COMMUNITY RISK IN CAIRNS

A MULTI-HAZARD RISK ASSESSMENT

by

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FOREWORD

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By The Hon. Warren Entsch MP, Parliamentary Secretary for Industry, Science and Resources.

The Australian Geological Survey Organisation (AGSO) is Australia's premier National geoscience research body.

The Cities Project was established within AGSO in 1996 and since then has taken the leading role in researching a range of geohazards and how they impact upon local communities.

Geohazards exist almost everywhere. In layman's terms a geohazard is simply a 'natural hazard' that exists within the local environment and can be in the bush, in a town or a city. They include landslides and rapid erosion.

AGSO has taken up the challenge to develop a better understanding of geohazards and the relationships that exist when they impact upon urban communities. Cairns is the first in a series of 'case studies' to develop and test the science, the techniques, the information and the tools needed to analyse and assess such complex problems that exist in our everyday environment.

The results are very interesting. Having lived in and around Cairns for all of my life I was amazed to learn so much about a place that I thought I knew well.

This booklet provides an introduction to the Cairns multi-hazard risk assessment and contains some interesting results. I urge you to investigate the comprehensive information in the full report on the Compact Disk. This is important, groundbreaking work and I commend it to you.

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OVERVIEW

Background

The AGSO *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. Geohazards are broadly defined to include all earth surface processes with the potential to cause loss or harm to the community or the environment. The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous. To provide a realistic focus to this research, and to achieve practical outcomes, the *Cities Project* is using a series of case studies based on Queensland centres to develop and test its science and techniques. Cairns is the first of these multi-hazard case studies.

Cairns is the most northerly of Queensland's cities and one of the fastest growing communities in Australia. It is also an isolated community, located some 1 400 km from Brisbane (**Figure (i)**). Cairns has a resident population of approximately 120 000 and this total can exceed 150 000 at the height of the tourist season. An aerial image of Cairns city and inner suburbs viewed from the east is shown in **Figure (ii)** (reproduced by permission of Brian Cassey Photography).

This report is considered to be 'provisional' because the information, the techniques and the tools needed to undertake a task as complex as assessing community risk in a major urban centre are still evolving. Because this is the first *Cities Project* case study to be finalised, we have gone to some lengths to describe and explain the methodologies that have evolved. This report may, therefore, be seen as containing both a detailed risk assessment of Cairns and a worked-through example of the risk assessment techniques. Readers are encouraged to view the report as a starting point, rather than an end in itself.

At the heart of this research is the view that risk is the outcome of the interaction between a hazard phenomenon and the elements at risk within the community (the people, buildings and infrastructure) that are vulnerable to such an impact. The relationship is expressed in pseudo-mathematical form as:

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

This approach is not only elegant, it is also very practical given that it lends itself to quantitative, qualitative and composite analytical approaches. It is also gives clear focus for our application of the risk management philosophy outlined in the standard *AS/NZS 4360-1995 Risk management*.

The vast majority of information, relationships and processes involved in understanding risk are spatial in nature. We have, therefore, made extensive use of geographic information system (GIS) to drive our analysis and assessment. *Risk-GIS*, as it has been christened in the *Cities Project*, is a fusion of the decision support capabilities of GIS and the philosophy of risk management expressed in the standard. The processes in which *Risk-GIS* are applied, and our understanding of the risk management process are summarised in **Figure (iii)**. These issues are described in **Chapter 1**.

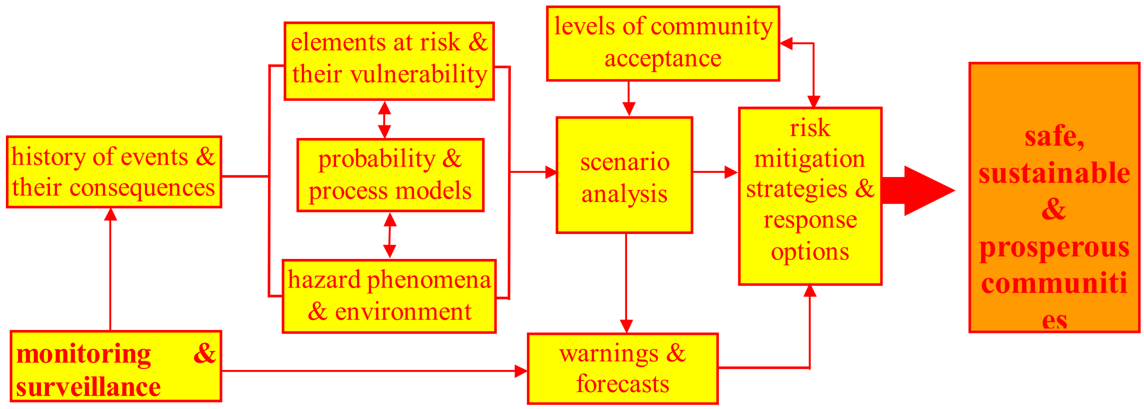

Figure (iii): *Cities Project* understanding of risk management and *Risk-GIS* processes

Community Vulnerability

The elements at risk in the community and their vulnerability to hazard impact are described in detail in **Chapter 2** and **Chapter 3**. We have adopted a systematic approach to this description, grouping the various elements into the five themes of setting, shelter, sustenance, security and society (the 'five esses'). The topics addressed under these themes include:

- ***Setting:*** basic regional topics 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), population and administrative arrangements (local government, suburb and other administrative boundaries);

- ***Shelter:*** the buildings that provide shelter to the community at home, at work and at play. Access to shelter is also significant, so information on mobility within the community is included here. Particular attention is paid to the capacity and vulnerability of the road network and the availability of vehicles.

- ***Sustenance:*** modern urban communities are highly reliant on their utility and service infrastructures such as water supply, sewerage, power supply and telecommunications. These *lifelines* are significantly dependent on each other and on other logistic resources such as fuel supply. The community is also dependent on the availability of food supplies, clothing, medical supplies and other personal items.

- ***Security:*** the security of the community is 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 facilities such as hospitals, nursing homes, industries, commercial premises, agricultural land use, ambulance stations, fire stations, police stations and works such as flood retention 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.

- ***Society:*** here we find most of the more intangible measures such as language, ethnicity, religion, nationality, community and welfare groups, education, awareness, meeting places, cultural activities and so on. Some of these may be measured in terms of the facilities that they use, such as churches, meeting halls, sporting clubs, libraries and so on; however, the more meaningful measures, such as education, relate specifically to the individuals, families and households that make up the community.

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. To overcome these shortcomings we have developed an overall vulnerability profile of Cairns by which to identify those suburbs that provide a disproportionate contribution to community risk because of the number and nature of the elements at risk they contain. Details of the methodology developed to produce this composite view of community vulnerability is contained in **Appendix E**.

Figure (iv) shows the distribution of suburbs according to their overall contribution to community vulnerability. The distribution strongly reflects the development history of the city, with the areas of greatest significance being the original city area, the original villages of Edmonton and Gordonvale to the south and the Yarrabah Aboriginal Community to the east.

Earthquake risk

The earthquake hazard in Cairns is moderate by global standards, but it is not negligible. Over the past 100 years there have been at least 11 significant earthquakes reported within 200 km of Cairns, the most damaging being the Richter magnitude 4.3 event of 1896. In many places of Australia, probably including Cairns, moderate to strong earthquakes of Richter magnitudes 5 to 6 make up about 90% of the total contribution to the overall earthquake hazard. The occurrence of such an earthquake close to Cairns would be a rare event. However, its impact could be great. An earthquake in this magnitude range (Richter magnitude 5.6) near Newcastle in 1989 caused arguably Australia's most costly 20th Century natural disaster.

We have constructed earthquake urban hazard zonation maps and, from the building database, produced an inventory of buildings, by construction type and usage, in the zones in these maps. Any earthquake of a magnitude likely to cause damage in Cairns will have an effect across all suburbs. The amount of damage, and consequently risk, will increase with the intensity of the event.

Whilst all suburbs have some degree of exposure, *Risk-GIS* analysis of the earthquake hazard reveals that some 86% of Cairns buildings stand on 'soft' sediments of the coastal plains and riverine deltas, or the sands, silts and clays of the lower footslopes. These sediments amplify earthquake shaking. The extensive 'soft' sediments beneath the coastal suburbs, in particular, would aggravate the impact of any significant earthquake. These are also the suburbs that contain many of the critical facilities and have significant concentrations of people, buildings and infrastructure. The remaining 14% of the buildings are mostly modern and are situated on the upper slope soils or rock of the hills where ground motions will be less damaging. Some of these buildings conform to the earthquake loading provisions of the Australian Building Code, and the majority conform to wind loading provisions.

In order to produce a suburb-by-suburb ranking of Cairns for earthquake risk from direct damage to buildings, we have introduced a vulnerability ranking of building construction types. The profile of risk exposure to earthquake and a total earthquake risk profile, which takes account of community vulnerability as well as the exposure to the hazard, are shown in **Figures (v) and (vi)**.

Landslide risk

Until the 1996 Gracetown tragedy in Western Australia, when 9 people were killed by a coastal rockfall, and the 1997 Thredbo New South Wales landslide which demolished 2 ski lodges, killing 18, there had been little public recognition that landslides were a significant threat to life in Australia. Where landslides occur, their physical impact is typically confined to a few properties or a short length of road or railway. Their effect, however, can be disturbing and disruptive and occasionally fatal. Insurance policies in Australia do not normally cover landslide, and this can add to the anguish of property owners.

For Cairns, landslide has been, and remains, a significant risk, as evidenced by events such as the massive Ellis Beach debris flows that buried 10 km of the Captain Cook Highway in 1951, and the frequent impact on road and rail links to Kuranda and elsewhere.

Most landslides recorded in the Cairns area appear to be associated with disturbances of the natural surface by activities such as the construction of roads and the excavation of building sites. As development extends increasingly onto the hill slopes in areas such as the Freshwater valley, the risk of landslide impact will increase unless appropriate mitigation strategies and engineering design standards are adhered to. Experience over at least 70 years has demonstrated that flash flooding and/or debris flows in the Freshwater valley have the potential to severely dislocate the Cairns water supply.

The landslide study undertaken here is the first to follow an internationally recognised quantitative landslide risk assessment methodology to be undertaken in Australia. It has been conducted at a relatively broad reconnaissance level, however, and should not be interpreted, without more detailed geotechnical investigation, at the individual property level.

Figures (vii) and (viii) show the profile of exposure to landslide and the total risk (based on community vulnerability).

Flood risk

Whilst flooding causes inconvenience and some dislocation in Cairns on average about once every 12 years, it poses a relatively limited threat to people and buildings because urban development has largely been excluded from the most flood-prone areas of the Barron River delta. This exclusion reflects the community's experience of at least seven episodes of major flooding since the establishment of the Trinity Inlet settlement in 1876.

The loss of sugar cane and damage to roads and other infrastructure on the delta and along Freshwater Creek carries with it a significant economic loss. The most significant inconvenience caused by moderate to major flooding in the Barron River system is the isolation of the northern beachside suburbs from downtown Cairns, with its critical facilities such as hospitals and airport. Road and rail access to Cairns can also be blocked from the south by flooding in the Mulgrave and Russell Rivers.

Limited flood mitigation works have been established, the main work being the levees that protect the airport. The flood warning system for the Barron River operated by the Bureau of Meteorology is very effective and provides residents in flood-prone areas with adequate time to prepare for flood and/or to evacuate if that is indicated. Formal land use planning constraints on development within the area likely to be affected by a flood with an average recurrence interval of 100 years have been in force since the early 1990s.

Flash flooding in the other catchments, especially the streams that flow into Trinity Inlet, is a potentially significant problem. Not only are there significantly more properties exposed to urban drainage surcharge in the downtown area than there are on the Barron delta, but also the risk to life is significant because of the rapid onset of flash floods and the propensity for careless or foolish behaviour by some people in and around floodwaters.

Using *Risk-GIS*, we have assessed the number of buildings, length of roads and area of cane land in each of the Barron River delta suburbs which would be affected by Barron River flood scenarios of various annual exceedence probabilities (average recurrence intervals). The impact on these communities, emergency management issues, and key facilities affected have been discussed. **Figures (ix) and (x)** show the flood risk exposure and total flood risk profiles for the Barron River.

Cyclone risk

Tropical cyclones pose a considerable threat to Cairns. In the 123 years since the settlement was established there have been 53 cyclones that have had some effect on the town - that is, an average of a cyclone every two years. They bring with them the multiple threats of destructive winds, heavy rain and storm tide inundation.

Using *Risk-GIS*, we have assessed the suburbs in terms of wind risk exposure. We have also modelled various annual exceedence probability storm tide scenarios to quantitatively assess their impact on the elements at risk in the Cairns community.

The conventional response to an impending cyclone impact is for people to take shelter in their own homes. In those areas that would be subject to storm tide inundation, however, this is not an appropriate option as many people in such areas would be exposed to a significant risk of drowning, especially if the level of inundation exceed 1 m over floor level.

Evacuation of those people at risk must be completed before the winds reach 75 km/hr (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 of 1% or greater (an average recurrence interval of at most 100 years) 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 manage the numbers of evacuees involved unless the vast majority were prepared to undertake their own evacuations beginning at least 24 hours before the forecast cyclone impact time. Delay in commencing a major evacuation process will increase 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 a severe cyclone will have a major immediate impact on Cairns with potentially significant loss of life and massive damage, the long term impact will also be catastrophic. In an extreme event, most survivors would 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 would be such that the city would be virtually uninhabitable for an extended period.

The application of building code standards for domestic structures since 1982 and the inclusion of storm tide hazard as a constraint in the urban planning process in Cairns since the early 1990s have certainly slowed the rate at which risk would otherwise have increased. Significant reduction in risk will not be possible until the concentration of population, economic activity and community services in the highest risk areas of Aeroglen, Cairns North, City, Machans Beach, Manunda, Parramatta Park and Portsmith is reduced significantly. Some proposed developments, such as the creation of a major residential precinct in Trinity East, could, unless carefully implemented, exacerbate an already risk-laden situation. **Figures (xi) and (xii)** portray the wind exposure and total risk profiles and **Figures (xiii) and (xiv)** show the storm tide exposure and total risk profiles.

Risk evaluation

There is no doubt that tropical cyclones pose the greatest threat to Cairns and that **the destructive winds accompanying cyclones pose the greatest level of risk**. Cairns has come within the radius of destructive winds at least 21 times since 1876. Not only do they have a high frequency of occurrence, they also have a wide-spread impact. The introduction of building construction standards for wind loads beginning in 1975 has proved to be a most effective form of mitigation. Very few buildings constructed since 1975 have suffered more than minor damage by winds in the 10 cyclones that have had an effect on Cairns since that time, though substantial damage has been done to vegetation and power lines. There is little, however, that can be done to reduce the risk of wind damage to sugar cane or tree crops such as banana and pawpaw.

Of the other hazard phenomena generated by cyclones, **storm tide clearly ranks second**. Destructive storm tides have been relatively rare events in Cairns history (only three or four instances over the past 123 years). There is absolutely no doubt, however, that they hold the greatest potential to cause major loss of life and to wreak widespread and massive damage. Their potential for destruction is derived largely from the large numbers of people, buildings and critical facilities that are located within the area in which storm tide impact would be greatest. All of this development pre-dates the introduction of planning constraints aimed at reducing storm tide risk, consequently it provides a substantial residual risk that will need to be addressed by other mitigation strategies.

Whilst earthquake is not widely recognised as a significant threat to Cairns, our research and the known record of seismic activity along the entire east coast of Australia leads us to conclude that **strong earthquake poses the third greatest risk to the Cairns community**. This risk is largely derived from the geology of the region. Much of Cairns is built on thick sediments. In addition, the sediments that underlie much of the downtown area are classed as 'soft'. All these sediments are likely to significantly amplify strong ground motions, even from relatively distant earthquakes. Much of the major construction boom in Cairns took place after the publication of the first Australian earthquake loadings standard in 1979. However, this standard was not used widely in Queensland and, unlike its 1993 successor, it did not cover domestic buildings. Nonetheless, many Cairns buildings are earthquake-resistant to a degree, having been designed to comply with wind loading standards from around the late 1950s for engineered buildings and 1982 for domestic buildings.

Except in the event of a very strong earthquake we would not expect significant loss of life. Given the experience of the relatively moderate 1989 Newcastle earthquake (Richter magnitude 5.6), however, the catastrophic failure of one or more major buildings in the CBD, because of inappropriate design, poor construction and/or poor condition, can not be ruled out.

Flooding of the Barron River delta is the fourth ranked risk for Cairns. Major flood levels on the delta have been reached seven times since 1911 giving an average recurrence interval over the past 88 years of around 12 years. Even though planning constraints for development in the flood-prone areas of the delta were not introduced until the early 1990s, land use is predominantly agricultural. Urban areas in Caravonica, Holloways Beach, Machans Beach, Redlynch and Yorkeys Knob together with the road network which links them to the city centre are all susceptible to inundation. 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 evacuations if that course of action is indicated.

Landslide and flash flooding share the fifth place in terms of risk priority. Whilst these closely related hazards occur fairly frequently in Cairns, in developed localities they tend to affect only small areas and are a problem for only short periods. The experience of the massive 1951 Ellis Beach debris flows, however, is a clear indicator of what can happen along the Cairns escarpment in extreme circumstances. Our information, however, does not permit us to know with any certainty just how rare or extreme that event was. Even at the smallest scale, either phenomenon can be lethal because of its rapid onset and the lack of warning. Both flash flooding and debris flows in the upper Freshwater Creek valley hold the potential to disrupt the Cairns water supply by damaging the intake and pipeline.

Is Cairns a risky place?

For an isolated community of more than 120 000 people located in the wet tropics, Cairns has a relatively low level of risk exposure to most hazards within the 1% annual exceedence probability range (i.e. an average recurrence interval of 100 years or less). Whilst events within this range will cause some loss and put lives at risk**, the warning systems and other mitigation strategies already in place should keep loss of life to virtually zero and economic loss to the community as a whole to nuisance, or at least tolerable, levels** so long as the population is aware and prepared**. There are cost effective steps that can be taken to reduce the current level of risk even further.**

Importantly, there have been no fatalities directly attributable to the impact of a natural hazard in the Cairns community in the past two decades, in spite of this being a period of

very rapid population growth. This record, in part, can be attributed to the fact that there were no significant earthquakes and very few major cyclone or flood impacts during that time. It can also be attributed to the implementation of hazard-based planning constraints, the introduction of building codes and an effective local emergency management capability. These risk mitigation strategies have minimised the exposure of new developments to hazards and maximised resilience of structures to the more common hazard impacts. Overall, we would assess Cairns as having a tolerable level of risk exposure to the more frequently occurring hazards**.**

The Cairns community does, none the less, have a very high level of residual risk exposure to the less frequent and more severe events, especially strong earthquakes, severe cyclones and major debris flows**. Events with an annual exceedence probability of 0.2% or less (an average recurrence interval of 500 years or more) will inevitably cause significant economic harm and some (and potentially significant) loss of life. In these rarer and more extreme events, the loss of critical facilities, especially in Cairns North, City, Parramatta Park and Portsmith, 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.**

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 to even the most extreme event, over time, by implementing long-term planning strategies (such as the relocation of critical facilities) and by maintaining a vigorous campaign of community awareness and involvement in the community risk management process.

A wide range of risk mitigation strategies are available, many of them of a low cost and non-structural nature. These include the:

- **development of a strong commitment to the process of risk management by the whole community;**
- **creation and maintenance of appropriate information to support risk management decision making;**
- **operation of effective hazard monitoring and warning systems;**
- **creation and maintenance of a strong level of community awareness through an ongoing program of risk communication;**
- **ongoing review and update of building and planning standards and codes;**
- **ongoing enhancement of emergency management plans, training and resources;**
- **implementation of effective plans to protect critical facilities, such as the hospitals, the loss of which will compound community hardship and risk; and,**
- **building of cost-effective structural defences.**

The quicker these strategies are established, the sooner community risk will be reduced to an even more acceptable level. If this is done, Cairns will be one of Queensland's safest, most sustainable and most prosperous communities.

CHAPTER 1: URBAN GEOHAZARD RISK ASSESSMENT

This Report

This report provides details of the first comprehensive report of the risks faced by the Cairns community that are posed by a range of natural hazard phenomena. It has been developed as a primary resource for those who have a responsibility and interest in the management of those risks. Those individuals and groups span a very wide spectrum from the individual concerned citizen, through elected officials to professional engineers, planners and emergency managers.

This is the first in a series of case studies to be 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*. The report should be seen as the first step in the process of comprehensive community risk management. We see it as providing the foundation on which the Cairns community can build its strategies to mitigate those risks and to cope with the impact of hazards when they occur. It is also intended to provide a model for other communities in Australia and elsewhere. We encourage readers to view it as a starting point, rather than an end in itself.

This is a pioneering study. As such it will undoubtedly change as better information, techniques and tools develop. We are confident that it 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 from 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 United Nations International Decade for Natural Disaster Reduction (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) which encouraged the emergency management community to modify its doctrine from one 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. Cairns is the first of these case studies.

Our view of 'geohazards' is deliberately very broad and includes ***all earth surface processes with the potential to cause loss or harm to the community or the environment***. Whilst our focus in the *Cities Project* is mainly on potentially fatal acute geohazards such as earthquakes, landslides and floods, the importance of more chronic geohazards such as acid sulphate soils, coastal erosion, reactive soils and dry land salinity is also recognised. This report, however, deals only with the acute geohazards.

Such a broadly based program of research obviously requires a multi-disciplinary approach. To enable AGSO 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

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

partners of great quality and enthusiasm. They span a very broad range of scientific disciplines, administrative responsibilities and industry sectors, as can be seen from the list in Appendix B. Of particular value has been the close collaboration with Cairns City Council, the Queensland Department of Emergency Services and researchers involved in the Tropical Cyclone Coastal Impacts Program (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 Standard *AS/NZS 4360:1995 Risk management* (Standards Australia, 1995). This generic guide provides the philosophical framework within which the *Cities Project* studies are developed. That process is outlined in **Figure 1.1**.

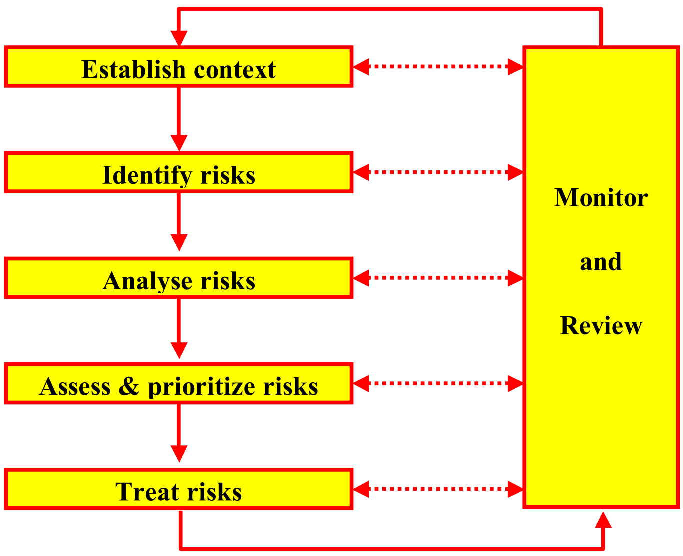

Figure 1.1: Risk management overview (Standards Australia, 1995, Fig 3.1)

This study deals largely with the risk identification, risk analysis and risk assessment stages of the process. Whilst we provide some opinion on matters relating to risk prioritisation and risk treatment these are the responsibility of those, such as the Cairns City Council and the Queensland Government agencies, that have that statutory responsibility.

What is Risk?

Standard *AS/NZS 4360:1995* defines 'risk' as:

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

This definition is really too general for our purposes, consequently we have chosen to follow the conceptual basis 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, 1989 and 1993).

It is clear that uncertainty is a key factor, indeed it can be argued that, in many instances, the effectiveness of risk mitigation strategies is inversely proportional to the level of uncertainty that exists. The risk management process, particularly the risk analysis and risk assessment 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 (BoM) maintains comprehensive 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 Cairns. This history is not only important in establishing levels of probability for future events but also to illustrate that such threats are very real.

It is worth noting that the earthquake of record occurred in 1896 when Cairns consisted of a string of perhaps a hundred timber buildings on the shores of Trinity Inlet. The flood of record occurred in 1911 when there was virtually no development on the Barron River delta. The most significant cyclone impact on record was probably that of 1920 which put a storm tide of about 1 m above high tide level through the town, the population of which was only 10% of its current level. Even the most spectacular technological disaster, Australia's first BLEVE (boiling liquid expanding vapour explosion) accident in 1987, occurred when the population of the city was less than half its current level.

Risk Analysis

AS/NZS 4360:1995 (p. 5) 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 develop very detailed data on the principal elements at risk in the built environment of Cairns, whilst comprehensive statistics of good resolution are available from the quinquennial national censuses to provide at least basic measures of human vulnerability. The broad groups of elements at risk for which data have been collected in Cairns include:

***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) and administrative arrangements (local government, suburb and other administrative boundaries).

***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. A database containing such details on some 35 000[2] individual buildings in Cairns 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 Cairns have been identified in the *BUILDING* database and basic data on power and water supply infrastructure are 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 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.

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[2] Initial collection of these data on the first 20 000 buildings was made possible by a grant from the Australian Coordinating Committee for the IDNDR to the Queensland Department of Emergency Services in 1995. They have subsequently been expanded in both coverage and detail under the *Cities Project*.

Synthesis and modelling: Clearly, the range and variety of information needed to fuel a comprehensive risk analysis is enormous. While there are now many sources for such, 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. Some hazards, such as bushfires and 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 Cairns 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 Assessment and Prioritisation

AS/NZS 4360:1995 (p. 5) defines 'risk assessment' as:

> *the process used to determine risk management priorities by evaluating and comparing the level of risk against predetermined standards, target risk levels and 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 4360:1995*, 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 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 Cairns, 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 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.

Not all acceptability criteria can be expressed as categorically as this because they deal with human nature and the political *outrage* dimension of risk management. They also vary considerably over time. The threshold of acceptance is typically much lower immediately after a hazard impact than it was immediately before the impact. This reinforces the need for a strong feedback mechanism between establishing acceptability and the formulation of risk mitigation and response strategies.

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 Cairns, 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 deep soft sediments are most likely to maximise earthquake impact. Conversely these are the areas that are at least risk from landslide impact and, to some degree, from severe wind impact. Additionally, the impact on the Cairns community of a cyclone hazard with an average recurrence interval (ARI) of once in 150 years is likely to be more severe than the impact of the shaking associated with an earthquake with an ARI of 150 years. The maximum credible earthquake event, however, may have a greater potential for catastrophe, than the maximum credible cyclone.

The ultimate responsibility for determining what levels of risk are 'acceptable' rests with the Cairns community and the Cairns City Council.

Risk Mitigation Strategies

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

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 the country, whilst the Bureau of Meteorology maintains some 45 weather radar sites, 246 automatic weather stations and 3,029 stream gauging stations. The Bureau also takes data from the Japanese Geostationary Meteorological Satellite 26 times a day in addition to data taken from the polar orbiting US NOAA.

Warnings and forecasts: An effective warning and forecasting system, combined with a high level of community awareness and risk appreciation, is clearly one of the most potent mechanisms by which to achieve risk reduction. These are typically taken to mean short-term warnings, such as those issued by the Bureau of Meteorology for the hazards that can literally be seen coming, such as cyclones, floods and severe 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 remit 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 and training 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.

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

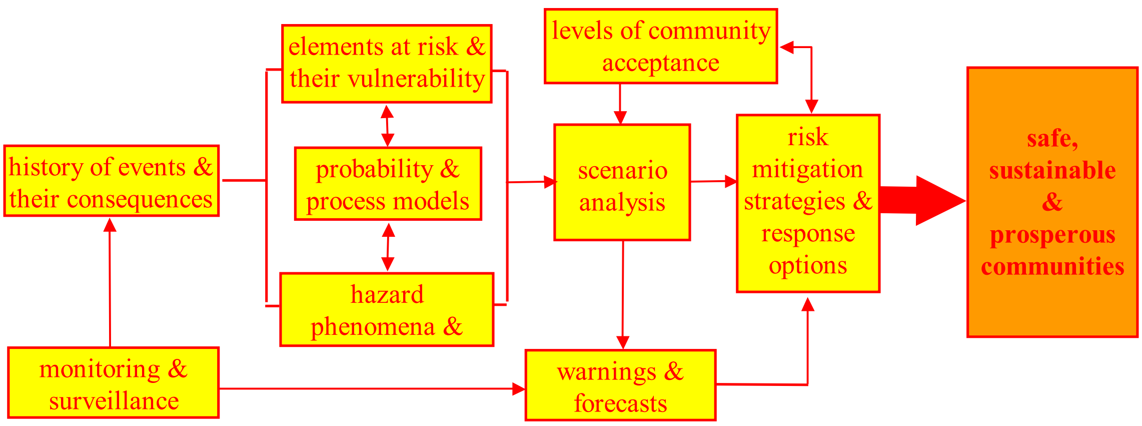

Figure 1.2: *Cities Project* understanding of the risk management process

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

Confidence, Uncertainty and Probability

The analysis of issues as complex as community risk is highly dependent on the accuracy, currency and appropriateness of the data that it employs. Every effort has been made to ensure that the best available data have been used in the various analyses included in this report.

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. For example, a common description of event probability is the 'return period' of a particular event, 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 records, 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 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.*

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 Cairns. The record of earthquakes, floods and cyclones extends over a little more than 100 years. That record is certainly incomplete. For the first 75 years or so of that time there was minimal instrumental measurement except for floods. Most of the smaller or more distant events went unreported. The recording of landslides has been even less complete.

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.

CHAPTER 2: THE CAIRNS SETTING

Introduction

Cairns is the most northerly of Queensland's cities and one of the fastest growing communities in Australia. It is also an isolated community, located some 1 400 km in a direct line, or 1 706 km by road, from Brisbane. Melbourne is marginally closer to Brisbane than is Cairns. An aerial image of Cairns city and inner suburbs viewed from the east is shown in **Figure 2.1** (reproduced by permission of Brian Cassey Photography).

The 160 square kilometre area administered by Cairns City Council has a resident population of approximately 120 000. This total can exceed 150 000 at the height of the tourist season in July-August. This combination of size, rapid growth and isolation, together with its significant history of natural hazard events (most notably cyclones and floods) makes Cairns an ideal community on which to base a case study of urban vulnerability to a range of geohazards.

Community risk research on Cairns commenced under the TCCIP in 1995 with a particular focus on the risks associated with storm tide inundation. That effort provided an ideal base on which to develop the wider community risk research described in this report.

The Physical Setting

Topography: The major structural features of the Cairns area are shown in **Figure 2.2**. The dominant feature is the very steep coastal scarp that forms the eastern edge of the Atherton Tableland. That scarp is marked by (from south to north) the Isley Hills, the Lamb Range and the McAlister Range. The Whitfield Range is an offshoot from the Lamb Range and separated from it by the valley of Freshwater Creek. To the east of, and running parallel to, the main range system lies the Thompson Range. Elevations within the study area range from sea level to approximately 800 metres (m).

The main drainage features are:

- the Barron River, which rises on the Atherton Tableland and enters the coastal plain through the spectacular Barron Gorge;

- Freshwater Creek, which joins the Barron River below the Gorge and drains the Lamb and Whitfield Ranges. The Freshwater is dammed at Copperload Falls to create Lake Morris - the main storage for the Cairns water supply; and,

- the network of small creeks that flow into Trinity Inlet. This system represents the original delta of the Mulgrave River.

The Mulgrave River itself, which flows onto the coastal plain to the south of Gordonvale, is not significant within the study area, although the alluvial sediments deposited in the Mulgrave River corridor certainly are significant to this study. The course of the Mulgrave probably alternated north and south after flowing eastward from the mountains onto the broad, relatively high alluvial plain near Gordonvale. During a sea level fall in the Pleistocene, it incised a channel into the sediments southward and has flowed south to Mutchero Inlet since then (Willmott and others, 1988). The basalt flows at Green Hill volcano, north-east of Gordonvale, have been dated at 986 000 years (Muller and Henry,

1982) and doming associated with this volcanic episode does not seem to be responsible for damming the Mulgrave river course north to Trinity Inlet (Willmott and others, 1988).

Geology: Bedrock in the Cairns region consists of more than 200 million year old sequences of folded and cleaved metamorphosed sediments and granite bodies. The prominent escarpments were probably formed from a modified land surface more than 65 million years old, which was formerly a continental highland. The granite bodies probably formed the highest points of this land surface because of their resistance to erosion.

Around 60 million years ago the eastern part of the continental highland was rifted, leaving a steep eastern slope. This slope has been retreating since, and reached close to its present position about 1 million years ago. Erosion has occurred most rapidly in the metamorphosed sediments leaving the granite as isolated hills and ranges (Willmott and others, 1988). Whether or not there has been further uplift or faulting since the rifting of around 60 million years ago is not known. There is little direct evidence that the Mulgrave River corridor is a former rift valley, however, this seems possible given its flat, sediment-floored valley, steep bedrock sides and the presence of the Green Hill volcano.

Climate: Cairns lies on the coast of Queensland at approximately 17^{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. Cairns comes under the influence of tropical cyclones on average at least once every two years, though 'direct hits' by severe tropical cyclones are not common.

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

The main climatic statistics are summarised in **Table 2.1**.

Table 2.1: Selected climatic statistics for Cairns (BoM, 1998)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean max temp (^{o}C)	31.4	31.1	30.5	29.2	27.5	25.9	25.6	26.5	27.9	29.4	30.6	31.4	28.9
Mean min temp (^{o}C)	23.6	23.7	23.0	21.5	19.9	17.7	17.1	17.5	18.6	20.5	22.2	23.3	20.7
Highest daily temp (^{o}C)	40.4	38.9	37.7	36.8	31.3	30.1	30.1	31.0	33.9	35.4	37.2	40.5	
Lowest daily temp (^{o}C)	18.2	17.9	18.6	13.0	10.1	6.2	7.3	7.8	11.1	12.4	14.6	17.1	
Av. rainfall (mm)	405	432	417	195	98	49	30	28	36	41	92	179	2001
Highest daily rain (mm)	368	286	403	186	90	70	31	63	80	87	185	230	
Av. daily sunshine (hrs)	6.8	6.1	6.4	6.8	6.4	7.5	7.3	7.8	8.5	8.8	8.6	7.7	7.4

Vegetation: The natural vegetation of the area is a species-rich tropical rainforest. Extensive areas of this type still exist along the ranges and are now incorporated, under World Heritage listing, into the Wet Tropics Management Area. Rainforest grades to various forms of eucalypt-dominated forest or woodland and grassland in areas exposed to frequent burning, especially on the hill slopes. Most of the valley and coastal plain areas not occupied by urban development are under sugar cane cultivation or are covered by mangrove communities.

Settlement

The present-day boundaries of Cairns City were established in 1995 following the amalgamation of the former local governments of Mulgrave Shire and Cairns City. The area covered by this study includes all of the significant urban areas extending from the suburb of Palm Cove in the north to the settlement of Gordonvale in the south. It also includes the Yarrabah Aboriginal Community to the east of Cairns. This area is shown in **Figure 2.3**.

European settlement of Cairns was established in 1876 to provide a port and supply base for the Hodgkinson River goldfields (to the north-west of present-day Mareeba) and named for the then Governor of Queensland, Sir William Wellington Cairns. Over the ensuing 123 years the city has continued to play a major role as the transport, logistic and administrative centre for an increasingly large hinterland. Today, that hinterland includes Cape York Peninsula, Torres Strait, the savanna country facing the Gulf of Carpentaria and extends as far as the mineral-rich areas of the Mount Isa district. It also reaches beyond Australia to cover significant mining operations in Papua New Guinea and the Indonesian Province of Irian Jaya.

Cairns is a major tourist destination with about one million international and one million domestic passengers passing through the Cairns International Airport annually. It is also the centre for a significant proportion of Australia’s sugar industry, based on the Mulgrave Mill at Gordonvale, and fishing operations in the northern Great Barrier Reef.

The original settlement was established along the low-lying swamp and dune country that formed the shores of Trinity Bay and Trinity Inlet. The area occupied by settlement has been progressively filled (by between two and four metres) to bring it above tide and flood level, initially using material dredged from the inlet and material excavated during the building of the Cairns to Kuranda railway.

This low-lying area is still the focus for commercial, transport, logistic and tourist activities. Residential development first grew around the port and subsequently spread across the coastal plain to the north and west. In more recent times, development has spread north across the Barron River to the northern beaches, west onto the low hills and foot slopes of the Whitfield Range, and south into the Mulgrave River valley towards Gordonvale.

Population

According to the National Census taken in September 1996, the population of the Cairns Statistical Local Area (SLA - a combination of the total Cairns City local government and Yarrabah Aboriginal Community Council areas) was 128 026 (64 330 males and 63 696 females). Of these, 15 131 were recorded as ‘visitors’ of whom 9 269 (or about 60%) were from overseas. The study area contained 123 826 people (62 149 male and 61 677 female).

The age/sex makeup of the resident Cairns population is shown in **Figure 2.4** compared to the makeup of the Queensland population as a whole. Of particular note in Cairns is the significant bulge in the working age cohorts from 20 to 50 for both sexes (50.4% of the total population compared with 46.4% in the Queensland population) and the relatively small proportion of people over 65 (9.1% of the total compared with 12.5% in the whole of Queensland). The very young (under 5 years) make up 7.5% (Queensland total is 7.4%). Gender balance is 0.99 females to every male as opposed to 0.92 females to every male in the total Queensland population.

Growth of the Cairns population is shown in **Figure 2.5**. Until around 1970, growth was reasonably steady and was based to a large degree on a rural economy. It took off rapidly after 1970 as the tourist industry became significant. It took almost 100 years for Cairns to reach a population of 50 000; it only took another 20 years for it to add the next 50 000!

It is interesting to note that overseas arrivals numbers are at their greatest during the Cairns summer (i.e. the northern winter) whilst domestic arrivals are at their greatest during the winter. Average length of stay in Cairns by tourists ranges from 5 days during the March quarter (January-March); to 4.6 days in the June quarter; to 5.2 days in the September quarter; and 4.7 days in the December quarter. Given these figures, we estimate that the total population of the city on any given day will range from around 122 000 to 125 000 in May to between 130 000 and 150 000 in August.

The tourist population in Cairns adds significantly to the total and fluctuates seasonally as shown in **Figure 2.6**.

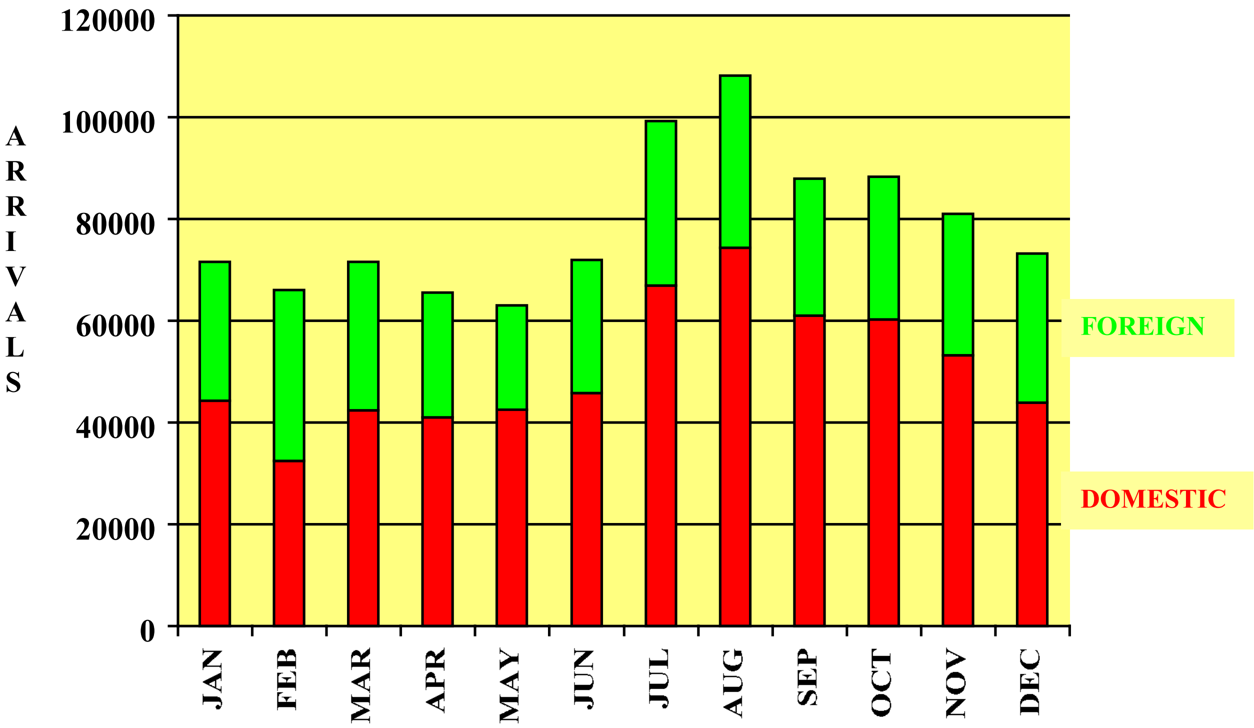

Figure 2.6: Cairns monthly tourist arrivals during 1997 (Source: various ABS bulletins)

External Links

Cairns is not a self sufficient community. It depends very heavily on outside sources of supply for its food, energy and material requirements as well as its principal sources of income. Such dependence clearly imposes limits to the community's resilience.

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

- the main road links including: to the south, via the Bruce Highway to Brisbane (1 706 km) and beyond; north to Mossman and Port Douglas via the Captain Cook Highway (75 km); west to Mareeba via the Kennedy Highway (64 km) and beyond to Cooktown or the Cape; or south-west to Atherton via the Gillies Highway (80 km) and beyond to the Gulf;

- the main-line rail link to the south to Brisbane which carries regular passenger and freight services; a low capacity link (mainly freight) also exists to the west via Kuranda and beyond to Chillagoe or south-west to Forsayth;
- the international airport, located at the mouth of the Barron River, has over 300 domestic services per week; nine major international carriers operate 94 services each week to countries including Indonesia, Singapore, Malaysia, Hong Kong, Taiwan, Korea, Japan, PNG, the USA and New Zealand; and,

- the sea port with berths for passenger/cruise ships, general cargo, containers, bulk dry cargo, tankers discharging both oil and LPG and a bulk sugar terminal; a patrol boat base for the RAN (HMAS *Cairns*) and a commercial fishing base is also located within the port; extensive provision of marinas and pile moorings also cater for charter vessels and other small craft.

Power supply for the Cairns area is drawn from the State grid. The closest major power stations are at Stanwell (near Rockhampton) and Gladstone, each more than 1 000 km to the south. Peak loads are supplemented by power from the Barron Gorge and the Kareeya (north-west of Tully) hydro-power stations. The 60 megawatt Barron Gorge station does not have the capacity to supply Cairns on its own without significant load shedding. Stanwell, Barron Gorge and Kareeya power stations are 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 Cairns region is managed by the Far North Queensland Electricity Company (which trades as FNQEB) - both are state-owned enterprises.

Hazard Monitoring

Cairns is an ideal first pilot study location because of its significant history of hazard impacts, as well as its expanding exposure to risk. Historically, Cairns has come under the influence of at least 53 tropical cyclones, seven major river flooding events, major landslides, earthquakes up to Richter magnitude 5.0, bushfires and Australia's first major LPG explosion. Details of the significant hazard impacts will be dealt with more fully in subsequent chapters.

The hazard environment of Cairns is now amongst the best understood and monitored in Australia. Seismic monitoring has been enhanced with the installation of new instruments under the Joint Urban Monitoring Program (JUMP - a joint Commonwealth-State program). These instruments, consisting of a combined seismograph and accelerograph located at Henley Hill and an accelerograph at Tunnel Hill, were installed in February 1997.

Prior to their installation, seismic events in the Cairns region were only recorded on more distant instruments, the closest of which is at Carron Creek (near Koombooloomba Dam) approximately 100 km to the south. The smallest magnitude earthquake at Cairns that could be detected prior to installation of the JUMP instruments was around Richter magnitude 3.5. The JUMP instruments can now detect events as small as Richter magnitude 1.5. A detailed discussion of the seismic monitoring coverage of Cairns is included in **Chapter 4** and a list of seismic recording stations within 500 km of Cairns is in **Table 4.1**.

Cairns is also covered by a sophisticated monitoring and warning systems for tropical cyclones and floods, operated by the Bureau of Meteorology. At the heart of this system are the weather radars at Mornington Island, Cairns (Saddle Mountain), Townsville (Mount Stuart) and on Willis Island. The radar data is complemented by data from a range of imaging satellite systems such as the Japanese Geostationary Meteorology Satellite (GMS) and the Advanced Very High Resolution Radiometer (AVHRR) instrument on polar orbiting satellites operated by the US National Oceanographic and Atmospheric Administration (NOAA). The Bureau also operates an extensive coverage of automatic weather stations as well as having access to data from a network of rainfall and climatic instruments operated by various public agencies and private citizens.

The Bureau and the Queensland Department of Natural Resources also operate networks of stream gauging stations. These range from digital ALERT stations, which are accessed by radio telemetry, to manual stations. The Queensland Department of Environment's Coastal Management Branch also collects 'real-time' wave and tidal data from remote gauges by telemetry.

CHAPTER 3: THE ELEMENTS AT RISK AND THEIR VULNERABILITY

In the first chapter we introduced the 'five esses' (shelter, sustenance, security, society and setting) into which we have organised our consideration of the elements at risk in the community and their vulnerability. The broader 'setting' elements were outlined in the previous chapter. In this chapter we describe the key aspects of the remaining four groups.

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 35 000 individual buildings in Cairns has been developed. For convenience, this mass of detail has been summarised down to the suburb level in the **Table C1** and **Table C2**, contained in **Appendix C**, whilst the content and structure of the building database are described in **Appendix D**.

Table C1 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.

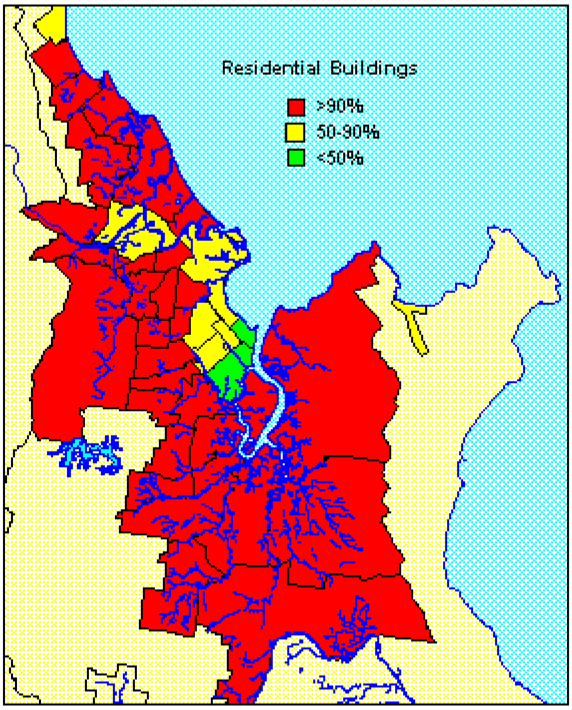

Figure 3.1: Proportion of residential buildings by suburb

Overall, around 91% of all buildings are residential (houses, flats and commercial accommodation) though the distribution is uneven across all suburbs, as shown in **Figure 3.1**. In City and Portsmith less than 50% of buildings are residential, whilst Aeroglen, Cairns North, Manunda, Parramatta Park, Westcourt and Yarrabah have between 50 and 90% residential. All other suburbs are more than 90% residential.

Table C2 provides tallies of the three key structural characteristics of houses in each suburb, namely floor height, wall materials and roof materials.

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 77.5% of all houses are built on a slab (notionally 0.3 m above ground level); 8.8% have suspended floors of less than 1.0 m above the ground; and 13.7% 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 City and Parramatta Park, and the hill-slope suburbs such as Edge Hill. In the older suburbs, many original 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. Overall, the proportions of wall material are given in **Table 3.1**.

Table 3.1: Wall materials of houses and flats in Cairns

MATERIAL	HOUSES	FLATS
Brick	12.3%	16.0%
Concrete block	62.6%	78.6%
Timber	14.9%	3.0%
Fibro	7.8%	1.9%
Metal	2.3%[3]	0.4%

Roof material for both houses and flats is overwhelmingly metal (typically the classic corrugated iron) at 96.4%, with tile (3.3%) and fibro (0.3%) making up the remainder.

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

This is in strong contrast to houses in the more recent suburbs (e.g. Bentley Park, Brinsmead and Mount Sheridan) in which houses are almost universally on a slab, have walls of concrete block and large areas of glass. Roof forms are fairly evenly split between hip and gable ended, but typically have a much lower pitch than those in the older suburbs.

Brick walls are most common in suburbs that developed in the 1960's and 1970's such as Earlville, Edge Hill, Mooroobool, Westcourt and Whitfield. Given their general vintage, the majority are likely to be of brick veneer construction, rather than 'solid' or cavity construction, given that brick veneer became an accepted construction method in Queensland in the late 1950s and has been the predominant brick form since then.

[3] The metal clad walls are mostly those which were formerly fibro clad and have been upgraded with aluminium or vinyl-coated cladding, though a few old houses have corrugated iron walls.

The pattern of urban growth in Cairns over the past 60 years 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 aerial photography and field observation.

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 houses included in the Cairns *BUILDING* database, by decade of construction, are as follows:

Pre 1945	3.4%	1945-1954	5.3%
1955-1964	6.8%	1965-1974	11.4%
1975-1984	14.6%	1985-1994	54.3%
1995-(1997?)	4.1%		

Current residential growth in Cairns is predominantly to the south along the Bruce Highway towards Gordonvale and beyond, whilst some growth continues in the north to the west of the Captain Cook Highway. A somewhat controversial proposal has been presented to Cairns City Council to develop the Trinity East area, on the low-lying delta country opposite the CBD, as a satellite town to house approximately 20 000 people.

Mobility: The ability of people to get to and from shelter is almost as significant as the shelter itself. Cairns 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 65.8 km of highway (Bruce Highway and Captain Cook Highway); 23.7 km of urban main roads; 101.2 km of suburban access roads and 898.4 km of suburban roads.

Passenger transport in Cairns is based largely on the family car as shown in **Table 3.2**. Mobility is, consequentially, very heavily dependant on household access to private cars, of which there are an estimated 53 200. **Figure 3.8** shows the distribution of households with no access to a vehicle and **Table C3** provides the detailed proportions by suburb. Both of these are based on data from the 1996 census.

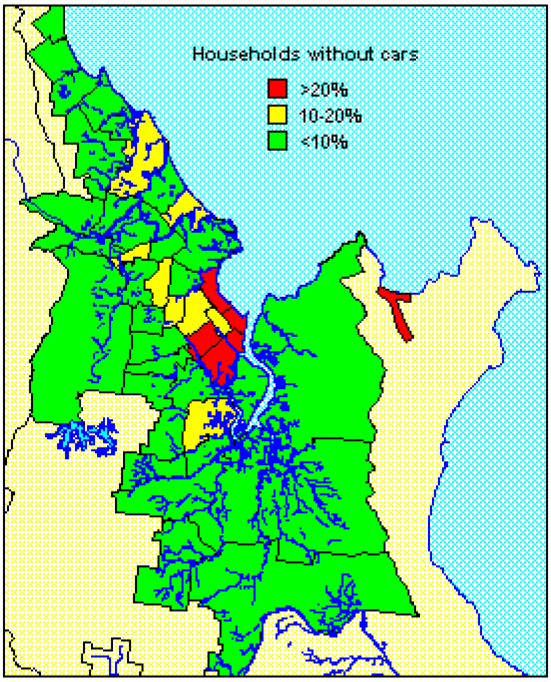

Figure 3.8: Proportion of households with no car (Source: ABS, 1998a)

Table 3.2 shows the proportions of travel mode used to get to work in Cairns 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 3.2: Mode of travel to work in Cairns (Source: ABS, 1998a)

MODE	NUMBER	PERCENT
Bus	952	1.7
Taxi	436	0.8
Car driver	31,556	57.3
Car passenger	4,914	8.9
Motor bike	808	1.5
Bicycle	1,829	3.3
Walk	2,228	4.0
Worked at home	2,219	4.0
Did not go to work	7,422	13.5
Other modes (eg boat)	1,610	2.9
Not stated	1,047	1.9

Because of the very large tourist industry in Cairns, there are large numbers of coaches, taxis, hire cars and other passenger vehicles available. A scheduled bus service provides coverage of most suburbs.

Sustenance

The Cairns 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 interdependency as illustrated in **Figure 3.9**. In this figure 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	AFLD	PORT
POWER		**S**	**S**	**S**	**M**	**S**		**S**	**S**
WATER	**M**		**S**					**M**	**M**
SEWER		**S**						**M**	**M**
COMMS	**S**	**S**	**S**		**M**	**S**		**S**	**S**
ROAD	**M**	**M**	**M**	**M**		**M**	**M**	**M**	**M**
RAIL					**M**		**M**		**M**
BRIDGE	**S**	**S**	**S**	**S**	**S**	**S**			
AFLD									
PORT									

(developed from Granger, 1997, Table 2)

Figure 3.9: Interdependency of lifeline assets

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

Power supply: As described in Chapter 2, the main source of the Cairns power supply lies some 1 000 km to the south from the power stations near Rockhampton and at Gladstone. Transmission lines operated by Powerlink bring that supply to the Kamerunga Bulk Supply Substation at Caravonica (on low ground less than 800 m from the Barron River). There are two transmission lines. Each enters Cairns via the escarpment rather than the coastal lowland.

Reticulation within the Cairns urban area is managed by FNQEB. Full details of the reticulation system are not available to us, however, within the most densely settled area (from the Barron River south to Woree) there are 210 km of high voltage and 368 km of low voltage service strung on about 9 000 poles. This above-ground service is susceptible to disruption during periods of high wind, mostly as a result of debris or tree branches bringing down the lines. Since the experience of Cyclone *Justin*, which left the city without power for at least 36 hours, FNQEB has paid particular attention to reducing the risk posed by tree hazards.

Reticulation within the CBD area (generally south of Minnie Street and east of McLeod Street) is underground. Underground mains also service critical facilities, such as the Cairns and Calvary Hospitals. The Cairns City Substation (32-38 Hartley Street), which controls distribution to this key area, is a two-story structure with the sensitive facilities said to be located on the upper level.

Water supply: The bulk of the Cairns water supply is drawn from Lake Morris, formed by the Copperlode Falls Dam on Freshwater Creek. Lake Morris has a capacity of 45 000 megalitres and has a secure rainforest catchment. Water is released from the dam into Freshwater Creek and is picked up at the intake structure just upstream of Crystal Cascades. From there it is piped to the Freshwater Creek Water Treatment Plant.

Distribution to consumers is by gravity feed from at least 16 reservoirs and water towers throughout the study area. Reticulation involves some 1 720 km of water main of various sizes, materials and age. Almost half of the water reticulation network is constructed of brittle material (asbestos-cement or cast iron). This is particularly prevalent in the older areas of the city and in the larger trunk mains. The more modern segments of the network overwhelmingly employ ductile PVC pipe.

The water supply to the Yarrabah Community feeds from a large reservoir on a ridge to the west of the settlement and is piped to a small chlorine treatment plant just to the south of the Yarrabah Police Station. Water is reticulated throughout the settlement. Details of the network are not available.

Sewer: Most of the Cairns urban area is connected to the reticulated sewerage network. Sewerage treatment plants are located close to the mouth of the Barron River in Aeroglen; in Woree, at the head of Trinity Inlet (the Southern Pollution Control Plant); in Brinsmead; and in Smithfield. There are at least ten sewerage pumping stations throughout the city, most being in the low-lying inner area.

Disruption of power supply as a result of the impact of Cyclone *Justin* in 1997 caused raw sewage to escape the system because of the shut down of the pumping stations.

Telecommunications: Much of the telecommunications network infrastructure operated by Telstra in the Cairns urban area (both copper wire and optical fibre) is underground. Links to suburbs along the northern beaches are backed up by microwave links. Details of the infrastructure operated by Optus are not available, however their Cairns hub is located in Portsmith, close to the main Telstra depot.

The landfall station for the Cairns to Port Moresby (PNG) submarine cable is located in North Cairns.

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. Telstra exchanges are located in City (the main regional exchange), Clifton Beach, Earlville, Edge Hill, Edmonton, Gordonvale, Holloways Beach, Stratford, White Rock and Yarrabah. Most of these suburban exchanges are housed in re-locatable metal cabins.

Broadcast radio and TV services covering the region are provided from studios in City (ABC, 4CA, HOT FM, 4KZ & Radioactive 558), Earlville (Channel Ten TV), Manunda (WIN TV, 4CCR FM) and Parramatta Park (Sunshine television), however, transmitters are located on Mount Bellenden Ker (all TV and most FM radio), near Gordonvale (ABC Radio) and Trinity East (4CA).

Dedicated telecommunications networks are also operated by Australian Defence Force units (Far North Queensland Regiment at Westcourt and HMAS *Cairns* in Portsmith), the Civil Aviation Agency (mostly at the airport in Aeroglen) and numerous private sector organisations such as fishing and mining companies, many of them located in Portsmith. Many of the private VHF and UHF networks, such as those used by taxis, police, emergency services and so on, operate from base stations on Bellenden Ker and/or on prominent features on the coastal escarpment.

The key lifeline facilities throughout Cairns are located on **Figure 3.10**.

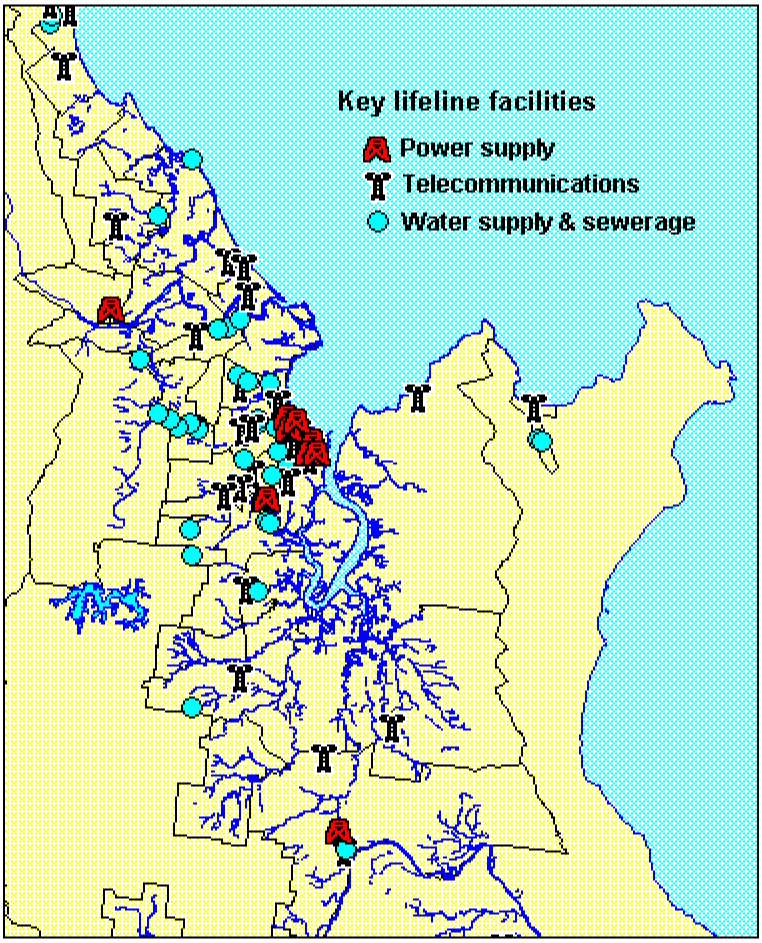

Figure 3.10: Key lifeline facilities

Logistic support: The supply and distribution of essential 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 are obviously of great significance. Apart from small quantities of fruit and vegetables, meat and seafood, very little of the food consumed in Cairns 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 Portsmith area. One of the few exceptions is the Country Bake bakery, commissioned in 1997, which is located in Bentley Park. Regional retailing facilities are located in City (Cairns Central), Earlville (Stockland Plaza), Manunda (Festival Faire), Smithfield (Smithfield Plaza) and Westcourt (Westcourt Plaza). Suburban shopping centres and 'corner stores' with smaller supermarkets or convenience stores, as well as smaller bakeries, butchers, green grocers, and so on, service most suburbs. The levels of stock held for basic foodstuffs are not known.

