360 km to the north east of Mackay. The main impact was flooding at Mackay and Lucinda.

19 January 1976

Severe Category 3 Cyclone *David* crossed the coast north of St Lawrence, around 110 km south of Mackay. No reports of damage in Mackay have been identified, though a storm surge of 0.6 m above the predicted astronomical tide was recorded at Mackay.

5 March 1976

Category 1 Cyclone *Dawn* developed in North Queensland and tracked along the coast passing within 30 km to the west of Mackay. Two houses were unroofed in North Mackay.

28 April 1976

Category 2 Cyclone *Watorea* tracked parallel to the coast at a fairly constant distance of around 180 km from the Cairns area to Fraser Island. No reports of damage in Mackay have been identified.

9 March 1977

Category 1 Cyclone *Otto* formed in the Gulf and crossed into the Coral Sea near Cape Tribulation before making landfall near Bowen. It tracked within 125 km of Mackay. No reports of damage in Mackay have been identified.

11 January 1979

Category 1 Cyclone *Gordon* crossed the coast as a rain depression about 80 km north of Mackay. No reports of damage in Mackay have been identified.

1 March 1979

Category 1 Cyclone *Kerry* crossed the coast near Proserpine, about 80 km north of Mackay. Significant wind damage was suffered by at least 26 houses in Mackay (a maximum gust of 76 knots was recorded in Mackay) and huge seas caused $1 million (1979 dollars) damage to boats in the harbour. Hinterland roads were blocked by landslides. A storm surge of at least 1 m was recorded at Brampton Island in the Whitsunday Group close to the track of the eye and a surge of 0.7 m was recorded at Mackay.

7 January 1980

Category 1 Cyclone *Paul* moved from the Gulf to enter the Coral Sea at St Lawrence to the south of Mackay. This track brought the cyclone within 40 km of Mackay. Major flood levels were achieved in the Pioneer River.

24 February 1980

The track of severe Category 3 Cyclone *Simon* brought it within 200 km of Mackay. Whilst significant damage was experienced in the area between Heron Island and Hervey Bay, only limited effects appear to have been experienced in Mackay.

26 February 1981

Category 2 Cyclone *Freda* formed near Cooktown and tracked south-east. It was around 360 km off Mackay and caused a 10 m trawler to founder 300 km east of the city. The crew of 4 was rescued.

4 March 1983

Category 2 Cyclone *Elinor* crossed the coast in Broad Sound where it produced a storm surge of 1 m. Two yachts were lost near the coast to the south of Mackay.

22 February 1985

Category 1 Cyclone *Pierre* paralleled the coast approaching to within 75 km off Mackay. No reports of damage in Mackay have been identified.

1 March 1988

Severe Category 3 Cyclone *Charlie* crossed the coast near Ayr before degenerating rapidly as it moved south. It produced very heavy rainfall that caused major flood levels to be reached in the Pioneer River. A storm surge of 0.6 m was recorded at Mackay.

4 April 1989

Severe Category 4 Cyclone *Aivu* crossed the coast at Ayr, some 230 km north-east of Mackay. Its main impact on Mackay was major flooding in the Pioneer River.

25 March 1990

Cyclone *Ivor* was a Category 3 system when it crossed the coast at Princess Charlotte Bay. It then crossed to the Gulf, recurved to again enter the Coral Sea at Cairns before weaving its way down the coast to the south of Mackay as a rain depression. Heavy rain produced major flood levels in the Pioneer River.

26 December 1990

Severe Category 4 Cyclone *Joy* eventually made landfall near Townsville (as a Category 2 system) after harassing the Cairns community for several days. Early on 27th a tornado at Mackay demolished two houses and damaged another 40. Extensive damage was also done to a sea-side caravan park. One person was drowned at Mackay whilst attempting to surf in the cyclone-generated seas. Some rainfall stations in the Pioneer River catchment recorded around 2 m of rainfall between 23 December and 7 January.

19 January 1994

Cyclone *Rewa*, which reached Category 4 at its most intense, approached to within 240 km to the east of Mackay at Category 2 intensity, before turning away to the south. Mackay emergency managers were on alert to begin evacuations of low lying areas of the city because it appeared likely that, given its consistent westerly track during the 18th, it would impact on the city. No damage eventuated in Mackay.

