COMMUNITY RISK IN GLADSTONE

A MULTI-HAZARD RISK ASSESSMENT

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(editors)

Cities Project
AGSO – Geoscience Australia

Produced in conjunction with the Bureau of Meteorology

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Chapter 6 (compiled by Ken Granger, with the Landslides section written by Marion Michael-Leiba) draws on material developed for the *Cities Project's* South-East Queensland multi-hazard risk study. The contribution of Bruce Harper (severe thunderstorms), Michael Berechree (heat wave) and Dave Luxton (bushfire) to that material is acknowledged with appreciation. Sarah Hall did the historical research that provided the specific landslide information for Gladstone.

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KG

EXECUTIVE SUMMARY

Community Risk in Gladstone is the fourth of a series of multi-hazard case studies by the AGSO *Cities Project*. The report considers tropical cyclone, including severe wind and storm tide, and earthquake. It also provides an overview of the risks posed by severe thunderstorm, flood, landslide, heat wave, and bushfire.

The risk assessments in this report focus on building damage. The vast majority of buildings in Gladstone are residential but the major risks facing Gladstone are economic risks that could arise from interruption to the major industry, including the Boyne Smelters, and Queensland Alumina Refinery, and to the facilities of this important regional port.

The study serves as an introduction to the natural hazard risks facing the Gladstone community and as a focus for discussion on those risks. It provides material that may assist decisions on the importance of undertaking further, more rigorous risk assessments and cost/benefit analyses.

We have adopted a systematic approach to the description of the elements at risk in the community and their vulnerability, grouping the various elements into the five themes of setting, shelter, sustenance, security and society. We have developed an overall vulnerability profile of Gladstone that identifies those census collector's districts and suburbs that provide a disproportionate contribution to community risk because of the number and nature of the elements at risk. Of the five census collector's districts that contribute most to overall community vulnerability, two are in Barney Point, one is in Clinton, and two are in South Gladstone.

Our analysis enables us to make the following comments regarding the 'riskiness' of Gladstone.

- **Tropical cyclone severe wind:** The amount of damage estimated to occur as the result of a design level event, a 0.1% annual exceedance probability wind, would equate to total damage to 700 dwellings. Strong winds pose a threat to power reticulation which in turn could pose a very serious threat to industry, especially the aluminium smelter. There are localised areas in which the combination of building age, construction and site conditions could produce high damage levels. The main area of concern lies along the coastal strip in which shielding from the wind and storm tide is likely to be minimal. The neighbourhoods in which the overall wind risk is greatest are located in the following suburbs (in alphabetical order): Barney Point, Boyne Island, New Auckland, Tannum Sands and West Gladstone.

- **Storm tide inundation:** At the 1% annual exceedance probability level, it is *estimated* that 247 buildings or facilities will experience over-floor inundation. The Callemondah area, with its concentration of key transport and logistic facilities on low-lying filled land, together with its high vulnerability index, clearly has the greatest level of risk. Next are the Barney Point port area and the Boyne Island area. These are the two most significant census collector's districts from an economic resources perspective and amongst the most important in Queensland. The viability of Gladstone rests on its port and the port facilities, including the coal loader, the bauxite import and alumina export facilities. These may be made inoperative for a period because of storm tide damage. The residential neighbourhoods that have a high storm tide risk index tend to be in the areas of older residential coastal development, particularly Barney Point and the northern end of Boyne Island. These are neighbourhoods that contain more elderly people and/or people in the lower socio-economic ranges.

- **Earthquakes:** Our study area is on the northern margin of the Wide Bay – Burnett earthquake zone, which is the most active earthquake area in Queensland. The earthquake hazard for Gladstone, as read from a national map, is relatively high for an urban centre in Australia, being only marginally lower than that for Newcastle or Adelaide. We have insufficient data at this stage to estimate earthquake risk for the study area. We recommend investigating the feasibility of collecting additional information to produce a reliable, detailed earthquake hazard map, taking site conditions into account, as soft sediments or land fill tend to amplify earthquake shaking. There are localised areas in which the combination of building age, construction and site conditions could produce high damage levels but, fortunately, less than 10% of the structures in the study area are built on soft sediment or land fill. An earthquake risk assessment would enable one to ascertain whether a high magnitude earthquake close to Gladstone would cause damage to the power reticulation network as well as to buildings and other infrastructure. Much of the domestic water reticulation, for example, consists of brittle, and consequently fragile, pipes. Unlike cyclones, there would be no warning of an earthquake by which to shut down plant in a safe and timely manner.

- **Floods:** Flood, urban stormwater and flash flooding caused by cyclones, east coast lows or severe storms pose a threat of both fatalities and economic loss in localised areas. There is currently insufficient information available on which to base a risk assessment.

- **Severe thunderstorms:** Severe thunderstorms pose a threat of economic loss and fatalities from hail, lightning and wind. We do not have enough information at present to quantify the level of risk. The impact from any one storm will be more localised than that of a tropical cyclone.

- **Heatwaves:** In the period between 1803 and 1992 at least 4287 people died in Australia as a direct result of heat waves (Coates, 1996). Given the lack of detailed information about the incidence of heat wave in the Gladstone region, it is not possible to provide a specific risk assessment. The elderly, especially those living alone, are a particularly susceptible group. In the Gladstone study area there were 531 people that were within this group in 1996. They were present in 49 of the 53 census collector’s districts in the study area, with the largest number (38) in a census collector’s district located in South Gladstone.

- **Bushfires:** Whilst bushfires in Gladstone have not been as severe as the worst fires in the southern states, serious fires have occurred in the region during most months of the year. Bushfires do destroy property (including urban property) and they do kill people in Queensland. The overall risk of bushfire damage is higher in rural areas, and in urban areas near the interface with the ‘bush’, than in built-up areas further from the vegetation boundary.

- **Landslides:** Auckland Hill, one of the lower hills in the study area, was subject to landsliding in the 1960s and in 1988. There are a number of other hills that may also experience slope instability in torrential or prolonged heavy rain, particularly in areas developed with cut and fill without appropriate mitigation measures. We recommend establishing a database of landslides from cuts and natural slopes to aid in risk assessment.

CHAPTER 1: URBAN MULTI-HAZARD RISK ASSESSMENT

Ken Granger

This Report

This study provides details of the outcomes of research into the risks faced by the Gladstone community that are posed by a range of natural hazard phenomena. In this study, the acute (i.e. potentially fatal) hazards considered include tropical cyclones and earthquakes. In addition, the potential impacts of climate change are also addressed. It has been developed as a primary resource for those people who have a professional or personal interest in community risk within the Gladstone region.

The risk assessments in this report focus on building damage and the vast majority of buildings in Gladstone are residential. However, the major risks facing Gladstone are economic risks that could arise from interruption to the major industry in Gladstone. The city itself is a major industrial centre and a major regional port. The study, therefore, serves as an introduction to the natural hazard risks facing the Gladstone community and as a focus for discussion on those risks. It provides material that may assist decisions on the importance of undertaking further, more rigorous risk assessments and cost/benefit analyses.

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

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

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

The Cities Project

The *Cities Project* was established in 1996 to undertake research directed towards the mitigation of the risks faced by Australian urban communities that are posed by a range of geohazards. **The ultimate objective is to improve the safety of communities, and consequently make them more**

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

sustainable and prosperous. It formed a significant part of Australia's contribution to the International Decade for Natural Disaster Reduction (IDNDR) which ran through the 1990's and continues to be a focus for Commonwealth community risk research. It can also be seen as a response to the findings of the 1993 Senate Inquiry into Major Disasters and Emergencies (Senate, 1994). In its findings the Senate Committee encouraged the emergency management community to modify its doctrine from one that had been traditionally dominated by attention to disaster response, to one which gives greater attention and emphasis to risk mitigation and the reduction of community vulnerability.

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

- the Bureau of Meteorology;
- the Queensland Departments of Emergency Services, Mines and Energy and Natural Resources;
- the Gladstone City and Calliope Shire Councils; and,
- researchers in various CSIRO Divisions, academic centres and a number of private sector agencies.

Risk Management

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

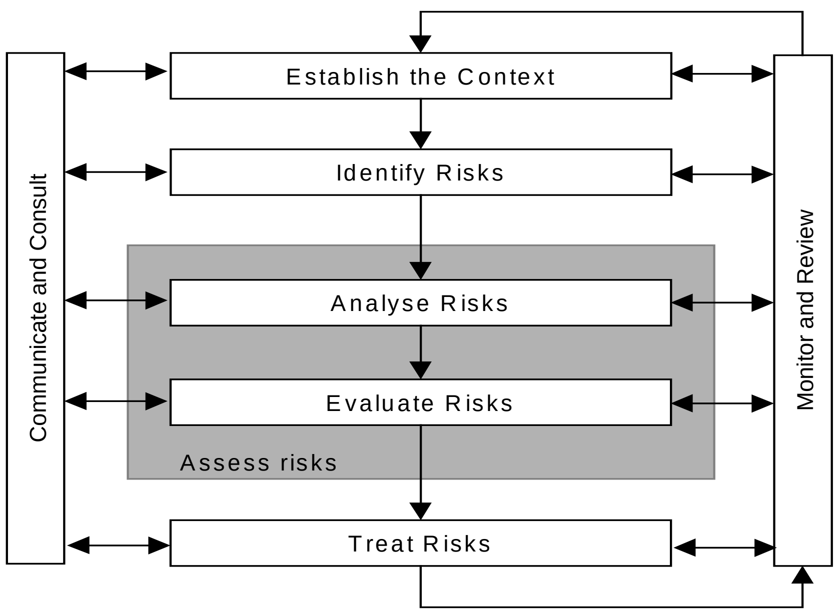

Figure 1. 1 Risk management overview (Standards Australia, 1999a, after Fig 3.1)

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

What is Risk?

The risk management Standard defines 'risk' as:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

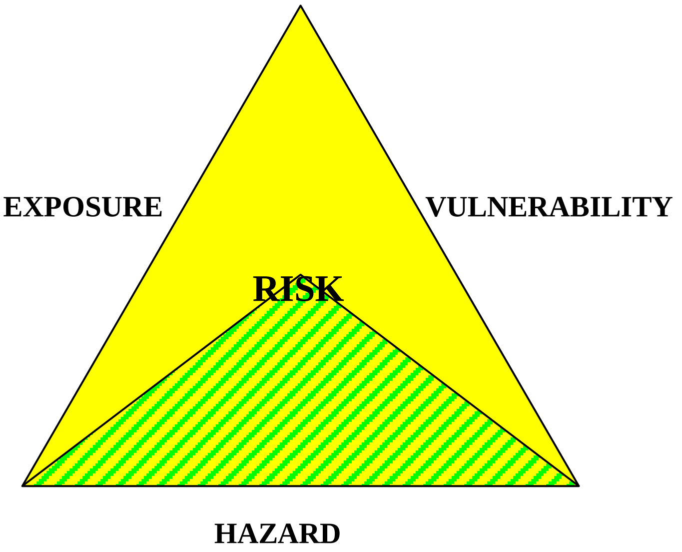

Figure 1. 2 The risk – hazard – exposure – vulnerability relationship

Risk Identification

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

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

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

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

Natural Hazard	Period Covered	Fatalities
Heatwaves	1803 - 1992	4287
Tropical cyclones	1827 - 1989	1863 – 2312*
Floods	1803 - 1994	2125
Bushfires	1827 - 1991	678
Lightning strikes	1803 - 1992	650
Landslides	1803 - 1999	83
Earthquakes	1803 - 1999	15

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

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

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

Risk Analysis

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

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

We have identified three distinct aspects of this process.

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

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

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

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

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

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

Table 1. 2 Relative contribution of building characteristics to vulnerability

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

In Table 1.2 the number of stars reflect the significance of each attribute's contribution to building vulnerability, where the greater the number of stars, the greater the relative contribution of an attribute to building vulnerability.

In this study, comprehensive structural data were developed on approximately 11 500 buildings in the Gladstone study area. Most of this information was gained from direct field observation during several field trips in 1997 and 2000. It was supplemented by data made available by several local agencies.

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

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

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

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

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

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

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

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

Risk Evaluation

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

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

We see two key components of this.

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

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

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

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

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

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

Risk Mitigation Strategies

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

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

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

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

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

Community Risk Thresholds

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

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

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

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

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

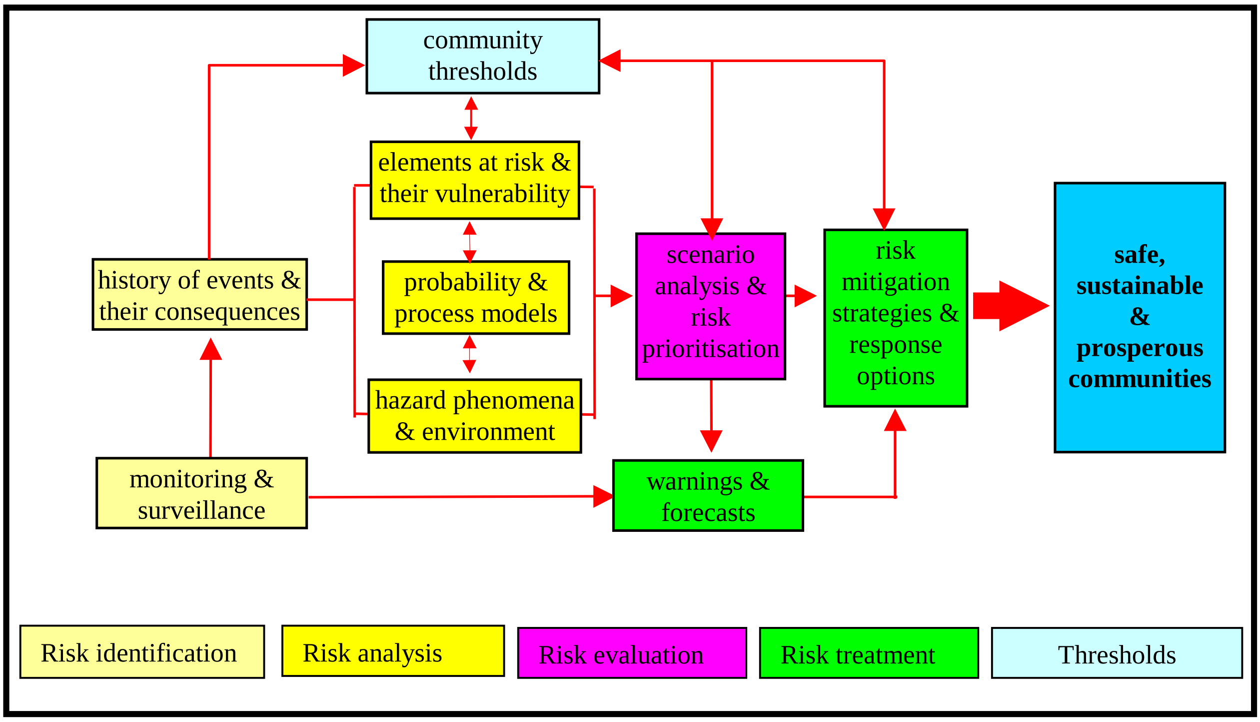

Figure 1. 3 Cities Project interpretation of the risk management process

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

Confidence, Uncertainty and Probability

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

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

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

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

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

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

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

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

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

Similar information is shown graphically in Figure 1. 4.

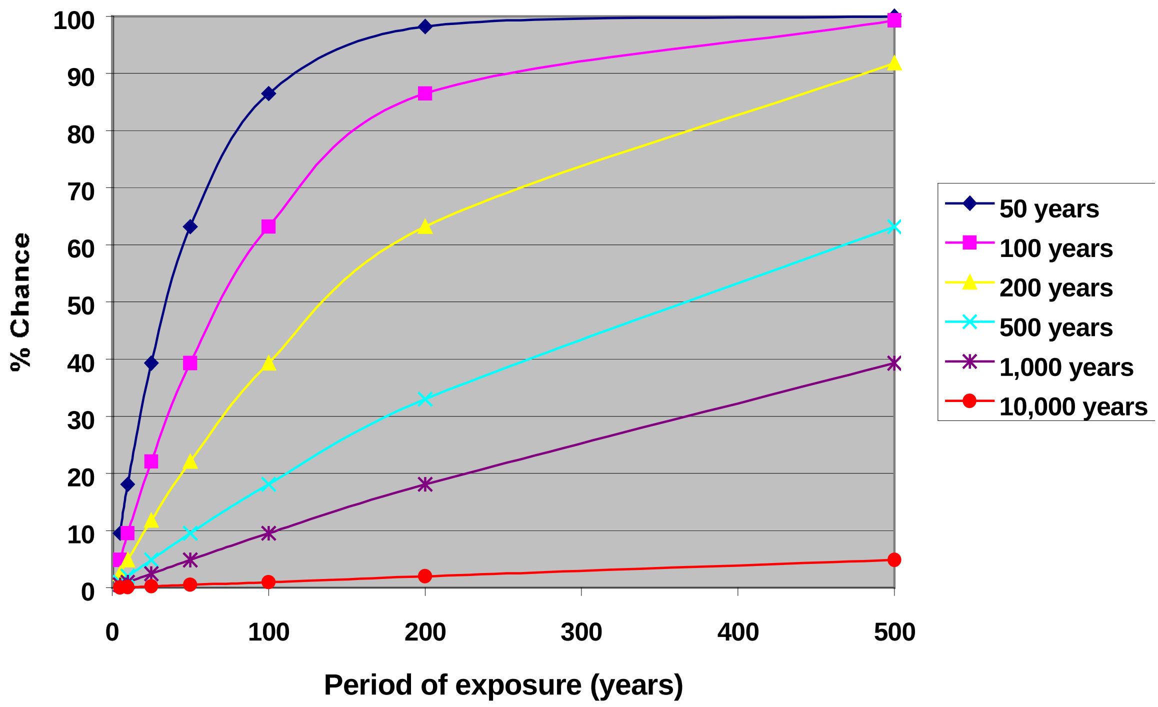

Figure 1. 4 Chance of one or more events with a given ARI occurring in a given time frame

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

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

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

CHAPTER 2: THE GLADSTONE SETTING

Ken Granger, Sarah Hall and Marion Michael-Leiba

Introduction

Situated approximately 500 km north of Brisbane, Gladstone City, together with the immediately adjoining areas of Calliope Shire, is Queensland’s most significant industrial and coal export centre.

The area covered by this study is confined to the developed urban centres Gladstone and the Tannum Sands/Boyne Island centres of Calliope Shire. Some consideration is given to the areas that have been identified for future major industrial and urban growth, however, significant further work would be required to bring that work to a level comparable to that possible for the existing urban centres. The study area is approximately 320 sq km. There were approximately 33 000 people living in the study area in 1996. The study area and the surrounding local government areas are shown in Figure 2.1.

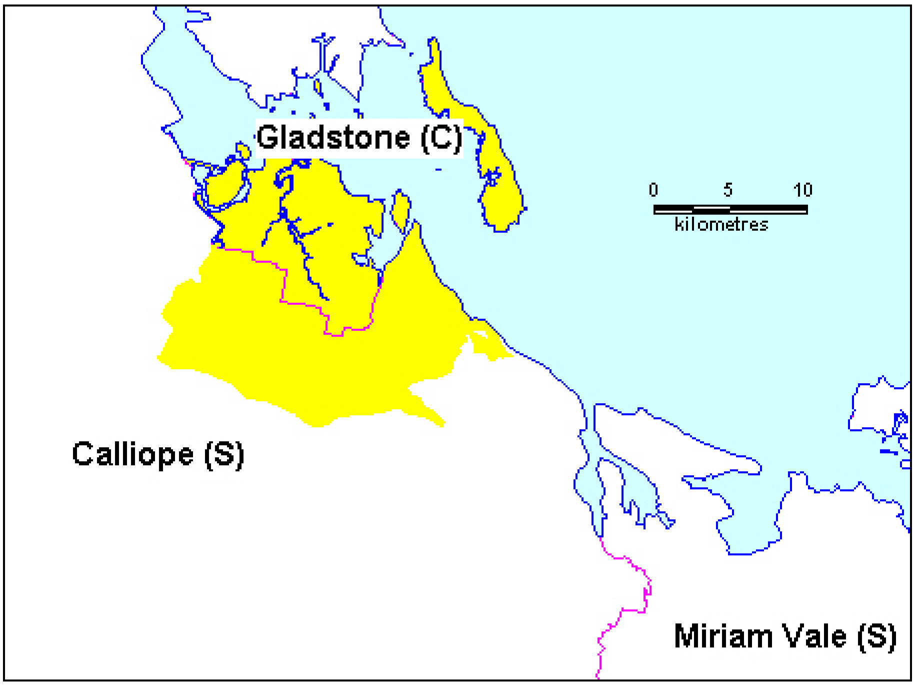

Figure 2.1 The Gladstone study area location

The Physical Setting

Topography: The area has a complex landscape ranging from the low-lying estuarine flats and islands that form the shoreline of Port Curtis to the hills and ridges of the interior. Curtis Island (to the north east) and Facing Island (to the east) form the eastern shore of Port Curtis. This sheltered waterway extends north to the Narrows, which links it with Keppel Bay and the mouth of the Fitzroy River. To the south, Boyne Island is only separated from the coastline by a narrow tidal stream. The area is also roughly bounded by the region’s two major rivers, the Calliope in the north and the Boyne in the south. Both have their catchments in the Many Peaks Range which generally lies parallel to the coast.

North of the Calliope River the area is dominated by saline coastal flats which extend approximately 5 km inland before rising to roughly 20 m. Further west the landscape is dominated by the Mt Larcom Range, with Mt Larcom (632 m) the highest point in the district. Numerous small intermittent creeks flow from this range to the east onto the coastal flats.

The urban area of Gladstone itself is dominated by Auckland Hill (40 m) at the port end of a ridge that slopes back towards the older urban settlement. Suburban development expanding from the City centre is on a series of ridges and undulations of approximately 40 m elevation. The dominant topographical feature of this urban landscape is Round Hill with an elevation of 134 m.

The townships of Boyne Island and Tannum Sands are bounded by the second mouth of the Boyne River and Wild Cattle Creek. Most development in this area is elevated at around 20 m. Lilly Hills to the west, where the Boyne River diverges, has an elevation of 94 m.

Tidal Regime: Studies undertaken by the Gladstone Port Authority and Department of Environment & Heritage (1994) identify that the 'standard' tidal regimes for the estuary around Gladstone are influenced by three relatively local factors -The Great Barrier Reef, ocean floor topography and inshore islands and headlands.

There are further effects on these 'standard' tides however, the most notable of which is the shape of Port Curtis itself. The topography of the Port acts to constrict the area of tidal flow; the volume, however, does not change, with the result that the tide height is increased. Gladstone Harbour, the Narrows and Sea Hill, for example, can expect an increase in tidal range of between 15% and 50 % over that experienced at the entrance to the Port at Gatcombe Head on Facing Island. As well as influencing the range of the tide, coastal topography also influences the time of the forecast tide. This can be delayed due to physical constrictions such as the Narrows which experience the predicted tide height one hour behind the ocean tides for the same latitude. Thirdly, the velocity of the water flow is also dependant on the depth of the channel through which it flows. There can be a difference of around 3 knots in the short distance between Auckland Point and the slower moving Narrows.

The key tidal statistics are given in Table 2.1.

Table 2.1 Tidal planes at Gladstone relative to AHD (from Queensland Transport, 2001)

Tidal Plane	Gatcombe Head	Gladstone	The Narrows
Highest astronomical tide	1.90	2.42	3.12
Mean high water springs	1.13	1.64	2.23
Mean high water neaps	0.39	0.79	1.25
AHD (mean sea level)	0	0	0
Mean low water neaps	-0.95	-0.75	-0.53
Mean low water springs	-1.75	-1.60	-1.50
Lowest astronomical tide	-2.27	-2.27	-2.27

Geology: The study area is largely underlain by Devonian and Carboniferous sedimentary rocks, 290-408 million years old. A geological map is shown as Figure 2.2.

The older rocks, around 360-408 million years old, crop out in the far western and south western part of the area. These are the sandstones, conglomerate, volcanic rocks, minor mudstone and limestone of the Calliope beds (Dc), and the chert, mudstone, minor volcanic fragmental rock and sandstone of the Doonside Formation(DCd).

The younger rocks, around 290-360 million years old, crop out in the central and eastern parts of the study area. Of these, the Wandilla Formation (DCw) occupies about one third of the study area, underlying most of the central part, the Gladstone Central Business District, and the central part of Boyne Island. It consists of mudstone, sandstone and chert. The Shoalwater Formation (Cs) occurs in the south eastern part of the study area including Boyne Island, and on Facing Island. It consists of quartz sandstone, mudstone and schist. There are small outcrops of the Miriam Vale Granodiorite (Pgm), a granitic rock about 250-270 million years old, in the far south eastern part of the area.

The Doonside –Wandilla Formation boundary is a nort-west/south-east trending fault largely covered by alluvium. Parallel to this fault is the Boyne River Fault, which is the boundary between the Doonside Formation and the Calliope beds.

Young, unconsolidated sediments (Qa, Qhct, Qhcb, Qhcd, Qrs and TQr) have been deposited by rivers, creeks and the sea. Alluvium (Qa) occurs along rivers and creeks. There are extensive areas of tidal flats (Qhct) around the mouth of the Calliope River and South Trees Inlet including the northern part of Boyne Island; and some beach ridges (Qhcb) along the coast of Boyne Island, parts of Facing Island, and in the Tannum Sands area.

There are areas of land fill in the Clinton Wharf-Marina area to the west of Auckland Inlet; in the Auckland Point-Gladstone Harbour-Barney Point area; to the west of the mouth of South Trees Inlet; and on the southern part of Boyne Island.

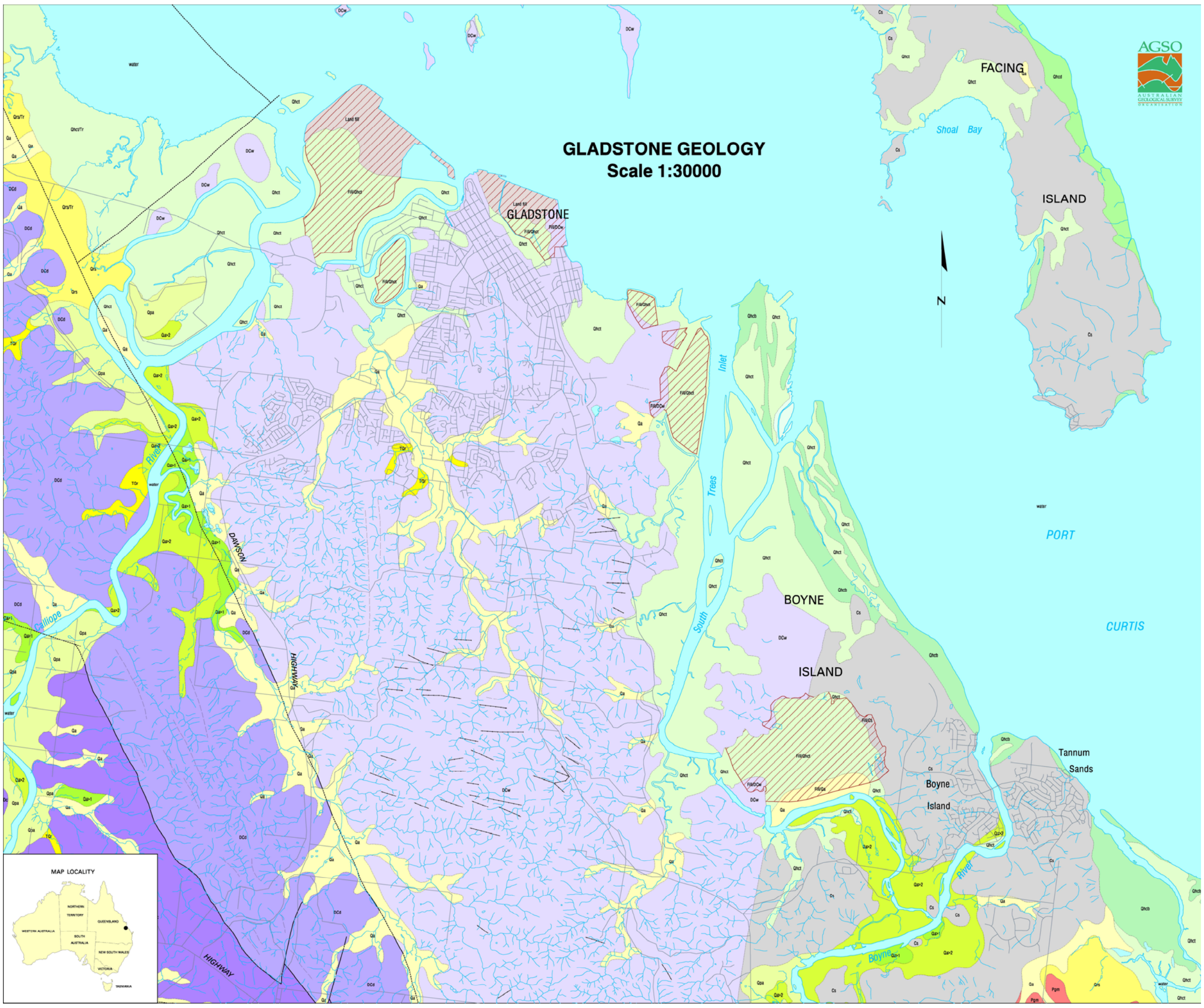

Figure 2.2 Geology of the Gladstone area

Climate: Gladstone lies on the coast of Queensland at approximately 23.9°S latitude and has a moist tropical maritime climate. Three main factors influence the climate of Gladstone: the area's proximity to the ocean's moderating influences, its topographical features, and the prevailing airflow. Rainfall is seasonal, with the heaviest rain occurring during the summer months. Extreme rainfall events are associated with tropical cyclones. Gladstone comes under the influence of tropical cyclones on average at least once every two years, though 'direct hits' by severe tropical cyclones are less common.