Bulk fuel and gas storage facilities are also concentrated in Portsmith, with secondary (especially operational) storage of specialist products at facilities such as the airport (avgas and jet fuel), HMAS *Cairns* (bunker and diesel fuel) and some of the larger industrial and transport 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 Mulgrave Road/Bruce Highway and Sheridan Street/Captain Cook Highway. There is no reticulation of gas in Cairns, so supply is provided in bottles or to bulk 'bullet' tanks. Distribution is, consequently, largely by dedicated tanker trucks. Transfer of aviation fuels from the port to the Joint Underground Hydrant-refuelling Installation (JUHI) at the airport utilises a dedicated B-double tanker unit. The capacity of bulk storage for most products is believed to be sufficient for approximately three weeks of normal usage. Tankers typically provide resupply from Brisbane and/or Sydney.

Most other bulk storage and distribution centres for products as diverse as cement, agricultural chemicals, pharmaceuticals, raw sugar, molasses, timber and hardware, as well as transport and handling equipment (such as fork lifts and cranes), are also concentrated close to the port and rail head facilities of Portsmith. Significant amounts of freight, including foodstuffs and goods such as pharmaceuticals, are also handled through the Cairns International Airport located at the mouth of the Barron River.

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 providing for public safety. In addition to identifying the physical elements at risk that relate to these aspects, we have identified a range of factors that will provide relative measures of community vulnerability and their distribution across Cairns.

Health: The key health facilities in Cairns are the Cairns Hospital (Cairns North) and Calvary Hospital (City), together with the Gordonvale Memorial and Yarrabah Hospitals. The two larger facilities are located within two blocks of the waterfront, and each other, in downtown Cairns. The Cairns Hospital is currently undergoing major re-development on the site occupied by the region’s main public hospital since 1884. Both major hospitals provide a comprehensive range of medical, emergency and surgical services, whilst the smaller centres are somewhat more basic.

There are six major nursing homes. Four are located adjacent to each other in Westcourt, close to the Westcourt Plaza shopping complex (Good Samaritan, Nazareth Village, Bethlehem and FARNOHA – Far Northern Home for the Aged); the W.B. Winfield Nursing Home is located in Whitfield; and the Pyramid Retirement Centre is located on the northern edge of Gordonvale.

A wide range of private specialist medical practices, including pathology, surgery, and medical imaging are located within a few blocks of the two main hospitals. 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 city, with some degree of concentration in the downtown area. Community health services, such as Blue Nurses, 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 5 years) and elderly (over 65) considered to be the most vulnerable groups. The relative distribution of these age groups is shown in **Figure 3.11** and **Figure 3.12** respectively. These maps show the distribution at the suburb level.

The distribution of under 5-year olds is clearly dominant in the newer, so-called ‘nappy valley’, suburbs such as Bentley Park, Kamerunga, Mount Sheridan and White Rock. High proportions of under 5’s are also found in the cane growing areas of Gordonvale, Mount Peter and Trinity East. The highest concentration, however, is in Yarrabah, where a remarkable 16% of the population is under 5.

By contrast, the distribution of the elderly is concentrated more in the northern beach suburbs of Clifton Beach and Palm Cove, the older suburbs of the city (Aeroglen, Earlville, Edge Hill, Manunda Parramatta park, Portsmith, Westcourt, Whitfield and Woree) and the cane growing areas of Gordonvale and Trinity East. Both are sourced from ABS (1989a).

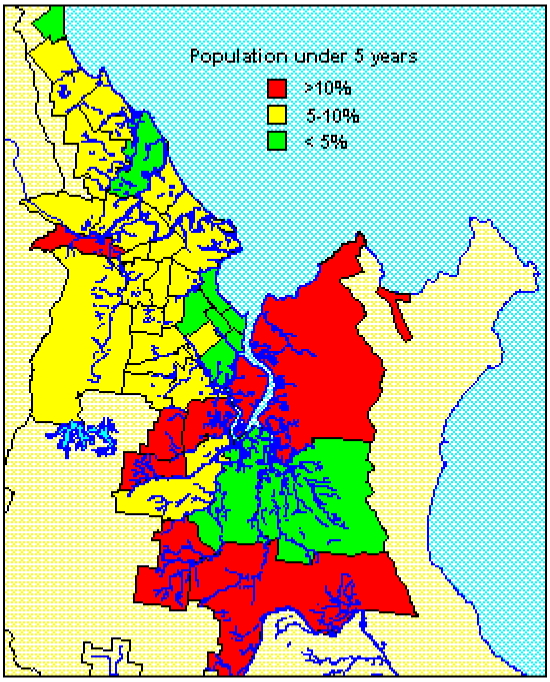

Figure 3.11: Cairns - population aged under 5

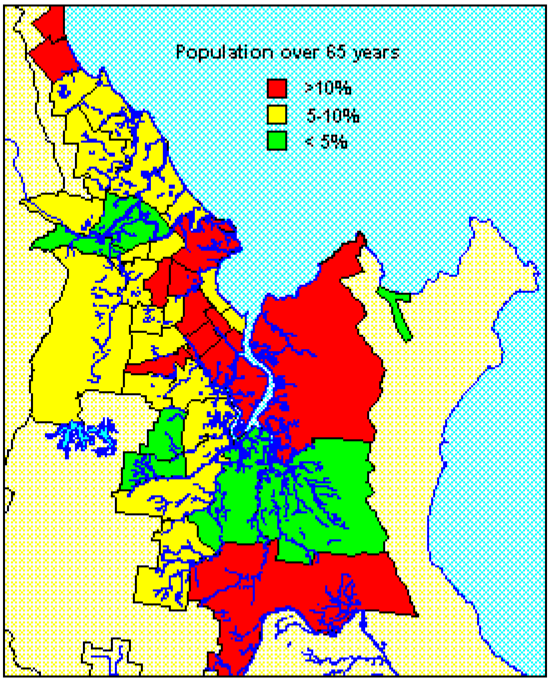

Figure 3.12: Cairns - population aged over 65

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

Wealth: The economy of Cairns is undoubtedly dominated by tourism and sugar production, however, industries including fishing, building and construction, ship building and retailing also make a significant contribution. The following statistics provide some indication of the relative importance of these various sources of local wealth:

- retail expenditure in Cairns is currently estimated at $1.5 billion annually;
- the tourist industry brings approximately $1 billion into Cairns annually. Of that amount, takings from tourist accommodation in 1997 totaled $200.8 million ($162.8 million from hotels, motels and guest houses; $21.4 million from holiday flats and units; $7.5 million from caravan parks; and $9.2 million from hostels);
- the value of the Cairns/Far North Queensland region's agricultural production is around $800 million annually of which sugar makes up about 65%;
- the construction industry in Cairns is worth around $600 million annually;
- servicing the mining industry earns Cairns over $350 million per annum - the Freeport Indonesia mine in Irian Jaya accounts for at least $240 million of this figure. The value of the mining industry to Cairns will increase as more mines, such as the large kaolin mine north of Weipa on Cape York begin to use Cairns as their fly in/fly out base;
- a local shipbuilding firm is currently building two hydrographic research vessels for the RAN worth $200 million;

- the fishing industry of the region (including the Gulf), which is largely serviced from Cairns, is worth around $140 million per annum.

These economic indicators have been taken largely from material produced by Cairns-based W.S. Cummings Economic Research Services for a local real estate development business and published on the Web at *www.patonpartners.com.au.* Another indicator of the make-up of the Cairns economy is the number of people employed in each major industry sector. This is shown in **Table 3.3**.

Table 3.3: Cairns employment by industry (Source: ABS, 1998a)

INDUSTRY GROUP	PERSONS EMPLOYED	INDUSTRY PERCENT
Agriculture, forestry and fishing	1645	3.0
Mining	383	0.7
Manufacturing	3971	7.0
Electricity, gas and water supply	275	0.5
Construction	4632	8.2
Wholesale trade	2779	4.9
Retail trade	8769	15.4
Accommodation, cafes and restaurants	5796	10.2
Transport and storage	4674	8.2
Communication services	752	1.3
Finance and insurance	1427	2.5
Property and business services	4932	8.7
Government administration and defence	3173	5.6
Education	3151	5.5
Health and community services	4560	8.0
Cultural and recreational services	1764	3.1
Personal and other services	2195	3.9
Non-classifiable economic units	807	1.4
Not stated	1109	2.0
Total persons employed	56794	

The spatial distribution of 'wealth' within the city can be gauged from indicators such as unemployment, individual income 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.

Unemployment rates recorded at the 1996 census of over 10% are concentrated close to the 'downtown' area of Cairns in suburbs including Cairns North, Holloways Beach, Machans Beach, Manoora, Manunda, Parramatta Park, Portsmith and Westcourt. Portsmith, with 21.3% unemployment is the highest. The lowest rate of 3.07% was recorded in the rural suburb of Barron. These are shown in **Figure 3.13**.

A similar spatial pattern is evident in the proportion of dwellings that are being rented (**Figure 3.14**). The suburbs with the highest proportion of rental accommodation are Yarrabah (49%), the older and more central city suburbs (Cairns North, City, Manoora, Parramatta Park, Portsmith, Manunda, Westcourt and Woree) and areas along the northern beaches (Holloways Beach, Palm Cove and Yorkeys Knob). By contrast, the highest areas of home ownership (ie less than 20% rental) are in the newer suburbs such as Brinsmead and Redlynch. Again both figures have been derived from data in ABS (1989a).

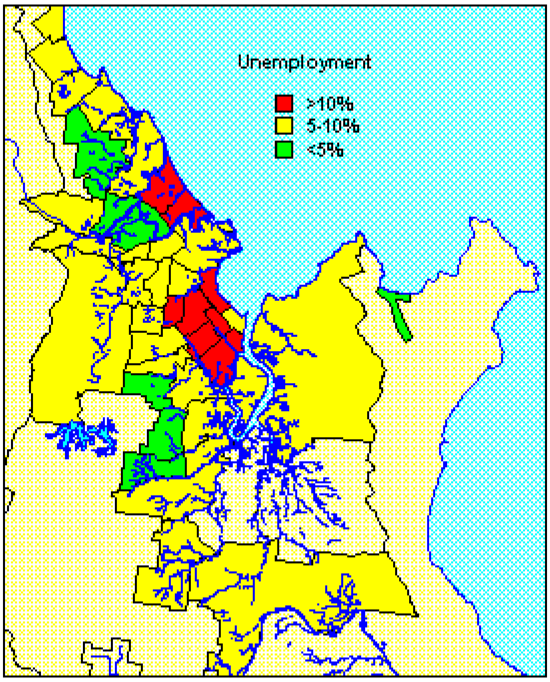

Figure 3.13: Cairns - unemployment rate

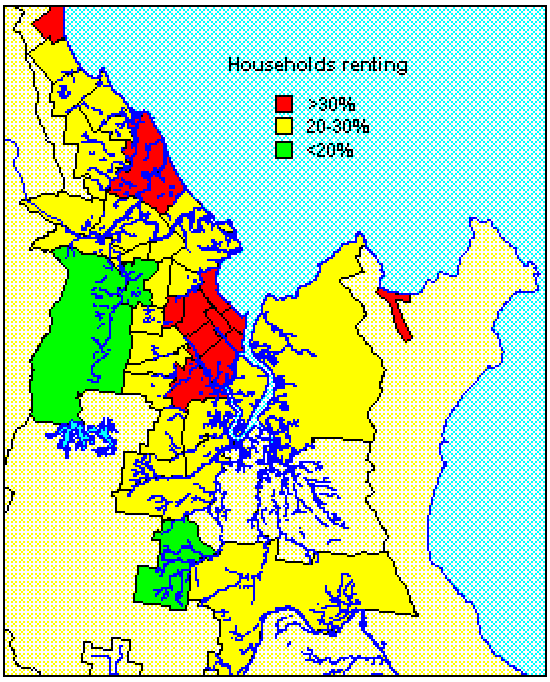

Figure 3.14: Cairns - percent of rental dwellings

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 C4** for a list of variable used). The resulting index has been standardised to have a mean of 1 000 and a standard deviation of 100 across all census collectors districts (CCD) in Australia (ABS, 1998b). For Cairns, the mean suburb average index value is 1 015.28, values ranging from a high (advantaged) value of 1 093.0 in Barron to a low (disadvantaged) value of 684.96 in Yarrabah and 842.33 in Portsmith as shown in **Figure 3.15**.

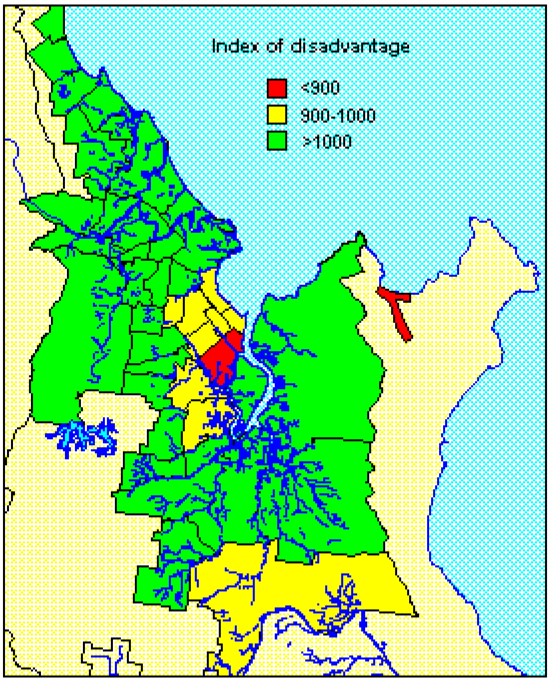

Figure 3.15: Cairns - areas of relative socio-economic disadvantage

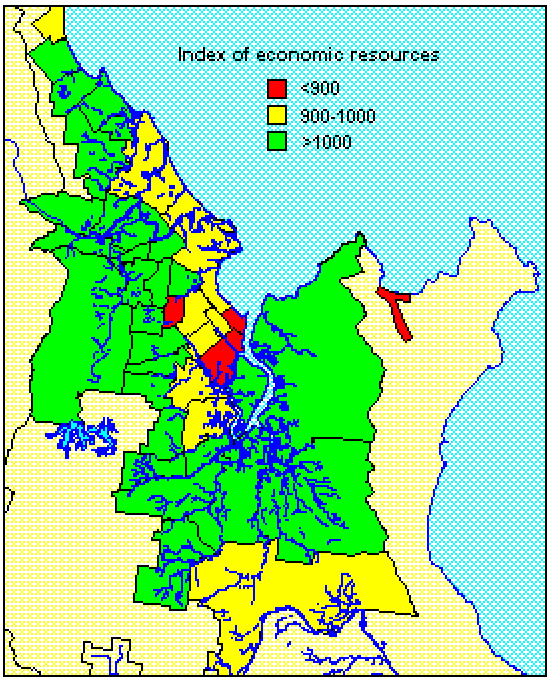

Figure 3.16: Cairns - areas of relative abundance of economic resources

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 C5** for a list of variables used). This index is also standardised with a national mean of 1 000 and a standard deviation of 100. The Cairns mean index value is 999.01. At the disadvantaged end of the spectrum the four lowest suburbs are Yarrabah (747.48), Portsmith (839.66), Manoora (881.63) and City (889.17). At the high end, the top four are Bayview Heights (1 117.03), Brinsmead (1 101.57), Redlynch (1 096.76) and Barron (1 089.42). The spatial distribution is shown in **Figure 3.16**. Both figures are based on data contained in ABS (1998b).

Protection: The full range of public safety services is provided in Cairns.

The city is the headquarters for both the Far North Region, and the Cairns District, of the Queensland Police Service (QPS). QPS establishments are located at:

Far North Region HQ	14 McLeod Street, City
Cairns District HQ	5 Sheridan Street, City
City Police Station & watchhouse	5 Sheridan Street, City
Cairns Police Beat	Esplanade, City
Edmonton Police Station	103 Bruce Highway, Edmonton
Gordonvale Police Station	13 Cannon Street, Gordonvale
Smithfield Police Station	Captain Cook Highway, Smithfield
Yarrabah Police Station	7 Range Road, Yarrabah

The Cairns District Disaster Coordination Centre, when activated, is located in the QPS District HQ building in Sheridan Street. If that location were not viable, the centre would be relocated to the Royal Flying Doctor Service office in Junction Street, Edge Hill. 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.

The Queensland Department of Emergency Services (DES) Far North District is also headquartered in Cairns (in the State Government Building, 36 Shield Street). This department is the administrative head for the Queensland Ambulance Service, the Queensland Fire and Rescue Authority and the Emergency Services Division, the latter incorporating the Aviation Service, the Chemical Hazards and Emergency Management (CHEM) Unit and the Disaster Management Service.

Ambulance Stations are located at:

Cairns City	40 Anderson Street, Manunda
Edmonton	32 Hartill Street, Edmonton
Gordonvale	1 Cannon Street, Gordonvale
Smithfield	1-3 Stanton Road, Smithfield
Yarrabah	12 Stanley Road, Yarrabah

The Royal Flying Doctor Service (RFDS) provides the major air ambulance service throughout the north of the state. It operates from its hangar in the general aviation area of the airport (Royal Flying Doctor Street, Aeroglen) and headquarters at 5 Junction Street, Edge Hill. The St Johns Ambulance Society also provides volunteer ambulance services from its headquarters at 44 MacNamarra Street, Manunda.

Fire Stations are located at:

Cairns City	Gatton Street, Westcourt
Edmonton	103 Bruce Highway, Edmonton
Gordonvale	105 Norman Street
Smithfield	12 Lesley Street, Smithfield

The specialised Airport Rescue and Fire Service protects the airport. It is located on the airfield in Sir Sydney Williams Street, Aeroglen.

The DES Aviation Service operates a rescue helicopter from its base in Bush Pilots Avenue in the general aviation section of the airport.

Training and administration of State Emergency Service (SES) units in the Far North District is coordinated by the Disaster Management Service office in Cairns. Local SES units are the responsibility of Cairns City Council as is the coordination of the Local Disaster Committee (LDC). The LDC, chaired by the Deputy Mayor and supported by a full time executive officer, is responsible for the local disaster plan.

Cairns City SES units have ‘sheds’ at:

Gordonvale	Simmons Street, Gordonvale
Manunda	46 MacNamara Street, Manunda
Marlin Coast	Captain Cook Highway, Palm Cove
Trinity	Pecten Close, Trinity Beach

DES also provides support to the volunteer marine rescue service provided by the Australian Volunteer Coast Guard, which is based in Marlin Parade, City. It operates a number of small craft for mainly inshore search and rescue. It is supported to some degree by the Cairns Marine Radio Club, which is based at 52 MacNamara Street, Manunda.

There are two Australian Defence Force establishments in Cairns; the HMAS *Cairns* naval base, and the headquarters for the 51st Battalion of the Far North Queensland Regiment (FNQR). The primary role of HMAS *Cairns* is to support patrol boat operations, especially for fishery patrols, in the Coral Sea, Torres Strait and Gulf. Its key facilities, including stores, fuel and repair facilities, are located within the port area, whilst junior sailor accommodation is in Sheridan Street, Cairns North. The FNQR is a Defence Force Reserve army unit with a key role in reconnaissance and surveillance operations in the Cape York and Gulf areas. Most of its part-time troops live in the small and isolated settlements of the Cape and Gulf region. Its base is in Coxall Street, Westcourt.

The locations of the major public safety service facilities are shown on **Figure 3.17**.

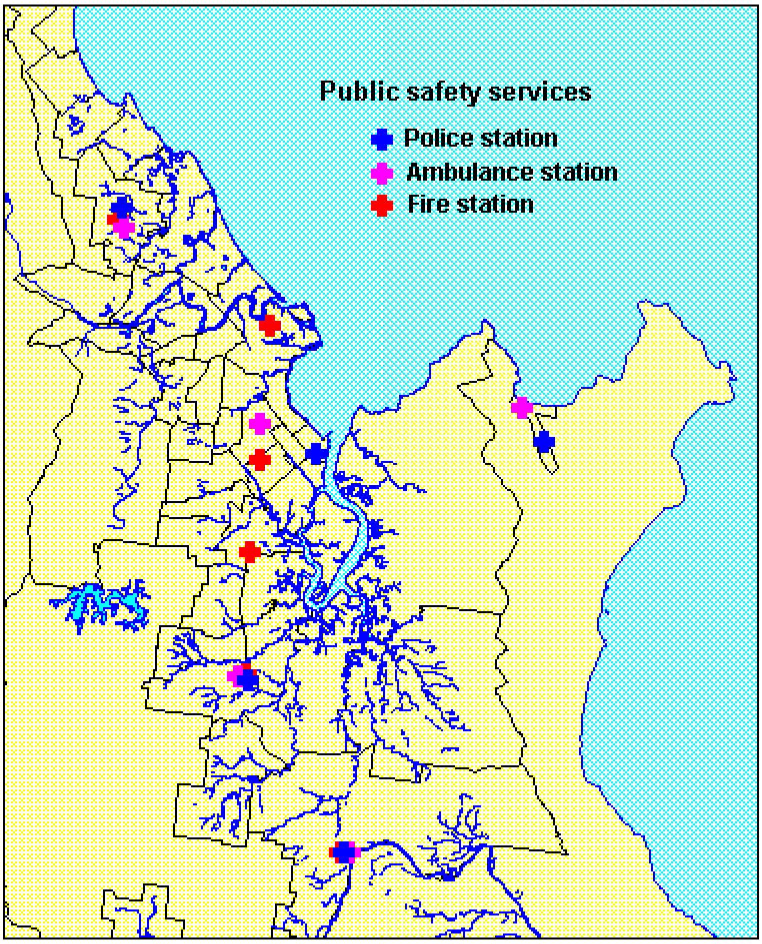

Figure 3.17: Cairns public safety services

The Australian Federal Police, the Australian Maritime Safety Authority and the National Safety Council also represent the Commonwealth Government's public safety role in Cairns. None of these agencies has a significant role in land-based disaster management in the Cairns region.

Apart from a system of levees protecting the airport and some bank protection works in the lower Barron River, there are no significant engineered mitigation structures such as levees or sea walls. Cairns City Council has, however, imposed development constraints for both flood and storm tide inundation below the 100 year average return interval (ARI) level since the mid-1990s. It was, in fact, the first local authority in Queensland to impose such development constraints for storm tide. The Australian Building Code, with its guidance for both earthquake and wind loads, is also enforced.

The protective services available in Cairns are more comprehensive than those found in most other regional Queensland centres. This is partly explained by the fact that Cairns is the headquarters for regional and district-level services, by its strategic location in Australia's north, by its history of disaster impacts and by its relative isolation.

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 large and as transient as that found in Cairns. The research that has been done by the Centre for Disaster Studies at James Cook University, however, suggests that it varies considerably across the city. The Machans Beach community, for example, is considered to have a particularly high degree of cohesion and community spirit, whilst areas in the Bungalow area of Parramatta Park have particularly poor levels of community identity. The development of indices of social vulnerability has still a long way to go, however, the measures discussed below appear to be amongst the most relevant.

Language and ethnicity: One of the strongest social links in a community is derived from language and ethnicity. For the resident population, English is clearly the most common language spoken, with 86.2% of the resident population over age 5 speaking it at home. The next largest groups are 'other' (with 3 226 or 3.0%) and Italian (1 290 or 1.2%). The 'other' group appears to include mainly Japanese and possibly Korean speakers. The published census results do not include data on these Asian languages spoken at home. These Asian languages are found most commonly in the suburbs of Cairns North, Mooroobool, Parramatta Park and Westcourt. The Italian speaking population is concentrated mainly in the sugar cane growing areas to the south of the city. The most common of the minor languages are German (942), various Aboriginal languages (655), Chinese (563), Tagalog (Filipino - 472), Dutch (384), French (362) and Greek (272).

Japan is clearly the largest source of tourists, though their dominance has been declining gradually in both absolute and proportional terms over the past five years. Their numbers also fluctuate seasonally, with January, February, August and December being the peak months.

Table 3.4 shows the average monthly numbers of foreign tourist arrivals in Cairns over the four years from 1993 to 1997. Assuming that all arrivals from Canada, New Zealand, PNG, Singapore, the United Kingdom and the United States, plus half of those from Hong Kong, speak English, and that none of the other visitors do, on average, more than 70% of all foreign visitors do not speak English. Of the non-English speaking visitors, close to 80% speak Japanese.

The only enclave in which a particular ethnic group dominates in the Cairns study area is the Aboriginal community of Yarrabah where 95% of the population are of Aboriginal and/or Torres Strait Islander descent. A few neighbourhoods in Manoora, Mooroobool and Westcourt also have significant (around 25%) proportions of indigenous people.

Religion: One of the more significant linkages that tend to span social cleavages such as ethnicity, is religion. In Cairns, the overwhelming majority (76%) of people who provided answers to the questions on religion in the 1996 census was Christian. Of the remainder, 3% was divided between Buddhism, Islam, Hindu and Judaism (in that order), whilst 21% said they had no religion. Of the Christian faiths, Catholic (38.8%), Anglican (32.8%), Uniting (9.5%) and Presbyterian (7.6%) 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 nursing homes, or, in the case of Yarrabah, because of its foundation as an Anglican mission.

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 Cairns is clearly an extremely mobile one, with growth being 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 (i.e. five years previously).

Table 3.4: Cairns average monthly foreign tourist arrivals 1993-97 (Source: ABS Overseas Arrivals bulletins)

COUNTRY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Canada	334	334	381	268	186	229	381	311	283	638	411	300	4056
China	92	54	21	51	33	43	78	51	45	98	126	118	810
Germany	413	443	528	623	429	438	649	594	770	944	700	587	7118
Hong Kong	1302	3282	1865	1263	771	1471	1950	1455	988	1598	1883	2543	20371
Indonesia	235	240	334	209	216	233	262	200	213	133	166	303	2744
Italy	59	63	35	46	74	95	237	227	118	99	106	163	1322
Japan	16102	14810	15516	11971	12123	12220	14410	17928	12910	13172	12684	17282	171138
Korea	590	226	213	382	389	486	516	378	284	446	318	524	4752
Netherlands	66	97	89	81	67	115	213	117	185	259	241	194	1724
New Zealand	383	203	317	633	641	1318	1675	1798	1797	1016	506	447	10734
PNG	1678	1141	1031	1304	1221	1690	1779	1210	1569	1328	1644	2305	17900
Singapore	310	701	353	492	568	712	371	421	434	466	922	1929	7679
Sweden	149	130	92	60	30	169	134	60	138	242	170	320	1694
Switzerland	138	108	128	137	92	97	231	139	269	299	322	293	2253
United Kingdom	1277	1695	1659	1407	1241	1194	1564	1682	1541	2164	2241	1962	19627
United States	1176	1408	1861	1407	1181	1764	1834	1591	1577	1998	1734	1010	18541
Rest of the World	1493	1641	1066	1121	999	1120	1430	1360	1102	1415	1510	1740	15997
All Countries	25797	26576	25489	21455	20261	23394	27714	29522	24223	26315	25684	32020	308450

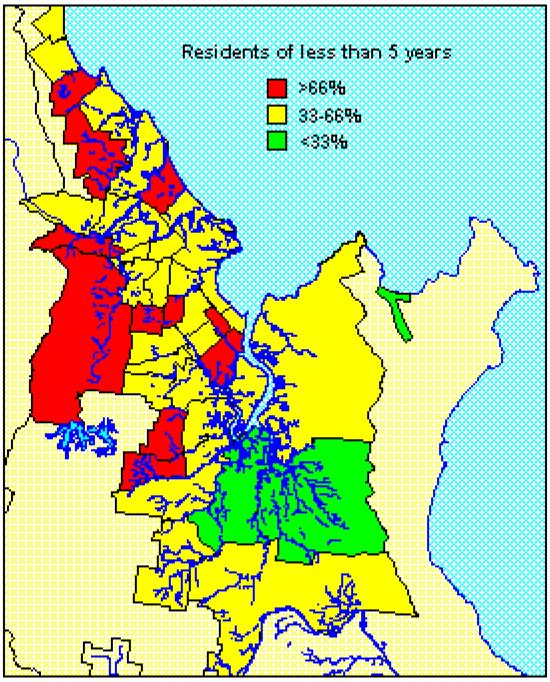

Figure 3.18: Proportion of population at census address for less than 5 years (Source: ABS, 1998a)

It is noteworthy that the more stable populations coincide largely with the cane growing areas, rather than the urban areas. The suburbs in which the greatest mobility is experienced include the growth centres of Caravonica, Holloways Beach, Kanimbla, Kewarra Beach, Manoora, Mount Sheridan, Redlynch and Smithfield. There is also significant mobility in the inner suburb areas of Parramatta Park and Portsmith, which are undergoing residential redevelopment.

From figures published from the 1991 census, 41.8% of people were recorded at the same address that they were at for the previous census, 13.7 % had been living elsewhere in Cairns, 25.2% were living elsewhere in Queensland, 6.7% were living overseas, 5.1% were in NSW and 3.3% were in Victoria. The other states and territories together contributed the remaining 4.2%. It might be assumed from these figures that some 80% of the population (those who have lived in Queensland for five years or more) could be expected to have at least some awareness of the local hazard environment and emergency arrangements, though the research of Berry (undated) in the northern beach suburbs strongly suggests otherwise

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 Cairns, for example, some 45% 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 C6** lists the locations of the 42 primary and secondary schools in Cairns. Schools are also centres in which there are concentrations of more vulnerable people for significant parts of the day. The table also included statistics for the numbers of enrolments and teaching staff at government schools.

James Cook University (McGregor Street, Smithfield) and the Far North Queensland Institute of TAFE (14-42 Eureka Street, Manunda) provide tertiary-level education and training.

Other post-secondary training institutions include:

English language training centres -
Cairns Language Centre (91 Mulgrave Road, Parramatta Park),
International House Queensland (130 McLeod Street, City),
Holmes Colleges (18 Lake Street, City) and
Windmill College (Poolwood Road, Kewarra Beach);

and vocational training centres -
Cairns Hospitality Centre (383 Draper Street, Parramatta Park),
Cominos House Arts and Environment Centre (27 Greenslopes Street, Manunda),
Employment Training Centre (207 Bunda Street, Parramatta Park),
Endeavour Training Support Centre (37 Hoare Street, Manunda),
Retail Skills Centre (383 Draper Street, Parramatta Park) and
Skill Share (11 Federation Street, Westcourt).

At the other end of the educational process are the more than 40 child care centres and kindergartens that serve areas of employment (e.g. City, Manunda, Parramatta Park and Westcourt) and the 'nappy valley' suburbs (e.g. Bentley Park, Edmonton, Mooroobool, Mount Sheridan, White Rock and Woree). These centres are listed in **Table C7**. Given the very young age and vulnerability of children at these centres, they deserve particular attention.

The location of educational facilities across Cairns is shown in **Figure 3.19**.

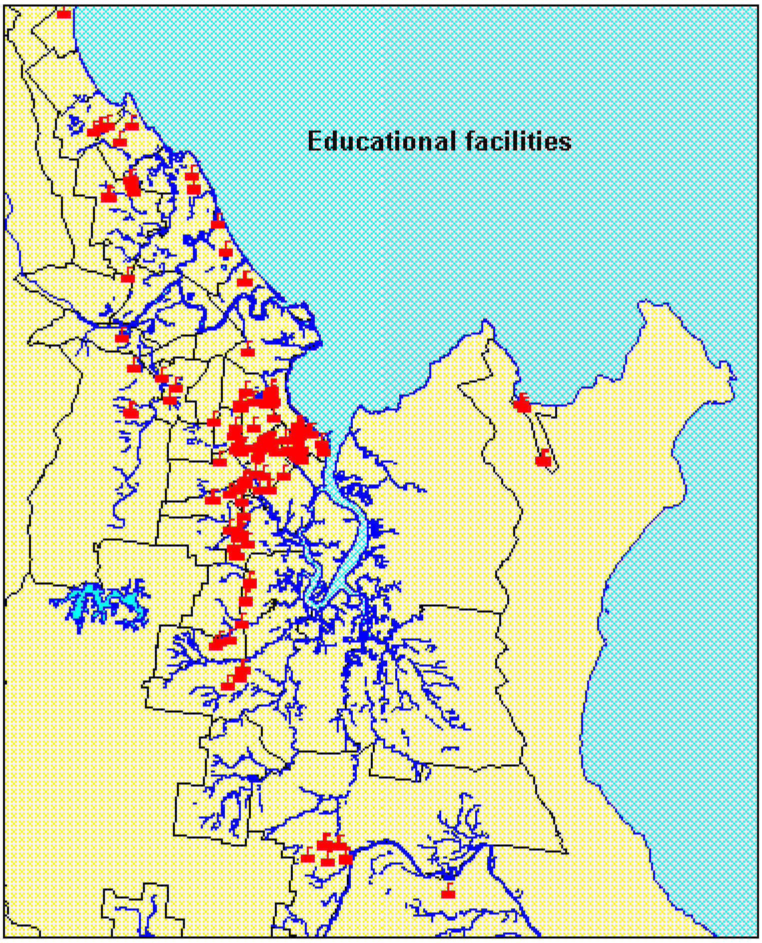

Figure 3.19: Cairns educational facilities.

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 1 000 and a standard deviation of 100. The Cairns mean value is 1 001.25 and range from a high (high educational levels and high occupation status) of 1 085.05 in Palm Cove to a low (low education levels and job status) of 807.59 in Yarrabah. **Table C8** lists the variables used to build this index.

Community services: Community based groups provide a significant level of social resilience and effective networks for the dissemination of information. Cairns 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. 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, to greatly enhance community resilience and cohesion.

A detailed community service guide for Cairns has not been available to this study, however, the list provided in **Table C9**, compiled from the Yellow Pages Directory, provides an (incomplete) 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 59 such facilities have been selected as representing the most critical to the overall vulnerability of the Cairns community. These are listed in **Table C10**.

Some of these facilities could, under certain circumstances, exacerbate the impact of a hazard event by adding to the danger. The loss of containment of hazardous materials such as chemicals or flammable substances as the result of a hazard impact, for example, would magnify the danger because of toxic contamination, fire or explosion. The facilities that are considered to contain secondary hazards are annotated in **Table C10**. 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 very dangerous if not properly contained and stored. Some chemicals, such as the various forms of cyanide, can be extremely dangerous, even in very small quantities. Some of these are used in a wide range of processes and can be found in the most obscure businesses such as fibreglass manufacture, electro-plating, jewellery manufacture and the manufacture of dental prostheses. Most facilities that store quantities of hazardous substances over certain thresholds, however, must display safety placards that identify the chemicals and the nature of the hazard they represent.

One unusual facility included in **Table C10**, on the strength of its potential hazardousness, is the Cairns Crocodile Farm located at the head of Trinity Inlet. This facility contains some 9 000 salt water crocodiles ranging from a few tens of centimetres to more than five metres in length. Their escape as the result of a hazard impact, such as a storm tide or flood, would add a very interesting dimension to community risk.

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 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.

A Composite View of Community Vulnerability

In this chapter so far we have described a broad range of the elements at risk within the Cairns 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 Cairns since 1995. Whilst these data provide a detailed quantitative description of <u>specific</u> aspects of the city's risk environment, they do not, of themselves, provide an adequate measure of <u>overall</u> community vulnerability. Nor do they individually reflect the <u>relative</u> levels of vulnerability across the city.

We consider that it is highly desirable, however, to be able to identify those parts of the city 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 to that level.

There is little in the risk or disaster management literature to provide a guide for this task so we have created our own methodology based on the 'five esses' described in this chapter and a composite, or combined community vulnerability assessment. **Appendix E** provides a detailed explanation of the methodology and the logic behind the selection of the variables included.

The following six figures illustrate the spatial distribution of the suburbs according to their contribution to community vulnerability from the setting (**Figure 3.20**), shelter (**Figure 3.21**), sustenance (**Figure 3.22**), safety (**Figure 3.23**) and society (**Figure 3.24**) groups plus a composite view (**Figure 3.25**). The accompanying tables (**Table 3.5**, **Table 3.6**, **Table 3.7**, **Table 3.8, Table 3.9**, **Table 3.10**) list the suburbs in rank order, grouped in the same manner as shown on the maps. A full listing of the rank for each suburb, for each group, is provided in **Table 3.11**, whilst **Table C8 Table C9**, **Table C10** list the variables used in the assessment of each of the SEIFA indexes used.

It is of interest to note that the settlements of Gordonvale and Yarrabah both rank highly on the five individual measures and the composite measure. Both have been, or continue to be, 'central places' that provide a range of services to their immediate hinterland. In the case of Gordonvale, its role as the centre of the sugar industry and its history as the centre of the former Mulgrave Shire is reflected in the range of services (such as hospital, nursing home, commercial activity and so on) provided. Yarrabah, by contrast, is a separate and self administering Aboriginal Community. Its isolation from Cairns and its separate administration has seen it become largely self sufficient in terms of health services, education facilities and other services.

The former rural village of Edmonton, which has now become absorbed into the Cairns suburban growth, also reflects a residual central place character. On the northern beaches, Smithfield is rapidly developing as the regional service centre and will probably emerge, over the next few years, as a key central place.

It is emphasised that values in **Table 3.10** and the 'Overall' column in **Table 3.11** do **not** equate to a risk rating. **They simply provide an indication of the relative contribution made to overall community risk by each suburb, assuming that an even and equal exposure to the impact of all hazards existed.** This is clearly not the case, as will be explored in the following chapters.

In the next chapters, we bring together an analysis of the earthquake (Chapter 4), landslide (Chapter 5), flood (Chapter 6) and cyclone (Chapter 7) hazards, and their threat to the Cairns community. In Chapter 8 we draw these together into an assessment of the total multi-hazard risk faced by the Cairns community and link that assessment to a consideration of some risk mitigation strategies.

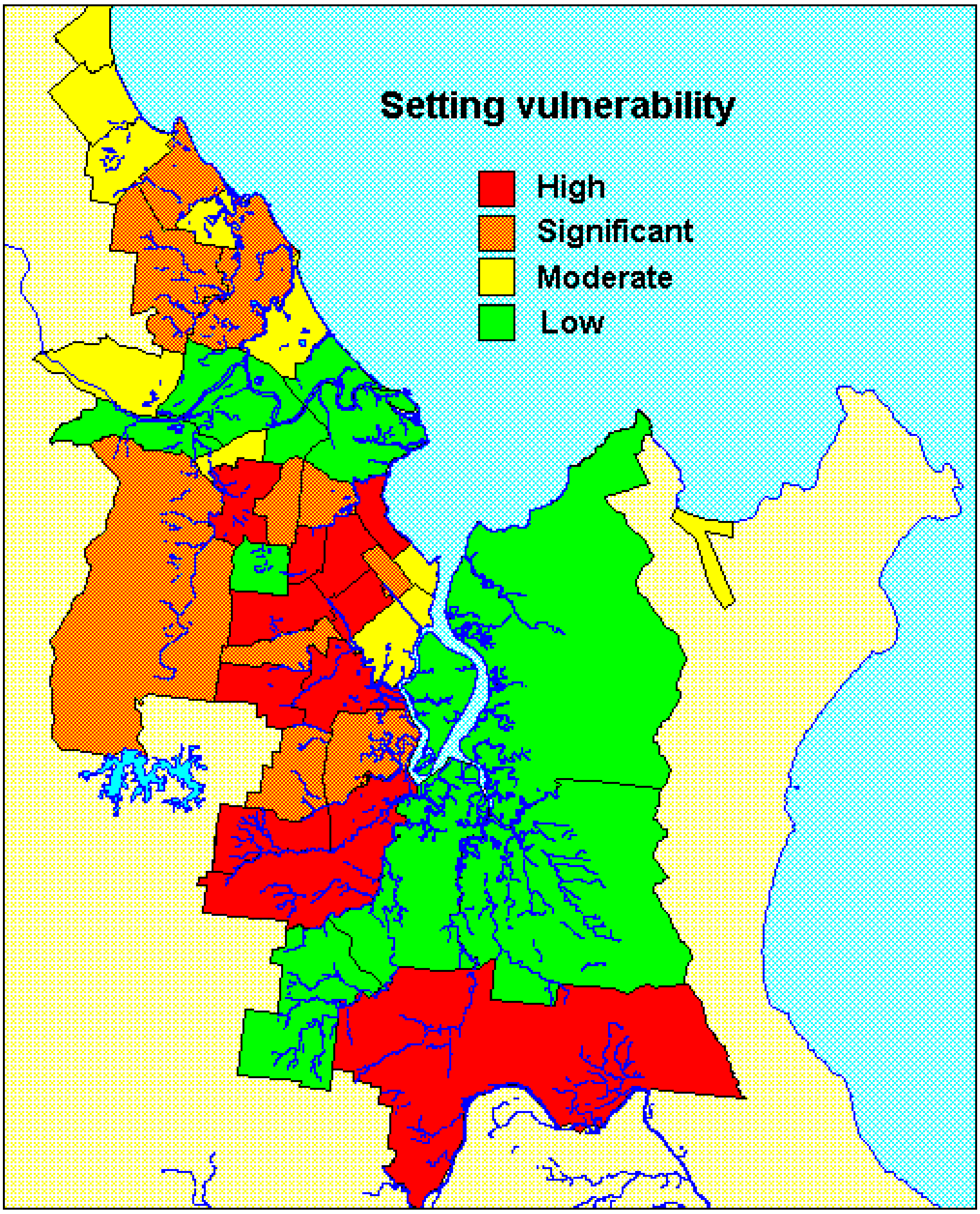

Figure 3.20: Relative suburb contribution to setting group vulnerability

Table 3.5: Relative suburb contribution to setting group vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Mooroobool, Manoora, Westcourt, Manunda, Edmonton, Cairns North, Woree, Gordonvale, Bentley Park, Brinsmead, Bayview Heights
SIGNIFICANT	White Rock, Edge Hill, Trinity Beach, Smithfield, Earlville, Whitfield, Redlynch, Parramatta Park, Yorkeys Knob, Mount Sheridan
MODERATE	Holloways Beach, Kewarra Beach, Freshwater, Yarrabah, City, Clifton Beach, Palm Cove, Caravonica, Trinity Park, Portsmith
LOW	Machans Beach, Kanimbla, Stratford, Kamerunga, Trinity East, Mount Peter, Aeroglen, Barron, Kamma, Wright's Creek

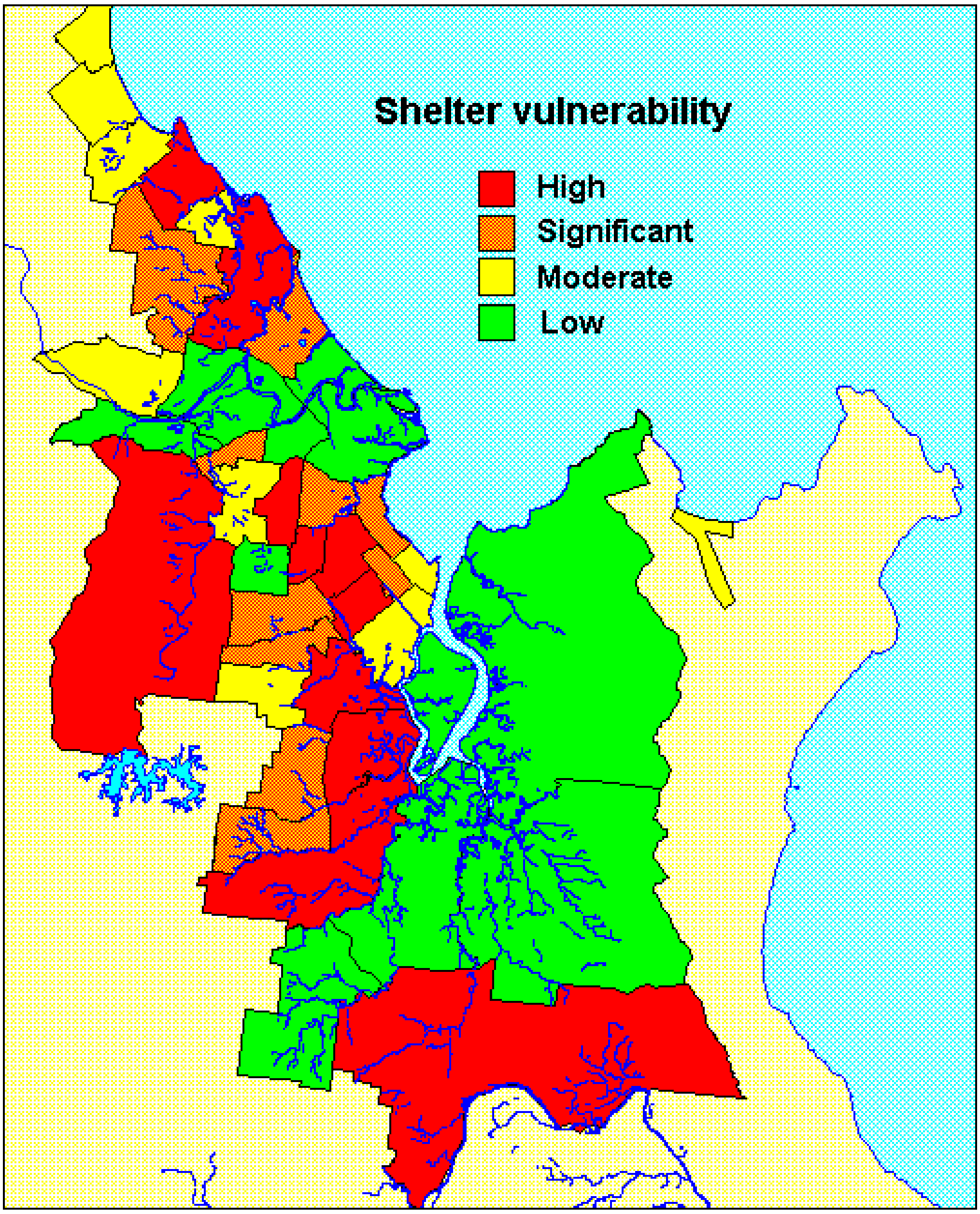

Figure 3.21: Relative suburb contribution to shelter group vulnerability

Table 3.6: Relative suburb contribution to shelter group vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Edmonton, Manunda, Woree, Westcourt, Whitfield, Manoora, Gordonvale, Trinity Beach, White Rock, Yorkeys Knob, Redlynch
SIGNIFICANT	Mooroobool, Holloways Beach, Edge Hill, Cairns North, Bentley Park, Freshwater, Earlville, Parramatta Park, Smithfield, Mount Sheridan
MODERATE	Kewarra Beach, Bayview Heights, Yarrabah, Palm Cove, Clifton Beach, Brinsmead, Portsmith, City, Caravonica, Trinity Park
LOW	Kamerunga, Machans Beach, Stratford, Trinity East, Kanimbla, Aeroglen, Mount Peter, Kamma, Barron, Wright's Creek

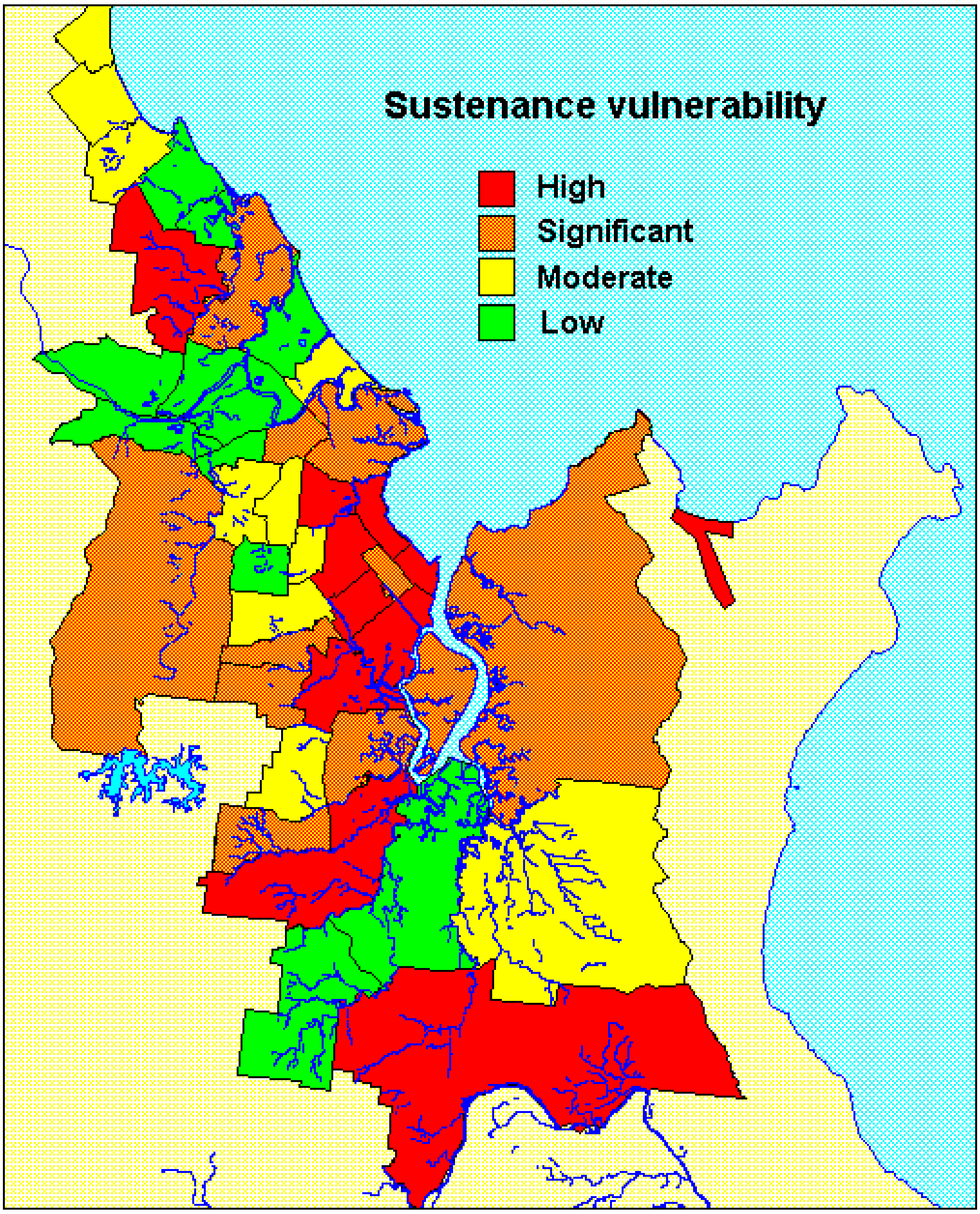

Figure 3.22: Relative suburb contribution to sustenance group vulnerability

Table 3.7: Relative suburb contribution to sustenance group vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Gordonvale, Portsmith, Manunda, Westcourt, Yarrabah, City, Cairns North, Smithfield, Woree, Edmonton, Edge Hill
SIGNIFICANT	Parramatta Park, Earlville, Redlynch, Bentley Park, Stratford, White Rock, Trinity East, Aeroglen, Yorkeys Knob, Bayview Heights
MODERATE	Palm Cove, Mooroobool, Clifton Beach, Kamma, Brinsmead, Whitfield, Mount Sheridan, Manoora, Kewarra Beach, Machans Beach
LOW	Wright's Creek, Trinity Beach, Holloways Beach, Kanimbla, Freshwater, Caravonica, Mount Peter, Kamerunga, Trinity Park, Barron

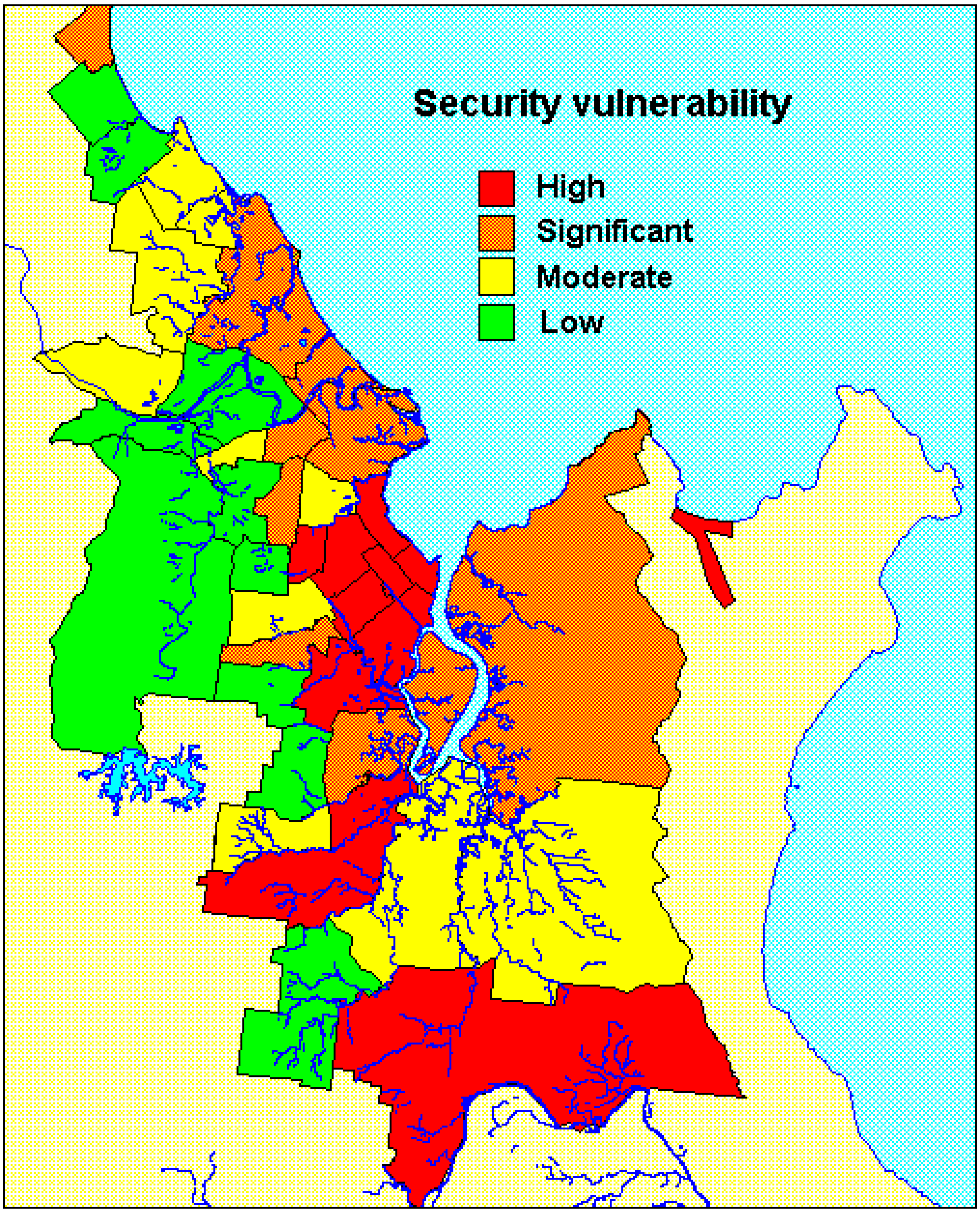

Figure 3.23: Relative suburb contribution to security group vulnerability

Table 3.8: Relative suburb contribution to security group vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Westcourt, Gordonvale, Yarrabah, Portsmith, Parramatta Park, Manunda, Cairns North, Woree, Manoora, City, Edmonton
SIGNIFICANT	Earlville, White Rock, Aeroglen, Trinity East, Whitfield, Yorkeys Knob, Palm Cove, Machans Beach, Holloways Beach, Stratford
MODERATE	Bentley Park, Edge Hill, Wright's Creek, Trinity Beach, Smithfield, Kamma, Mooroobool, Caravonica, Trinity Park, Freshwater
LOW	Clifton Beach, Kanimbla, Mount Sheridan, Mount Peter, Redlynch, Kewarra Beach, Barron, Kamerunga, Bayview Heights, Brinsmead

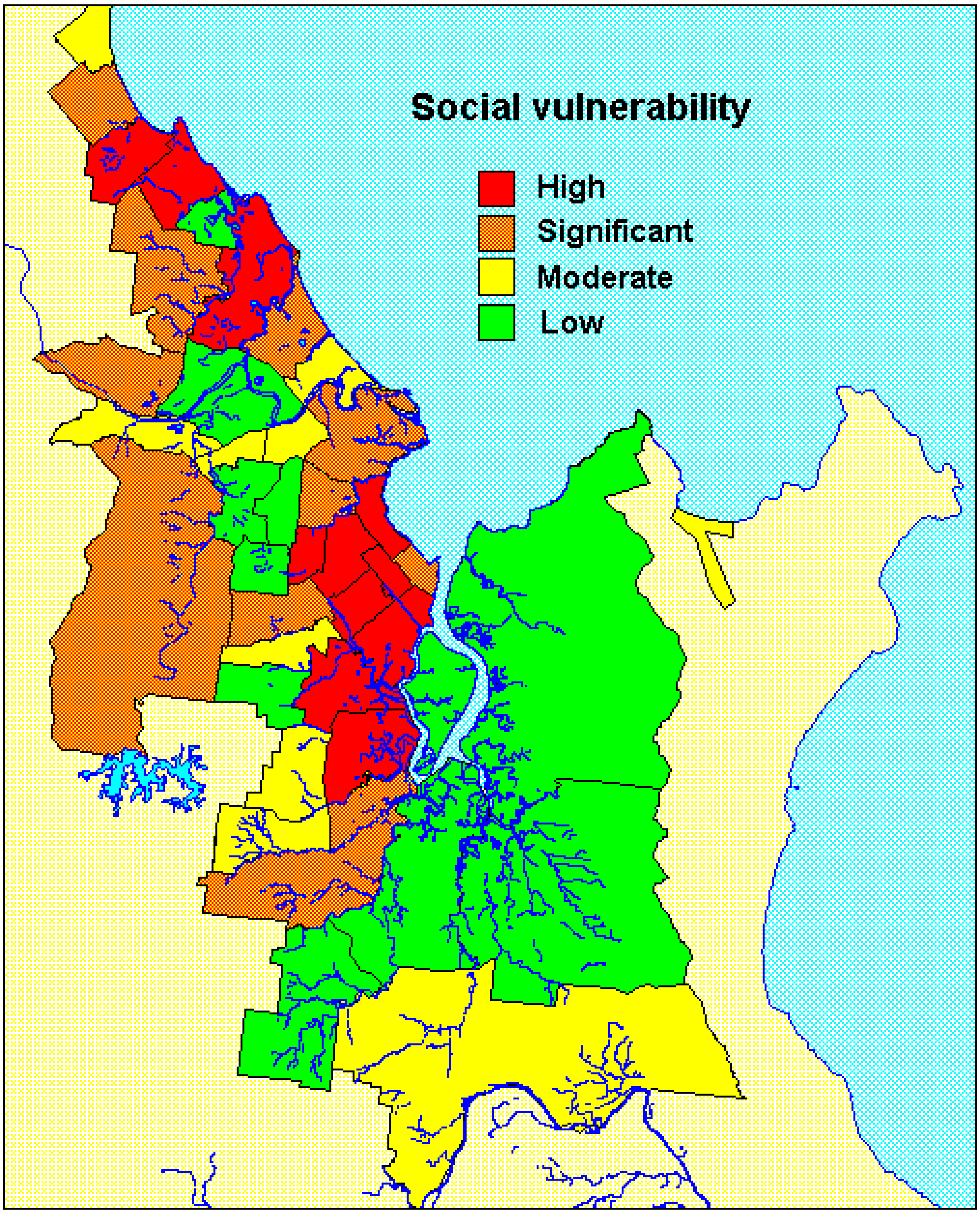

Figure 3.24: Relative suburb contribution to society group vulnerability

Table 3.9: Relative suburb contribution to society group vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Parramatta Park, Manoora, Portsmith, Yorkeys Knob, Cairns North, Westcourt, Manunda, Woree, White Rock, Kewarra Beach, Trinity Beach
SIGNIFICANT	Mooroobool, Redlynch, Smithfield, Holloways Beach, Edmonton, Edge Hill, Aeroglen, City, Caravonica, Clifton Beach
MODERATE	Gordonvale, Earlville, Bentley Park, Mount Sheridan, Palm Cove, Yarrabah, Kamerunga, Stratford, Freshwater, Machans Beach
LOW	Whitfield, Trinity Park, Brinsmead, Kanimbla, Trinity East, Mount Peter, Bayview Heights, Wright's Creek, Kamma, Barron

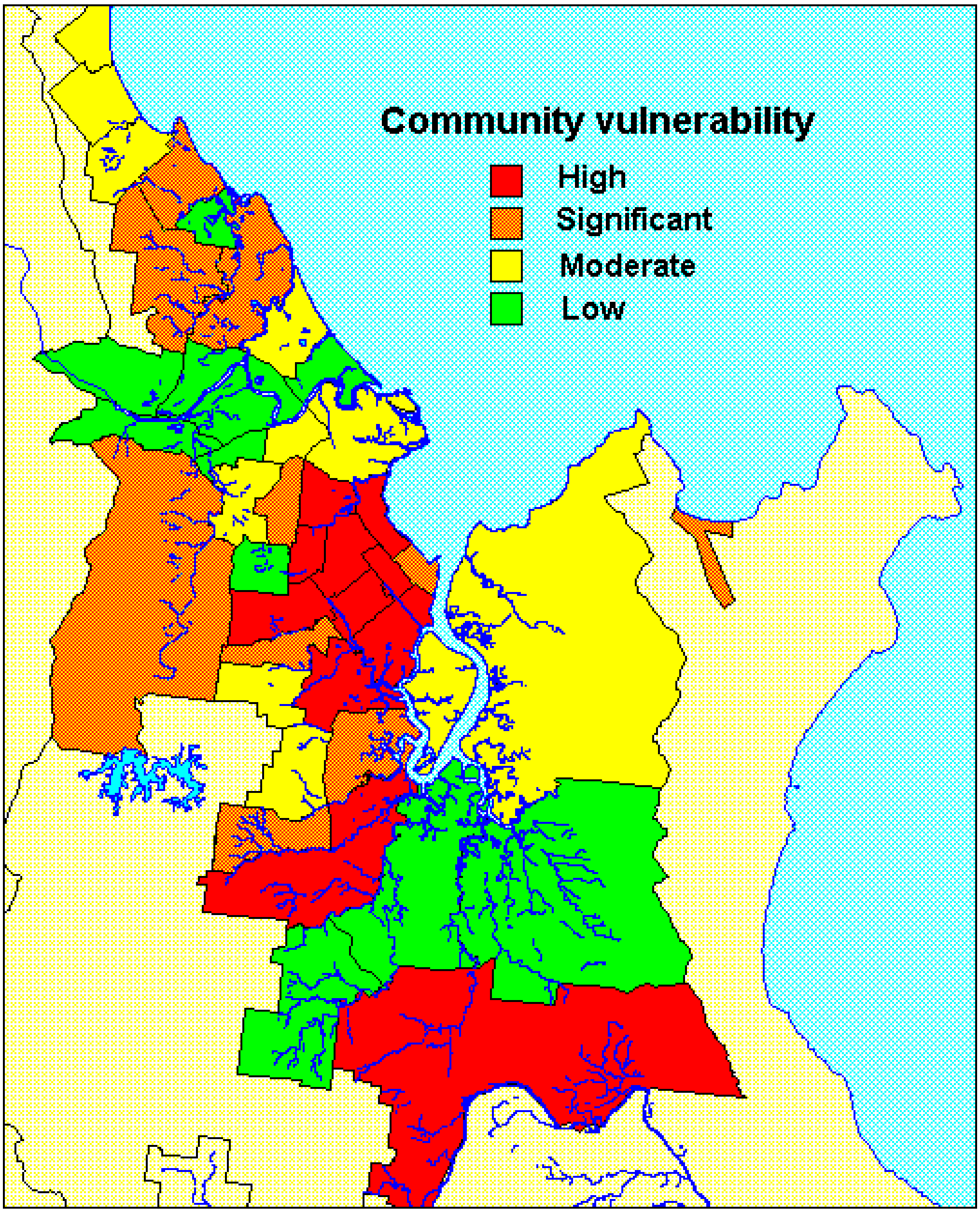

Figure 3.25: Relative suburb contribution to overall community vulnerability

Table 3.10: Relative suburb contribution to overall community vulnerability

RANK GROUP	SUBURBS (in rank order)
HIGH	Westcourt, Manunda, Gordonvale, Manoora, Edmonton, Woree, Portsmith, Parramatta Park, Cairns North, Mooroobool, White Rock
SIGNIFICANT	Yarrabah, Yorkeys Knob, Edge Hill, City, Smithfield, Trinity Beach, Earlville, Bentley Park, Whitfield, Redlynch
MODERATE	Holloways Beach, Kewarra Beach, Aeroglen, Palm Cove, Bayview Heights, Brinsmead, Mount Sheridan, Stratford, Clifton Beach, Trinity East
LOW	Freshwater, Caravonica, Machans Beach, Trinity Park, Kamma, Kamerunga, Kanimbla, Wright's Creek, Mount Peter, Barron

Table 3.11: Ranking of each suburb's contribution to overall community vulnerability

SUBURB	SETTING	SHELTER	SUSTAIN	SECURITY	SOCIETY	OVERALL
Aeroglen	38	37	19	14	18	24
Barron	39	40	41	38	41	41
Bayview Heights	11	23	21	40	38	26
Bentley Park	9	16	15	22	24	19
Brinsmead	10	27	26	41	34	27
Cairns North	6	15	7	7	5	10
Caravonica	29	30	37	29	20	33
City	26	29	6	10	19	15
Clifton Beach	27	26	24	32	21	30
Earlville	16	18	13	12	23	18
Edge Hill	13	2	3	6	7	2
Edmonton	5	1	10	11	16	6
Freshwater	24	17	36	31	30	32
Gordonvale	8	7	1	2	22	4
Holloways Beach	22	13	34	20	15	22
Kamerunga	35	32	39	39	28	37
Kamma	40	39	25	27	40	36
Kanimbla	33	36	35	33	35	38
Kewarra Beach	23	22	30	37	10	23
Machans Beach	32	33	31	19	31	34
Manoora	2	6	29	9	2	5
Manunda	4	2	3	6	7	2
Mooroobool	1	12	23	28	12	11
Mount Peter	37	38	38	35	37	40
Mount Sheridan	21	21	28	34	25	28
Palm Cove	28	25	22	18	26	25
Parramatta Park	19	19	12	5	1	9
Portsmith	31	28	2	4	3	8
Redlynch	18	11	14	36	13	21
Smithfield	15	20	8	26	14	16
Stratford	34	34	16	21	29	29
Trinity East	36	35	18	15	36	31
Trinity Beach	14	8	33	25	11	17
Trinity Park	30	31	40	30	33	35
Westcourt	3	4	4	1	6	1
White Rock	12	9	17	13	9	12
Whitfield	17	5	27	16	32	20
Woree	7	3	9	8	8	7
Wright's Creek	40	41	32	24	39	39
Yarrabah	25	24	5	3	27	13
Yorkeys Knob	20	10	20	17	4	14

CHAPTER 4: EARTHQUAKE RISKS

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 1 000 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 G**.