27 January 1996

Rapidly forming Category 3 Cyclone *Celeste* approached Bowen from the north before turning out to sea. Its track brought it within 180 km of Mackay. Significant damage was experienced in the Whitsunday Group, however, limited damage was reported in Mackay.

9 March 1997

Severe Cyclone *Justin* (Category 4 at its peak) was a very large and long lived storm. In its early stage, whilst coming no closer to Mackay than 450 km, it generated massive seas and a storm surge that was recorded on the Mackay Port tide gauge to be 0.5 m above the predicted astronomical tide. Peak waves of 8.45 m (trough to crest) were recorded off Mackay. Significant coastal erosion was experienced along all of Mackay’s beaches.

APPENDIX N: CONTEMPORARY REPORTS OF THE 1918 CYCLONE

Below are three contemporary reports of the 1918 cyclone. The first account, from the *Mackay Daily Mercury*, describes in some detail the impact of the cyclone on the city of Mackay. The second and third accounts describe attempts to communicate the plight of Mackay to Brisbane and elsewhere.

The following material is taken from the account of the January 1918 cyclone published in the *Mackay Daily Mercury* on Saturday 26 January 1918.

A GREAT CYCLONE

MACKAY AND DISTRICT DEVASTATED

Fifty-five inches of Rain in 83 Hours

Destruction of Raw Sugar Stocks
and Sugar Mills

Damage Estimated at _1 000 000

It will be twenty years on the 3rd of next month when the cyclone, known as Eline, wrought considerable damage to Mackay. A far more serious visitation of a similar kind occurred this week. When daylight broke on Monday morning last the inhabitants, who had spent a thrilling night, were able to witness what the wind is capable of doing when its force increases somewhat beyond the ordinary [Plate N.1]. *No one who has passed through the experience of the present week will ever forget the Mackay cyclone of 1918. The noise of the violent rainfall, the collapse of buildings and the grating of iron as it was torn from its position will probably remain a nightmare for a long time to come. It was unsafe to move from a safe shelter for several hours on Monday morning because of flying sheets of iron, and when this ceased the inhabitants were equally endangered by the rising flood waters which seemed to be spreading everywhere. A brief description of what the cyclone effected is given below. We have not attempted in this article to describe the damage done to the business houses of the town; that must be left to another issue for the work of destruction was so complete that none seemed to escape, not even the largest and most substantial buildings - Barne's fine block in Sydney Street, for instance, collapsed; Marsh and Webster Ltd. had their beautiful plate glass windows destroyed and the attractive block in Victoria Street, newly erected, and known as Dalrymple's buildings, faired like all the others. Probably no business house, whether large or small, escaped scatheless. To add to the discomfort of the people the gas and water both failed. The gas works were inundated by the flood waters and the pumping station also. The water supply was restored yesterday afternoon but it will be some days before gas will again be available.*

The first warning reached Mackay on Sunday afternoon. Further messages received at intervals during the night stated that the gale was approaching Mackay, also that it was dangerous, and heavy rain might be expected. On receiving the late advices nautical men expressed the opinion that the centre of the disturbance would pass over the Flat Top and this proved correct. About midnight on Sunday the condition of things began to look serious and the barograph at the Post Office registered the unprecedented reading of 27.90. The instrument does not register lower than that reading but private instruments registered 27.86. The force of the wind at this time would be about 120 mile an hour. Naturally damage commenced to be inflicted over a wide area. The ornamental trees in the principal streets were uprooted, and although it was pitch dark, the sound of flapping iron on the roof of public and private buildings and flying sheets indicated that those places were being unroofed or demolished. When daylight appeared iron was being carried great distances like so many pieces of paper and those aerial flights made it dangerous to emerge from cover. Heavy rain accompanied the wind and both increased in severity as minutes passed. The cyclone continued with unabated force until 8 o'clock when the centre passed and with it a change of the wind to the north. The change of direction brought no abatement to the hurricane conditions; instead the wind blew with greater violence. Much of the damage that was inflicted corresponded with the change in the wind. The southeast gale had partially or wholly destroyed many buildings and had severely shaken the portion that remained intact. When the gale shifted around to the north it completed the work of destruction. A lull occurred late in the afternoon which seemed to indicate the cyclone had spent itself so far as the town was affected and that it had passed away. The damage was practically over, and it was very extensive. During the night heavy rain commenced to fall. The lull in the wind and the heavy rain buoyed the stricken town with the hope that the end of their troubles were in sight. But it was not so. The rain continued almost incessantly until noon on Thursday. The rainfall for this period may not be a record for Australia, but there are very few occasions which exceed it. Between 8 o'clock on Sunday night and 10 o'clock on Tuesday morning 24.70 in were registered; from 10 a.m. to 5 p.m. on Tuesday, 9.20 in; from 5 p.m. till 9 a.m. on the 23rd, 8.05 in; to 9 a.m. on the 24th, 13.61 in, making a total of 55.56 in 83 hours. For the succeeding 24 hours the rainfall was 68 points.