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

The main climatic statistics are summarised in Table 2.2.

Table 2.2 Selected climatic statistics for Gladstone for the period 1957 to 2000 (BoM, 2000a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean Max Temp (°C)	31.1	30.9	30	28.2	25.4	23	22.5	23.9	26.3	28.2	29.8	30.9	27.5
Mean Min Temp (°C)	22.4	22.4	21.4	19.6	16.9	14.1	13.2	14.1	16.3	18.6	20.5	21.9	18.4
Highest Daily Temp (°C)	38.3	40.1	37	34.1	31.3	29.3	28.7	30.4	33.8	40	40.1	39.8	40.1
Lowest Daily Temp (°C)	12.8	18	16.2	13	8.5	6.1	4.4	7.6	9.6	10.9	15.1	15.6	4.4
Average Rainfall (mm)	149.3	132.1	91.1	51.4	69.5	33.8	37.4	32.9	27.7	61.3	76.7	129.5	892.7
Highest 24hr rain (mm)	640.1	709.8	311.6	250.4	316.4	220.3	170.2	141.6	89.6	276.8	218.1	508.9	

Vegetation: The most widespread vegetation throughout the study area is an open eucalypt-dominated savannah. This vegetation generally reflects the generally low rainfall regime and the thin soils of the region. The savannah grades to dry sclerophyll forest or riparian forest in the more protected gullies and along the larger waterways. Along the coast and in estuarine areas, mangroves dominate. These may be backed by areas of saline sedge or un-vegetated salt pan. Sea grasses are prevalent in the shallow areas of Port Curtis.

Outside of the urban areas there has been minimal modification of the natural vegetation other than for the improvement of pastures to support the local cattle industry.

Settlement

The Port Curtis area was home to three main groups of Aborigine, the Byellee, Goeng-Goeng and Toolooa. Reports by the early visitors to the area indicate that these people were very nomadic because of the scarcity of permanent water in the area. The early settlers also found them to be quite aggressive in their resistance to white settlement. The history of contact and the development of Gladstone is chronicled by Lorna McDonald (1988) in her excellent work *Gladstone – City that waited*.

The first Europeans to sight the area were with James Cook on the *Endeavour* in May 1770. Cook described what became known as Curtis Island as 'barren'. The first Europeans to actually set foot in the area were with Mathew Flinders during his 1802 expedition in the *Investigator* and *Lady Nelson*. Flinders charted and named Port Curtis. Flinders was unimpressed by the area. Approximately twenty years later, further exploration was made by Oxley. His impressions were even less enthusiastic. From the observations made by Oxley and his crew in 1823 it appears that the region was not well regarded in context of the requirements of the new colony. Most notable of his observations at this time was the shortage of available water and the unsuitability of the existing river (the Boyne) for settlement due to likelihood of flooding. The lack of an adequate water supply became a recurrent theme in the history of Gladstone.

It has had an interesting, if chequered, development history, being first settled as the capital of the Colony of North Australia, which covered most of present day Queensland and the Northern Territory, in January 1847, a status it enjoyed for only three months. It subsequently evolved from a largely rural town servicing surrounding settlements and small enterprises to becoming a city that today is the largest coal export port in Queensland and home to the world's largest alumina refinery. It is Australia's fourth busiest port exporting minerals, chemicals, processed alumina and agricultural produce. Deposits of coal in the Biloela region, around 100km to the south-west, fuel the Gladstone power station, the State's largest, that provides energy for the massive demands of local industries, and into the State grid. Gladstone is undoubtedly the 'engine' that is driving much of the industrial economy of Queensland and is poised to enter a phase of greatly increased industrial development.

Port Curtis was selected by the then Colonial Secretary, William Gladstone, to be the capital of the Colony of North Australia which was established by Letters Patent signed by Queen Victoria in February 1846. In January 1847 the *Lord Auckland*, carrying George Barney, the man chosen to be the lieutenant governor and superintendent of the new colony, and 87 soldiers, settlers and convicts ran aground in charted waters at the entrance to the Port. The first settlement site was on Facing Island. It was here that the 'townspeople' sheltered from bad weather in tents and witnessed the pomp of Barney declaring the Colony of North Australia and officiating at the governmental business of the new colony. Three months later, following a change of government in England, the Colony was disbanded, and the fledgling Port Curtis suffered the first of its many setbacks in development.

Port Curtis was renamed Gladstone in 1854 in honour of the English politician who had championed its establishment. At that time it had a population of 215. The town was described as a 'settled district'. History suggests a limited enthusiasm by the government to encourage the development of infrastructure and services at Gladstone after the drawing of the northern boundary that declared Queensland a separate colony, with Brisbane as the capital in 1959. Growth was slow and even the discovery of gold at Canoona Station in 1857 saw the influx of fortune seekers heading to Rockhampton taking with them more Gladstone residents. At one point the population was just 12! Instead of bringing people and capital to the area, the northern gold rush served to undermine Gladstone's progress in favour of Rockhampton. In spite of such setbacks, Gladstone persisted and on 21 January 1860 it was declared a town. In 1863 it was declared a municipality, and in 1879 the Calliope Divisional Board was established. The present day boundaries of the local governments included in the study have changed little since that time.

Economic development and urban growth continued at a slow pace in spite of the excellent port and the town's location close to rich mineral and agricultural resources. The lack of a reliable and adequate water supply remained a major limiting factor until the construction, and subsequent extension of the Awoonga Dam on the Boyne River between 1966 and 1977.

The establishment of an alumina refinery by Queensland Alumina Limited (QAL) in 1967, the Callide Dam for the irrigation of grain growing, a new power station and three coal loading facilities in the 60's brought rapid economic growth and a massive shift in the physical and social environment of the region. By 1970 the town's population had grown to 14 000. The drought of the late 1960's coincided with the commissioning of the refinery, and the failure of the Awoonga Weir to provide adequate water created a conducive environment for private sector subsidisation of public works – such as the raising of the Awoonga Dam. It marked a future trend of private sector funding public works for Gladstone.

Concurrent with this development was the successful export of coal. Discouraged for many years by a lack of governmental support for opening up the coal fields, even to the point of government subsidisation of South African imports, Thiess Peabody Mitsui (TPM) began selling coal to Japan. Mitsui provided $1million to deepen the entrance to the Harbour. They developed their own facilities at Barney Point to export coal which came via a circuitous rail route through Rockhampton. The construction of the Gladstone – Moura railway, in 1968, expanded the opportunity for export and the Harbour Board reclaimed 33 hectares of tidal flats around the point to lease to TPM. Coal was also shipped from Blackwater. This coal was eventually railed directly to the power station established to supply the alumina refinery and a new aluminium smelter and the State grid. By this stage the future of Gladstone as an industrial centre was assured.

Population

According to the National Census taken in September 1996, the combined population of Gladstone City and Calliope Shire was 40 407 (26 453 in Gladstone and 13 954 in Calliope) of whom 20 990 were males and 19 417 females. Of this total, 3067 were recorded as 'visitors', of whom only 274 (or about 9%) were from overseas (ABS, 1998a). The more limited study area, however, contained 33 068 people (17 191 male and 15 877 female and 2461 of the visitors).

Population density varies across the study area with the most densely populated neighbourhood (as represented by the census collectors districts - CCD - used in the 1996 census), with 3088 persons per square kilometre, in Kin Kora. The lowest population density, at 14 persons per square kilometre, was in Callemondah around the power station. The distribution of population, by density, is shown in Figure 2.3.

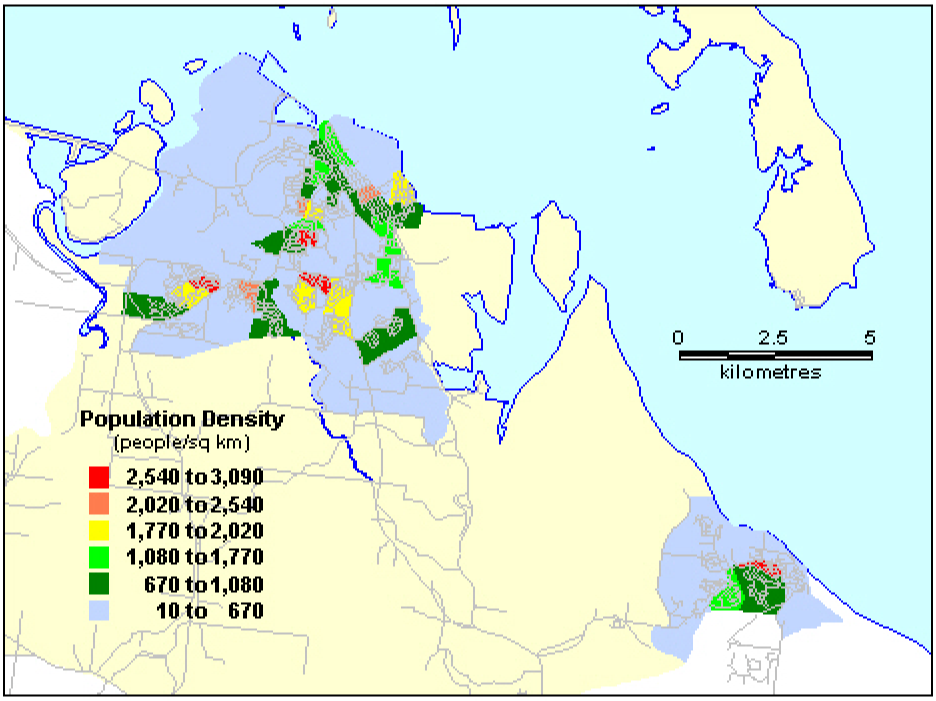

Figure 2.3 Population density (based on ABS 1998a figures)

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

Unfortunately there are no statistics available that detail population distributions during the day or the weekend or during school holidays and so on. It can be assumed, however, that neighbourhoods with numbers of industrial, commercial and educational establishments, for example, will have a higher concentration of population during their normal hours of business, whilst, during the same hours, residential neighbourhoods will have a lower concentration than that measured by the census. Extreme concentrations, like those experienced in the marina area during festivals such as New Year and Australia Day, can be well in excess of 10 000 people per sq km. Similar densities may prevail at times in the larger shopping, sporting and entertainment venues such as the Kin Kora Plaza.

Gender balance also varies across the study area. They range from 110 females to every 100 males in one neighbourhood in South Gladstone immediately north of Philip Street to 61 females to every 100 males in the City neighbourhood between Goondoon Street and Hanson Road. The mean value across the area is 91.7 females per 100 males, reflecting the industrial nature of the area.

The age/sex structure of the resident population of the area is shown in Figure 2.4. Gladstone is clearly a working-age community (consistent with its status as an industrial centre) with 17.6% of the total population under 15 years of age, 23.5% aged 20 to 34 and 23.8% aged 35 to 49. Another important feature is the relatively small proportion of the population over 65 years of age (7.3%).

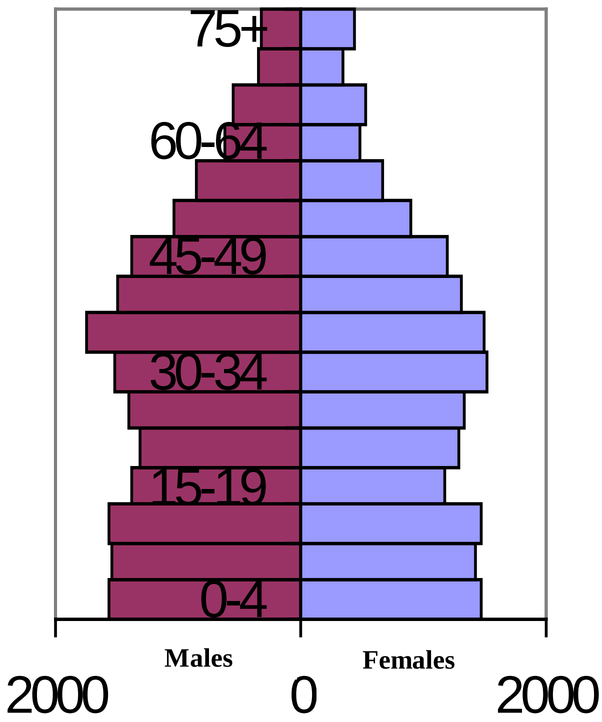

Figure 2.4 Age/sex structure of the 1996 Gladstone population

The Department of Communication and Information, Local Government and Planning (DCILGP) Planning Information and Forecasting Unit population growth forecast produced in January 1998 indicate that the population of the Gladstone area will increase over the next 16 years as shown in Table 2.3.

Table 2.3 Population projections for the Gladstone area (DCILGP, 1998)

	1996	2001	2006	2011	2016
Gladstone City	26 453	88 810	95 830	102 530	108 870
Calliope Shire (Part A)	8150	13 030	14 910	16 440	17 940

Gladstone is not a self sufficient community. In spite of the fact that the district is a significant producer and exporter of food, especially beef cattle, it depends very heavily on outside sources of supply for its water supply, fuel, material requirements and much of its food. Such dependence clearly imposes limits to the community's resilience.

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

- by road, the Dawson Highway connects Gladstone to the Bruce Highway (20 km) which provides access to Brisbane 529 km to the south, or to Rockhampton (109 km) and beyond. The Dawson Highway continues south west to Biloela (101 km) where it meets the Burnett Highway. Much of the general freight, such as food, as well as specialised freight such as anhydrous ammonia for the ICI ammonium nitrate plant, to Gladstone is carried by road.

- by rail via the North Coast line to Brisbane or Rockhampton. This line was upgraded in 1999-2000 to facilitate the operation of the 'Tilt Train' very fast passenger service between Brisbane and Rockhampton. The main freight yards are located adjacent to the railway station in Tooloola Street, Barney Point. The Moura Short line is dedicated to the haulage of coal to the Gladstone loading facilities from as far west as the Moura field. The marshalling yards for coal trains are in Callemondah just to the north of the airport.

- the Gladstone airport is currently located close to the intersection of the Dawson Highway and Phillip St. in Clinton. It has regular services to and from Brisbane and other regional destinations. There are plans to relocate the airport to Kangaroo Island at the northern end of Port Curtis due to the increasing height and nature of obstacles, such as power pylons, on the current approach paths. The Gladstone Airport is operated jointly by the Gladstone City and Calliope Shire Councils.

- the Port of Gladstone is the largest in Queensland and the fourth largest in Australia. It is administered by the Gladstone Port Authority (GPA). The main facilities include:

    - the RG Tanna Coal Terminal which handles bulk coal export
    - Auckland Point No 1 wharf is a multi user/multi produce facility which handles the export of bulk produce such as wood chips and calcite
    - Auckland Point No 2 wharf is used for export of grain
    - Auckland Point No 3 wharf is used for the import of petroleum products, LP gas and chemicals
    - Auckland Point No 4 wharf handles containers
    - Barney Point Coal Terminal is a multi-user facility for coal and other dry bulk cargo export
    - Boyne wharf handles the export of aluminium products and the import of petroleum coke, liquid pitch and general cargo
    - Fishermans Landing No 4 wharf is used for the export of bulk cement clinker, cement and flyash and the import of caustic soda
    - Fishermans Landing No 5 wharf is used for the import of liquid ammonia and the export of shale oil and naptha
    - South Trees West wharf is used for the import of bauxite
    - South Trees East wharf is used for the export of alumina and the import of fuel and caustic soda.

    In 1998-99 the port had a record throughput of 43 million tonnes of cargo valued at $4 billion. This included the export of 27.3 million tonne of coal and the import of 8.4 million tonne of bauxite.

    The GPA also operates the Gladstone marina which provides the full range of berthing services including recreation, service and shopping facilities. There are 204 public mooring pens and a further 30 charter vessel mooring pens.

    Details of the port can be found on the GPA web site at www.gpa.org.au.

Power supply for the Gladstone area is drawn from the State grid with the Gladstone power station, operated privately by NRG, being the principal source. Other power stations in the general area include Callide (west of Gladstone) and Stanwell (near Rockhampton). The Gladstone power station has a total generating capacity of 1650 megawatts of electricity from six coal fired steam turbines, roughly half of the total Queensland generating capacity. The major transmission lines, switching yards and substations of the State grid are operated by Powerlink Queensland, state-owned enterprise, whilst reticulation to most consumers is managed by Ergon Energy (Capricornia Division).

Powerlink operates four major distribution control facilities:

- a switching yard at the Gladstone Power Station;

- a switching yard at Wurdong which feeds directly into Boyne Smelter;
- a substation at the QAL refinery in Gladstone; and,
- a substation on Benaraby Road in Tooloola.

All of the water used in Gladstone (including the Callide power station) is drawn from the Awoonga Dam, operated by the Gladstone Area Water Board (GAWB). This source is now very close to its capacity with demand now at around 55 000 Ml annually, around 10% over its ‘historical no failure yield’ (HNFY) of 49 400 Ml per year. Plans have been developed to raise the wall of the Awoonga Dam by 10 m, thus increasing its capacity from 283 000 Ml to 800 000 Ml and its HNFY to 88 000 Ml per year. Supply from Awoonga is via a major pipeline to the water treatment plant which is located in South Gladstone. Distribution is managed by each LGA and consumption is metered. Details of the major waer supply infrastructure can be found on the GAWB web site at www.gawb.qld.gov.au.

The major telecommunications operators in the area are Telstra, Optus and Vodaphone who provide telephone, mobile telephone, facsimile and internet access. These must all go through the Telstra exchange in Goondoon St. The mobile phone system base stations are in the telephone exchange, Mt Maurice and Randall Hill. Most of the telecommunications throughout the urban area are through copper wire or fibre optic cables which are underground. A major microwave relay station is located in town at Round Hill and another relay station further inland at Maurice Hill.

The GPA and the Department of Marine Transport run a number of radio connections in their operations. The industrial nature of the town and the number of small business and contractors requires private two-way radio communications. For example, Queensland Rail carry their own network up the east coast along their rail line. Primarily this is for their own use but carries other State Department communications as required. The large microwave dish for the railway control centre is in the city in Toolooa Street. Gladstone Marina can be contacted at VL4FK on channel 82 and 16.

Local radio broadcast coverage is from HOT FM, Radio Rhema and the ABC whilst TV broadcast services are mainly from studios in Rockhampton.

Jurisdictions

The boundaries of the two local governments involved in this study are shown in Figure 2.1, and suburb boundaries in Figure 2.5. The port area comes under the jurisdiction of the GPA, a statutory authority responsible to the State Government. There is close collaboration between the GPA and the local governments in matters such as planning and development.

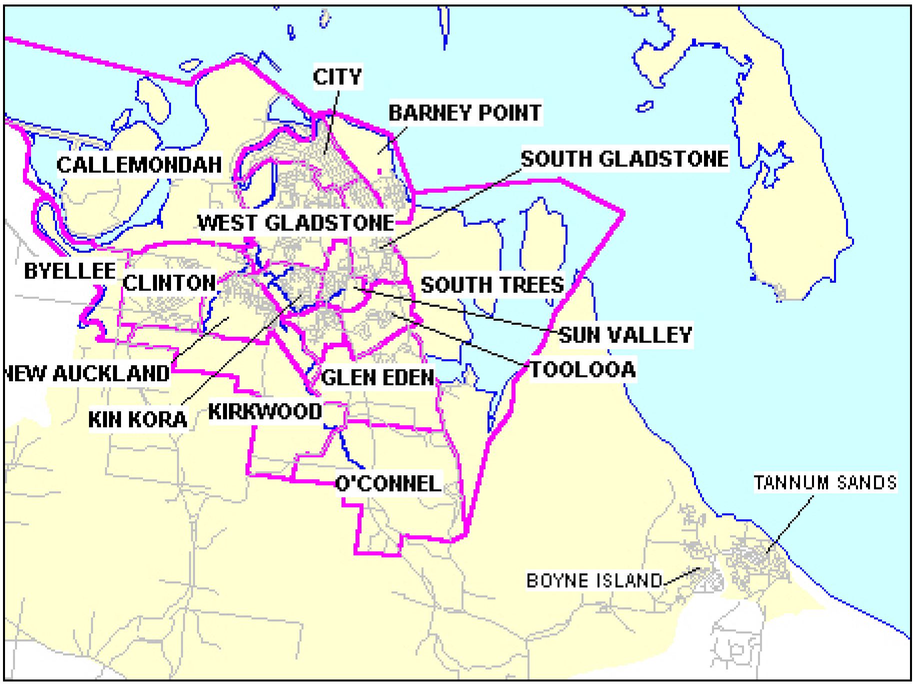

Figure 2.5 Gladstone area suburbs

Industrial Development

Gladstone is unique amongst Queensland cities because of the concentration of major industries of global and national significance. These include the world's largest alumina refinery, an aluminium smelter with a capacity of almost 500 000 tonnes annually, a major cement plant, major chemical plants producing ammonium nitrate (used as an explosive in the mining industry) and sodium cyanide (used in the gold industry), magnesium refinery, a pilot extraction plant for shale oil, and the State's largest power station. A well developed transport infrastructure is also evident.

According to the Gladstone Area Promotion and Development Ltd, the current level of capital investment in the area is around $10 billion, with perhaps another $7 to 10 billion in the offing. For example, plans have already been announced for Gladstone to be the terminus of the Chevron natural gas pipeline from the Lake Kutubu (PNG) field and the preferred site for the new Comalco alumina refinery and aluminium smelter, and so on. Much of this development will be established in the existing Yarwun area to the north and the proposed Aldoga area (between Gladstone and Mount Larcom township) to the north-west. A further wharf complex immediately north of the mouth of the Calliope River at Wiggin, is also planned. This development will make Gladstone one of Australia's most significant industrial complexes.

Conclusions

Until the 1960s the Gladstone area had a history of boom-and-bust growth. Since then, however, it has become one of the most important centres of industry in Queensland and Australia. This concentration of economic development gives it a significance that is well beyond its size. As a consequence of this concentration of very high value development the risks posed by the impact of a significant hazard event on Gladstone could have consequences that would be felt far beyond Gladstone, and even Queensland.

CHAPTER 3: THE ELEMENTS AT RISK AND THEIR VULNERABILITY

Ken Granger and Sarah Hall

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

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 11 515 individual buildings in Gladstone has been developed.

Table 3.1 provides a tally of the uses to which buildings are put in the Gladstone and Calliope portions of the study area. It should be noted that, for the most part, 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. Some of the larger and more complex industrial developments, however, such as the QAL alumina refinery, are treated as a single 'building' entity. Around 89% of all buildings are residential (houses, flats and commercial accommodation).

Table 3.1 Building use by area

	Gladstone	Calliope Part	Study Area
All buildings	9297	2218	11 515
Houses	7874	1954	9828
Flats	356	67	423
Commercial accommodation	40	22	62
Business & industry	426	68	494
Logistic & transport	157	16	173
Public safety & medical	46	5	51
Community	212	42	254
Utilities	40	5	45
Telecommunications	6	1	7

The period of development of each suburb is strongly reflected by the general style of housing it contains. In the older suburbs the most common houses are low set with fibro walls and metal rooves. They also (typically) have high pitched hip ended roof shapes and small windows. In these older suburbs, however, there has been some re-development of existing housing stock with two storey blocks of brick flats. This is predominantly on the coastal inner city suburbs such as Barney Point..

This is in strong contrast to houses in the more recent suburbs which are almost universally on a slab, have walls of brick (or concrete block) and large areas of glass. Roof forms are predominantly gable ended, but typically have a much lower pitch than those in the older suburbs.

Most of the suburban development along the ridges through the residential areas is typical of the 1970's architecture and are predominantly 'company' houses. Being on sloping ground, these are generally high set tile roofed and 'fibro' asbestos cement (AC) clad construction. As is typical of high set houses, extra living space has been created by 'filling in ' under the house with a concrete slab.

The lower level of these houses, which contains the garage and laundry, appear to have been enclosed by fibro-sheeted walls as a standard, though the lower levels in some of these houses have subsequently been upgraded to provide living space. It is this style of house that accounts for the relatively large proportion of fibro-walled houses in Gladstone.

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

Commercial and industrial buildings also vary in their construction form. Metal frame with metal or concrete block cladding are common, whilst pre-cast reinforced concrete tilt-up construction is becoming increasingly more common. Older public and commercial buildings of brick are likely to be of the 'solid' or 'cavity' form of construction.

The mix of wall materials in Gladstone buildings is given in Table 3.2.

Table 3.2 Wall material of Gladstone buildings

Material	Residential	Other	Total
Brick	3900	262	4162
Timber	1165	62	1227
Fibro	4815	79	4894
Metal	60	262	322
Concrete block	206	223	429
Reinforced concrete	0	9	9
Not recorded	105	364	469

Floor height is also seen as a good indicator of building vulnerability, not only for inundation hazards, but also for earthquakes. The detailed data show that 47.5% of all buildings are built on a slab (notionally 0.3 m above ground level); 21.2% have suspended floors of less than 1.0 m above the ground; and 31.3% have suspended floors that are 1.0 m or more above ground level. The reason for the high proportion of buildings with suspended floors can probably be explained in part by the age of development and the hilly nature of the Gladstone urban area – it was cheaper and easier to build with posts or piers than excavate for a slab. In some areas, supporting poles in excess of 4 metres were noted at the rear of some houses whilst the front of the house was less than half a metre above the ground level.

Roof material for both houses and flats is overwhelmingly metal (typically the classic corrugated iron) at 86.2%, with tile (12.8%) in newer areas and fibro (1.0%) in the older suburbs making up the remainder.

The pattern of urban growth in Gladstone over the past 50 years can be seen in the following four figures. These maps have been compiled from a range of sources including historic maps and aerial photography.