The Modified Mercalli Intensity scale is useful because it is easily applied and understood, and because it can be used to extend our knowledge of earthquakes 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 which 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 Modified Mercalli intensities on the scale have been defined in part by compiling 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.

Updated versions of the MM intensity scale have been devised to extend its usefulness. New versions include that of Dowrick (1996) given in **Appendix G**. New versions describe the expected effects of earthquakes on new types of building construction including buildings incorporating modern, earthquake-resistant design.

None-the-less, it remains difficult to use MM intensities to compare ground shaking from earthquakes occurring in different countries or for different historical times in the same country. The aim of such comparisons is to predict losses from future earthquakes. The damage patterns from particular earthquakes are often complex and depend upon the types of buildings present, their age and condition, geological conditions and the nature of the earthquake itself.

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. Cairns is situated more than 1 100 km from this plate boundary. Nonetheless, earthquakes have occurred in Australia, and more will occur.

The most damaging earthquakes in Australia in 1950-1999 are listed in **Table 4.1**.

Table 4.1: Most-damaging Australian earthquakes, 1950-1999

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

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events ranks them amongst the most costly of natural hazards to the community. According to Insurance Council of Australia (ICA) figures, of the $7.068 billion insured losses from natural hazards in Australia in the 20 years 1967-1998, earthquakes and floods each caused about one-sixth of total insured damage, tropical cyclones caused nearly one-quarter, and hailstorms accounted for more than one-fifth (Blong, 1998). At the time of publication (May 1999), ICA estimates of the insured losses from the 1999 Sydney hailstorms of more than $1 billion will alter these proportions significantly. With increasing urbanisation and reliance on power, water and telecommunications lifelines, Australian communities are becoming increasingly vulnerable to the impact of earthquakes.

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, some ten years before the establishment of Cairns. Recent research, however, has brought to our attention a significant earthquake (possibly around ML 6.0) felt in the Noosa area of south-east Queensland in 1862. This recent addition 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. This is especially the case in the north and far north of the State where isolation, low population densities and poor instrumental coverage provide a more fragmented record of earthquakes than in other coastal areas of Queensland generally.

No permanent seismographs were installed in the north or far north of Queensland before the Charters Towers seismograph, operated by the University of Queensland, was installed in 1957. This seismograph is some 340 km south of Cairns and, although it will detect Cairns earthquakes with magnitudes larger than about Richter magnitude 3.0, such earthquakes cannot be located accurately using the Charters Towers seismograph data alone (R. Cuthbertson, QUAKES, personal communication, 1998). Three seismographs, optimally placed, are usually considered the minimum number required to locate earthquakes. Apart from the Charters Towers seismograph, other seismographs were installed to monitor the safety of dams along the Burdekin River around 1984, and near Tully around 1990.

Table 4.2 lists the seismographs within about 500 km of Cairns and their dates of operation. Their locations are shown on **Figure 4.1** (the Burdekin network is off the map to the south-east of Townsville). Although the Burdekin and Tully seismographic networks have improved the capability to locate north-east 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. Rynn (*op cit*) listed a seismograph operating at Kuranda from 1959 to 1964 and another operating at Townsville from 1956 to 1965 but the effectiveness of these instruments is not known. The Townsville instrument, however, was a long period horizontal seismograph, which would be unsuitable to detect local, moderate magnitude earthquake activity.

Given the instrumental coverage and low population densities of the region, many small and moderate earthquakes will almost certainly have gone undetected and consequently the earthquake catalogues for north-east Queensland are incomplete. Indeed, prior to the installation of the Charters Towers seismograph, potentially damaging earthquakes of Richter magnitude 5.0 or even slightly larger may have been overlooked and consequently omitted from the catalogue. Small to moderate earthquakes (e.g. with Richter magnitudes 3½ to 4½) occurring between the installation of the Charters Towers seismograph and the mid-1980s would have been detected by that seismograph but it may not have been possible to locate them all. 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 north-east Queensland should have been located using the Australian national network of seismographs (operated by AGSO). Further, any large north-east Queensland earthquakes (~ magnitude 6 or larger) should have been located by the global network of seismographs for the past 90 years or more. The Cairns 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 north-east Queensland Zone 30, which includes Cairns, 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.

An indication of earthquake activity that may be missing from the catalogue for most years is given by the 140 or so very small earthquakes located in period 1990-1993 with the assistance of the Tully instruments, now decommissioned. About half of these were located about 40 km offshore from Innisfail in 1990 and 1991 following the nearby 1989 and 1990 Richter magnitude 4.0 events. Another 75 or so small events in 1990-1993 were located about 65 west-south-west of Innisfail. In total numbers, if not in importance, these small events comprise more than half the catalogue for the Cairns region. Most of this group of 140 events have one of only two epicentres, so that they do not appear numerous in **Figure 4.1**. Their coincident epicentres give an example of the inability of the north-east Queensland seismographic network to locate earthquakes accurately.

The seismographic coverage of Cairns improved with the installation of two Cairns instruments in 1997 under the Joint Urban Monitoring Program (JUMP), an initiative of the Commonwealth and States following the disastrous 1989 Newcastle earthquake. One instrument is an accelerograph (installed at Tunnel Hill), which records strong earthquake ground shaking data for use in developing earthquake building code standards. The other instrument in Cairns is a combined seismograph and accelerograph and is installed at Henley Hill. Seismographs are far more sensitive than accelerographs, and are used primarily to locate earthquakes.

The significant recorded earthquakes within 200 km of Cairns are listed in **Table 4.3**, and the complete listing of all recorded earthquakes in the Cairns region is listed in **Appendix F**. This detailed list of approximately 260 events comprises information on approximately 220 earthquakes from the Australian Earthquake Database, maintained by AGSO, and an additional 40 or so small events from the database of the Queensland University Advanced Centre for Earthquake Studies (QUAKES) not contained in AGSO's database.

Most historic earthquakes in the Cairns region, including seven of the eight earthquakes of Richter magnitude 4.0 or greater listed in **Table 4.3**, occurred within about 100 km of the coastline. There is, however, a considerable degree of uncertainty regarding the locations of all earthquakes that occurred up to the time of installation of the Burdekin seismographic network - some epicentres may be several tens of kilometres from the true locations of the earthquakes.

Table 4.2: Seismographs within about 500 km of Cairns

Code	Site name	Operator[1]	Type[2]	Latitude °S	Longitude °E	Opening date	Closing date
CTAO	Charters Towers	AGSO/QLD	DWWSSN	20.08	146.255	09-57	Open
CN1	Henley Hill	QLD	DSA	16.954	145.736	07-03-97	Open
CN2	Tunnel Hill	QLD	DA	16.911	145.710	05-03-97	Open
TV1	Townsville	QLD	DSA			1998	Open
TV2	Townsville	QLD	DA			1998	Open
BGR	Glenroy	QLD	S	20.549	147.105	16-02-81	Open
BLO	Burdekin Lookout	QLD	S	20.624	147.120		Open
BSL	Bruslee	QLD	S	20.867	146.564	02-03-84	Open
CVL	Collinsville	QLD	S	20.59	147.609	30-04-85	Open
DLB	Dalbeg	QLD	S	20.151	147.264		Open
DNG	Doongara	QLD	S	20.555	146.475		Open
MCP	Mt Cooper	QLD	S	20.552	146.806		Open
MHP	Mt Hope	QLD	S	21.396	146.802	10-04-84	Open
PFD	Peter Faust Dam	QLD	S	20.385	148.374	18-04-91	Open
UKA	Ukalunda	QLD	S	20.899	147.127	28-03-84	Open
BCS	Camp Site	QLD	S	20.619	147.131	11-01-81	15-01-81
BGC	Glendon Crossing	QLD	S	20.614	147.160	12-12-81	29-04-85
BMG	Mt. Graham	QLD	S	20.614	147.060	13-02-81	30-04-85
BNG	Bungobine	QLD	S	21.344	147.312	05-05-85	30-08-85
DBG	Dalbeg	QLD	S	20.275	147.299	05-03-84	02-04-84
GVA	Glen Eva	QLD	S	21.489	147.482	18-03-86	01-06-87
BLP	Blunder Park	QLD	DS	17.758	145.422	19-01-90	1995
CCQ	Carron Ck Quarry	QLD	DS	17.849	145.567	20-01-90	1995
DPT	Dingo Pocket	QLD	S	17.912	145.822	1994	1995
HRD	H Road	QLD	DS	17.76	145.65	23-01-90	1995
MNH	Munroe Hill	QLD	S	17.97	145.8	21-01-90	1994
RVH	Ravenshoe	QLD	S	17.633	145.484	16-01-90	1995
SCY	Sunday Creek Yard	QLD	DS	17.878	145.337	18-01-90	1995

NOTES:

[1] QLD = QUAKES (University of Queensland)

[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

The largest known earthquake in north-east Queensland, the Richter magnitude 5.7 Ravenswood earthquake of 18 December 1913, is listed in **Table 4.3** for reference, although its epicentre is more than 350 km south of Cairns. This event also appears to have occurred within 100 km of the coast. 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 the Australian Building Code minimum design loads on structures for earthquakes, known as Australian Standard *AS1170.4-1993* (Standards Australia, 1993). These contours show the relative expected severity of earthquake ground motion across the state expressed as an 'acceleration coefficient'.

Three estimates of regional earthquake hazard are known for Cairns. All three estimates relate to a 10% probability of exceedence in 50 years at 'rock' or 'firm' sites. The 10% probability of exceedence in 50 years corresponds to an annual exceedence probability (AEP) of approximately 1/475.

The first estimate is found in Gaull and others (1990). Their estimate is described in **Appendix H**. The second estimate is found in *AS1170.4-1993*. An acceleration coefficient of 0.06 for the Cairns area was provided in Table 2.3 of *AS1170.4-1993*. This value approximates a peak horizontal ground acceleration, or PGA, of 0.06 g, where 'g' is the acceleration of a falling object under gravity. The third estimate of hazard originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.2 g on rock, in line with their estimates of PGA for Queensland 2-3 times higher than previous estimates. A comparison of the three results is given in **Appendix H**.

Considerable debate has surrounded the contrasting earthquake hazard estimates of Cuthbertson and Jaume (1996) and those in *AS1170.4-1993.* We prefer to use the acceleration coefficient in *AS1170.4-1993* until new estimates of earthquake hazard for Queensland are made under the current revision of *AS1170.4-1993*. The revised standard is expected to be published within several years.

The earthquake hazard for Cairns is moderate by Australian standards. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993,* including Cairns, has an acceleration coefficient in the range 0.05 - 0.1. The coefficient values across Australia range from a minimum 0.03 to highs of up to 0.22 in 'bullseye' areas.

The magnitude of the Maximum Probable Earthquake has a moderate effect on earthquake hazard estimates. In light of the incomplete history Gaull and others (1990) estimated maximum magnitude to be half a magnitude unit higher than that observed. For the Cairns area, their estimate was magnitude 5.8. This value is too low and the estimate of Cuthbertson and Jaume (1996), magnitude 7, is more appropriate.

Appendix H presents the rock response spectrum of Somerville and others (1998) which may be used to complement, or augment, earthquake hazard estimates for Cairns in *AS1170.4-1993.*

The Cairns Earthquake Experience

Earthquakes so far have not caused significant damage in Cairns. The 1896 earthquake produced the highest known ground shaking intensities in Cairns, MM V, and caused cracking in concrete railway tunnels. At Mareeba, small objects were thrown off shelves. The 1913, 1950, 1958 and 1989 earthquakes were also felt in Cairns. The 1913 Ravenswood earthquake was felt over a large part of north-east Queensland, including Cairns, although apparently without causing damage (Rynn and others, 1987). The 1958 earthquake caused ground shaking intensities of MM IV in downtown Cairns and MM V in what are now the northern beach suburbs of Cairns. The QUAKES database notes 'minor damage' for this earthquake. A foreshock and several aftershocks, all within a period of eight hours, apparently were felt in Cairns. **Figure 4.2**, **Figure 4.3**, **Figure 4.4** and **Figure 4.5** show the seismic intensities recorded from the 1896, 1913, 1950, and 1958 earthquakes respectively.

We note some minor discrepancies in the catalogue for the 1950 and 1958 earthquakes. The magnitude of the 1950 earthquake is listed as ML 3.2 in the AGSO catalogue (**Appendix F**) and as ML 4.0 in **Figure 4.4**. Different sources provided these two magnitude values. We consider the magnitude of ML 3.2 is more appropriate. **Figure 4.5** contains two further errors. The origin time of the 1958 earthquake listed in **Figure 4.5** is probably incorrect. We think the event occurred at 10 hr 35 min. 31 sec. and that one of the aftershocks occurred at 10 hr 38 min., although this has not been confirmed. **Figure 4.5** lists a magnitude of ML 4.4 for this event but a more recent estimate of the magnitude is ML 4.7.

The most recent earthquakes close to Cairns occurred at 1:55 am and 4:38 am local time on 25 November 1997 (see **Appendix F** and **Figure 4.1**). Although these two earthquakes were small (Richter magnitudes 2.5 and 2.1 respectively) and apparently were not felt in Cairns, they are a reminder that the area near Cairns is seismically active and that larger earthquakes are possible. These earthquakes would have been poorly located, if at all, without the JUMP instruments.

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

Date	Time (UTC[2]) hr min	Lat. (°S)	Long. (°E)	Place	ML[3]	I_{max}[4]	Comments
27-02-1896	10 58	17.0	145.7	15 km SW Cairns	4.3(I)	V	Cracking in five concrete railway tunnels and two culverts, Cairns
18-12-1913	13 54	20.0	147.0	Ravenswood	5.7(I)	V	Weakly felt Cairns
10-04-1942	03 00	16.2	145.7	Daintree	3.8(I)	IV	Not felt Cairns
19-06-1950	09 00	17.5	145.5	Atherton	3.2	IV	Weakly felt Cairns
01-12-1958	10 35	16.5	145.5	50 km NNW Cairns	4.7(I)	V	'Minor damage' Cairns
19-08-1961	02 26	15.8	144.7	170 km NW Cairns	4.1		
28-03-1963	04 29	17.6	146.2	Innisfail	3.2(I)	IV	Not felt Cairns
06-05-1974	16 55	17.5	146.0	Innisfail	4.0		
16-11-1989	10 43	17.39	146.30	Near Innisfail	4.0		Felt Cairns
13-05-1990	05 35	17.29	146.14	Near Innisfail	4.3		
04-09-1994	08 02	16.99	144.50	Chillagoe	4.0		

NOTES:

[1] Earthquakes ML ≥ 4 and earthquakes felt at or near Cairns. Sources: Australian Earthquake Database (AGSO); Queensland Railways Commissioner's Report, 1896; Everingham and others, 1982; Rynn and others, 1987

[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 (Dowrick, 1996; see **Appendix G**)

Urban earthquake hazard in Cairns

In addition to the regional earthquake hazard represented by, for instance, the 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 major damage in many earthquakes, including the 1989 Newcastle earthquake, the 1989 Loma Prieta (California) earthquake and the 1995 Kobe (Japan) earthquake. Additionally, in Kobe the focussing of seismic waves at the edge of a geological basin may have had a significant role in producing the strongest shaking. Observed data 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.

We prepared urban earthquake hazard maps (or microzonation maps) for Cairns. Two examples are shown in **Figure 4.6** and **Figure 4.7**. These maps indicate zones in Cairns where potential earthquake shaking is expected to be relatively weaker or stronger. They were prepared using existing 1:100 000 scale geological maps (Willmott and others, 1988), geotechnical data from borehole logs and test pits, and microtremor data from recordings of low level 'background' ground vibrations (described below). **Appendix H** gives a detailed description of the methods used to prepare the urban hazard maps.

The Cairns geology has been grouped into four site classes for the urban earthquake hazard maps (**Table 4.4**). Our site classifications are based on those developed for the 1994 provisions of the US National Earthquake Hazard Reduction Program (NEHRP). The provisions were published in FEMA (1995) and we have referred to the version reproduced by Hwang and others (1997).

Sites requiring special consideration, 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 almost certainly exist in Cairns.

Table 4.4: Site classifications for earthquake hazard maps

Site class	Description	Cairns setting
A	Rock	Largely coastal ranges
B	Hard and/or stiff/very stiff soils; mostly gravels	Higher foothill slopewash gravels, sands and silts
C	Sands, silts and/or stiff/very stiff clays, some gravels	Lower foothill slopewash sands, silts and clays
D	Profile containing at least 3 m of soft/medium stiff clay	Coastal plain organic clays and sands

Figure 4.6 shows the first urban zonation map for Cairns. This map is designed for a particular period of vibration of earthquake ground shaking, period T = 0.3 seconds (i.e., the time taken to complete one cycle of vibration). Earthquake ground shaking with this period of vibration may affect low-rise buildings (1-3 storeys) and other structures with similar natural periods of vibration.

NOTE: <u>Limitations of the earthquake hazard maps</u>

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 relative strength of shaking in the zones is described by a set of amplification factors linked to the site classes. Amplification factors in this map range from 1.0 (Site Class A), through 1.3 (Site Class B) and 1.5 (Site Class C) to 2.0 (Site Class D). The amplification factors were determined from recordings of Californian earthquakes (Borcherdt, 1994; Crouse and McGuire, 1996).

These amplification factors are similar to the Site Factors in *AS1170.4-1993*, and indicate a difference of a factor of two in hazard for different parts of Cairns. That is, the shaking of soft sediments on the low-lying coastal plains, found underlying suburbs such as Cairns North and City, would be twice as strong as that experienced on rock, found in parts of suburbs such as Bayview Heights, Kanimbla and Mooroobool, 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 two mentioned above, between the strength of ground shaking on rock and soft sediments, could, in fact, be higher in Cairns. Hard basement rock underlying sediments will increase the amplification factors and this may well be the case for Cairns. 'Rock' in Australia (*AS1170.4-1993)* is equivalent to 'Hard rock' in California (Hwang and others, 1997). *AS1170.4-1993* includes a Site Factor of S = 0.67 for '… rock strength Class L (low) or better', resulting in amplification factors of three between hard rock and soft sediments. Crouse and McGuire (1996) had insufficient recordings of Californian earthquakes to distinguish between 'Hard rock' and 'Rock' response and they aggregated the recordings as 'Rock' (Site Class A for Cairns). We choose to use the empirical Californian data and we note that more research is needed to develop appropriate Australian amplification factors.

The hazard map indicates areas in Cairns that are likely to undergo the strongest shaking. These areas are inner city suburbs including Aeroglen, Cairns North, City, Parramatta Park, Portsmith, Manunda and Westcourt, together with the northern beach suburbs of Holloways Beach, Machans Beach and Yorkeys Knob. Buildings in the proposed urban development in Trinity East would also experience the strongest shaking.

A second, similar earthquake hazard map for Cairns is shown in **Figure 4.7**. This map shows zones of earthquake hazard for earthquake ground shaking with a period of vibration T = 1.0 second. It is pertinent to ground shaking that may affect some high rise buildings (10 storeys and higher) and other structures with similar natural periods of vibration. The reader will note that the zones in this map are identical to those in the previous map. However, the amplification factors are different and in this map they range from 1.0 through 1.7 and 2.0, to 2.9. Except for the unity rock value, these amplification factors are significantly higher (around 50%) than the Site Factors in *AS1170.4-1993*. The amplification factors are summarised in **Table 4.5**.

The areas of Cairns expected to undergo the strongest shaking at this period of vibration include Cairns North and City where all of the city's high-rise buildings are located.

The amplification factors in the two earthquake hazard maps (**Table 4.5**) are appropriate for moderate input levels of earthquake ground motion. The maps show an input level of Peak Horizontal Ground Acceleration (PGA) of 0.1 g. Our amplification factors are derived from empirical values recorded from Californian earthquakes (Crouse and McGuire, 1996).

With increasing levels of incoming peak ground acceleration, the amplification factors reduce to an extent. Also, as we have seen, the amplification factors differ for different periods of vibration of the ground. In general then, the amplification factors in the earthquake hazard maps depend on the strength of earthquake input ground motion and on the period of vibration of the ground motion under consideration.

Table 4.5: Amplification factors for Cairns hazard maps (input PGA ~ 0.05 g - 0.2 g)

Site class	Amplification factor[1]	
	T = 0.3 s	T = 1.0 s
A	1.0	1.0
B	1.3	1.7
C	1.5	2.0
D	2.0	2.9

NOTE: [1]Crouse and McGuire (1996)

A range of Cairns earthquake hazard maps, for periods of vibration of the ground in the range $T = 0.1$ seconds to $T = 3.0$ seconds, and for input shaking from PGA = 0.1 g to PGA = 0.4 g, can be produced. Their appearance is identical to **Figure 4.6** and **Figure 4.7** but the amplification factors will differ. We can model earthquake scenarios of varying severity and their effects on a range of building types by selecting the input parameters. **Appendix H** describes how to derive the range of Cairns earthquake hazard maps.

Multiplying the regional (input) earthquake hazard value by the relevant amplification factor in the zone produces absolute estimates of earthquake hazard in a particular zone. For example, a regional input PGA of 0.1 g is amplified by 2.0 on Site Class D at a period of $T = 0.3$ seconds, producing a value of PGA = 0.2 g on Site Class D at this period.

Map of natural resonant period of vibration of ground motion in Cairns

The alluvial sediments underlying the coastal plains of the corridors of the Barron River and the Mulgrave River (including the area north of the Mulgrave River extending into Cairns inner suburbs) are extraordinarily thick. A maximum thickness of at least 80 m of Quaternary alluvium has been recorded in the Mulgrave River corridor and more than 90 m has been recorded beneath the Barron River delta (Muller and Henry, 1982).

The earthquake response of these sediments may have a bearing on building behaviour in future earthquakes, especially that of high-rise buildings. In the simplest case, these sediments may resonate with characteristic periods of vibration when excited by seismic waves. 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) may receive significant seismic energy from the ground. This may lead to larger and larger displacements of the building with a consequently increased risk of damage. This phenomenon is thought to be responsible for the preferential damage to certain classes of buildings, in certain parts of Mexico City, in the September 1985 earthquake. The epicentre for this earthquake was more than 350 km away from Mexico City but site effects of a drained lake beneath parts of Mexico City resulted in extensive damage and 8 000 deaths. Resonance in the period range of 1-2 seconds is thought to have been responsible for the damage to buildings between 10 and 14 storeys high, which had resonant periods of between 1 and 2 seconds, where lower and taller buildings did not suffer structural damage (Bolt, 1988).

Cairns has had some experience of what could occur in a strong local or regional earthquake. On 19 March 1995, an earthquake of magnitude 7.1 in Irian Jaya caused movement in the 15-storey National Mutual Building in Cairns City. Although the earthquake was more than 1 900 km away from Cairns, blinds, pictures and doors were seen to move. The 'slow' swaying was described as 'strong' on Floors 14 and 15 and included 'creaking and cracking' sounds in a concrete column (C. Lynam, QUAKES, written communication, 1999).

The map of natural resonant period of ground vibration for Cairns (**Figure 4.8**) supplements the maps of amplification of ground shaking. It provides additional information on the fundamental period of vibration of the ground during earthquake shaking. It also provides additional 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 map was prepared by measuring the natural period of vibration of the ground by recording microtremors (very weak motion of the ground caused by 'background' noise from traffic, wind, surf, etc.) with portable seismographs in a joint AGSO-QUAKES survey in 1997 (Jaume and others, 1997). The point values of natural ground period taken at nominal 500 m intervals at more than 300 sites in Cairns were contoured to produce the map.

The contoured natural period is remarkably high in many parts of Cairns (more than one second). The contours are subparallel to the margins of the ranges in many parts, indicating a thickening of sediments toward the centres and mouths of the Barron and Mulgrave river corridors. Remarkably, areas of Edmonton and Gordonvale also have high natural periods, indicating thick sediments near the margins of the river corridors in these areas. No measurements were taken between these two suburbs and fill-in data in this area would be useful. There is a noticeable agreement between the areas of highest natural period and the areas of Site Class D in the earthquake hazard maps, indicating both thick sediments at depth in these areas and also slow seismic wave velocities in the near surface sediments. The latter are responsible for the Site Class D rating of these areas. In areas where no measurements were taken, natural period was estimated using information on thickness and the types of sediments present.

In the simplest case, where the fundamental mode of vibration of the sediments dominates and the fundamental mode of vibration of buildings with a high degree of symmetry is excited by earthquake shaking, the map of natural period provides a guide to areas which may be potentially hazardous for buildings of particular natural period. *AS1170.4-1993* stated that:

> *the structure period (T), in seconds, may be determined by a rigorous structural analysis. Alternatively, the fundamental period of the structure, and where the structure has different properties in two orthogonal directions, the period for the orthogonal direction for structures of uniform vertical distribution of mass and stiffness may be approximated by the following equations:*
>
> *Fundamental period:* $T = h_n / 46$ ... *6.2.4(1)*
>
> *Period for the orthogonal direction:* $T = h_n / 58$ ... *6.2.4(2)*
>
> *where* h_n *= total height of the structure above the structural base (in metres). The fundamental period shall be associated with the more flexible structure direction and the period for the orthogonal direction shall be associated with the most rigid structure direction.*

From these formulae, a typical 10 storey building in Cairns, with reasonably symmetric distribution of mass and stiffness around horizontal and vertical axes, may have a fundamental period of around 0.9 seconds, and a 15 storey building a fundamental period of around 1.4 seconds. Similarly, a three-storey building may have a fundamental period of around 0.25 seconds.

Numbers of buildings at risk and vulnerability of building stock

The total number of buildings, by suburb for Cairns, built on each Site Class (A to D), is shown in **Figure 4.9**. The suburbs are ranked, from left to right in the figure, according to the number of buildings on Site Class D, Site Class C, and so on. This comparison gives a first impression of suburb-by-suburb risk from direct damage to buildings. For example, Westcourt is entirely situated on Site Class D, the most hazardous site class, and also has the second largest number of buildings of any suburb. By contrast, we may expect that Caravonica is much less at risk from earthquake because it has a relatively small number of buildings, and over half of these buildings are situated on the two least hazardous site classes.

However, these data are not sufficient to assess suburban risk posed by building performance during earthquakes. The performance depends on building characteristics such as type of construction, age, height, condition, symmetries in the distribution of mass and stiffness and so on. The risk is a function of the damage states of the buildings, building usage indicating the numbers of people likely to be occupants, the degree of business interruption and the likelihood of secondary hazards such as fire and hazardous chemical spills.

We prepared detailed building inventories for each suburb, classifying by building type and also by site class, to calculate the number of elements at risk. The Cairns building database was used. This database was compiled from field observations of the exterior of buildings and, consequently, provides only details of wall cladding material rather than construction type. To assess building vulnerability to earthquakes, however, information on the type of structural frame or load-bearing walls is needed.

The importance of identifying the types of load bearing elements of a building, rather than simply the wall cladding, and the difference it can make to estimates of direct damage to buildings, is seen in the following example. In the 1989 Newcastle earthquake, solid brick houses performed about twice as poorly as brick veneer, in terms of percentage losses of the total insured value of the building stock. Houses with timber frames (brick veneer, fibro and timber cladding) all performed similarly (Blong, 1998). There is, none-the-less, a reasonably good degree of correlation between the type of wall cladding and construction type.

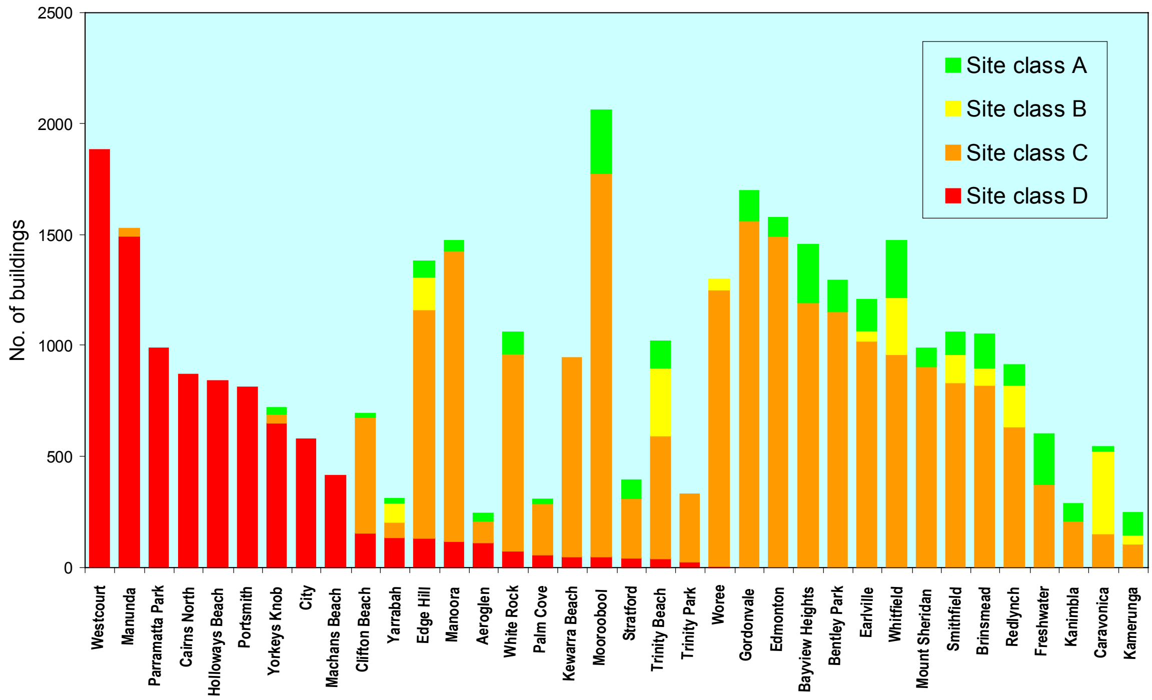

Figure 4.9: Number of buildings on Site Classes A-D for Cairns suburbs

Reinforced concrete block is the most common type of construction type in Cairns (**Photo 4-1**), outnumbering buildings with timber frames by a factor of about two. The overwhelming majority of these concrete block buildings are residential, and new housing increases the trend towards concrete block construction. We consider that concrete block buildings complying with modern wind loading standards will probably perform well under the moderate seismic loadings expected in Australia. However, the earthquake vulnerability of concrete block buildings may vary with age. Older concrete block buildings not built to either a wind or earthquake loading standard may be less earthquake-resistant than equivalent modern buildings complying with the codes. We have separated the concrete block buildings into several groups to reflect this expected difference in vulnerability according to their age (age data are available for residential buildings and we have estimated ages of non residential buildings). In 1975, as a consequence of Cyclone *Tracy,* wind loadings provisions were included in the Queensland Building Act. We consider that concrete block buildings constructed prior to 1975 are more vulnerable to earthquakes than those constructed after this date. However, domestic buildings were not included in the wind loading provisions until 1982. We consider that concrete block residences built before 1983 retain the earthquake vulnerability of the non domestic concrete block buildings built prior to 1975.

The wall type 'brick' in the Cairns building database includes both solid brick and brick veneer construction types. We separated brick veneer construction from solid brick by making the assumption that all 'brick' houses and low-rise flats built up to 1960 in Cairns are solid brick (unreinforced masonry), and all 'brick' houses and low-rise flats built after 1960 have timber frames with brick veneer (**Photo 4-2**). Unreinforced masonry has a poor history of performance in earthquakes worldwide although its strength may be improved by the presence of cross walls (J. Wilson, verbal communication, 1999).

Buildings with light timber frames behave in a ductile manner in earthquakes. In Cairns they comprise buildings with walls of timber (**Photo 4-3**), fibro, brick veneer, and metal (used in residential buildings). No attempt has been made to subdivide these buildings by their second-order vulnerability to earthquakes, although the building database contains information that could be used for this purpose. For example, floor height vertical asymmetry displayed by the stump-mounted 'Queenslander' design, tile or steel roofing material, and size of window openings are all factors described in the database that have the potential to affect building performance of timber frame buildings in earthquakes.

The cyclone resistance of some classes of new 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. We consider that all domestic buildings in Cairns designed since that date also have significant earthquake resistance through their conformity to that code. In developing the building inventory for Cairns we have aggregated all domestic buildings constructed after 1982 into a group with common earthquake vulnerability.

'Engineered' (generally multi-storey) buildings were generally designed for resistance to strong winds much before that. The SAA Interim 350 Standard of 1952 provided stringent design standards for these buildings, and we consider that older, multi storey buildings in Cairns may have intrinsic earthquake resistance through the application of this standard.

Metal wall cladding is found on timber frame houses, both new and old, and also covering light steel frames on low-rise factories, small businesses, warehouses, etc. We separated the buildings with metal wall cladding into these two frame types, largely through assessing the building usage *Type* field in the Cairns building database (house or business/commercial/logistic, etc.).

Medium rise and high rise buildings in Cairns, apart from medium-rise concrete block buildings, have reinforced concrete frames and masonry infill (C. Baker, Cairns City Council, verbal communication, 1998), with a variety of wall claddings. Newer buildings have reinforced masonry (concrete block) infill and concrete slab floors. Some multi-storey buildings of pre-1975 vintage, have concrete shear walls poured in situ. Other older buildings, such as Calvary Hospital and the main (older) block of Cairns Hospital have unreinforced masonry (brick) infill. Buildings with concrete frame and unreinforced masonry infill panels are more vulnerable to earthquake shaking than those with reinforced masonry infills. One reason is that the unreinforced masonry infill is more prone to cracking. Upon cracking of the infill, the performance of the structure becomes largely dependent on the strength of the concrete frame.

We note that our count of only five buildings in Cairns with concrete tilt-up walls underestimates the future extent of this increasingly popular method of construction for low-rise business, commercial and industrial premises.

The older (pre-war) 'Queenslander' timber houses (**Photo 4-4**) on stumps are of special interest because they are found in tropical Australia but not elsewhere in Australia or in many other countries. Most of these are in older, inner Cairns suburbs such as Parramatta Park. Their performance in strong earthquake shaking is not known. If they are in good condition they will have vertical joints connected, will be tied down from piers to roof and may be less vulnerable to earthquakes than houses built in the 1960s and 1970s (John Ginger, James Cook University, verbal communication, 1999). 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 poorer, particularly if the stumps are not cross-braced.

None-the-less, old 'Queenslanders' may not pose an enhanced risk in terms of direct losses or casualties compared to other residential building types. Although we may expect that old 'Queenslander' houses will have larger horizontal displacements in earthquakes than newer timber frame houses on concrete slabs because of the 'inverted pendulum' effect of their elevated floors and walls, we would not expect this to lead to greatly increased casualties. These houses are not massive and occupants will not be vulnerable to the collapse of masonry walls and gables, or tile roofs.

These buildings are also the properties in Cairns that are most at risk from fire following a severe earthquake, because of the potential for breakage of electric and gas supply mains to them, and overturning of containers of flammable material. They may also be the most likely to spread fires due to their close proximity to one another in some areas (**Photo 4-5**), although the risk of fire is probably very low.

The revised building database (**Table 4.6**) shows that the most common construction types of buildings in Cairns are overwhelmingly:

- concrete block masonry (56% of total number of buildings constructed after 1974 and another 7.6% prior to 1975);
- timber frame domestic buildings (33%);
- light steel frame buildings used for small business and factories, etc. (1.6%); and
- unreinforced masonry (1.0%).

The remainder, which comprises only about 0.02% of the total Cairns building stock, is:

- medium and high rise concrete frame buildings with either unreinforced or reinforced masonry infill; and
- low rise concrete tilt-up buildings.

Table 4.6: Cairns building inventory by Site Class

Construction type	Site Class A	Site Class B	Site Class C	Site Class D	Total
Domestic after 1982, light timber non domestic after 1982, reinforced masonry non domestic after 1974	2228	1213	14799	2735	20975
Light steel frame	0	2	69	472	543
Light timber frame before 1983	267	244	2839	3658	7008
Concrete frame & reinforced masonry infill	0	0	2	41	44
Reinforced masonry domestic before 1983, reinforced masonry non domestic before 1975	206	254	2565	2227	5252
Concrete frame & unreinforced masonry infill	1	0	13	13	27
Unreinforced masonry	9	13	82	213	317
Other	0	0	5	5	10

NOTE: See **Table 4.4** for an explanation of the site classes

We consider that: buildings with timber frames; concrete block buildings complying with wind loadings codes; buildings with reinforced concrete frames and reinforced masonry infills; and buildings with light steel frames, are less vulnerable to earthquake. Older concrete block buildings not complying with wind codes; buildings with reinforced concrete frames and unreinforced masonry infills; and, (especially) unreinforced masonry buildings, are most vulnerable.

The more vulnerable buildings, which are typically older, are concentrated in the older suburbs that are situated on the most hazardous ground conditions, especially Site Classes C and D.

An indication of the earthquake risk from direct damage to buildings in each suburb may be obtained from the plots by:

- the total number of buildings in the suburb; and
- the types of buildings on each Site Class and their numbers.

To use our previous example, Westcourt has a large number of buildings, all of which are located on Site Class D, and it also has a significant proportion of older concrete block and unreinforced masonry buildings, making it among the suburbs with the greatest exposure to earthquake damage. Caravonica, by contrast, has fewer buildings, all of timber frame or modern concrete block construction, and more than half its buildings are on Site Class A or B. It has a relatively low exposure to earthquake damage.

In order to produce a ranking of Cairns suburbs for earthquake risk from direct damage to buildings we have introduced a vulnerability ranking of building types, given in **Table 4.7**. The ranking is not a measure of building vulnerability.

Table 4.7: Vulnerability ranking for Cairns building types

Building type	Vulnerability ranking
All domestic buildings built after 1982	1
Light timber frame non domestic buildings built after 1982	1
Non domestic reinforced masonry (concrete block) built after 1974	1
Reinforced concrete frame with reinforced masonry infill	1
Light steel frame	1
Light timber frame built before 1983	2
Domestic reinforced masonry (concrete block) built before 1983	3
Non domestic reinforced masonry (concrete block) built before 1975	3
Reinforced concrete frame with unreinforced masonry infill	3
Unreinforced masonry	4

Earthquake risk assessments

Suburb-by-suburb ranking of building damage: We used the earthquake hazard map for Cairns (**Figure 4.6**), the revised Cairns building database and the building vulnerability index (**Table 4.7**) in the formula:

Risk coefficient = Σ[(amplification factor) x (number of buildings at risk) x (vulnerability ranking)]

to produce an earthquake risk ranking for Cairns suburbs. An example of the calculation follows. Unreinforced masonry has a vulnerability ranking of 4. Suppose there are 10 unreinforced masonry buildings in a particular suburb on Site Class A, none on Site Class B, 30 on Site Class C, and 50 on Site Class D. The amplification factors for Site Classes A-D at T = 0.3 seconds are 1, 1.3, 1.5 and 2 respectively. The contribution to the risk coefficient from unreinforced masonry is then (1 x 10 x 4) + (1.3 x 0 x 4) + (1.5 x 30 x 4) + (2 x 50 x 4) = 620. The contribution from other types of buildings would be added to this figure to determine the total risk coefficient. The results for Cairns are given in **Table 4.8** and can be seen in **Figure 4.10**.

The ten suburbs most at risk have diverse compositions. A range of usages are present in Manunda, Parramatta Park and Westcourt; Cairns North contains much tourist accommodation; and Bayview Heights, Earlville, Edge Hill, Mooroobool, Whitfield and Woree are predominantly residential. Newly developed suburbs fare better than old or established suburbs in the ranking, largely through the use of more appropriate building construction types. Interestingly, City does not rank in the top ten positions, simply because of its low total number of buildings, although if the importance and cost of buildings and risk of casualties were considered, its ranking would be higher.

The suburb ranking is indicative, and a different order could be established by altering the vulnerability ranking in **Table 4.7**. However, we consider that the suburb ranking order would not change radically with reasonable excursions of the vulnerability ranking. The ranking is expected to apply consistently, regardless of whether the earthquake is mild or violent; that is, regardless of the degree of resultant damage.

We have not undertaken a comprehensive earthquake loss assessment for Cairns in this report, preferring instead to continue to develop our earthquake risk assessment methods. Available methods for calculating direct earthquake losses mostly refer to ground shaking in terms of the Modified Mercalli Intensity scale but, as we have mentioned, Modified Mercalli Intensity does not adequately describe ground shaking. We prefer not to make loss estimates based on the scale.

Our preferred risk assessment method describes earthquake shaking in terms of response spectra (see **Appendix H**). Damage to buildings and infrastructure in earthquakes are appropriately described by fragility curves, and the time required to restore infrastructure function by restoration curves.

Earthquake risk based on building usage: Businesses, commercial activities, industry, logistic facilities, and storage and transport are concentrated in City, Manunda, Parramatta Park, Portsmith and Westcourt (**Figure 4.11**). Most commercial accommodation is located in City and Cairns North and, although flats are located in most suburbs of Cairns, there are large numbers of them in Cairns North, Manunda Parramatta Park and Westcourt. All of these suburbs are situated on Site Class D. By contrast, the bulk of domestic housing is located on Site Class C.

In spite of our relatively limited knowledge of the structural characteristics of buildings in the inner suburbs that are situated on Site Class D, we are confident that Cairns North, City, Manunda, Parramatta Park, Portsmith and Westcourt, between them, have the highest total risk of direct earthquake damage, disruption to the community, business interruption and secondary hazards.

Our analysis shows that 86% of all buildings in Cairns are built on ground with either of the two most hazardous site classifications. **Figure 4.12** shows how building usage is distributed across zones of all four hazard site classes. This remarkable distribution increases earthquake risk in Cairns in at least two ways. The first is that direct losses may be relatively high from any damaging earthquake. The second is that the community's ability to respond to, and recover from, a strong earthquake may be impaired because of damage to medical, public safety, logistic, lifeline and government facilities that are concentrated in the areas most susceptible to strong ground motion.

Table 4.8: Earthquake risk ranking for Cairns suburbs

Suburb	Risk coefficient	Risk rank	Suburb	Risk coefficient	Risk rank
Westcourt	6994	1	Bentley Park	1864	19
Manunda	5660	2	Machans Beach	1722	20
Mooroobool	4275	3	White Rock	1631	21
Parramatta Park	4110	4	Clifton Beach	1596	22
Edge Hill	3977	5	Kewarra Beach	1484	23
Bayview Heights	3907	6	Smithfield	1468	24
Whitfield	3778	7	Brinsmead	1465	25
Cairns North	3588	8	Mount Sheridan	1457	26
Earlville	3382	9	Redlynch	1401	27
Woree	3382	10	Stratford	1242	28
Manoora	3263	11	Freshwater	1181	29
Holloways Beach	3076	12	Trinity Park	879	30
Yorkeys Knob	2850	13	Palm Cove	875.5	31
City	2620	14	Yarrabah	756.5	32
Portsmith	2594	15	Caravonica	733.6	33
Gordonvale	2534	16	Aeroglen	690	34
Trinity Beach	2355	17	Kamerunga	419.2	35
Edmonton	2319	18	Kanimbla	395	36

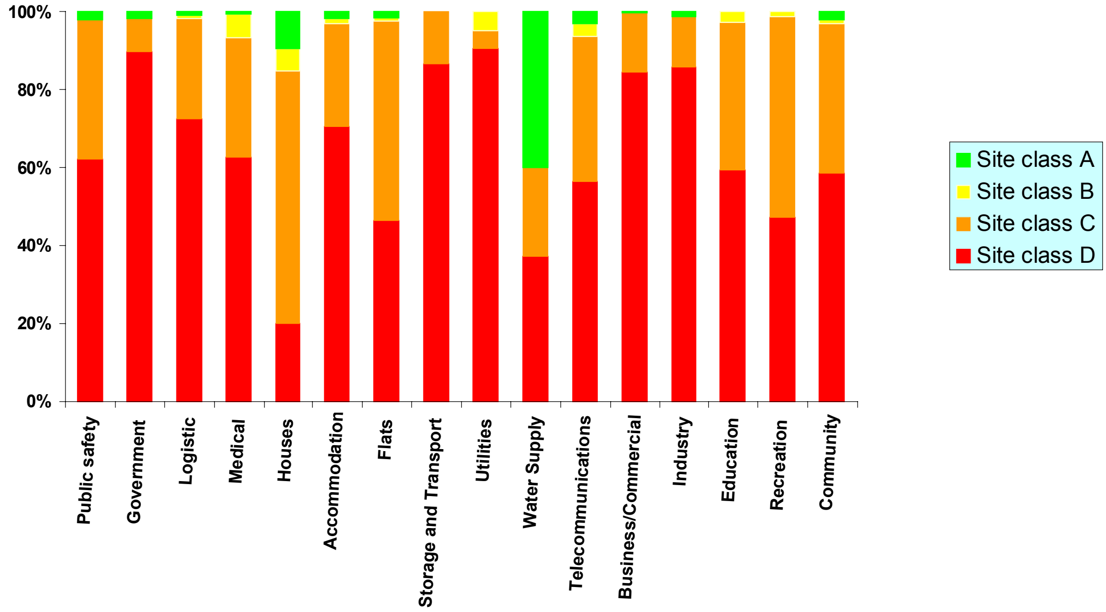

Figure 4.12: Building usage and earthquake site class relationships

Interpretation

The earthquake hazard in Cairns is moderate by global standards, but it is not negligible. Gaull and others (1990) constructed a seismic source zone in northern Queensland that included Cairns. Cuthbertson and Jaume (1996) identified a seismic source zone with one of the highest rates of activity in Queensland extending several hundred kilometres south-east from Cairns.

In many places of Australia, probably including Cairns, moderate to strong earthquakes of magnitudes in the range 5 to 6 comprise around 90% of the total contribution to the overall earthquake hazard. The occurrence of such an earthquake close to Cairns would be a rare event. However, the impact of such an event could be very high. An earthquake in this magnitude range (ML 5.6) near Newcastle in 1989 caused arguably Australia's most costly 20th Century natural disaster.

The impact would be aggravated by extensive thick sediments at Cairns that, beneath coastal suburbs, are also 'soft'. These sediments are expected to behave unfavourably in strong earthquakes.

As a contrast, the modern, cyclone-resistant building stock in Cairns would perform better in earthquakes than the buildings in many Australian cities where significant proportions are older and constructed of unreinforced masonry. This cyclone-resistant stock comprises about two-thirds of the total number of buildings in Cairns.

However, the risk to other one-third of buildings comprising the most vulnerable buildings in Cairns is compounded because they are located overwhelmingly on the two least favourable ground conditions – Site Class C and Site Class D. These buildings are the older concrete block and older timber frame buildings, unreinforced masonry buildings and, of medium-rise buildings, those with concrete frames and unreinforced masonry infill. In any future earthquake affecting Cairns, the most pronounced direct damage may occur to these buildings because of their construction type, their condition, and their location.

Limitations and Uncertainty

We consider the earthquake hazard maps for Cairns and the revised building inventory to be reasonably well developed and appropriate for their usage. We are, none-the-less, mindful that future building inventories undertaken under the *Cities Project* will need to contain information on frame or load bearing wall type and floor type if they are to be more useful for earthquake risk calculations.

The methods used to calculate earthquake risk require considerably more development. Earthquake risk methods need to assess:

- direct economic losses;
- direct social losses;
- indirect economic and social losses; and
- the impact of secondary hazards including fire, hazardous material spills, debris and inundation by tsunami or seiche.

To achieve this, the assessment methods must address the impact of earthquakes on essential facilities and engineering lifelines as well as on the general building stock.

The suburb-by-suburb ranking of earthquake risk for Cairns is useful, but it is no substitute for rigorous risk assessment using quantitative data on building and engineering lifeline performance under a range of earthquake scenarios.

AGSO's *Cities Project* is actively developing these risk assessment methods.

Remarkably, because we have ranked earthquake risk suburb-by-suburb rather than quantified risk in this chapter, the effects of uncertainties in the risk assessment process are less evident than they otherwise would be.

Large uncertainties certainly do exist. Briefly, they 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, which is certainly the case for Cairns. The 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 Californian data for Australian conditions needs to be investigated further;
- the Cairns 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 empirical local earthquake recordings. The inclusion of these data and techniques would improve the rigour of the results.

Uncertainties in the assessment of building performance

- the performance of different construction types of buildings in earthquakes needs to be investigated further;
- we did not account for building condition and nor did we assess the effect of soft storeys or asymmetries in building configuration although the Cairns building database contains information that could be used for this purpose. These factors may be of primary importance on an individual building basis in any future earthquake.

The effect of the uncertainties in building performance are masked by our use of a building performance ranking instead of the preferable method of using fragility curves and building capacity curves to calculate building vulnerability.

CHAPTER 5: LANDSLIDE RISKS

The Landslide Threat

A landslide is the movement of a mass of rock, debris or earth down a slope. Whilst the causes of slope movement can be quite complex, all landslides have two things in common - they are the result of failure of part of the soil and rock materials that make up the hill slope and they are driven by gravity. They can vary in size from a single boulder in a rock fall or topple to tens of millions of cubic metres of material in a debris avalanche.

Landslides can be caused in a number of ways. These include saturation of slope material from rainfall or seepage; vibrations caused by earthquakes; undercutting of cliffs by waves; or by human activity. Almost half the landslides causing injury or death in Australia were the results of human activity including:

- removal of vegetation;
- interference with or changes to the natural drainage;
- leaking water mains;
- modification of slopes by the construction of roads, railways or buildings on steep terrain;
- mining activities;
- vibrations from heavy traffic or blasting; or
- accidental displacement of rocks.

Certainly the most common trigger for landslides is an episode of intense rainfall. The rainfall threshold values for slope failure are in the range 8 - 20 mm over one hour, or 50 - 120 mm over a day, depending on geology and slope conditions. In Cairns, rainfall intensities of such magnitude have an average recurrence interval (ARI) of considerably less than one year, and landslides are not rare events.

The landscape around Cairns is dominated by a series of escarpments that are developing by scarp retreat. Weathering, erosion and removal of debris cause scarp retreat from the slope by two main processes (Michael-Leiba and others, 1999, in preparation):

- on steeper bedrock slopes, and bedrock slopes masked with a relatively thin mantle of broken rock and finer material, weathering and erosion leads to landslides (rock falls, rock slides, debris slides, and small debris flows confined to the slope). By this process rock and soil move down slope under the influence of tropical rainstorms and gravity; and,

- during the more extreme rainfall events, the combined effect of multiple landslides in the upper parts of gully catchments, and the remobilisation of accumulated debris in the major gully systems, periodically results in large debris flows. These can extend onto the depositional plains at the base of the bedrock slopes (**Photo 5-1**). Debris flows are a type of landslide triggered by the action of torrential rain on loose material on a mountainside or escarpment. The boulders and finer material, mixed with water, flow down the slope as a torrent. The coarser material (the proximal part of the debris flow) is deposited near the base of the slope, while the finer material (the distal part of the debris flow) travels further as a flash flood across the floodplain. Debris flows can be highly destructive.

These processes are illustrated in **Figure 5.1**.

Based on existing geological mapping, the model of slope processes, field inspection and interpretation of aerial photographs, a geomorphic classification (**Table 5.1** and **Figure 5.1**) and landslide data map (**Figure 5.2**) have been created (Michael-Leiba and others, 1999, in preparation). A catalogue of landslides in the Cairns area (extracted from AGSO's *Australian Landslide Database*) is included as **Appendix I**. This catalogue was compiled from field observations in February and April 1997; from discussions with Cairns residents; from examining contemporary newspapers; and from literature searches in the Cairns Historical Society Library and the Cairns Public Library.

Table 5.1. Geomorphological units and potential hazards

Unit	Hazard
b0 - upper interfluves, creep slopes and convex creep slopes - remnants of Mesozoic peneplain	Landslide?
b1 - fall faces or steep slopes with cliff lines, developed in bedrock	Rockfall
b2 - transportational midslopes developed as ridges and gullies in bedrock	Rockfall, small landslides confined to slope
b3 - bedrock footslopes, concave or planar deeply weathered bedrock sometimes locally covered with varying thickness of clayey colluvium from one to several metres thick	Rockfall, small landslides confined to slope
fc - massive core debris flow deposit with irregular lobate surface, numerous boulders greater than one metre	Proximal part of debris flow
fp - proximal debris flow fan/outwash with gentle undulating convex slope forms	Proximal part of debris flow
fd - distal outwash fan with uniform low angle slopes	Distal part of debris flow
a2 - distal outwash fan with uniform low angle slopes and no obvious major debris flow source (note that fd can grade into a2 or a2 alone can occur at the base of b3)	Distal part of debris flow
a3 - seasonal floodway incised into surface, possible transport corridor for debris flow	Distal part of debris flow grading into flood
as - Recent sands and gravels, flooded regularly	Not considered
af - possible floodway for extreme events in the Redlynch area	Distal part of debris flow grading into flood

The Cairns Landslide Experience

One definite, and two probable, large debris flow events are known to have occurred in the Cairns region since European settlement.

On 12 January 1951, a torrential deluge of about 700 mm of rain in just under five hours, triggered debris flows that affected 10 km of the Captain Cook Highway between Buchan and Simpson's Points (Ellis Beach). Huge quantities of debris were swept from the mountainside onto the road and over the precipice into the sea. Boulders up to three metres long were hurled into the Pacific “like marbles”. Large slabs of bitumen were tilted up from the road and landslide debris was piled up as high as three metres. All culverts and inverts in this area were either damaged considerably or washed away entirely. The highway was not expected to carry normal traffic for at least two weeks (*Cairns Post*, 15 January 1951). The debris (**Photo 5-2**) is visible to this day on the landward side of the highway behind Ellis Beach, and large boulders (**Photo 5-3**), as well as pieces of concrete entrained in these debris flows, can still be seen on the beach.

The probable debris flow events happened in 1878 and 1911 on the eastern side of Trinity Inlet. Deposits from numerous debris flows have been identified in this area. On 8 March 1878, a “flood” followed by a severe cyclone triggered many landslides across the Inlet. They could be heard distinctly in Cairns (Jones, 1976). On 1 April 1911, a big landslide occurred in the Nisbet Range, also across the Inlet from Cairns. The scar could be seen in photos for several years afterwards (A. Broughton, Cairns Historical Society, personal communication, 1997). This landslide brought away trees, rocks and everything else from a considerable distance up the mountain side (*Cairns Post*, 3 April 1911).