The barometer readings were: Sunday 9 a.m., 29.659; 3 p.m., 29.476; 9 p.m., 29.371. Monday 9 a.m. 27.90 (the barograph does not register below this reading, but as explained elsewhere, the register fell four points lower); 1.30 p.m., 29.123. Tuesday 10.20 a.m., 29.686; 4.45 p.m., 29.615. Wednesday 9 a.m., 29.177. Thursday, 9 a.m., 29.628. It will be noticed that the cyclone reached its greatest force between 9 p.m. on Sunday and 1.30 p.m. on Monday.

The destructive period of the cyclone was about ten hours and it was almost incredible the amount of damage that was done in that short period [Plate N.2]. *Some of the residents are able to report that not a pane of glass was damaged in their homes, but they are very few. Of the 1200 or 1400 houses within the Municipality of Mackay, not more than one quarter escaped damage of some kind, and in a great many cases the buildings were levelled to the ground. The town on Monday afternoon presented an appalling spectacle. The damage in most cases consisted of the houses being unroofed, and this particularly applied to the larger buildings such as hotels, churches, public halls and two-storeyed buildings. As with other classes of buildings some of them collapsed entirely and some sustained partial damage only. The residential area suffered severely. A great many of the residences were thrown down and completely destroyed, while others were unroofed or otherwise damaged. No particular part of the town suffered more than any other part. The damage was general in town and country and confirms the opinion that the centre of the cyclone traversed the district.*

SOUTH WARD

The South Ward had its full share of the disaster. The low areas in the ward became inundated more rapidly than other parts of the town, and when the destructive force of the cyclone on the buildings was added to the inundation by storm water and the tidal wave the deplorable conditions that prevailed must be left to the imagination. Many thrilling rescues were effected and many lives were saved in an almost miraculous manner. Our limited space will not permit us to attempt to describe the sensational experiences of very many residents in that ward.

CHURCHES AND HALLS

A visit to the churches revealed a spectacle saddening to all. Many broken windows and a damaged northern wing represented the damage at the Presbyterian Church, but the Sunday School adjoining was levelled and the manse suffered severely. The Church of England, one of the prettiest churches in town collapsed and practically every thing inside was destroyed, including a valuable pipe organ. The Sunday School also gave way, and the beautiful ornamental trees in the grounds were either blown down or stripped of their foliage The Rectory also suffered severely. The Catholic Church weathered the storm fairly well, but the same cannot, unfortunately, be said of the Convent School which was demolished [Plate N.3]*. The German Lutheran Church was stripped of its roof and portal, and is off its blocks at one end. At one time the building was poised at a very precarious angle, but the wind changed and righted the structure.*

Practically all that remains of the Theatre Royal is the floor and a portion of the covered-in overhead structure. The stage and screen could not be located. The whole of the covered-in portion of the Olympic was blown away, and a portion of one wall collapsed and fell into Wood Street [Plate N.4]*. The Britannia Hall escaped with the loss of a few sheets of iron, but in strong contrast to this was the Freemasons' Hall close by, which was totally demolished. The Star Theatre was almost unroofed, especially above the stage. At the rear of this building St. George's Hall was unroofed. In common with all iron structures the Star Court suffered severely, the only wall standing being that in Victoria Street.*