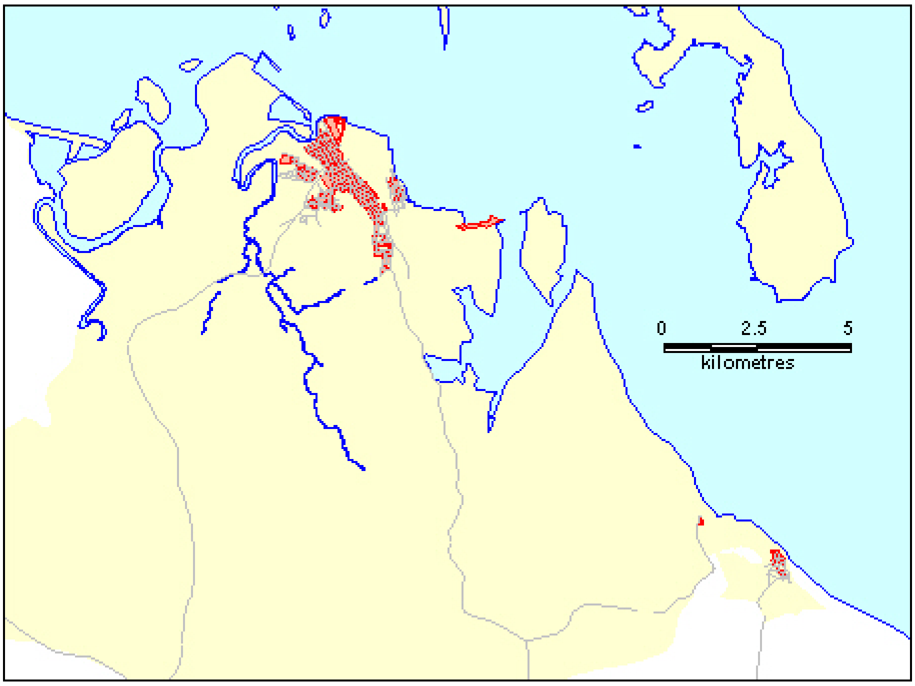

Figure 3.1 Gladstone 1958

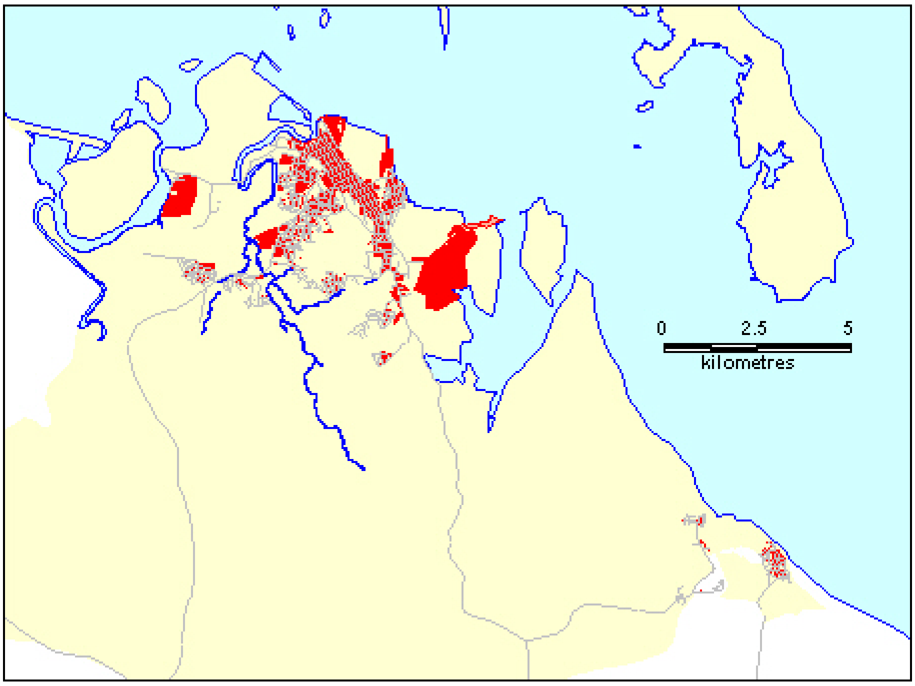

Figure 3.2 Gladstone 1973

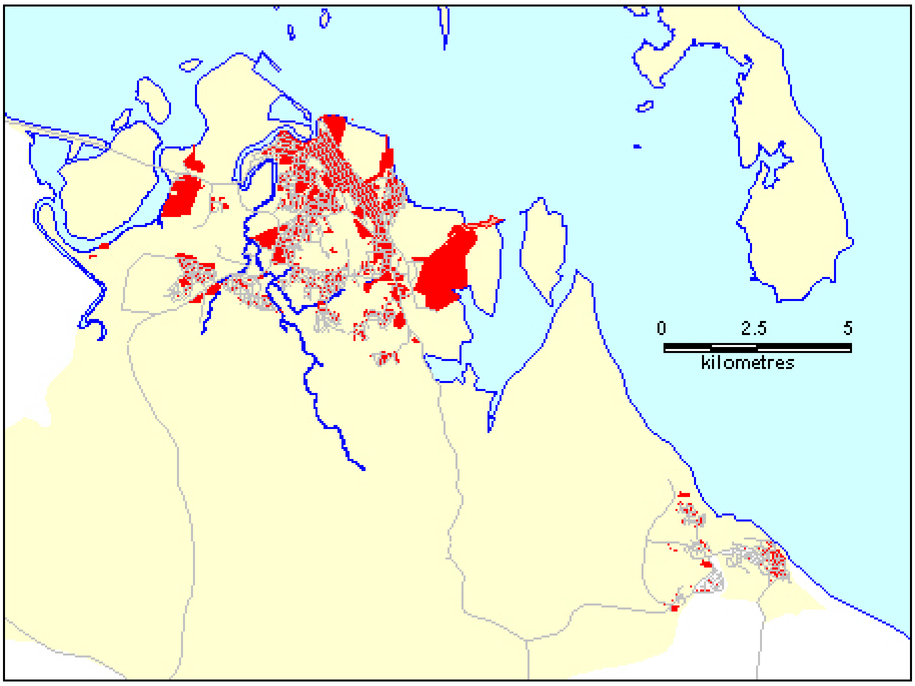

Figure 3.3 Gladstone 1985

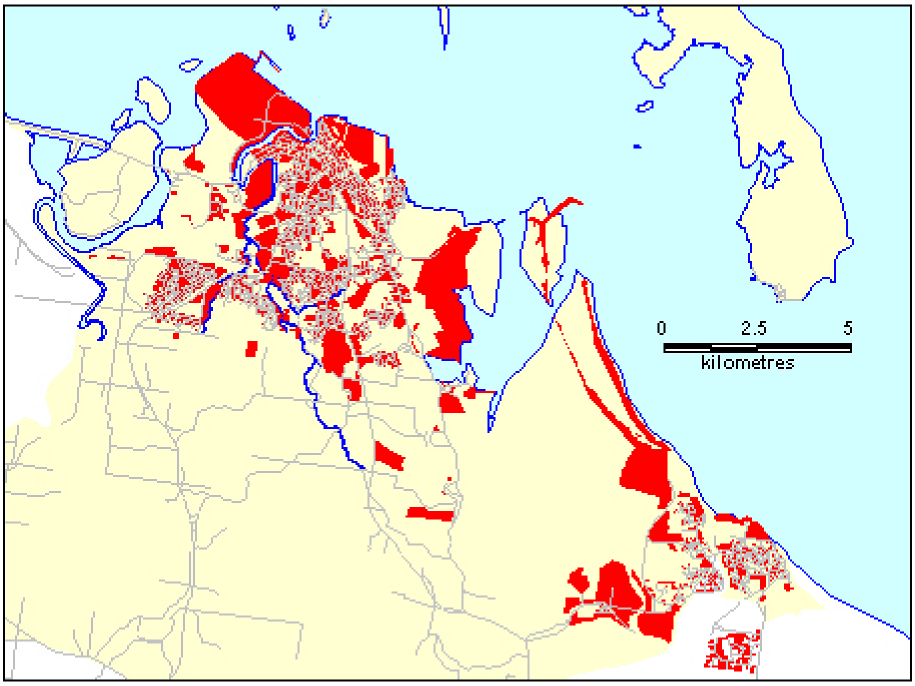

Figure 3.4 Gladstone 2000

Engineered buildings constructed since 1975 have been subject to the Wind Loading provisions of the Australian Building Code, whilst domestic buildings have been covered since 1983; Earthquake Loading provisions were introduced in 1979 and upgraded (and extended to domestic construction) in 1993. The approximate proportions of buildings included in the Gladstone building database, built before and after 1983, are as follows:

Pre 1983	71.6%	Post 1983	28.4%

It is clear that the majority of domestic buildings have not been constructed according to the Australian Building Code wind loading provisions. Whilst construction in the newer areas such as Clinton, Seaview Heights, Carinya, Boyne Island and Tannum Sands has, at least in theory, complied with wind loading provisions, their actual resilience to strong wind or earthquake shaking will also be influenced by the thoroughness of the builder and/or building inspector, subsequent maintenance and material fatigue or corrosion.

Mobility: The ability of people to get to and from shelter is almost as significant as the shelter itself. Gladstone 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.

Maintenance of the roads in the study area is largely the responsibility of the respective LGA and the GPA. However, due to the nature of the heavy vehicles and the hazardous loads carried on some routes, the Department of Main Roads (DMR) contributes to maintenance and design issues. The DMR is responsible for the Bruce and Dawson Highway. The closest DMR depot is in Rockhampton.

Public transport is limited in Gladstone and the climate and terrain make pedestrian or bicycle travel unattractive. Passenger transport in Gladstone is, therefore, based very strongly on the family car. Mobility is, consequentially, very heavily dependant on household access to private cars, of which there were an estimated 16 200 in the study area in 1996. Households without access to a car are considered to be more vulnerable than those with access. Figure 3.5 shows the distribution of households with no access to a car. Over a thousand households in the Gladstone study area, or about 9.0% of the total, have no car. There are five neighbourhoods across Callemondah, City, Barney Point and South Gladstone in which more than 25% of all households lack car access. By and large these neighbourhoods also have more elderly residents and are within walking distance of the CBD. By contrast, seven neighbourhoods across Clinton, Kin Kora, Glen Helen, Tannum Sands and Telina have fewer than 2% of households without car access.

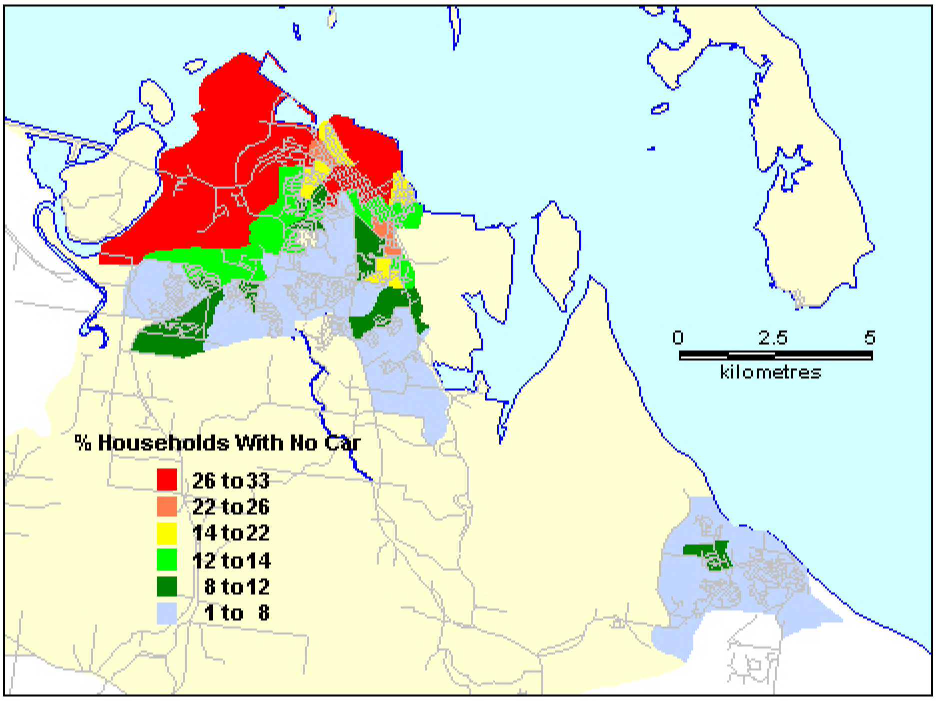

Figure 3.5 Households with no access to a car (based on ABS 1998a figures)

This dependence on the private car is quantified in Table 3.3 which shows the proportions of travel mode used to get to work in Gladstone 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. Of the people who went to work and answered the census question 79.3% travelled to work by car.

Table 3.3 Mode of travel to work in Gladstone study area (Source: ABS, 1998a)

MODE	NUMBER	PERCENT
Train	0	0.0
Bus	321	2.2
Ferry	3	0.0
Taxi	83	0.6
Car driver	8783	59.2
Car passenger	1487	10.0
Motor bike	481	3.2
Bicycle	460	3.1
Walk	488	3.3
Worked at home	465	3.1
Did not go to work	1635	11.0
Multiple modes	214	1.4
Not stated	258	1.7

Because Gladstone serves as an entry point for tourists going to nearby island resorts and visitors on commercial or government business to the area's industry, the city has a good number of private coaches, taxis, hire cars and other passenger vehicles available. A private company, Gladstone Bus and Coach, services most suburbs.

Sustenance

The Gladstone 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 its own right. There is, however, a very significant degree of interdependence as illustrated in Table 3.4. In this table the loss of the lifeline in the left-hand column will have an impact on the lifelines across the row to a significant (**S**) or moderate (**M**) degree.

Table 3.4 Interdependence of lifeline assets

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

(developed from Granger, 1997, Table 2)

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

Power supply: Gladstone heavy industry has priority for the power available to the State grid. The Bowen basin provides coal that fuels the power station to the west of the city. The American company NRG produces the power; the transmission grid that runs throughout the State is owned by Powerlink and Ergon distributes from the grid and is responsible for delivery to the private user.

In addition to the major distribution control facilities operated by Powerlink (see Chapter 2), Ergon has a major substation out of the power station where it receives its supply at 132Kv and breaks it down to 66Kv for further reticulation. From Boat Creek it provides power to ICI, the Stuart Oil Shale pilot plant and Minproc. The power is also broken down to 66Kv for distribution to the industrial area at the back of Gladstone. Ergon's 32Kv substations are in the Clinton Industrial Estate, at Fisherman's Landing (powering QCL), and in the Boyne Valley at the Littlemore. This last substation controls supply to areas out of Gladstone such as Miriam Vale and Biloela.

Water supply: The supply of water to Gladstone has been a concern since early settlement. The lack of a sustainable supply was a major inhibitor to the growth of industry and the subsequent increase in residential population, as already described in Chapter 2.

Water from the Awoonga Dam is carried via a pressurised main above ground for the 25km to Gladstone where it is redistributed via reticulation networks maintained by the Calliope Shire and Gladstone City Council. The water treatment plant is in Mc Cann St, South Gladstone.

Distribution to consumers is by gravity feed from at least 10 reservoirs and water towers throughout the study area. Details of the water reticulation network were not available for this study; however, we estimate, given the history of urban growth, that more than half of the water reticulation network is constructed of brittle material (AC or cast iron). This type of pipe is likely to be particularly prevalent in the older areas of the city, especially in the inner urban and port areas, and in the larger trunk mains. The more modern segments of the network probably employ ductile material such as PVC.

Sewer: Almost all of the Gladstone study area is connected to the reticulated sewerage network. The main sewerage treatment plants are located on South Trees Drive and Hanson St in Callemondah. There are 129 pumping stations throughout the study area with the two main stations with 600mm diameter piping being on Aerodrome Road and on the corner of Lord and Chappel Streets. These are maintained by the Council from their depot at the Power Station Sewerage Plant.

Telecommunications: Much of the telecommunications network infrastructure operated by Telstra in the Gladstone study area (both copper wire and optical fibre) is underground, though network details were not available for this study. The key to telecommunications - regardless of whether it is by conventional telephone, mobile phone, fax or Internet, and regardless of the service provider - is the network of telephone exchanges. There are telephone exchanges in the CBD, Boyne Island, Yarwun and the QAL refinery.

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

Food supply and distribution is obviously of great significance. Apart from small quantities of fruit and vegetables, meat and seafood, very little of the food consumed in Gladstone is grown or processed locally. There is, consequently, a significant reliance on imported foodstuffs or raw materials such as flour. There are regional shopping centres such as the Kin Kora Plaza and Kin Kora Mall in West Gladstone, Boyne Island suburban shopping centres and the CBD, with smaller supermarkets or convenience stores such as 4plus Food Mart in Barney Point, as well as smaller bakeries, butchers, green grocers etc. The older part of Gladstone in the city has a few food outlets that are more convenience sites than distributors of stocks. The levels of stock of basic foodstuffs held are not known but are likely to be not more than a week for most grocery items. Resupply is very much dependant on road transport and supply from bulk facilities in Brisbane.

Bulk fuel and gas storage facilities including the Mobil, Shell, Caltex and Ampol depots are all concentrated in Auckland Point wharf area. Operational storages of specialist products are held at facilities such as the airport (avgas and jet fuel) and some of the larger industrial and transport facilities (mostly diesel). There is no domestic reticulation of gas in Gladstone, so supply is provided in bottles or to bulk 'bullet' tanks. Distribution is, consequently, largely by dedicated tanker trucks. Industrial supply, however, is provided via the Wallumbilla to Gladstone Pipeline which terminates in Yarwun.

Most other bulk storage and distribution centres for products such as cement, woodchips and agricultural chemicals are also concentrated either close to the port in Gladstone Port or the rail-head facilities in Barney Point.

Industrial equipment that is necessary in the event of a disaster includes cranes, lighting and earth moving equipment. Hire agencies are located in French Street, South Gladstone, Hanson Road, Callemondah and at Barney Point.

Security

In the context of our risk assessment methodology, 'security' relates to aspects of community health, wealth and the services and structures that provide for public safety. In addition to identifying the physical elements at risk that relate to these aspects, we have identified a range of factors that will provide relative measures of community vulnerability and their distribution across Gladstone.

Health: The key health facility in the area is Gladstone Hospital, located in West Gladstone. This facility provides maternity, mental and community health services as well as casualty and emergency medicine. In addition to the hospital, there are at least 26 general and specialist medical centres, medical imaging, pathology, pharmacies, physiotherapists, dentists, etc in the area. More than half of these are located within the CBD area. There are also two aged care facilities, one in South Gladstone and the other at Boyne Island, and a day respite care centre (in the hospital grounds).

A range of other community health services, including Blue Nurses, is 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 Figures 3.6 and 3.7 respectively.

The distribution of under 5-year olds is clearly dominant in the newer suburbs of Boyne Island, Clinton Glen Eden, New Auckland and Tannum Sands. By contrast, the distribution of the elderly is concentrated in central urban areas especially in the City, South and West Gladstone and in Boyne Island.

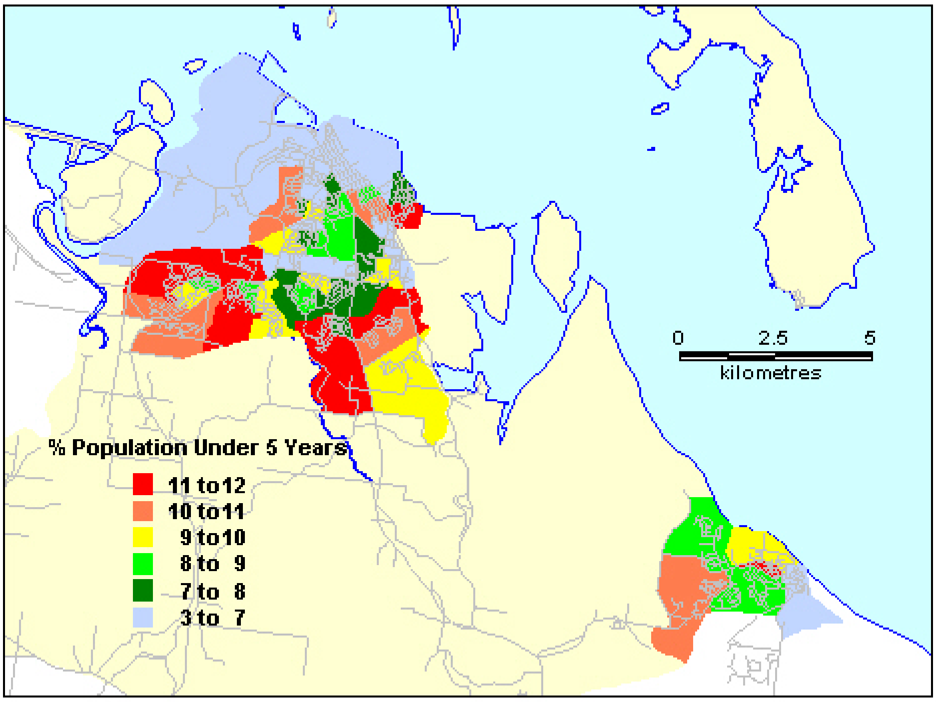

Figure 3.6 Gladstone population aged under 5 years (based on ABS 1998a figures)

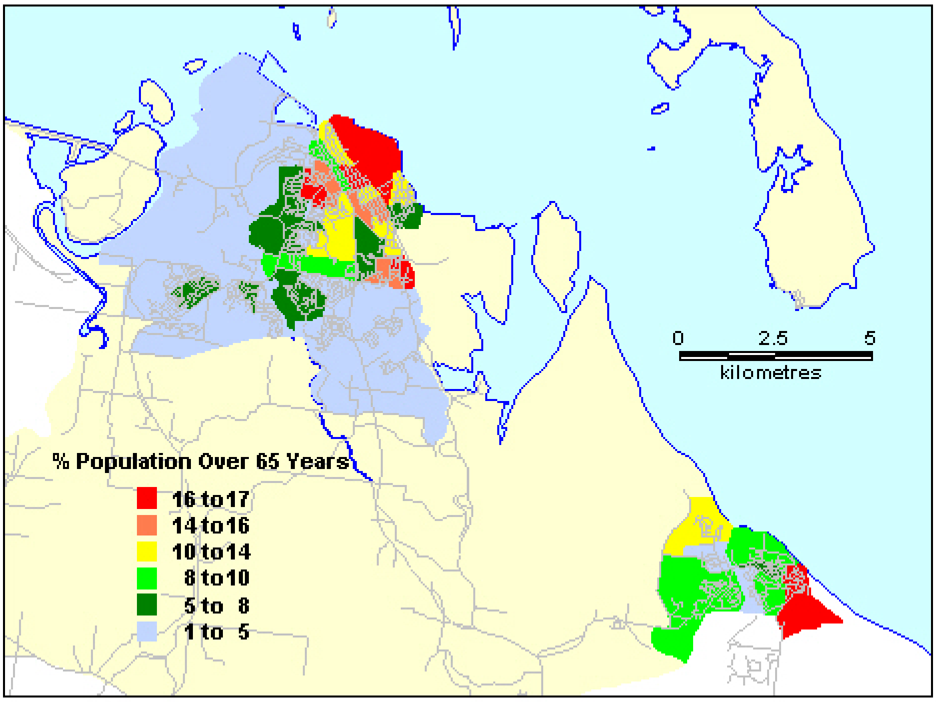

Figure 3.7 Gladstone population aged over 65 years (based on ABS 1998a figures)

Across the whole population, 8.5% are under 5 years and 6.9% are over 65 years.

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

<u>Wealth</u>: Given its focus on export industries, the economy of the Gladstone area is inexorably linked to the global trade and prices of raw materials and resources. This can manifest itself in the following ways:

- because Gladstone is a major element in global aluminium production, the global price of alumina determines the level of productivity at the QAL refinery, the Boyne Island smelter, the port facilities and a wide range of ancillary industries;
- the price of coal similarly affects levels of export which in turn impacts on the port and the explosives plant. It will also have an effect on the profitability of the power station;
- the production of cyanide is indirectly determined by the global price of gold;
- the level of prosperity in the regional and national building industry affects the trade in local products such as limestone, cement and cement clinker.

An analysis of employment types (Table 3.5) shows that manufacturing, retail and construction are the three most important industries and together account for 45% of all employment. This reflects clearly the nature of Gladstone as a heavily industrialised region and a service centre for surrounding districts.

Table 3.5 Gladstone employment by industry (Source: ABS, 1998a)

INDUSTRY GROUP	PERSONS EMPLOYED	INDUSTRY PERCENT
Agriculture, forestry and fishing	174	1.2
Mining	97	0.7
Manufacturing	2886	19.3
Electricity, gas and water supply	589	4.0
Construction	1835	12.3
Wholesale trade	628	4.2
Retail trade	2013	13.5
Accommodation, cafes and restaurants	600	4.0
Transport and storage	1286	8.6
Communication services	100	0.7
Finance and insurance	261	1.8
Property and business services	1286	8.6
Government administration and defence	410	2.8
Education	875	5.9
Health and community services	799	5.4
Cultural and recreational services	145	1.0
Personal and other services	326	2.2
Non-classifiable economic units	322	2.2
Not stated	266	1.8
Total persons employed	14 898	

The concentrations of commercial properties (and hence employment) is shown in Figure 3.8. The greatest concentration is in Barney Point, Callemondah and City in which there are CCD with more than 25% of all buildings having a commercial function. By contrast, there are 12 CCD in which there are no commercial buildings. These are spread across the southern suburbs.

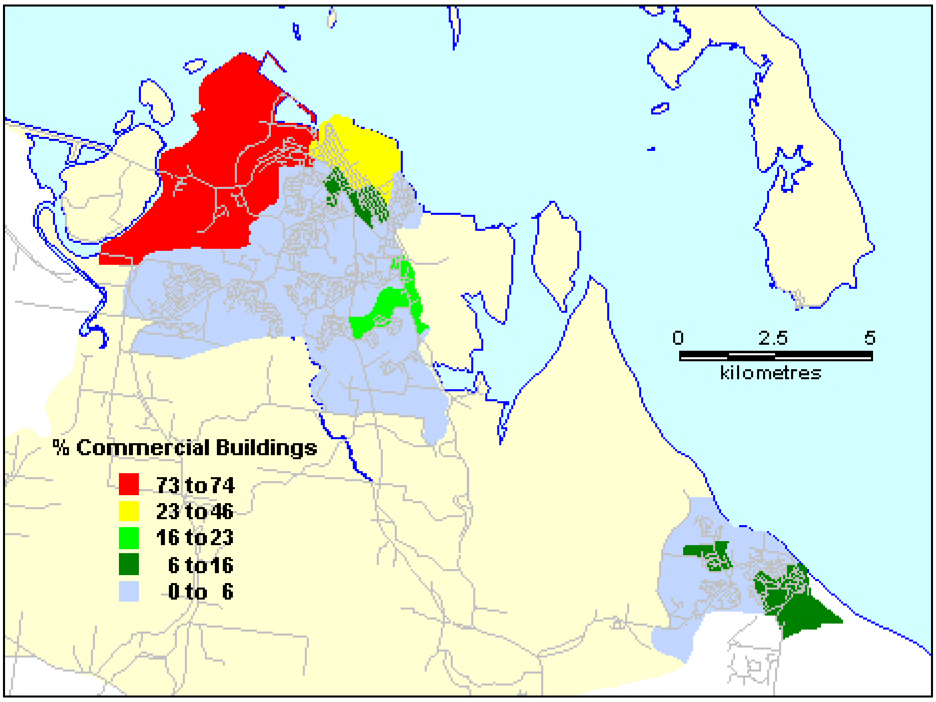

Figure 3.8 Percentage of commercial buildings

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

The level of employment is relatively high in Gladstone. This is a consequence of a thriving industrial sector. The average percentage of unemployed for all CCDs in the study area in 1996 was 9.6% compared with a state-wide CCD average of 10.2%. There were nine CCD in which the unemployment rate was over 15%. These were located in Barney Point (3), Callemondah, City, South Gladstone, Toolooa and West Gladstone (2). At the other end of the scale there were six CCD with less than 5% unemployment. These were in Clinton (2), Glen Helen, Kin Kora, Tannum Sands and Telina. The spatial distribution of unemployment in 1996 is shown in Figure 3.9.

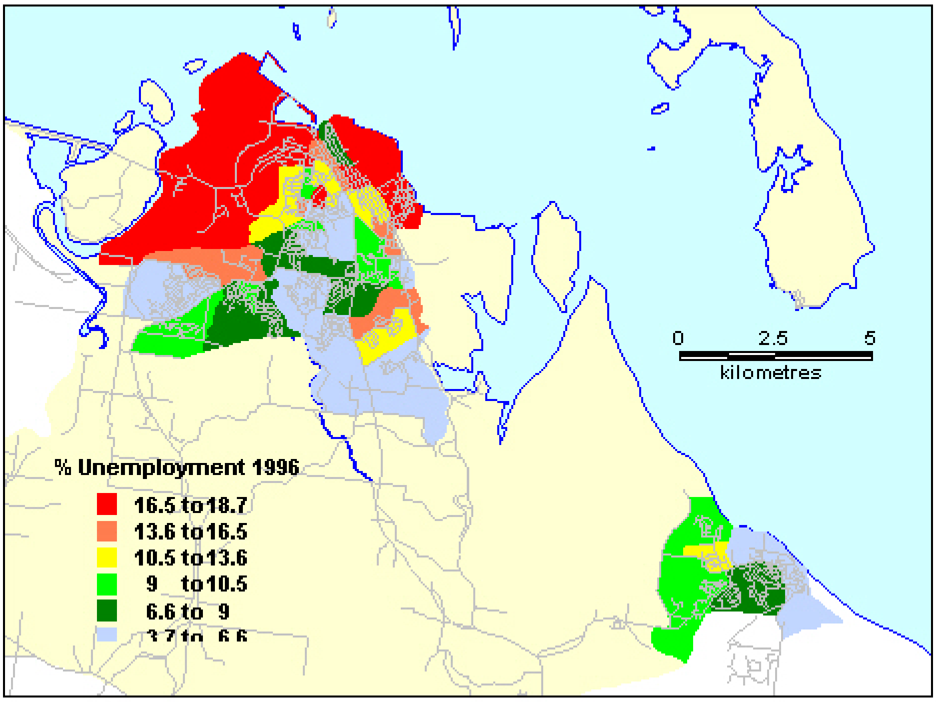

Figure 3.9 1996 unemployment rate (based on ABS 1998a figures)

Across the study area 32.8% of all households were in rented accommodation in 1996. This is a relatively high proportion, for example the proportion across the whole of the South-East Queensland region is 28.5%, and probably reflects the remaining strength of the 'company town' regime in Gladstone. There are four CCD with more than 50% of households renting. Three are in the City area and the fourth is in Barney Point. At the other end of the spectrum there are four CCD with fewer than 20% of households renting. These are in Boyne Island, Glen Helen, Kin Kora and West Gladstone. Figure 3.10 shows the spatial distribution which is very similar to that for unemployment.