On 31 May 1900, the landslide with the fourth largest number of Australian landslide fatalities happened in Cairns. Five men were killed and one buried alive for ninety minutes when an 8 m deep tramway cutting they were constructing at Riverstone for the mill at Gordonvale caved in. The location was at “Dead Man’s Gully” or “Dead Man’s Cutting” (A. Broughton, Cairns Historical Society, written communication, 1999), in a river terrace in Gordonvale, 3 km WNW of Walsh’s Pyramid. The cutting was partly bulldozed in the 1980s, but the overgrown upper part of one side is still visible (**Photo 5-4**).

Landslides on hill slopes periodically block roads, particularly Lake Morris Road (**Photo 5-5**) and Kuranda Range Road (**Photo 5-6**). For example, detailed records of landslides along Lake Morris Road both before and after Tropical Cyclone *Justin* (22-23 March 1997) were made. Analysis of this information indicates that 21 batter failures and two fill failures occurred along this road during the 1997-1998 wet season prior to *Justin*, compared with 52 new batter failures after *Justin*. Forty-six new batter failures (**Photo 5-7**) and one new fill failure were logged along Kuranda Range Road after the 1997 cyclone.

The Cairns-Kuranda railway has an even more spectacular history of dislocation by landslides, the earliest of which was recorded during its construction in 1891. The most disruptive incident started on 15 December 1910, when a landslide at the Kuranda end of No. 10 tunnel partly closed the tunnel for more than two months. Several episodes of sliding occurred during this time (Broughton, 1984). The line was cleared for goods traffic on 25 February 1911 and for all traffic on 6 March 1911 (*Cairns Post*, 27 February and 7 March 1911). Another disruptive episode started on 5 March 1954 when a large landslide in the Red Bluff area, with its head well above the railway, and toe well below it, blocked the railway until 22 April 1954 (A. Broughton, Cairns Historical Society, personal communication, 1997).

In 1927 and again in 1984 or 1985, boulders smashed the water main at the No. 1 and No. 3 crossings respectively of Freshwater Creek. During the latter incident, the water supply pipeline slipped with a mudflow which took out the anchor blocks (Cairns City Council, 1927 and D. Gallop, Cairns City Council, personal communication, 1997).

Instances of landsliding have been recorded in the established suburbs (**Photo 5-8**), either on cuts behind houses or road cuts or fills. Two houses have been destroyed and several building blocks written off as a result. The following observations are relevant (Michael-Leiba and others, 1999, in preparation):

- most of the landslides appear to be associated with disturbances of the natural surface in the process of development;

- virtually all of the small landslides observed appear to be related to weak structures in bedrock or very steep cuts in colluvium; and,

- most of the landslides are less than 100 cubic metres in volume.

Landslide hazard and risk analysis

Using a detailed catalogue of events based on field observations in Cairns and extensive historical research, the recurrence relation (ARI) for landslides per 10 km of escarpment on fully developed slopes has been tentatively established.

The extent to which future debris flows might extend from gullies has been estimated using an approach based on 'shadow angles' that geometrically define run-out distances. The shadow angle is the angle between the horizontal and a line drawn from the limit of the proximal or distal part (defined below) of the debris flow to the top of the escarpment. It is measured in the field using a clinometer.

The proximal portion is that part of the debris flow closest to the source of the landslide. It has a lumpy or convex surface and contains large boulders up to several metres in length. The distal portion of a debris flow is the more gently sloping and contains the finer grained, thinner sediments that are deposited further from the landslide source. Individual debris flows large enough to run out on to the plain may vary in size from tens of cubic metres to tens of thousands of cubic metres in the Cairns area. The large debris flow fans in the Redlynch area have volumes of millions of cubic metres, but these are built up over probably tens of thousands of years. The 1951 Ellis Beach debris flows had a total volume of over 300 000 m^3.

If the top of the escarpment is represented by a line in a GIS, and representative shadow angles are chosen to define the runout distances of the proximal and distal parts of a debris flow, then the GIS can be used to produce a map highlighting the areas below the escarpment which may be impacted by debris flow runout. The shadow angles were chosen initially from a variety of field observations (Michael-Leiba and others, 1999, in preparation), then refined by doing a series of trial runs using the GIS on a map of the South Redlynch debris flow fan (**Figure 5.8**). Maps were plotted with shadow angles being incremented or decremented one degree at a time from the values measured in the field. The shadow angles were selected which best matched the mapped proximal and distal debris flow runout, erring so as to slightly underestimate the runout, because South Redlynch is a large fan. These shadow angles were then checked by doing a GIS plot of predicted debris flow runout superimposed on the Cairns landslide data map (**Figure 5.2**). The overall fit appeared visually as good as could be expected when only one set of shadow angles was being used for the entire Cairns escarpment.

GIS polygons have been used to delineate and characterise the areas that could be affected by landslides.
Three main categories were chosen (Michael-Leiba and others, 1999, in preparation):

- the escarpment;
- areas which could be affected by the proximal portions of debris flows; and,
- areas which could be affected by the distal portions of debris flows.

In the following text and in **Table 5.3**, the average recurrence intervals (ARI) and hazard and risk probabilities per annum have been rounded to one significant figure. This is because of the large uncertainties in the estimates – the error bars on the ARI graphs are up to two orders of magnitude in length.

For each polygon, information on the ARI has been used (Michael-Leiba and others, 1999, in preparation) to estimate the landslide hazard (probability, *H*, per annum of a point being impacted by a landslide), and a GIS landslide hazard map has been prepared for the Cairns area. For points on the escarpment, the hazard occurrence probability is estimated to be 0.02% (an ARI of 6 000 years), assuming that the slope is developed. Thus, for undeveloped parts of the escarpment, this figure predicts what the hazard would be *if* the slope were to be developed *without adequate mitigation measures being taken*. The hazard would be expected to be considerably less on slopes developed with geotechnical consultation. It would also probably be less on undisturbed slopes. The hazard probability in areas which may be impacted by the proximal parts of debris flows is calculated to be 0.01% (an ARI of 8 000 years), and for the distal parts of debris flows, 0.01% (an ARI of 9 000 years).

The GIS polygons have then been interrogated to assess the nature and number of elements at risk (*E*). The vulnerabilities (*V*) of people, buildings and roads to destruction by landslides and debris flows were assessed (Michael-Leiba and others, 1999, in preparation). The vulnerability was taken to be the probability of destruction given that the person, building or road was hit by a landslide. For people and buildings on hill slopes, the assessment was based on information in the *Australian Landslide Database*, and for roads on hill slopes, the vulnerability was estimated from information provided by the Cairns City Council. There was insufficient information in the Australian Landslide Database to calculate vulnerabilities to large debris flows, so volumes were assumed from knowledge of the type of event and from overseas experience. The value of *V* ranges between 0 (none destroyed) and 1 (all destroyed) with the type of landslide and element at risk, as shown in **Table 5.2**. We do not have estimates of the uncertainties in these values.

Specific annual risk of destruction is the probability per annum of a person, building or section of road at a given point in the Cairns area being destroyed by a landslide. The specific risks to individual people, buildings and roads in susceptible parts of Cairns, if the areas were to be developed, have been calculated (Michael-Leiba and others, 1999, in preparation) from the equation *specific risk* = $H \times V$ and mapped using the GIS. **Figure 5.3** shows the specific risk to buildings. The values obtained are shown in **Table 5.3**, along with the annual probability of a road being blocked by debris at a locality.

Table 5.2. Assessed vulnerabilities of people, buildings and roads to destruction

Unit	**Vulnerability of people**	**Vulnerability of buildings**	**Vulnerability of roads**
Hill slopes	0.05	0.25	0.3
Units susceptible to proximal debris flow	0.9	1.0	1.0
Units susceptible to distal debris flow	0.05	0.1	0.3

A risk map depicting the estimated annual probability of a total road blockage somewhere in a 10 km length of road parallel to the escarpment was also prepared. For this risk map, 10 m wide roads were assumed. For the hill slopes, the estimated annual probability is 63% (an ARI of one to two years). For roads in potential proximal debris flow runout regions it is 1.0% (an ARI of 100 years), and in potential distal debris flow runout regions it is 0.4% (an ARI of 200 years).

Table 5.3: Specific annual risk of destruction of individuals, buildings and roads, and of road blockage

Unit	Specific annual risk of death - people	Specific annual risk of building destruction	Specific annual risk of road destruction	Specific annual risk of road blockage
Hill slopes	0.0008% (ARI of 100 000+ years)	0.004% (ARI of 20 000 years)	0.005% (ARI of 20 000)	0.02% (ARI of 6 000 years)
Units susceptible to proximal debris flow	0.01% (ARI of 9 000 years)	0.01% (ARI of 8 000 years)	0.01% (ARI of 8 000 years)	0.01% (ARI of 10 000+ years)
Units susceptible to distal debris flow	0.0005% (ARI of 200 000 years)	0.001% (ARI of 90 000 years)	0.003% (ARI of 30 000 years)	0.007% (ARI of 10 000+ years)

The paucity of the data from which the landslide magnitude-recurrence relations (ARI) were derived must be emphasised. As the error bars for the data points are, in some cases, more than two orders of magnitude long, errors in all the hazard and risk estimates may be large.

Because the Captain Cook Highway, Kuranda Range Road and Cairns-Kuranda Railway, which provide access to Cairns from the north and the Tableland, each pass through country with steep slopes, they may be blocked by landslides in the event of intense precipitation such as that associated with tropical cyclones. Outside the study area, the Bruce Highway and particularly the Gillies Highway (which links Gordonvale to the Atherton Tableland), may also be blocked by landslide. This makes the Cairns community particularly vulnerable to isolation.

Total risk is the number of elements at risk expected to be destroyed by a landslide in a given GIS polygon in a given period of time. Maps (**Figure 5.4** and **Figure 5.5**), which quantitatively depict the total risks per km^2 per 100 years for residential people and buildings in each GIS polygon in the currently developed parts of Cairns, were constructed (Michael-Leiba and others, 1999, in preparation) from the data for each polygon. These were based on the equation *total risk = H x E x V*, where *E* is the number of houses and flats, or people living in houses and flats, in a polygon. The greatest total risk for buildings (houses and flats) is on the hill slopes, where it is estimated that a total of 13 buildings throughout the map area could be destroyed in 100 years, *if no mitigation measures were taken*. The highest total risk for people living in houses and flats is in the proximal parts of debris flows. It is estimated that a total of 16 people in the map area could die over 100 years in these areas.

The values for all types of buildings, by suburb in alphabetical order, are listed in **Table 5.4**. These values do not compensate for the differing areas of the suburbs, because the data are used in the multi-hazard risk assessment, which is carried out on a suburb by suburb basis in **Chapter 8**. The suburbs are ranked from greatest to least total risk for buildings. The spatial distribution is shown in **Figure 5.6**.

The parts of these suburbs that are at greatest risk of landslide are in the Freshwater Valley, the lower slopes of the coastal escarpment, or near the base of Mount Whitfield. Note that with good engineering practice, such as adequate drainage and retaining walls, commonly used in developing the hill slopes in Cairns, the actual number of buildings destroyed per 100 years would be expected to be considerably less that that shown in the **Table 5.4**.

Landslide risk scenarios

Most of the areas susceptible to debris flow in Cairns have only become closely settled in recent years, so it has not been possible to use data gained from historic debris flows in suburban Cairns for planning, mitigation or emergency management purposes. By choosing a realistic torrential rainfall scenario, and assessing its effects on a vulnerable part of Cairns, we can acquire valuable information *before* the event.

Table 5.4: Total risk of destruction of buildings by landslide

Suburb	Risk Rank	Total risk	Suburb	Risk Rank	Total risk
Aeroglen	13	0.6	Mooroobool	2	2.6
Bayview Heights	3	2.5	Mount Peter	26	0.01
Bentley Park	25	0.1	Mount Sheridan	12	0.7
Brinsmead	6	1.2	Palm Cove	16	0.4
Caravonica	20	0.3	Redlynch	1	5.5
Clifton Beach	22	0.2	Smithfield	6	1.2
Earlville	9	0.9	Stratford	8	1.0
Edge Hill	10	0.8	Trinity Beach	14	0.5
Edmonton	16	0.4	Trinity East	11	0.8
Freshwater	4	1.6	White Rock	24	0.1
Gordonvale	26	0.01	Whitfield	5	1.4
Kamerunga	19	0.4	Woree	22	0.2
Kanimbla	18	0.4	Wrights Creek	29	0.004
Kewarra Beach	26	0.02	Yarrabah	14	0.6
Manoora	21	0.2			

NOTE: In this table Total Risk relates to the estimated number of buildings that would be destroyed in the suburb in any 100 year period.

Let us suppose that 450 mm of rain falls in one day on the escarpment on the west side of Freshwater Valley. This is a rainfall event with an ARI of approximately 20 years (5% annual probability) on the escarpment in the Cairns area, and is approximately the rainfall intensity and duration involved in the January 1998 Townsville floods and the August 1998 Wollongong floods.

Redlynch fan: The southern part of this debris flow fan includes Redlynch shopping centre and the suburban area to its west. This fan has been examined using aerial photography, and briefly in the field. The southern part of the fan is bounded by an ENE-trending erosional gully in the north and an ESE-trending creek to the south. Both could serve as conduits for debris flows and flash floods. These features are shown in **Figure 5.7**.

Up to five houses, the most likely number being two, may be susceptible to destruction by the proximal part of debris flows. Because these landslides are highly destructive, the probability of a person being killed in a house in the proximal part of a debris flow is about 90%. If the debris flows occurred at night, with an average occupancy rate of about three persons per house, the estimated number of fatalities would be six. During the day, when residents are at work or school, there may be about two fatalities caused by the proximal part of debris flows.

Because of the rapidly flowing, mud laden water, the distal parts of debris flows and flash floods could damage a further 60 houses. Of these, perhaps 20 are regarded as being particularly vulnerable, and one or two people could be killed.

As the roads out of the fan would almost certainly become flooded, evacuation from the area would need to take place before flooding commenced. Relief efforts into the area would also be hindered. Unless flooding was all encompassing, however, residents could take refuge on the higher part of the fan if sufficient warning and suitable shelter were available.

South Redlynch fan: This debris flow fan is south of Redlynch shopping centre. It contains many relatively new houses and the Redlynch State School and Pre-school. This fan has also been mapped using both aerial photography and field observation (Michael-Leiba and others, 1999, in preparation). **Figure 5.8** is a map of the debris flow fan and in it, the geomorphological units are as described in **Table 5.1**, except that **as** is alluvium of Freshwater Creek subject to regular flooding.

Debris flows and flash floods in channels tend to block culverts, and when they encounter a sharp change in direction in their channels, part of the material may continue to flow in the original direction. Taking this behaviour into account, the map has been used to assess the possible consequences of torrential rain in the catchment.

Between zero and six houses may be destroyed by the proximal parts of debris flows, the most likely number of houses being two. If the debris flows occurred at night, the estimated number of fatalities would be six. During the day when many residents are at work or school, there may be about two fatalities caused by the proximal part of debris flows.

Because of the rapidly flowing, mud laden water, around 30 houses would be expected to be damaged by the distal part of debris flows and flash flooding, and one or two residents could be killed.

Water and/or debris in several places would likely block Redlynch Intake Road, Harvey Road and Robb Road. In some of these places, scouring may destroy the roads. The Cairns-Kuranda Railway would probably be rendered impassable by debris flows, other landslides and wash-outs. Because of these blockages, the South Redlynch area would be isolated. For many residents, evacuation to centres either in the area or elsewhere would need to take place before the onset of flooding. Freshwater Creek would probably be in flood, causing inundation to low lying adjacent areas. It is possible that the road or creek flooding may also claim one or two people.

Southern, upper, part of Freshwater Valley: About 50 houses may be damaged by river flooding, flash flooding and minor debris flows. This could lead to one or two deaths. The Cairns water mains could also be damaged or destroyed by boulders where they cross Freshwater Creek.

Interpretation

Until the Thredbo landslide tragedy in 1997 there had been little public recognition that landslides were a significant threat in Australia. Where landslides occur, their physical impact is typically confined to a few properties or a short length of road or railway, but the effect can be disturbing or disruptive. Insurance policies in Australia do not normally cover landslide, and this can cause anguish to property owners. One landslide blocking a road or railway can cause inconvenience and economic loss. The evidence is clear that in Cairns landslide has been, and remains, a significant risk. Whilst the risk of significant debris flows impacting on suburban development is relatively small in terms of probability, the impact of such an event would be considerable. Flash flooding in Freshwater Creek, or debris flows, have the potential to disrupt the Cairns water supply by blocking the intake or destroying sections of the pipeline.

Limitations and Uncertainties

There are some specific technical limitations that may be recognised but cannot be dealt with in this reconnaissance report. The most important of these are:

- the regional nature of this study, and

- the paucity of the data from which the landslide magnitude-recurrence relations were derived. As the error bars for the data points are, in some cases, more than two orders of magnitude long, errors in the risk estimates may be large.

The chief simplifying assumptions of the risk assessment are as follows:

- a uniform process rate across, and from top to bottom of, the entire escarpment, irrespective of local geomorphology, rock type, soil cover or position on the escarpment, and

- a uniform shadow angle for debris flows. The assumption implicit in this is that the runout distance of debris flows is greater for higher escarpments, and depends only on the height of the escarpment, not on the volume of source material available to be incorporated in the landslide, nor the height on the escarpment at which the landslide originates.

The uniform process rate assumption will have a smoothing effect on the results. Hazard and risk will be overestimated in some areas and underestimated in others. However, because the magnitude-recurrence relation for landslides on hill slopes was weighted heavily by observations of landslides along the Kuranda Range Road, the Cairns-Kuranda Railway and Lake Morris Road, the hazard and risk will tend to be grossly overestimated in suburban areas where mitigation measures have been put in place.

The uniform shadow angle assumption may overestimate the area susceptible to debris flow runout in some cases. This is because the shadow angles assumed in the risk analysis were mainly derived from the large south Redlynch debris flow complex which has accumulated in a part of the escarpment which has had favourable conditions for debris flow production for tens of thousands of years.

Also, while very large debris flows can bury an entire settlement, smaller debris flows can be slowed when they encounter buildings, causing the landslide to deposit most of its load of boulders and thus lose much of its destructive potential – a possibility not taken into account in our analysis. This happened with the debris flow that hit the Magnetic Island International Resort in January 1998. Only units in the row furthest uphill were damaged or destroyed by boulders. These buildings reduced the rate of flow and all but a few boulders were dumped there. Buildings further down the slope were affected only by water and the finer sediments that remained.

Finally, the reconnaissance nature of the field mapping must be emphasised. Polygon boundaries are approximate only and some details on the landslide data map may change with further and more detailed field work. For detailed site-specific assessments, our broad findings should be checked by geotechnical specialists.

CHAPTER 6: FLOOD RISKS

The Flood Threat

Floods occur when the water entering the catchment, usually as a result of rainfall, is too much to be contained within the banks of the drainage network and spills out over the floodplain. Such events can range from very localised and short-term events, such as a flash flood in a suburban storm water system, to major flooding lasting several days or more across an extensive river catchment. The key determinants of whether floods occur or not include:

- the overall amount of rain that falls in the catchment;
- how much and what parts of the catchment receive the rain;
- the intensity of that rainfall; and
- the state of the catchment before the rainfall episode commenced.

A long period of steady rain over a portion of a catchment may eventually produce flooding, however, a large volume of rain falling over a short period (say over 12 to 24 hours) over just a portion of a catchment that is already saturated from earlier rainfall, will almost certainly produce a flood. No two flood events, therefore, are identical and it is difficult to define, with any degree of certainty, an 'average' flood.

The normal benchmark used to overcome this problem is to describe floods in terms of an average recurrence interval (ARI) or, preferably, an annual exceedence probability (AEP). AEP is the probability of a given flood discharge magnitude occurring, or being exceeded, in any one year period.

Cairns has a rather peculiar flood hydrology. The delta on which the bulk of the city stands has not been fed by a river for perhaps many tens of thousands of years. It does not, therefore, have the level of threat from major riverine flooding experienced in other coastal Queensland cities, such as Brisbane, Bundaberg, Mackay, Rockhampton or Townsville, which grew around their river ports.

The only river that poses a significant flood threat within the study area is the Barron River (**Photo 6-1**), which separates the city from its northern beachside suburbs, though smaller catchments can cause serious localised flooding throughout the area. The trauma of major flooding of the Barron River in the early days of the Trinity Inlet settlements has probably minimised the risk to the present-day Cairns community - the lessons of its flood potential were learned at an early stage. Floods in successive years in 1877, 1878 and 1879 sped the abandoning of the original Smithfield settlement on the Barron (sited in the area of present-day Stewart Road, Barron), reinforcing the choice of the shores of Trinity Inlet as the preferred site for the port and settlement.

The Barron River catchment covers about 2 300 square kilometres. The river rises on the Atherton Tableland near Atherton and flows north through Mareeba before turning east to enter the lowland delta through the spectacular Barron Gorge below Kuranda. It is fed by several major tributaries on the Tableland, the largest of which are Granite Creek and the Clohesy River, whilst Freshwater Creek, joins the Barron below the Gorge. The delta covers about 45 sq km with Thomatis Creek - Richards Creek providing a distributary channel at the mouth. Freshwater Creek is the most significant of the tributaries as far as flood in the Cairns suburban areas of Redlynch and Freshwater are concerned - see **Chapter 5** (Landslide Risks). The Barron River catchment is shown in **Figure 6.1**.

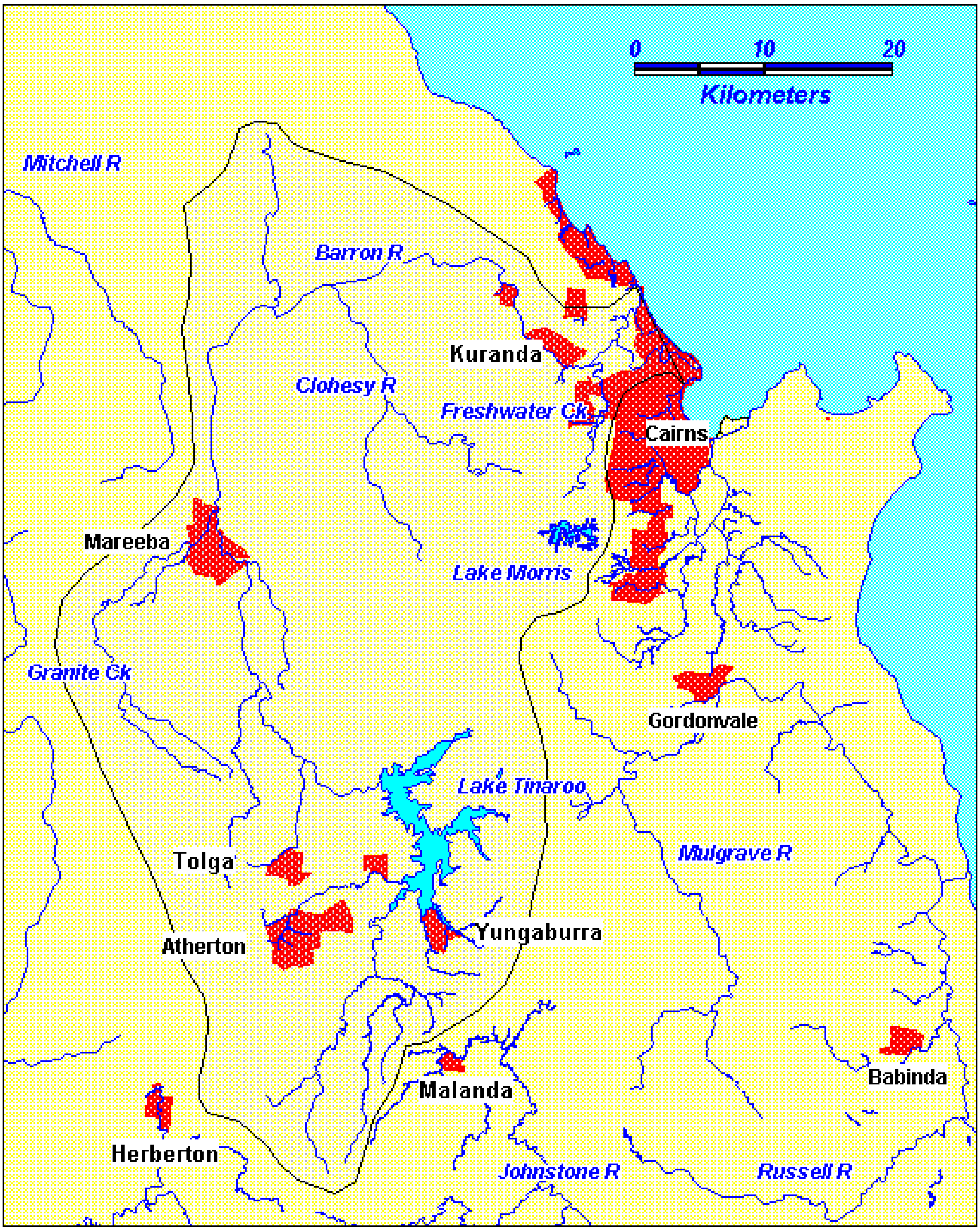

Figure 6.1: Barron River catchment

The study area contains a further four catchments: the MacAlister Range catchment; the Trinity Inlet catchment; the Mulgrave/Russell Rivers catchment; and the Yarrabah valley catchment. Several small creeks that flow off the escarpment of the MacAlister Range dissects the strip occupied by the northern beach suburbs north of Yorkeys Knob. They include (from north to south) Sweet Creek, Delanys Creek, Deadmans Gully, Deep Creek, Moores Gully and Moon River. These water courses are susceptible to flash flooding, though this tends to be localised and of short duration.

The Trinity Inlet catchment receives runoff from Mount Whitfield in the north, the Whitfield Range in the west and the north-western escarpment of the Thompson Range in the east. The main streams that drain the urban area are Saltwater Creek, Lily Creek, Moodys Creek, Chinamans Creek, Clarkes Creek, Gordon Creek, Skeleton Creek and Blackfellows Creek.. These creeks have been augmented or modified by large concrete drains that flow either into Saltwater Creek or the Inlet. The flood threat in this catchment comes mainly from flash flooding or local storm water discharge during an intense rainfall episode, especially if it coincides with a very high tide. Extreme rainfall events in the Cairns area can dump more than 700 mm of rain in less than 12 hours. Most flooding of this 'urban drainage surcharge' kind, however, is of relatively short duration. It can, none-the-less, be very damaging and lead to loss of life.

The Mulgrave and Russell Rivers drain the mountain country dominated by Bellenden Ker and Bartle Frere, Queensland's highest mountains and the highest rainfall area in Australia. Only the Mulgrave River arm is of interest in this study. Gordonvale is the only urban area threatened by flooding in the Mulgrave, however, considerable areas of sugar and other crops that occupy the floodplain can be at risk. Flooding in the Mulgrave River can also cut the Bruce Highway and the main rail link to the south.

The Yarrabah valley receives runoff from the eastern slopes of the Thompson Range and the western slopes of the low range of hills that separate Yarrabah from Cape Grafton. There is no well defined drainage in the valley though there are fairly large areas of wetland. The main threat is from flash flooding in creeks that flow off the high country. There appears to be only a limited threat of flooding on the valley floor itself.

There are three dams in the Barron catchment: the Tinaroo Falls Dam, completed in 1958; the Barron Gorge Weir, close to Kuranda, built in 1935 to provide storage for the Barron Falls hydro-electric power station; and the Copperlode Falls Dam (Lake Morris) on Freshwater Creek completed in March 1976. None of these dams was constructed to provide a flood mitigation capacity. Given the configuration of the catchment and the location of these dams, they have little influence on reducing a flood.

An extensive network of rainfall and river height gauging stations monitors the Barron River. A flood warning ALERT network was established jointly by the Bureau of Meteorology, the then Mulgrave Shire Council and the Cairns Port Authority in 1995. Stations in the network are linked by VHF radio to a base station computer in Cairns. The data produced by these instruments are provided to hydrological models to produce river height predictions on which flood warnings are based. Quantitative river height predictions are given for Kamerunga, which is the reference gauge for flooding on the delta.

Floods are classified in three levels of severity in warnings issued by the Bureau of Meteorology. These are defined generically in a Bureau pamphlet (BoM, 1997a) as follows:

> ***Minor flooding:*** *This causes inconvenience such as closing minor roads and submerging low level bridges…*
>
> ***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.*

The Cairns Flood Experience

The reference gauge for flood levels in the Barron River, with the longest record, is at Myola, a few kilometres upstream from Kuranda. This site has been used to measure river heights in the Barron since 1915, though earlier gauges in the same vicinity give us reasonably equivalent data for major floods back to at least 1910. A level of 7 m or more on the current Myola gauge constitutes a flood; with levels below 8.5 m, flooding is relatively minor; whilst levels above 10 m are considered major floods. **Figure 6.2** shows the annual flood peak measured on the Myola gauge from 1916 to 1999, with the major floods of 1911 and 1913 also included. The gauge at Kamerunga, on the lowland, provides more direct measures for the delta. For this gauge, a minor flood commences at 6 m, a moderate flood is over 8 m and a major flood is above 9 m.

It is clear from the river gauging record that the flood of late March to early April 1911 is the greatest flood on record. That flood was recorded at 15.37 m on the Myola gauge, although this may not be directly comparable with heights at the current gauge. It was caused by widespread rain across the catchment between 31 March and 2 April 1911, including falls of 617 and 732 mm recorded at Kuranda on the last two successive days. This rain fell onto a catchment that had already been saturated by rain brought by a cyclone that crossed the coast near Port Douglas on 16 March. According to figures quoted in a study of flooding on the delta published in 1981 (Harbours and Marine, 1981) this record flood had a discharge of 7 221 cubic metres per second (cumecs) which was estimated to be around 70% of the estimated probable maximum discharge. This makes it an extreme and fairly rare event, with an AEP of between 0.2% and 0.1% (an ARI of between 500 and 1 000 years). There appears, however, to have been little damage, given that there was little development other than some agriculture, at that time, on the Barron River delta.

The second greatest flood on record came two years later and was caused by a cyclone that crossed the coast about 70 km north of Cairns on the night of 29-30 January 1913. A flood peak of 14.76 m on the Myola gauge was recorded on 31 January. The discharge recorded in this flood was 6 569 cumecs, putting it in the region of a 0.5% AEP event. Again, there appears to have been little damage reported, other than to crops, on the floodplain.

Further 'major' floods, measured on the Myola gauge, occurred in 1934, 1967, 1977, 1979 and 1999. The greatest of these was made up by the events of 5 to 11 March 1977. As with the 1911 flood, this event was produced by a period of heavy rain and minor flooding in the catchment being followed within a few weeks by a second heavy rainfall episode. This flood reached a peak of 12.62 m on the Myola gauge (with a discharge of 4 556 cumecs) and 9.5 m on the Kamerunga gauge. The Myola discharge rate would make this a 1:50 year flood on the basis of the most recent revisions of rainfall. The meteorological sequence is described in the Barron River delta flood study (Harbours & Marine, *ibid*) as follows:

> *The start of the wet season* (in February 1977) *was marked by the development of tropical lows in the Gulf of Carpentaria and off the east coast. There was some easting of the weather on the 9th as these lows* (in the monsoonal trough) *moved away from the coast. Tropical cyclones "Lily" and "Miles" developed north and east, respectively, of Willis Island, whilst the low in the Gulf moved onto the coast on the 10th and 11th, bringing further heavy rain on those days. Tropical cyclones "Lily" and "Miles" were not particularly active, and moved generally east to southeast before degenerating without directly affecting Queensland's coastline. However, tropical cyclone "Nancy" developed comparatively close to the coast on the 12th, and maintained cyclonic strength for about 9 hours before crossing the coast near Bloomfield River Mission* (Wujal Wujal) *as a rain depression in the early hours of the 13th.*

As a result of these weather patterns, the northern half of the State received heavy to flood rains during the first half of the month. During this period stations at Babinda and Innisfail recorded their highest monthly totals since records commenced. In the Barron River catchment, high monthly totals (above 600 mm) were recorded on the coast and in inland areas, including most of the Tableland…..

Overbank flow from the Barron River and Thomatis Creek during the flood submerged the Captain Cook Highway and Yorkeys Knob road pavements, linking these floodwaters with the runoff from Avondale Creek catchment. However, there was no flow across the Brinsmead-Kamerunga Road north of the Barron, nor any overland flow west of this road into Avondale Creek. Although large tracts of cane land were inundated, there was no evidence of scouring.

The flood peak in the Barron River passed Lake Placid at 7.00 a.m., and reached B14 gauge at Machans Beach at 9.30 a.m. on February 11, 1977.

A similar weather pattern to February emerged in early March with a high pressure system in the Tasman Sea extending a ridge up to the monsoonal trough. This situation, which continued for much of the first half of the month, caused continuous showers and thunderstorms in the vicinity of the trough.

Again, tropical low pressure systems became active in the trough, developing in the Gulf and off the east coast. The low in the Gulf eventually developed into tropical cyclone "Otto" on the 7th. Tropical cyclone "Otto" traversed Cape York peninsula and moved down the east coast before recrossing it on the 8th and dissipating inland near Townsville.

Tropical Cyclone "Otto" brought particularly heavy flood rains to most areas of the Barron catchment on the 6th and 7th, and subsequent heavy falls on the coast west to the range on the 8th and 9th as it degenerated.

The heavy falls which occurred overnight on the 6th resulted in the highest flood level measured at Myola since systematic recording began (12.62 metres with a corresponding estimated discharge of 4556 cubic metres per second).

The flood rose very steeply, at one time at a rate of 0.75 metres per hour, and the flood peak was almost coincident with the high tide which occurred around midday. The peak occurred at 9.00 a.m. at the Lake Placid Kiosk, and at 11.30 a.m. on the Yorkeys Knob road….

In addition, significant flooding occurred in the built-up areas of Yorkeys Knob, Holloways Beach and Machans Beach. Most of the Delta, consisting mainly of cane land and non-urban areas, was submerged during the flood. The records show that just in excess of 100 houses, mainly located at Machans Beach, were evacuated during the flood. Scouring was evident in the cane fields and on river banks, particularly on the river bend adjacent to the end of the Cairns Airport main runway.

Figure 6.3 shows the extent of the March 1977 flooding which covered approximately 43.5 sq km. It should be noted that the airport layout shown in the figure is the current (1999) airport. In 1977 there were no protective levees and the main runway was under water for a day or so.

The other four major floods, for which measurements are available, were those of March 1934 (10.5 m), March 1967 (11.62 m at Myola, 9.5 m at Kamerunga), January 1979 (10.7 m at Myola, 9.4 m at Kamerunga) and February 1999 (11.4 m at Myola and 8.65 m at Kamerunga). Again the Barron River delta flood study provides an excellent description of the weather systems that produced the 1979 flood and the response of the river to those events.

In all there were six main flood events between 1 January and 6 March 1979. Two (1-9 January and 25-27 January) were well over the bank and inundated large sections of the delta. The other four peaked at, or close to, bank-full discharge. The largest two floods are described here:

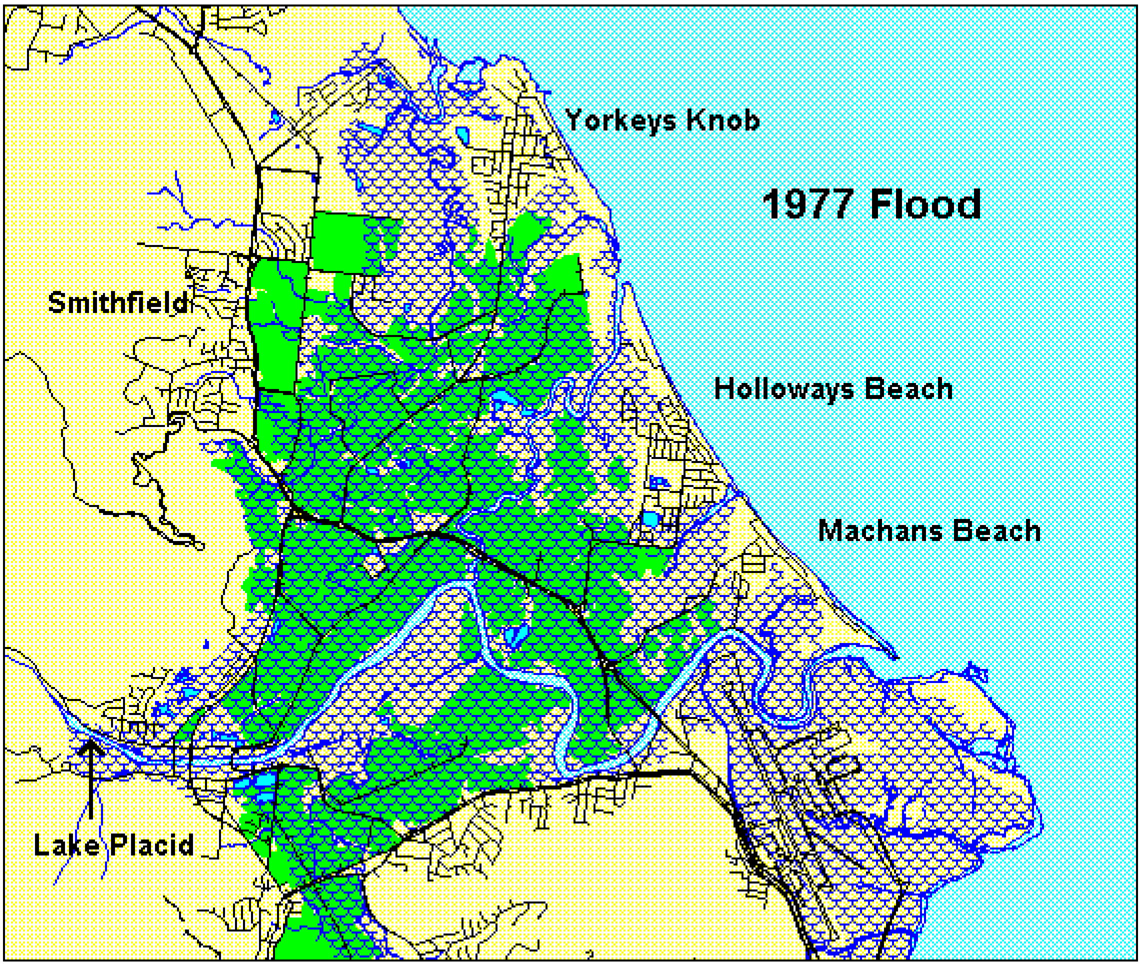

Figure 6.3: Barron River inundation in the flood of March 1977 (after Harbours & Marine, 1981, Figure 4-36)

The main feature of the first flood were the concentration of rainfall on the eastern side of the catchment, the particularly high rainfalls at Kuranda and the continuity of rain which maintained the flood peak heights for three days. Tinaroo Falls Dam did not commence spilling until water levels from the first flood began to fall.

The first flood was associated with Cyclone "Peter" which crossed from the Gulf and was located over Cape York Peninsula as the month began. Meanwhile, the southern half of the State was being influenced by a ridge extending along the coast from a high in the Tasman Sea to the active monsoonal trough lying across the Cape. "Peter" subsequently moved onto the east coast and weakened into a rain depression centred on the coast to the north of Cairns.

This situation caused flood rains in the Barron catchment, resulting in prolonged and extensive flooding of the Delta. As this flood receded, the monsoonal trough was still active. A second cyclone named "Greta" crossed the Cape on a similar path to "Peter" and, like "Peter", weakened into a rain depression in the monsoonal trough. However, unlike "Peter", "Greta" moved inland and did not cause any overbank flooding on the Barron Delta. In the middle of the month, the ridge along the coast weakened and rainfall eased on the Barron catchment.

However, later in the month as the coastal ridge strengthened again, a low developed in the Gulf, moved onto the Peninsula on January 25 and caused the flood of January 25-27.

The peak of this flood occurred overnight on the 25th reaching 10.03 metres at Myola. This flood rose very sharply from 4 metres to 10 metres in about 6 hours (an average of 1 metre per hour with a peak rate of rise of 2 metres per hour at 11.00 p.m.). This gives a clear indication of the severity of the storm which produced it, and reflects the completely saturated state of the catchment from the earlier heavy falls. Peak flood levels measured on the Delta were within 0.5 metres of the first January flood peak.

The flood which occurred early in January had a peak which lasted at least three days. Although the peak of this flood was below the March 1977 flood, its total discharge was much greater. Measurements taken on the Delta also indicated that, compared with the 1977 flood, the first January 1979 flood had a greater contribution from watercourses downstream from Myola….

The beach areas of Yorkeys Knob, Holloways Beach, and Machans Beach were isolated during the flood and just in excess of 100 houses had to be evacuated….

The flood had a number of peaks, the highest of which passed Lake Placid at 5.30 a.m., and reached Machans Beach at 8.00 a.m., on January 5, 1979.

The inundation map for the 1-9 January 1979 flood is provided as **Figure 6.4**. The extent of inundation for the 1979 flood, which covered about 40.0 sq km, is very similar to that for the 1967 and 1977 floods. Indeed, the stage heights on the Kamerunga gauge (at the head of the delta) vary only 0.4 m between the three events.

A survey of the extent of inundation caused by the February 1999 flood had been commenced at the time of writing.

One or more of the trio of floods in 1877, 1878 and 1879 may well have reached 'major' levels. Unfortunately no measurements of these floods appear to exist though Broughton (1984b) describes these floods in the following terms:

Even at the height of its (Smithfield's) *glory, the seeds of disaster were quickening when, in February 1877, the Police Magistrate in Cairns, Edmund Morey, reported that "the township of Smithfield was, on Wednesday last, all but submerged." The siting of the town on the banks of the Barron had not been a wise choice as was evident in the wet season of 1877, and even more so in 1878 when the wet season ushered in a cyclone - but what was left of any enthusiasm or optimism seemed to have completely disappeared by the wet season of 1879 when a tremendous flood completed the destruction already begun by time and termites.*

In the early 1970s evidence emerged that the lower course of the river was in the process of change. Of particular concern was erosion at the junction of the main channel and Thomatis Creek that indicated that the latter could become the main channel of the river. Erosion on the major loops of the river immediately to the west and east of the airport runway also indicated that the course of the river was in the process of change. These changes led to the Harbours and Marine study of the Barron River delta in 1979-80 and some bank protection work.

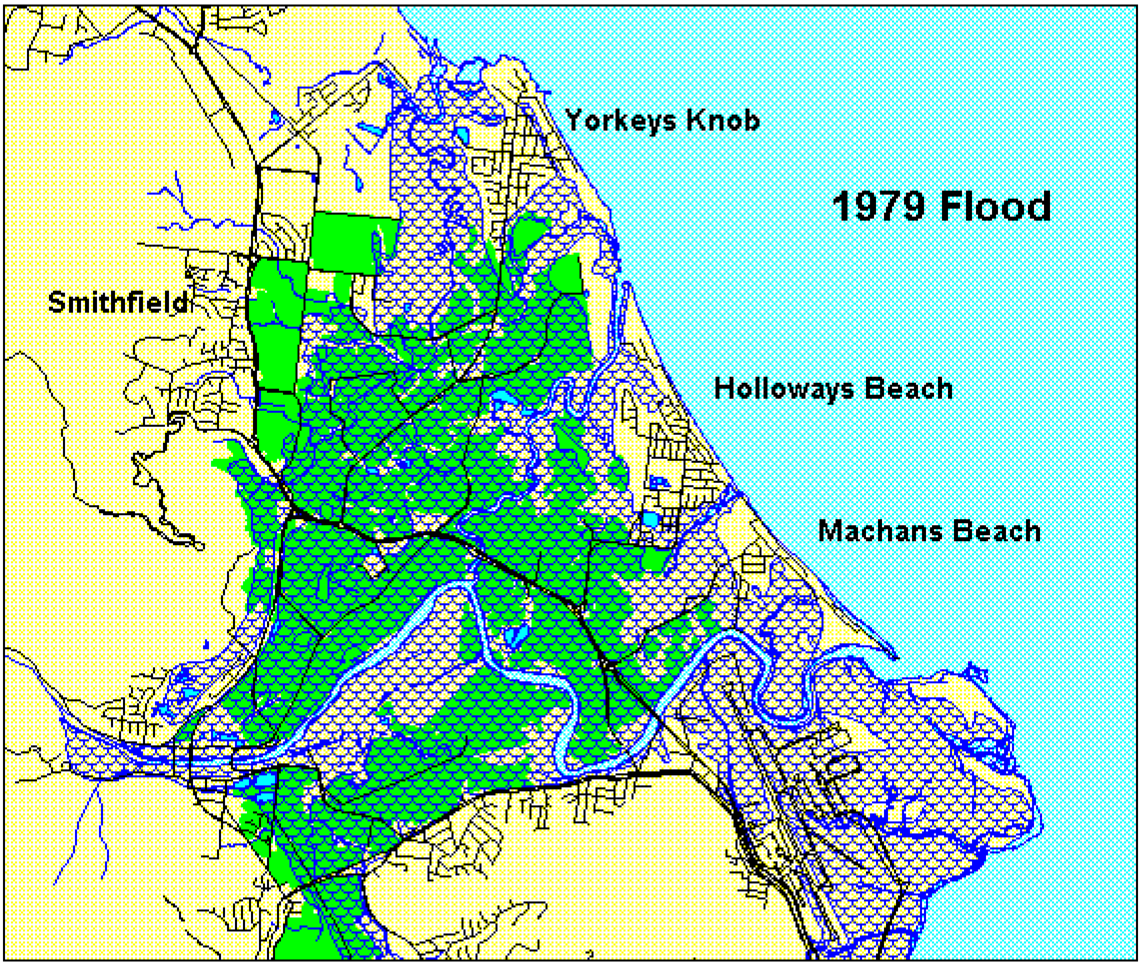

Figure 6.4: Barron River inundation in the flood of January 1979 (after Harbours & Marine, 1981, Figure 4-37)

The Barron River delta has been the subject of several detailed hydrological studies other than the Harbours and Marine study already quoted. In 1981 a study by consultants Cameron McNamara recommended the construction of levees to protect Holloways Beach and Machans Beach. Macdonald Wagner conducted a further study in 1988 for the Cairns Port Authority and the then Mulgrave Shire Council. That study included investigation of the effect on flood levels of cutting a channel across the neck of the loop to the east of the airport and the construction of levees to protect the extensions of the airport's main runway that were about to commence (Macdonald Wagner, 1988). This study was also based on the updated rainfall recurrence values published by the Bureau of Meteorology in 1987. The 1988 flood study was updated in 1994 by Connell Wagner (successor to Macdonald Wagner) and provides the basis for the current Q100 flood model employed by Cairns City Council for planning and regulatory purposes (Connell Wagner, 1994).

Apart from the airport levees, none of these other mitigation works were undertaken. A change in the lower course of the river in a major flood remains a potential threat to the delta suburbs of Holloways Beach and Machans Beach in particular, and Yorkeys Knob to a lesser extent.

Barron River Flood Risk Scenarios

In developing appropriate flood scenarios, the ideal would be to have four-dimensional models (the horizontal extent dimensions, depth over ground level and velocity or discharge rates) for flood events ranging from the 10% AEP (10 year ARI) up to, and including, the probable maximum flood (PMF). PMF is generally taken to have an AEP of between 0.001% and 0.0001% (an ARI of between 100 000 and one million years). Apart from the experience of the more recent historic events that have already been described, the only scenario model that we have available is the so-called 'Q100' model used by Cairns City Council for urban planning purposes. This is the modelled 1% AEP flood. Neither the 1% AEP model, nor the historic record, provides us with sufficient three-dimensional data with which to undertake a detailed risk assessment. They do, however, provide sufficient two-dimensional data to at least provide an indicator of the likely impact.

The two-dimensional data only tells us what land was, or would be, inundated. It tells us nothing about the depth of water at any given point **so we can not identify, with certainty, the buildings that would have water over floor level**, for example, rather than water simply on the property. Likewise we can only identify the road segments and cane fields that would be under water, but not how deep that inundation would be. The lack of velocity information also precludes making estimates of the number or location of buildings that might fail because of the combined effect of water depth and velocity.

Table 6.1 provides the comparative stage height figures for the Myola and Kamerunga gauges. There are difficulties with the Kamerunga data, however, because of the relocation of the gauge. The figures given have been adjusted to the estimated equivalent on the current gauge. It should also be noted that whilst the current Myola gauge is in a slightly different locality to that for which these figures are provided, the relative values remain relevant.

Table 6.1: Barron River gauge height comparisons (Source: BoM, 1999)

GAUGE	MARCH 1967	MARCH 1977	JANUARY 1979	FEBRUARY 1999
Myola	11.12 m	12.29 m	10.42 m	11.4 m
Kamerunga	9.5 m	9.8 m	9.4 m	8.64 m

There is also a significant degree of uncertainty, or at least divergence, in calculations of the recurrence intervals of floods of various magnitudes in the Barron River. The key differences appear to come from the statistical treatment of data from the various Myola gauges and whether the data for the 1911 and 1913 floods are included or not. Based on the discharge, the ARI estimate for the 1977 flood, for example, varies from around 200 years from the 1981 Harbours and Marine study and current modelling by the Department of Natural Resources in Mareeba, to around 40 to 50 years from the 1988 Macdonald Wagner study. **Table 6.2** provides a comparison of AEP estimates.

Because the Connell Wagner figures are those used by Cairns City Council for planning purposes we have chosen to base our analysis on their more conservative estimates. These are shown, with equivalent stage heights and representative historic floods in **Table 6.3**.

The 4% AEP flood scenario: The flood of January 1979 is probably close to a 4% AEP (25 year ARI) flood and has already been described in detail. Were that flood to occur again, some 375 buildings, 35.84 km of roads and 15 800 ha of cane lands would be affected. The distribution of these effects, by suburb, is given in **Table 6.4**.

The northern suburbs would be isolated from the rest of the city because both crossings of the Barron River and extensive lengths of the Captain Cook Highway would be inundated (sections of the Captain Cook Highway can be inundated in a 20% AEP, i.e. 5 year ARI, flood). The suburbs of Holloways Beach, Machans Beach and Yorkeys Knob would be further isolated because their single access roads would also be inundated. Of the 375 buildings that could be affected by flooding, almost 90% would be either houses or blocks of flats. Up to 6 350 people could be isolated for a few days of whom up to 800 may need to be relocated temporarily.

Table 6.2: Comparison of AEP estimates for flood discharge (in cumecs) at Myola

SOURCE	**100%**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.1%**
Harbours & Marine A	81	953	1769	2329	3020	3511	3975		
Harbours & Marine B	91	973	1979	2783	3919	4833	5786	6785	
Connell Wagner					3517	4600	5400	6400	
Natural Resources A	83	852	1602	2139	2626	3332	3826	4305	5379
Natural Resources B	430	972	1511	1969	2686	3332	4088	4972	7647

NOTES:

Harbours & Marine A = recorded floods from 1916 to 1978 only used from Table 4.6 Harbours & Marine (1981)
Harbours & Marine B = as for A plus values for 1911 and 1913 from Table 4.6 Harbours & Marine (1981)
Connell Wagner =
Natural Resources A = annual peaks for all 83 years 1916-1998 (Neile Searle, DNR, personal communication)
Natural Resources B = highest 83 discharges over the period 1916-1998 (Neile Searle, DNR, personal communication)

Table 6.3: AEP for historic flood levels at Myola

AEP (%)	**DISCHARGE** (cumecs)	**STAGE HEIGHT** (m)	**INDICATIVE FLOOD** (year)
100	80	2.0	
50	950	6.4	
20	1820	8.5	1932,1949, 1964, 1968, 1974, 1990
10	2600	10.0	1927, 1934, 1956, 1972
4	3517	11.3	1967, 1979, 1999
2	4600	12.7	1977
1	5400	13.6	
0.5	6400	14.6	1913
0.2-0.1?	7200	15.4	1911

Table 6.4: Indicative impact on Barron River delta suburbs of a 4% AEP flood

SUBURB	**BUILDINGS**	**ROADS** (km)	**CANE LAND** (ha)
Aeroglen	19	0.62	
Barron	8	9.13	6426
Caravonica	80	1.18	138
Freshwater	6	0.97	296
Holloways Beach	90	4.06	1928
Kamerunga	27	4.67	902
Machans Beach	80	3.86	505

Smithfield	6	0.87	1810
Stratford	2		
Yorkeys Knob	36	9.89	4290
TOTALS	371	35.84	15810

Key facilities that could be isolated, if not at risk, would include the FNQEB Kamerunga Bulk Supply Substation, the approach radar for the airport and the sewerage treatment plant at the northern end of the airport.

The 2% AEP flood scenario: The 1977 flood is now considered to be around a 2% AEP (50 year ARI) event. Using the extent of that flood as our model, but excluding the buildings that are now protected by the airport levees, the impact would see 755 buildings, 50.10 km of road and 16 526 ha of cane land affected. It is likely that the numbers of buildings and length of road in Machans Beach could be more than indicated because the construction of the levees to protect the airport in 1988 would increase flood levels in that area by about 120 mm in a flood of this magnitude (Macdonald Wagner, 1988). **Table 6.5** provides the suburban breakdown.

Table 6.5: Indicative impact on Barron River delta suburbs of a 2% AEP flood

SUBURB	**BUILDINGS**	**ROADS** (km)	**CANE LAND** (ha)
Aeroglen	22	0.5	
Barron	8	9.74	6530
Caravonica	297	4.73	191
Freshwater	2	0.97	296
Holloways Beach	209	5.90	1943
Kamerunga	56	5.75	951
Machans Beach	82	3.87	505
Smithfield	16	3.85	1594
Stratford	10	1.34	
Yorkeys Knob	44	10.10	4349
Redlynch	3		167
Trinity Park	17	0.72	
TOTALS	766	50.10	16526

The northern suburbs would be isolated from the rest of the city because both crossings of the Barron River and extensive lengths of the Captain Cook Highway and the alternative Brinsmead-Kamerunga Road route would be flooded. The suburbs of Holloways Beach, Machans Beach and Yorkeys Knob would be further isolated because their single access roads would also be inundated. Of the 755 buildings that could be affected by flooding, 702, or 93% would be either houses or blocks of flats. Up to 6 350 people could be isolated for a few days, of whom up to 2 000 may need to be relocated temporarily.

A flood of this magnitude poses an interesting emergency management challenge - should the population of the beachside suburbs be completely evacuated before the flood reaches its forecast peak or should they be left isolated, but safe, in their homes? The concern is, however, that should the flood become more severe than forecast, the people left isolated on their suburban islands could become overwhelmed, thus posing a far more difficult evacuation problem, with a greatly increased risk of fatalities and material loss.

Key facilities that could be at risk would include the FNQEB Kamerunga Bulk Supply Substation, the approach radar for the airport and both the Aeroglen and Smithfield sewerage treatment plants.

The 1% AEP flood scenario: The modelled 'design' flood used by Cairns City Council and developed by Connell Wagner in 1994 is shown in **Figure 6.5**. A flood of this magnitude would result in about 1 730 buildings, almost 80 km of roads and 17 500 ha of cane lands being affected. The key statistics for each affected suburb are given in **Table 6.6**.

This model indicates that approximately 5.7 km of the Captain Cook Highway would be inundated and Brinsmead-Kamerunga Road, the alternate north-south link, would also be impassable. Extensive sections of the pavement of both roads would probably be destroyed or seriously damaged, delaying their return to trafficability once the floodwaters recede. Such flooding would isolate the city's northern suburbs and towns to the north (Port Douglas, Mossman and beyond) and west (Kuranda, Mareeba and beyond). The impact on cane land would also be significant, with floodwater velocity, scouring and siltation likely to destroy or damage standing cane on as much as 17 500 ha (about 10% of the total area served by the Mulgrave Central Mill).

Table 6.6: Indicative impact on Barron River delta suburbs of a 1% AEP flood

SUBURB	**BUILDINGS**	**ROADS** (km)	**CANE LAND** (ha)
Aeroglen	21	2.65	
Barron	8	9.94	6530
Caravonica	417	6.80	138
Freshwater	8	1.40	6
Holloways Beach	669	17.33	2054
Kamerunga	49	6.22	868
Machans Beach	342	10.15	505
Smithfield	16	4.18	1576
Stratford	36	3.06	
Yorkeys Knob	147	13.00	4681
Redlynch	3		863
Trinity Park	17	0.86	
TOTALS	1733	79.32	17514

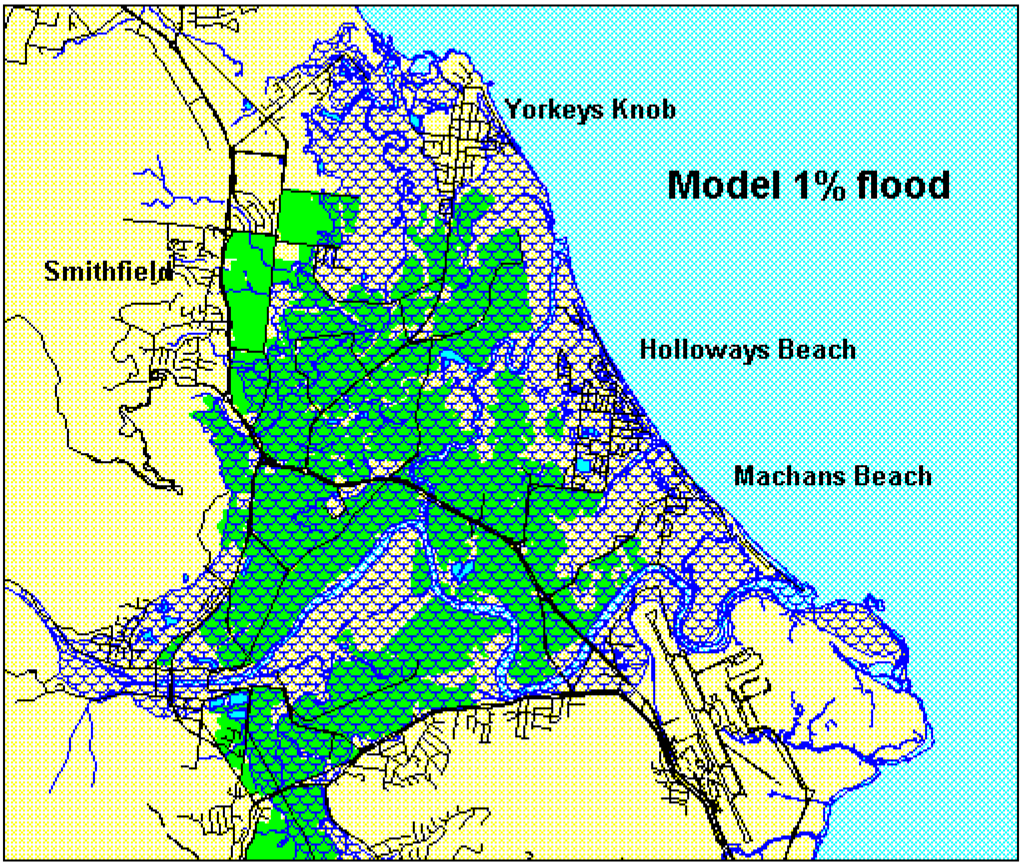

Figure 6.5: Cairns City Council Q100 (1% AEP) flood zone

About 1 640 houses and blocks of flats would be affected. This equates to about 4 600 people overall. Given the isolation and potential threat to the beachside suburbs in particular, a total evacuation of their 6 350 inhabitants, ahead of the flood peak, is probably indicated. There is also an increased likelihood of buildings being destroyed in a flood of this magnitude, especially in low-lying areas of Caravonica and the three beachside suburbs, given the greater depth of inundation and the greater velocity of the flood. This threat could be further increased if, as a result of the flood, the course of the river near its mouth were to change.

Key facilities that would be inundated include the FNQEB Kamerunga Bulk Supply Substation, the approach radar for the airport, the Aeroglen and Smithfield sewerage treatment plants and the Holloways Beach Telephone Exchange. Loss of the major power substation, either by damage or by the cutting of power as a safety procedure, would have widespread impact on all of Cairns. Were the airport levees to be breached or overtopped by this level of flooding, the damage to and dislocation of the Cairns economy would be even more significant. Two state schools (Caravonica and Machans Beach) would also be affected by at least water in the grounds.

The 0.2% AEP to PMF flood scenarios: No estimates of the extent and character of flood events in the 0.2% AEP (ARI of 500 years) to PMF range, such as the 1911 flood, are available to us. There is little doubt, however, that their impact would be substantial, with the likelihood of many buildings being destroyed in the suburbs of Aeroglen (including the airport), Caravonica, Holloways Beach, Machans Beach, Stratford and Yorkeys Knob - at least. As many 3 000 buildings could be at risk, with perhaps 10 000 people directly affected by a PMF-level event in Cairns.

Until hydraulic modelling of these low probability, but high impact, events is undertaken, however, it will not be possible to provide more definitive estimates of flood risk.