THE HOTELS

Practically all the hotelkeepers suffered severely. Our space makes it impossible to give a detailed description of the havoc wrought, but the following brief outline will convey some ideas. The Belmore Arms Hotel was completely unroofed. The balconies of the Post Office Hotel collapsed and the greater portion of the roof was blown away. The Prince of Wales and Tattersall's Hotels were partially unroofed; the Riverview Hotel and Crown Hotel, situated in close proximity in River Street, were completely unroofed, while the balconies of the latter collapsed and most of the walls fell in leaving practically a shell. The balconies on Barry's Hotel were demolished, but the roof stood good. Most of the iron on the balconies and roof of the Grand Hotel was blown away, and the damage inside was very heavy. Wills', the Railway, and the Federal stood the storm very well and the damage outwardly was very slight. The Palace, opposite Wills', was sheered of its balconies, part of its roof, etc. going. Ready's was partially unroofed. The Metropolitan was completely unroofed, while part of the framework fell inside, causing great damage. Pearson's and the Queensland, had most of the iron blown away while the balconies of the Victoria were demolished. The Pioneer was unroofed and the iron from the greater part was blown away. The balconies of both the Australian and the Queen's were completely demolished and part of the roofs blown away. The Gympie collapsed altogether and the Cremorne across the river was almost demolished. On Nebo Road the Commercial Hotel, Brewery, Shamrock and Caledonian suffered more or less heavily.

THE RIVER

While the cyclone was at its height another terror, in the shape of a tidal wave, swept the town and caused consternation amongst the fear wracked householders. It struck the coast about 5 o'clock when the cyclone was raging and it is alleged a wall of water 25 ft. high swept over the beaches; and taking a southwesterly direction submerged the town to varying depths as far out as the Nebo Road. It was five or six feet deep on Beach Road and about two feet deep at the Ambulance corner. The water flowed inland in waves, carrying debris of a substantial character with it. In the river the wave played havoc with the shipping, wharves, stores and houses, while a large section of the Sydney Street bridge, which is the main avenue between Mackay and North Side, was washed away [Plate N.5]*. The Brinawarr and a barge were lying tied up to Adelaide wharf. At 6.30 the force of the wind and tide carried the two boats away. Captain Hine and his son W. Hine, together with the cook W. Burrows, were aboard the ship, but were powerless to do anything in the face of such a tempest and when the Binawarr struck the bridge she was so badly knocked about that she sank. In the meantime, Captain Hine and the other two men clambered on to the bridge and thus escaped with their lives. For some time a portion of the vessel was seen above the swirling waters but in the flood on Tuesday it disappeared entirely. The barge was joined later by the 'Tenior Tay (?)', and there the two remained until the bridge gave way, when they drifted up the river and stuck on the northern bank above Mr C. Palmor's property. The tug Pelican and the Harbour Board barge Alice May were piled up on the end of the bridge near the Cremorne, and are now high and dry. The smaller vessels suffered almost total destruction, with the exception of Mr. J.M. Kingwell's launches, one of which, the Florence, was landed on the bank above the bridge, and the other, the Bellita, floated up in front of 'The Folly', and there remained.*

The wharves from Michelmore and Co's store down to Howard Smith were submerged to a depth of several feet, and the contents of the sheds were washed out into River Street and those running at right angles, where after the flood waters had subsided piles of articles barricaded the roadway and against them were piled debris of every description. The main wharf adjoining Michelmore and Co's store was demolished and lower down, a shed containing 500 tons of sugar was practically stripped. The main building of Paxton and Co. suffered comparatively little damage, but the wharf and store were badly knocked about. At the Adelaide sugar shed the water rose up to the third tier of sugar, while a portion of the roof was blown away and the water streamed down on the sugar causing a great deal of damage. In a portion of the building the water did not enter except in flood and most of this sugar, it is expected, will be in fair order. The coal bunkers were washed away, with a quantity of gear, and the coal scattered all over the street. The front of the building is littered with debris, and a number of coal trucks are standing on the line, blown from the Beach Siding by the hurricane at a terrific rate. The big Harbour Board pump 'Mick Berly (?)' is also stranded in the middle of River Street. A barge was sunk on the slip adjoining the wharf. The Bond and Queen's wharf were wrecked, and the Government steamer Relief sunk at her moorings. The sheds along the river bank were washed away, and the building at the Pilot Station which housed a lot of material used by the Harbour Master in connection with the marking of the river. All that is left is a whale boat and another small craft.