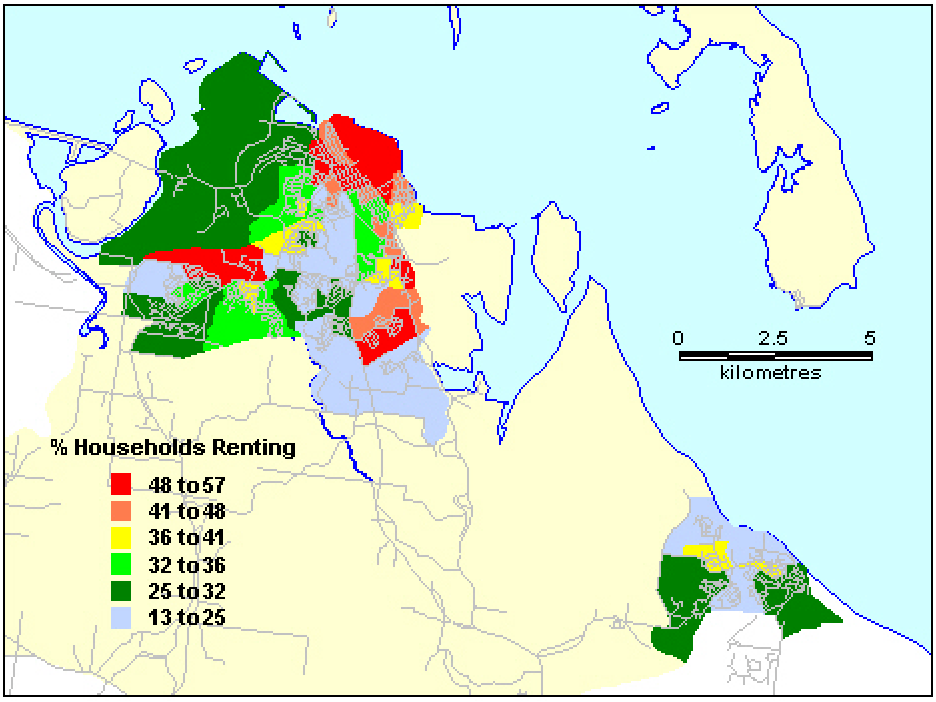

Figure 3.10 Percentage of households in rented accommodation (based on ABS 1998a figures)

An *Index of Socio-Economic Disadvantage* has been compiled by the ABS by undertaking a principal components analysis on 20 weighted variables from the 1996 census. The attributes, such as low income, low educational attainment, high unemployment and jobs in relatively unskilled occupations, were selected to highlight disadvantage (see Table B1 for a list of variables used). The resulting index has been standardised to have a mean of 1000 and a standard deviation of 100 across all census collectors districts (CCD) in Australia (ABS, 1998b). The lower the index number, the greater the level of 'disadvantage'. The mean index for Gladstone is 977.8 which is slightly below the national mean. There are three CCD with index values below 850 (two in Barney Point and one in Toolooa) whilst the highest index values are in Clinton (1090) and Tannum Sands (1073). The distribution is shown in Figure 3.11.

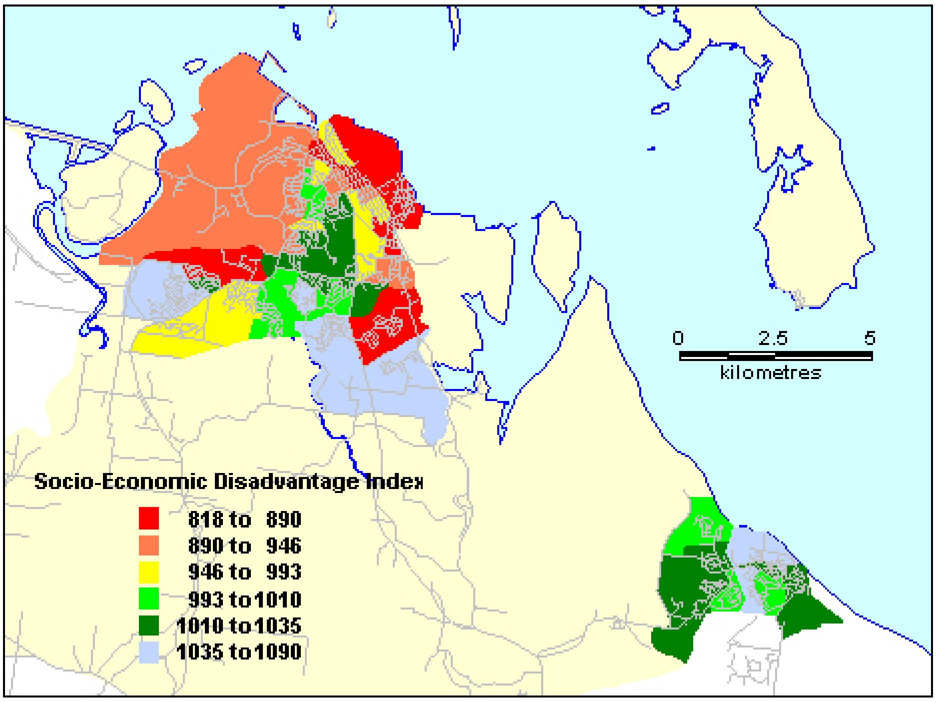

Figure 3.11 Index of Socio-Economic Disadvantage (based on ABS 1998b figures)

A similar *Index of Economic Resources* is also available. This index is based on a profile of the economic resources of families. It is compiled from 22 weighted variables that reflect the income and expenditure of families, including measures of income, rent and home ownership (see Table B2 for a list of variables used). This index is also standardised with a national mean of 1000 and a standard deviation of 100. The lower the index number, the greater the level of 'economic resources'. There is only one CCD (in Barney Point) with an index value below 850 (one and a half standard deviations below the national mean), whilst there are three with values over 1100 (one standard deviation above the national mean). They are in Clinton (2) and Glen Helen. The distribution is shown in Figure 3.12.

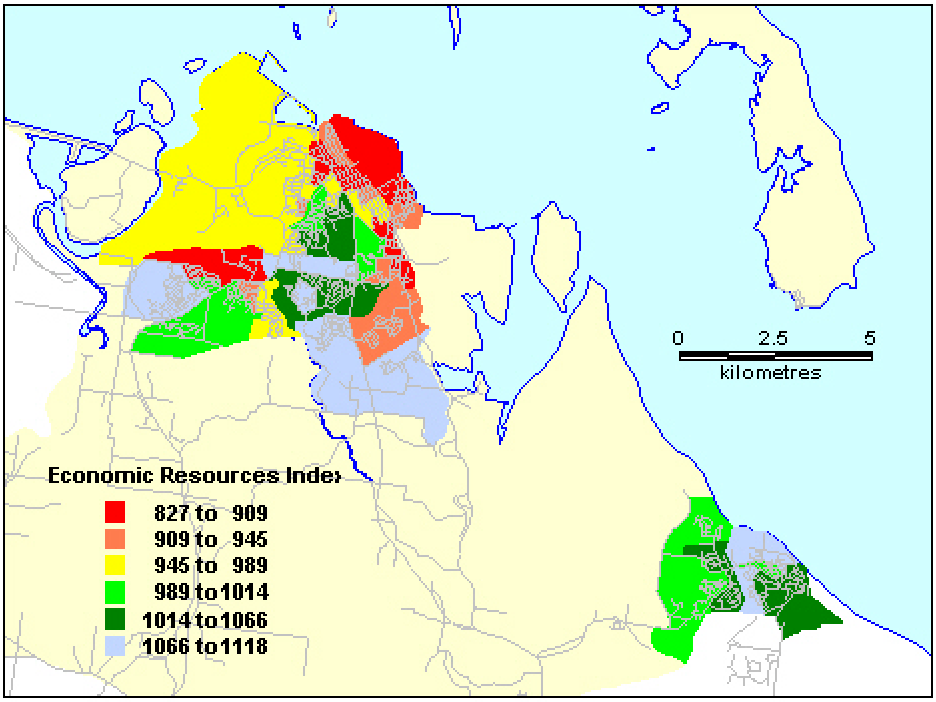

Figure 3.12 Index of Economic Resources (based on ABS 1998b figures)

Protection: The full range of public safety services is provided throughout the study area in each of the developed areas, i.e. Tannum Sands, Mt Larcom, Gladstone and Many Peaks.

The city headquarters for the Queensland Police Service (QPS) Gladstone Police is located at the corner of Yarroon and Auckland Streets in the centre of Gladstone. It also hosts the Gladstone District Disaster Coordination Centre. Events that involve natural disasters and require community mobilisation are administered through the Counter Disaster Centre which operates from the offices of the Gladstone/Calliope Aerodrome Board on Aerodrome Road at Clinton. The SES unit is based in Lamington Street, South Gladstone.

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

Boyne Island	24 Orana Ave
Gladstone	120 Glenlyon Street

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

Boyne Island	Gilbert Court
Gladstone	1 Charles Street

Most of the major industries in the area have their own on-site fire fighting resources, including personnel trained and equipped to respond to incidents such as fires and chemical spills. There is also a rural fire brigade located on the Dawson Highway near its junction with the Bruce Highway.

There are no permanent Australian Defence Force units in Gladstone, though a Defence Force Reserve unit (C Company, 42nd Capricornia Battalion) operates from the drill hall at 11 Palm Drive, Gladstone.

Society

The capacity of individuals, families, households and neighbourhoods to withstand the impact of disaster has much to do with the cohesiveness and resilience of those communities. Social cohesion is a very complex thing and difficult to measure, especially in a population as mobile as that found in Gladstone. 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.

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

Table 3.6 summarises the number of families in the Gladstone study area according to their size and structure. There are 4458 households made up of a couple plus their children, of which 27% contain 5 or more people (i.e. notionally 3 or more children). There are 1028 households made up of a single parent and their children, of which 21% contain 4 or more people (likewise three or more children). By contrast, there are 2719 couple families without children.

Table 3.6 Number of households by type and size (source: ABS, 1998a)

	Number of people usually resident					
	2	**3**	**4**	**5**	**6+**	**Total**
Couple with children		1369	1893	858	338	4458
One parent family	437	379	139	40	33	1028
Totals	437	1748	2032	898	371	5486

The spatial distribution of large families and single parent families expressed as a percentage of all families, based on ABS (1998a) data, is shown in Figures 3.13 and Figure 3.14. There are nine CCD with more than 15% of all families that have more than 3 children present. These are located in Clinton, Kin Kora (2), New Auckland, Tannum Sands, Telina, Toolooa (2), and West Gladstone. There are six CCD with more than 15% of all families with only one parent present. These are located in Barney Point (2), City, Clinton and Toolooa (2).

The census data does not identify the gender of the parent present in single parent households; however, of the 25 CCD with more than 10% single parent families, only four also had more females than males. This suggests that there are many male-led single parent households in Gladstone.

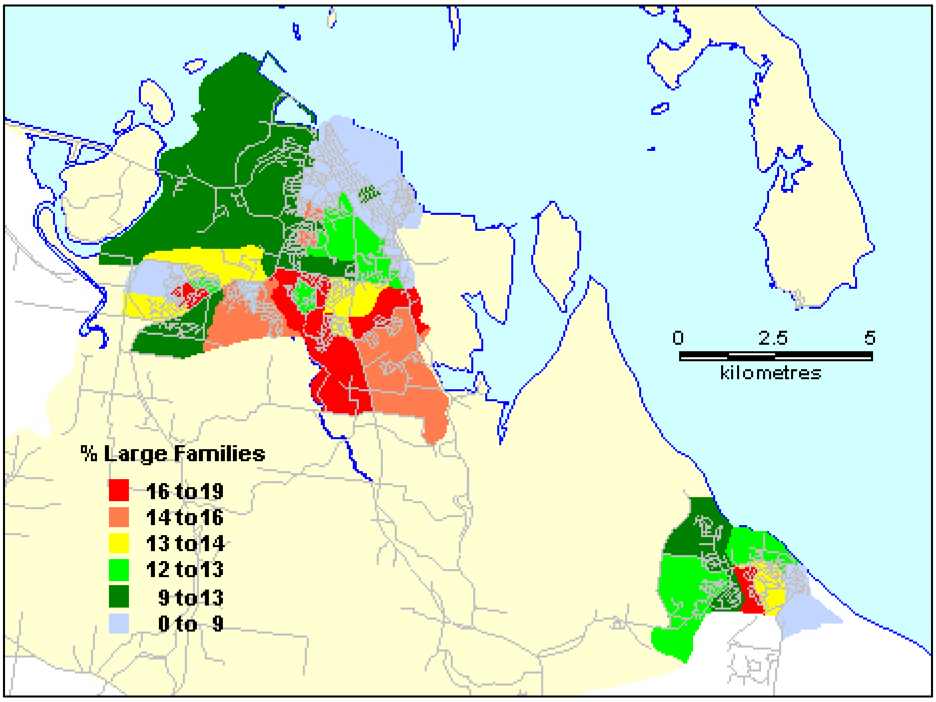

Figure 3.13 Percentage of large families (based on ABS 1998a figures)

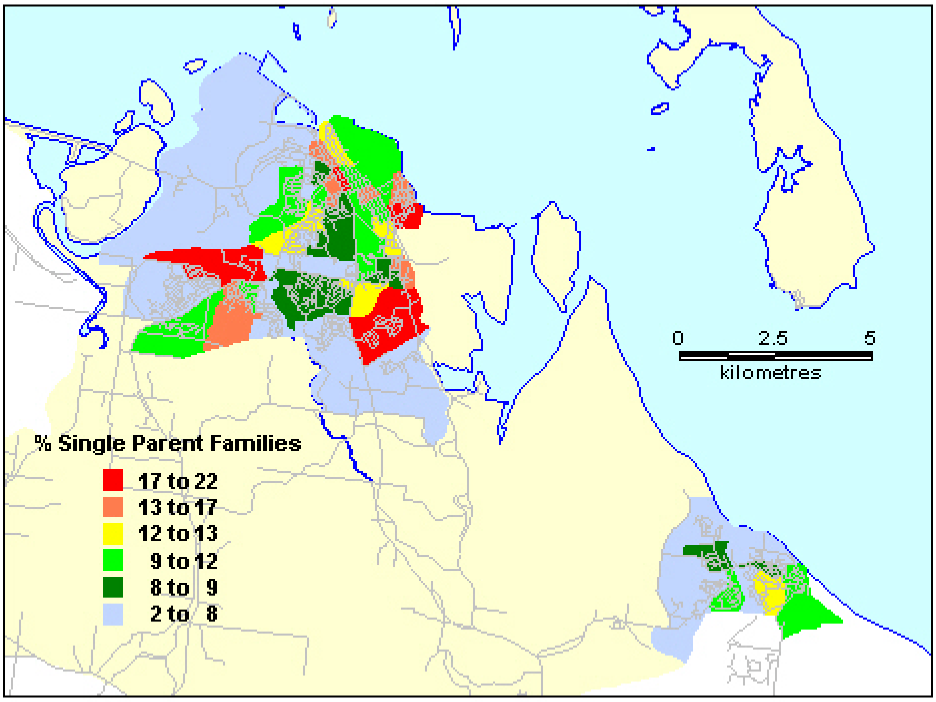

Figure 3.14 Percentage of single parent families (based on ABS 1998a figures)

Language and ethnicity: One of the strongest social links in a community is derived from language and ethnicity. For the resident population, English is overwhelmingly the most common language spoken, with 93.8% of the study area population over 5 speaking it at home. The next largest groups are all with less than 1.0% but in descending order are German, Greek and Tagalog (Filipino).

Eighty-five percent of the 1996 population were born in Australia. Of these, 3.4% were of Aboriginal or Islander descent. The largest groups born outside of Australia were born in the United Kingdom (4.2%) and New Zealand (2.7%).

Religion: One of the more significant linkages that tend to span social cleavages such as ethnicity, is religion. Of those that answered the census question on religious affiliation, almost three quarters of the population (73.4%) responded as being of the Christian faith. Of these, 34.5% were Anglican, 31.4% were Catholic, 11.9% were Uniting Church and 9.4% were Presbyterian. Apart from Christians, those that claimed to follow a organised religion were, in descending order, Buddhists, Hindus, and Muslims. Some 16.8% of the population claimed to have no religious affiliation.

Length of residence: Awareness of the local hazard history, environment and how to cope with disaster, as well as the level of integration into the local community, can be measured by the length of time people have lived in the area. The population of the Gladstone study area is clearly a mobile one, with only 50% of the population at the 1996 census living at the same address that they were living at five years previously. This change is overwhelmingly based on in-migration. Figure 3.15 shows the proportion of the total population that was living at a different address at the 1991 census.

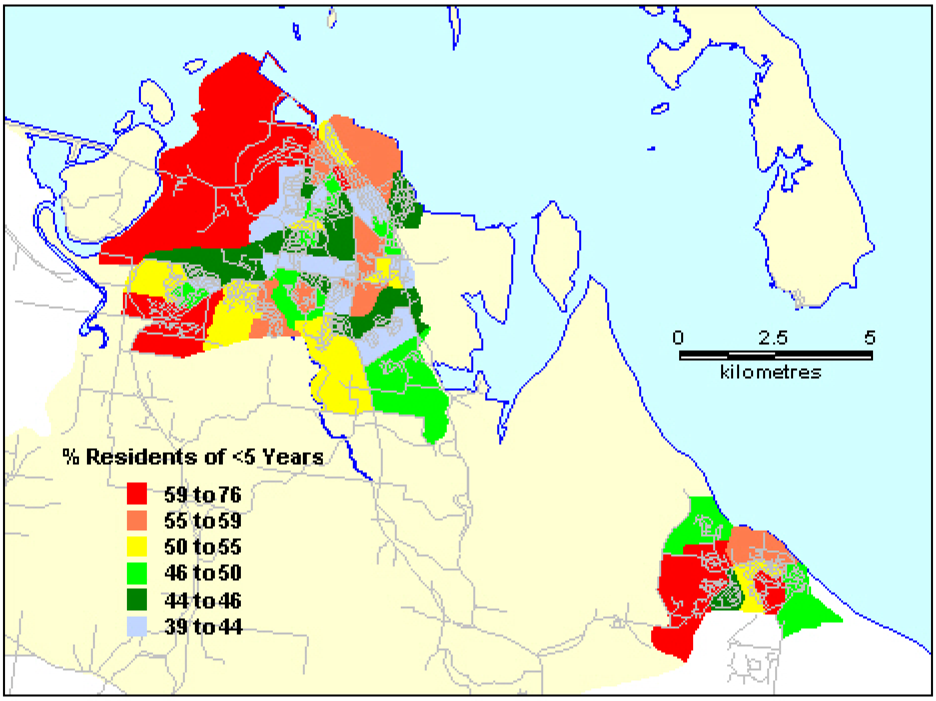

Figure 3.15 Proportion of population at census address for less than 5 years (based on ABS 1998a figures)

There were only two CCD in which more than 60% of the population were at the same address as they had been five years previously. These were in Tannum Sands and West Gladstone. By comparison, three CCD had less than 40% of their population at the same address. These were in Boyne Island, Clinton and Tannum Sands.

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 Gladstone, for example, some 73.7% of the people in the workforce 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. Schools are also centres in which there are concentrations of more vulnerable people for a third of the day.

There are 23 pre/primary and nine schools offering secondary education. There is one 'special school' in Park Street and the Clinton Special Education School in Harvey Road for preschool disabled children. A campus of the Central Queensland University (CQU) is located on the reclaimed land next to the marina.. This, together with the Gladstone TAFE and the Queensland Open Learning Network Gladstone Centre provide tertiary-level education and training. Other post-secondary training institutions include Training Services and associated Club extension programs

At the other end of the educational process are 14 kindergarten or child care facilities and nine organised playgroups throughout the study area.. Given the very young age and vulnerability of children at these centres, they deserve particular attention.

The SEIFA *Index of Education and Occupation* also provides an overview of the distribution of population with an educational and occupational 'advantage'. As with the two SEIFA indexes already discussed, this index is also standardised with a national mean of 1000 and a standard deviation of 100. The lower the index number, the lower the level of 'education and occupation'. The mean value for the Gladstone study area is 943 which is even below the mean state value of 971; there were only seven CCD at or above the national mean. The lowest value of 793, recorded in a Toolooa neighbourhood, is over two standard deviations below the national value. The areas in which the higher values were recorded were in Clinton (2), City (2), Tannum Sands and West Gladstone (2). The distribution is shown in Figure 3.16.

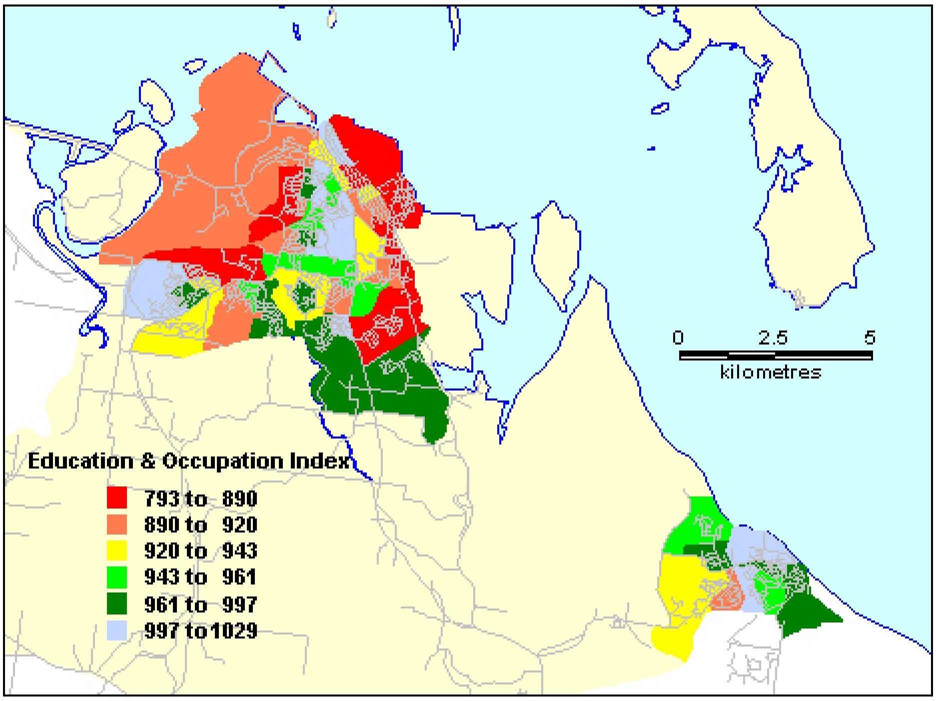

Figure 3.16 Index of Education and Occupation (based on ABS 1998b figures)

<u>Elderly living alone</u>: Another category of community members that have a particularly elevated level of susceptibility are the elderly folk who are living on their own. In many instances these people can become isolated from their neighbours and the community as their mobility declines. Overall, the number of people in this category is relatively small (a total of 531 or 1.6% of the total population in 1996) compared with areas such as Brisbane (3.9%) and the Gold Coast (3.3%). Their distribution, however is highly localised as is shown in Figure 3.17.

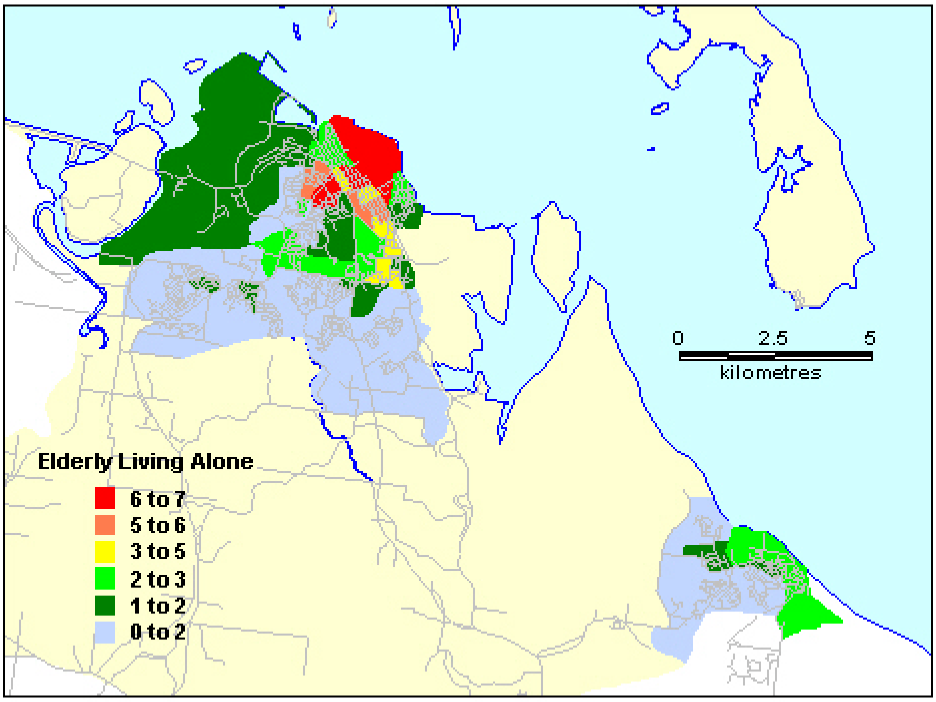

Figure 3.17 Percentage of population who are over 65 years and living alone (based on ABS 1998a figures)

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

From a list of all the social, sporting and social interest groups available it appears that there is a depth to the diversity of interests and capabilities within the community. This is likely to increase social cohesion across traditional demographic barriers such as gender or ethnicity. Secondly there appears to be strong 'area-identification' within the study area. This is likely to manifest as another layer of social cohesion on geographic basis.

Cultural and Natural Heritage: There are several sites of cultural and natural heritage significance in the area. These include the Gladstone Art Gallery and Museum (the former council chambers), the Gladstone Library and the Gladstone Entertainment Centre. The archives of the Council, the Port Authority, the Gladstone and District Historical Society and the *Gladstone Observer* also represent important cultural assets. The waters of Port Curtis and the estuaries of the Calliope and Boyne Rivers contain important marine habitats that could be put at risk in a disaster.

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. There are many such in Gladstone, ranging from the police and emergency services stations, the hospital and the telephone exchanges, up to and including the port facilities and the power station.

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. Most of the major industrial facilities, such as the QAL alumina refinery and the Tricor and ICI chemical plants, fall into this category.

The hazards contained at some 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. Facilities that store quantities of hazardous substances over certain threshold quantities, however, must display safety placards that identify the chemicals and the nature of the hazard they represent.

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

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

The significance of a facility may extend beyond the community in which it is located if a wider community of interest depends on it for services or supply. For example, the bulk fuel and gas depots that are concentrated in Gladstone port area supply consumers throughout a region that extends beyond the study area. Clearly, the loss or isolation of those facilities would have a proportionately greater impact overall than would the loss of a neighbourhood service station, for example. Likewise, the TAFE and CQU campuses attract students from a much wider catchment than does the suburban primary school. At a higher level, the coal and mineral export facilities at the port; the major export industries including the QAL alumina refinery and the Boyne Island smelter; and the power station, have an economic importance that extends well beyond the local area. Indeed, some are so significant that their loss or long-term dislocation could have an impact on the global economy.

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

A Composite Community Vulnerability Profile

In this chapter so far we have described a broad range of the elements at risk within the Gladstone 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 Gladstone since 1997. Whilst these data provide a detailed quantitative description of specific aspects of the area's risk environment, they do not, of themselves, provide an adequate measure of overall community vulnerability. Nor do they individually reflect the relative levels of vulnerability across the city.

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

There is little in the risk or disaster management literature to provide a guide for this task so we created our own methodology for the Cairns study (Granger and others, 1999), based on the 'five esses' described in this and the previous chapter, and a composite, or combined community vulnerability assessment. We modified that methodology slightly for the Mackay study (Middelmann and Granger, 2000) and the South-East Queensland study (Granger and Hayne, 2001 in press) to take account of a review of the Cairns work by the Centre for Disaster Studies, James Cook University (King, Moloney and MacGregor, 2000) and that approach has been maintained, with some further minor additions, here. Appendix D provides a detailed explanation of the methodology and the logic behind the selection of the variables included in this study. The key difference in the method used here, as opposed to Cairns, is that vulnerability profiles have not been aggregated to the suburban level but have been calculated at the CCD level only. Suburb boundaries are overlain on the 'vulnerability surfaces' for ease of reference.

It is emphasised that the values indicated on the following maps do **not** equate to a risk rating. They are simply index values that provide an indication of the **relative contribution** made to overall community vulnerability across the study area regardless of the exposure to any hazard (the lower the index number, the greater the relative degree of susceptibility). The following six figures show the 'vulnerability surfaces' for each of the five 'esses' (setting, shelter, sustenance, security and society) and a composite 'community vulnerability' surface.

The index values represent the percentage of the possible rank score in each group. A CCD that ranks in the top 10 or so for each variable will have a very low index number whilst a CCD that ranks in the bottom 10 or so will have a high index value.

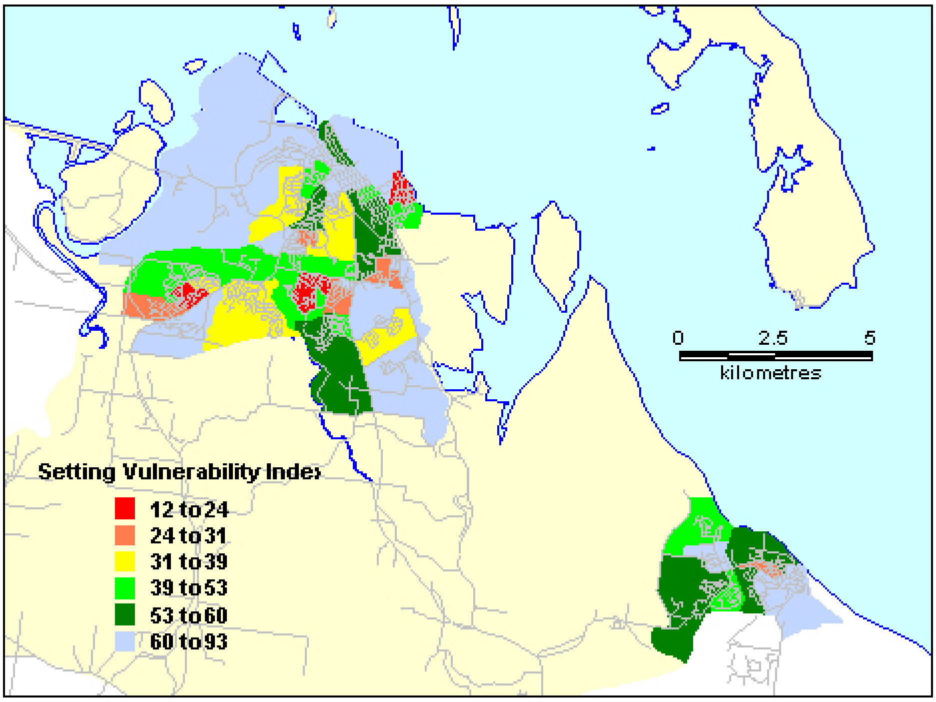

Figure 3.18 Setting Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to setting vulnerability) are:

Barney Point, Clinton, Kin Kora (2) and Tannum Sands.