The risk coefficient for suburbs exposed to flooding in the Barron River (excluding Freshwater Creek) has been calculated by simply summing the total number of houses, length of road and area of cane land likely to be affected. Given the significant economic impact on the cane industry of serious flooding, the inclusion of cane lands was considered to be relevant in this calculation. The 1% AEP model was used as the reference scenario. **Table 6.7** shows the coefficient value and the risk exposure rank of the suburbs involved, whilst **Figure 6.6** shows the spatial distribution.

Table 6.7: Risk exposure of suburbs to Barron River delta flooding

SUBURB	RANK	COEFFICIENT	SUBURB	RANK	COEFFICIENT
Aeroglen	10	23.65	Machans Beach	6	857.15
Barron	1	6545.94	Redlynch	5	865.00
Caravonica	7	561.80	Smithfield	3	1596.18
Freshwater	11	15.4	Stratford	9	39.06
Holloways Beach	8	274.00	Trinity Park	12	13.86
Kamerunga	4	923.22	Yorkeys Knob	2	4841.00

Freshwater Creek Flood Risk Scenarios

Freshwater Creek, the main tributary of the Barron River below the Gorge, has a catchment of 44 sq km above the Copperlode Falls Dam and 60 sq km below the dam. Whilst it has a history of flooding, the area affected is typically confined to the agricultural land on the floodplain and to low-lying areas and roads in Barron, Brinsmead, Freshwater, Kamerunga, and Redlynch. Communities in these suburbs can be isolated for periods of a day or so during such floods, especially if they coincide with flood peaks in the Barron River itself. Under most flood scenarios involving the whole Barron River catchment, the flood peak in Freshwater Creek is likely to precede the peak in the main channel by several hours.

We are unable to estimate the likely impact of flood in Freshwater Creek in this study because we have not had access to information on the extent of historic flood episodes in Freshwater Creek or modelled floods. Anecdotal evidence, however, suggests that suburban developments in Redlynch at least have a relatively low risk of inundation.

Dam Failure

Community recognition of dam failure as a realistic public safety issue is not widespread in Australia, largely because we have fortunately never suffered a major dam failure disaster like the Buffalo Creek Dam tragedy in West Virginia (USA) in 1972. The failure of that coal sludge dam killed 125 people, injured over 1 000 others and left 4 000 homeless. In the USA, some 9 200 regulated dams have been classified as being ‘high-hazard’. Lin (1998) makes the comment that:

> *If we* (dam engineers) *mandate the design of a dam for a theoretical “spillway design flood”, for instance, then we should not be surprised if the dam fails in a larger flood. If we design a dam without taking into account all the development that later springs up upstream and downstream, then we should not be surprised if regulators later determine the dam is no longer safe for increased runoff and hazards. Management of dam safety is complex business, because of changes in the dam itself, its watershed and downstream conditions.*

There are two significant dams on the Barron River, the Tinaroo Falls Dam and the Copperlode Falls Dam. The failure of either would pose a considerable threat to communities on the Barron River delta and Freshwater Creek.

The Tinaroo Falls Dam is now 40 years old. It is a mass concrete dam operated by the Department of Natural Resources. The spillway capacity of 1 160 cumecs was determined by an empirical maximum rainfall/area relationship in use at the time of design and construction. That capacity is currently equivalent to a 0.5% AEP (200 year ARI) flood. The dam can be safely overtopped provided that its foundations do not erode. Such an event is considered by the Department to be extremely unlikely since the dam is founded on massive granite rock. The Department of Natural Resources has a dam safety program in place which ensures that the dam is under constant surveillance and action plans exist to cope with any emergencies.

A dam failure alert system has been established for Tinaroo Falls Dam. It is designed to provide warning to communities downstream from the wall in the event of a threatened or actual failure. The major concern with such a possibility is for the population of Mareeba given the relatively short warning time that would be possible. Potential inundation extents have been modelled and mapped for the Barron River as far as the Barron Falls and modelling of the likely impact on the delta is being undertaken at the time of writing. Given the massive volume of water released in a short period it is likely that flood levels would be greater than the 1911 and 1913 floods and perhaps close to PMF levels. The scouring of existing creeks on the delta and the possible break out of the flood from the main channel through Thomatis Creek, is a distinct possibility under such a scenario.

Copperlode Falls Dam, which is operated by the Cairns – Mulgrave Water Board, is a rock and earth fill dam that is now 23 years old. The dam has also undergone a safety review which resulted in minor raising so that it can safely withstand PMF-level flooding. A dam break flood study of Copperlode Falls Dam was undertaken in 1991 by Guttridge Haskins and Davey and areas of possible inundation identified, however, details were not available for this study.

Apart from the likely damage to development in the Freshwater valley and the potential break out of the flood through Thomatis Creek, failure of Copperlode Falls Dam would eliminate the main source of water supply for the Cairns community.

Urban Drainage Surcharge

There are some 17 100 properties at risk from the overflow of the urban storm water system between Saltwater Creek and Chinamans Creek, i.e. in the suburbs of Cairns North, City, Bayview Heights, Earlville, Edge Hill, Kanimbla, Manoora, Manunda, Mooroobool, Parramatta Park, Portsmith, Westcourt and Whitfield. This number is several orders of magnitude greater than the number at risk from flood on the Barron River delta. The main risk here is associated with intense rainfall over a relatively short period (say 6 to 12 hours) directly over the urban area.

Rainfall episodes that would give rise to significant urban drainage surcharge have occurred in the Cairns area. For example, on 2 April 1911, 778 mm of rain were recorded at Yarrabah in 24 hours and on 12 January 1951, 760 mm were recorded in the Ellis Beach area in eight hours. Such falls are comparable to those experienced in Townsville in January 1998 and in Wollongong (NSW) in August 1998. Both of those episodes caused widespread urban drainage inundation and many landslides, including a large and potentially lethal debris flow on Magnetic Island off Townsville. In Cairns, storm water inundation on the coastal plain will be exacerbated by high tides. Very few of the storm water outlets that discharge into the Inlet have one-way tide valves.

Cairns City Council has recently had modelling of this problem undertaken, however, the results have not been available to this study.

Interpretation

Whilst flooding causes inconvenience and some dislocation in Cairns on average about once every 12 years, it poses a relatively limited threat to urban areas and people because urban development has largely been excluded from the most flood-prone areas of the Barron River delta. The loss of sugar cane and damage to roads and other infrastructure on the delta, however, carries with it a significant economic loss. The most significant inconvenience caused by Barron River flooding is the isolation of the northern beachside suburbs from downtown Cairns, with its critical facilities such as hospitals and airport.

The flood warning system for the Barron River operated by the Bureau of Meteorology is very effective and provides residents in flood-prone areas with adequate time to prepare for flood and/or to evacuate if that is indicated. The Bureau of Meteorology hydrologists who are responsible for the ALERT system point out, however, that the behaviour of floods in the lower Barron River is close to that of a 'flash flood' and that only six to nine hours warning can be given. Such a level of warning was sufficient to safely evacuate around 2 000 people from the Lake Placid area of Caravonica as a result of the flooding brought on by Cyclone *Rona* in February 1999.

Flash flooding in the other catchments, especially the streams that flow into Trinity Inlet, is a potentially significant problem. Not only are there significantly more properties exposed to urban drainage surcharge, the risk to life is significant because of its rapid onset the propensity for careless or foolish behaviour by some people in and around floodwaters.

Limitations and Uncertainties

The absence or unavailability of key information significantly limits the assessment of flood risk in Cairns provided here. Many of these shortcomings have been recognised by Cairns City Council and others. Work is already under way to model urban drainage surcharge risks in the low-lying areas of the city and work has commenced on modelling the potential impact of dam failure on the delta, especially for Tinaroo Falls Dam.

Perhaps the most significant limitation, however, is the lack of flood depth data associated with records of historic flood events and with the modelled 1% AEP flood. The lack of these data precludes the assessment of the magnitude of over-floor flooding. Such data is essential input to models of building loss and contents damage, as well as models of road network dislocation.

Further research, probably of an economic nature, is required to determine the relative significance of buildings, roads and cane lands in establishing the risk coefficient for each suburb on the Barron River delta. The approach used here of simply summing the values for each element assumes an the loss for one house is equal to the loss for one hectare of cane land and one kilometre of road. Whilst this is clearly a dubious assumption, we are reasonably confident that the coefficients used (regardless of their absolute quantum) produce a reasonably accurate relative ranking of each suburb's flood risk.

CHAPTER 7: CYCLONE RISKS

The Cyclone Threat

There is little doubt that tropical cyclones pose the greatest natural threat overall to Cairns. Since the settlement was founded in 1876 there have been at least 53 cyclones that have had a reported or measured impact on the city, indeed the cyclone of 8 March 1878 almost destroyed the settlement before it had a chance to get established. An inventory of those cyclones, based largely on an historical listing compiled from many sources by the Bureau of Meteorology's Queensland Regional Office in Brisbane, is included in **Appendix J**.

Of the 53 cyclones included in **Appendix J**, 22 have either crossed, or approached, the coast within 75 km of Cairns. A further 14 cyclones have approached to between 75 and 150 km of the city. An approach to within 75 km would bring Cairns within the radius of destructive winds of most cyclones.

This reality is in marked contrast to the view held in some quarters in Cairns that the city does not have a significant cyclone threat. A good example of this urban myth was provided in a letter to the Editor of the *Cairns Post* on 14 May 1998, in which the author opined:

> *After 120 years of records and 11 cyclones, we have never had a higher than normal tide, let alone a storm surge. Even the severe cyclone of 1986 which crossed the coast south of Innisfail with winds of up to 250-plus km/h, did not cause a surge or even a high tide.*
>
> ***The reef being so close to the coast will always act as a damper, and the mountains around Cairns always keep the winds to a maximum of 190 km/h.*** *Check the records!*
>
> (our emphasis)

There are three components of a cyclone that combine to make up the total hazard - strong winds, intense rainfall and oceanographic effects including high energy waves, strong currents and storm tide - though their destructive force is usually expressed in terms of the strongest wind gusts experienced. Maximum wind gust is loosely related to the central pressure of the system.

The Bureau of Meteorology uses the five-category system shown in **Table 7.1** for cyclones in Australia. Severe cyclones are those of Category 3 and above.

Table 7.1: Australian tropical cyclone category scale

Category	Maximum Wind Gust (km/hr)	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** (Landslide Risks) and **Chapter 6** (Flood Risks).

The Cairns Cyclone Experience

The cyclone season in Cairns extends from December to April, with the greatest numbers being spread across January, February and March. **Figure 7.1** shows that January and March are the months in which, historically, more of the close cyclones occur; February and March have more of the mid-distance cyclones; and February has more of the distant cyclones.

Of the 53 cyclones that have had some effect on Cairns, at least eleven have done substantial damage or caused significant dislocation, though it is difficult to make direct comparisons of damage done between individual cyclones because the settlement (and buildings) on which they had their impact has changed greatly over time. The eleven most notable cyclones are:

- 8 March 1878 - at least a Category 3 storm which almost wiped out the settlement and sank four ships in Trinity Inlet with the loss of all hands;
- 28 January 1910 - a Category 2 or 3 storm that caused much building damage and produced a storm tide of at least 0.7 m above high tide level;
- 31 January 1913 - probably a Category 3 storm which destroyed many buildings, sank at leat one ship, severely damaged the sea wall and produced the second greatest flood in the Barron River on record;
- 10 March 1918 – at least a Category 4 storm crossed the coast at Innisfail and widespread wind damage was done in Cairns and Babinda;
- 3 February 1920 - probably a Category 3 storm and possibly the worst cyclone impact to date. This cyclone destroyed many buildings and produced a storm tide that inundated the town to a level of about 1 metre above high tide level in spite of crossing the coast near Cape Tribulation, about 75 km to the north;
- 9 February 1927 - probably a Category 3 storm crossed the coast within 50 km of Cairns and produced substantial damage to buildings, including at least 16 buildings destroyed;
- 12 March 1934 - a Category 3 storm, that also crossed the coast near Cape Tribulation, caused substantial building damage in Cairns. At least 75 people perished at sea in the Cairns area;
- 1 February 1986 - Cyclone *Winifred* (Category 3) crossed the coast near Innisfail but caused heavy building damage and many trees to be uprooted from winds which gusted to around 120 km/hr from the west and south-west;
- 22-25 December 1990 - Cyclone *Joy* (Category 4) approached to within 120 km to the east of Cairns and produced wind gusts of up to 180 km/hr on Green Island causing building damage and bringing down many trees;
- 22 March 1997 - Cyclone *Justin* (Category 2) crossed the coast at Yorkeys Knob and produced light damage to buildings but caused the power supply to be out for about 36 hours and produced minor flooding, many small landslides and minor sea water inundation in coastal areas; and,
- 11 February 1999 – Cyclone *Rona* (Category 3) crossed the coast near Cape Tribulation and produced light wind damage but created major flooding in the Barron River and many small landslides.

The Cyclone Phenomenon

The definition of tropical cyclone offered by the Bureau of Meteorology (BoM, 1992) is:

Tropical cyclones *are low pressure systems in the tropics which, in the southern hemisphere, have well-defined clockwise wind circulations with mean surface winds (averaged over ten minutes) exceeding gale force (63 km/hr) surrounding the centre. Short period* ***wind gusts*** *are often 50 per cent or more above the mean wind speed.*

Severe tropical cyclones *(referred to as hurricanes or typhoons in other countries) have surface wind speeds in excess of 120 km/hr surrounding the centre. These are potentially the most dangerous of all meteorological phenomena.*

For a tropical cyclone to form, the sea surface temperature needs to be above 26^{o} C (to provide its energy) and the precursor low pressure system to be more than 5^{o} of latitude from the Equator so that the Coriolis effect of the earth's rotation is sufficient to cause it to spin up. Once formed, cyclones then tend to move polewards. 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. History indicates that Cairns is around 40% less likely to be hit by a coast crossing cyclone of given intensity than is Mackay (see Harper, 1998), largely because the islands of Papua New Guinea to the north-east, occupy the area in which the cyclones that would theoretically have the greatest impact on Cairns, would form. This 'plus' is, however, offset by the cyclones which form in the shallow Gulf of Carpentaria and cross Cape York to impact directly on Cairns or to re-form in the Coral Sea in the vicinity of Cairns.

It is worth keeping in mind, however, that, of the two most intense and damaging cyclones ever recorded on the Queensland coast, one (Cyclone *Mahina*, March 1899) crossed the coast from the Coral Sea at Bathurst Bay, about 300 km **north** of Cairns, whilst the second (Innisfail, March 1918) crossed the coast only 70 km to the south of Cairns. *Mahina* was a Category 5 storm (central pressure of 914 hPa) and the Innisfail cyclone was either a very high Category 4 or Category 5 (central pressure approximately 928 hPa). Both cyclones caused great loss of life and were accompanied by substantial (up to 14 m in the case of *Mahina*) storm surge. Cyclone *Mahina* remains the most lethal natural hazard impact in Australia's history, with at least 307 dead on vessels sheltering in Bathurst Bay and as many as 100 people (mostly Aboriginals) killed on the land.

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 atmospheric pressure is lowest. It is typically 20 to 50 km in diameter, skies are often clear and winds are light. The eye wall is an area of cumulonimbus clouds which swirls around the eye. Recent studies suggest that anomalously high and extreme winds can occur in the vicinity of the eye wall due to instabilities as the cyclone makes landfall. The heaviest rainfall and the strongest winds are associated with the eye wall. Tornado-like vortices of extreme winds can also be associated with the eye wall instability and in the outer rain bands. The rain bands, from which heavy convective rains can fall, spiral inwards towards the eye and can extend over 1 000 km in diameter.

Severe Wind Risks

A detailed assessment of risks posed by strong cyclonic winds to residential structures is the subject of a study being undertaken by the Cyclone Testing Station at James Cook University in Townsville under a project sponsored by the Queensland Department of Emergency Services. Until the results of that detailed study become available, a number of observations can be made. The comments here are based on research results reported to various conferences and workshops run under the TCCIP, and by the University of Queensland or by James Cook University since 1994, and the community's experience of the impact of Cyclone *Justin* on Cairns in 1997.

Most of the loss created by tropical cyclones globally comes from the damage 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 is propelled, frequently with great force, by the wind.

Wind damage tends to increase over-proportionally to the wind speed. For example, winds of 70 m/sec (250 km/hr) cause, on average, 70 times the damage of winds of 35 m/sec (125 km/hr) (Meyer, 1997). Damage tends to start where sustained wind speeds begin to exceed 20 m/sec (about 75 km/hr). 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 Whitfield. This problem of turbulence and wind speed-up caused by the terrain effect was dramatically demonstrated in Cyclone *Agnes* in 1951 and again in Cyclone *Winifred* in 1986 where the winds were from the inland, rather than the seaward side. Buildings and trees closest to the hill slopes are said to have suffered the worst damage.

Buildings: The construction, design, age and location of buildings each have an influence on their risk of damage. Metal roofs are more susceptible to wind damage than are tile roofs, though the latter is more susceptible to damage by wind-driven debris; brick and concrete block walls are resilient, however, 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. These were key features addressed by the wind loading aspects of the Building Code (AS 1170.2-1989 *Wind loads*) introduced in 1975 and upgraded for domestic structures in 1989 and 1992.

Some of the key forces on buildings are illustrated in **Figure 7.2** and **Figure 7.3**. These are based on Meyer (op cit, p18). The first figure shows the way in which the suction forces generated on low pitched roofs are countered by the reduced pressure inside the building where the integrity of the walls and windows are maintained. The second figure shows how an overpressure inside the building is created when that integrity is compromised by a window being broken. The additional force can destroy the roof, if not the whole structure.

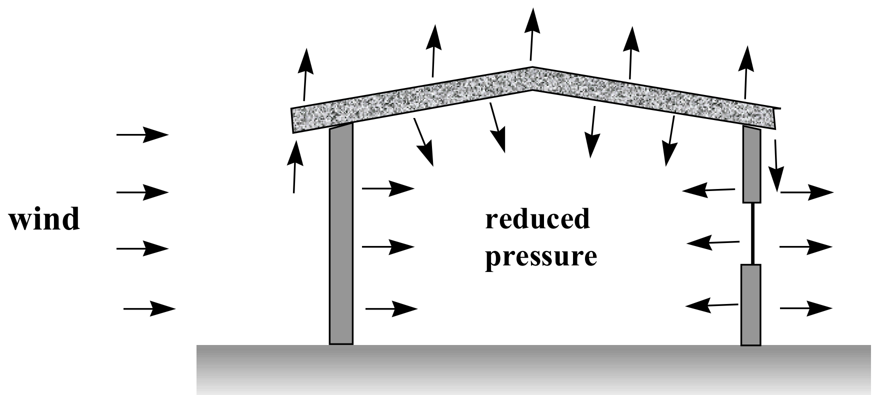

Figure 7.2: Wind forces working on a building with external integrity

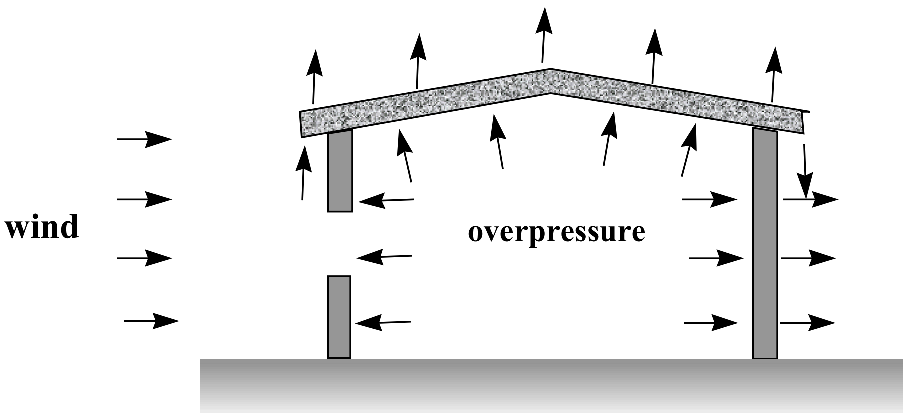

Figure 7.3: Wind forces working on a building where its external integrity is lost

The Building Code also takes account of the site on which the building stands. Buildings on ridge crests, for example, are more exposed than are buildings on flat ground, especially where they are grouped in a suburban situation.

Building age is not only significant because it denotes the degree of conformance to the Building Code, it also can be used to assess the level of exposure to metal fatigue experienced by the roof. Mahendran (1995) reported that exposure of metal roofs to strong cyclonic winds, such as those experienced in 1986 with Cyclone *Winifred* and in 1990 with Cyclone *Joy*, sets up fatigue around the fastening screws. Roofs in which fatigue has been established and exacerbated by further events may subsequently fail in winds significantly lighter than those that they were designed to withstand.

In the absence of more rigorous modelling we have employed an obviously simplistic approach to establish a measure of the severe wind exposure of suburbs. A wind 'risk coefficient' has been calculated based on the following values:

- the number of gable ended buildings built before 1985 and located on slopes of more than 3^o in each suburb weighted by a factor of 5;
- the number of hip ended buildings built before 1985 and located on slopes of more than 3^o in each suburb weighted by a factor of 4;
- the number of gable ended buildings built before 1985 and located on slopes of 3^o or less in each suburb weighted by a factor of 3;
- the number of hip ended buildings built before 1985 and located on slopes of 3^o or less in each suburb weighted by a factor of 3;
- the number of buildings constructed since 1985 and located on slopes of more than 3^o in each suburb unweighted; and,
- the number of buildings constructed since 1985 and located on slopes of 3^o or less in each suburb weighted by 0.8.

The results are summarised in **Table 7.2** and the spatial distribution is shown in **Figure 7.4**.

Lifelines and other assets: With Category 2 Cyclone *Justin* in March 1997, the greatest amount of inconvenience was caused by damage to the power reticulation infrastructure. Power lines were brought down, mainly by tree branches, palm fronds and other wind-blown debris. The loss of power for around 36 hours led to the failure of the water supply and sewerage systems. These outages, however, posed little in the way of economic, health or social risks. Since the impact of Cyclone *Justin,* FNQEB have undertaken a major tree management program in an effort to reduce the risk of power dislocation in future cyclones. Those efforts proved useful as a protection in Category 2 Cyclone *Rona*, however, they may be of limited value in severe cyclones where whole trees are likely to be uprooted rather than having the odd branch broken off.

Table 7.2: Severe wind risk exposure ranking for Cairns suburbs

Suburb	Risk coefficient	Risk rank	Suburb	Risk coefficient	Risk rank
Bayview Heights	3316	1	Stratford	925	22
Whitfield	3173	2	Clifton Beach	920	23
Mooroobool	3120	3	Smithfield	877	24
Westcourt	3029	4	Yarrabah	867	25
Edge Hill	2937	5	Redlynch	864	26
Manunda	2615	6	Mount Sheridan	839	27
Earlville	2486	7	Kewarra Beach	782	28
Woree	2306	8	Trinity Park	617	29
Manoora	2002	9	Palm Cove	527	30
Trinity Beach	1881	10	Portsmith	473	31
Parramatta Park	1665	11	Caravonica	454	32
Holloways Beach	1662	12	Aeroglen	306	33
Yorkeys Knob	1536	13	Kamerunga	275	34
Cairns North	1347	14	Kanimbla	257	35
Edmonton	1243	15	City	224	36
Machans Beach	1070	16	Trinity East	150	37
Bentley Park	1058	17	Barron		38
Gordonvale	1004	18	Kamma		38
Freshwater	946	19	Mount Peter		38
White Rock	936	20	Wright's Creek		38
Brinsmead	932	21			

Tree-fall also represents a significant threat to buildings and other 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. The disposal of debris produced by wind damage to trees in cyclones inevitably presents 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 antenna by the wind will disrupt the networks that they support. In the stronger winds, the large transmission or relay towers may even be brought down.

The substantial commercial and pleasure boat fleets in Cairns are also at risk in strong winds and waves. During Cyclone *Justin*, for example, part of the marina that serves the tourist industry at the entrance to Trinity Inlet was destroyed by high seas whipped up by the strong winds. Damage amounted to around $2 million. No boats were lost, however, because the majority took shelter in the various emergency cyclone shelter areas in the many creeks that lead off the Inlet that have been designated and publicised by the Cairns Port Authority. These locations are shown in **Figure 7.5**.

Strong winds also carry salt spray from the surf they whip up 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.

Cairns has come within the radius of destructive winds of cyclones at least 21 times since 1876, giving an ARI for destructive winds of around 5 years. Since wind load provisions were introduced into the Australian Building Code in 1975, wind damage to buildings in Cairns has been relatively light. Whilst that is encouraging, it should be noted that none of the 10 cyclones that have had an impact on Cairns since 1975 brought winds that approach the design levels in the Code.

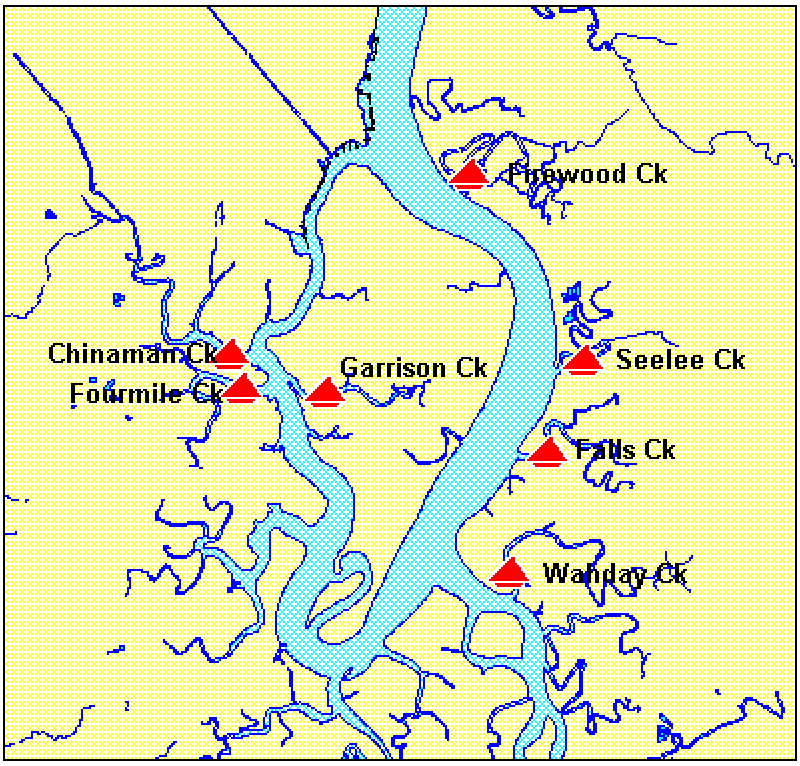

Figure 7.5: Cairns emergency boat shelters

The Storm Tide Phenomenon

A *storm tide* is created by the *storm surge*, which is generated by the cyclone, adding to the normal sea level produced by the *astronomical tide*. The storm surge is a raised dome of water, some 50 or more kilometres in diameter, and up to several metres in height at its peak. It is a massive movement of sea water, rather than a single travelling wave, as with a tsunami. Its effect of raising the sea above the level of the normal tidal movement lasts for several hours.

The height (amplitude) of the storm surge depends on a range of factors. The central pressure, wind profile, the radius of maximum winds and the forward speed of the storm combine to produce the surge in open water. As it approaches the shore, the natural slope of the sea bed (bathymetry) and the general shape of the coastline also have an influence. The height of the storm tide is then influenced by:

- the time that the cyclone eye crosses the coast (to provide the state of the astronomical tide);
- the location of the crossing relative to the community at risk; and,
- the angle of the cyclone track in relation to the coast and local coastal topography.

The location of crossing is important given that the maximum surge height on the Queensland coast is in the south-west quadrant of the cyclone in the band of maximum onshore winds (i.e. in the eye wall). A cyclone crossing the coast 25 to 50 km to the north of Cairns, 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 will typically experience a reduced sea level.

Whilst the Great Barrier Reef in the Cairns area will retard the passage of the largest swells and waves, it is not an unbroken or absolute barrier. The opening of Trinity Passage, for example, is wide enough to permit large seas to penetrate, and may, under some circumstances, actually amplify them. Because Trinity Inlet is funnel-shaped and open to the north-east, it will tend to concentrate and magnify the surge effect of cyclones approaching from any direction in the north to east quadrant.

The contribution of the storm surge to overall storm tide height will be determined by the height of the astronomical tide at the time the cyclone crosses the coast. A surge arriving at dead low tide will have far less impact than it would if it reached the coast on top of the highest summer king tide. It has become standard practice amongst emergency managers to relate storm tide inundation levels to the Highest Astronomical Tide (HAT). In Cairns, HAT is approximately 1.78 m above mean sea level (or the Australian Height Datum - AHD). A storm surge of 3 m, therefore, would be largely absorbed by the tidal range were it to arrive at dead low tide, but would inundate land up to 3 m above the highest tide level if it coincided with the HAT. Such inundation declines as the astronomical tide falls. Storm tide inundation would, therefore, tend to last for not more than six hours.

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 7.6** is an example of a 'still water' storm tide hazard map of Cairns. It shows zones in increments of one metre above HAT, the current Queensland standard.

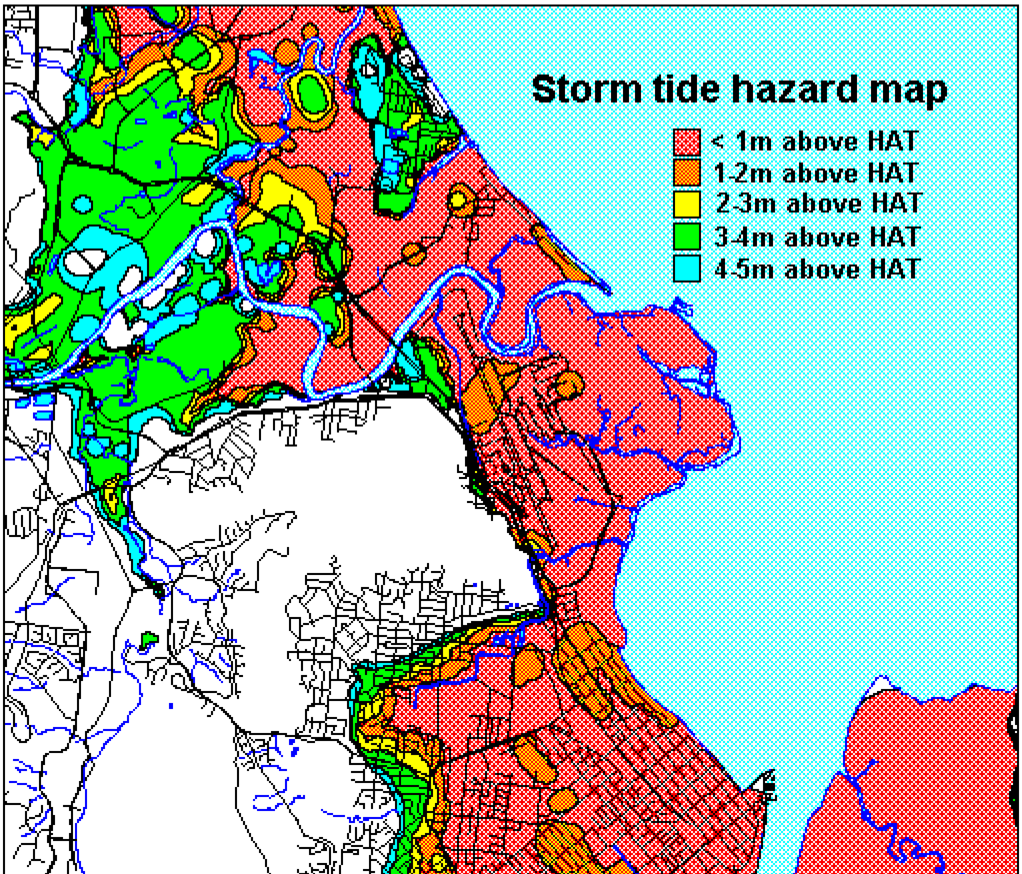

Figure 7.6: Cairns storm tide hazard zonation map

Inundation by storm tide lasts from only a few hours to around six or eight hours and largely subsides with the next low tide. The outward run of this water, however, will have its own velocity derived from the drop in elevation of the sea by as much as 3 m. This 'back wash' is often associated with scouring around structures and the mobilisation of large volumes of debris.

Vulnerability to Storm Tide

The 'still water' model does not take account of any wave setup or wave runup. Wind-generated waves of several metres in height can be anticipated with cyclones. These are on top of the surge. As waves enter the shallow waters of the coast, where their amplitude becomes limited by the sea bed, they will build in height to substantial levels. The combination of wave setup height and wave power (a combination of mass and velocity) can have a massive impact on the shore line and any structure that is exposed to those forces. Sea wave height and power, however, decay rapidly as the wave moves inland. Smith and Greenaway (1994), for example, provide a curve (their Figure 3.7) 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 (and, by inference, the height) of sea waves, based on a wind speed of 130 km/hr, 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 will be present in all areas inundated by the storm tide. These waves can attain heights of about half as much again as the still water depth. Whilst they are likely to increase inundation levels, they will probably not add significantly to the destructive force of the storm tide. They will also slightly extend the area inundated, beyond the simple 'still water' contour level, because of wave runup.

Inundation depth is important, not only because of the damage caused by emersion, but also because of the stress placed on structures by moving water. Smith and Greenaway (*op cit*, p38) make the assumption that 'if the combination of still-water and wave height exceeded floor level by 1.0 m building failure will occur.' In the USA, the Federal Emergency Management Agency (FEMA) have adopted one metre 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, though it is likely that structures engineered to withstand the high levels of lateral loads typical of those established in the wind or earthquake components of the Building Code, 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 concrete block buildings, for example. The experience in the USA, however, indicates that substantial engineered buildings are not immune to total destruction from storm tide, especially if they are located in the '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 one metre over floor level 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 Cairns.

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

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

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

Storm Tide Risk Scenarios

There is some debate in the literature about the height/recurrence relationship for storm tide in Cairns. The storm tide (above AHD) height annual exceedence probabilities cited in Appendix 2 in Harper (1998), which are based on published estimates by other authors, are compared with those presented by McInnes, Walsh and Pittock (1999) in **Table 7.3** to illustrate the degree of variation that exists. The difference between the northern beach suburbs and the city area are explained in terms of off shore bathymetry rather than the domed shape of the storm surge.

Cairns City Council base their planning constrains for storm tide on values developed by James Cook University (G. Underwood, Cairns City Council, personal communication). These are essentially the same as those of McInnes, Walsh and Pittock. We have adopted the values employed by Cairns City Council for our modelling.

Table 7.3: 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
Northern Beaches[1]	1.9 m	2.0 m	2.7 m	3.0 m	4.0 m
City[2]	2.2 m	2.5 m	3.2 m	3.5 m	4.5 m
Cairns general[3]	1.76 m	2.15 m	3.39 m	3.75 m	n/a

NOTES:

1. Based on Mason and others (1992) as cited by Harper (1998)
2. Based on Hardey and others (1987) as cited by Harper (1998)
3. From McInnes, Walsh and Pittock (1999)

Wave action on top of the storm surge adds to the overall height to which the sea level is raised under severe cyclone conditions. This is termed 'wave setup' and has been defined by Harper (1998) as:

> *a quasi-steady super-elevation of the water surface due to the onshore mass transport of water caused entirely by the action of breaking waves.*

The storm tide estimates given in **Table 7.3** do not include an allowance for wave setup. Harper suggests that for Cairns an additional 0.5 m be allowed in all scenarios. The wave setup addition is sustained inland for a considerable distance and should be added to the storm tide height (M. Allen, Coastal Management Branch, personal communication).

In the surf zone itself, the height of breaking waves is a further addition. The depth of water limits the height of waves in this zone to the extent that they can attain an average height of around half of the combined depth of the storm tide and wave setup over the shore. The power of these sea waves dissipates rapidly, however, as they move inland.

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, 1 000 and 10 000 years respectively), the 'still water' inundation values adopted by Cairns City Council were used. The modelling is aimed at identifying the buildings that would be inundated to more than 1 m over floor; over the floor but less than 1 m in depth; water on the property but not over floor level, and properties that would be free of inundation. To take account of the wave setup, sea wave power and wind driven shallow water wave components, the following adjustments were made:

- the wave setup allowance of 0.5 m recommended by Harper was added to the storm tide height in all cases;
- sea wave height calculated as the mean depth of inundation over the land surface was discounted by 20% in the first 150 m from the shore; 60% in the second 150 m; 80% in the third 150 m; and 100% for the remainder;
- an allowance of around 30% of the mean depth of over ground level inundation is made for shallow water wind waves in the calculation of over-floor inundation; and,
- buildings with more than 1 m of water over floor were further identified according to their relative risk of destruction based on their distance from the shoreline (HIGH for those within 750 m of the shore; MEDIUM between 750 and 1 500 m from the shore; LOW more than 1 500 m from the shore).

Similar critical levels of inundation have also been set for roads. Roads with more than 0.5 m of water over the pavement are considered impassable to all vehicles; vehicles with high clearance, such as trucks, busses and four wheel drives, could negotiate roads inundated to levels up to 0.5 m; sedans would only be able to negotiate roads with less than 0.25 m of water over the pavement.

No adjustment has been made to reflect the way in which the height of the storm surge declines away from its peak. We are confident that this characteristic can be taken into account in modelling an actual event in an operational environment, especially with the benefit of the Bureau of Meteorology's MEOW data. We have not included the dome effect here, however, because the objective of our scenario analysis is to produce a generic assessment of storm tide exposure across the area of study.

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 D**. Floor heights were estimated in the field for most buildings and are, in at least 90% of observed cases, accurate to within 0.25 metre. Where buildings were not observed in the field, a default value of 0.3 metre (i.e. slab-on-ground construction) was used.

Ground height for each building was interpolated in the GIS from the digital elevation model (DEM) developed by Andre Zerger (as part of his PhD research at the ANU). Given the topographic mapping sources used for this elevation model, inherent uncertainties exist for those interpolated elevation data. Zerger (1998) reports that in the elevation range from 2.5 to 5.0 m above AHD, 90% of elevation values in the DEM are accurate to within 0.75 m; and in the range 5.0 to 10.0 m above AHD, 90% of DEM elevation values are within 1.0 m of true elevation.

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. In the original source, 90% of values of less than 5.0 m above AHD were accurate to within 1.25 m and for the values 5.0 to 10.0 m above AHD zone, 90% were accurate to within 2.5 m.

There are also uncertainties associated with the inundation models used. For example, the uniform 0.5 m wave setup value suggested by Harper, and recommended by Department of Environment coastal engineers, is sensitive to cyclone characteristics such as track and velocity. Similarly, the sea wave height decay values used have been based largely on the velocity decay curve provided by Smith and Greenaway (1994) but lack empirical calibration. A sampling of authorities, however, suggests that they are at least intuitively reasonable.

These uncertainties, however, 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) figures probably makes little overall difference to the final assessment. Certainly the results reported here are conservative but look both realistic and logical.

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

- inundation over ground level only: $Gd\_ht < std + 0.5 + (w \times v\_zone)$
- inundation over floor level: $Fl\_ht + Gd\_ht < std + 0.5 + sww + (w \times v\_zone)$
- inundation > 1.0 m over floor level: $Fl\_ht + 1 + Gd\_ht < std + 0.5 + sww + (w \times v\_zone)$

where:

Gd_ht is the height of the ground above AHD;
Fl_ht is the height of the building floor above ground level;
sww is the height allowance for shallow water wind waves calculated as 30% of the mean depth of over-ground inundation;
w is the allowance for sea wave height in the surf zone equivalent to the mean depth of over-ground inundation;
v_zone is the percentage of sea wave height (*w*) allocated in each of the first three 150 metre-wide zones from the shoreline (80% in the first, 40% in the second, 20% in the third);
std is the storm tide height adopted for the specified scenario AEP;
0.5 is the wave setup value.

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.

Similar models have also used to identify the road segments and cane fields at risk in the various scenarios. These 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 with substantial rainfall. Even if peak rainfall were to coincide with cyclone landfall, it would typically take at least 12 hours for that rainfall to produce flooding on the Barron River delta. This assumption is consistent with the engineering flood models of the Barron River undertaken for the former Mulgrave Shire Council and the Cairns Port Authority in 1988 (Macdonald Wagner, 1988).

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

The 2% AEP scenario: In a ‘worst case’ scenario, a storm tide of 1.76 m above AHD (essentially the same as HAT), but excluding wave setup, could be produced by a cyclone crossing the coast say 25 km north of Cairns at, or close to, a very high tide and bringing with it a storm surge of as little as 0.3 or 0.4 m. There have been at least 15 occasions in the past 110 years that storm surges of this or greater levels have been either reported or measured on the Cairns tide gauge. Category 2 cyclones *Justin* in 1997 and *Rona* in 1999, for example, both produced a storm surge of around 0.6 m at Cairns (*Rona* produced a surge measured at 1.6 m at Mossman) but both crossed the coast close to low tide. Such levels of storm tide inundation have been experienced on at least two occasions - with the 31 January 1913 cyclone and the 12 March 1934 cyclone.

By applying our storm tide risk model for inundation to 1.76 m above AHD, a 0.5 m wave setup figure and no allowance for breaking sea wave some 1 860 buildings could be affected as follows (rounded numbers):

- fewer than 10 buildings are likely to have more than 1 m of water over floor level. These are all in low lying areas close to drainage channels such as Saltwater Creek (Cairns North) and Moon River (Yorkeys Knob), or close to the Inlet in Portsmith and have floors at ground level;
- up to 870 buildings could have water over floor level to a depth of less than 1 m. Many of these are in City and Portsmith, but a significant number are in the low lying areas of Manunda, Parramatta Park and Westcourt that are drained by the Fearnley Street storm water channel, Chinamans Creek and Saltwater Creek;
- up to 1 400 buildings could have water on the property, but not over floor level. Most of these are in Machans Beach, Manunda, Parramatta Park, Portsmith and Westcourt;
- the remaining 32 800 or so buildings would be free of inundation;
- around 70 km of road could have 0.5 m or more of water over the pavement at the height of storm tide impact;

- a further 15 km of road could have more than 0.25 but less than 0.5 m of water over the pavement; and
- almost 30 km of road could have up to 0.25 m of water over the pavement;
- up to 8 500 ha of cane fields could have sea water above ground level.

Overall, the impact of a 2% AEP (ARI of 50 years) storm tide event would not cause significant loss, though short-term dislocation could be significant. The greatest impact will be felt in City, Machans Beach, Manunda and Portsmith. At least twelve critical facilities could be affected by over-floor inundation. They include Calvary Hospital, Boral Gas, two of the four fuel depots and two of five cold stores. These are detailed in **Table K1** (**Appendix K**). Many of the other critical facilities in Portsmith and City, including the Cairns Hospital, would be isolated for a few hours because of water over the roads. **Figure 7.7** shows the buildings that would be affected by a 2% AEP storm tide scenario and **Figure 7.8** provides a larger scale view of the central Cairns area. **Table K2** provides the key statistics for each of the suburbs affected.

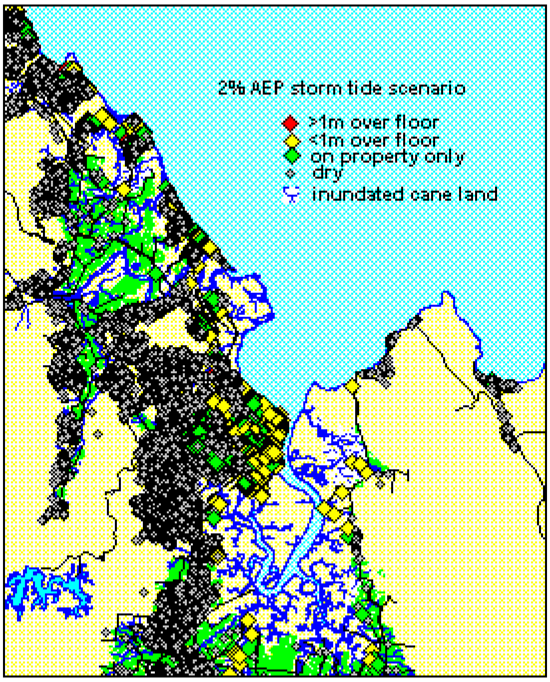

Figure 7.7 Modelled impact of a 2% AEP storm tide scenario

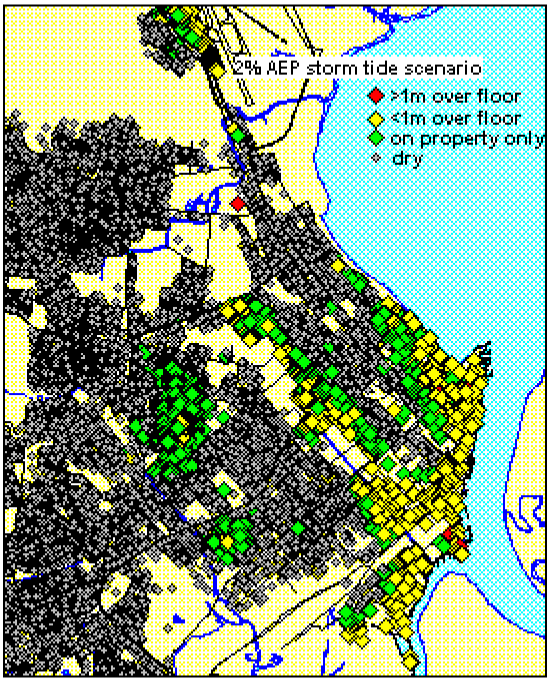

Figure 7.8: Modelled impact of a2% AEP storm tide (detail)

The 1% AEP scenario: The minimum storm surge required to create a storm tide of 2.15 m above AHD (0.4 m above HAT) would be around 1 m arriving at or close to a very high tide. The cyclone of 3 February 1920 produced a storm tide close to this level in Cairns, though closer to the eye (around Port Douglas) the storm tide height was significantly greater.

By applying our model for a storm tide of 2.15 m above AHD, a 0.5 m wave setup figure, a depth-limited wind wave height of 0.1 m and a breaking sea wave height of 0.4 m around 7 150 buildings could be affected as follows (figures rounded):

- up to 325 buildings could have more than 1 m of water over floor level - of these 240 are within the first 750 m of the shore line and would be at significant risk of being severely damaged, if not destroyed; 45 are in the second 750 m and would have a moderate risk of destruction; and around 40 are more than 1 500 m from the shore and would have a relatively low risk of being destroyed, though they would obviously suffer substantial structural and contents damage;

- up to 2 240 buildings could have water over floor level of less than 1 m;
- up to 5 100 buildings could have water on the property, but not over the floor;
- the remaining 27 000 buildings would be free of inundation;
- up to 100 km of road could have 0.5 m or more of water over the pavement at the height of the storm tide impact;
- a further 60 km of road could have more than 0.25 but less than 0.5 m of water over the pavement; and
- about 90 km of road could have up to 0.25 m of water over the pavement;
- as many as 13 100 ha of cane fields could have sea water above ground level.

Of the 240 buildings at greatest risk:

- 60 are houses and 15 are blocks of flats;
- 20 are commercial accommodation such as resorts, hotels and hostels in City;
- 75 are business or industrial buildings in City and Portsmith;
- 45 are logistic support and transport related buildings in City and Portsmith, including most of the wharf facilities;
- 10 are related to public safety; and,
- 15 are community facilities.

The pattern of inundation clearly reflects the drainage and micro-topography of the inner city area. Apart from the ‘front row’ area, the areas of greatest impact are to the east of both Chinamans Creek and the Fearnley Street drainage channel and to the south of Saltwater Creek (near the airport). Inundation in Manunda, Westcourt and Parramatta Park would largely be caused by water flowing up these drainage features. None of these drainage features is equipped with one-way flood valves.

Approximately 250 people could need to be evacuated from the houses and flats at greatest risk in advance of the storm tide impact. A further 370 people would probably need, or want, to be evacuated from the houses and flats with more 1 m over floor level but further than 750 m from the shore. Most of these people are in Manunda and Westcourt. Assuming an average occupancy of 1.5 persons per room in the commercial accommodation at significant risk, a further 1 250 people could require evacuation ahead of the cyclone crossing the coast.

Machans Beach, would be the most seriously affected residential suburb, with most of its 413 buildings either flooded or isolated by water. The single access road into Machans Beach would be impassable to light traffic at the height of storm tide inundation. Early and total evacuation of that suburb’s 1 055 inhabitants would need to be seriously considered. Evacuees in most other suburbs could probably be accommodated locally.

The impact of a 1% AEP storm tide event would be significant, with as many as 1 870 people at risk of harm. Almost 250 buildings could be at risk of destruction or significant damage with as many as 2 350 additional buildings suffering substantial contents damage. More than 13 000 hectares of cane lands would also be inundated by sea water. Twent-three critical facilities would be affected by over-floor inundation. They would include Calvary Hospital, the main Cairns Ambulance Station, QPS headquarters, Cairns City Council headquarters, the main telephone exchange, four of six nursing homes, and so on. A full list is contained in **Table K1**.

Figure 7.9 shows the buildings that would be inundated and **Figure 7.10** provides a larger scale view of the central Cairns area. **Table K3** provides the key statistics for each of the suburbs affected.

The 0.2% AEP scenario: The minimum storm surge required to create a storm tide of 3.39 m above AHD (1.63 m above HAT) would be around 1.75 to 2.0 m arriving at or close to a very high tide. Cairns has not yet experienced a storm tide impact of this magnitude, however, several cyclones in the area have had the potential to produce such an impact had they crossed the coast closer to and/or north of Cairns. These include the 1920 Port Douglas cyclone, Cyclone *Winifred* in 1986 and Cyclone *Joy* in 1990.

By applying our model for a storm tide of 3.39 m above AHD, a 0.5 m wave setup figure, shallow water wind waves of 0.4 m and 1.5 m of breaking sea wave, around 10 000 buildings would be affected as follows (numbers rounded):

- as many as 6 900 buildings could have more than 1 m of water over floor level - of these about 2 200 are within the first 750 m of the shore line and would be at significant risk of being destroyed; 1 575 are in the second 750 m and have a moderate risk of destruction but would sustain significant damage; and around 3 100 are more than 1 500 m from the shore. Whilst the last group would have a relatively low risk of being destroyed, they would obviously suffer substantial damage;
- up to 1 930 buildings could have water over floor level of less than 1 m depth;
- a further 1 560 buildings could have water on the property;
- the remaining 24 3000 or so buildings would be free of inundation;
- up to 310 km of road could have 0.5 m or more of water over the pavement, including the key Barron River Bridge;
- a further 20 km of road would have less than 0.5 m of water over the pavement;
- as many as 21 400 ha of cane fields would have sea water above ground level.

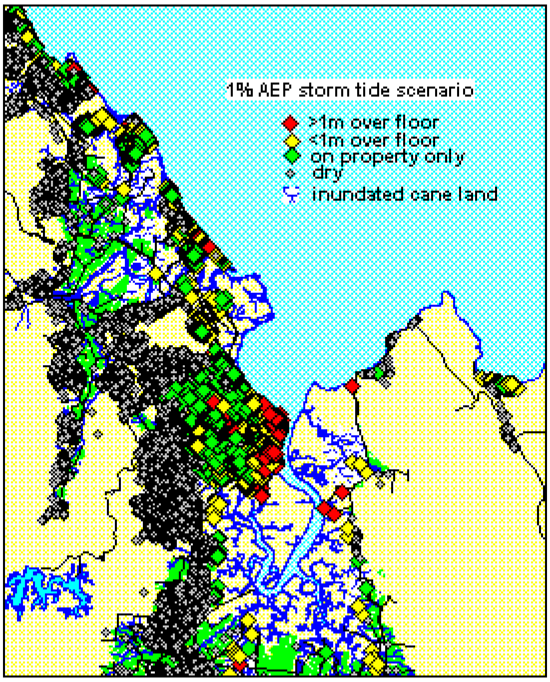

Figure 7.9: Modelled impact of a 1% AEP storm tide event on Cairns

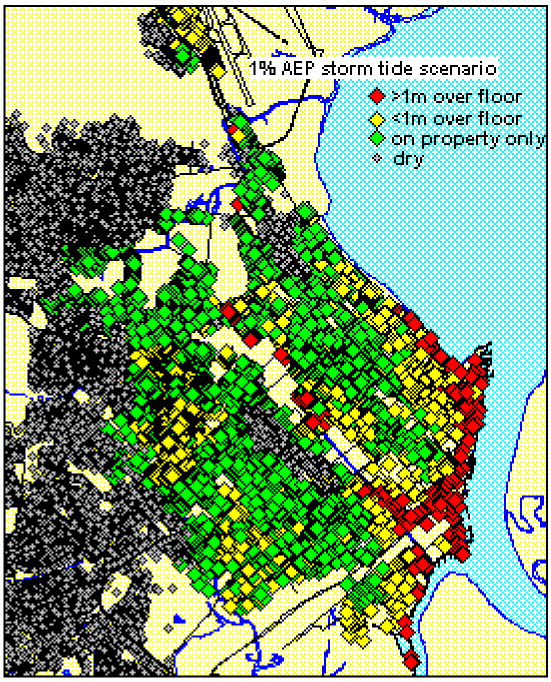

Figure 7.10: Modelled impact of a 1% AEP storm tide event on Cairns (detail)

Of the 2 200 buildings at greatest risk:

- 1 055 are houses and 300 are blocks of flats;
- 150 are commercial accommodation, predominantly in City, Cairns North, Yorkeys Knob, Trinity Beach, Clifton Beach and Palm Cove;
- 390 are business or industrial buildings, mostly in City and Portsmith;
- 100 are logistic support and transport related buildings in City, Portsmith (including all of the wharf facilities and fuel depots) and Aeroglen (with the airport and its facilities);
- 40 are related to public safety (including both major hospitals); and,
- 130 are community facilities.

The spatial extent of inundation under the 0.2% AEP scenario would be little different to that for a 1% AEP event, however, the depth of inundation (and the numbers of buildings affected) would be significantly greater. The major increase of impact would be in Cairns North, Westcourt and the northern beachside suburbs. The inundation facilitated by inflow along Chinamans Creek and the Fearnley Street drainage channel is substantially greater, whilst a similar problem along Saltwater Creek (at the southern end of the airport) would cause problems in low lying areas of Edge Hill and the northern parts of Manunda.

Approximately 4 550 people could need to be evacuated in advance of the storm tide impact from the houses and flats at greatest risk. A further 10 760 people would probably need to be evacuated from the houses and flats with more 1 m of water over floor level but further than 750 m from the shore. Evacuation of the entire population of Machans Beach, at least six hours before the cyclone crossed the coast, would be the only way of maximising their safety. Assuming an average occupancy of 1.5 persons per room in the commercial accommodation at significant risk, a further 6 300 people could require evacuation to managed shelters ahead of the cyclone crossing the coast. 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.

Evacuation of both the Cairns and Calvary hospitals, which are close to the shoreline, and the four major nursing homes in Westcourt that would be affected by over-floor inundation, would probably represent the most significant evacuation task required under this scenario. Many of the 750 to 1 000 very vulnerable people involved would require ambulance transport and trained carers such as nurses (the numbers of both of which are limited) to ensure their safety. Some would require specialised equipment and accommodation (such as dialysis or intensive care) at their destination. It could take at least 24 hours to complete such an evacuation.

The impact of a 0.2% AEP storm tide event would be potentially catastrophic. As many as 21 600 people could be at risk of serious harm. As many as 2 200 buildings could be at risk of destruction or significant damage and as many as a further 2 000 buildings could suffering lighter structural damage but substantial contents damage. Around 21 400 hectares of cane lands would also be inundated by sea water. Thirty-nine of the 60 critical facilities would be affected by a 0.2% AEP storm tide event, 35 of them with greater than 1 m of sea water over floor level. These are detailed in **Table K1**.

Eleven suburbs could have more than 50% of their buildings affected. Of these, six (City, Parramatta Park, Portsmith, Machans Beach, Manunda and Cairns North) could have more than 90% of their buildings affected. **Figure 7.11** shows the buildings that would be inundated whilst **Figure 7.12** provides a more detailed view of the central Cairns area. **Table K4** provides the key statistics for each of the suburbs affected.

The 0.1% AEP scenario: The minimum storm surge required to create a storm tide of 3.75 m above AHD (2.0 m above HAT) would be around 2.5 m arriving at or close to a very high tide. Cairns has not yet experienced a storm tide impact of this magnitude, however, many high Category 3 and Category 4 cyclones crossing the coast within 50 km to the north of the city could produce such an impact. There are 14 definite or possible Category 3 storms listed in **Appendix J**, though none crossed the coast close to Cairns.

Our model for a storm tide of 3.75 m above AHD, 0.5 m of wave setup, 0.5 m of shallow water wind waves and 1.7 m of breaking sea wave height indicates an impact on around 10 350 buildings as follows (numbers rounded):

- as many as 7 900 buildings could have more than 1 m of water over floor level - of these about 2 490 are within the first 750 m of the shore line and would be at a very high level of risk of being destroyed; 1 800 are in the second 750 m and have a moderate to significant risk of being destroyed; and 3 640 are more than 1 500 m from the shore and would have some risk of being destroyed, though they would obviously suffer substantial damage;
- up to 1 980 buildings would have less than 1 m of water over floor;
- up to 1 160 buildings would have water on the property, but not over the floor;
- the remaining 23 600 or so buildings would be free of inundation;
- around 325 km of road would have 0.5 m or more of water over the pavement;
- a further 20 km would have less than 0.5 m of water over the pavement;
- around 24 200 ha of cane fields could have sea water above ground level.

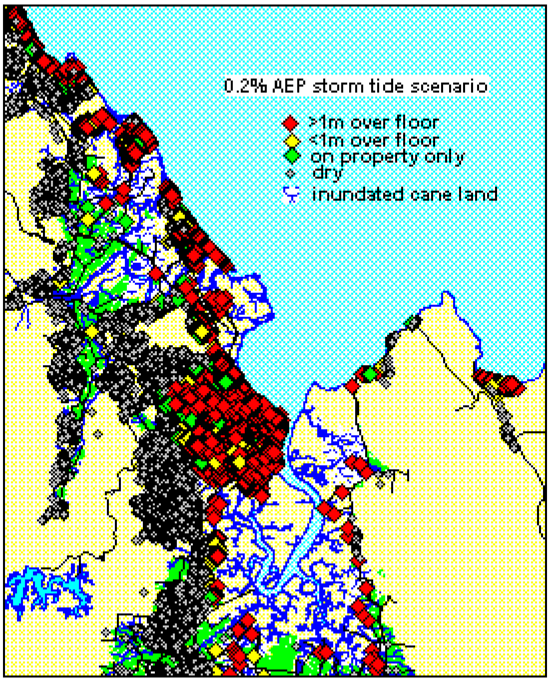

Figure 7.11: Modelled impact of a 0.2% AEP storm tide scenario

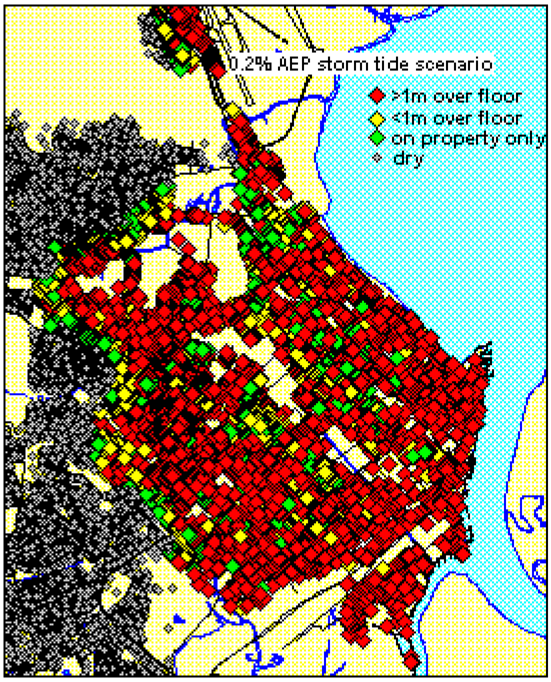

Figure 7.12: Modelled impact of a 0.2% AEP storm tide scenario (detail)

Of the 2 490 buildings at greatest risk:

- 1 260 are houses and 330 are blocks of flats;
- 160 are commercial accommodation;
- 400 are business or industrial buildings;
- 100 are logistic support and transport related;
- 45 are related to public safety (including both main hospitals); and,

- 140 are community facilities.

The spatial extent of inundation under a 0.1% AEP scenario is little different to that for a 1% AEP event. The depth of inundation, however, would be, on average, 1.4 m greater, especially in the low-lying area occupied by Manunda, Parramatta Park and Westcourt.