The heavy rain, combined with the big tide, caused a record flood in the river on Tuesday. There is no authentic record as to the height the river rose, as the gauges were all washed away, but the Harbour Master (Captain Greenfield) states that the water rose at least 20 ft. The lower portion of the town was inundated to a depth of .... The river broke across below Devil's Elbow into Barnes Creek and relieved the pressure in the main outlet, and on Thursday morning the back water in the land near the cemetery overflowed and crossing Nebo Road, rushed down Shakespeare Street and a parallel street to a depth of 3 ft. It is the opinion of experienced men that had this second diversion not occurred the loss of life would have been enormous. The flood commenced to subside on Thursday afternoon and is already back to normal.

The buildings along River Street, apart from those mentioned, are all more or less damaged, the worst being the hotels, Anvil Stores, Mr. Hossack's premises, Mr Ungerer's blacksmith's shop, and a small shop opposite the Adelaide wharf, which was completely demolished.

HOUSING THE REFUGEES

During the early hours of Monday morning people whose houses had been demolished, or were in danger of early destruction, sought refuge with friends. Many were accommodated in this way, but as the work of destruction continued hundreds found themselves homeless. Speedily the Ambulance, Technical College, Ready's Rooms, Town Hall, Red Cross rooms, School of Arts, Fire Station, Drill Shed and Catholic Club rooms together with the larger private dwellings were requisitioned and the refugees were given shelter. At the Red Cross rooms, women and children were assisted with dry clothing as most of them left their homes too hurriedly to even clothe themselves fully.

It was when the refugees commenced to arrive that some of the worst features of the tempest were revealed and it became known that serious loss of life had occurred.

One of the first deaths recorded was that of Mr Robert Morton, engineer on the Government steamer Relief. On Monday morning the water surrounded his dwelling on the river bank and fearing the worst, and seeing the tide gradually rising, he climbed into the ceiling to make a hole in the roof where his wife and daughter could seek shelter. It was while in the ceiling that the building collapsed and he was killed. Mrs. Morton and Miss Morton managed to escape and swimming with the current were carried in the direction of Mr Weir's residence, where a landing was effected.

Mr J. Shanks and his brother Mr Frank Shanks, also had a terrible experience. They resided in the old butter factory and when the tidal waters entered the building took refuge in what they considered the strongest room in the house and put their wives and families on a table. The water rose above the level of the table and another one was placed on top and as the waters still continued to rise chairs were provided. When everything seemed secure, the kitchen from the house adjoining collapsed and partly demolished the building where the people were. Mr Frank Shanks was rendered insensible through being struck by falling timber and all were thrown into the water. Mr J. Shanks then heroically secured rafts and ultimately, after a fierce battle with the elements, and a most perilous journey, during which his wife and children and his brother's baby disappeared, he reached the Waterside Workers Hall and gained entrance through a window. Mr Frank Shanks afterwards reached Tennyson Street and upon his information a rescue party was organised and a number of people, including Mr. and Mrs. Weir and several who had sought refuge in their residence, together with those who were in the hall, were rescued. The force of the rain was terrible, Mr Shanks remarking that he was bruised all over with the driving rain and had every stitch of clothing ripped off his body.

The family which appears to have suffered most so far as loss of life is concerned, is that of Mr Peter Welsh. He was living in George Street, and when surrounded by the waters from the tidal wave the roof was removed by the wind and the walls .... and five children were swept away by the flood. He managed to grab the baby and one of his sons. With them he reached the higher ground, only to find that the baby was drowned but the son was safe. The other members of the family perished. Mrs. Welsh was subsequently found tangled in a fence.

Mr. Benson, who lives opposite Queen's Park, states that the water was eight feet high in the vicinity when the tidal wave occurred and four men who were compelled to leave their homes took refuge in a tree in the Park and remained there for hours. Mr. Benson was unable to give relief on account of the water being so high around his dwelling.

FATALITIES

Following is a list of fatalities reported to police up to yesterday:-

Alice Amelia Shanks (37), John Joseph Shanks (# years), Alice Shanks (seven months), wife and family of John Shanks. Cecil Shanks, nine months (son of Frank Shanks).