The suburbs that contain the bottom 5 CCD are:

Callemondah, City, Barney Point, South Gladstone and Toolooa.

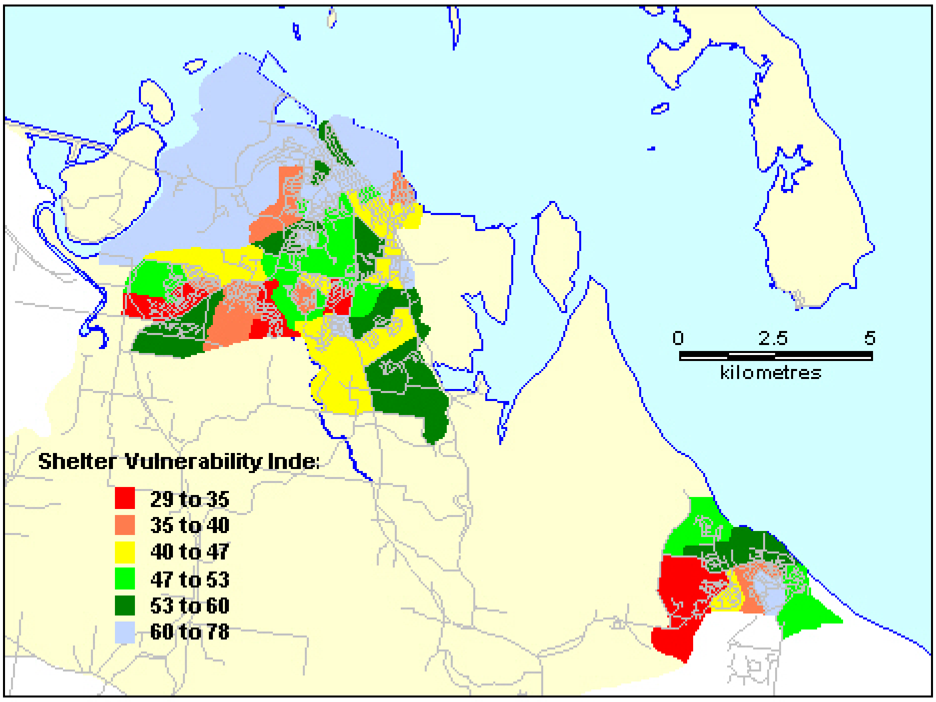

Figure 3.19 Shelter Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to shelter vulnerability) are:

Boyne Island, Clinton(2), New Auckland and Tannum Sands.

The suburbs that contain the bottom 5 CCD are:

Callemondah, City, West Gladstone (2) and Tannum Sands.

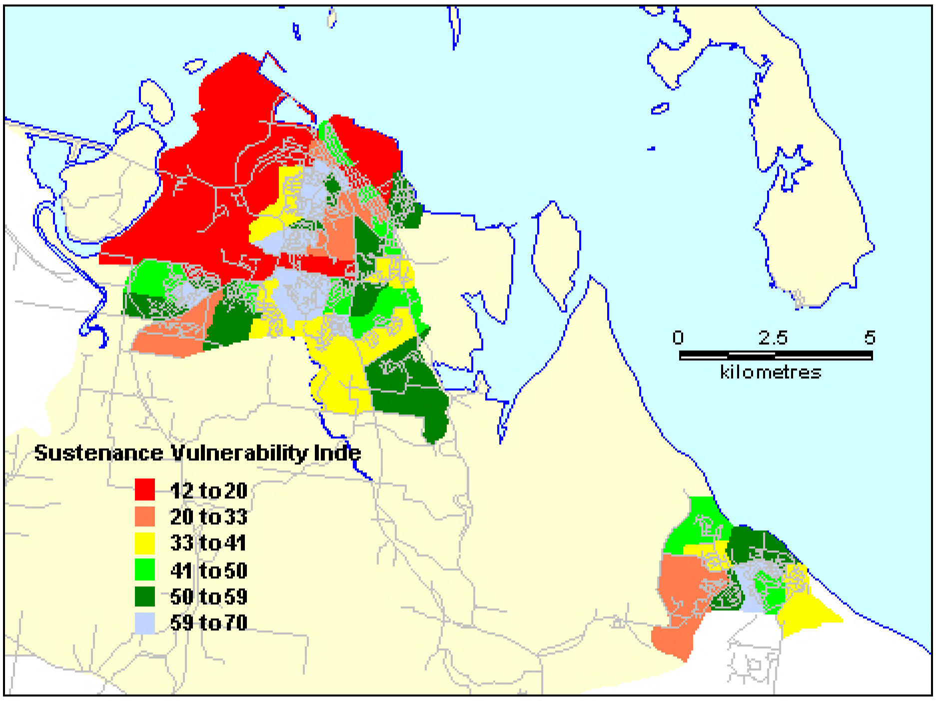

Figure 3.20 Sustenance Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to sustenance vulnerability) are:

Barney Point, Boyne Island, Callemondah, Clinton and West Gladstone.

The suburbs that contain the bottom 5 CCD are:

City and West Gladstone (4).

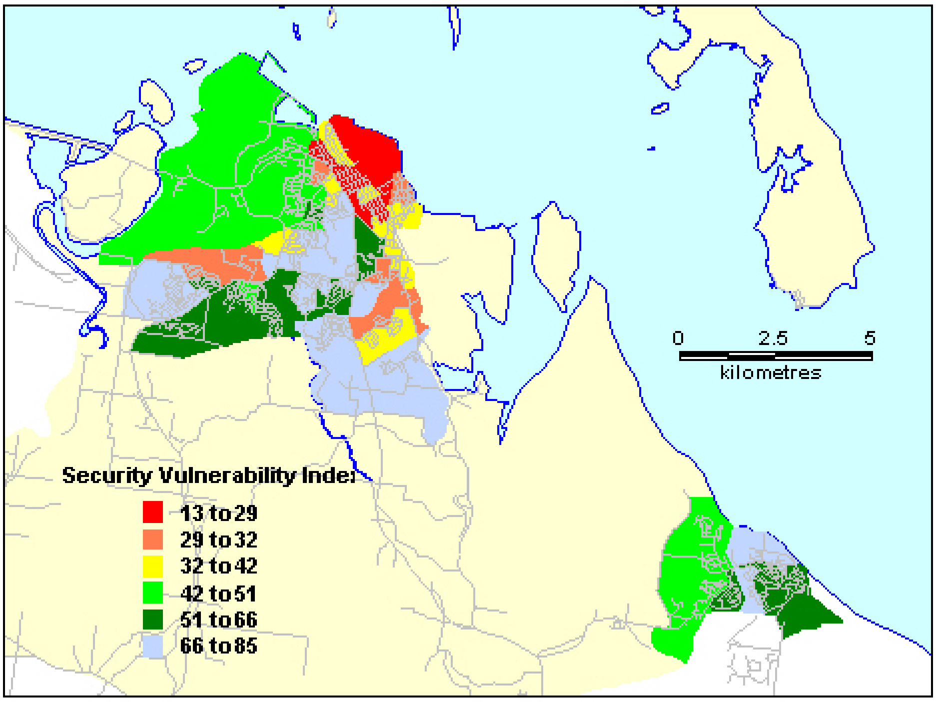

Figure 3.21 Security Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to security vulnerability) are:

Barney Point (2), City (2) and South Gladstone.

The suburbs that contain the bottom 5 CCD are:

Clinton, Glen Helen, Kin Kora, Telina and West Gladstone.

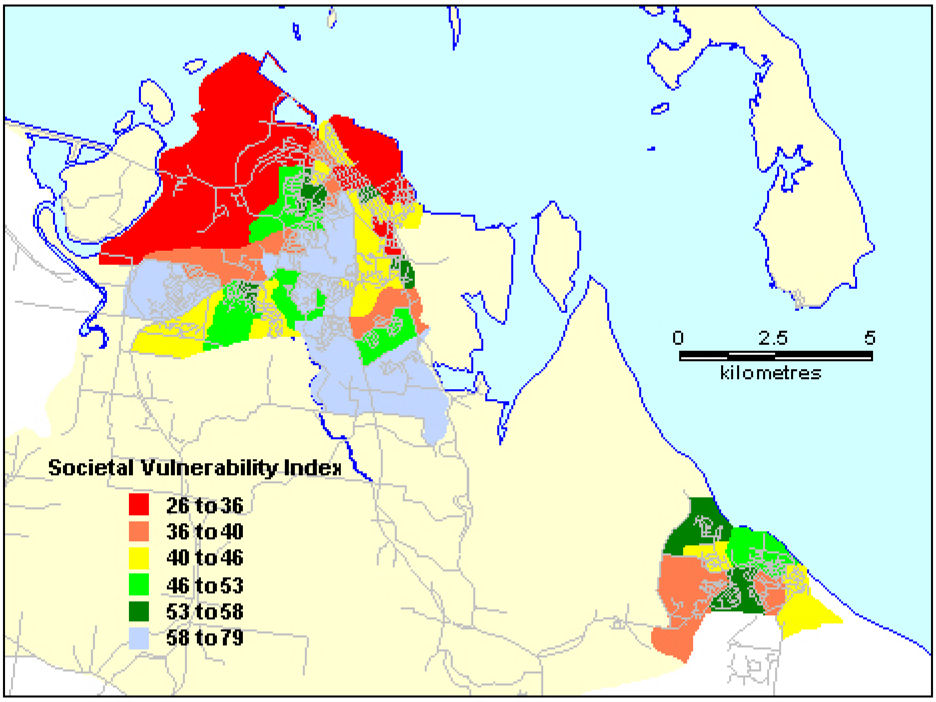

Figure 3.22 Societal Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to societal vulnerability) are:

Barney Point (2), Callemondah, City and South Gladstone.

The suburbs that contain the bottom 5 CCD are:

Clinton, Glen Helen, Telina (2) and West Gladstone.

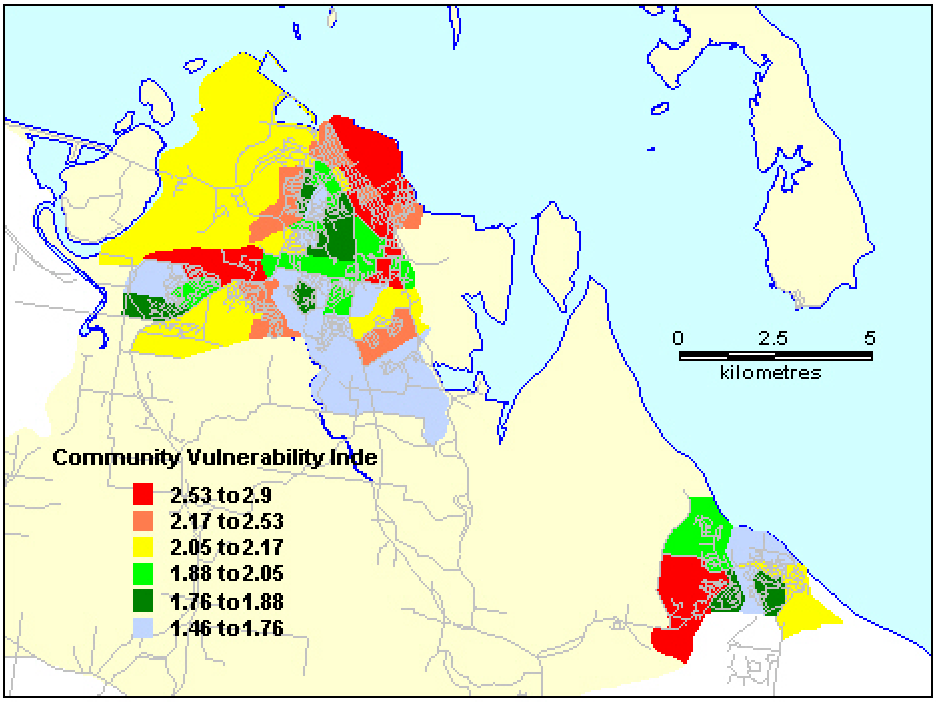

Figure 3.23 Community Vulnerability Index

The suburbs which contain the top 5 (10%) CCDs (i.e. those that are contributing most to overall community vulnerability) are:

Barney Point (2), Clinton and South Gladstone (2).

The suburbs that contain the bottom 5 CCD are:

Clinton, Glen Helen, Telina and West Gladstone (2).

Conclusion

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

CHAPTER 4: TROPICAL CYCLONE RISKS

Ken Granger, Bruce Harper and Sarah Hall

The Cyclone Threat

There is little doubt that tropical cyclones (TC) pose a significant threat to Gladstone. These spectacular meteorological phenomena are very large in scale, and have the potential to bring severe losses to a wide region. On long-term average, 1.4 cyclones pass within 500 km of Gladstone each year. In the past 91 years of detailed record, the centres of 10 of these storms have passed within 100 km of the city. Perhaps the most significant impact by a tropical cyclone on Gladstone in recent history was that wrought by the so-called 'devil's cyclone' of March 1949 which damaged or destroyed every church in the town but left every pub intact.

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

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

Table 4.1 Australian tropical cyclone category scale

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

The Cyclone Phenomenon

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

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

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

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

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

Thermodynamic parameters include:

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

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

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

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

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

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

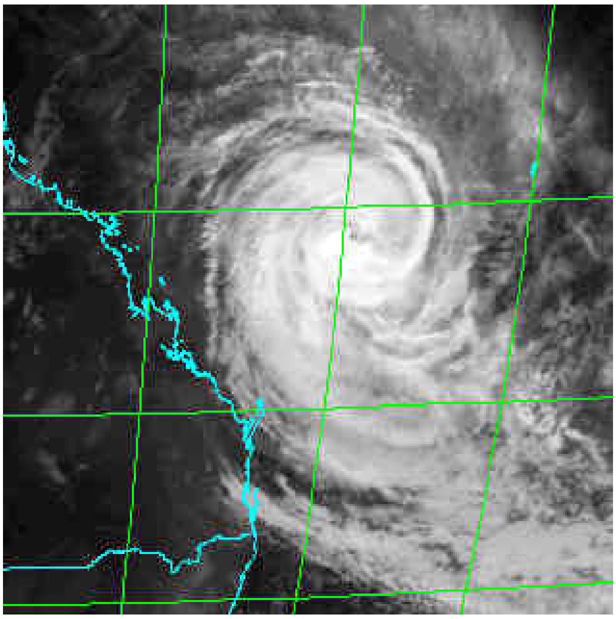

Figure 4.1 TC *Fran* approaching the Queensland coast in March 1992

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

Cyclonic winds circulate clockwise in the southern hemisphere. The windfield within a moving cyclone, however, is generally asymmetric so that, in the southern hemisphere, winds are stronger to the left of the direction of motion of the system (the 'track'). This is because on the left-hand side, the direction of cyclone movement and its circulation act together; on the right-hand side they are opposed. During a coast crossing in the southern hemisphere, the cyclonic wind direction is onshore to the left of the eye (seen from the cyclone) and offshore to the right.

For any given central pressure, the size of individual tropical cyclones can vary enormously. Large cyclones can have impacts far from their track, especially with the generation of large waves and storm tide. For example, TC *Justin* in March 1997 was at least 500 km offshore from Gladstone, yet the seas it generated did significant damage along the foreshore at Canoe Point (Tannum Sands).

Climatology: Historical searches for tropical cyclones affecting the Gladstone region have uncovered significant community impacts as early as 1863 but the detailed record maintained by the Bureau of Meteorology's National Climate Centre begins in the 1907/08 season. An overview of this 91 year official record is given below, summarising cyclone activity within a radius of 500 km from Gladstone, which includes all cyclones which may have been capable of having an influence on the region within a nominal 24 hour period.

Figure 4.2 summarises the frequency of occurrence on an annual basis. It includes 129 storms since 1910. This produces an average of 1.4 storms per year, but varies between 0 and 5 occurrences in any one season. While this is an extensive period of record, Holland (1981) advises caution in utilising records prior to 1959/60 in any detailed statistical analysis of the frequency of occurrence or intensity because of the major changes in observing technology, standards of reporting and increasing scientific understanding over that time. Experimental satellite imagery first became available in 1960, leading to the adoption of objective intensity estimating methods from 1968 onwards, with the later Dvorak technique (Dvorak, 1975) still in regular usage. While evidence of incomplete detection is suggested in the record prior to the 1930s, restricting the data set to post-1959/60 results gives a total of 51 storms in the 40 year period, producing a slightly decreased average occurrence rate of 1.28 per season.

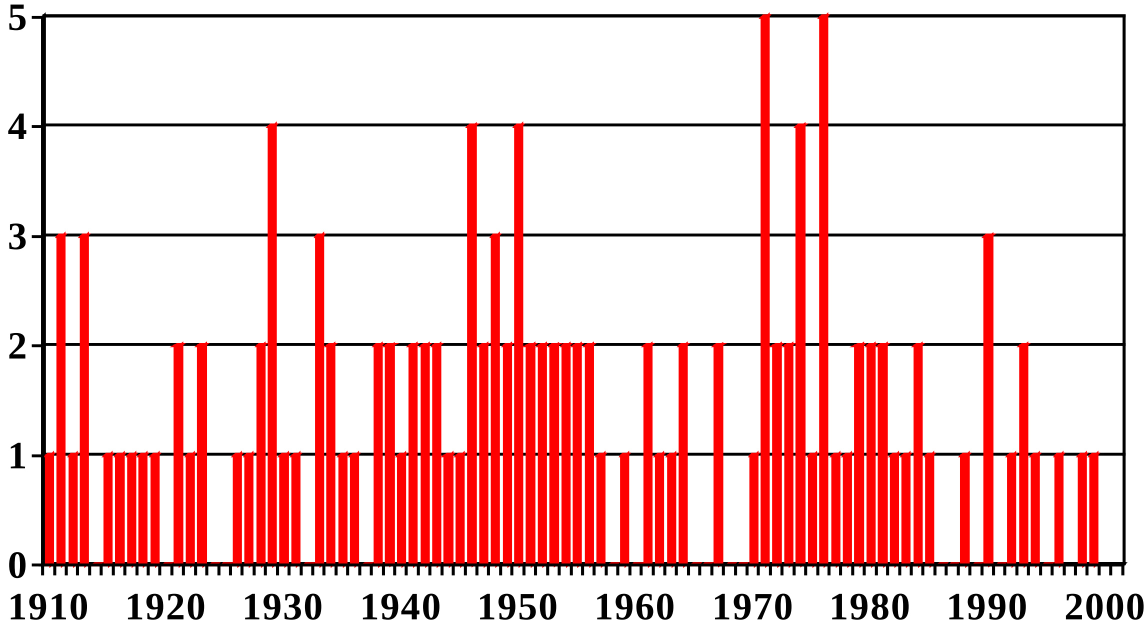

Figure 4.2 Frequency of occurrence of tropical cyclones within 500 km of Gladstone.

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

Some measure of the destructive power of cyclonic winds can be gauged from the following account of damage caused to the Star of the Sea Convent by the 1949 cyclone:

> *When the cyclone struck Gladstone on Ash Wednesday 1949, most telephones and radios were out of action by the time the destructive winds cut a swathe through the town's church buildings. No one knew what was happening beyond their own vision and there were no warnings. Mercifully the Sisters moved the children to safety before the school began to collapse. Sisters and boarders inside the Convent itself sheltered in the lower part of the building as the roof began to blow off and crash into the side of the Presbytery. Shortly before the whole building collapsed they were rescued by parishioners and the Ambulance Brigade and taken to private homes.*
>
> (McDonald, 1988, p 239)

Heavy Rainfall: Before proceeding to discuss the risks associated with severe wind and the oceanic effects of storm tide and extreme waves in Gladstone, it is worth touching briefly on the climatology associated with the severe rainfall that frequently accompanies tropical cyclones. The consequences of this intense rainfall are dealt with in Chapter 6.

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

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

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

Severe Waves: The Queensland Beach Protection Authority (BPA - now within the Environment Protection Authority) has maintained a near-continuous record of wave heights at various sites along the Queensland coast, dating back to 1976, using moored buoy systems offshore. The closest buoy to Gladstone is at Emu Park but it was only installed in July 1996. The Point Lookout buoy off North Stradbroke Island, however, provides a longer record. A recent analysis of some 21 years of data from that buoy (Allen and Callaghan, 2000) revealed the maximum recorded significant wave height of 7.4 m occurred during TC *Roger* in 1993. Based on their statistical analyses, Table 4.2 indicates the average recurrence interval (ARI) for significant wave heights at this location caused by tropical cyclones. The significant wave height (Hs) is an estimate of the average height of the highest one-third of waves in a 20 minute period, and is found to be similar to the visually estimated wave height made by an experienced observer. The single highest wave (Hmax) during the same period is typically around 1.8 times higher than Hs. Gladstone is likely to have a similar wave regime.

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

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

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

One of the principal impacts of severe waves is significant beach erosion, especially when combined with storm tide effects. In March 1997, for example, wave action created by TC *Justin* caused at least 10m of shoreline to be lost from Canoe Point at the mouth of the Boyne River. Severe wave action inside Port Curtis, however, appears to be significantly reduced because of the protection afforded by Facing and Curtis Islands.

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

Figure 4.3 summarises the various components which work together to produce an extreme storm tide. Firstly, the storm surge is generated by the combined action of the severe surface winds circulating around the storm centre generating ocean currents, and the decreased atmospheric pressure causing a local rise in sea level (the so-called *inverted barometer* effect). The strong currents impinging against the coast are normally responsible for the greater proportion of the surge. As shown in Figure 4.3, the surge adds to the expected tide level at the time the storm makes landfall.

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

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

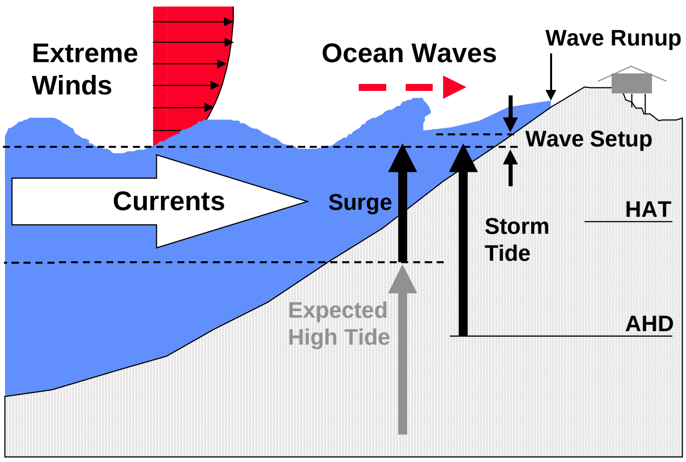

Figure 4.3 Components of a storm tide (from Harper, 1998)

Table 4.3, extracted from Harper (1998), provides a summary of recorded storm tide events within 150 km of Gladstone. This list should be regarded as indicative only but shows that at least 8 separate surge events have occurred over the past 55 years. Of these, about a quarter resulted in storm tide levels reaching above the HAT (Highest Astronomical Tide) level.

Table 4.3 Historical storm tide events within 150 km of Gladstone (from Harper, 1998)

Date	Place	Event	Storm Surge (m)	Storm Tide Level (m on AHD)	Inundation Above HAT (m)
2 Mar 1949	Gladstone		>1.2	2.2	0.2
29 Jan 1967	Bundaberg	*Dinah*	0.7		
21 Feb 1971	Gladstone	*Fiona*	0.6		
2 Apr 1972	Gladstone	*Emily*	0.9	2.2	
24 Jan 1974	Gladstone	*Wanda*	0.3		
9 Mar 1974	Gladstone	*Zoe*	0.4		
14 Feb 1981	Burnett Heads	*Cliff*	0.5		
15 Mar 1992	Gladstone	*Fran*	0.8		
16 Mar 1992	Burnett Heads	"	1.0	2.1	0.2

Modelling of the storm tide hazard was undertaken for the Coordinator General's Department in 1980 (McMonagle, 1980) as part of a wider study of storm tide along the Queensland coast. Based on his figures, as cited in Appendix 2 of Harper (1998), the predicted storm tide levels at Gladstone are given in Table 4.4. These figures include the **combined effects of tide, storm surge and wave setup** (i.e the total level of inundation expected). Levels are given relative to AHD and the highest expected tidal level (HAT) is also indicated (from Queensland Transport, 2001).

Table 4.4 Predicted total storm tide levels for Gladstone (Harper, 1998)

Site	HAT m above AHD	Average Recurrence Interval (ARI) years				
		50 m on AHD	100 m on AHD	500 m on AHD	1000 m on AHD	10 000 m on AHD
Gladstone	2.42	3.3	3.5	4.1	4.4	5.2

It is understood that more recent storm tide modelling has been undertaken to determine the likely levels that could be experienced within Port Curtis in the Fisherman Landing/Kangaroo Island area as part of the EIS for the proposed Rundle shale oil mine. A copy of that material has not been available to us, however we understand that it indicated a level that was higher than for Gladstone.

Climatic Variability: Figure 4.2 shows that the incidence of tropical cyclones can be quite variable from one year to the next. This is because of the complex set of factors which influence their genesis. For many years, one of the most frequently used indicators of seasonal cyclonic activity has been the so-called *El Niño*-Southern Oscillation (ENSO) phenomenon (Nicholls, 1992). This is the name given to a near-periodic (between one and three year) cycle of alternating cold and warm ocean temperatures between one side of the Pacific Ocean and the other. The *El Niño* phase sees abnormally warm ocean temperatures off the coast of South America and along the central and eastern Pacific equatorial zone, and simultaneously cooler ocean temperatures in the western Pacific and the Coral Sea. During the reverse cycle, or *La Niña*, ocean temperatures near the Queensland coast are typically above average. Ocean temperature is not the only factor causing cyclone variability but it is a prime contributor. When combined with associated shifts in large-scale zones of atmospheric convergence (Basher and Zheng, 1995), the regions of tropical cyclone genesis in the South Pacific tend, as a result, to move further towards the east (*El Niño*) or the west (*La Niña*).

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

Another common method is to use sea surface temperature (SST) readings from various zones in the Pacific. These data have become routinely available from satellites as well as from ships, drifting buoys and from moored buoy networks positioned along the equator. Using an accepted SST-based sequence from 1959 to 1997 (e.g. from Pielke and Landsea, 1999), Figure 4.4 shows that when the historical record is separated into *El Niño* and *La Niña* periods, there is a quite noticeable effect on the tracks of tropical cyclones in the Coral Sea. During *La Niña* (the positive SOI phase), cyclone activity tends to be located closer to the east coast of Queensland and further south than during the *El Niño* (negative SOI) phase. While the ENSO phenomenon appears to be somewhat random, *El Niño* years have outnumbered *La Niña* years by about a factor of 3 since the mid-1970s. This has been reflected along much of the east coast of Queensland by a corresponding reduction in the frequency of cyclone occurrence and Figure 4.2 indicates this effect from about 1975 onwards within 500 km of Gladstone. Exactly why this preference for *El Niño* episodes has persisted during this period is not entirely clear but it may be related to longer period climatic variability as discussed below, or even global climate change. From 1998 to early 2000 there was a return to mild *La Niña* and near-neutral conditions.

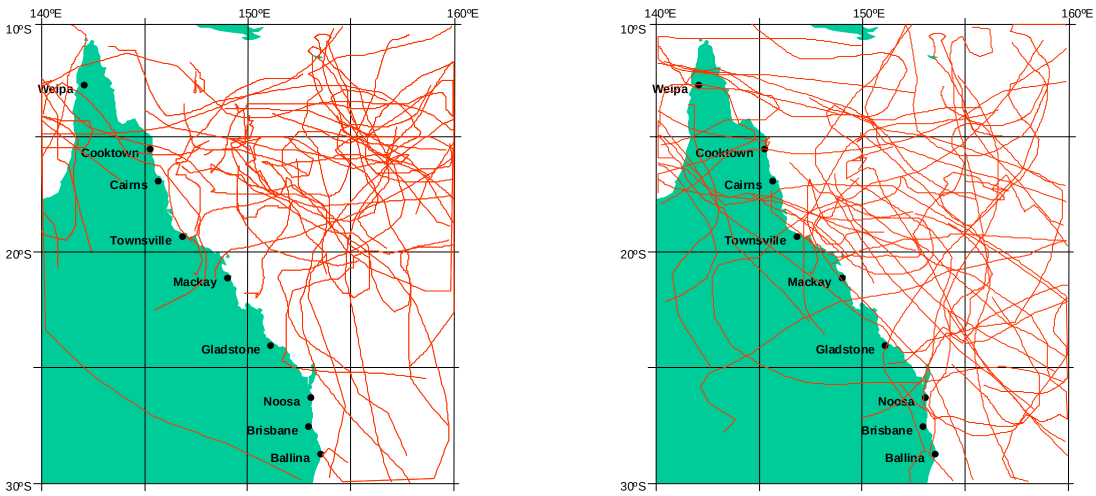

Figure 4.4 Differences in tropical cyclone tracks between *El Niño* (left) and *La Niña* (right) years.