Approximately 5 250 people would need to be evacuated from the houses and flats at very great risk of destruction. A further 12 800 people would probably need to be evacuated from the houses and flats with more than 1 m over floor level but further than 750 m from the shore. Most of these are in Manunda and Westcourt. Assuming an average occupancy of 1.5 persons per room in the commercial accommodation at significant risk, a further 6 400 people could require evacuation to managed shelters ahead of the cyclone crossing the coast. 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 (ARI of 1 000 years) storm tide event would be catastrophic. As many as 24 500 people could be at considerable risk of serious harm. Some 8 000 buildings would be at risk of destruction or significant damage and as many as 1 750 further buildings would suffer substantial contents damage. Around 24 200 ha of cane lands would also be inundated by sea water. Thirty-nine of the 60 critical facilities would be at significant risk of severe damage if not destruction. These are detailed in **Table K1**. The extent of the area affected is illustrated in **Figure 7.13**, whilst **Figure 7.14** provides a larger scale view of the central city area. Table K5 provides the key statistics for each of the suburbs affected.

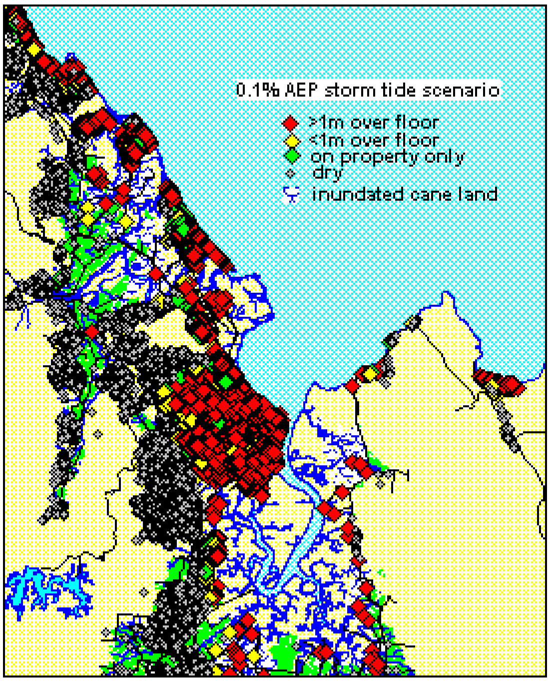

Figure 7.13: Modelled impact of a 0.1% AEP storm tide scenario

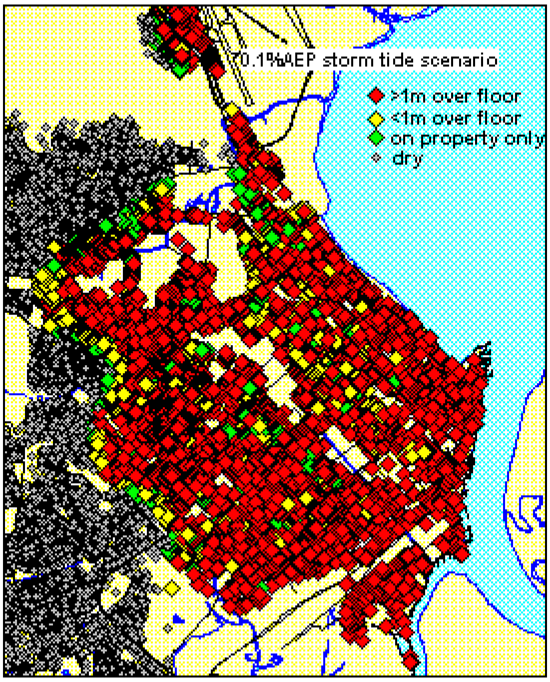

Figure 7.14: Modelled impact of a 0.1% AEP storm tide scenario (detail)

The 0.01% AEP scenario: This is close to the maximum credible 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 4.5 m above AHD (2.72 m above HAT) would be around 3.0 m arriving at or close to a very high tide. Obviously, Cairns has not yet experienced a storm tide impact of this magnitude, however, Category 5, Category 4 and some high Category 3 cyclones crossing the coast within 25 to 50 km to the north of the city could produce such an impact. There are three definite or possible Categories 4 or 5 storms listed in **Appendix J**, though those that crossed the coast did so to the south of Cairns.

Our model for a storm tide of 4.5 m above AHD, a 0.5 m wave setup, a shallow water wind wave weight of 0.7 m and a 2.5 m breaking sea wave height indicates that at least 11 600 buildings would be affected as follows (numbers rounded):

- up to 9 900 buildings could have more than 1 m of water over floor level - of these about 3 110 are within the first 750 m of the shore line and would be at extreme risk of being destroyed - many of these would have substantially more than one metre of water over floor; 2 250 are in the second 750 m and would have a high risk of destruction; and 4 530 are more than 1 500 m from the shore and would have a moderate to high risk of being destroyed;
- around 2 24000 buildings could have water over floor level less than 1 m deep;
- around 590 buildings could have water on the property, but not over the floor;
- the remaining 22 000 or so buildings would be free of inundation;
- 385 km of road would have 0.5 m or more of water over the pavement;
- a further 20 km would have water over the pavement of less than 0.5 m;
- around 30 700 ha of cane fields would have sea water above ground level.

Of the 3 110 buildings at greatest risk:

- 1 820 are houses and 370 are blocks of flats;
- 170 are commercial accommodation;
- 405 are business or industrial buildings;
- 105 are logistic support and transport related buildings;
- 50 are related to public safety (including both major hospitals); and,
- 145 are community facilities.

The extent of inundation under the 0.01% scenario would be little different to that for a 0.1% event, however, the depth of inundation would be on average 2.2 m greater.

Approximately 7 000 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 16 500 people would also need to be evacuated from the houses and flats with more 1 m over floor level but further than 750 m from the shore. In addition, approximately 6 640 people in commercial accommodation would require evacuation to managed shelters ahead of the cyclone crossing the coast.

The impact of a 0.01% AEP storm tide event would be catastrophic. Perhaps as many as 30 000 people would be at risk of drowning if not evacuated to appropriate shelter well in advance of the cyclone crossing the coast. Storm tide alone could place at risk of destruction or significant damage up to 9 900 buildings with a further 1 500 buildings likely to suffer substantial contents damage. More than 30 000 hectares of cane lands would also be inundated by sea water. Thirty-nine out of 60 critical facilities would have more than 1 m of water over floor level and would consequently suffer severe damage if not total loss. These are detailed in **Table K1**. **Figure 7.15** shows the buildings that would be inundated and **Figure 7.16** shows greater detail of the central area of the city.

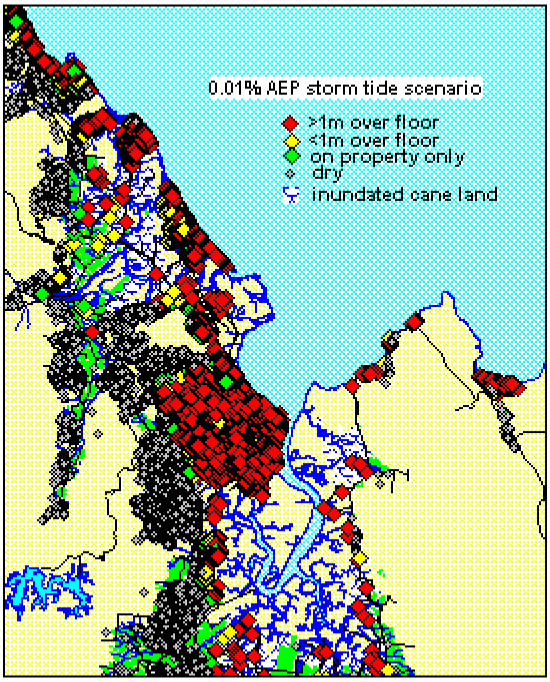

Figure 7.15: Modelled impact of a 0.01% AEP AEP tide scenario

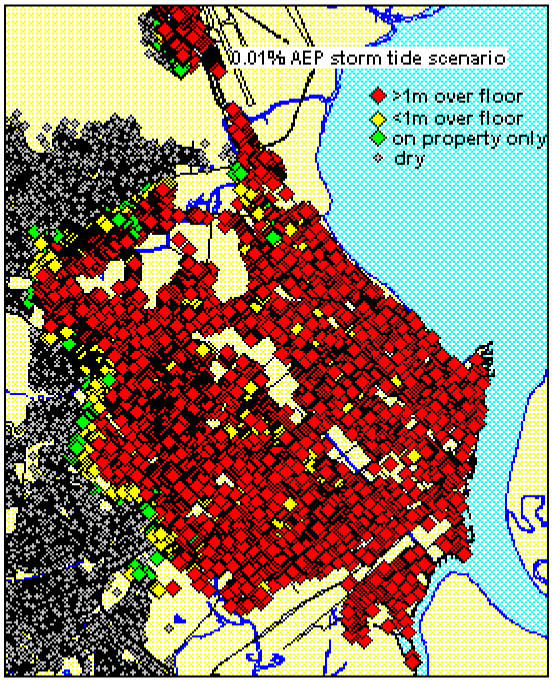

Figure 7.16: Modelled impact of a 0.01% storm storm tide scenario

Comparative Storm Tide Risk

It is clear that the potential impact of storm tide on Cairns is considerable, though the spatial extent is limited by topography. The former delta of the Mulgrave River on which Cairns has been established, is the major area of concern given that its low lying terrain permits the intrusion of storm tide inundation for almost four kilometres from the coastline. Inundation of this area is certainly facilitated by natural drainage, such as Chinamans Creek and Saltwater Creek, as well as the constructed storm water drains, the largest being that which runs between the two arms of Fearnley Street (Portsmith) and drains the Parramatta Park and Manunda area. A similar concern exists with the Barron Delta, especially with the airport and the suburb of Machans Beach. In the Yorkeys Knob area Moon River and Yorkeys Creek also permit storm tide inundation to penetrate well inland. Once the limits of the lowlands have been reached (typically with an event in the 1% to 0.2% range) inundation depth increases significantly. This is well illustrated in **Figure 7.17** which shows the cumulative number of buildings affected as the magnitude of a storm tide impact increases (and probability of occurrence decreases).

An analysis of the function of buildings affected under each scenario reveals that the ‘business and industrial’ properties and the ‘logistic, storage and transport’ properties would suffer the greatest proportional impact, whilst the proportion of domestic accommodation (‘houses’ and ‘flats’) affected is the smallest. The figures provided in **Table 7.4** for each class of function are the percentages of all buildings in Cairns, within each functional class, that would have water of any depth over floor level.

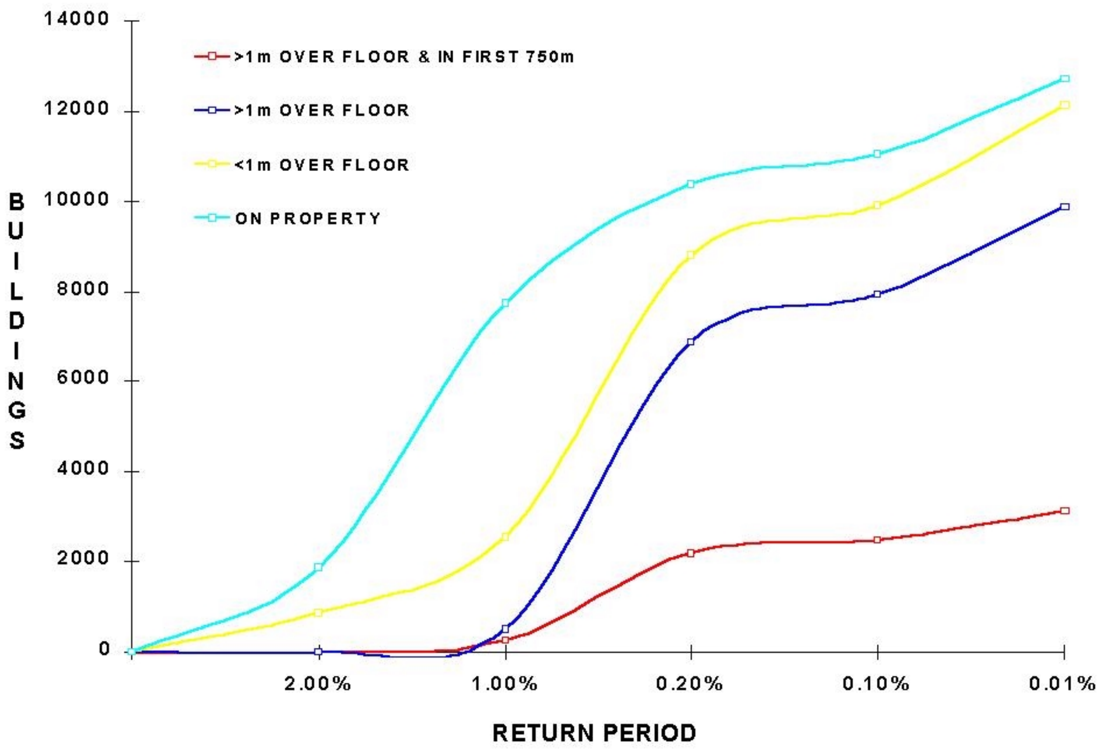

Figure 7.17: Cumulative impact on buildings of storm tide in Cairns

Table 7.4: 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	0.9	3.5	17.3	20.3	25.5
Flats	3.1	14.2	48.6	50.2	57.1
Commercial accommodation	9.5	21.4	66.9	68.2	71.3
Business & industry	17.7	41.7	83.6	84.3	85.7
Logistic, transport & storage	30.3	50.1	80.2	80.5	81.7
Public safety & health	10.7	33.2	63.6	64.0	65.0
Community, education & sport	8.3	17.7	58.1	58.8	60.7
Utilities	4.6	14.9	56.3	57.5	59.8

A number of conclusions regarding community risk may be drawn from these figures.

For **houses**, the dominant form of shelter in the community, even under the most severe scenario, the numbers indicate that:

- a relatively small proportion of houses are located in storm tide prone areas.
- for the vast bulk of the population, shelter in their own home is clearly the preferred option;
- for those people whose homes would be at risk of hazardous levels of inundation, the most abundant form of shelter would be with friends, relatives, colleagues or others in their homes in safer areas.

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

- there is a degree of concentration of flats in storm tide-prone areas.
- for the lower magnitude scenarios (up to 1% AEP) flats will provide shelter for substantial numbers, however, for the higher magnitude scenarios, significant numbers of people who live in flats could need to be relocated;
- many blocks of flats are multi-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 high degree of concentration of these facilities in storm tide-prone areas;
- for scenarios of 0.2% 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. The option of 'vertical evacuation' could be viable in commercial accommodation other than those along the 'front row';
- caravan parks (of which there are 20) 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 strongly concentrated in storm tide-prone areas;
- the potential for economic loss is significant in even 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 businesses may suffer 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 strongly concentrated in storm tide-prone areas;
- the sustainability of Cairns would be under significant stress with a 2% AEP event, but would probably be untenable under any of the high intensity events. The loss of food, fuel and other essential commodities would place the Cairns community at extreme peril. The most likely response option under those circumstances would probably involve the evacuation of substantial numbers of people to other centres in Queensland, or further afield, until those services could be restored;
- damage and loss of these facilities, under all scenarios, 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 disbursed throughout the community;

- the capacity of public safety and health authorities to support the community during and after a storm tide impact will be significantly diminished, especially with the higher intensity events. This would reach critical levels for events beyond the 2% AEP level because of the increased probability of loss or isolation of the two main hospitals, the QPS headquarters (which houses the District Disaster Coordination Centre) and the main ambulance station (which also houses the joint ambulance and fire service communications centre);
- alternate facilities in areas that would not be affected by storm tide inundation would be available to provide a reduced 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 well dispersed throughout the community;
- 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 potential shelter buildings undertaken by Q-Build in 1998, however, indicates that very few 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, Rossitier & Mollee, 1998).

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

- these facilities are well dispersed. This, in part, reflect 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 the two main sewerage treatment plants, the two major power substations and the main telephone exchange, which are located in storm tide prone areas, may render the whole utility sector inoperable;
- 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 infrastructure that is exposed to storm tide inundation may suffer significant damage.

Storm tide risk exposure. The relative exposure of the Cairns community to the storm tide hazard may be measured by the following coefficient:

$$Exposure_{\text{storm tide}} = 5A + 4B + 3C + 2D + E$$

where:

A = the total number of buildings with >1 m over floor within 750 m of the shore
B = the total number of buildings with >1 m over floor between 750 & 1500 m of the shore
C = the total number of buildings with >1 m over floor greater than 1500 m from the shore
D = the total number of buildings with <1 m over floor
E = the total number of buildings with water on the property but less than floor level.

The coefficients and their ranks for each suburb exposed to a storm tide with an AEP of 1% are given in **Table 7.5** and their distribution is shown in **Figure 7.18**.

Table 7.5: Storm tide risk exposure of Cairns suburbs

Suburb	Risk coefficient	Risk rank	Suburb	Risk coefficient	Risk rank
Aeroglen	200	11	Palm Cove	123	15
Barron	2	27	Parramatta Park	1250	5
Cairns North	763	6	Portsmith	1431	3
City	1252	4	Smithfield	10	26
Clifton Beach	140	14	Stratford	1	28
Edge Hill	74	17	Trinity Beach	162	13
Edmonton	12	24	Trinity East	29	20
Holloways Beach	76	16	Trinity Park	212	10
Kamma	13	23	Westcourt	1559	2
Kewarra Beach	21	21	White Rock	41	19
Machans Beach	676	7	Woree	20	22
Manoora	233	9	Wright's Creek	11	25
Manunda	2043	1	Yarrabah	186	12
Mooroobool	64	18	Yorkeys Knob	544	8

Interpretation

Tropical cyclones pose a considerable threat to Cairns. In the 123 years since the settlement was established there have been 53 cyclones that have had some effect on the town - that is an average of a cyclone every two years. They bring with them the multiple threats of strong winds, heavy rain and storm tide inundation.

The conventional response to an impending cyclone impact is for people to take shelter in their own homes. In those areas that would be subject to storm tide inundation, however, this is not an appropriate option, as many people in such areas would be exposed to a significant risk of drowning, especially were the level of inundation to exceed 1 m over floor level.

Evacuation of those people at risk must be completed before the winds reach 75 km/hr (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 manage the numbers of evacuees that would be involved unless the vast majority are prepared to undertake their own evacuations beginning at least 24 hours before the forecast cyclone impact time. Delay in commencing a major evacuation process will increase 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 Cairns will have a major immediate impact with potentially significant loss of life and massive damage, the long term impact will also be catastrophic. In an extreme event, a major proportion of the survivors would 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 would be such that the city would be virtually uninhabitable for an extended period.

The application of building code standards since 1975 and the inclusion of storm tide hazard as a constraint in the urban planning process in Cairns since the early 1990s have certainly slowed the rate at which risk would otherwise have increased. Significant reduction in risk will not be possible until the concentration of population, economic activity and community services in the highest risk areas of Aeroglen, Cairns North, City, Machans Beach, Manunda, Parramatta Park, Portsmith and Yorkeys Knob is reduced significantly. Some proposed developments, such as the creation of a major residential precinct in Trinity East, could, unless carefully implemented, exacerbate an already risk-laden situation.

Limitations and Uncertainties

We have already discussed at some lengths 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 are realistic.

One clear area in which further research is required is in the weights to apply for buildings in the calculation of risk coefficients. The values used here for both the wind and storm tide risk coefficients are purely subjective. That said, whilst they will probably exaggerate the numerical value of the coefficients, we are confident that they reflect the relative level of risk between suburbs quite accurately.

It is also important here to test the sensitivity of the storm tide impact model that we have employed. Four models, ranging from the simplistic 'still water' model that projects the level of inundation to the same contour value as the height of the storm tide above AHD, to the much more complex, but complete, model used in this study are compared:

1. the simple 'still water' model without any allowance for wave setup, shallow water wind wave or sea wave force;
2. a 'still water + shallow water wind wave' version in which an allowance equal to 30% of the average over-ground inundation depth is added to the storm tide level to take account of the shallow water wind waves;
3. a 'storm tide + 0.5 m wave setup + shallow water wind wave' model; and,
4. the *Cities Project* model which adds a sea wave component to model 3.

The statistics for each model, against each scenario, are provided in **Table 7.6**.

From the figures in this table it is clear that the 'still water' model significantly underestimates the number of buildings at risk and should not be used. The significance of including the wave setup component is clearly evident, as is the shallow water wind waves. The breaking sea waves are relatively less significant, except along the 'front row'.

Table 7.6: Comparison of buildings affected under four storm tide impact models in Cairns

SCENARIO	LEVEL	MODEL 1 (buildings)	MODEL 2 (buildings)	MODEL 3 (buildings)	MODEL 4 (buildings)
2% AEP	>1m over floor	2	5	9	9
	<1m over floor	224	705	865	865
	not over floor*	449	1150	1425	1425
1% AEP	>1m over floor	5	129	214	327
	<1m over floor	587	1615	2052	2239
	not over floor	870	5148	5259	5170
0.2% AEP	>1m over floor	959	4575	6596	6880
	<1m over floor	5928	3377	2032	1927
	not over floor	2477	1913	1634	1561
0.1% AEP	>1m over floor	2266	6472	7720	7923
	<1m over floor	5454	2080	1970	1977
	not over floor	2006	1676	1085	1162
0.01% AEP	>1m over floor	7153	8103	9585	9892
	<1m over floor	1924	2066	2302	2237
	not over floor	1413	1105	637	591

NOTES:
* Water on the property but not over floor level
1. Model 1 = the 'still water' model.
2. Model 2 = the 'still water' model plus an allowance for shallow water wind waves.
3. Model 3 = the '0.5 m wave setup model + shallow water wind wave' model.
4. Model 4 = the *Cities Project* model which includes allowance for sea wave impact.

CHAPTER 8: A MULTI-HAZARD RISK ASSESSMENT

Overview

Our approach in developing this multi-hazard risk assessment of Cairns has been consistent with the general risk management process outlined in *AS/NZS 4360:1995 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 Cairns community that are posed by range of natural hazards; and,
- analysed and characterised those risks.

In this chapter we assess (or evaluate) these risks and prioritise their significance to the Cairns 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)

In simplistic terms we have expressed the relationship between the various components as follows:

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

To assess overall community risk, therefore, it is necessary to bring together the assessment of each suburb's exposure to hazard impact and their contribution to overall community vulnerability to reach an assessment of that suburb's 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 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 flooding that kill people and produce massive economic loss are typically 'unacceptable'. Whilst this seems to be an eminently reasonable approach, it is unrealistic, especially where the event is 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 flooding. Similarly, it would be prohibitively expensive to build structures to withstand the impact of the largest possible earthquake. 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 and socially acceptable to implement. Events that exceed those thresholds are coped with, if and when they occur. In Cairns the following thresholds are either explicitly or implicitly accepted:

- for earthquake - under the criteria established in *AS 1170.4-1993*, no building should fail unless it is exposed to earthquake loads greater than those for which there is less than a 10% probability of exceedence in any 50 year period (i.e an ARI of around 500 years). More stringent construction standards are required for structures used for what we have termed 'critical facilities';
- for landslide - there are no explicit thresholds other than 'good engineering practice', though some areas proposed for development have been 'quarantined' by Cairns City Council pending further geotechnical investigation;
- for flood - planning constraints apply to new development within the area likely to be effected by a 1% flood in the Barron River delta (i.e. an ARI of 100 years);
- 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 less than a 5% probability of exceedence in any 50 year period (i.e. an ARI of around 1 000 years);
- for storm tide - planning constraints apply to new development within the area subject to inundation under a notional 1% AEP storm tide (i.e. an ARI of 100 years).

This inconsistent approach to standards of 'risk acceptance' is certainly not unique to Cairns. These thresholds have largely been set by agencies outside Cains, especially those involved in establishing the various standards under the Building Code. The 1% thresholds for inundation hazards appear to have been accepted because of their widespread adoption elsewhere in Australia as 'best practice'. This latter threshold originated in Europe and has simply been adopted in some areas of Australia without being tested for its appropriateness or its universal applicability in all catchments.

These thresholds do not 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 has, however, recently been addressed with publication of *AS 3826-1998 Strengthening existing buildings for earthquake* (Standards Australia, 1998) and a similar standard for upgrading older buildings to meet wind loads is close to publication.

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

Total Risk Assessments

In **Table 8.1** we have brought together the rank values of Cairns suburbs for their contribution to overall community vulnerability (from **Table 3.11**) and their rank values for exposure to earthquake (from **Table 4.8**), landslide (from **Table 5.4**), flood (from **Table 6.6**), strong winds (**Table 7.2**) and storm tide (from **Table 7.5**). Each of the exposure rankings is based on scenarios that match or exceed the threshold values described above.

By plotting each suburb's rank of contribution to overall community vulnerability against their 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 20	low contribution ranks 21 to 41
high earthquake exposure ranks 1 to 20	low earthquake exposure ranks 21 to 41
high landslide exposure ranks 1 to 14	low landslide exposure ranks 15 to 29
high flood exposure ranks 1 to 6	low flood exposure ranks 7 to 12
high storm tide exposure ranks 1 to 14	low storm tide exposure ranks 15 to 28

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

Table 8.1: Ranking of Cairns suburbs according to vulnerability and hazard exposure

Suburb	Vulnerability	Earthquake	Landslide	Flood	Wind	Storm Tide
Aeroglen	24	34	13	10	33	11
Barron	41	41		1	38	27
Bayview Heights	26	6	3		1	
Bentley Park	19	19	25		17	
Brinsmead	27	25	6		21	
Cairns North	10	8			14	6
Caravonica	33	33	20	7	32	
City	15	14			36	4
Clifton Beach	30	22	22		23	14
Earlville	18	9	9		7	
Edge Hill	2	5	10		5	17
Edmonton	6	18	16		15	24
Freshwater	32	29	4	11	19	
Gordonvale	4	16	26		18	
Holloways Beach	22	12		8	12	16
Kamerunga	37	35	19	4	34	
Kamma	36	37			38	26
Kanimbla	38	36	18		35	
Kewarra Beach	23	23	26		28	21
Machans Beach	34	20		6	16	7
Manoora	5	11	21		9	9
Manunda	2	2			6	1
Mooroobool	11	3	2		3	18
Mount Peter	40	40	26		38	
Mount Sheridan	28	26	12		27	
Palm Cove	25	31	16		30	15
Parramatta Park	9	4			11	5
Portsmith	8	15			31	3
Redlynch	21	27	1	5	26	
Smithfield	16	24	6	3	24	26
Stratford	29	28	8	9	22	28
Trinity Beach	17	17	14		10	13
Trinity East	31	11	11		37	20
Trinity Park	35	30		12	29	10
Westcourt	1	1			4	2
White Rock	12	21	24		20	19
Whitfield	20	7	5		2	
Woree	7	10	22		8	22
Wright's Creek	39	39	29		38	25
Yarrabah	13	32	14		25	12

Yorkeys Knob	14	13		2	13	8

Total earthquake risk: Any earthquake of a magnitude likely to cause damage in Cairns will have an effect across all suburbs. The amount of damage, and consequently risk, will increase in direct proportion to the intensity of the event. All suburbs, therefore, have some degree of exposure. 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 8.1** and the spatial distribution in **Figure 8.2**.

There is a significant degree of correlation between the two sets of rank. This can be explained in terms of the history of urbanisation in Cairns where the oldest (and most vulnerable) buildings are located on the extensive, 'soft' coastal sediments that are most likely to amplify earthquake peak ground acceleration. These are also the suburbs that contain many of the critical facilities and have significant concentrations of people, buildings and infrastructure. The more modern suburbs, in which the majority of buildings and other structures conform to the earthquake loading provisions of the Australian Building Code, are on the shallow soils or rock of the hill slopes where peak ground accelerations will be less damaging.

The grouping of suburbs (in alphabetical order) according to total risk is provided in **Table 8.2**.

Table 8.2: Level of total earthquake risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Bentley Park, Cairns North, City, Earlville, Edge Hill, Edmonton, Gordonvale, Manoora, Manunda, Mooroobool, Parramatta Park, Portsmith, Trinity Beach, Westcourt, Whitfield, Woree, Yorkeys Knob
Significant total risk	Bayview Heights, Holloways Beach, Machans Beach
Moderate total risk	Smithfield, White Rock, Yarrabah
Low total risk	Aeroglen, Barron, Brinsmead, Caravonica, Clifton Beach, Freshwater, Kamerunga, Kamma, Kanimbla, Kewarra Beach, Mount Peter, Mount Sheridan, Palm Cove, Redlynch, Stratford, Trinity East, Trinity Park, Wright's Creek
No discernible risk	nil

Total landslide risk: Unlike earthquakes, which will have an effect across Cairns, landslide risk is localised. Even within the suburbs identified as having a high level of total landslide risk, the impact in any single landslide event is likely to be localised. The assessment of total risk relates, therefore, to the cumulative landslide risk over time across each suburb. The relationship between each suburb's vulnerability contribution and its exposure to landslide is shown in the scattergram (**Figure 8.3**) and their distribution in the map (**Figure 8.4**).

There is a very low degree of correlation between the two sets of rank. This can be explained by the fact that the suburbs with the greatest exposure to landslide are found mainly on the hill slopes. Such suburbs tend to be largely residential and the most recently developed areas in Cairns. As the level of development in those suburbs increases, so will the magnitude of the risk also increase. The relative level of total landslide risk is given in **Table 8.3**.

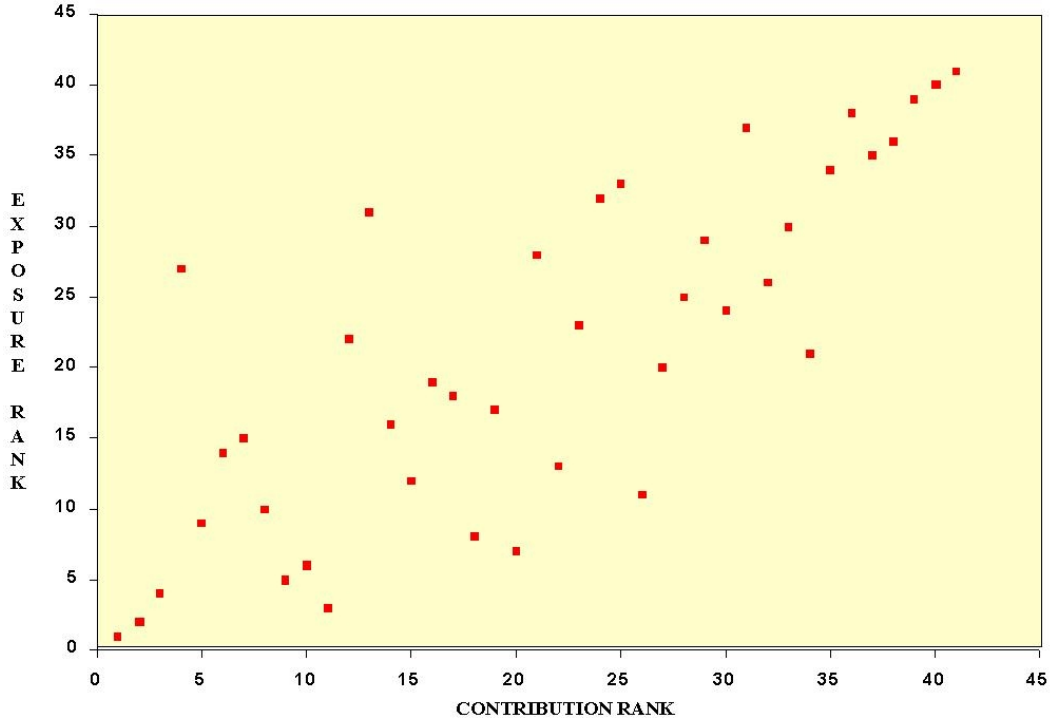

Figure 8.1: Earthquake total risk relationship

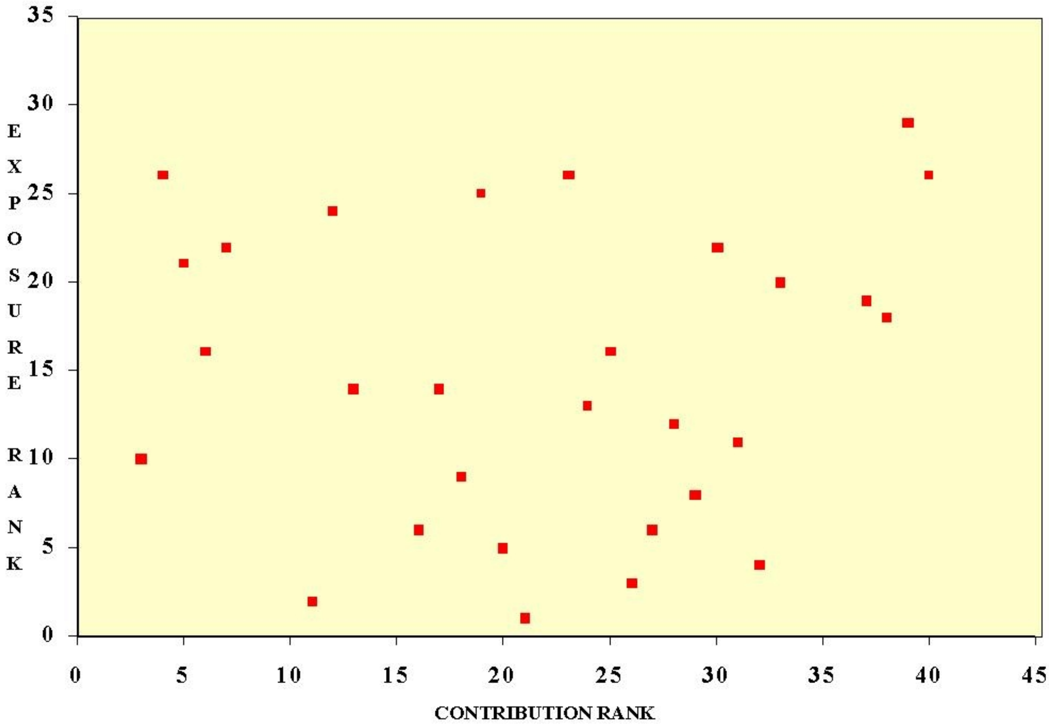

Figure 8.3: Landslide total risk relationship

Table 8.3: Level of total landslide risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Earlville, Edge Hill, Mooroobool, Smithfield, Trinity Beach, Whitfield, Yarrabah
Significant total risk	Aeroglen, Bayview Heights, Brinsmead, Freshwater, Mount Sheridan, Redlynch, Stratford, Trinity East
Moderate total risk	Bentley Park, Edmonton, Gordonvale, Manoora, White Rock, Woree
Low total risk	Caravonica, Clifton Beach, Kamerunga, Kanimbla, Kewarra Beach, Mount Peter, Palm Cove, Wright's Creek
No discernible risk	Barron, Cairns North, City, Holloways Beach, Kamma, Machans Beach, Manunda, Parramatta Park, Portsmith, Trinity Park, Westcourt, Yorkeys Knob

Total Barron River flood risk: The total flood risk, based on an event with a 1% AEP (ARI of 100 years) in the Barron River, presents a further variation. Whilst flooding in the Barron River delta will affect less than one third of all Cairns suburbs, in most flood events all delta suburbs will be affected to some degree. In spite of the spatially confined nature of the threat, the scattergram (**Figure 8.5**) shows a degree of correlation between the exposure of suburbs to flood and their contribution to community vulnerability. The fact that the scatter commences well to the right of the diagram (i.e. into the low contribution ranks) can be interpreted to indicate that there has been limited overall development, other than agriculture, in the more flood prone areas of the delta.

The spatial distribution is shown in **Figure 8.6** and the listing of suburbs according to the level of total risk is provided in **Table 8.4**. It is emphasised that this assessment relates only to the Barron River. When data relating to the flood exposure in the other Cairns catchments (MacAlister Range, Trinity Inlet, Mulgrave River and Yarrabah) become available it will be possible to produce an overall total flood risk assessment. Flash flooding in the other catchments, especially the streams that flow into Trinity Inlet, is a potentially significant problem. Not only are there significantly more properties exposed to urban drainage surcharge in the downtown area than there are on the Barron delta, but also the risk to life is significant because of the rapid onset of flash floods and the propensity for careless or foolish behaviour by some people in and around floodwaters.

Table 8.4: Level of total Barron River flood risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Smithfield, Yorkeys Knob
Significant total risk	Barron, Kamerunga, Machans Beach, Redlynch
Moderate total risk	nil
Low total risk	Aeroglen, Caravonica, Freshwater, Holloways Beach, Stratford, Trinity Park
No discernible risk	Bayview Heights, Bentley Park, Brinsmead, Cairns North, City, Clifton Beach, Earlville, Edge Hill, Edmonton, Gordonvale, Kamma, Kanimbla, Kewarra Beach, Manoora, Manunda, Mooroobool, Mount Peter, Mount Sheridan, Palm Cove, Parramatta Park, Portsmith, Trinity Beach, Trinity East, Westcourt, White Rock, Whitfield, Woree, Wright's Creek, Yarrabah

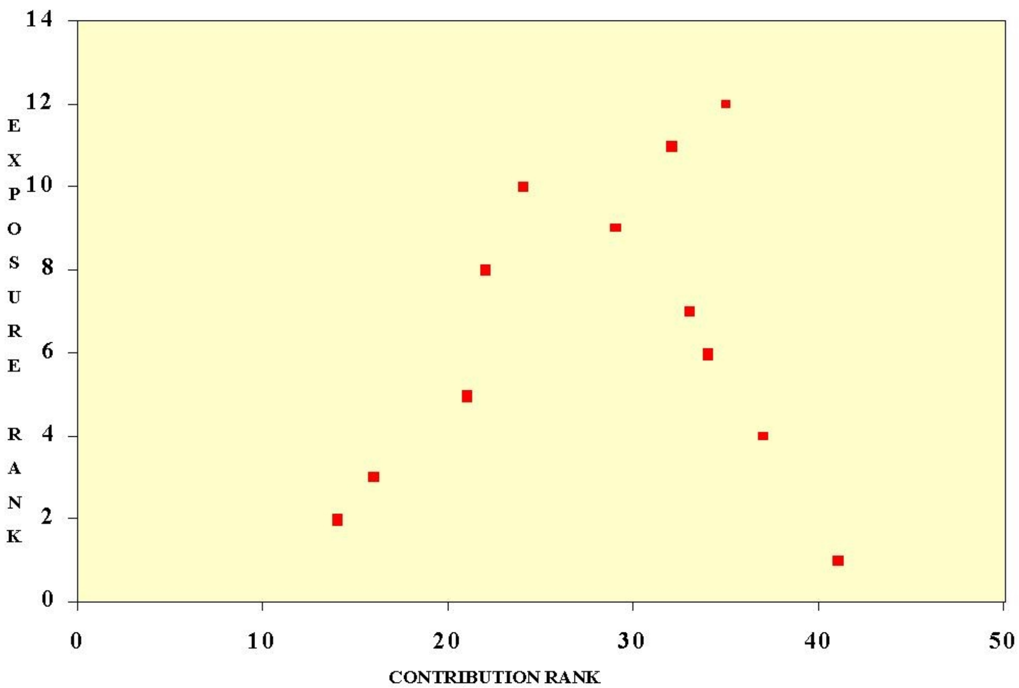

Figure 8.5: Barron River flood total risk relationship

Destructive wind total risk: Whilst there is a reasonable degree of correlation between exposure and vulnerability contribution shown in the scattergram (**Figure 8.7**), it is certainly weaker than for either earthquake or storm tide. This may be explained by the fact that the highest exposure levels are for suburbs on the hill slopes that have older buildings followed by the older buildings on the flat country. The spatial distribution is shown in **Figure 8.8** and the suburbs are listed by total risk in **Table 8.5**.

Table 8.5: Level of total destructive wind risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Bentley Park, Cairns North, Earlville, Edge Hill, Edmonton, Gordonvale, Manoora, Manunda, Mooroobool, Parramatta Park, Trinity Beach, Westcourt, White Rock, Whitfield, Woree, Yorkeys Knob
Significant total risk	Bayview Heights, Freshwater, Holloways Beach, Machans Beach
Moderate total risk	City, Portsmith, Smithfield, Yarrabah
Low total risk	Aeroglen, Barron, Brinsmead, Caravonica, Clifton Beach, Kamerunga, Kamma, Kanimbla, Kewarra Beach, Mount Peter, Mount Sheridan, Palm Cove, Redlynch, Stratford, Trinity East, Trinity Park, Wright's Creek
No discernible risk	nil

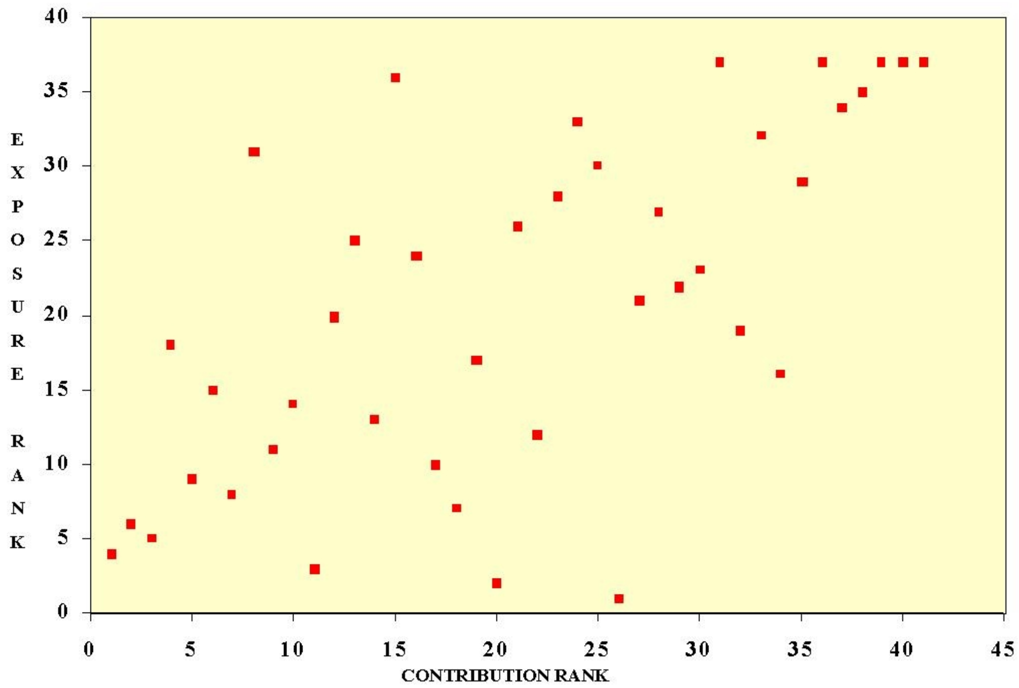

Figure 8.7: Destructive wind total risk relationship

Total storm tide risk: The total storm tide risk, based on an event with an AEP of 1% (ARI of 100 years), reflects both the history of Cairns settlement and the confining aspects of terrain. As such it contains elements of both the earthquake total risk and the Barron River flood total risk assessments.

The scattergram (**Figure 8.9**) shows a degree of correlation between exposure rank and contribution rank. This reflects the way in which both factors diminish away from the CBD on the low-lying inner area. The spatial distribution, shown in Figure 8.10, clearly reflects the coastal focus of the storm tide threat. **Table 8.6** lists the suburbs of Cairns according to their total storm tide risk.

Table 8.6: Level of storm tide risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Cairns North, City, Manoora, Manunda, Parramatta Park, Portsmith, Trinity Beach, Westcourt, Yarrabah, Yorkeys Knob
Significant total risk	Aeroglen, Clifton Beach, Machans Beach, Trinity Park, ,
Moderate total risk	Edge Hill, Edmonton, Mooroobool, Smithfield, White Rock, Woree
Low total risk	Barron, Holloways Beach, Kamma, Kewarra Beach, Palm Cove, Stratford, Trinity East, Wright's Creek
No discernible risk	Bayview Heights, Bentley Park, Brinsmead, Caravonica, Earlville, Freshwater, Gordonvale, Kamerunga, Kanimbla, Mount Peter, Mount Sheridan, Redlynch, Whitfield

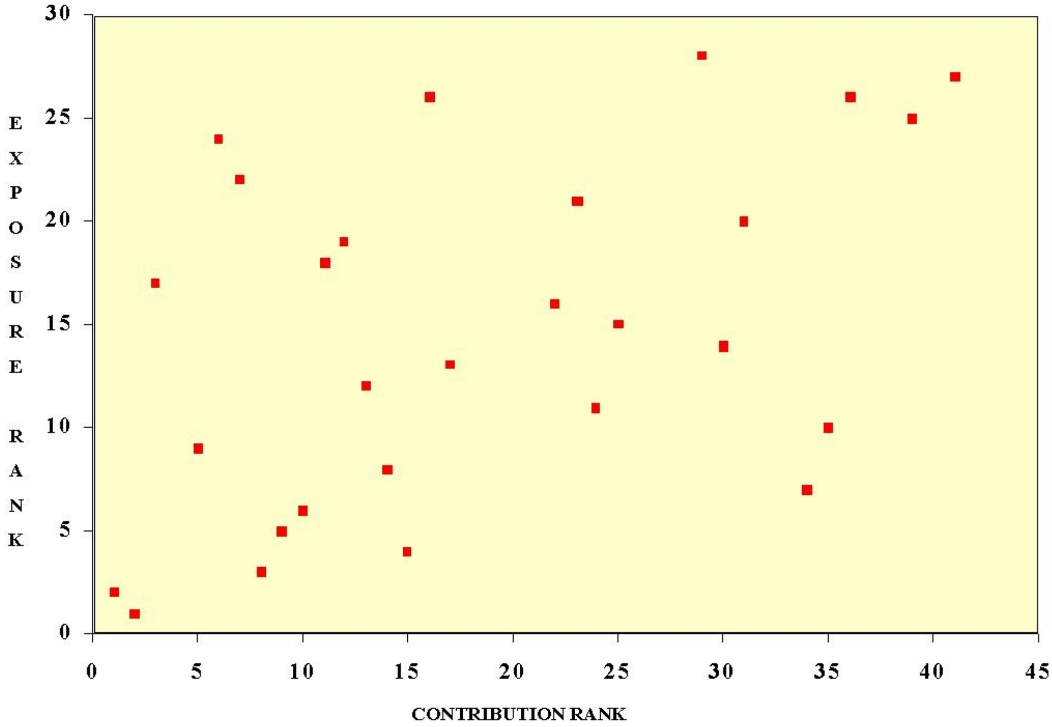

Figure 8.9: Storm tide total risk relationship

Total cyclone risk: Given that cyclones are compound hazards which bring with them (in severe cases) destructive winds, storm tide, flood and landslide, it is appropriate to consider the cumulative total risk represented by a severe cyclone impact. To do this we have taking the highest total risk value for each suburb identified in **Table 8.3** (landslide), **Table 8.4** (flood), **Table 8.5** (destructive wind) and **Table 8.6** (storm tide). **Table 8.7** lists the suburbs according to their overall total cyclone risk and the distribution is shown in **Figure 8.11**.

Table 8.7: Level of total cyclone risk of Cairns suburbs

RISK LEVEL	SUBURBS
High total risk	Bentley Park, Cairns North, City, Earlville, Edge Hill, Edmonton, Gordonvale, Manoora, Manunda, Mooroobool, Parramatta Park, Portsmith, Smithfield, Trinity Beach, Westcourt, White Rock, Whitfield, Woree, Yarrabah, Yorkeys Knob
Significant total risk	Aeroglen, Barron, Bayview Heights, Brinsmead, Clifton Beach, Freshwater, Holloways Beach, Kamerunga, Machans Beach, Mount Sheridan, Redlynch, Stratford, Trinity East, Trinity Park
Moderate total risk	nil
Low total risk	Caravonica, Kamma, Kanimbla, Kewarra Beach, Mount Peter, Palm Cove, Wright's Creek
No discernible risk	nil

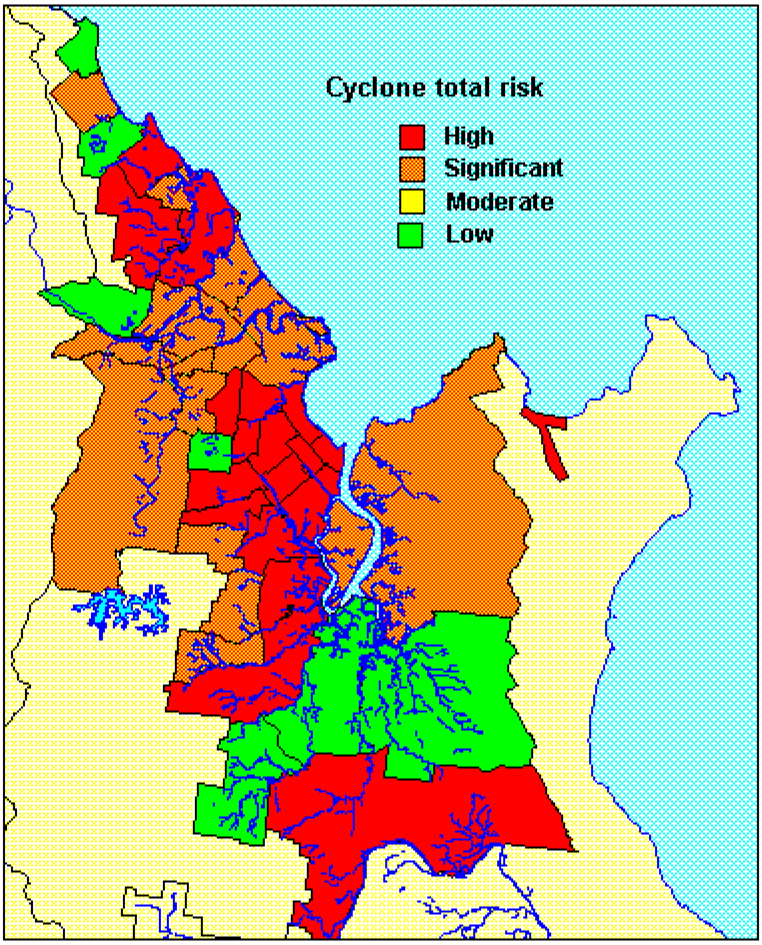

Figure 8.11: Distribution of cyclone total risk

The roughly concentric zonation, centred on the CBD/port area, reinforces the impression gained throughout this study that, in Cairns at least, there is a very strong correlation between the suburbs that contribute most to the overall vulnerability of the community and the degree to which they are exposed to the most significant hazard phenomena. The secondary core risk areas on the northern beaches, at Yarrabah and at Gordonvale reflects the significance of those communities as distinct from the central Cairns community. It is likely, as Cairns grows more to the south, that a similar concentric zonation will develop around the centre that evolves to be the service centre for the southern community. The similarity of the distribution of total risk for cyclones to the distribution of total risk for earthquakes (**Figure 8.2**) is also of significance.

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 Kepner 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 4360:1995*) provides a similar approach based on a matrix to qualitatively rate risk likelihood against its consequences (see Standards Australia, 1995 Appendix D).

Whilst both of these approaches provide a useful method for reaching a qualitative evaluation of risk, especially for a single hazard, they are rather limited and 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 subjective means of identifying the risks that pose the greatest threat to the total community. It also provides a means for identifying the risks that pose the greatest threat to individual suburbs (even neighbourhoods and individual buildings) within the community.

There is no doubt that tropical cyclones pose the greatest threat to Cairns and that **the destructive winds that accompany cyclones pose the greatest level of risk**. Not only do they have a high frequency of occurrence, they also have a wide-spread impact across the entire community. Cairns has come within the radius of destructive winds at least 21 times since 1876 and has suffered severe damage and dislocation as a result. Locally developed design practice aimed at making buildings more resilient to strong winds came into use in the 1950s and were enhanced and formalised with the introduction of national building construction standards in 1975 for major buildings, and 1982 for domestic structures. These have proved to be an effective form of mitigation. Very few buildings constructed since 1975 have suffered more than minor damage by winds in the 10 cyclones that have had an effect on Cairns since that time, though substantial damage has been done to older buildings, unapproved structures (such as patios and sheds) as well as to vegetation and power lines. Even the best constructed modern building, however, is still at significant risk of damage from trees brought down by winds and from wind-blown debris. There is little, however, that can be done to reduce the risk of wind damage to sugar cane or tree crops such as banana and pawpaw which produces significant economic loss.

Given the capacity of the cyclone monitoring and warning system operated by the Bureau of Meteorology there is now virtually no chance of the Cairns community being caught by surprise by a cyclone impact. Thanks to the annual community awareness campaign mounted jointly by the Bureau, the Queensland Department of Emergency Services and Cairns 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 two relatively minor cyclone emergencies in the past three seasons. The risk to life from destructive cyclone winds, therefore, should be small and confined to the foolhardy, who ignore the warnings and advice, or those who do not hear or understand the warnings.

Of the other hazard phenomena generated by cyclones, **storm tide clearly ranks second**. Destructive storm tides have been relatively rare events in Cairns history (only three or four instances over the past 123 years). There is absolutely no doubt, however, that they hold the greatest potential to cause major loss of life and to wreak widespread and massive damage. Their potential for destruction is derived largely from the large numbers of people, buildings and critical facilities that are located within the area in which storm tide impact would be greatest. All of this development pre-dates the introduction of planning constraints aimed at reducing storm tide risk, consequently it provides a substantial residual risk that will need to be addressed by other mitigation strategies.

A significant storm tide would invariably have major environmental impacts. These could include significant coastal erosion and/or deposition that would in turn pose a threat to beachside suburbs such as Holloways Beach, Machans Beach, Yarrabah and Yorkeys Knob. The secondary risk of contamination by salt water and by the impact of the storm tide on facilities such as sewerage treatment works and major agricultural chemical warehouses should also be taken into account.

Whilst earthquake is not widely recognised as a significant threat to Cairns, our research and the known record of seismic activity along the entire east coast of Australia leads us to conclude that **strong earthquake poses the third greatest risk to the Cairns community**. This risk is largely derived from the geology of the region. Much of Cairns is built on thick sediments. In addition, the sediments that underlie much of the downtown area are classed as 'soft'. All these sediments are likely to significantly amplify strong ground motions, even from relatively distant earthquakes. Much of the major construction boom in Cairns took place after the publication of the first Australian earthquake loadings standard in 1979. However, this standard was not used widely in Queensland and, unlike its 1993 successor, did not cover domestic buildings. None-the-less, many Cairns buildings are earthquake-resistant to a degree, having been designed to comply with wind loading standards from around the late 1950s for engineered buildings and 1982 for domestic buildings.

Except in the event of a very strong earthquake we would not expect significant loss of life. Given the experience of the relatively moderate 1989 Newcastle earthquake (Richter magnitude 5.6), however, the catastrophic failure of one or more major buildings in the CBD, because of inappropriate design, poor construction and/or poor condition, can not be ruled out.

The economic risk posed by earthquake in Cairns is substantial, especially in the older parts of the city. The risk to the most vulnerable types of buildings in Cairns is compounded because they are located overwhelmingly on the two least favourable ground conditions – Site Class C and Site Class D. In any future earthquake affecting Cairns, the most pronounced direct damage may occur to these buildings because of their construction type, their condition, and their location. The older and more brittle underground utilities, such as water and sewerage reticulation networks, are especially susceptible to damage. Strong earthquakes also have the potential to create secondary risks such as the spread of fire in the older suburban and commercial areas and the loss of containment of hazardous materials in bulk storage areas such as fuel depots and service stations, although we consider these secondary risks to be low.

As a contrast, the modern, cyclone-resistant building stock in Cairns would perform better in earthquakes than the buildings in many Australian cities where significant proportions are older and constructed of unreinforced masonry. This cyclone-resistant stock comprises about two-thirds of the total number of buildings in Cairns.

Flooding of the Barron River delta is the fourth ranked risk for Cairns. Whilst major flooding in the Barron is clearly more frequent than damaging earthquakes we have ranked the flooding risk behind earthquake risk to the total Cairns community because flooding is confined to a small area, the bulk of which is occupied by agriculture. A damaging earthquake, though rare, will have an impact on the entire community, hence the higher rank we have assigned.

Major flood levels on the Barron River delta have been reached 7 times since 1911 giving an ARI over the past 88 years of around 12 years. Even though planning constraints for development in the flood-prone areas of the delta were not introduced until the early 1990s, land use is predominantly agricultural. Urban areas in Caravonica, Holloways Beach, Machans Beach, Redlynch and Yorkeys Knob together with the road network which links the northern beach suburbs to the city centre are all susceptible to inundation. 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 evacuations if that course of action is indicated.

An extreme flood, such as that experienced in 1911, or the unlikely event of the failure of either the Tinaroo or Copperload Falls Dams, would certainly result in the loss of buildings and could see the course of the Barron River change. The risk of fatalities in such events is significant, especially where people ignore warnings to evacuate, or indulge in stupid behaviour such as ‘surfing’ in the floodwaters or attempting to negotiate flooded roads.

Under such a scenario the Cairns International Airport and the facilities that surround it would also be at significant risk because the levees that protect them would be overtopped. Relief and recovery operations into Cairns would be significantly dislocated by the loss of the airfield. Significant environmental harm would be caused by contamination from facilities such as the sewerage treatment works, the waste chemical treatment facility and the airport bulk fuel stores that would also be inundated.

Landslide and flash flooding share the fifth place in terms of risk priority. Whilst these closely related hazards occur fairly frequently in Cairns, in developed localities they tend to affect only small areas and are a problem for only short periods. The experience of the massive 1951 Ellis beach debris flows, however, is a clear indicator of what can happen along the Cairns escarpment in extreme circumstances. Our information, however, does not permit us to know with any certainty just how rare or extreme that event was.

Even at the smallest scale, either phenomenon can be lethal because of their rapid onset and the lack or warning. Both flash flooding and debris flows in the upper Freshwater Creek valley hold the potential to disrupt the Cairns water supply by damaging the intake and pipeline.

Risk Mitigation Options

The development and implementation of risk mitigation strategies for Cairns lie outside the remit of the *Cities Project*. Our experience in working with emergency managers and others, in Cairns 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 Cairns City Council. The compartmentation and isolation of emergency risk management from the mainstream can best be attributed to the lack of a broad culture of risk management.

Risk management in organisations like Cairns City Council is still at an early stage of development. Whilst the philosophy and practice has taken root in areas such as finance, it has yet to penetrate all areas of Council. 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 Cairns 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 – included elsewhere on this CD-ROM).

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 the Historical Society of Cairns, the Cairns City Library, the *Cairns Post* and the Centre for Disaster Studies at JCU each maintain collections on the community experience of disaster, there is no consolidated index or coordination of information about the Cairns history of disasters and their impact on the community;

- modern event experience: whilst there have been some *ad hoc* efforts made in recent years to collect detailed information about particular episodes, such as Cyclones *Justin* and *Rona* (largely as a part of TCCIP research), such activity is yet to be regarded, or funded, as an essential aspect of risk management. Much of this 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;

- 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 it 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)

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 investments in risk information, warning systems, risk science and emergency planning is completely wasted unless they also influence the community to adopt risk reduction strategies. An effective strategy of risk communication is, therefore, essential.

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. 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, none-the-less, 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 mitigation. 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 Cairns with the Council's Flood Immunity Policy.

If planning constraints are not a viable option (as is the case with destructive winds and earthquakes), 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.

Cairns City Council enforces the provisions of the Australian Building Code, which establish minimum standards for construction to safely withstand established levels of earthquake and wind risk. Whilst these standards minimise the risk to new buildings, standards have also been, or are in the process of being, 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.

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 Cairns City Council has a Flood Immunity Policy for new development. It requires immunity to the 100 year ARI flood/storm tide event for fill levels for buildings, 150 mm above the 100 year ARI immunity for the floor level of residential, tourist and special facilities, and immunity to the 100 year ARI flood event for the floor level of commercial and industrial buildings.

The IPA also contains provisions that will enable councils to change past planning decisions that did not take into account public 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 a previous use redevelopment.

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. The importance of these issues can be seen in the following Cairns examples:

- with the centre of gravity of Cairns population consistently moving south towards Gordonvale, sites for the redevelopment of critical facilities such as hospitals, nursing homes, bulk fuel supply depots, cold stores and telecommunications hubs should be identified and set aside as soon as possible. Such developments should take into account the likely future needs of the community, as well as making provision to satisfy the needs of the current community. Encouragement should be given to the redevelopment of critical facilities, especially those in suburbs such as Cairns North, City and Portsmith, on less hazard prone sites, as they reach the end of their current operational life;

- were the development of the Trinity East area to proceed as proposed, with the area being filled to at least 3.40 m above AHD to withstand inundation events to that level, careful modelling of the affect that such a change would have on storm tide levels in suburbs such as City, Parramatta Park and Portsmith should be required. With the experience of the effect on flood levels on the Machans Beach side of the Barron River produced by the construction of levees to protect the airport in 1988 as a guide, consideration of impacts beyond the Trinity East development should be mandatory.