Robert Morton, engineer on Government steamer Relief, killed.

Mrs Welsh and five children (wife and children of Peter Welsh) drowned.

Richard Henry Francis, killed at Show Ground by collapse of building.

Joseph Carr, drowned by collapse of residence on the town beach.

Geogina Phyllis Renor, 2 months, drowned. It was also reported that three other members of the Renor family are missing.

Edward Hehir, ganger of Pioneer Shire Council, killed through collapse of Hill End School, where he took refuge.

William Coakley, died from exposure. Mr Coakley was one of the first men to cross the Range when Mackay was being settled in the early days: he crossed with the late Mr. James Ready.

THE HOSPITALS

Next to the death roll the story relating to the effect of the cyclone on the hospitals is the most pathetic. At the District Hospital the building suffered severe damage and patients and staff had an experience which they will never forget. At Lister private hospital the roof was almost completely removed and all the rooms flooded. The hospital was full at the time and the doctors and nursing staff had a very trying time to protect the patients until they could be removed elsewhere. At Mrs. Gibbs' private hospital the patients had also to be removed while the rain was falling. This work was carried out expeditiously with the assistance of the ambulance officers, who secured volunteers and in many cases removed patients during heavy rain through deep water on stretchers. To make provision for patients, the Girls State School is being fitted up as a temporary hospital. It might be here mentioned that all the local doctors worked untiringly to relieve the sick wherever they were located.

RELIEF MEASURES

We have not space to record the heroic work done by rescue parties. It became apparent early on Monday morning that prompt relief measures were necessary to succour the homeless and prevent a condition which if left to itself would speedily become deplorable. Following the work of rescuing people from flooded homes, meetings were held to control the food supplies, health, and other vital matters to the afflicted community. The upshot of these numerous conferences was a meeting of citizens at which a series of resolutions were passed controlling the food supplies, the health of the town and as far as possible put a check on the pilfering of iron and other articles that had become notorious. Committees were formed and these, assisted by the police, the military, and medical men, are now doing what is possible to regulate in as equitable a manner as possible the distribution of food and the protection of inhabitants. At present food tickets are issued daily, covering one days supply of bread and one week's provisions. The meat supply is ample for requirements.

A source of danger to health of the community is the dead animals that are lying about the municipality, but especially in the South Ward where losses in stock, mostly horses, is very great. Hundreds of fowls were drowned, as well as many goats. In connection with pilfering, the police are doing what they can to bring the offenders to justice and have already made an arrest. The way that iron from about the town was illegally removed and the articles that floated into River and Victoria Streets stolen was disgraceful.

THE RAILWAY SERVICE

The railway station buildings and rolling stock suffered as a result of the cyclone. On the line connecting the station with the wharves two covered wagons were blown over, while at the station, and a great deal of damage was done. When interviewed yesterday the Traffic Manager (Mr J. Strachan) stated that about one-third of the goods shed remained, while other buildings were partially or wholly unroofed. A quantity of sugar in trucks in the station yards was badly damaged. A number of homeless people arrived at the station on Monday and were accommodated in railway carriages. On Wednesday, 23rd, a train left for the country in hopes of reaching Newbury. The first obstruction met with was the shelter shed at Ooralea, which was overturned and thrown on to the main line, but not seriously damaged. The sheds at Te Kowa, Alexandra and Pleystowe were smashed and debris had to be removed from the track to enable the train to get through as far as Pleystowe. Here the Newbury ganger met the train and reported that the line was intact, but the shelter shed at Newbury had been blown over. The train returned to Mackay at .... subsequently one of the railway employees arrived from Garget on the pumper and reported that Cattle Creek bridge was submerged. Mr. Jones (Departmental accountant) arrived from Rocky Dam and reported that on Monday the camp there was partially wrecked by the cyclone, but other buildings were intact. On Tuesday the water came over the walls to a depth of 12 (?) inches and flooded the camp site. Considerable damage was done at Koumala, while at Sarina the quarters and shed were unroofed, also the enginemen's quarters. The damage on other sections of the line was not serious except at Rosella where the shed was unroofed. Serious washaways have occurred on both sides of Bakers Creek, and this cannot be repaired until the flood waters subside. Nos 1, 2 and 3 spans of the concrete piers of the Sandy Creek bridge were wrecked, and the train service to Sarina is suspended until repairs are effected or a diversion put in. A washaway also occurred on the station side of the Kiran bridge, and the train which arrived there on Thursday had to tranship passengers to Mackay. Mr. Strachan said he was in hopes of resuming an ordinary service on this line today. On Monday morning the train from Hatton started away at the usual hour but the line was obstructed to such an extent with fallen timber that it took four hours to go from Hatton to Pinnacle.