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

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

The Gladstone cyclone experience

Most tropical cyclones in the region occur during the period between January and March. Figure 4.5 shows the recorded monthly occurrences, combined with a closest approach analysis. March can be seen to have the highest incidence, with 37 cyclones, followed by January with 35 and February with 34. In terms of closest distance to Gladstone, March has the greatest proportion with about 11% being within 100 km. Almost half the storms have been at least 300 km distant.

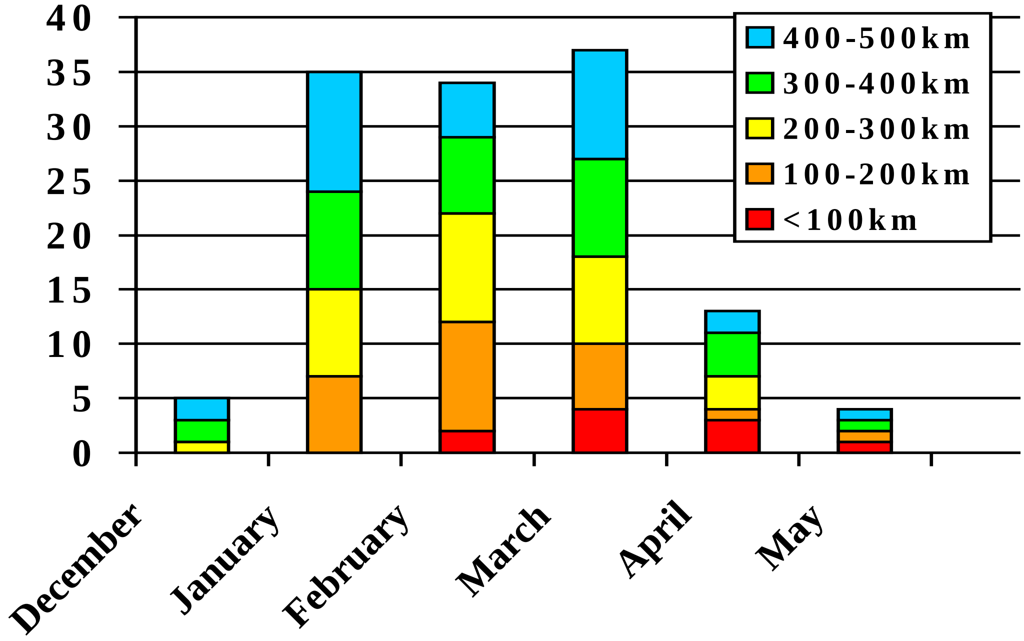

Figure 4.5 Seasonal distribution of tropical cyclones and closest approach analysis

East coast lows (so-called 'winter cyclones') can also have an impact on Gladstone. For example, such a storm in June 1929 caused significant damage, including gales and flooding in the Fitzroy River at Rockhampton.

Table 4.5 lists the cyclones that have approached to within 100 km of Gladstone, that is, the city came within the radius of their destructive winds. Whilst the most severe damage can be expected from such cyclones, it is possible for damage to occur from more distant systems. TC *David* in 1976, for example, passed no closer than 200 km yet it brought widespread damage to the town.

Accounts of three cyclones that have made their mark on Gladstone over the past 52 years illustrate the effects experienced in the city.

Table 4.5 Cyclones which have approached to within 100 km of Gladstone

Date	Name	Category	Pressure
5 April 1921		1	988
30 May 1941		?	?
30 April 1948		1	1002
2 March 1949		3	972
26 February 1950		1	998
22 March 1953		1	1009
21 February 1971	*Fiona*	1	996
2 April 1972	*Emily*	2	974
5 March 1973	*Dawn*	1	988
15 February 1992	*Fran*	2	980

1949: On Ash Wednesday (2/3 March) in 1949 a severe cyclone passed over Rockhampton and Gladstone. The central pressure at 5am on 2 March was 972 hpa. The cyclone caused widespread damage in 15 towns and at least four deaths. In Rockhampton an estimated 1000 houses were damaged and widespread flooding was experienced through Central Queensland. The impact on Gladstone, however, was apocalyptic and gave the cyclone it's name as the 'devil's cyclone'. The Anglican, Catholic and Presbyterian churches were each severely damaged, whilst all of the town's drinking palaces were spared damage. A brick church in Goondoon Street was completely destroyed, as was the wooden Catholic Convent and School. Roofs in Auckland Street were ripped off, fences, homes and out buildings were destroyed, moored vessels were sunk. Power and communications were cut off, which led the Gladstone Town Council to write to the ABC requesting the provision of better services to Gladstone, especially the provision of storm warnings.

As if to prove the old adage that it is an ill wind that blows nobody any good, the Sisters of Mercy described the 'devil's cyclone' as an Act of God because it did result in a new convent being built in 1952. The showgrounds got a new grandstand and a new jetty was constructed at South End. The Secretary of the Queensland Cruising Yacht Club, Mr Drouyn, announced that revenue gained from holding the inaugural Brisbane to Gladstone Yacht race (in the days following the cyclone) would in future fund assistance for victims of cyclones.

1976: From the 18 to 20 January TC *David,* which crossed the Queensland coast about 250 km to the north of Gladstone, produced some of the strongest winds and wildest seas on record. Mr Noel Boely of the GPA witnessed a tide at least 0.5 m higher than the forecast high tide level. This forced sea water onto the roads and foreshore bordering Auckland Inlet. The bund wall system between Auckland Inlet and Calliope River was also seriously eroded. The retaining wall at Barney Point Beach was covered by the 3.5metre tide on the 20th and when it receded, 92 m of the wall collapsed. Industry was affected, with the power station giving its employees the day off on full pay and QAL assisted in producing community emergency action leaflets. The Port was particularly affected and was closed at 4.30pm on the 20th. There was 'considerable erosion' at Barney point coal handling facilities, with the worst affected area being the 'eastern side of the newly reclaimed foreshore' and the No.5 loader approaching the wharf. A Mr Warburton was reported, in the *Gladstone Observer,* as saying that 'had the erosion eaten a further 3.5m in the reclaimed foreshore, it would have claimed the loader.' Boyne Island was cut off from telephone and electricity services as trees fell across roads and lines. Benaraby Road was cut by tidal water at noon on the 19th. There was beach erosion at Tannum Sands through to Oaks Road and the caravan park was evacuated.

Electrical services were cut to many residents as a result of low voltage conductors clashing together from the high speed winds. The substation at the Fisher Street reservoir caught fire and a feeder line had to be isolated. High voltage power lines which serviced the sawmill at Briffney Creek had been brought down, and two conductors had been knocked to the ground and a piece of steel wrapped around the pole.

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1992: TC *Fran* will probably be the most recent cyclone event in the minds of many of Gladstone's current residents. This Category 3 storm finally dissipated on St Patrick's Day after three days of strong winds and heavy rains. *Fran* had been preceded three weeks earlier by very heavy rainfall. The combination of sodden ground and the cyclone's strong winds led to a number of large trees being uprooted in Sun Valley, Calliope and the CBD area. Power supply and telecommunications were again seriously disrupted. Mobile generators were sent to telephone exchanges, whilst the Capricornia Electricity district manager reported that there had been 'multiple power losses in Gladstone, Tannum Sands and Calliope areas'. The *Gladstone Observer* reported that Radio Station 4CC was 'inundated with hundreds of calls during the weekend from people seeking information on Cyclone *Fran's* movements', further disrupting communications. The eye of the cyclone was directly over Heron Island for seven hours on 15th March. Roads were cut south to the Town of 1770, Agnes Water and Lowmead. Rail services were suspended and coal deliveries were halted. Rail services were also suspended to Rockhampton and the west. Aerial services were cancelled although the airport facilities were not affected. Gladstone Hospital records indicate that TC *Fran* did not cause serious injuries or fatalities.

Severe wind risk

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

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

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

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

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

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

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

Some of the key forces on buildings are illustrated in Figure 4.6 and Figure 4.7. The first figure shows the way in which the suction forces generated on low pitched roofs may be countered by a reduced pressure inside the building where the integrity of the windward walls and windows are maintained and there is a predominance of openings on the leeward side. The second figure shows how an overpressure inside the building is created when that integrity is compromised by a window being broken on the windward side. The additional force can destroy the roof, if not the whole structure.

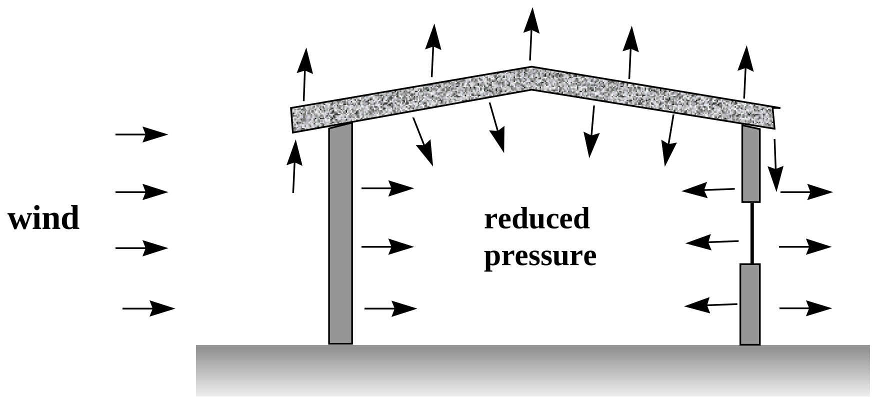

Figure 4.6 Wind forces working on a building with external integrity

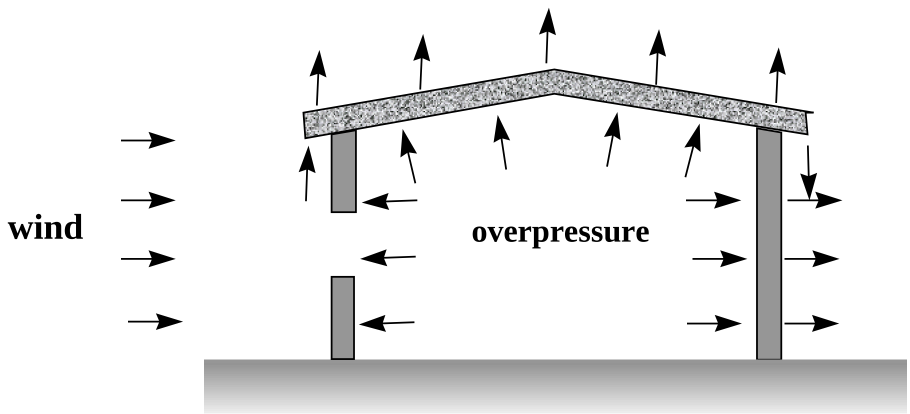

Figure 4.7 Wind forces working on a building where its external integrity is lost

Wind loading standards in Australia were first implemented by structural engineers in 1952 and have been variously updated over time. After the experience of the severe destruction wrought by TC *Althea* (Townsville) in 1971 and TC *Tracy* (Darwin) in 1974, special efforts were made to strengthen building standards in Queensland and elsewhere in Australia, especially for domestic structures. Standard *AS1170.2 Minimum design loads on structures: Part 2 – Wind loads* was first published in 1973 and was subsequently revised in 1975, 1981 and 1983. The current (5^{th}) edition was published in 1989 (Standards Australia, 1989). This Standard was first adopted under the Queensland *Building Act* in 1975. Before this, each local authority had its own building regulations, and many authorities would have referred to the wind code. However, housing was not explicitly addressed in the *Act* until Appendix 4 was included in the 1981 publication of the Act. Implementation of the 1981 publication did not occur until 1 July 1982 (George Walker, Aon Reinsurance, personal communication, 2001). *AS1170.2* is now encompassed by the Building Code of Australia. The wind loading standard is based on a design event for which there is a 5% probability of exceedence in any 50 year period (i.e. a notional 1000 year ARI or 0.1% AEP).

To model an <u>indicative</u> impact of severe wind across the study area from a range of scenarios we have adopted the approach of AGSO in its multi-hazard risk assessment of Mackay (Middelmann and Granger, 2000). We have modelled the damage losses to residential buildings (houses and flats) in Gladstone.

We have adopted the probabilistic Mackay cyclonic wind hazard model of Harper (1999b) for Gladstone because a probabilistic wind model for Gladstone was unavailable to us. The wind speeds for Gladstone for various ARIs may be slightly lower than those for Mackay because Gladstone is about three degrees south of Mackay. Gladstone is, none the less, within Zone B (cyclone winds) of the wind loading code. The indicative estimates of wind damage for Gladstone may, none-the-less, be slightly overestimated.

We have adopted a simple terrain model for three broad zones in Gladstone that are consistent with the wind loading standard AS1170.2-1989. They are:

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

Two age classes have also been established, that is, nominally pre and post 1983. The tallies for all Gladstone buildings and all domestic buildings in each of the resulting six categories are given in Table 4.6.

Table 4.6 Gladstone buildings by wind terrain categories (domestic buildings in parentheses)

	Foreshore	**Town**	**Inland**	**Total**
Pre 1983	1468 (1187)	6725 (6821)	21 (0)	8214 (8008)
Post 1983	323 (207)	2602 (2430)	199 (146)	3124 (2783)
Totals	1791 (1394)	9327 (9251)	220 (146)	11 338 (10 791)

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

> *The problem in estimating domestic quality building behaviour in strong winds stems from a number of issues:*
> - *relatively few instances of severe damage being available;*
> - *a lack of accurate wind measurements at, or near building exposure conditions;*
> - *structural redundancy, variable load paths and variety of fixings;*
> - *wide variations in building style and quality of construction; and,*

- *second-order effects such as debris damage.*

Based on damage assessments undertaken primarily for the insurance industry [since 1971] *it has been possible to develop indicative 'damage curves' for Australian domestic construction (Harper and Holland 1998, Walker 1994) which are also deemed consistent with US experience in Hurricane 'Andrew' (Sparkes 1993).*

The damage loss curves presented by AGSO (Middelmann and Granger, 2000), reproduced here in Figure 4.9, clearly illustrate the significance of the introduction of building code standards in the 1980s. This point was clearly evident in the experience of the impact of TC *Winifred* near Innisfail in 1986 and most recently with TC *Vance* at Onslow in Western Australia in 1999 (Reardon, Henderson and Ginger, 1999). The '% damage' values shown are relative to the nominal insured value of a dwelling and contents or, when aggregated, a total residential community. Industrial and commercial buildings, where individual engineering design and inspection have been applied, are expected to suffer significantly less damage than dwellings in similar conditions (Bruce Harper, personal communication, 2000). It is therefore expected that damage to dwellings will play a large part in the total community losses from building damage alone under extreme wind conditions.

By applying the peak wind gusts from the probabilistic model of Harper (1999b) to the domestic building stock vulnerability curves, it is possible to establish an indicative estimate of the percentage of damage losses likely to be experienced by domestic buildings under a range of scenarios. These proportions, across the entire community are given for pre-1983 buildings in Table 4.7 and for post-1983 buildings in Table 4.8. The expected total levels of damage under these four scenarios are summarised in Table 4.9.

A summary of the indicative building damage losses generated by wind scenarios with likelihoods ranging from 2.0% AEP (50 years ARI) to 0.1% AEP (1000 years ARI) is shown in Table 4.9.

It is worth noting that Gladstone has a high proportion of fibro-clad buildings that may be prone to damage from wind-blown debris.

Table 4.7 Expected level of damage to pre-1983 domestic buildings

	Foreshore (% damage)	**Town** (% damage)	**Inland** (% damage)
50 year ARI	0.7	0.1	0.1
100 year ARI	2.7	0.1	1.2
500 year ARI	19.7	2.0	11.0
1000 year ARI	36.0	4.1	18.4

Table 4.8 Expected level of damage to post-1983 domestic buildings

	Foreshore (% damage)	**Town** (% damage)	**Inland** (% damage)
50 year ARI	0.1	0.1	0.1
100 year ARI	0.1	0.1	0.1
500 year ARI	2.9	0.1	1.0
1000 year ARI	6.4	0.1	2.7

The percentages cited in Tables 4.7 and 4.8 have been taken from the multi-hazard risk assessment of Mackay (Middelmann and Granger, 2000).

Table 4.9 Indicative level of cyclonic wind damage losses to domestic buildings with respect to insured value of dwelling and contents (equivalent numbers of dwellings with 100% damage losses in parentheses)

	Foreshore (% damage)	**Town** (% damage)	**Inland** (% damage)	**Total** (% damage)
50 year ARI	0.006 (8.5)	0.001 (8.7)	0	0.002 (17.2)
100 year ARI	2.3 (32.2)	0.001 (8.7)	0	0.004 (40.9)
500 year ARI	16.5 (231.3)	0.002 (15.0)	0	2.4 (246.3)
1000 year ARI	31.6 (440.0)	3.0 (259.9)	0.003 (0.4)	6.8 (700.3)
10 000 year ARI	88.8 (1238.4)	13.8 (1205.4)	1.6 (2.4)	23.9 (2446.2)

The distribution of damage potential, expressed as the equivalent number of dwellings with 100% damage losses) for a 0.1% AEP wind event (i.e. the 'design' event in AS1170.2-1989) is shown in Figure 4.8.

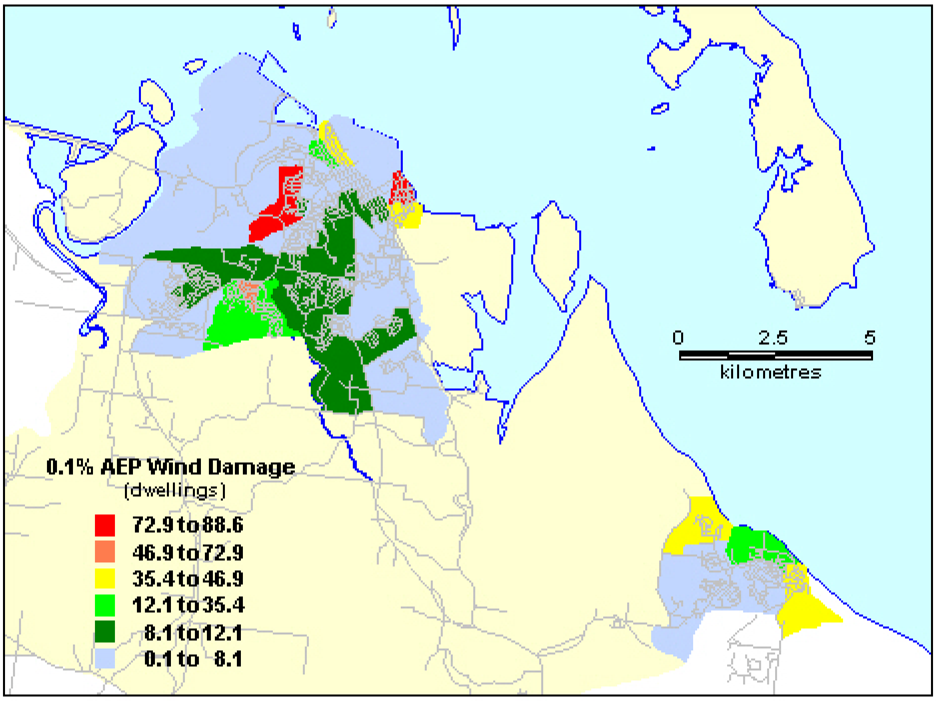

Figure 4.8 Indicative modelled wind damage losses for a 0.1% AEP event

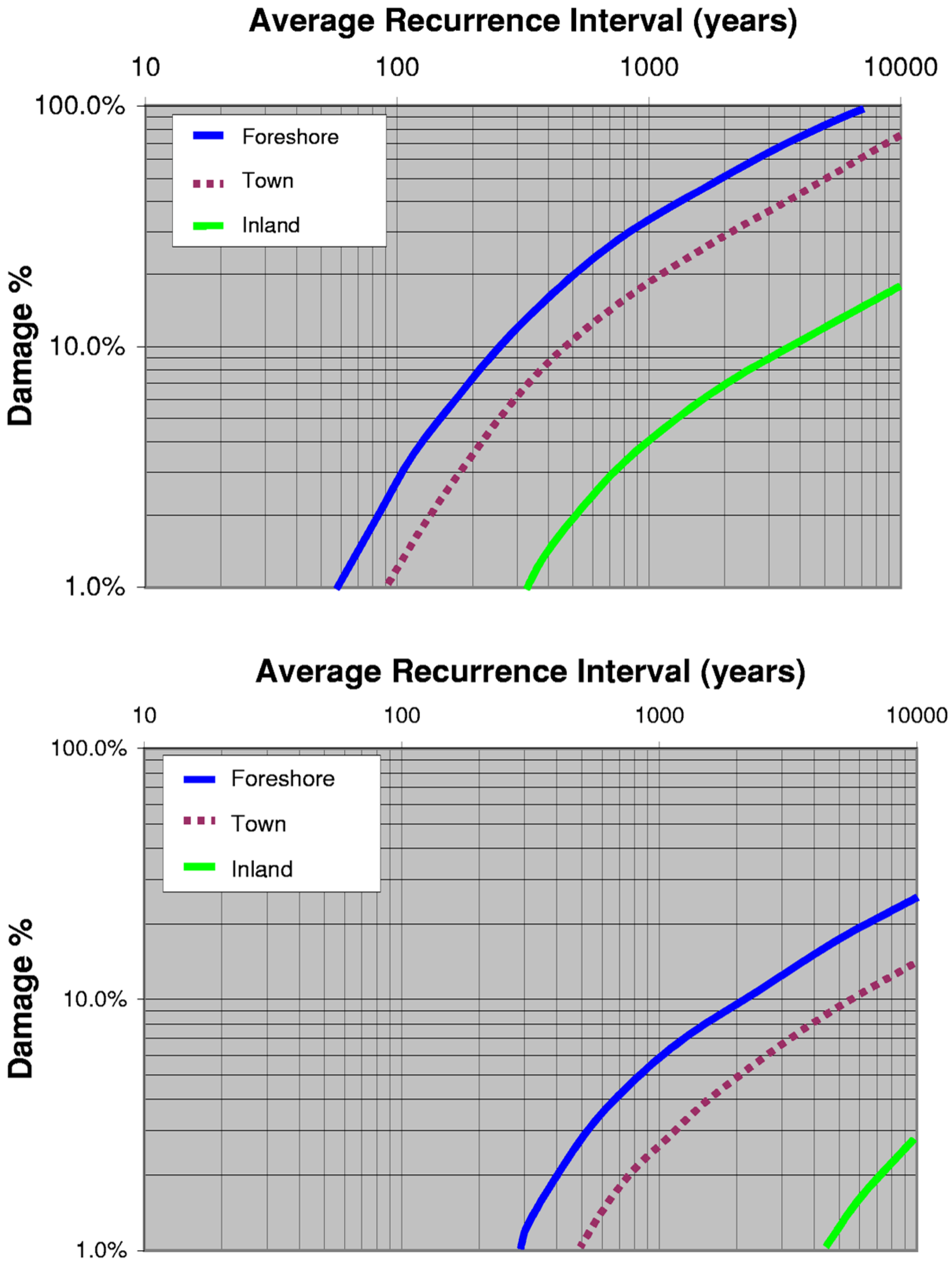

Figure 4.9 Top, pre-1983 dwellings; bottom, post-1983 dwellings. Indicative level of damage losses to domestic construction in Gladstone as a function of age of construction, terrain category and average recurrence interval (reproduced from Middelmann and Granger, 2000).

Lifelines and other assets: With most cyclones that approach to within the radius of maximum winds, the greatest amount of inconvenience has been caused by damage to the power reticulation infrastructure. Power lines are often brought down by tree branches, palm fronds and other wind-blown debris. Electricity authorities in coastal areas of Queensland tend to maintain good clearance of trees from power lines and the more critical areas tend to be serviced by underground mains. Whilst it is unusual for power poles and pylons to be brought down by high winds, it certainly has happened. In the Brisbane Valley in 1999, for example, several transmission line pylons were brought down in extreme wind gusts associated with a local storm (in the type of micro-burst conditions that could be experienced in the tornadic outbreaks experienced in cyclones). Also in TC *Steve* in Cairns (late February 2000), several poles were pushed out of the vertical because the ground they were in had been saturated by up to four weeks of continual heavy rainfall before the severe winds were experienced.

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

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

The substantial commercial and pleasure boat fleets in Gladstone are also at risk in strong winds and waves. During cyclone alerts, many small craft take shelter in, or close to the mangroves that fringe Auckland Creek, though the marina may provide greater protection for such craft.

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

Storm Tide Risk

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

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

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

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

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

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

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

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

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

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

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

Storm Tide Scenarios

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

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

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

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

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

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

Data uncertainty: In this model, the key values of floor height and ground height were taken from the detailed building database described in Chapter 3. Floor heights were estimated by observation in the field for all buildings with a likely storm tide risk and are considered accurate to within a few centimetres. For buildings built on a slab a floor height of 0.3m above ground level has been assumed.

The ground height for each property was interpolated in the GIS from the Digital Elevation Model (DEM) developed by AGSO from a range of sources including Department of Natural Resources and Gladstone City Council. DEM accuracy in the low lying coastal areas at risk from storm tide inundation is at best, plus-or-minus 0.2 to 0.3 m. The use of such ‘imprecise’ data may seem to introduce potentially significant error or uncertainty in the outcome. It should be recognised, however, that the error estimates for the AGSO DEM are substantially less than those published for the original topographic data and are the very best available.

There are also uncertainties associated with the inundation models used. For example, the uniform wave setup value of 0.3m recommended by the BPA, is sensitive to wave energy which is influenced by cyclone characteristics such as track, velocity and so on.

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

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

- inundation over ground level only: $Gd\_ht < std + sww$
- inundation over floor level: $Fl\_ht + Gd\_ht < std + sww$
- inundation > 1.0 m over floor level: $Fl\_ht + 1 + Gd\_ht < std + sww$

where:

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

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

The second assumption is that the population will be concentrated at their place of residence at the time of impact. We feel that this is also a reasonable assumption, given that there would be 24 and 48 hours warning of the impending cyclone impact and that families would seek shelter together at home wherever possible. This is in contrast to the situation with earthquakes (see Chapter 5), where a range of population distribution scenarios (e.g. day, night, weekend, holiday period, etc.) needs to be considered.

Open space (playing fields, parks, etc) and properties with miscellaneous uses (such as car parks) have been excluded from the analysis.

The damage levels are for building damage only and do not include contents of assets such as cars that may be garaged on the property.

<u>The 2.0% AEP scenario</u>: Under this scenario, a total storm tide elevation above AHD of 3.3m would be experienced in Gladstone. The modelled impact (with all the caveats outlined above), in terms of the inundation of buildings is summarised in Table 4.10.

Table 4.10 Buildings affected by a 2.0% AEP storm tide

Level of Inundation	Gladstone
>1m over floor	27
<1m over floor	185
on property but below floor level	63
not affected	11 063

Only 1.6% of the Gladstone area’s total building inventory would have water over floor level. All of the ‘buildings’ identified as having more than a metre of water over floor level, however, are facilities

such as boat ramps, wharves and similar features that are, by their very function, on or close to the water. Damage to these facilities would have a serious impact on Gladstone's role as a major export port. Of the buildings with water over floor level, only 28 would be houses or flats, four of which are in Barney Point and the remainder in Boyne Island or Tannum Sands. Fewer than 100 people would need to be evacuated as a precaution ahead of the cyclone's impact.

The impact on the town area is shown in Figure 4.10 and the Boyne Island/Tannum Sands area in Figure 4.11.