Emergency management: The emergency management process is based on consideration of the prevention, preparedness, response and recovery phases of disasters (known as PPRR). Under the adaptation of *AS/NZS 4360:1995* to emergency risk management, these traditional components of emergency management can be seen as risk treatment options. The emphasis is on the treatment of residual risks (i.e. the risks that can not be eliminated or reduced by other means), especially in the preparedness, response and recovery 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 with too few resources, too late. 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. One extreme is probably as dangerous as the other is.

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. 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 Cairns and other real urban centres.

Critical facility protection: The loss 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 uninteruptable power supply (UPS) or a stand-by generator to cover the loss of reticulated power supply. Or it may embrace costly structural defences such as the constructing 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.

Engineered defences: 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 or poor maintenance;
- they foster a false sense of security in the community that they are supposed to protect, with the result that when they fail, the community is exposed to a much greater degree of loss; and,
- a defence against one hazard may exacerbate the risk posed by another hazard. For example, to place extensive fill in an area to reduce an inundation risk could, unless adequately engineered, increase the risk of earthquake damage through enhanced shaking or permanent ground displacement.

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 Cairns a Risky Place?

For an isolated city of more than 120 000 people located in the wet tropics, Cairns has a relatively low level of risk exposure to all hazards within the 1% annual exceedence probability range (i.e. an ARI of 100 years or less). Whilst events within this range will cause some loss **and put lives at risk**, 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 **so long as the population is aware and prepared**. There are also cost effective steps that can be taken to reduce the current level of risk even further.

Importantly, there have been no fatalities directly attributable to the impact of a natural hazard in the Cairns community in the past two decades, in spite of this being a period of very rapid population growth. This record can, in part, be attributed to the fact that there were no significant earthquakes and very few major cyclone or flood impacts during that time. It can also be attributed, in part, to the implementation of hazard-based planning constraints, the introduction of building codes and an effective local emergency management capability. These risk mitigation strategies have minimised the exposure of new developments to hazards and maximised resilience of structures to the more common hazard impacts. **Overall, we would assess Cairns as having an tolerable level of risk exposure to the more frequently occurring hazards.** 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 tourism and agriculture**.** A tolerably low level of risk, in exchange for community wealth, is perhaps not such a bad deal!

The Cairns community does, none the less, have a very high level of residual risk exposure to the less frequent and more severe events, especially strong earthquakes, severe cyclones and major debris flows. Events with an AEP of 0.2% or less (an ARI of 500 years or more) will inevitably cause significant economic harm and some (and potentially significant) loss of life. In these rarer and more extreme events, the loss of critical facilities, especially in Cairns North, City, Parramatta Park and Portsmith, 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. The community will consequently be faced with a long recovery and restoration period. This is especially significant given the Cairns community's isolation and its heavy reliance on disaster-sensitive industries such as tourism and agriculture.

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 to even the most extreme event over time by implementing long-term planning strategies (such as the relocation of critical facilities) 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.

Where to From Here?

At the beginning of this provisional multi-hazard risk assessment of Cairns we stated that it was 'a starting point, rather than an end in itself'. We restate this view at its conclusion.

There is much that can be done to improve the assessment. We have, for example, deliberately avoided making economic assessments of potential loss because we lack the necessary expertise, models and data on which to base such an assessment. We are confident, however, that to add a soundly based economic dimension to the assessment would be a relatively minor undertaking.

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 near future and when they do, this study should be updated and its assessments re-evaluated.

Turning the information and the risk assessments provided here into risk mitigation strategies is a task for others, particularly Cairns City Council and the Cairns community. 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. There is also a strong level of commitment to risk management beginning to emerge. We are confident that Cairns is well on the way to becoming a much safer, and consequently more sustainable and prosperous community.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
AEMI	Australian Emergency Management Institute
AEP	annual exceedence probability
AGSO	Australian Geological Survey Organisation
AHD	Australian Height Datum
ANU	Australian National University
ARI	average recurrence interval
AVHRR	Advanced Very High Resolution Radiometer
BLEVE	boiling liquid expanding vapour explosion
BoM	Bureau of Meteorology
C	Celsius
CBD	central business district
CCD	Census Collection District
CHEM	Chemical Hazards and Emergency Management (Unit)
cumec	cubic metres per second
DDC	Disaster District Coordinator
DEM	digital elevation model
DES	(Queensland) Department of Emergency Services
EDRI	Earthquake Disaster Risk Index
FEMA	(US) Federal Emergency Management Agency
FNQEB	Far North Queensland Electricity Board
FNQR	Far North Queensland Regiment
GIS	geographic information system
GMS	Global Meteorological Satellite
ha	hectares
HAT	highest astronomical tide
hPa	hecto-pascals
HQ	headquarters
hr(s)	hour(s)
ICA	Insurance Council of Australia
JUHI	Joint Underground Hydrant-refuelling Installation
JUMP	Joint Urban Monitoring Program
km	kilometres
km/hr	kilometres per hour
LDC	Local Disaster Committee
LPG	liquid petroleum gas
m	metres
max	maximum
min	minimum
ML	Local (or Richter) magnitude
mm	millimetres
MM	Modified Mercalli intensity
m/sec	metres per second
MEOW	maximum envelope of water
MMI	Modified Mercalli Intensity
NIBS	(US) National Institute of Building Sciences
NOAA	(US) National Oceanographic and Atmospheric Administration
PGA	peak ground acceleration

PNG	Papua New Guinea
QPS	Queensland Police Service
QUAKES	Queensland University Advanced Centre for Earthquake Studies
RAN	Royal Australian Navy
RFDS	Royal Flying Doctor Service
SEIFA	Socio-Economic Indexes for Areas
SES	State Emergency Service
IDNDR	International Decade for Natural Disaster Reduction
SLA	Statistical Local Area
SP	short period (seismograph)
TCCIP	Tropical Cyclone Coastal Impacts Program
temp	temperature
UHF	ultra high frequency
UNDRO	United Nations Disaster Relief Organisation
VHF	very high frequency
WWSSN	World Wide Standardised Seismograph Network

APPENDIX B: PARTNERS

Operational Partners

Bureau of Meteorology
Emergency Management Australia
Queensland Department of Emergency Services
Cairns City Council

Research Partners

Australian National University (Centre for Resource and Environmental Studies)
James Cook University (Centre for Disaster Studies)
James Cook University (Cyclone Testing Station)
Macquarie University (Natural Hazards Research Centre)
University of Queensland (Queensland University Advanced Centre for Earthquake Studies)

Supporting Partners

Aboriginal Coordinating Council
Australian Coordinating Committee for the IDNDR
Australian Survey and Land Information Group
Cairns Port Authority
Centre for Earthquake research in Australia
CSIRO (various divisions)
Department of Natural resources
Department of Mines and Energy
Department of Environment and Heritage
ERSIS Australia P/L
Far North Queensland Electricity Board
Fred Baynes P/L
Golder Associates P/L
Gutteridge Haskins & Davey P/L
Mulgrave Central Mill P/L
Yarrabah Community Government

APPENDIX C: ELEMENTS AT RISK DETAILS

Table C1: Cairns building use by suburb

SUBURB	Av. elev	Buildings	Houses	Flats	Accom	Business	Logistic	Safety	Comm.
Aeroglen	5.4	245	148	3		19	60	6	6
Bayview Heights	52.9	1456	1446	5					3
Bentley Park	27.6	1293	1202	59		21	5		4
Brinsmead	25.3	1050	1037	1	3	2	1		3
Cairns North	2.7	871	471	161	68	69	15	15	47
Caravonica	12.2	546	532	8	1			1	3
City	2.1	581	53	31	63	316	22	26	56
Clifton Beach	9.8	695	649	23	7	2	2		6
Earlville	19.0	1206	1040	75	3	49	9	3	20
Edge Hill	13.9	1382	1215	107	3	15	4	1	34
Edmonton	21.0	1576	1407	115	4	21	3	3	18
Freshwater	22.9	606	534	48	4	6	3	1	8
Gordonvale	19.9	1697	1526	54	4	33	8	20	40
Holloways Beach	5.1	840	694	120	17	5		1	2
Kamerunga	20.9	247	239	3	1	1			2
Kanimbla	44.8	291	281	5					
Kewarra Beach	12.1	946	903	33	1		1		8
Machans Beach	2.3	413	398	4		1	3		5
Manoora	5.9	1307	1068	191	7	22	5	3	11
Manunda	2.4	1526	1015	229	46	85	14	9	118
Mooroobool	20.5	2062	1951	91		2	1		16
Mount Sheridan	30.6	1003	971	27		2			3
Palm Cove	13.2	310	208	29	47	7		2	7
Parramatta Park	2.3	989	667	122	2	133	13	7	37
Portsmith	2.3	812	184	39	4	392	148	8	11
Redlynch	37.6	913	875	13	3	5	4		10
Smithfield	22.0	1060	1008	2		21	9	4	14
Stratford	16.6	395	339	17	4	16	4	2	8
Trinity Beach	10.9	1019	900	78	19	9	1	2	10
Trinity Park	3.3	333	327	1		1	1		3
Westcourt	2.7	1882	1155	260	16	317	34	27	59
White Rock	9.5	1051	962	68	2	8	2		6
Whitfield	20.6	1474	1268	173	1	3	3	23	2
Woree	22.1	1298	1003	191	14	24	16	5	37
Yarrabah	6.7	312	215	17		7	3	14	42
Yorkeys Knob	4.3	721	559	130	10	4	4		11
TOTALS		34408	28450	2533	354	1618	398	183	670

Notes:
1. Counts relate to individual buildings rather than ‘dwelling units’ in the case of flats or ‘facilities’ in the case of business, etc.
2. **Av. Elev** is the average ground-level elevation of all buildings in the suburb above AHD.
3. **Accom** includes all commercial accommodation such as hotels, motels and caravan parks.
4. **Business** includes all industrial and office buildings most commercial buildings.
5. **Logistic** includes all bulk supply, cold stores, transport, storage and fuel distribution buildings major plus supermarkets and shopping malls.
6. **Safety** includes all defence, police, fire ambulance, SES and medical facilities.
7. **Comm.** (community) includes facilities such as churches, halls, public toilets, etc; schools and child care; recreational facilities; and government buildings.
8. The tally of individual uses may not agree with the total buildings because minor uses, such as utilities and developed open space, have not been included.

9. The rural suburbs of Barron, Kamma, Mount Peter and Wright’s Creek are not included.

Table C2: Structural characteristics of Cairns houses

	Sample	Floor height			Wall Material					Roof Material		
SUBURB	ratio	Slab	<1m	>1m	Brick	Block	Timber	Fibro	Metal	Metal	Tile	Fibro
Aeroglen	134:14:0	60	13	75	5	38	75	27	3	145	1	2
Bayview Heights	1362:75:9	1100	252	94	441	877	57	67	4	1311	132	3
Bentley Park	1138:57:7	1202			2	1200				1200	2	
Brinsmead	901:114:25	1005	4	28	101	860	62	10	4	1017	20	
Cairns North	438:34:1	118	40	313	18	39	279	107	28	454	6	11
Caravonica	501:31:0	514	2	16	18	451	41	20	2	482	50	
City	48:5:0	17	5	31	6	5	24	14	4	48	3	2
Clifton Beach	617:33:0	568	55	26	73	503	44	14	15	592	56	1
Earlville	1005:35:0	621	117	302	223	344	343	68	62	1017	20	3
Edge Hill	1170:47:0	692	124	399	236	428	367	157	27	1169	39	7
Edmonton	268:1139:0	1372	22	13	15	1355	18	16	3	1399	6	1
Freshwater	486:48:0	349	36	149	102	203	155	64	9	503	29	2
Gordonvale	184:441:901	1417	75	34	14	515	50	32	14	624		1
Holloways Beach	685:9:0	621	42	31	65	519	42	58	10	666	19	9
Kamerunga	136:103:0	186	6	47	11	143	75	6	4	237	2	
Kanimbla	254:26:1	278		3	22	254	3	2		258	23	
Kewarra Beach	769:134:0	891	7	5	37	833	25	6	2	805	98	0
Machans Beach	398:0:0	193	68	137	9	87	114	177	11	393	1	4
Manoora	1034:34:0	678	167	223	144	495	163	217	49	1051	16	1
Manunda	973:42:0	449	263	303	150	270	309	210	76	990	17	8
Mooroobool	1829:122:0	1784	77	90	539	1181	139	57	35	1776	175	
Mount Sheridan	768:203:0	971			9	960	2			964	7	
Palm Cove	201:6:0	170	19	15	8	157	21	19	3	193	14	1
Parramatta Park	659:8:0	150	86	431	23	69	376	131	68	658	4	5

Portsmith	181:3:0	50	63	71	7	24	87	43	23	183		1

Table C2 (cont.): Structural Characteristics of Cairns Houses

SUBURB	Sample ratio	Floor height			Wall Material					Roof Material		
		Slab	<1m	>1m	Brick	Block	Timber	Fibro	Metal	Metal	Tile	Fibro
Redlynch	667:66:142	808	8	59	25	643	12	52	1	723	10	
Smithfield	962:44:2	968	6	34	91	802	89	18	4	971	34	
Stratford	333:7:0	147	41	151	39	80	179	32	9	334	1	4
Trinity Beach	884:19:0	859	12	29	66	704	101	21	6	866	31	3
Trinity Park	327:0:0	290	28	9	17	284	11	10	4	325	1	1
Westcourt	1123:33:0	426	325	404	224	214	411	193	113	1107	17	31
White Rock	797:100:65	863	63	36	91	729	42	38		884	15	1
Whitfield	1205:63:0	876	148	244	316	591	255	89	17	1192	69	7
Woree	977:25:0	767	198	38	161	791	20	28	3	956	47	
Yarrabah	215:0:0	78	99	38		107	15	66	27	214		1
Yorkeys Knob	538:21:0	500	30	29	33	391	62	64	6	530	20	9
TOTALS		22038	2501	3907	3342	17070	4069	2134	647	26280	905	119

NOTES:

1. **Sample ratio** is the ratio between houses for which the data have been observed in the field, to those estimated (typically based on field sampling only), to those which remain unknown. Note that the largest proportion of 'unknown' are in suburbs with high proportions of rural dwellings such as Freshwater, Gordonvale and Redlynch.
2. **Slab** is taken to be 0.3m above ground level. A floor height of 0.3m (i.e. slab) has been set as the default value for 'estimated' and 'unknown' classes for inundation modelling purposes only.
3. **<1m** relates only to suspended floors.
4. **Wall Material** relates to the dominant material. In older areas there may be as many as four different wall materials in the one house.
5. **Metal** walls include aluminium and vinyl cladding, typically replacing (or covering) fibro.
6. The numbers in each group should be seen more as reflecting ratios rather than definitive and absolute values because of incomplete data in some of the southern suburbs.

Table C3: Cairns household access to vehicles (% of total households) 1996

SUBURB	0 car	1 car	2 cars	3+ cars	N/S
Aeroglen	3.8	44.8	32.2	15.3	3.8
Bayview Heights	1.1	34.1	37.2	24.1	3.4
Bentley Park	2.5	33.9	48.3	10.2	5.1
Brinsmead	2.1	30.4	45.7	17.4	4.4
Cairns North	28.6	35.4	19.4	5.1	11.4
Caravonica	8.2	42.6	39.3	4.9	4.9
City	36.2	33.0	8.5	3.2	19.1
Clifton Beach	7.7	40.6	38.3	7.7	5.7
Earlville	5.4	40.0	29.2	9.2	16.2
Edge Hill	4.4	36.4	35.1	21.5	2.6
Edmonton	7.9	44.3	36.2	6.2	5.3
Freshwater	10.5	42.6	30.2	8.5	8.1
Gordonvale	4.0	39.4	45.1	9.1	2.4
Holloways Beach	7.5	46.0	31.5	7.0	8.0
Kamerunga & Redlynch	8.2	34.7	40.8	11.2	5.1
Kanimbla	3.5	38.1	39.2	14.8	4.4
Kewarra Beach	1.4	43.9	44.9	7.1	2.7
Machans Beach	12.0	44.0	28.0	6.0	10.0
Manoora	14.5	46.6	28.1	4.1	6.8
Manunda	15.2	45.5	26.1	7.9	5.5
Mooroobool	1.5	25.0	49.5	13.5	10.5
Mount Sheridan	3.3	32.6	48.5	14.4	1.1
Palm Cove	9.1	53.6	24.6	6.0	6.7
Parramatta Park	17.2	45.2	21.5	6.5	9.7
Portsmith	42.3	38.3	9.5	0.0	10.0
Smithfield	4.2	37.9	39.1	14.2	4.6
Stratford	6.8	37.4	35.6	13.5	6.8
Trinity Beach	8.7	45.8	34.4	4.0	7.1
Trinity Park	6.0	38.6	39.5	14.1	1.8
Westcourt	24.3	42.4	19.0	7.3	7.0
White Rock	10.9	57.0	20.6	4.2	7.2
Whitfield	11.1	47.5	27.3	11.4	2.6
Woree	2.6	32.5	47.2	13.9	3.9
Yarrabah	45.2	32.8	10.7	3.8	7.5
Yorkeys Knob	19.9	45.3	24.3	3.6	6.9
TOTALS	7.9	32.0	27.6	9.5	5.7

Source: derived from data contained in *CData 96 Final Release* (ABS, 1998a)

Table C4: 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 (%)
households renting (government authority) (%)

Variables with weights between 0.1 and 0.2

persons aged 15 and over separated or divorced (%)
dwellings with no motor cars at dwelling (%)
employed females classified as ‘Intermediate Production & Transport Workers’ (%)
employed females classified as ‘Elementary Clerical, Sales & Service Workers’ (%)
employed males classified as ‘Tradespersons’ (%)
persons aged 15 and over who did not go to school (%)
Aboriginal or Torres Strait Islanders (%)
occupied private dwellings with two or more families (%)
lacking fluency in English (%)

Table C5: 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 4 or more bedrooms (%)
families with family structure other than two parent or single parent with dependent offspring
or consisting of a couple only, and income greater than $77,999 (%)
families consisting of a couple only, and with income greater than $62,399 (%)
families consisting of a single parent with dependent offspring, with income greater than $31,199 (%)
mortgage greater than $1,300 per month (%)
rent greater than $249 per week (%)

Variables with weights between 0 and 0.2

households purchasing dwelling (%)
households owning dwellings (%)
dwellings with 3 or more motor cars (%)
average number bedrooms per person (%)

Variables with weights between -0.2 and 0

households in improvised dwellings (%)
households renting (government authority) (%)
households renting (non-government authority) (%)
dwellings with 1 or no bedrooms (%)
rent less than $74 per week (%)
families consisting of a single parent with dependent offspring, with income less than $15,600 (%)

Variables with weights between -0.3 and -0.2

families consisting of a couple only, and with income less than $15,600 (%)
families with family structure other than two parent or single parent with dependent offspring or consisting of a couple only, and income less than $26,000 (%)
families consisting of a two parent family with dependent offspring, and income less than $26,000 (%)
dwellings with no motor cars (%)

Table C6: Cairns Schools

SCHOOL	ADDRESS	LOCALITY	PRE	PRI	SEC	STAFF
Aloomba State School	Neilsen Street	Aloomba		41		2
Balaclava State School	418 Mulgrave Road	Westcourt	62	561		32
Cairns Central State School	Aplin Street	City		na		na
Cairns Christian College	Brinsmead Road	Brinsmead			na	na
Cairns North State School	381 Sheridan Street	Cairns North	18	171		12
Cairns School of Distance Ed	Hoare Street	Manunda				na
Cairns SDA School	Bosanko & Gatton	Manunda		na		na
Cairns State High School	156 Sheridan Street	Cairns North			886	70
Cairns West State School	14-36 Mayers Street	Manunda	62	540		35
Caravonica State School	Kamerunga Road	Caravonica	39	531		32
Edge Hill State School	254 Pease Street	Edge Hill	100	663		41
Emmanuel College	83 Pease Street	Manoora			na	na
Freshwater State School	60 Old Smithfield Rd	Freshwater	50	437		25
Gordonvale State High Sch	85-107 Sheppards St	Gordonvale			498	40
Gordonvale State School	28 George Street	Gordonvale	88	458		29
Hambledon State School	77-81 Stokes Street	Edmonton	50	556		32
Holy Cross School	Reed Road	Trinity park		na		na
Machans Beach State School	61 Machans Street	Machans B		107		
Mother of God Counsel Sch	392 Sheridan Street	Cairns North		na		na
Our Lady Help of Christians	18 Balaclava Road	Earlville		na		na
Parramatta State School	122 Mulgrave Road	Parramatta Pk	66	312		28
Redlynch State School	Jungara Road	Redlynch	50	265		19
Smithfield State High School	O'Brien Road	Smithfield			966	70
St Augustine's College	Scott Street	Parramatta Pk			na	na

St Francis Xavier's School	5 Atkinson Street	Manunda		na		na
St Gerard Majela	63 Anderson Road	Woree		na		na
St Joseph's School	11 Loeven Street	Parramatta Pk		na		na
St Mary Catholic College	Anderson Road	Woree			na	na
St Michael's School	58 Mill Street	Gordonvale		na		na
St Monica's College	179 Abbott Street	City			na	na
St Therese's School	135 Roberts Road	Bentley Park		na		na
Trinity Anglican School	Poolwood Road	Kewarra Bch		na		na
Trinity Anglican School	Leftwich Street	White Rock		na		na
Trinity Bay State High School	Hoare Street	Manunda			1085	80
Trinity Beach State School	Wewak Street	Trinity Beach	98	702		40
White Rock State School	Progress Road	White Rock	50	401		22
Whitfield State School	McManus & Marino	Whitfield	38	425		25
Woree State High School	Rigg Street	Woree			910	67
Woree State School	82-96 Windarra St	Woree	96	775		43
Yarrabah State High School	Back Beach Road	Yarrabah			76	na
Yarrabah State School	Beach Street	Yarrabah	105	307		36
Yorkeys Knob State School	Clinton Street	Yorkeys Knob		156		8

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 C7: Cairns Child Care Centres

CENTRE	ADDRESS	SUBURB
Bayview Heights Community Kindergarten	6-8 Jasper Street	Woree
Bib an Baya Day Care	9 Brose Street	White Rock
Boopa Werem Kindergarten	12 Barrett Street	Westcourt
Brinsmead Valley Child Care	Loridan Drive	Brinsmead
Cairns Noahs Ark	92 Little Street	Manunda
Callum Early Learning Daycare	100 Callum Street	Mooroobool
Casey Clowns Childcare	274 Buchan Street	Westcourt
Cat and Fiddle Kindy and Childcare	60-64 Roberts Road	Bentley Park
Child Care and Development Association	108 Collins Avenue	Edge Hill
Childrens Centre	88 Balaclava Road	Earlville
Childs Play Day Care Centre	38 James Street	Manunda
Community Childcare Centre	Newton Street	Manunda
Eastville Early Learning	29 Cavallaro Avenue	Earlville
Edmonton Community Kindergarten	19 Hartill Street	Edmonton
Gordonvale Community Childcare	69-75 Moller Street	Gordonvale
Holloways Beach Kindergarten	7 Jacaranda Street	Holloways beach
Jack and Jill Daycare	70 Anderson Street	Manunda
Juniors Childcare Centre	160-162 Hoare Street	Manoora
Just Kids Childcare Centre	219 Draper Street	Parramatta Park
Karatane Kindy and Child care	2-4 kangaroo Street	Bentley Park
Kawana Day Care	3 Charlotte Close	Woree
Kewarra Beach Early Learning	11-13 Cottesloe Drive	Kewarra Beach
Kiddie Academy	12-14 Reservoir Road	Manoora
Kids and Hugs Day Care	Alfred Street	Manunda
Kids Corner Day Care	24 Ravizza Drive	Edmonton
Kindercare	21-23 Fisher Road	Gordonvale
Kindergarten Woree	614 Bruce Highway	Woree
Mulgrave Day Care	466 Mulgrave Road	Earlville
Mulgrave Road Day Care	464 Mulgrave Road	Earlville
Novotel Palm Cove Child Care Centre	Coral Coast Drive	Palm Cove
Preschool Day Care Centre	3 Marino Street	Whitfield
Seventh Day Adventist Child Care Centre	282-284 Birch Street	Manunda
Smithfield Childcare Centre	Cheviot Street	Smithfield
Sheridan Childcare	381 Sheridan Street	Cairns North
Tamarind Gardens Child Care	36-38 Trafalgar Road	Mount Sheridan
Tot Stop Child Care and Preschool	2-4 Slathiel Street	Brinsmead
Waratah Day Care Centre	8 Waratah Drive	Manunda
Windarra Day Care Centre	27 Windarra Street	Woree

Yarrabah Preschool Centre	Smith Street	Yarrabah

Table C8: Variables used in the SEIFA *Index of Education and Occupation* (ABS, 1998b)

Variables with weights between 0.2 and 0.4

employed males classified as 'Professionals' (%)
employed females classified as 'Professionals' (%)
persons aged 15 and over at CAE or university (%)

Variables with weights between 0 and 0.2

employed males classified as 'Associate Professionals' (%)
employed females classified as 'Advanced Clerical & Social Workers' (%)
employed males classified as 'Advanced Clerical & Social Workers' (%)
employed males classified as 'Intermediate Clerical, Sales & Service Workers' (%)

Variables with weights between -0.2 and 0

employed females classified as 'Tradespersons' (%)
employed males classified as 'Tradespersons' (%)
employed females classified as 'Elementary Clerical, Sales & Service Workers' (%)
employed females classified as 'Intermediate Production & Transport Workers' (%)

Variables with weights between -0.4 and -0.2

employed males classified as 'Intermediate Production & Transport Workers' (%)
employed females classified as 'Labourer & Related Worker' (%)
employed males classified as 'Labourer & Related Worker' (%)
males (in labour force) unemployed (%)
females (in labour force) unemployed (%)
person aged 15 and over who left school at or under 15 years of age (%)
person aged 15 years and over with no qualifications (%)

Table C9: Cairns Community Organisations

SPORTS AND HOBBIES REPRESENTED	SERVICES REPRESENTED
Archery	Aboriginal and Torres Strait communities
Athletics	Apex
Badminton	Asthma Association
Baseball	Australian American Association
Basketball	Blind Association
Bird fanciers	Boy Scouts
Bowling	Chamber of Commerce and Industry
Cars and motor racing	Conservation and environmental groups
Cats	Country Women's Association
Chess	Croatian community
Country music	Diabetes Association
Coursing and kennel	Endeavour Foundation
Cricket	Epilepsy Association
Dance	German community
Fishing	Girl Guides
Flying and gliding	Historical Society
Football (all codes)	Hungarian community
Gem and lapidary	Jaycees International
Golf	Lyons International
Gymnastics	Masonic and other lodges
Hockey	Police and Citizens Youth Club
Life saving and surfing	Professional and business groups
Martial arts	Rape Crisis and Incest Services
Model aeroplanes	Red Cross
Netball	Returned Services League
Racing, hunting and pony	Rotary
Scuba diving	Rotaract
Shooting	RSPCA
Squash	St Johns Ambulance
Swimming	Soroptimists International
Table tennis	UFO Research
Tennis	Women's Information and Referral
Vigoro	Yarrabah Women's Resources Centre
Volleyball	Young Australia League
Yachting and boating	Zonta International

Table C10: Cairns Critical Facilities

FACILITY	STREET	SUBURB	HAZARDOUS
ABC Studios	Sheridan St	City	
ABC Radio Transmitters	Warner Rd	Gordonvale	
Airport Control Tower	Airport Ave	Aeroglen	
Airport Rescue and Fire Service	Sir Sydney Williams St	Aeroglen	
Ambulance Station Cairns	Anderson St	Manunda	
Ambulance Station Edmonton	Hartill St	Edmonton	
Ambulance Station Gordonvale	Cannon St	Gordonvale	
Ambulance Station Smithfield	Stanton Rd	Smithfield	
Ambulance Station Yarrabah	Stanley Rd	Yarrabah	
Ampol Fuel Depot	Bunda St	Portsmith	major
Bethlahem Nursing Home	Gatton St	Westcourt	minor
Boral Gas Depot	Draper St	Portsmith	major
Cairns Central	McLeod St	City	yes
Cairns City Council Centre	Little Spence St	Portsmith	
Cairns City Council Works Depot	Martyn St	Manunda	yes
Cairns City Council Works Depot	Highleigh Rd	Gordonvale	yes
Cairns Crocodile Farm	Redbank Rd	Kamma	yes
Cairns Hospital	Abbott St	Cairns North	yes
Cairns Port Facilities	Wharf St	Portsmith	yes
Caltex Fuel Depot	Kenny St	Portsmith	major
Calvary Hospital	Abbott St	City	yes
Country Bake Bakery	Spence St	Westcourt	
Country Bake Bakery	Supply Rd	Bentley Park	
CSR Bulk Sugar Terminal	Cook St	Portsmith	yes
FARNOHA Nursing Home	Lyons St	Westcourt	minor
Festival Faire	Alfred St	Manunda	yes
Fire Station Cairns	Gatton St	Westcourt	minor
Fire Station Gordonvale	Cannon St	Gordonvale	
Fire Station Smithfield	Lesley St	Smithfield	
FNQEB Cairns Substation	Hartley St	City	yes
FNQEB Gordonvale Substation	Highleigh Rd	Gordonvale	yes
FNQEB Kamerunga Bulk Supply	Kamerunga Rd	Caravonica	yes
FNQR 51st Battalion Depot	Coxall St	Westcourt	yes

Fresha Products Cold Stores	Redden St	Portsmith	yes
Fortuna Seafood Cold Stores	Tingiri St	Portsmith	yes
Garozzo Agencies Wholesale Food	Redden St	Portsmith	yes
Gordonvale Memorial Hospital	Alley St	Gordonvale	minor
Good Samaritan Nursing Home	Tills St	Westcourt	minor
HMAS Cairns	Draper St	Portsmith	major
INCITEC	Dutton St	Portsmith	major
Mobil Fuel Depot	Kenny St	Portsmith	major
Nazareth Village Nursing Home	Gatton St	Westcourt	minor
Police Station Cairns	Sheridan St	City	
Police Station Smithfield	Captain Cook Hwy	Smithfield	
Police Station Yarrabah	Back Beach Rd	Yarrabah	
Portsmith Cold Stores	Redden St	Portsmith	yes
Pyramid Retirement Centre	Cairns Rd	Gordonvale	minor
Sewerage Treatment Plant	Greenbank rd	Aeroglen	yes
Shell Fuel Depot	Draper St	Portsmith	major
Smithfield Plaza	Captain Cook Hwy	Smithfield	yes
Southern Pollution Control Centre	Maconachie St	Woree	yes
FACILITY	**STREET**	**SUBURB**	**HAZARDOUS**
Stockland Plaza	Mulgrave Rd	Earlville	yes
Telephone Exchange Cairns	Shields St	City	yes
Tong Sing Wholesale Fruit & Veg	Little Spence St	Portsmith	yes
Water Treatment Plant Kanimbla	Reservoir Rd	Kanimbla	yes
Water Treatment Plant Yarrabah	Back beach Rd	Yarrabah	yes
WB Winfield Nursing Home	McManus St	Whitfield	minor
Westcourt Plaza	Mulgrave Rd	Westcourt	yes
Yarrabah Hospital	Smith St	Yarrabah	minor
Yarrabah Council Works Depot	Workshop Rd	Yarrabah	yes

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: CAIRNS 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	1
Fl_ht	Decimal	3,1
Gd_ht	Decimal	6,2
Stories	Decimal	2,0
Walls	Character	1
Roof	Character	1
Ro_shape	Character	1
Ro_pitch	Character	1
Windows	Character	1
Plan_reg	Character	1
Vert_reg	Character	1
Age	Character	1
Bldg_year	Character	4
Units1	Decimal	2,0
Units2	Decimal	2,0
Units3	Decimal	3,0
Plan_reg	Character	1
Vert_reg	Character	1
Status	Character	1
Comments	Character	35
Lot_plan	Character	15
Longitude	Decimal	9,4
Latitude	Decimal	9,4
Std50	Character	1
Std100	Character	1
Std500	Character	1
Std1000	Character	1
Std10000	Character	1
V_zone	Decimal	4,2
Velocity	Character	1
Slope	Integer	
Aspect	Character	2

NOTE: in the following description, attributes in **bold** need to be collected in the field; attributes underlined 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.

Number The building number in the street - used for mapping annotation purposes only.

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:

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 facility* 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 10cm. 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.

Stories The number of stories above ground.

Walls Material from which the features walls are constructed with the following codes:

B	brick, masonry or stone
C	concrete block
P	precast concrete slab
R	reinforced concrete frame
T	timber
F	fibro
M	metal

Roof Material from which the roof is constructed with the following codes:

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 ration (eg ‘soft story’ 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 (eg 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

In general terms these dates reflect significant changes in building regulations and/or practice (eg 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 vogue after 1955).

Bldg_year Year in which the building was completed. Used only where adequate council records are available or where there is other evidence such as a heritage plaque.

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 letter boxes; 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
- 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 the rates or 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 Discounting value applied to sea wave height on top of surge height and wave setup to estimate increased inundation level. Values used are 0.8 in the first 150 metres of the coast, 0.4 in the second 150 metres and 0.2 in the third 150 m from the coast. These values were derived from data provided in Smith and Greenaway (1994).

Velocity Distance from the shore where:

A	within 750 m of the shore
B	750 to 1 500 m from the shore
C	greater than 1 500 m from the shore

These are more or less arbitrary values except that the 750 m threshold is, according to Smith and Greenaway (1994), the distance by which sea wave velocity is largely dissipated.

Slope Average slope of the property derived from the DEM in the following zones:

3	Slopes from 0 to 3 degrees
6	Slopes from 3 to 6 degrees
12	Slopes from 6 to 12 degrees
17	Slopes from 12 to 17 degrees
30	Slopes from 17 to 30 degrees
90	Slopes from 30 to 90 degrees

These values are derived from AS 1170.2-1989 *Wind loads*.

Aspect Direction to which the property faces, derived from the DEM, in the following zones:

N	North
NE	North-East
E	East
SE	South-East
S	South
SW	South-West
W	West
NW	North-West
O	Omnidirectional (flat - no obvious aspect)

APPENDIX E: A METHODOLOGY FOR ASSESSING RELATIVE COMMUNITY VULNERABILITY

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 **Chapter 3** we describe individual aspects of the community and the contribution they make to community vulnerability. We also present an assessment of their relative contribution to the overall community vulnerability of Cairns. 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 three or four years, a large amount of high resolution data has been accumulated on the hazard phenomena, buildings, infrastructure and people of Cairns. 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 Indices

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, of which Cairns is one, 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 word 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 sophisticated statistical analysis such as factor analysis and analysis of variance.

The approach we have developed here is similar in most basic respects to both EDRI and the classic geographic numerical taxonomy studies. It differs from EDRI, however, in two main ways. First, it is being used to assess the risk to a range of hazards across a single city, and second, we have not been constrained by selecting indicators that are available 'universally'. It differs from the sophisticated multi-variate statistical techniques in that it was undertaken using MapInfo and Microsoft Excel rather than specialised and sophisticated 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.

Given that most members of the community already identify themselves at home and at work with a suburban locality, it was decided to use suburbs as the unit of analysis. This level of aggregation also provides computational convenience.

Assumptions

Because we are interested in showing the relative importance of each suburb to overall community vulnerability it was assumed that the most appropriate statistic to use would be the rank of the suburb 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 suburbs.

We have not, as yet, conducted a systematic sensitivity analysis, though our observations during the development of the techniques suggest that whilst relatively minor changes to the inclusion of variables may cause some variation to individual ranks, the overall results remained largely consistent. Further research is, however, required before this technique can be said to be 'proven'.

The choice of suburbs as the basic unit of reference is also problematic. The distribution of variables across suburbs are far from homogeneous; nor have their boundaries been designed to facilitate statistical analysis. Their choice was driven more by simplicity in presentation than any other reason. Most people relate to the suburb in which they live and/or work, few people are even aware of what CCD, for example, they live in. Further work will be done to develop risk 'surfaces' and to identify the most appropriate level of resolution at which to conduct urban risk assessments.

The Setting

Given that the setting group of factors 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 one variable (total population) was selected.

Population: Clearly the most significant element at risk is the population of the community. Suburbs were ranked on the basis of their proportion of the total Cairns population. Whilst the boundaries of the CCDs used in the 1996 census do not align perfectly with the Cairns suburb boundaries, they are, in most instances, close enough for our purposes. The poorest fit is with the three rural suburbs of Kamma, Trinity East and Wright's Creek which are divided between two CCDs. In this instance the values from the census were assigned to Trinity East. Mooroobool, Manoora, Westcourt and Manunda are the four most populous suburbs.

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. Suburbs were ranked on their proportion of the total inventory of houses. The top four suburbs are Mooroobool, Gordonvale, Bayview Heights and Edmonton.

Flats: Flats are the second most significant form of shelter. Again, the proportion of the total Cairns inventory of flats in each suburb was ranked. The top four suburbs on this ranking are Westcourt, Manunda, Woree and Manoora.

Commercial accommodation: For the vast majority of tourists and other visitors, resorts, motels, hotels, caravan parks and hostels provide their shelter. The four suburbs with the greatest proportion of the total commercial accommodation inventory are Cairns North, City, Palm Cove and Manunda.

Average house occupancy: Suburbs were ranked on the average number of people living in separate houses. This is seen as an appropriate measure of population density. These data were extracted from the 1996 census. The four suburbs with the greatest average occupancy rates are Yarrabah (6.4), Redlynch (3.3), Woree (3.2) and White Rock (3.2).

Average flat occupancy: In the suburbs with medium and high density settlement, the average number of occupants per flat, unit or townhouse provides a similar measure of density. These data were also taken from the 1996 census and relate to the occupancy of individual flats rather than the occupancy of buildings. The suburbs with the greatest flat occupancy rates are Trinity Park (2.7), Trinity Beach (2.3), Whitfield (2.1) and Palm Cove (2.1).

Roads: The road network provided the means for people to move to and from shelter. Suburbs were ranked on their proportion of the total Cairns road length. The top four suburbs for roads are Gordonvale, Edmonton, Kamma and Redlynch.

Cars: To the average household in Cairns, the family car (or cars) is their second most important investment after their house. Suburbs are ranked on their proportion of the estimated total number of private cars. This estimate is 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. The top four suburbs for cars are Mooroobool, Edmonton, Bayview Heights and Manoora.

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 suburb that do not have access to a car. The suburbs with the highest ranks are Yarrabah (45.2%), Portsmith (42.3%), City (36.2%) and Cairns North (28.6%).

To reach a composite value for the shelter group, the individual ranks for each variable were summed and the resulting totals ranked. No attempt was made to weight the individual variables. Because we have found no convincing evidence in the literature to suggest otherwise, we have regarded each variable as playing an equal part in establishing the theme's contribution to community risk. Were we developing a measure that emphasised economic risk or insurance exposure, then those variables such as the number of houses, flats and cars could be weighted, on the basis of 'value', more heavily than the number of households with no access to a car, for example.

The four top shelter group suburbs overall are Edmonton, Manunda, Woree and Westcourt.

Sustenance

Four variables were used to represent the sustenance group of elements at risk.

Lifelines: We consider roads to be a good general measure of lifelines. Not only do they represent an important lifeline in their own right, the location and distribution of other lifelines such as water supply, sewerage, power supply and telecommunications are also closely related spatially to the road network. As in the previous group, suburbs were ranked on their proportion of total Cairns road length. The top four suburbs for lifelines are Gordonvale, Edmonton, Kamma and Redlynch.

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 four suburbs with the greatest proportions of the community's total logistic facility inventory are Portsmith, Aeroglen, Westcourt and Parramatta Park.

Power and water supply: The proportion of above-ground facilities supporting both power and water supply, such as power sub stations and water reservoirs, have been used to rank suburbs for this variable. The four top suburbs are Cairns North, Kanimbla, Portsmith and Manunda.

Telecommunications: A similar measure, using the proportion of above ground facilities associated with telecommunications lifelines, such as telephone exchanges and microwave towers was used. The greatest concentration is in Portsmith.

To reach a composite value for the sustenance group, the individual ranks for each variable were summed and the resulting totals ranked. Here again we gave each variable equal weight. It is clear that this has led to the significant role of the airport and the suburb of Aeroglen being under-represented. This might be overcome by including a variable such as 'transport node' to the overall theme variables. The top four sustenance group suburbs overall are Gordonvale, Portsmith, Manunda and Westcourt.

Security

Eight variables were selected to represent the elements at risk that influence community security. In this context security is seen as including health, wealth and the protective services provided. Two of the variables used here have been derived from the *Socio-Economic Indexes for Areas* (SEIFA) product produced by the Australian Bureau of Statistics from the 1996 census. The SEIFA methodology is described in detail in ABS Information Paper 2039.0 (ABS, 1998).

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 top four suburbs for public safety buildings are Westcourt, City, Whitfield and Gordonvale. There are, however, 24 suburbs that do not contain a public safety facility.

Business premises: These facilities make a significant contribution to the overall economy and employment situation, as well as facilitation the distribution of goods and services. The four suburbs with the highest proportions of the total business inventory are Portsmith, Westcourt, City and Parramatta Park.

Sugar cane: Given the importance of the sugar industry to the Cairns economy we have included the cane lands as an element at risk. Suburbs are ranked according to their proportion of the total area of cane land available. These data are derived from material provided by the Mulgrave Central Mill Co. The top four (of 19) cane land suburbs are Gordonvale, Kamma, Wright's Creek and Edmonton.

Relative Socio-Economic Disadvantage: The SEIFA Index of Socio-Economic Disadvantage has been compiled by the ABS by undertaking a principal components analysis on 20 weighted variables from the 1996 census. The attributes, such as low income, low educational attainment, high unemployment and jobs in relatively unskilled occupations, were selected to highlight disadvantage (see **Table C7**). The resulting index has been standardised to have a mean of 1,000 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 1,200. A value above 1,200 reflects a significantly high degree of advantage, whilst a value of less than 800 reflects a significantly high level of disadvantage. For this work, the mean index value for all CCDs within each suburb was taken.

For Cairns, the mean suburb index values range from a high (advantaged) value of 1,093.0 in Barron to a low (disadvantaged) value of 684.96 in Yarrabah. Suburbs were ranked in inverse order (lowest to highest) of their mean index value. Yarrabah was followed by Portsmith (842.33), Manoora (921.86) and Westcourt (930.18). At the other end of the scale, following Barron are Redlynch (1,091.73), Kamerunga (1088.68) and Brinsmead (1,082.36). Apart from Yarrabah, which is more than three standard deviations below the national mean, all values are within one standard deviation of the national mean.

Economic Resources: SEIFA also provides an Index of Economic Resources. This index is based on a profile of the economic resources of families. It is compiled from 22 weighted variables that reflect the income and expenditure of families, including measures of income, rent and home ownership (see **Table C8**). This index is also standardised with a national mean of 1,000 and a standard deviation of 100. At the disadvantaged end of the spectrum the four lowest suburbs are Yarrabah (747.48), Portsmith (839.66), Manoora (881.63) and City (889.17). At the high, end the top four are Bayview Heights (1,117.03), Brinsmead (1,101.57), Redlynch (1,096.76) and Barron (1,089.42).

People under 5 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 suburb population at the 1996 census that was under five years of age. The highest ranked suburbs are Yarrabah, Bentley Park, Trinity East and Mount Sheridan.

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 suburb population at the 1996 census that was over 65 years of age. The highest ranked suburbs are Westcourt (with its four nursing homes and large retirement village), Clifton Beach, Whitfield and Trinity East.

Households renting: The proportion of households that were renting their accommodation is also seen as an indicator of economic resilience. The highest values are found in Yarrabah, Cairns North, Manoora and Parramatta Park.

The census data contains a wide range of measures, such as unemployment rate and individual or household income levels that could also be used in this group. They have not been used because they are incorporated in the SEIFA indexes.

To reach a composite value for the security group, the individual ranks for each variable were summed and the resulting totals ranked. Each variable was given equal weight. The four top suburbs overall are Westcourt, Gordonvale, Yarrabah and Portsmith.

Society

Five variables were used to reflect the social elements at risk.

Community services: A wide range of practical, social and cultural services supports the community. These range from churches and libraries, to sporting and social clubs, and from public toilets to government offices. Top ranking suburbs for the proportion of community buildings are Manunda, City, Cairns North and Yarrabah.

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. They are also the group that has the greatest concentration of non-English speakers. The figures for totals for visitors (both overseas and domestic) provided in the 1996 census were used. The four suburbs that host the greatest proportion of visitors are Cairns North, City, Palm Cove and Trinity Beach.

Education and Occupation: The third SEIFA index included in this study is the Index of Education and Occupation. This index is based on an analysis of 18 weighted variables selected to reflect the educational and occupation structures of communities (see **Table C9**). High scores reflect communities with high concentrations of people with higher education or undergoing further education and with people employed in higher skilled occupations. At the low end of the scale in Cairns are Yarrabah (807.59), Portsmith (899.91), Westcourt (935.65) and White Rock (937.43). At the high end are Palm Cove (1,085.05), Kamerunga (1,071.28), Barron (1,066.10) and Freshwater (1,061.86).

New residents: People who have lived at their census address for less than five years have been included as an indicator of a lack of local knowledge or strong community links. Suburbs were ranked on the proportion of people over 5 years of age that were living at a different address to that at the 1991 census to the total suburb population over 5 years. The highest ranked 'newcomer' suburbs are Mount Sheridan, Bentley Park, Kamerunga and Kewarra Beach.

No religious adherence: Lack of strong social links, such as adherence to a religion, are seen as an indicator of susceptibility. Suburbs were ranked on the proportion the total population who indicated in their response to the 1996 census that that they had 'no religion'. The suburbs that ranked highest are Machans Beach, Portsmith, Holloways Beach and Yorkeys Knob.

To reach a composite value for the social group, the individual ranks for each variable were summed and the resulting totals ranked. As with the previous groups no attempt was made to weight the individual variables. The four top suburbs overall are Parramatta Park, Manoora, Portsmith and Yorkeys Knob.

Composite Ranking

To provide a composite rating of the relative overall vulnerability of suburbs, the ranks for each of the five groups were multiplied and the resulting products ranked. They were multiplied, rather than added, to magnify the differences. The five suburbs **that contribute most to the overall vulnerability** of Cairns are Westcourt, Manunda, Edge Hill, Gordonvale and Manoora. The four lowest ranked suburbs (i.e. the least contribution) are the largely rural, low population suburbs of Barron, Mount Peter, Wright's Creek and Kanimbla. The ranking of each suburb for each group, the rank for the combined groups together with the raw score for the composite rating are provided in **Table 3.11**.

Each of the 'five esses' were treated as contributing equally and no weights were applied. We believe that this is reasonable for an assessment that emphasises total community risk rather than exploring a particular issue such as the magnitude of economic loss.

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. 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, or to weight the groups in reaching the overall value. Our research has not reached the stage where we could confidently judge the relative significance of, for example, houses, as opposed to flats, as opposed to the road network, in the shelter group; nor could we yet judge the relative contribution of each group to the overall evaluation.

There is, none-the-less, an weight inferred by simply including the attribute, and the number of attributes included in each group. The total population attribute, for example, carries a significantly greater weight than any other single attribute, simply because it is the sole attribute in the setting group. At this stage we are reasonably comfortable with this potential bias because population, after all, is the thing that turns a hazard phenomenon impact into a disaster. Likewise, we are reasonably comfortable with using the road length attribute in two different groups to represent two distinct elements at risk (roads and lifelines). It carries a greater weight in the sustenance group (where it represents lifeline density) than it does in the shelter group (where it represents road network density) simply because there are more attributes included in the latter.

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 schools 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; in addition to its role in the operation of the airport it is a major aeronautical telecommunications hub - equivalent in many ways to the regional telephone exchange. It was not, however, counted in the telecommunications attribute.

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 currently 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 no 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, Mackay, Greater Brisbane, Gold Coast, Newcastle and Sydney, will undoubtedly produce further refinements.

This is the first step on what will hopefully be a fruitful journey.

APPENDIX F: EARTHQUAKES IN THE CAIRNS REGION

AGSO World Earthquake Database 30-Nov-1998

Date: 01 January 1840 to 30 June 1998
Latitude: 14°S to 20°S
Longitude: 143.5°E to 147.5°E
Depth: 0 km to 100 km
Magnitude: greater than 0

Source	Date	UTC	Lat	Long	Depth	Local magnitude	Authority
RYNN	18940716	124500	-18.3	143.5	0	4	E/M
UQ	18960227	110000	-16.8	146.5	25	4.2	UQ
UQ	19000509	0	-19.3	146.8	0	2.2	UQ
UQ	19010627	0	-18.6	146.2	10	2.2	UQ
UNIQ	19131218	135400	-20	147	33	5.7	(I)
UQ	19280514	24655	-15	144	10	5.3	UQ
UQ	19420410	30000	-16.2	145.7	10	3.8	UQ
UQ	19500616	110000	-17.3	145.6	10	2.2	UQ
UQ	19500619	90000	-17.5	145.5	12	4.0	RYNN
JONES	19540504	170500	-17.7	146		3.2	(I)
RYNN	19570531	161548.1	-18.5	145.6		3.5	E/M
UQ	19571010	220349	-17.1	146.5	10	2.8	UQ
RYNN	19571109	212315.6	-18.8	146		3.5	E/M
RYNN	19571126	50539	-18.6	145.6		3.5	E/M
UQ	19580531	161554	-18.5	146.7	10	2.5	UQ
UQ	19580707	170632	-15.4	144	5	4.4	UQ
RYNN	19580730	21155	-19.2	145.7		3	E/M
RYNN	19581004	21020.1	-18.5	145.6		3.5	E/M
RYNN	19581105	51603.1	-18.7	145.5		3.5	E/M
RYNN	19581111	61222.1	-18.6	145.6		3.5	E/M
UQ	19581201	102000	-16.8	146.5	10	3	UQ
RYNN	19581201	103531	-16.5	145.5	10	4.7	(I)
UQ	19581201	103800	-16.8	146	10	3	UQ
UQ	19581201	160000	-16.8	146	10	3	UQ
UQ	19581201	180427.5	-16.8	146.5	10	3.2	UQ
UQ	19590102	194324.5	-17	146.5	10	3.4	UQ
UQ	19610227	162850	-16.5	144	10	3.7	UQ
UQ	19610624	93037	-17.8	145.6	10	2.9	UQ
UQ	19610819	22651.4	-15.8	144.7	10	4.1	UQ
UQ	19620216	121633	-14	144	5	4.4	UQ
UQ	19630328	41000	-17.6	146.2		3.2	(I)
UQ	19630328	42952.5	-17.6	146.2	7	3	UQ
UQ	19630622	195130.6	-18.15	144	15	3.4	UQ
UQ	19640115	90013.5	-18.15	144	15	4.2	UQ
UQ	19640213	73009	-18.15	144	15	2.5	UQ
UQ	19640213	74011	-18.15	144	15	2.5	UQ
UQ	19640223	122228.9	-18.2	144	15	3.5	UQ
UQ	19640224	83233	-18.15	144	15	3.1	UQ
UQ	19640224	164228	-18.15	144	15	2.8	UQ
UQ	19640225	165909	-18.15	144	15	3.1	UQ

UQ	19640831	181708	-18.15	144	15	3	UQ
UQ	19650216	124812	-18.15	144	15	3.4	UQ
UQ	19650328	73930.3	-18.8	145.8	10	2.3	UQ

Cairns earthquake catalogue (continued)

Source	Date	UTC	Lat	Long	Depth	Local magnitude	Authority
UQ	19660927	134115.5	-17.1	146.5	10	3.4	UQ
UQ	19670209	113050.1	-15.8	144.7	10	3.9	UQ
UQ	19670713	70946	-18.15	144	15	3.2	UQ
UQ	19671119	222514	-18.15	144	15	4.2	UQ
UQ	19671210	95850	-18.15	144	15	2.8	UQ
UQ	19671229	182415	-15.9	144	3	3.7	UQ
UQ	19680704	2313	-18.8	145.8		1.6	UQ
UQ	19680704	2316	-18.8	145.8		1.9	UQ
RYNN	19690111	210514	-18.3	145.7		3	E/M
RYNN	19710917	221316	-15	144	0	4	E/M
RYNN	19720505	133250	-19	146.5		3	E/M
RYNN	19740506	165511	-17.5	146	0	4	E/M
RYNN	19750405	141317	-19.8	145.7		3	E/M
RYNN	19750919	140454.5	-18.2	143.5		3.5	E/M
RYNN	19760309	101333.5	-18.2	143.5		3.5	E/M
UQ	19790613	1822	-18.1	147.2		1.9	UQ
UQ	19810226	457	-19.717	147.181		0.6	UQ
UQ	19810311	716	-19.018	147.484		1.4	UQ
UQ	19810325	628	-19.791	147.342		0.5	UQ
UQ	19810411	9	-19.459	146.981		1.1	UQ
UQ	19810508	504	-19.512	146.836		1.5	UQ
UQ	19810527	51	-19.785	147.23		0.4	UQ
UQ	19810710	153	-19.742	146.792		1.1	UQ
UQ	19810721	200	-19.197	146.776		0.9	UQ
UQ	19810807	558	-19.726	147.283		1.2	UQ
UQ	19810824	651	-19.718	147.305		1.5	UQ
UQ	19810902	650	-19.727	147.334		1.6	UQ
UQ	19810909	419	-19.711	147.296		1.1	UQ
UQ	19810930	57	-19.648	146.782		1.2	UQ
UQ	19811207	412	-19.706	147.272		1.7	UQ
UQ	19820115	2043	-19.49	146.7		1.4	UQ
UQ	19820315	2240	-19.782	147.225		1.4	UQ
UQ	19820323	425	-19.796	147.382		1.5	UQ
UQ	19820326	2225	-19.382	146.524		1.1	UQ
UQ	19820417	53	-19.444	146.943		1	UQ
GSQ	19820815	30435.6	-18.901	146.544	10	1.4	MD
UQ	19830517	1554	-19.661	144.097		1.8	UQ
UQ	19830709	1808	-18.507	146.557		1.6	UQ
UQ	19840612	1055	-18.794	147.005		1.8	UQ
UQ	19840717	620	-19.637	146.545		2	UQ
UQ	19850326	1027	-18.724	147.304		1.8	UQ
UQ	19850517	759	-19.235	147.07		1.5	UQ
UQ	19850517	800	-19.365	146.807		1.4	UQ
UQ	19850523	714	-19.555	146.975		1.3	UQ
UQ	19851108	819	-19.717	146.785		2	UQ

UQ	19860513	2224	-19.462	146.87		1.1	UQ
UQ	19861106	751	-19.79	146.437		1.4	UQ
UQ	19861214	132	-19.966	147.459		1.2	UQ
UQ	19870529	638	-19.717	146.771		1.3	UQ
UQ	19871224	917	-18.51	145.796		1.9	UQ
UQ	19890813	729	-18.969	146.794		2.7	UQ

Cairns earthquake catalogue (continued)

Source	**Date**	**UTC**	**Lat**	**Long**	**Depth**	**Local magnitude**	**Authority**
UQ	19890814	246	-19.055	146.738		2.9	UQ
BMR	19891116	104324.7	-17.386	146.296	5	4	BMR
QUNI	19900416	64433.4	-18.045	145.816	2	1.2	QUNI
QUNI	19900513	53524.3	-17.292	146.144	8	4.3	QUNI
QUNI	19900513	213700	-17.209	146.23	8	1.6	QUNI
QUNI	19900517	93600	-17.209	146.23	8	1.6	QUNI
QUNI	19900519	115800	-17.209	146.23	8	1.9	QUNI
QUNI	19900519	120700	-17.209	146.23	8	1.8	QUNI
QUNI	19900525	235800	-17.209	146.23	8	2	QUNI
QUNI	19900528	4200	-17.209	146.23	8	1.6	QUNI
QUNI	19900726	75800	-17.441	145.97	8	0.8	QUNI
QUNI	19900813	45200	-17.209	146.23	8	1.3	QUNI
QUNI	19900813	45500	-17.209	146.23	8	1.6	QUNI
QUNI	19900815	115643.5	-17.263	146.286	17	2.6	QUNI
QUNI	19900819	15800	-17.441	145.97	8	0.9	QUNI
QUNI	19900825	222800	-17.209	146.23	8	1.5	QUNI
QUNI	19900905	225730	-17.209	146.23	8	1.5	QUNI
QUNI	19900905	225731.5	-17.209	146.23	8	1.1	QUNI
QUNI	19900915	34100	-17.441	145.97	8	0.6	QUNI
QUNI	19900915	101604.1	-18.57	145.537	4	1.4	QUNI
QUNI	19901007	45100	-17.209	146.23	8	1.2	QUNI
QUNI	19901017	123915.2	-18.718	143.644	8	2.4	QUNI
QUNI	19901029	173032	-17.441	145.97	17	2.4	QUNI
QUNI	19901030	15900	-17.209	146.23	8	1.4	QUNI
QUNI	19901103	200131.3	-18.479	147.091	11	2.6	QUNI
QUNI	19901103	214500	-17.209	146.23	8	1.1	QUNI
QUNI	19901104	135900	-17.209	146.23	8	1.8	QUNI
QUNI	19901210	232300	-17.209	146.23	8	1.1	QUNI
QUNI	19901211	115700	-17.63	145.48	8	0.5	QUNI
QUNI	19901211	131100	-17.63	145.48	8	0.7	QUNI
QUNI	19910113	130000	-17.209	146.23	8	2	QUNI
QUNI	19910131	140200	-17.209	146.23	8	1.9	QUNI
QUNI	19910204	55100	-17.209	146.23	8	1.1	QUNI
QUNI	19910213	214400	-17.63	145.48	8	2	QUNI
QUNI	19910213	220800	-17.209	146.23	8	1.3	QUNI
QUNI	19910217	31917	-17.211	146.297	15	3.2	QUNI
QUNI	19910228	215200	-17.209	146.23	8	1.6	QUNI
QUNI	19910303	234700	-17.209	146.23	8	0.9	QUNI
QUNI	19910303	235000	-17.209	146.23	8	1.2	QUNI
QUNI	19910304	233100	-17.209	146.23	8	0.9	QUNI
QUNI	19910308	130000	-17.209	146.23	8	0.9	QUNI
QUNI	19910318	170200	-17.209	146.23	8	1.6	QUNI
QUNI	19910320	183500	-17.209	146.23	8	0.8	QUNI

QUNI	19910322	154500	-17.209	146.23	8	1.3	QUNI
QUNI	19910324	23500	-17.209	146.23	8	1.5	QUNI
QUNI	19910326	31400	-17.209	146.23	8	1.5	QUNI
QUNI	19910405	42900	-17.209	146.23	8	2.1	QUNI
QUNI	19910405	123900	-17.209	146.23	8	0.9	QUNI
QUNI	19910408	144000	-17.209	146.23	8	1.7	QUNI
QUNI	19910408	202600	-17.209	146.23	8	1.8	QUNI
QUNI	19910410	2400	-17.209	146.23	8	1.2	QUNI
QUNI	19910412	233800	-17.209	146.23	8	1.4	QUNI

Cairns earthquake catalogue (continued)

Source	Date	UTC	Lat	Long	Depth	Local magnitude	Authority
QUNI	19910414	10200	-17.209	146.23	8	1	QUNI
QUNI	19910420	202400	-17.209	146.23	8	1	QUNI
QUNI	19910425	110500	-17.209	146.23	8	1.7	QUNI
QUNI	19910502	84700	-17.209	146.23	8	1.1	QUNI
QUNI	19910502	214300	-17.209	146.23	8	1.1	QUNI
QUNI	19910509	163100	-17.63	145.48	8	0.4	QUNI
QUNI	19910522	100900	-17.63	145.48	8	0.1	QUNI
QUNI	19910606	92800	-17.209	146.23	8	1.1	QUNI
QUNI	19910607	24200	-17.209	146.23	8	1.8	QUNI
QUNI	19910611	211800	-17.209	146.23	8	2	QUNI
QUNI	19910612	82100	-17.209	146.23	8	1.9	QUNI
QUNI	19910628	85400	-17.209	146.23	8	1.1	QUNI
QUNI	19910701	231936	-17.253	146.371	8	2.7	QUNI
QUNI	19910708	800	-17.209	146.23	8	1.1	QUNI
QUNI	19910716	115	-17.63	145.48		-1	QUNI
QUNI	19910719	143000	-17.209	146.23	8	0.9	QUNI
QUNI	19910723	115200	-17.209	146.23	8	0.9	QUNI
QUNI	19910728	600	-17.209	146.23	8	1	QUNI
QUNI	19910806	141148.2	-18.222	143.506	17	4.8	QUNI
QUNI	19910809	74100	-17.209	146.23	8	1.3	QUNI
QUNI	19910823	212900	-17.63	145.48	8	1.7	QUNI
QUNI	19910920	173200	-17.209	146.23	8	1.4	QUNI
QUNI	19911003	41313.1	-17.277	146.285	8	1.8	QUNI
QUNI	19911009	94900	-17.209	146.23	8	1.1	QUNI
QUNI	19911028	231631.8	-17.191	146.37	8	1.3	QUNI
QUNI	19911029	232902	-17.367	146.279	13	1.7	QUNI
QUNI	19911130	213400	-17.209	146.23	8	0.9	QUNI
QUNI	19911205	71800	-17.209	146.23	8	1	QUNI
QUNI	19911209	134700	-17.209	146.23	8	0.6	QUNI
QUNI	19911214	133300	-17.209	146.23	8	0.8	QUNI
QUNI	19911215	2900	-17.209	146.23	8	1.1	QUNI
QUNI	19911221	211200	-17.209	146.23	8	1.6	QUNI
QUNI	19911230	143600	-17.63	145.48	8	0.1	QUNI
QUNI	19920103	70900	-17.633	145.484	0	0.7	QUNI
QUNI	19920105	43400	-17.633	145.484	0	0.5	QUNI
QUNI	19920106	104000	-17.633	145.484	0	0.9	QUNI
QUNI	19920115	131600	-17.633	145.484	0	1.5	QUNI
QUNI	19920115	134500	-17.633	145.484	0	1	QUNI
QUNI	19920116	221700	-17.633	145.484	0	1.5	QUNI

QUNI	19920117	174400	-17.633	145.484	0	1.1	QUNI
QUNI	19920117	194700	-17.633	145.484	0	0.5	QUNI
QUNI	19920117	225643.3	-17.326	146.156	8	2.3	QUNI
QUNI	19920118	74900	-17.633	145.484	0	0.9	QUNI
QUNI	19920119	234800	-17.633	145.484	0	0.1	QUNI
QUNI	19920124	51600	-17.633	145.484	0	0.5	QUNI
QUNI	19920129	120200	-17.633	145.484	0	2.7	QUNI
QUNI	19920130	140500	-17.633	145.484	0	0.9	QUNI
QUNI	19920217	225900	-17.633	145.484	0	1.2	QUNI
QUNI	19920324	185000	-17.633	145.484	0	0.6	QUNI
QUNI	19920330	2359	-17.633	145.484		-0.1	QUNI
QUNI	19920608	45433.6	-18.129	145.434	8	1.3	QUNI

Cairns earthquake catalogue (continued)

Source	**Date**	**UTC**	**Lat**	**Long**	**Depth**	**Local magnitude**	**Authority**
QUNI	19920625	104800	-17.633	145.484	0	1.5	QUNI
QUNI	19920625	144400	-17.633	145.484	0	1.1	QUNI
QUNI	19920625	221000	-17.633	145.484	0	1.5	QUNI
QUNI	19920724	4100	-17.633	145.484	0	1.6	QUNI
QUNI	19920726	173950.9	-17.425	146.239	6	2.1	QUNI
QUNI	19920731	214800	-17.633	145.484	0	1.4	QUNI
QUNI	19920827	5051.5	-17.552	144.411	0	1.6	QUNI
QUNI	19920828	11700	-17.633	145.484	0	0.8	QUNI
QUNI	19920830	55400	-17.63	145.48	0	1	QUNI
QUNI	19920901	84300	-17.633	145.484	0	1	QUNI
QUNI	19920903	12732.4	-17.482	144.725	0	1.6	QUNI
QUNI	19920910	105544	-17.324	146.174	8	1.5	QUNI
QUNI	19920914	140200	-17.633	145.484	0	0.8	QUNI
QUNI	19920922	232316.8	-17.262	146.219	8	1.9	QUNI
QUNI	19920926	141400	-17.112	145.484	0	1.3	QUNI
QUNI	19920927	135100	-17.633	145.484	0	1.3	QUNI
QUNI	19920927	143400	-17.633	145.484	0	1.2	QUNI
QUNI	19920929	13500	-17.633	145.484	0	1.6	QUNI
QUNI	19921001	174300	-17.633	145.484	0	1.4	QUNI
QUNI	19921029	82600	-17.633	145.484	0	1.3	QUNI
QUNI	19921103	80600	-17.633	145.484	0	1.6	QUNI
QUNI	19921106	40900	-17.633	145.484	0	3.5	QUNI
QUNI	19921118	163800	-17.633	145.484	0	1	QUNI
QUNI	19921221	13200	-17.633	145.484	0	1.2	QUNI
QUNI	19921221	13400	-17.633	145.484	0	0.8	QUNI
QUNI	19921222	55900	-17.633	145.484	0	1.2	QUNI
QUNI	19921224	11200	-17.633	145.484	0	1.5	QUNI
QUNI	19930419	113200	-17.633	145.484	0	1.7	QUNI
UQ	19930429	54800	-17.633	145.484	0	2.1	QUNI
UQ	19930503	185700	-17.633	145.484	0	1.1	QUNI
QUNI	19930518	190500	-17.633	145.484	0	1.5	QUNI
QUNI	19930610	110300	-17.63	145.48	0	1.1	QUNI
QUNI	19930611	105400	-17.63	145.48	0	0.9	QUNI
QUNI	19930611	111800	-17.633	145.484	0	0.6	QUNI
QUNI	19930708	104800	-17.633	145.484	0	2.2	MD
QUNI	19930717	173000	-17.633	145.484	0	1.1	QUNI

Cairns earthquake catalogue (continued)

Source	Date	UTC	Lat	Long	Depth	Local magnitude	Authority
QUNI	19930727	41800	-17.633	145.484	0	1.4	QUNI
QUNI	19930812	162500	-17.633	145.484	0	2	QUNI
QUNI	19930812	162600	-17.633	145.484	0	1.4	QUNI
QUNI	19930812	193200	-17.633	145.484	0	1.5	QUNI
QUNI	19930812	232600	-17.633	145.484	0	1.3	QUNI
QUNI	19930812	235300	-17.633	145.484	0	1.3	QUNI
QUNI	19930813	52400	-17.633	145.484	0	1.8	QUNI
QUNI	19930813	232800	-17.633	145.484	0	1.5	QUNI
QUNI	19930813	232830	-17.633	145.484	0	1.8	QUNI
QUNI	19930820	220745.3	-16.859	143.762	8	2.9	QUNI
QUNI	19930821	25127.2	-17.11	144.289	8	2.5	QUNI
QUNI	19930821	60600	-17.633	145.484	0	1.7	QUNI
QUNI	19930821	81500	-17.633	145.484	0	1.5	QUNI
QUNI	19930821	90500	-17.633	145.484	0	1.6	QUNI
QUNI	19930822	82844.9	-17.057	144.143	8	2.5	QUNI
QUNI	19930822	102700	-17.633	145.484	0	1.4	QUNI
QUNI	19930823	215300	-17.633	145.484	0	1.4	QUNI
QUNI	19930826	173200	-17.633	145.484	0	1.4	QUNI
QUNI	19930913	120700	-17.633	145.484	0	1.4	QUNI
QUNI	19931012	63900	-17.633	145.484	0	1.2	QUNI
QUNI	19931030	82100	-17.633	145.484	0	1.3	QUNI
QUNI	19940403	192414.1	-17.186	146.372	18	3.4	QUNI
QUNI	19940904	10802.1	-16.987	144.502	8	4	QUNI
AUST	19950317	174114.4	-18.25	146	5	3.2	AUST
QUNI	19951030	171842.2	-19.487	147.426	10	2.4	QUNI
QUNI	19971124	155514.1	-16.767	145.696	5	2.5	QUNI
QUNI	19971124	183847.1	-16.765	145.748	5	2.1	QUNI
QUNI	19990211	124524.0	-17.2	144.8	10	3.7	QUNI

APPENDIX G: MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY (after Dowrick, 1996)

MM I *People*
Not felt except by a very few people under exceptionally favourable circumstances.