> There follows a description of the impact of the cyclone on inland areas towards (Finch) Hatton, in other country areas and the impact on the region's sugar mills. It concludes with an account of the impact of the cyclone on Flat Top.

VISIT TO FLAT TOP

Yesterday morning the Harbour Master (Captain E.S. Greenfield) and Mr. P. Steele of the A.U.S.N. Company visited East Point and Flat Top with stores in the motor boat Elenor. At the signal station at East Point the residents had had much the same experience as those in Mackay. The house had been unroofed and the people driven to living quarters in a store room at the rear of the buildings. At Flat Top similar conditions prevailed and the Superintendent, Mr. Randell, informed the Harbour Master that they had had a very trying time. Portion of the roof of the house disappeared, the flag staff was blown down and the flag room also. The lighthouse had the windows smashed. The tidal wave cleared everything from the shores of the island including the boat sheds, etc.

The remainder of the report deals with the impact in the Mackay hinterland.

This extract from *The Mackay Daily Standard,* Monday, January 28, 1918, describes the use of morse to communicate Mackay's plight to Flat Top and further afield:

The successful signalling from the roof of the Grand Hotel (in Mackay) to the light-house keeper at Flat Top, who was able to transmit the message to steamers fitted with wireless, is our only means of communications with the outside world. The first message, as reported in Saturday's 'Standard', was got through to Flat Top and thence to the "Wyreema" on Thursday night, and was a concise but explicit statement of main facts of the catastrophe by Captain Greenfield (Harbourmaster) to the Portmaster in Brisbane. Last night further signalling was carried out, and the news received is detailed under another heading. The signalling was supervised by Mr. F.W. Boddington (Postmaster) and was carried out by Mr Harvey (telegraphist) assisted by Mr J. Vidulich, who proved himself to be an expert reader of flashes. The signals were in Morse code by motor-car lamp from the roof of the Grand Hotel, the wiring to which from Dr. Stuart Kay's residence was carried out by Messers. Pettigrew (telephone exchange) and R. Smith (line repairer), Dr Kay supplying the electricity for the flashes from his accumulators. Mr Rendell had charge of the signalling at Flat Top.

The following extract has been taken from the log of the Lightkeeper, Flat Top Island and describes the communications with Mackay following the 1918 cyclone. The log was supplied by Captain G.F. Long of the Company of Master Mariners of Australia.

The Master of the "Arawatta" decided to wait until the next morning in the hope of hearing some word from Mackay, and his judgement was sound in this respect, as soon after dark a flash of light could be seen from the direction of the town (on the 23rd), and the first signal being startling enough, it being S.O.S. meaning undoubtably 'send immediately assistance'.

The difficulty now experienced was that although I could see the light from the lamp quite plainly, it being a powerful lamp, they could not see my answering light. The signal after being given many times was followed by the words 'disastrous floods', but although I waited around all night the weather did not clear sufficiently for them to see my light, and I received no more details.

At 9 p.m. I signalled the following message to the "Arawatta" – "Mackay is morsing disastrous floods – weather is too bad to get remainder of message – please wire Brisbane to get assistance at once". This the ship promised to do, and the knowledge that the outside world knew of our straits made our minds a little easier.

Soon after 7 p.m. (on the 24th) the message was received from Mackay which disclosed how serious matters were. The message was as follows – "Cyclones, floods and tidal wave losses 14, bodies recovered, all wharves and sugar stores have collapsed. Relief, Quasha and Brinnawar sunk. Tay, Apa and Pelican ashore. Mackay is on military rations and only ten days food supply on hand. No lighterage plant available. The country has suffered badly. It is urgent that Government send steamer capable of entering river with supplies of food also large quantity of galvanised iron and timber. All buildings, Pilot Station and Signal Station unroofed and vacated by crew. All marks except lighthouse destroyed and no means of replacing same. Boatshed and all plant completely swept away". This message was from the (Mackay) Harbour Master to the Port Master, Brisbane.