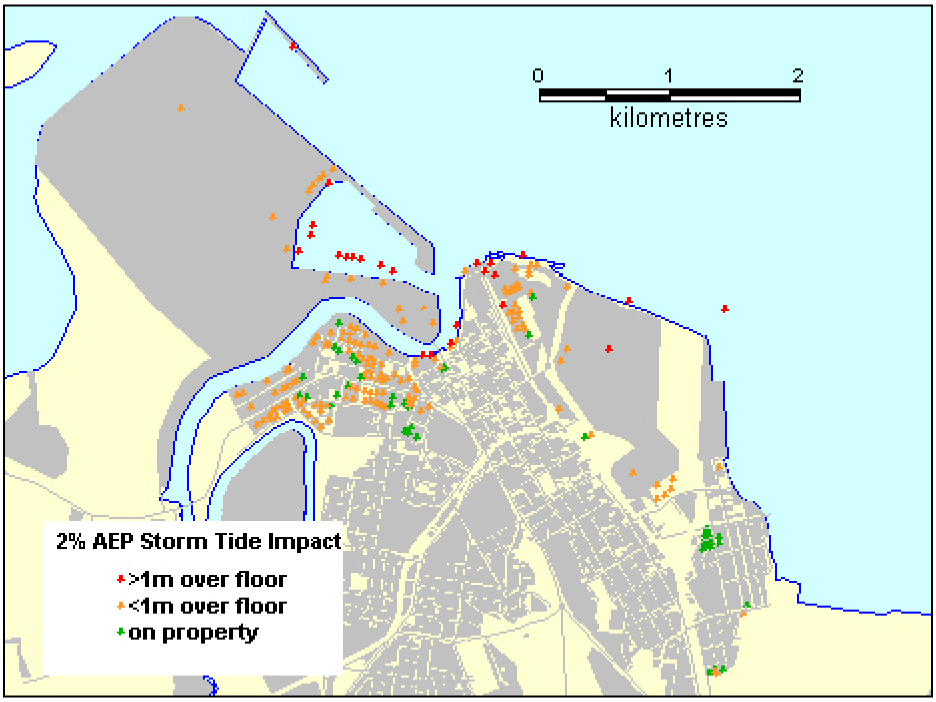

Figure 4.10 Modelled impact of a 2.0% AEP storm tide in Gladstone

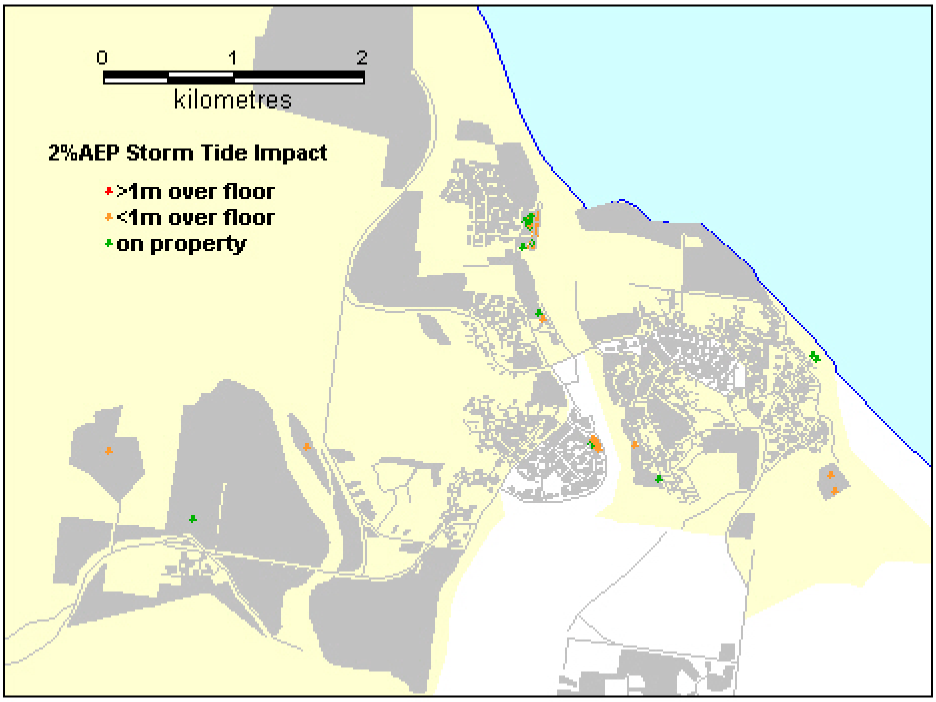

Figure 4.11 Modelled impact of a 2.0% AEP storm tide in Boyne Island and Tannum Sands

<u>The 1.0% AEP scenario</u>: Under this scenario, a total storm tide elevation above AHD of 3.5m would be experienced in Gladstone. The modelled impact (with all the caveats outlined above), in terms of the inundation of buildings is summarised in Table 4.11.

Table 4.11 Buildings affected by a 1.0% AEP storm tide

Level of Inundation	Gladstone
>1m over floor	27
<1m over floor	220
on property but below floor level	78
not affected	11 013

Around 2.2% of the Gladstone area buildings would have water over floor level under this scenario. As with the 2.0% AEP event, all of the 'buildings' identified as having more than a metre of water over floor level are facilities such as boat ramps, wharves and similar features that are, by their very function, on or close to the water. Damage to these facilities would have a serious impact on Gladstone's role as a major export port. Of the buildings with water over floor level, only 41 would be houses or flats, 11 of them in Barney Point and the remainder in Boyne Island or Tannum Sands. Perhaps 100 people would need to be evacuated ahead of the cyclone's impact, as a precaution.

The impact on the town area is shown in Figure 4.12 and the Boyne Island/Tannum Sands area in Figure 4.13.

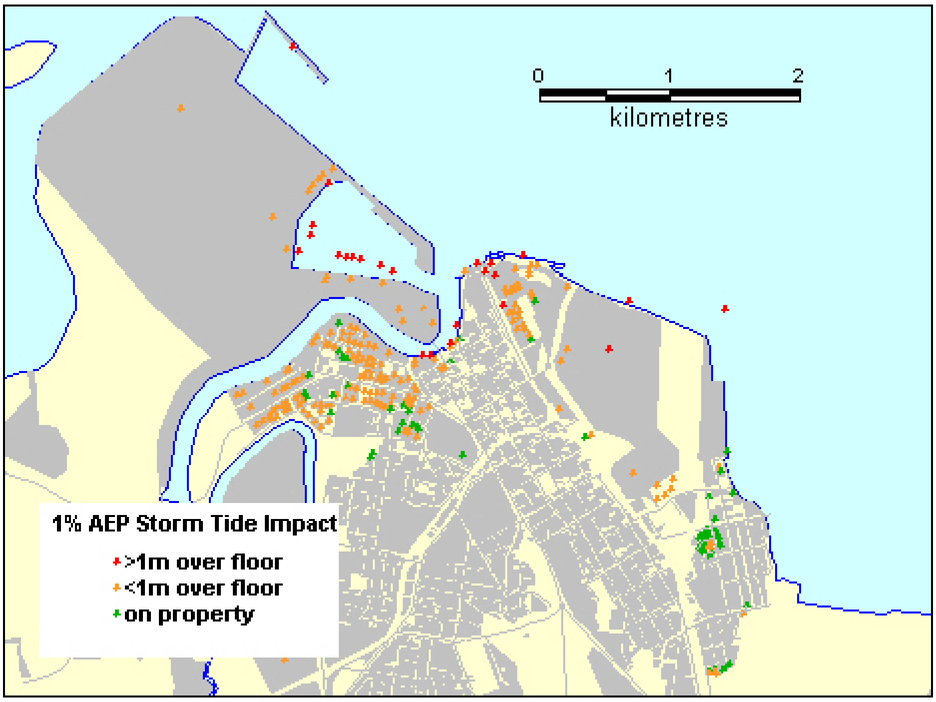

Figure 4.12 Modelled impact of a 1.0% AEP storm tide in Gladstone

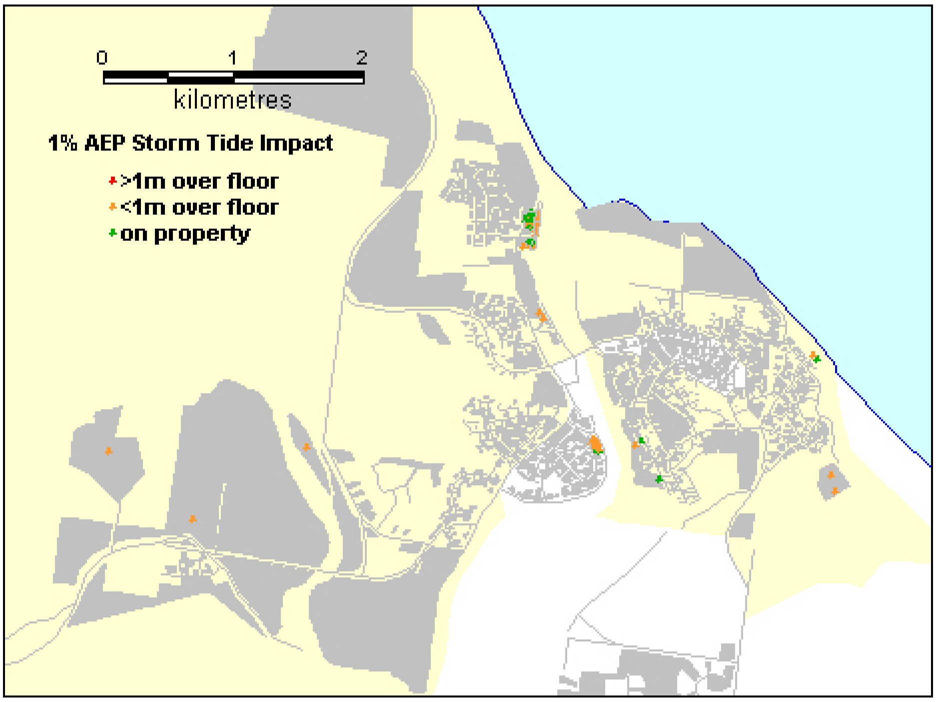

Figure 4.13 Modelled impact of a 1.0% AEP storm tide in Boyne Island and Tannum Sands

The 0.2% AEP scenario: Under this scenario, a total storm tide elevation above AHD of 4.1m would be experienced in Gladstone. The modelled impact (with all the caveats outlined above), in terms of the inundation of buildings is summarised in Table 4.12.

Table 4.12 Buildings affected by a 0.2% AEP storm tide

Level of Inundation	Gladstone
>1m over floor	196
<1m over floor	175
on property but below floor level	94
not affected	10 873

In all, 3.3% of the Gladstone area's buildings would have water over floor level under this scenario. Of the buildings and facilities with more than 1m of water over floor level, 23 are either houses or flats – all of them in the Boyne Island/Tannum Sands area. The 50 or 60 people resident in these dwellings would have to be evacuated at least six hours before the cyclone crossed the coast to ensure their safety. Cyclone winds typically reach 75 km/h by the time the eye is around six hours from crossing, hence the need to complete any evacuation before the winds reach that dangerous level. A further 72 houses or flats would have water over floor level but not as deep as 1m. The 125, or so, people affected may also wish to be evacuated as a precaution. Two thirds of the buildings with water of less than 1m over floor are in Gladstone (mostly in Barney Point).

The remaining 173 buildings or facilities with more than 1m of water over floor level are mostly commercial, logistic or transport-associated and are located mainly in the industrial area along Auckland Creek or in the Barney Point port area.

The impact on the town area is shown in Figure 4.14 and the Boyne Island/Tannum Sands area in Figure 4.15.

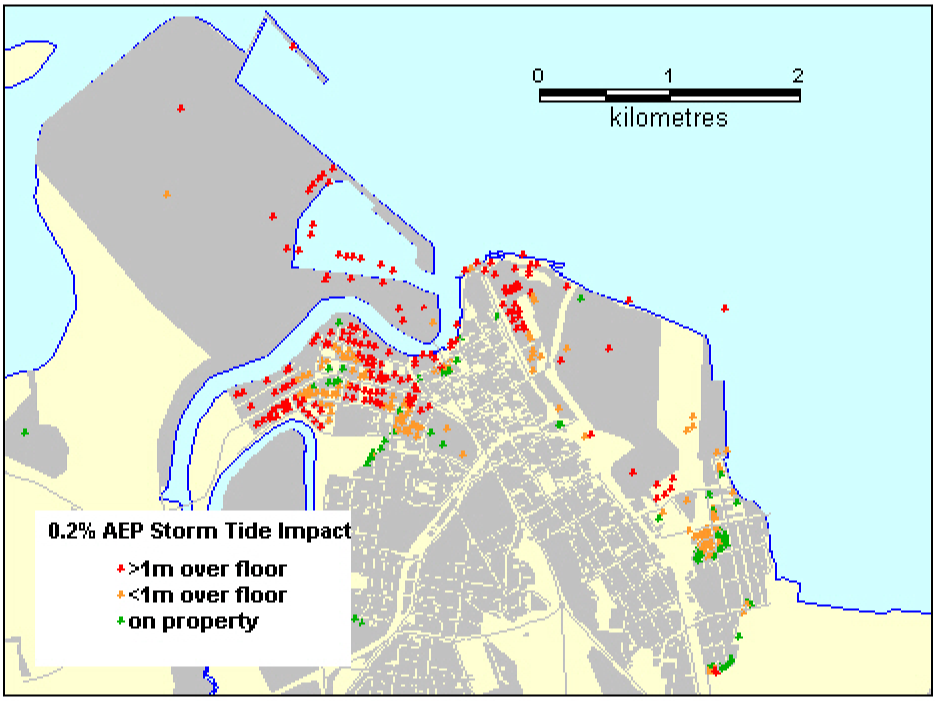

Figure 4.14 Modelled impact of a 0.2% AEP storm tide in Gladstone

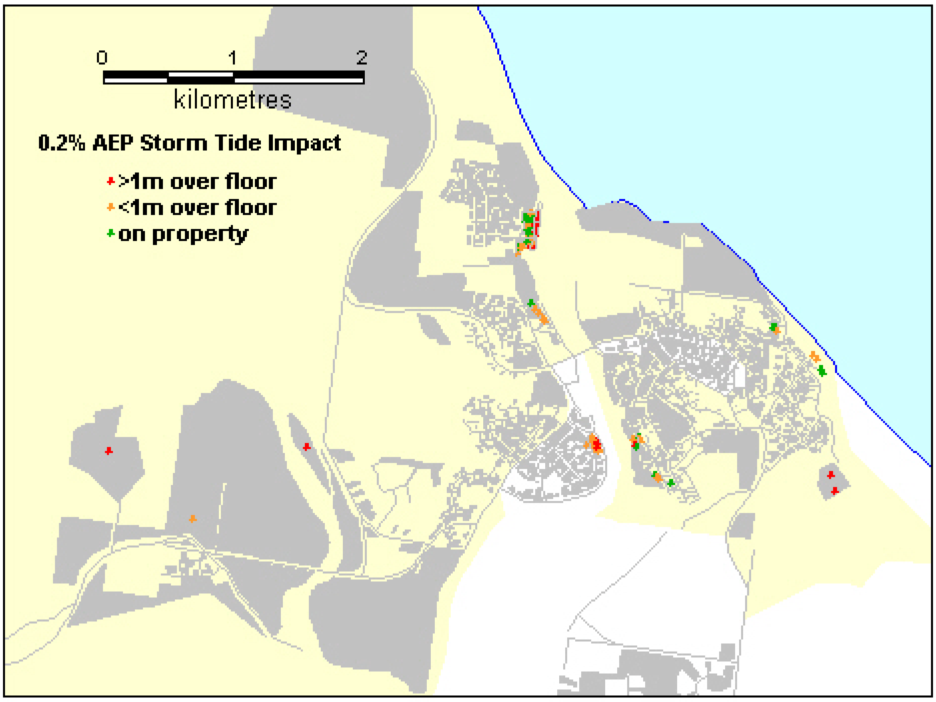

Figure 4.15 Modelled impact of a 0.2% AEP storm tide in Boyne Island and Tannum Sands

The 0.1% AEP scenario: Under this scenario, a total storm tide elevation above AHD of 4.4m would be experienced in Gladstone. The modelled impact (with all the caveats outlined above), in terms of the inundation of buildings is summarised in Table 4.13.

Table 4.13 Buildings affected by a 0.1% AEP storm tide

Level of Inundation	Gladstone
>1m over floor	250
<1m over floor	182
on property but below floor level	99
not affected	10 807

In all, 3.8% of the Gladstone area's buildings would have water over floor level under this scenario. Of the buildings and facilities with more than 1m of water over floor level, 42 are either houses or flats. The 100 or so people resident in those dwellings would have to be evacuated at least six hours before the cyclone crossed the coast to ensure their safety. A further 89 houses or flats would have water over floor level but not as deep as 1m. The 220, or so, people affected may also wish to be evacuated as a precaution.

It is likely that the Boyne Island and Tannum Sands area could be isolated for as much as six hours because of the inundation of access roads.

The impact on the town area is shown in Figure 4.16 and the Boyne Island/Tannum Sands area in Figure 4.17.

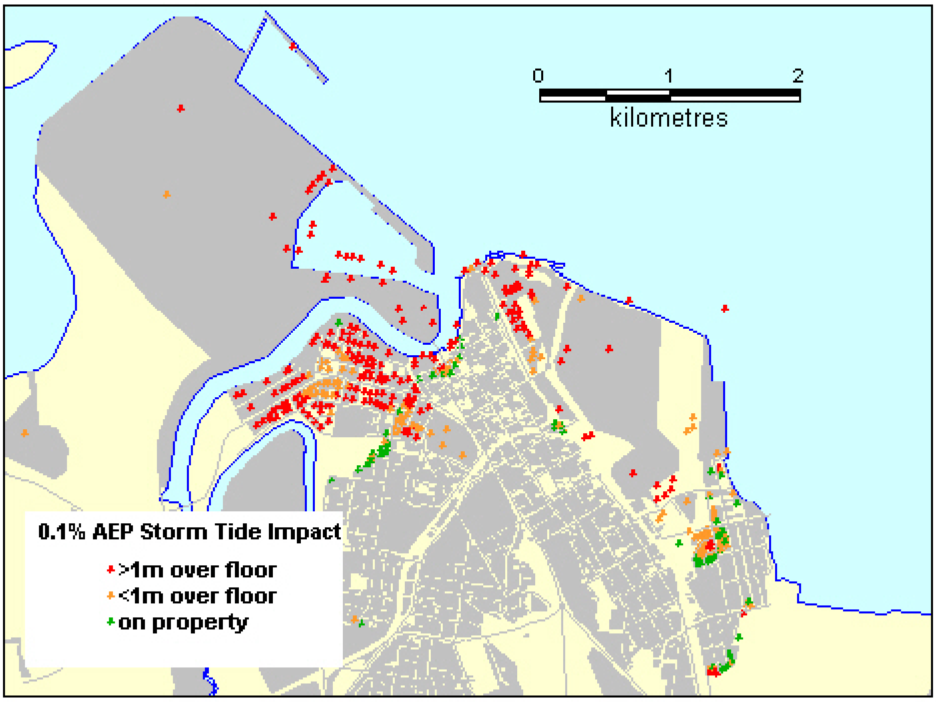

Figure 4.16 Modelled impact of a 0.1% AEP storm tide in Gladstone

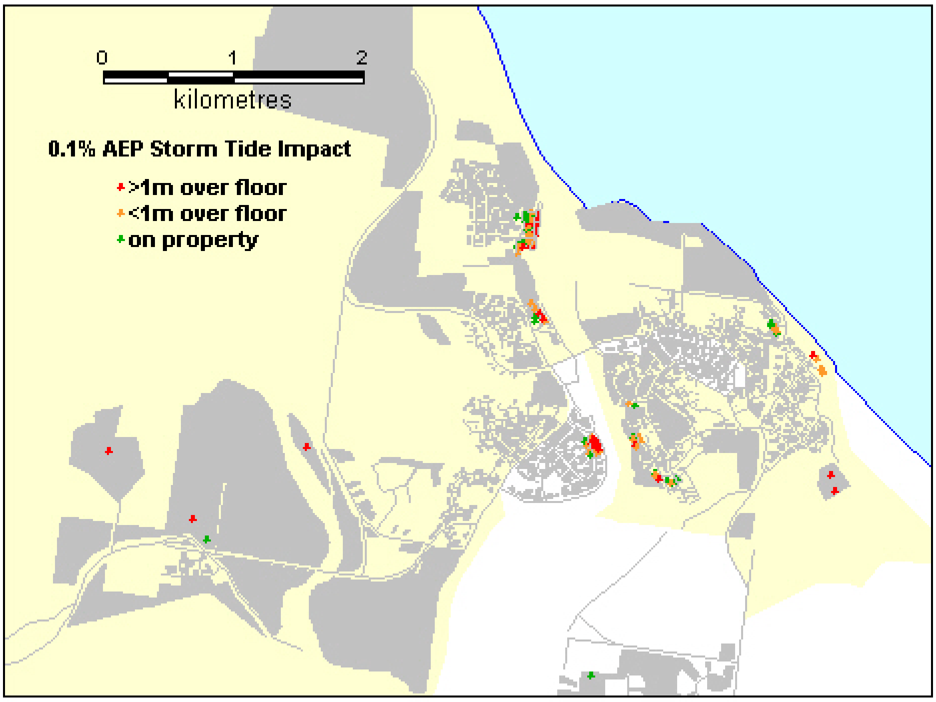

Figure 4.17 Modelled impact of a 0.1% AEP storm tide in Boyne Island and Tannum Sands

The 0.01% AEP scenario: Under this scenario, a total storm tide elevation above AHD of 5.3m would be experienced in Gladstone. The modelled impact (with all the caveats outlined above), in terms of the inundation of buildings is summarised in Table 4.14.

Table 4.14 Buildings affected by a 0.01% AEP storm tide

Level of Inundation	Gladstone
>1m over floor	414
<1m over floor	200
on property but below floor level	129
not affected	10 595

In all, 5.4% of the area's buildings would have water over floor level under this scenario. Of the buildings and facilities with more than 1m of water over floor level, 120 are either houses or flats. The almost 300 people resident in those dwellings would have to be evacuated at least six hours before the cyclone crossed the coast to ensure their safety. A further 161 houses or flats would have water over floor level but not as deep as 1m. The 400, or so, people affected may also wish to be evacuated as a precaution.

It is likely that the Boyne Island and Tannum Sands area could be isolated for as much as six hours because of the inundation of access roads.

The impact on the town area is shown in Figure 4.18 and the Boyne Island/Tannum Sands area in Figure 4.19.

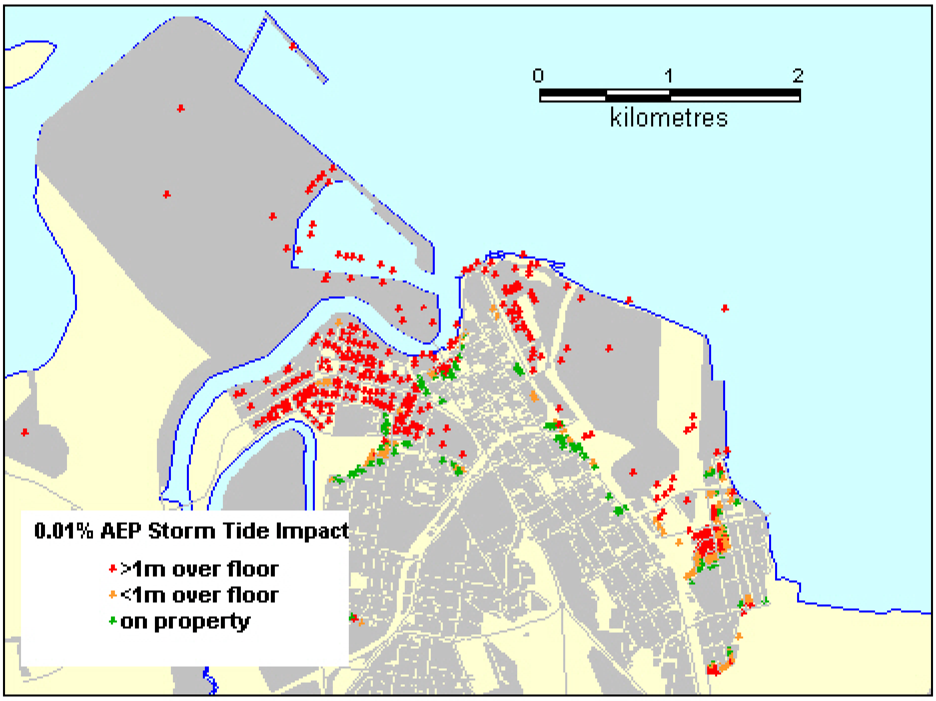

Figure 4.18 Modelled impact of a 0.01% AEP storm tide in Gladstone

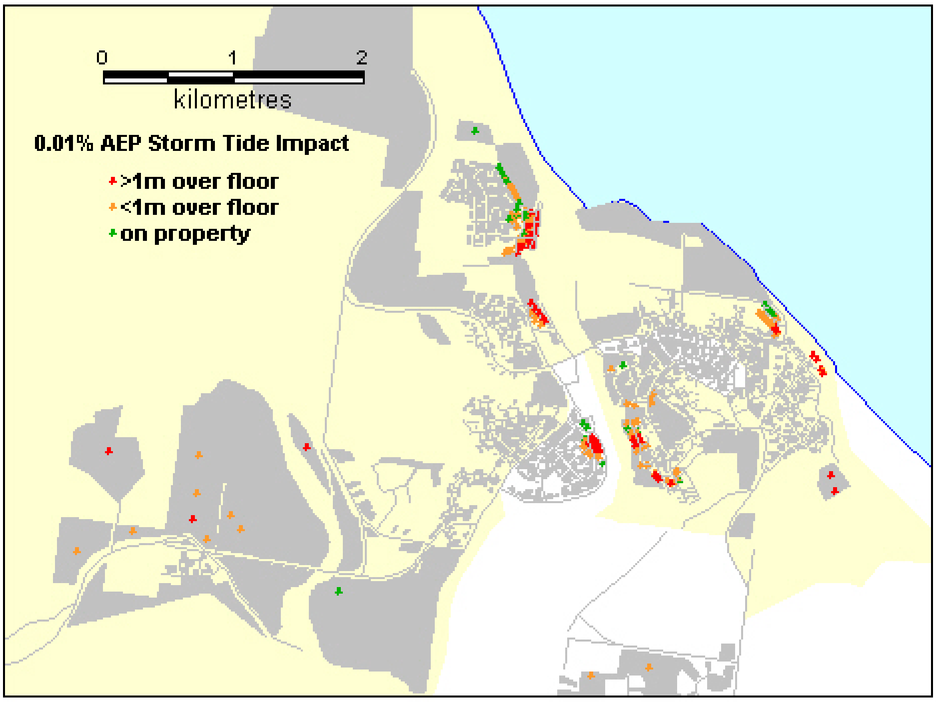

Figure 4.19 Modelled impact of a 0.01% AEP storm tide in Boyne Island and Tannum Sands

<u>Comparative storm tide risk</u>: It is clear that the impact of storm tide on Gladstone is potentially very serious, especially for the port facilities and industries that rely on them.

An analysis of the function of properties affected under each scenario reveals that the logistic, transport and storage facilities have the greatest per capita exposure at all event levels. This can, to some extent, be accounted for by the number of transport facilities such as marinas and port facilities that are at the water's edge, or are located close to or within the port area. Business and industrial facilities also carry a high exposure, again because of the concentration in the Auckland Creek industrial area. The figures provided in Table 4.15 for each class of function are the percentages of all developed properties in Gladstone, within each functional class, that would have water of any depth over floor level.

Table 4.15 Percent of properties, by function, affected by over-floor inundation in each scenario

Function	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
Houses	0.3	0.4	0.9	1.2	2.6
Flats	0.2	0.2	1.4	2.6	5.9
Commercial accommodation	3.2	4.8	8.1	11.3	21.0
Business & industry	16.8	19.8	28.1	31.0	33.4
Logistic, transport & storage	46.2	48.6	47.8	59.0	62.4
Public safety & health	2.0	2.0	2.0	2.0	2.0
Community, education & sport	6.3	6.6	9.4	11.0	13.0
Utilities	3.8	5.7	13.2	18.9	24.5

The low per capita proportions of houses and flats masks the fact that domestic properties are, by far and away, the largest numbers of buildings, in absolute numbers, that would be inundated above floor level.

To provide a more direct comparison between the potential damage from wind and storm tide we have calculated the damage to domestic buildings across the five scenarios. In calculating storm tide damage to buildings we have applied the stage damage curve developed for river flooding in Australia by Prof. Russell Blong of Macquarie University (Russell Blong, NHRC, Macquarie University, personal communication, 2001). In applying this stage damage curve we have made an assumption that the level of damage caused by sea water inundation will be higher than that for fresh (if muddy) water with the result that the damage levels are:

for water on the property but not over floor level	0.9% damage
for water less than 1m over floor level	28.0% damage
for water more than 1m over floor level	49.2% damage

The results are given in Table 4.16.

Table 4.16 Total expected level of storm tide damage to domestic buildings with respect to replacement/repair costs (equivalent numbers of buildings with 100% damage in parenthesis)

2.0% AEP	1.0% AEP	0.2% AEP	0.1% AEP	0.001% AEP
0.07% (7.6)	0.1% (11.1)	0.3% (30.9)	0.4% (44.8)	1.0% (101.5)

It should be noted that in a severe cyclone, building damage may occur from both severe wind and storm tide during the same event. A building would typically be damaged by severe wind prior to any storm tide damage. The damage estimates presented in Table 4.9 and Table 4.16 assume that a building will be damaged only by severe wind **or** by storm tide. It is not appropriate to simply add the two damage figures to represent the 'total' damage from a cyclone.

The distribution of storm tide damage to all buildings is shown in Figure 4.20 and for dwellings only is shown in Figure 4.21.