MM II *People*
Felt by persons at rest, on upper floors or favourably placed.

MM III *People*
Felt indoors; hanging objects may swing, vibrations may be similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM IV *People*
Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings
Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures
Walls and frame of building are heard to creak, and partitions and suspended ceilings in commercial buildings may be heard to creak.

MM V *People*
Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings
Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start, or change rate.

Structures
Some windows Type I cracked. A few earthenware toilet fixtures cracked.

MM VI *People*
Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily.

Fittings
Objects fall from shelves. Pictures fall from walls. Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved. Glassware and crockery broken. Very unstable furniture overturned. Small church and school bells ring. Appliances move on bench or table tops. Filing cabinets or "easy glide" drawers may open (or shut).

Structures
Slight damage to Buildings Type I. Some stucco or cement plaster falls. Windows Type I broken. Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM VII *People*
General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars who may stop.

Fittings
Large bells ring. Furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile contents of buildings.

Structures
Unreinforced stone and brick walls cracked. Buildings Type I cracked with some minor masonry falls. A few instances of damage to Buildings Type II. Unbraced parapets, unbraced brick gables, and architectural ornaments fall. Roofing Loose tiles, especially ridge tiles may be dislodged. Many unreinforced chimneys damaged, often falling from roof-line. Water tanks Type I burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II) may move and leak. Some windows Type II cracked. Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM VIII *People*
Alarm may approach panic. Steering of motor cars greatly affected.

Structures
Buildings Type I, heavily damaged, some collapse. Buildings Type II damaged, some with partial collapse. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down. Some pre-1965 infill masonry panels damaged. A few post-1980 brick veneers damaged. Decayed timber piles of houses damaged. Houses not secured to foundation may move. Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM IX *Structures*

Many buildings Type I destroyed. Buildings Type II heavily damaged, some collapse. Buildings Type III damaged, some with partial collapse. Structures Type IV damaged in some cases, some with flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V. Houses not secured to foundations shifted off. Brick veneers fall and expose frames.

Environment
Cracking of the ground conspicuous. Landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM X *Structures*
Most Buildings Type I destroyed. Many Buildings Type II destroyed. Buildings Type III heavily damaged, some collapse. Structures Type IV damaged, some with partial collapse. Structures Type V moderately damaged, but few partial collapses. A few instances of damage to Structures Type VI. Some well-built timber buildings moderately damaged (excluding damage from falling chimneys). Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves.

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe.

MM XI *Structures*
Most Buildings Type II destroyed. Many Buildings Type III destroyed. Structures Type IV heavily damaged, some collapse. Structures Type V damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.

MM XII *Structures*
Most Buildings Type III destroyed. Many Structures Type IV destroyed. Structures Type V heavily damaged, some with partial collapse some collapse. Structures Type VI moderately damaged.

Construction types

Buildings Type I Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Type I–III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed in detail to resist earthquake forces.

Structures Type IV Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid 1930s to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI Structures dating from c. 1980 with well defined foundation behaviour, which have been especially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high (value) contents, or new generation low damage structures.

Windows
Type I – Large display windows, especially shop windows.
Type II – Ordinary sash or casement windows.

Water tanks
Type I – External, stand mounted, corrugated iron water tanks.
Type II – domestic hot-water cylinders unrestrained except by supply and delivery pipes.

APPENDIX H: METHOD TO ESTIMATE URBAN EARTHQUAKE HAZARD IN CAIRNS

NOTE: <u>Limitations of the earthquake hazard maps</u>

The maps were produced mainly from considerations of published geology and sparse geotechnical data. The resultant zonations are largely based on the 1:100 000 scale mapped geological units. 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 four-stage method to estimate the earthquake hazard in Cairns. We first identified an appropriate rock response spectrum to use as a basis for regional hazard estimates. Next, we prepared urban earthquake hazard maps (microzonation maps) for Cairns in a two-stage process. In the final stage, we adopted response spectra to describe the hazard in Cairns on each of the site classes in the urban hazard maps. Briefly, these site classes are rock, hard or very dense sediments, stiff sediments, and soft sediments.

A description of each of the four stages of earthquake hazard estimation is given below.

Stage 1 - Estimate the Regional Earthquake Hazard

Three estimates of regional earthquake hazard are known for Cairns. All three estimates relate to a 10% probability of exceedence in 50 years at 'firm' sites. The 10% probability of exceedence in 50 years corresponds to an AEP of approximately 1/475 if the earthquake occurrence is assumed Poissonian.

The first estimates are found in Gaull and others (1990). They estimated a Modified Mercalli Intensity (MM) of approximately MM VI, a peak horizontal ground acceleration (PGA) of approximately 0.04 g, and a peak horizontal ground velocity (PGV) of around 30 mm s^{-1}. The second estimate is found in *AS1170.4-1993*. The earthquake hazard map in *AS1170.4-1993* was compiled by an Australian Standards Committee and was a development of the work of Gaull and others (1990). The acceleration coefficient of 0.06 for a 'firm' site in the Cairns area in *AS1170.4-1993* is equivalent to a PGA value of approximately 0.06 g. The third estimate of hazard originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.2 g on rock, in line with their estimates of PGA for Queensland 2-3 times higher than previous estimates. They also estimated a higher MMI than Gaull and others, and a similar value of PGV to the estimate of Gaull and others. A comparison of the three studies is shown in **Table H1**.

Table H1: Earthquake hazard for Cairns with a 10% probability of exceedence in 50 years

PGA (g)	PGV (mm s^{-1})	MMI	Source
~0.04	~30	~VI	Gaull and others, 1990
~0.06	-	-	*AS1170.4-1993*
~0.2	~25	V-VII	Cuthbertson and Jaume, 1996

Considerable debate has surrounded the contrasting earthquake hazard estimates of Cuthbertson and Jaume (1996) and those in *AS1170.4-1993.* We prefer to use the acceleration coefficient in *AS1170.4-1993* until new estimates of earthquake hazard for Queensland are made under the current revision of *AS1170.4-1993*. The revised standard is expected to be published within several years.

The earthquake hazard for Cairns is moderate by Australian standards. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993,* including Cairns, has an acceleration coefficient in the range 0.05 - 0.1. The coefficient values across Australia range from a minimum 0.03 to highs of up to 0.22 in 'bullseye' areas.

Spectral values of earthquake hazard for Cairns on rock foundation can be taken from the new response spectrum proposed for the revision of *AS1170.4-1993* (Somerville and others, 1998). The elastic, 5% damped spectrum, normalised to a PGV of 50 mm s^{-1}, is shown in **Figure H1**.

The spectrum may be scaled by selecting values for peak ground acceleration, velocity, or displacement. It was derived from recordings of reverse faulting earthquakes of magnitude 6.0 ± 0.6. However, limitations on scaling will occur for scenarios where the major contribution to hazard does not arise from earthquakes of those magnitudes. For example, if larger earthquakes are being considered the long period part of the spectrum should be enhanced (Somerville and others, 1998).

Scaling the Pseudo Spectral Relative Velocity (PSRV) values in **Figure H1** by a factor of 0.6 provides spectral estimates of the earthquake hazard on rock in Cairns that may be appropriate for a 10% probability of exceedence in 50 years. This factor of 0.6 is the ratio between the PGV estimate of Gaull and others (1990) for the Cairns region of approximately 30 mm s^{-1} and the PGV of 50 mm s^{-1} of the normalised spectrum.

However, we remind the reader of the uncertainties in this estimate arising from the differences in hazard estimated by various authors.

Additional estimates of earthquake hazard for the Cairns region are required so that quantitative comparisons can be made of the earthquake risk to Cairns and the extreme wind, rainfall and inundation risks from tropical cyclones. Known estimates of earthquake hazard all refer to a 10% probability of exceedence in 50 years. Estimates of the regional earthquake hazard for AEPs of 1%, 0.1%, 0.01%, and the Maximum Probable Event would be valuable.

Stage 2 - Subdivide the City into Zones of Different Earthquake Hazard According to Site Class (see **Figure 4.6** and **Figure 4.7**).

We used the physical properties of the rocks and the mean seismic shear wave velocity to a depth of 30 m below the earth's surface (Vs) as the fundamental parameters to describe the localised earthquake hazard. Site Classes A-D defined from the combination of these factors are shown in **Table H2**.

Our site classifications are based on those developed for the 1994 provisions of the US National Earthquake Hazard Reduction Program (NEHRP). The provisions were published in FEMA (1995) and we have referred to the version reproduced by Hwang and others (1997). Many of the correlations between physical properties of the rock or sediment and the shear wave velocity were produced from extensive measurements of Vs, lithological descriptions and geotechnical testing over 20 years in San Francisco and Los Angeles. Borcherdt (1994) summarised these results. Several versions of nomenclature for the site classes are published (e.g., Borcherdt, 1994; Crouse and McGuire, 1996; Hwang and others, 1997) but they differ mainly in detail. The correlation between the physical description of the rocks and mean shear wave velocity in the top 30 m has become more rigorously defined recently but the classifications remain essentially the same.

Table H2: Site classifications for earthquake hazard maps

Site Class this study	Site Class 1994 NEHRP provisions	Description and Site Class definition[1]
A	A	Hard rock, Vs > 1 500 ms^{-1}
A	B	Rock, 760 ms^{-1} < Vs ≤ 1 500 ms^{-1}
B	C	Hard and/or very stiff soils, 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
C	D	Sands, silts and/or stiff clays, some gravels, 180 ms^{-1} ≤ Vs ≤ 360 ms^{-1} or with either 15 ≤ N ≤ 50 or 50 kPa ≤ s_u ≤ 100 kPa
D	E	Profile with Vs < 180 ms^{-1} or containing at least 3 m of soft clay defined as sediment with PI > 20, w ≥ 40%, and s_u < 25 kPa
NA[2]	F	Special sites: • sites vulnerable to potential failure or collapse under seismic loading (liquefiable sediments, quick and highly sensitive clays, collapsible weakly-cemented sediments, etc.) • 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 > 37 m)

NOTES:

[1] Modified from definitions in Crouse and McGuire (1996) and Hwang and others (1997)
[2] Special sites in Cairns have not been assessed separately
Vs = Mean shear wave velocity to a depth of 30 m
N = Mean Standard Penetration Test blow count
s_u = Mean Undrained Shear Strength
w = Mean moisture content

We have collapsed the NEHRP classifications 'Hard rock' and 'Rock' into Site Class A, simply termed 'Rock'. The metasediments of the Hodgkinson Formation and the granitic batholiths underlying Cairns probably have shear wave velocities that would clearly mark them as 'Hard rock' under the NEHRP classification but we do not have the information to make the distinction.

In this study we estimated urban earthquake hazard at a localised level rather than at a site-specific level and we have not identified special sites (**Table H2**).

We used the published interpretation of the 1:100 000 scale geological map (Willmott and others, 1988) and geotechnical and geophysical information to form the zones defined by site class. No measurements of shear wave velocity were available for Cairns (few are available in Australia) and so estimates of mean shear wave velocity in the topmost 30 m were made, first for sites where geotechnical data were available, and then more broadly, largely by geological unit. The measured shear wave velocities in sediments and rock in the Los Angeles and San Francisco Bay regions, classified by type and augmented by Standard Penetration Test data, presented by Borcherdt (1994), were a valuable reference for estimating Vs in the Quaternary geological units of Cairns.

Geotechnical data from reports at approximately 40 sites were provided by Queensland Main Roads, Golder Associates, and Cairns Port Authority. These data comprised borehole, test pit, and cone penetrometer test logs and their interpretations. Some data were provided on the understanding that they would not be released in primary form for commercial in confidence reasons. The sites are shown on **Figure H2**. About 30 of the boreholes and Cone Penetrometer Tests sampled sediments consequently classified as Site Class D and, of these, about 20 were located in the City and inner suburbs. These data highlighted up to 20 m of loose/very loose sands and/or soft/very soft clays immediately underlying Portsmith, Trinity East, Parramatta Park, Cairns City, Manunda, North Cairns and Westcourt. Beneath these sediments are beds of Pleistocene alluvium up to 70 m thick interfingered with Pleistocene/Pliocene estuarine and marine sediments (Willmott and others, 1988).

Willmott and others (1988) provided a typical example of the foundation under Cairns City. They reported that a bore in Aplin Street, City, intersected 3.6 m of loose, fine to coarse sand of a former beach ridge, 0.4 m of silt-clayey marine sand, underlain by 2.4 m to 3 m of soft estuarine mud and, below this, firm, dense sandy clay at a depth of 6.4 m to 7 m. A thickness of 5 - 10 m of soft or very soft clays and/or loose to very loose sands overlying stiff clays and/or dense sands appears to be a representative foundation underneath the City. In the City area the groundwater table is probably tidal and is likely to be within 2 m of the surface (F. Baynes, written comm., 1997).

The Site Class D classification was reached for these 30 sites largely on the basis of estimated mean shear wave velocity Vs in the topmost 30 m. Where data were available, there was very good agreement between the criterion Vs < 180 ms^{-1} and the presence of estuarine muds and beach ridge sands of Holocene age (Units Qhct and Qhcb; **Table H3**.)

A further six boreholes were located in Pleistocene silty gravels, sands, silts and clays and from this limited data set there was also agreement between estimates of Vs and the physical properties for these sediments that resulted in these sediments being rated as Site Class C.

For other geological units the relation between mapped geology and site class was less clear. The Holocene alluvium of the Barron River delta (Unit Qha2) was variously rated Site Class B, C and D. The borehole and microtremor information overrode classifications made from lithological description alone. This simple example shows the limitations of producing urban earthquake hazard maps from mapped geology alone (the lowest level of hazard map) and the capacity of geotechnical, hydrogeological and geophysical datasets to improve the hazard maps.

Stage 3 - Assign Amplification Factors to the Site Classes

We next assigned amplification factors to each site class. The amplification factors describe the relative severity of earthquake shaking. The amplification factor for Site Class A, 'Rock', is unity and the peak value of the earthquake shaking on other site classes will be stronger in proportion to the amplification factor. In the absence of sufficient recordings of Australian earthquakes, our amplification factors are derived from empirical values recorded from central and southern Californian earthquakes in the years 1933-1989 (Crouse and McGuire, 1996). **Table H4** and **Table H5** present the amplification factors of Crouse and McGuire for periods of vibration T = 0.3 seconds and T =1.0 second.

In general, the amplification factors are dependent on the period of vibration of the ground during earthquakes and on the strength of earthquake input ground motion. With increasingly strong input ground motion, up to 0.4 g, the amplification factors become somewhat reduced, indicating a degree of nonlinearity in the ground behaviour.

For Cairns, we adopted the amplification factors of Crouse and McGuire (1996) at low levels of input ground motion, PGA = 0.1 g to 0.2 g. The amplification factors used in the hazard maps for Cairns are shown in **Table H6**. They are appropriate for a range of annual exceedence probabilities both larger and smaller than the AEP = ~0.2% of *AS1170.4-1993*.

Table H3: Relationship between site class and geological unit for Cairns

Site class	Geological unit[1]	Lithological Description
A	Pg, Pgt, PRg, PRgb, PRgf	Permian fine to coarse biotite granites and pegmatites
A	SDh	Silurian-Devonian argillite, slate, arenite, greywacke, quartzite, greenstone, some micaceous phyllite and schist (Hodgkinson Formation)
B	Qpfc	Pleistocene steep alluvial and colluvial fans, cones and aprons - coarse boulder deposits (on granites), silty and clayey gravel (on metasediments)
B	Qpvm	Pleistocene basaltic lava, scoria, agglutinate
B	TQvf	Pliocene- Pleistocene basaltic lava, rare limestone
C	Qa	Pleistocene-Holocene undivided creek and river alluvium in west of area
C	Qha	Mainly Holocene undivided younger creek alluvium - silt, clay, sand and gravel
C	Qha_1	Holocene younger alluvium, lowest terraces and channel deposits - gravel, sand, silt
C[2]	Qha_2	Mainly Holocene younger alluvium, intermediate terraces - silt, clay, sand and gravel
C	Qhcd	Presumed Holocene quartz sand in high vegetated dunes

C	Qhcw	Presumed Holocene thin humic sand and mud in freshwater swamps
C	Qpa	Pleistocene old alluvium of the highest terraces of the Mulgrave River - gravelly clay and silt, sand and gravel at depth
C	Qpcb	Pleistocene silty and loamy quartz sand in degraded beach ridges
C	Qpcd	Pleistocene quartz sand in high vegetated dunes
C	Qpfp	Pleistocene gentle to very gentle coalescing alluvial fans - silty cobbles and gravels grading to gravelly clay, clay and silt
D	Qhcb	Holocene silty and loamy quartz sand in degraded beach ridges
D	Qhct	Holocene mud, sandy mud of estuaries and chenier ridges

NOTES:

[1] Reference Willmott and others, 1988
[2] Some parts are rated Site Class B or Site Class D (see text)

Table H4: Amplification factors for $T = 0.3$ s, from Crouse and McGuire (1996)

Site class	Amplification factor			
	PGA = 0.1 g	PGA = 0.2 g	PGA = 0.3 g	PGA = 0.4 g
A	1.0	1.0	1.0	1.0
B	1.3	1.3	1.3	1.3
C	1.6	1.5	1.4	1.3
D	2.1	1.9	1.8	1.7

Table H5: Amplification factors for $T = 1.0$ s, from Crouse and McGuire (1996)

Site class	Amplification factor			
	PGA = 0.1 g	PGA = 0.2 g	PGA = 0.3 g	PGA = 0.4 g
A	1.0	1.0	1.0	1.0
B	1.7	1.7	1.7	1.7
C	2.0	2.0	1.9	1.9
D	2.9	2.7	2.6	2.6

Table H6: Amplification factors for Cairns hazard maps (PGA ~ 0.05 g - 0.2 g)

Site class	Amplification factor	
	T = 0.3 s	T = 1.0 s
A	1.0	1.0
B	1.3	1.7
C	1.5	2.0
D	2.0	2.9

The range of amplification factors in Table H6 could, in fact, be higher in Cairns. Hard basement rock underlying sediments will increase the amplification factors

and this may well be the case for Cairns. 'Rock' in Australia (*AS1170.4-1993)* is equivalent to 'Hard rock' in California (Hwang et al., 1997). *AS1170.4-1993* includes a Site Factor of S = 0.67 for '… rock strength Class L (low) or better', resulting in amplification factors of three between hard rock and soft sediments. Crouse and McGuire (1996) had insufficient recordings of Californian earthquakes to distinguish between 'Hard rock' and 'Rock' response and they aggregated the recordings as 'Rock' (Site Class A for Cairns). We choose to use the empirical Californian data and we note that more research is needed to develop appropriate Australian amplification factors.

Stage 4 - Produce Response Spectra Describing the Earthquake Hazard for Each Site Class

We have slightly modified the results of Somerville and others (1998) to produce response spectra for Site Classes A-D (**Figure H3**). They used the amplification factors of Crouse and McGuire (1996) to produce spectra recommended for Australia.

The rock (Site Class A) response spectrum in **Figure H3** is unchanged from Somerville and others (1998). Our spectra for Site Classes B-D are also identical to those of Somerville and others except at periods greater than T = 0.7 s. For periods T= 0.1 s to 0.7 s the amplification factors are 1, 1.3, 1.5 and 2 (**Table H6**). At periods less than T = 0.1 s the amplifications are 1, 1.15, 1.25 and 1.5. At periods greater than T = 0.7 s we adopted the amplification factors 1, 1.7, 2 and 2.9 seconds (**Table H6**). These are slightly lower than the values 1, 1.95, 2.25 and 3 that Somerville and others used. We have preferred to use the empirical factors determined by Crouse and McGuire for an input PGA of 0.1 g at a period of T = 1 s (**Table H5**) whereas Somerville and others adopted amplifications 50% greater than the amplifications in the mid-period velocity band of the spectra.

The response spectra (**Figure H3**) give estimates of the earthquake hazard in Cairns for Site Classes A-D at periods in the range T = 0.03 s to 3.0 seconds, which cover most periods of interest to designers of structures and non-structural components. As mentioned earlier, the spectra may be scaled to estimate hazard for different annual exceedence probabilities.

APPENDIX I: CAIRNS LANDSLIDES - MASTER LIST

The reference number is that in the AGSO Cairns Landslide GIS database.

1. 8 March 1878: Flood followed by severe cyclone triggered many landslides across the inlet. They could be heard distinctly in Cairns (Jones, D., 1976, p. 125).

1891: During the construction of the Cairns railway, a heavy landslide occurred during an early, heavy and prolonged wet season (Ellis, R.F., 1976).

16 April 1894: 965 mm of rain fell during the month. The railway was blocked by 20 landslides and numerous wash-outs (Broughton, 1984).

2./3. 1896: Following a prolonged wet season, large landslides blocked the line at the Springs between No. 14 tunnel and Red Bluff, and at No. 15 tunnel (Broughton, 1984).

1897-1906: Minor rock falls occurred on the Cairns railway (Broughton, 1984).

31 May 1900: Five men were killed and one buried alive for one and a half hours when a 7.6 m (25 ft) deep tramway cutting they were constructing in alluvial sandy loam, clay and gravel in a river terrace at Riverstone for the Mulgrave Central Mill caved in (Morton, 1995; Morning Post, Cairns,N.Q., 1, 8 &15 June 1900). The locality is now known as "Dead man's Gully" or Dead man's Cutting" (A. Broughton, Cairns Historical Society, written communication, 1999) and is situated 3 km WNW of Walshs Pyramid in Gordonvale.

5. 1910: There was a landslide on the Cairns railway at Surprise Creek (Broughton, 1984).

4. 15 December 1910: Landslide at Kuranda end of No. 10 tunnel on Cairns railway partly closed the tunnel for more than two months. Several episodes of sliding occurred during this time (Broughton, 1984). The line was cleared for goods traffic on 25 February 1911 and for all traffic on 6 March 1911 (*Cairns Post*, 27 February and 7 March 1911).

Early January 1911: A *Cairns Post* reporter noted that there had been small landslides at various places, but that the obstructions had been removed. The most serious fall was at the 15 Mile, but that it would be cleared quickly. Lower down the line, one or two trivial falls had also been cleared (*Cairns Post*, 4 January 1911).

Early January 1911: There were rumours of a big washaway at 3.5 miles from Cairns near Edge Hill quarry, which would be repaired in a few hours (*Cairns Post*, 4 January 1911).

6. 7 February 1911: There was a big fall on the railway at 17.75 mile near Surprise Creek (Broughton, 1984).

Ca. 13 February 1911: A landslide blocked the tramway on the Aloomba side of the Mulgrave River. It was expected to be cleared on 15 February 1911 (*Cairns Post*, 15 February 1911).

8. 3 March - 2 April 1911: A failure under the railway line between No. 11 and No. 12 tunnels was caused by heavy rain (Broughton, 1984).

4. 16 March 1911 cyclone: At No. 10 tunnel, earth and boulders from overhead fell and blocked the railway line (*Cairns Post*, 18 March 1911).

7./5. 16 March 1911 cyclone: Falls occurred on the railway line near Stony Creek bridge and at Surprise Creek (Broughton, 1984).

7. 16 March 1911 cyclone: There was a fall at 14.25 miles which temporarily blocked the line (*Cairns Post*, 18 March 1911).

6. 16 March 1911 cyclone: There was another subsidence at 17 miles 50 chains (*Cairns Post*, 18 March 1911).

9. 1 April 1911: A big landslide occurred in the Nisbet Ranges across the inlet from Cairns. The scar could be seen in photos for several years afterwards (A. Broughton, Cairns Historical Society, personal communication, 1997). The landslide brought away trees, rocks and everything else from a considerable distance up the mountain side (*Cairns Post*, 3 April 1911).

10. 31 March - 2 April 1911: On the railway at Horseshoe Bend, south of Redlynch, the formation was washed out (Broughton, 1984).

11. 31 March - 2 April 1911: Landslides covered the line near No. 6 tunnel (Broughton, 1984).

12. 31 March - 2 April 1911: On the railway, from Stony Creek to the Springs, there were wash-outs and the undermining of the embankment (Broughton, 1984).

13. 31 March - 2 April 1911: From the Springs to Red Bluff, two big landslides of about 1000 tons had blocked the line for a considerable distance (Broughton, 1984).

3. 31 March - 2 April 1911: On the Kuranda side of No. 15 tunnel, there was a large fall (Broughton, 1984).

14. 31 March - 2 April 1911: Further along, the railway line was badly undermined and scouring had left the line hanging (Broughton, 1984).

5. 31 March - 2 April 1911: Near Surprise Creek, 1500 tons of mud and rock covered the line for five chains (Broughton, 1984).

15. 31 March - 2 April 1911: Just up the line was another fall of 500 tons (Broughton, 1984).

16. 31 March-2 April 1911: At Mervyn Creek, the line was covered to a depth of 4-6 m by another large landslide (Broughton, 1984).

1912: More landslides occurred on the Cairns railway (Broughton, 1984).

30 January 1913 cyclone: There was a landslide on the range between Kuranda and Cairns (*Cairns Post*, 1 February 1913).

17. 9 February 1927 cyclone: In upper Freshwater Creek, east of Jigol Creek, boulders pounded the concrete, in which new pipes had been set, to pieces and carried away the pipes (Cairns City Council, 1927).

18. 9 February 1927 cyclone: A portion of Chirio's farm was washed away - possibly on 12 February (Cairns City Council, 1927).

19. 9 February 1927 cyclone: At Freshwater Creek, about 1 km WSW of Brinsmead, a pipe was broken near a wash-out about 1 km long (Cairns City Council, 1927). The creek here alters course (G. Haussmann, retired City Engineer, personal communication, 1997).

19A. 1932: The construction of the original above-ground hydro-electric power station at the bottom of the Barron Falls was abandoned because of major rock falls and other complications (Jones, D., 1976, p. 460).

March 1934 cyclone: At Slip Cliff Point on the Captain Cook Highway, about 200 000 tons of rock crashed down across the road, closing it. The road was relocated to a higher alignment. There are claims that the sound was heard in Port Douglas and Cairns (Richards, 1996).

19B. 1939: There were several landslides in new cuttings in Redlynch Intake Road near the last crossing on Freshwater Creek (Mulgrave Shire Council).

20. 12 January 1951: A torrential deluge of about 700 mm of rain in just under five hours, triggered debris flows over 10 km of the Captain Cook Highway between Buchan and Simpson's Points. Huge quantities of debris were swept from the mountainside on to the road and over the precipice into the sea. Boulders up to 3 m long were hurled into the Pacific like marbles. Large slabs of bitumen were tilted up from the road, and landslide debris was piled as high as 3 m. All culverts and inverts in this area were either damaged considerably or washed away entirely. The highway was not expected to carry normal traffic for at least two weeks (*Cairns Post*, 15 January 1951).

21. 5 March 1954: A large landslide in the Red Bluff area, with its head well above the railway and the toe well below it, blocked the Cairns railway from 5 March until 22 April 1954 (A. Broughton, Cairns Historical Society, personal communication, 1997).

21B. 1967: 300,000 m^3 of the hillside slipped down on to the road going to the base of the quarry face at White Rock. The quarry was closed temporarily (Don Healy, personal communication).

21A. 10 March 1970: Following about two weeks of rain at 25 mm a day, then about 200 mm of rain in two hours on 10 March, about 50 landslides occurred on hills in Whitfield - Edge Hill and other areas to the west of Cairns CBD. Hillview Crescent, Whitfield was the worst affected. A slide 50 m long, almost liquid, went under a house and on to the road in front of it. There were phone calls from residents with landslides pushing against their houses in various parts of Cairns (G. Haussmann, personal communication, 1997).

22. 1979: Following very heavy rain, a 60 m x 60 m batter and fill failure on Lake Morris Drive behind Earlville/Bayview Heights took out a section of road which was then closed for about six months. This section of road was 50% damaged again in 1981, and the road was nearly abandoned (G. Haussmann, personal communication, 1997).

23. Around 1979: A landslide near the reservoir tanks on the south side of Brinsmead-Kamerunga Road blocked the road (Member of Cairns Historical Society, personal communication, 1997).

21A. Around 1979: On Hillview Crescent, Whitfield, the hill gave way and went straight through houses. Mud went into the back of one house (Member of Cairns Historical Society, personal communication, 1997). Is this the event of 10 March 1970?

24. Around the 1980s: Mud went straight a newly completed house in Smithfield Heights. The house was not structurally damaged (*Cairns Post* employee, personal communication, 1997).

24A. 1984 or 1985: Boulders smashed the water main at No. 3 crossing on Freshwater Creek and, either before or after that, the main slipped with a mudflow which took out the anchor blocks (D'Arcy Gallop, Cairns City Council, personal communication, 1997).

25. 1988: A landslide at Sydney Street, Bayview Heights wrote off two or three building blocks.

26. 1990 or earlier: A fill failure on the NW side of Granadilla Drive, Earlville caused one lane to be closed permanently.

27. 23 December 1990 Cyclone Joy: Undercutting by a creek caused a landslide on the south side of Granadilla Drive/Comet Street, Earlville/Bayview Heights which closed this section of road permanently - only a walkway remains.

28. ?1990s: There have been slope stability problems in City View Estate, Mooroobool (Two different citizens of Cairns, personal communication, 1997).

29. ?1990s: A landslide caused part of the Rainforest Estate subdivision to be permanently abandoned (three different reports from technical consultants). The roadway and stormwater drains were broken.

30. ?1990s: A partly built house at 263 Toogood Road, Bayview Heights has a slump in talus in the excavation at the back. This landslide was reactivated by Tropical Cyclone *Justin* in March 1997.

31. ?1990s: At 5 Juno Close, Mooroobool, a house was destroyed due to batter failure at the rear, and rebuilt.

32. ?1990s: On the corner of Grandview Crescent and Barnes Street, Earlville a partly completed house was written off due to 300 mm of movement.

October 1995: A landslide in the Kuranda Range closed the Cairns railway for several days (Linda Berry, James Cook University, personal communication, 1997).

33. 1997: A debris slide about 3 m high by 2 m wide occurred in the batter on the north side of the Brinsmead-Kamerunga Road.

34. 1997: Small batter failures occurred on the hillslope to the east of Brinsmead.

36. 1997: Recent failure in weathered rock in rainforested area in Barron Gorge, estimated 20 m high x 2m wide, on opposite side of gorge to railway line.

37. 1997: Near Barron River Falls Railway Station, there are three batter failures in red, highly weathered rock. Two are 2-3 m high x 2 m wide and one is 2-3 m high x 1 m wide.

1997: In Freshwater Valley, on the Cairns Railway, there is a small batter failure about 0.7 m high x 2 m wide in weathered rock.

13. 1997: On the south side of Red Bluff, debris frequently falls, including in 1997 (Linda Berry, James Cook University, personal communication, 1997).

1997: Small batter failures occurred during this wet season along Lake Morris Drive.

23 March 1997, T.C. *Justin*: Numerous batter failures occurred along Lake Morris Drive, and the Kuranda Range Road. Batter failures were also logged along the Cairns Railway, Toogood Road, Redlynch Intake Road, Yarrabah Road, Reservoir Road, and in Rainforest Estate.

96J. 23 March 1997, T.C. *Justin*: A landslide about 600m long and 15 m wide occurred on a natural slope on the escarpment 8.5 km west of Gordonvale.

APPENDIX J : CAIRNS 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, 1998), a database of cyclone tracks developed by the Bureau's Severe Weather Section in Brisbane (BoM, 1997) and Appendix 1 in Harper (1998).

Cyclones which passed within 75 km of Cairns are shown with their date in **bold**; those which passed between 75 and 150 km of Cairns are shown with their dates underlined.

8 March 1878

An unnamed but severe cyclone (Category 3?) hit Cairns. Iron roofing was flung through the air and many properties were destroyed. The steamer *Louise* and sailing vessels *Merchant*, *Kate Conley* and *Hector Miss* were sunk in the Cairns inlet with the loss of all hands. Major debris flows occurred on the eastern side of Trinity Inlet and coastal inundation occurred.

2 February 1882

An unnamed cyclone (Category 2?) hit Cardwell (150 km south) with considerable damage. It is likely that Cairns was also affected by winds from this cyclone.

29 March 1890

An unnamed but severe cyclone (Category 3?) crossed the coast at Ingham (200 km south). Cairns probably experienced some effect from this cyclone.

28 January 1906

An unnamed cyclone (Category 3?) crossed the coast at Cairns causing 'devastation'.

19 January 1907

An unnamed severe cyclone (Category 3?) crossed the coast near Cooktown (170 km to the north) with 9 fatalities and severe damage. Cairns would have felt the effects of this event.

28 January 1910

An unnamed cyclone (Category 2-3?) crossed the coast around Cape Tribulation and passed within 60 km of Cairns to the west before re-crossing the coast near Townsville. It produced heavy gales and 'tremendous' seas at Cairns. Storm tide inundation of perhaps 0.7 metres was experienced. The vessel *Bombala* ran aground.

10 February 1911

An unnamed cyclone (Category 1-2?) passed to the east of Port Douglas and tracked down the coast passing within 80 km of Cairns. Port Douglas buildings and crops suffered with wind damage. Similar damage probably also occurred in Cairns.

16 March 1911

An unnamed, but severe cyclone (Category 3?) crossed the coast near Port Douglas (55 km north of Cairns) where there were 2 fatalities and much damage. In Cairns balconies were stripped off buildings and roofs damaged. Verandahs collapsed and some buildings were unroofed. Rainfall caused major landslides which blocked the Kuranda railway for several months.

7 April 1912

An unnamed low category cyclone (Category 1-2?) recurved to within 70 km to the east of Cairns. No damage was reported in Cairns but several houses were badly damaged in Innisfail (70 km to the south).

31 January 1913

An unnamed but severe cyclone (Category 3?) crossed the coast about 70 km north of Cairns. Damage included the front of the Stock Exchange being blown in, balconies stripped off buildings; a house lifted off its stumps; a sawmill and several sheds unroofed. Storm tide inundation of unknown depth caused damage to many boats and the sea wall was smashed. The schooner *Dancing Wave* was lost with all hands.

10 March 1918

An unnamed, but very severe (possible Category 5) cyclone crossed the coast at Innisfail (70 km to the south). The large storm tide and severe winds causing large loss of life - as many as 100 people perished in the area between Bingle Bay and South Mission Beach. Whilst the main centre of damage was in the Innisfail area, Cairns and Babinda (50 km south) and centres on the Atherton Tableland suffered widespread damage.

3 February 1920

An unnamed severe cyclone (probably Category 3) crossed the coast north of Cairns within 80 km of the town. Widespread building damage occurred throughout the district (nearly every building in Kuranda was unroofed). Storm tide inundation to approximately 1 metre above HAT was experienced in Cairns and at least one building on the coast was destroyed by the sea.

26 February 1925

An unnamed (Category 1-2?) cyclone crossed the coast near Mossman (65 km north) with building damage as far north as Cooktown. Cairns probably experienced some wind damage.

9 February 1927

An unnamed (Category 3?) cyclone crossed the coast perhaps 50 km to the north of Cairns. At least 16 buildings were totally destroyed whilst many others were unroofed or otherwise damaged.

20 January 1930

An unnamed (Category 1-2?) cyclone crossed the coast near Mossman (65 km north). No reports of damage in Cairns have been noted, but widespread flooding was caused across Queensland.

1-8 February 1931

An unnamed (Category 1-2?) cyclone entered the Coral Sea near Cooktown and moved down the coast, passing within 300 km of Cairns, and going as far south as Hervey Bay. Significant flooding was experienced in all areas.

19 January 1932

An unnamed (Category 1-2?) cyclone tracked from the Gulf to the east of Townsville producing disastrous flooding in the area from Cairns to Mackay.

22 January 1934

An unnamed (Category 1-2?) cyclone crossed the coast within 35 km of Cairns with serious flooding over a large part of the state.

12 March 1934

An unnamed (Category 3?) cyclone crossed the coast south of Cape Tribulation (about 75 km to the north of Cairns) with a 9.1 metre storm tide recorded at nearby Bailey Creek and 1.8 metres storm tide at Port Douglas. Several luggers and 75 persons were lost at sea. Cairns probably suffered damage in this cyclone given its strength and proximity.

<u>18 February 1940</u>

An unnamed Category 3 cyclone crossed the coast at Cardwell (150 km to the south). The worst impact was to the south of Cardwell, including significant storm tide damage in Townsville, however, some wind damage in Cairns was likely given its proximity and strength.

6 March 1940

An unnamed (Category 1-2?) cyclone crossed the coast north of Cooktown (perhaps 240 km to the north) causing significant flooding along Cape York. Some wind impact may have been experienced in Cairns.

23 March 1940

An unnamed (Category 1-2?) cyclone which formed in the Gulf of Carpentaria crossed Cape York about 300 km north of Cairns causing flooding in the north, including in the Barron River.

3 April 1941

An unnamed (Category 1-2?) cyclone recurved to within about 190 km of the coast near Cairns with high seas and coastal damage reported.

<u>16 February 1942</u>

An unnamed (Category -2?) cyclone crossed the coast near Cardwell (150 km south) before moving south to Mackay. Limited damage probably occurred in Cairns.

<u>31 January 1945</u>

An unnamed (Category 1-2?) cyclone crossed the coast near Cooktown produced floods in the Barron River.

18 March 1945

An unnamed possible Category 3 cyclone crossed the coast north of Cooktown (perhaps 200 km to the north). Major loss of life caused by the sinking of a freighter and a ketch. A storm surge of greater than 0.8 metres was reported from Cairns but no inundation.

8 February 1946

An unnamed cyclone (Category 1-2?) crossed the coast about 35 km south of Cairns. Widespread floods were reported.

2 March 1946

An unnamed Category 2 cyclone recurved over Cairns and Townsville. Considerable damage and some loss of life was experienced. A storm surge of more than 0.7 metres was reported from Cairns but apparently no inundation.

7 January 1948

An unnamed Category 1-2 cyclone, which formed in the Gulf crossed Cape York, causing heavy flooding from Cooktown to Cardwell. It recrossed the coast as a low about 60 km south of Cairns. A storm surge of around 0.5 metres was reported from Cairns but no inundation.

10 February 1949

An unnamed Category 1-2 cyclone crossed the coast north of Cooktown (perhaps 200 km to the north of Cairns) causing extensive structural damage in Cooktown. Light damage may have been experienced in Cairns.

<u>15 January 1950</u>

An unnamed Category 1-2 cyclone recurved near Cooktown to within about 120 km of Cairns bringing gales and floods to most coastal centres. A storm surge of 0.5 metres reported from Cairns but no inundation.

6 March 1950

An unnamed (Category 1-2?) cyclone crossed the coast near Mossman about 70 km north of Cairns. Its main impact was to produce minor flooding in the Barron River.

12 January 1951

The intense rainfall event that triggered the major debris flow at Ellis Beach reported in Chapter 5 was probably associated with a Category 1 cyclone in the Gulf, with a closest point of approach to Cairns of about 450 km.

6 March 1956

Category 3 cyclone *Agnes* crossed the coast at Townsville then moved northwards as far as Ingham before turning west. Wind gusts <u>from the west</u> of up to 150 km/hr recorded in Cairns with widespread damage.

20 January 1959

Category 2 Cyclone *Bertha* from the Gulf crossed into the Coral Sea between Cairns and Cooktown and passed within 20 km of the city. Widespread flooding and wind damage to banana crops was reported.

15-16 April 1964

Recurving Category 1 cyclone *Gertie* which made its closest coastal approach in the Whitsunday Group (500 km to the south-east) caused extensive damage to sugar cane around Cairns together with flooding and dislocation of both road and rail networks.

6 December 1964

Category 1 cyclone *Flora* crossed from the Gulf to enter the Coral Sea near Innisfail, passing within 40 km to the south of Cairns. Some wind damage and flooding in Cairns was likely given its proximity.

30 January 1965

Category 1 cyclone *Judy* crossed from the Gulf to enter the Coral Sea close to Innisfail. Again, wind damage and flooding in Cairns was likely.

14 March 1967

Category 1 Coral Sea cyclone *Elaine*, which approached to within 100 km of the coast near Cairns, generated a storm surge recorded as 0.5 metres in the city. There was no reported inundation.

24 December 1971

Category 3 cyclone *Althea*, which crossed the coast at Townsville, generated a 0.7 metres storm tide at Cairns whilst the cyclone was at least 250 km distant. No inundation was reported in Cairns.

4 March 1973

Category 1 cyclone *Madge*, which crossed from the Gulf just north of Cooktown (about 250 km to the north) brought widespread flooding. The Bruce Highway was cut in six places between Townsville and Cairns.

19 December 1973

Category 1 cyclone *Una*, which came within 220 km of Cairns and eventually crossed the coast east of Townsville, generated a 0.4 metre storm surge at Cairns.

6 February 1974

Category 4 cyclone *Pam*, which was about 1,700 km from Cairns at its closest point of approach, generated a storm surge measured at 0.3 metres in Cairns.

1 February 1976

Category 1 cyclone *Alan* crossed the coast near Bloomfield Mission (155 km to the north). Minor damage in Cairns is likely to have been experienced.

8 March 1977

Category 1 cyclone *Otto* crossed from the Gulf into the Coral Sea near Cape Tribulation (80 km to the north). No significant wind damage was reported by serious flooding occurred between Cairns and Ingham.

31 January 1977

Category 1 cyclone *Keith* made landfall just to the east of Cairns before moving south along the coast. Only minor wind damage to buildings was reported, however, extensive loss of banana and sugar crops occurred.

1-2 January 1979

Category 1 cyclone *Peter* approached to within 130 km of Cairns after crossing from the Gulf and degenerating into a rain depression. There was no significant wind damage, however, very intense rainfall led to serious flooding in and around Cairns (1,140 mm of rain was recorded on Mount Bellenden Ker, 50 km south, in 24 hours). There were two drowning fatalities.

26 February 1981

Category 1 cyclone *Freda* formed near Cooktown before moving away from the coast. Significant flooding occurred in the Barron River.

22 February 1985

Category 1 cyclone *Pierre* paralleled the coast about 160 km off Cairns on a southward track. Minor local flooding only was reported.

<u>1 February 1986</u>

Category 3 cyclone *Winifred* crossed the coast south of Innisfail (about 90 km to the south) with wind gusts in Cairns recorded at 118 km/hr. Substantial wind damage, especially uprooted trees, was reported from Cairns, mainly from westerly winds. A storm surge of 0.5 metres was measured at Cairns, however, no coastal inundation was reported.

<u>22-25 December 1990</u>

Category 4 cyclone *Joy* approached, and hovered, to within 120 km of Cairns before decreasing in intensity and moving south. Strongest winds in Cairns were measured at 124 km/hr on 23 December, whilst Green Island recorded a gust of 180 km/hr. A storm surge of 0.5 metres was measured at Port Douglas but no coastal inundation was reported from the area.

22 March 1997

Category 2 cyclone *Justin* made a bullseye impact on Cairns with wind gusts of 128 km/hr. About $2 million damage was done to the Cairns Marina and extensive, but relatively minor damage was done to buildings and power supply infrastructure. A peak storm surge of 0.66 metres was recorded at Cairns at about one hour before low tide. Minor sea wave and storm tide inundation of roads in northern beach suburbs occurred. The Barron River was in high flood.

11 February 1999

Weak Category 3 cyclone *Rona* crossed the coast near Cape Tribulation from the south-east. Wind damage was relatively light but heavy rain brought the Barron River to major flood levels. A storm surge of 0.6 m was measured on the Cairns tide gauge, though closer to the eye wall the surge was measured at 1.0 m at Port Douglas and 1.6 m at Mossman. Landfall was close to low tide.

APPENDIX K: STORM TIDE SCENARIO STATISTICS

Table K1: Storm tide impact on Cairns critical facilities

FACILITY	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
ABC Studios		C	A	A	A
ABC Transmitters					
Airport Control Tower		C	A	A	A
Airport Rescue and Fire Service		C	B	A	A
Ambulance Station Cairns		B	A	A	A
Ambulance Station Edmonton					
Ambulance Station Gordonvale					
Ambulance Station Smithfield					
Ambulance Station Yarrabah					
Ampol Fuel Depot		C	A	A	A
Bethlehem Nursing Home	C	B	A	A	A
Boral Gas Depot	B	A	A	A	A
Cairns Central	C	B	A	A	A
Cairns City Council Centre	C	B	A	A	A
Cairns City Council Works Depot		C	A	A	A
Cairns City Council Gordonvale					
Cairns Crocodile Farm			A	A	A
Cairns Hospital		C	A	A	A
Cairns Port Facilities	B	A	A	A	A
Caltex Fuel Depot	C	B	A	A	A
Calvary Hospital	B	B	A	A	A
Country Bake Bakery (Westcourt)			A	A	A
Country Bake Bakery (Bentley Pk)					
CSR Bulk Sugar Terminal	A	A	A	A	A
FARNOHA Nursing Home		C	A	A	A
Festival Faire		C	A	A	A
Fire Station Cairns		C	A	A	A
Fire Station Gordonvale					
Fire Station Smithfield					
FNQEB Cairns Substation	B	B	A	A	A

FNQEB Gordonvale Substation					
FNQEB Kamerunga Bulk Supply					C
FNQR 51st Battalion Depot		C	A	A	A
Fresha Products Cold Stores	C	B	A	A	A
Fortuna Seafood Cold Stores	B	B	A	A	A
Garozzo Agencies Wholesale Food	B	B	A	A	A
Gordonvale Memorial Hospital					
Good Samaritan Nursing Home		B	A	A	A
HMAS Cairns	B	A	A	A	A
INCITEC	B	A	A	A	A
Mobil Fuel Depot	B	B	A	A	A
Nazareth Village Nursing Home	C	B	A	A	A
Police Station Cairns	C	B	A	A	A
Police Station Smithfield					
Police Station Yarrabah					
Portsmith Cold Stores		C	A	A	A
Pyramid Retirement Centre					
Sewerage Treatment Plant		C	A	A	A

Table K1(cont.): Storm tide impact on Cairns critical facilities

FACILITY	1:50	1:100	1:500	1:1,000	1:10,000
Shell Fuel Depot	B	A	A	A	A
Smithfield Plaza					
Southern Pollution Control Centre	B	B	A	A	A
Stockland Plaza					
Telephone Exchange Cairns		B	A	A	A
Tong Sing Wholesale Fruit & Veg		C	A	A	A
Water Treatment Plant Kanimbla					
Water Treatment Plant Yarrabah					
WB Winfield Nursing Home					
Westcourt Plaza		B	A	A	A
Yarrabah Hospital					
Yarrabah Council Works Depot			A	A	A

NOTES:

A = water more than 1.0metre over floor level B = less than 1.0 metre of water over floor level

C = water on the property but not over floor level

Table K2: Impact of a 2% AEP storm tide on Cairns suburbs

SUBURB	>1m over floor - A	>1m over floor - B	>1m over floor - C	<1m over floor	on ground only	roads >0.5m under (km)	roads .25-.5m under (km)	roads <.25 under (km)	cane fields (ha)
Aeroglen				44	34	1.7	1.2	5.4	
Barron					1	1.2		1.1	1380
Cairns North		1		6	33	3.8	3.3	12.0	
City	2			233	135	10.7	1.4	3.5	
Clifton Beach				3	24	3.4	0.4	1.0	
Edge Hill						1.0	0.2	1.3	
Edmonton				5	1	2.1	3.0		983
Holloways Beach				8	1	1.9	0.2	2.9	881
Kamma				2	4	7.5	1.6		1091
Kewarra Beach						2.1	0.4	0.1	
Machans Beach				70	83	5.9	1.7	4.1	464
Manoora								4.7	
Manunda				93	516	7.7	8.8	12.3	
Palm Cove				21	16	3.1	0.1		
Parramatta Park				101	272	6.7	4.4	6.1	
Portsmith	3			194	51	11.7	3.6	10.5	
Smithfield					1	1.5	0.2		437
Stratford						0.2		0.6	
Trinity Beach	1			12	15	2.8	0.4	0.4	
Trinity East				8	1	5.2	4.3	0.2	4134
Trinity Park				15	17	1.2	1.8	1.7	
Westcourt				22	184	3.7	4.7	17.7	
White Rock				6	2			0.6	97
Woree				3	2	1.3	2.0	0.2	
Wright's Creek				3	2	4.2			2048
Yarrabah					9			1.6	
Yorkeys Knob		2		15	13	4.9	1.4	7.2	2255
TOTALS	6	3	0	866	1424	95.8	45.6	97.6	14007

NOTE:

A= buildings within the first 750 metres of the shoreline; B = buildings between 750 and 1,500 metres of the shoreline; C = buildings further than 1,500 metres from the shoreline.

Table K3: Impact of a 1% AEP storm tide on Cairns suburbs

SUBURB	**>1m over floor - A**	**>1m over floor - B**	**>1m over floor - C**	**<1m over floor**	**on ground only**	**roads >0.5m under (km)**	**roads .25-.5m under (km)**	**roads <.25 under (km)**	**cane fields (ha)**
Aeroglen				79	42	4.3	4.1		
Barron				1		1.2	1.1		1571
Cairns North		2		122	513	8.5	11.6	2.6	
City	96			287	198	13.1	2.5		
Clifton Beach	1			53	32	1.5	2.4	0.8	
Edge Hill					74	1.4	1.1	1.3	
Edmonton				6		5.1			1076
Holloways Beach	1			14	43	1.6	2.9	0.2	1329
Kamma				6	1	9.1	0.81	2.9	1350
Kewarra Beach				2	15	1.1	0.8	0.6	
Machans Beach	41			120	231	6.9	4.3	0.2	505
Manoora				6	221		6.2	1.2	
Manunda		17	16	515	897	21.1	8.7	0.9	
Mooroobool				4	56	0.5	1.1	0.6	
Palm Cove	12			26	11	3.1		0.1	
Parramatta Park		3	17	219	749	11.9	5.3		
Portsmith	74	20		263	455	18.1	7.6		
Smithfield				1	8	1.7			496
Stratford					1	0.2	0.6	1.1	
Trinity Beach	8			37	50	2.8		1.4	
Trinity East	1		3	6	3	7.3		2.1	4169
Trinity Park		1		33	142	3.3	1.5	0.7	
Westcourt			1	269	1018	13.5	14.1	3.7	
White Rock			3	6	20		1.1	0.5	116
Woree				10		3.3	0.2		
Wright's Creek			1	4		4.2	2.1	3.7	2718
Yarrabah				53	80		1.6	1.6	
Yorkeys Knob	7	2		97	307	7.2	6.6	1.2	2481
TOTALS	241	45	41	2239	5170	161.8	87.4	27.6	16130

NOTE:
A = buildings within the first 750 metres of the shoreline; B = buildings between 750 and 1,500 metres of the shoreline; C = buildings further than 1,500 metres from the shoreline.

Table K4: Impact of a 0.2% AEP storm tide on Cairns suburbs

SUBURB	>1m over floor - A	>1m over floor - B	>1m over floor - C	<1m over floor	on ground only	roads >0.5m under (km)	roads .25-.5m under (km)	roads <.25 under (km)	cane fields (ha)
Aeroglen	6	55	41	31	34	8.4	0.2		
Barron			1			2.3			1685
Cairns North	393	82		179	217	23.2	0.1		
City	485	52		20	24	15.7			
Clifton Beach	123			30	14	5.2			
Edge Hill			92	119	80	4.4	0.8	0.4	
Edmonton			7	2		5.1			1590
Holloways Beach	73			66	44	6.0	1.2		1634
Kamma			9			14.1			2009
Kewarra Beach	43			60	21	2.8	0.1	0.4	
Machans Beach	291	48		49	25	11.8			505
Manoora			247	168	106	7.6	0.8	0.2	
Manunda		154	1015	169	177	30.7	0.2		
Mooroobool			64	88	60	2.6	0.8	0.7	
Palm Cove	57			5		3.2			
Parramatta Park		504	47	216	222	17.2			
Portsmith	140	265	311	42	54	25.7			
Smithfield			10	1		1.7		0.4	602
Stratford			1	2	10	2.1	0.3		
Trinity Beach	129			80	27	6.2	0.3	0.1	
Trinity East	12		11	5	4	10.3	0.8	5.5	4254
Trinity Park	25	162	4	43	18	5.5		0.2	
Westcourt			1180	305	359	32.1	0.4		
White Rock			35	53	22	1.9	0.4	1.0	215
Woree			11			3.7			
Wright's Creek			7	12		14.7	1.7	0.9	3980
Yarrabah	143			21	11	4.8	0.2		
Yorkeys Knob	282	233	3	137	11	16.9	0.6		2990
TOTALS	2202	1575	3103	1927	1561	296.1	8.8	11.1	20169

NOTE:
A = buildings within the first 750 metres of the shoreline; B = buildings between 750 and 1,500 metres of the shoreline; C = buildings further than 1,500 metres from the shoreline.

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