Plate N.1: Mackay 1918 cyclone - Cremorne Hotel, on the northern side of the Pioneer River
Collection: John Oxley Library, Brisbane

Plate N.2: Mackay 1918 cyclone - Sydney Street, looking south
Collection: John Oxley Library, Brisbane

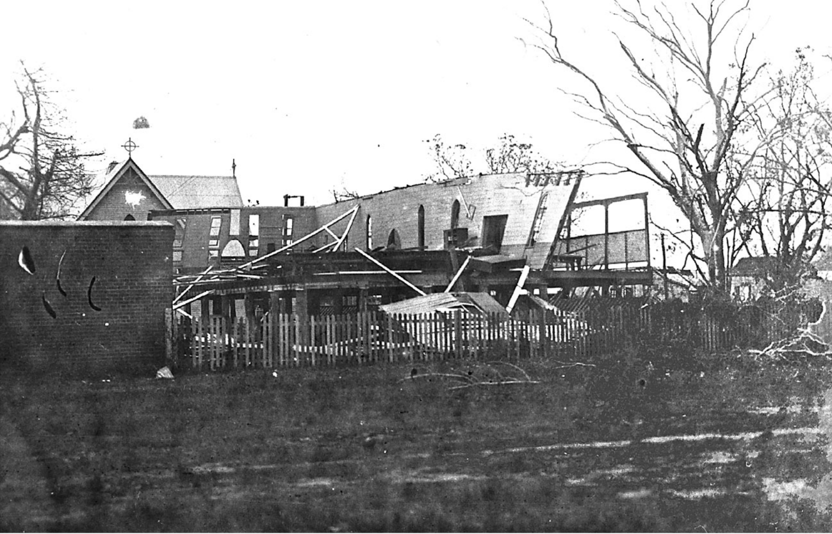


Plate N.3: Mackay 1918 cyclone - Catholic Convent School, River Street
Collection: John Oxley Library, Brisbane

Plate N.4: Mackay 1918 cyclone - Olympic Theatre
Collection: John Oxley Library, Brisbane

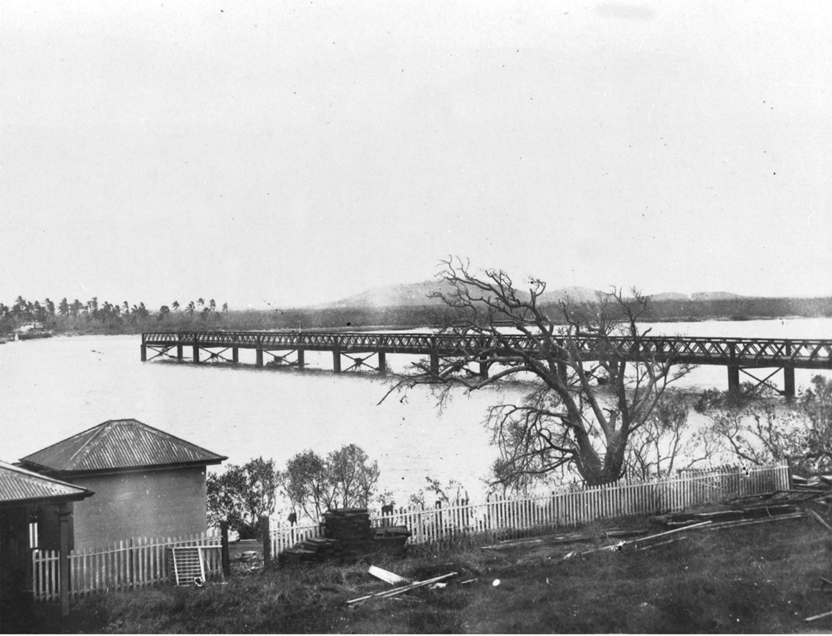


Plate N.5: Mackay 1918 cyclone - Partially destroyed Sydney (Forgan) Bridge, looking north
Collection: John Oxley Library, Brisbane