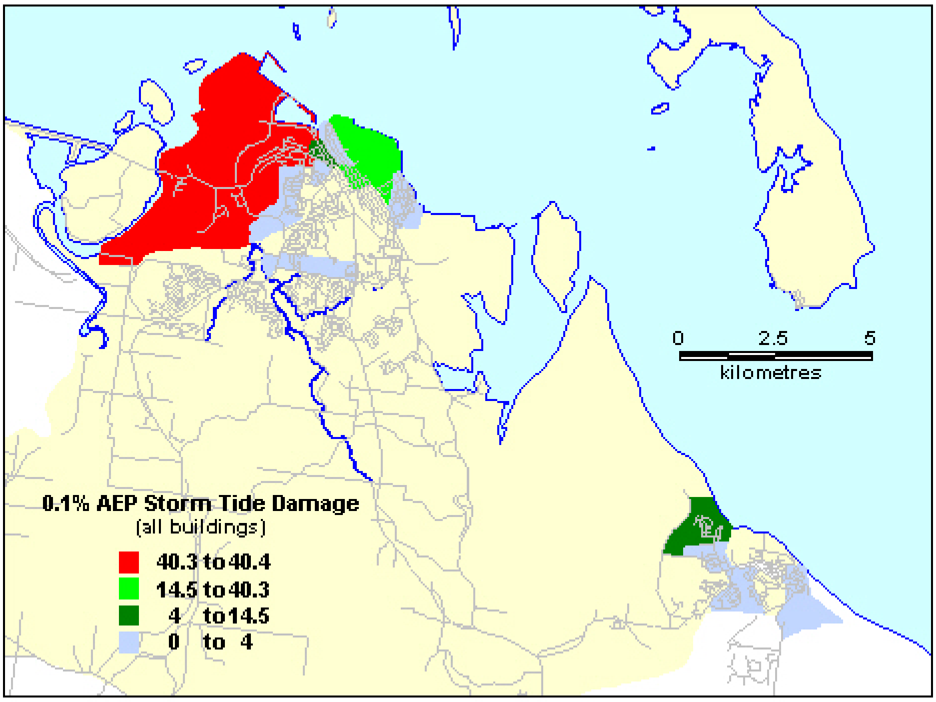

Figure 4.20 Modelled storm tide damage for all buildings for a 0.1% AEP event

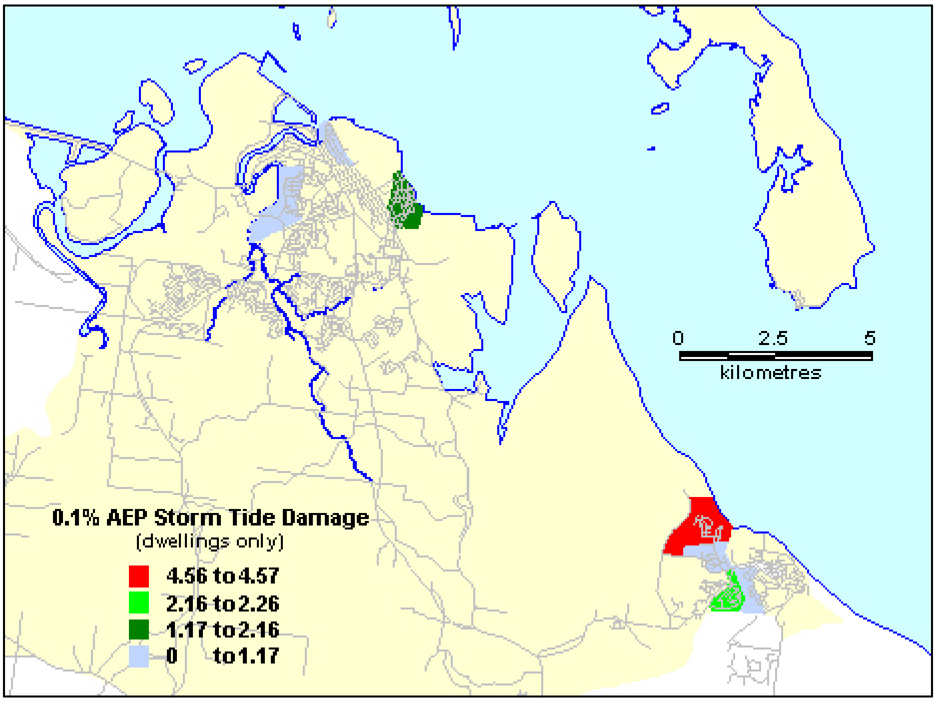

Figure 4.21 Modelled storm tide damage for dwellings only for a 0.1% AEP event

Climate change and sea level rise: All of the statistics contained in the above scenarios are based on current sea levels and climate. As indicated earlier in this chapter, the climate change models developed since the mid 1980s indicate that global warming and consequent sea level rise will occur as the result of the so-called 'Greenhouse' effect. The most recent estimates published by the IPCC indicate that, under 'business as usual' Greenhouse gas regimes, by 2100, sea level globally will have risen by between 20 cm and 80 cm, with a best estimate of 50 cm. There is some suggestion in the international literature, however, that the Australian region will be at the lower end of this scale. The impact of an increase in sea level on storm tide inundation in Gladstone, based on the current extent of development and assuming that there is no change to cyclone recurrence and intensity, is shown in Table 4.17.

Table 4.17 Gladstone properties affected by over-floor inundation under different sea level estimates

Sea Level	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
Current sea level	212	247	371	432	614
Low estimate (+0.2 m)	270	310	438	494	692
Best estimate (+0.5 m)	329	376	494	587	773
High estimate (+0.8 m)	398	438	587	654	854

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

Risk Assessment

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

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

The 0.1% AEP wind risk represents the product of the number of dwellings exposed and the vulnerability index (described in Chapter 3), therefore, the higher the index number, the greater the degree of overall risk at the 'design' level of exposure. The distribution is shown in Figure 4.22.

The neighbourhoods in which the overall wind risk is greatest are located in the following suburbs (in alphabetical order):

Barney Point, Boyne Island, New Auckland, Tannum Sands and West Gladstone.

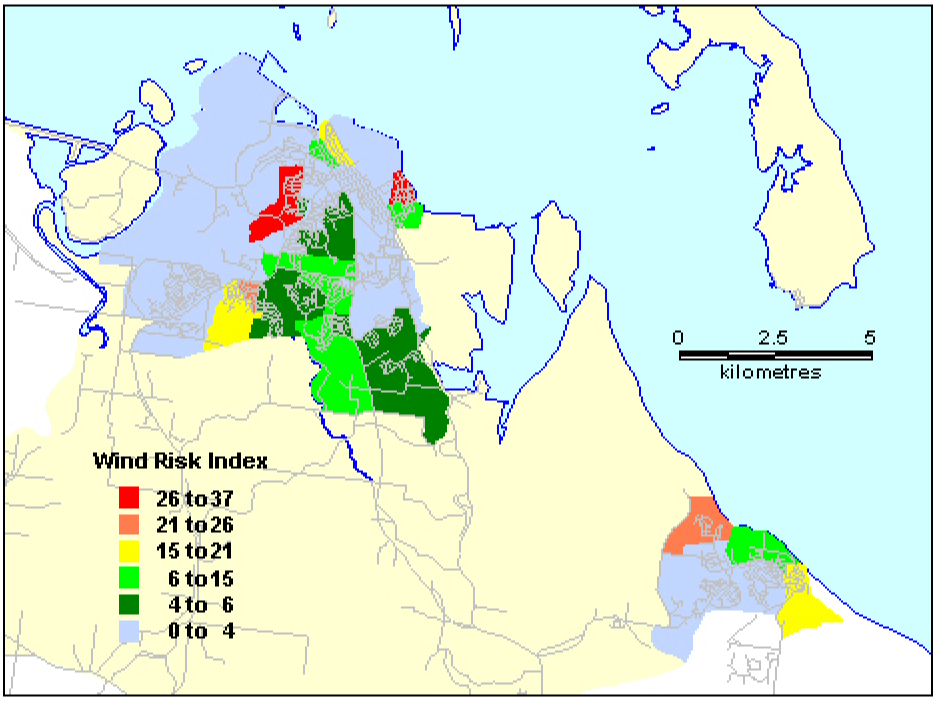

Figure 4.22 Wind risk index

Storm Tide Risk: Inundation hazards are, by their very nature, limited by topography. This is particularly evident with storm tide which is, in effect, inundation caused by a temporary increase in sea level. Where local councils in Queensland have a recognised storm tide risk in the area they have established, or are moving to establish, the 100 year ARI storm tide level for their planning threshold. This, then can be used as the 'design' level against which community risk can be measured. The index using the damage to all buildings for a 1% AEP storm tide is shown in Figure 4.23 and the dwellings-only risk index is shown in Figure 4.24.

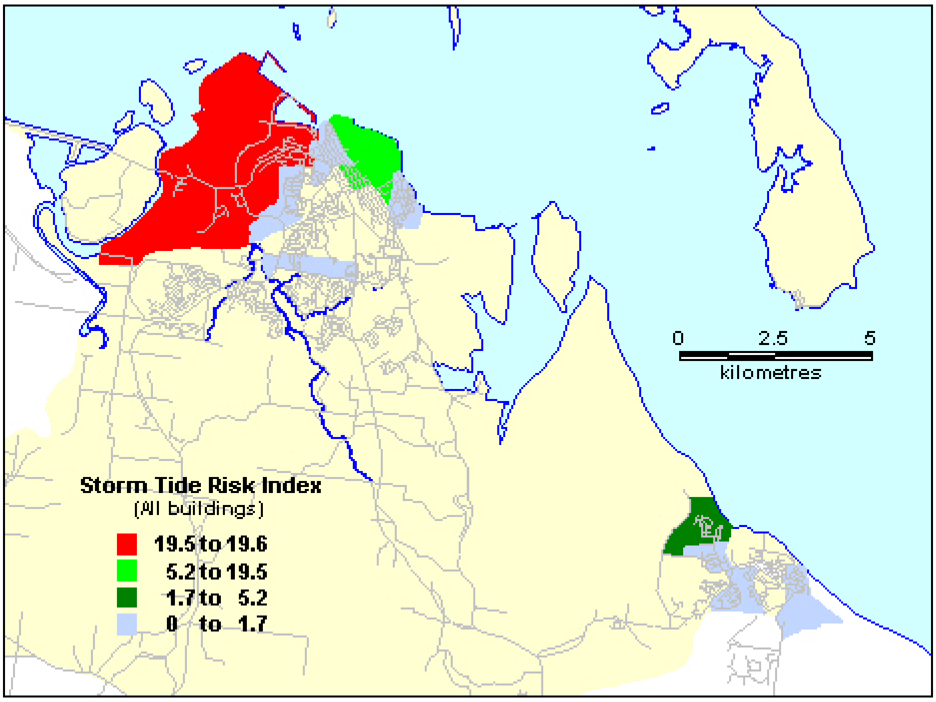

Figure 4.23 Storm tide risk index using all buildings

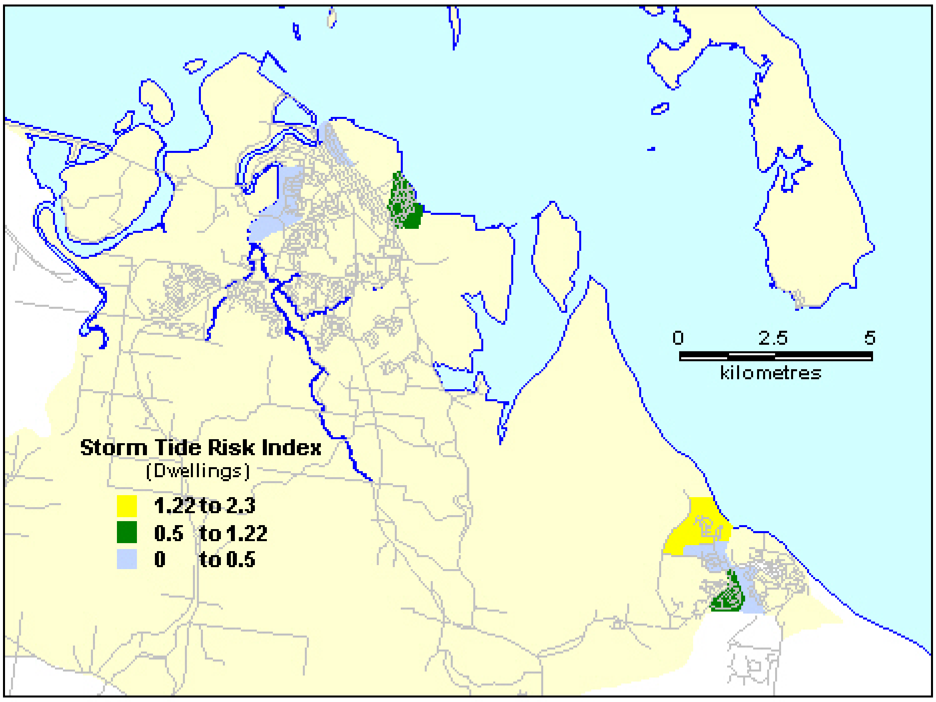

Figure 4.24 Storm tide risk index using dwellings only

The Callemondah area, with its concentration of key transport and logistic facilities on low-lying filled land, together with its high vulnerability index, clearly has the greatest level of risk when all buildings are taken into account. Next in line are the Barney Point port area and the Boyne Island areas. These are the two most significant CCD from an economic resources perspective and amongst the most important in Queensland.

When only dwellings are taken into account the level of the index drops significantly (from 19.6 to 2.3), which indicates a relatively low vulnerability contribution and a small number of buildings at risk. The northern end of Boyne Island has the highest dwellings-only risk index.

The residential neighbourhoods that have a high storm tide risk index tend to be in the areas of older residential coastal development, particularly Barney Point and the northern end of Boyne Island. These are neighbourhoods in which there tend to be more elderly people and/or people in the lower socio-economic ranges. The main cautionary note that should be made here is that **sea water inundation is not** (as a general rule) **an insurable risk** and even the residents of the more expensive neighbourhoods at risk of storm tide inundation could suffer a significant economic loss.

Community Awareness

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

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

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

Cyclone Forecasting and Warnings

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

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

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

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

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

Further Information

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

CHAPTER 5: EARTHQUAKE RISKS

Marion Michael-Leiba, Trevor Jones and Ingo Hartig

The Earthquake Threat

On 28 December 1989, Newcastle was shaken by a Richter magnitude (ML) 5.6 earthquake. Thirteen people died, around 150 were injured, and the insurance loss was almost $1 billion. The question is, are earthquakes of this size a rare event in Australia? Potentially damaging earthquakes have happened in all States of Australia. On average, 22 earthquakes per year with Richter magnitudes of 4.0 and above occur in Australia and its continental shelf. A ML 4.0 earthquake can be expected to cause minor damage if it happens under a populated area.

Earthquakes with the magnitude of the Newcastle earthquake or larger, happen on average at a rate of one per 16 months in Australia and its continental shelf, so they are *not* rare events. The great damage done by the Newcastle earthquake was because it occurred under a city where many buildings were old or not built to withstand earthquake shaking. Many were built on soft soil that amplified the shaking.

A potentially highly damaging ML 6.0 or greater earthquake can be expected to happen on average at a rate of once every 7 years, when foreshocks and aftershocks are excluded from the calculations. However, it must be remembered that the rates of occurrence, given above, of earthquakes of various magnitudes, are average figures only. In some years, very few earthquakes of a given magnitude or greater may occur, in other years, many.

The most damaging earthquakes in Australia during the period 1950-2000 are listed in Table 5. 1.

Table 5. 1 Most-damaging Australian earthquakes, 1950-2000

Date	Location	Magnitude	Damage	
			Contemporary	2000 [1]
03/01/1954	Adelaide SA	5.4	$8.8 M	$100 M
22/05/1961	Robertson/Bowral NSW	5.6	$0.5 M	$4.7 M
14/10/1968	Meckering WA	6.9	$5 M	$39 M
10/03/1973	Picton NSW	5.5	$0.5 M	$3.2 M
02/06/1979	Cadoux WA	6.2	$3.7 M	$11 M
22/01/1988	Tennant Creek NT (3 events)	6.2, 6.3, 6.5	$1.1 M	$1.7 M
28/12/1989	Newcastle NSW	5.6	13 killed, $862 M insured damage, est. $1500 M total damage	$1994 M
06/08/1994	Ellalong NSW	5.4	$34 M	$39 M

[1] Source: Australian Bureau of Statistics Web Site, 2001

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events on the community has made them a costly natural hazard. Recent figures put the historical cost of earthquakes in context. The Bureau of Transport Economics (2001) has estimated that the direct cost of natural disasters to the Australian community in the period 1967-1999 was about $37.3 billion. Of this total, floods contributed about 28%, severe storms about 25%, tropical cyclones about 24%, and earthquakes about 13%.

With increasing urbanisation and reliance on power, water and telecommunications lifelines, Australian communities are becoming increasingly vulnerable to the impact of earthquakes.

The recorded history of earthquake activity in Queensland is brief in comparison to the time-scale of geological processes - too brief for us to obtain an accurate estimate of the true rate of earthquake activity in the area. According to Rynn (1987) the first earthquake report for Queensland was from Cape York Peninsula in 1866. Recent research, however, has brought to our attention an account of a strong earthquake felt in the Noosa area of South-East Queensland in 1862. The account vividly describes a landscape-altering earthquake, but further research is needed to validate its occurrence. This earthquake reinforces Rynn's observation that a significant proportion of the available earthquake data for Queensland has come from reports of felt earthquakes, and not from instrumental data provided by a sparse seismographic coverage in Queensland.

The Earthquake Phenomenon

Earthquakes occur when stresses in the Earth's crust 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.

On a global scale, earthquakes tend to occur in belts, surrounding quieter areas called tectonic plates. These belts of earthquakes are caused by the plates that make up the Earth's crust moving relative to one another – either grinding past one another, colliding with each other, or moving away from one another. Australia and India are on a tectonic plate moving north at a rate of 7 cm per year. This rate of movement has been measured by laser ranging. The Australian Plate is colliding with plates to the north. Indonesia, Papua New Guinea and Solomon Islands are part of this collision zone, and this is why they have so many earthquakes and volcanoes. The Himalayas are so high because they are also part of this collision zone.

The Australian continent is distant from the boundary between the Australian and Pacific plates. This narrow band of earthquake activity passes through Papua New Guinea, the South West Pacific countries and New Zealand. Gladstone is situated about 1500 km from this plate boundary. Because the tectonic plates are moving relative to one another, their interiors are getting squeezed. Most Australian earthquakes are caused by compression. Large earthquakes (ML 6.0 or greater) in Australia often produce surface faulting that looks like an overhanging step, with older rocks squeezed up over younger rocks.

AGSO runs a network of 34 permanent seismographs in Australia and the Australian Antarctic Territory. The readings from these, and recorders run by other organisations, are used to determine the locations of earthquakes, and their Richter magnitudes. To determine the location of an earthquake, the time at which the waves from it arrive at a minimum of three seismographs must be read. The earthquake location program in the computer uses these arrival times, the geographic coordinates of the seismographs, and a table of the speed at which the earthquake waves travel through the various layers of the Earth, to work out where the earthquake happened.

The Richter magnitude for a local earthquake is obtained by measuring the largest oscillation on a seismogram and putting this into a mathematical formula that takes into account the distance of the seismograph from the earthquake, because earthquake shaking tends to die out with distance. Theoretically, the Richter magnitude obtained should be the same from all seismographs, irrespective of their distances from the earthquake. In practice, the magnitudes from a number of seismographs are averaged to give the quoted figure. The Richter magnitude is related to the energy of the earthquake. A ML 6.0 earthquake has about 32 times the energy of a ML 5.0, and 1000 times that of a ML 4.0 event.

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 <u>effects</u> 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 D. This scale is useful because it is easily applied and understood, and because it can be used to extend our knowledge of earthquakes not recorded by instruments (e.g. 19th Century earthquakes). However, Modified Mercalli intensity is a coarse measure of ground shaking. It does not correlate well with instrumental recordings of strong earthquake ground shaking. Instrumental recordings usually have not been available for Australian earthquakes, although they are much preferred.

The Gladstone Earthquake Experience

Table 5.2 lists earthquakes, with ML 4.0 or greater, occurring within about 200 km of Gladstone. Since 1878, there have been 29 events recorded with Richter magnitude greater than or equal to 4.0, but the number may well be larger as there were no seismographs in Australia prior to the first decade of the 20th Century. Their epicentres are shown in Figure 5.1. Seven of these are recorded as having been felt in Gladstone (Everingham & others, 1982; Rynn & others, 1987). Two of the seven caused minor damage in Gladstone – the 1918 offshore Bundaberg and the 1953 Many Peaks earthquakes (Rynn, 2001). In addition, a magnitude 2.4 aftershock of the 3 December 1953 earthquake was felt with a Modified Mercalli intensity of II.

Table 5. 2 Historical earthquakes, with ML greater than or equal to 4.0, in the Gladstone region

Date	Time (UTC[2]) hr min	Lat (°S)	Long (°E)	Place	ML[3]	I[4]
03/03/1878	02 45	24.7	153.2	Fraser Island	4.3	
28/08/1883	16 55	25.5	151.67	Gayndah	5.6	IV
28/08/1883	18 20	25.5	151.67	Gayndah	5.0	III
15/06/1897	19 00	24.9	151.1	Monto	4.0	
24/11/1910	22 52	25.7	151.2	Mundubbera	4.7	IV
14/04/1916	06 45	24.6	152.1	Watalgan	4.0	
06/06/1918	18 14	23.5	152.5	Offshore Bundaberg	6.0	V
06/06/1918	18 15	23.5	152.5	Offshore Bundaberg	5.1	
06/06/1918	18 23	23.5	152.5	Offshore Bundaberg	5.5	
06/06/1918	19 00	23.5	152.5	Offshore Bundaberg	5.1	
06/06/1918	19 20	23.5	152.5	Offshore Bundaberg	5.7	
06/06/1918	19 45	23.5	152.5	Offshore Bundaberg	5.1	
06/06/1918	20 15	23.5	152.5	Offshore Bundaberg	5.1	
07/03/1922	16 54	23.5	152.5	Offshore Bundaberg	4.5	
12/04/1935	01 32	25.5	151.67	Gayndah	5.5	III
01/06/1935	12 12	25.5	151.67	Gayndah	4.0	

Date	Time (UTC[2]) hr min	Lat (°S)	Long (°E)	Place	ML[3]	I[4]
11/06/1947	10 03	25.48	152.7	Maryborough	4.3	
30/12/1951	20 34	25.9	151	Mundubbera	4.0	
24/06/1952	01 44	25.5	152.8	Maryborough	4.8	
03/12/1953	15 42	24.5	151.4	Many Peaks	4.0	IV
03/03/1964	06 13	25.4	151.7	Gayndah	4.5	
25/03/1964	06 14	25.3	151.4	Mundubbera	4.0	
24/12/1974	02 25	21.81	153.21	South West Cay	5.1	
28/11/1978	17 33	23.55	152.14	Heron Island	4.8	IV
28/11/1978	18 44	22.95	153.06	Coral Sea	4.5	
30/10/1984	06 29	26.31	151.96	Murgon	4.2	
08/02/1985	08 23	25.12	153.62	Fraser Island	4.7	
13/02/1998	23 20	25.70	150.62	Redbank	4.0	
02/11/1998	17 09	22.81	151.15	NE of Yeppoon	4.7	

[2] UTC = Coordinated Universal Time = Australian Eastern Standard Time minus 10 hrs; [3] ML = Richter (or local) magnitude; [4] I = seismic intensity (from published isoseismal maps) in Gladstone, measured on the Modified Mercalli Scale

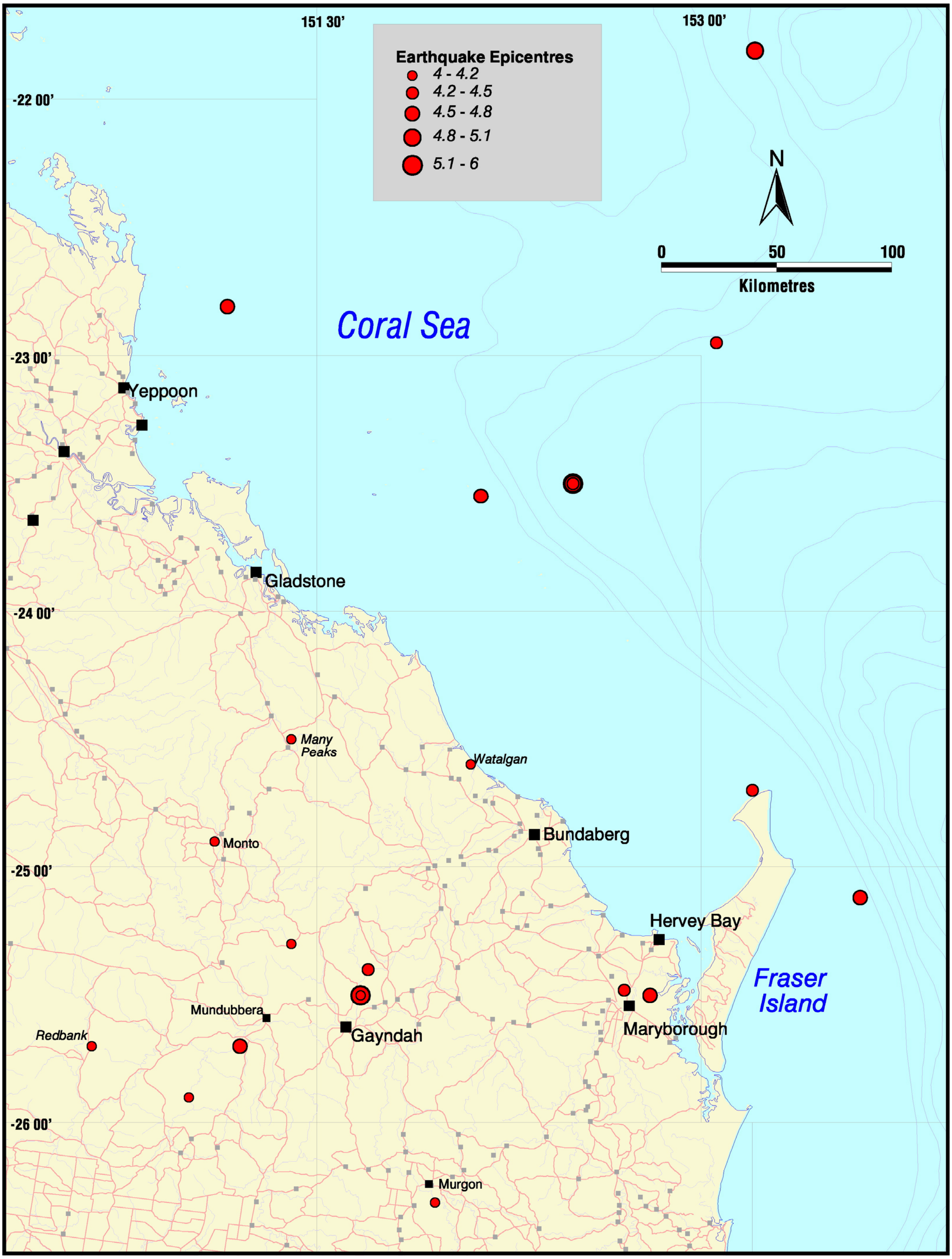

Figure 5.1 Earthquakes with Richter magnitude 4.0 or greater in the Gladstone region

Rynn (1997) gathered information on the effects of some of these earthquakes from newspaper reports and personal interviews. His findings are summarised in Table 5.3. He remarked that those earthquakes had only small effects in Gladstone.

Table 5.3 Felt effects in the Gladstone region of some significant earthquakes

Date, magnitude; & distance	Locality at which effects noted	Effects
7 June 1918; ML 6.0; 125 km from Gladstone	South Gladstone Parsons Point Gladstone City	Severe shaking of houses House shook strongly Many houses shook; crockery shaking
12 April 1935; ML 5.5; 200 km from Gladstone	South Gladstone Goondoon Street Gladstone City	Old Queenslander house shook; windows rattled; crockery in cabinet shook Severe shaking Many reports of houses and contents shaking
24 June 1952; ML 4.8; 75 km from Gladstone	Boororan	Felt shaking
4 December 1953; ML 4.0; 75 km from Gladstone	"Makowath" (14 miles from Miriam Vale)	House shook
29 November 1978; ML 4.8; 160 km from Gladstone	Gladstone City West Gladstone Wurdong Heights Boyne Island Bustard Head	Police station; felt over whole city Base hospital – woke patients Floor boards shook Felt Lighthouse - felt

Our study area is on the northern margin of the Wide Bay – Burnett earthquake zone, which is the most active earthquake area in Queensland (Gaull & others, 1990). The largest earthquakes known to have occurred in this zone were the ML 6.0 offshore Bundaberg earthquake and two of its aftershocks in 1918, and the ML 5.6 and 5.5 Gayndah earthquakes of 1883 and 1935. The offshore Bundaberg earthquake, 125 km from Gladstone, is classified as a "large" earthquake, and would have had the potential to be highly damaging if it had occurred onshore under a population centre. The two Gayndah earthquakes were of similar magnitude to the 1989 Newcastle earthquake. Earthquakes of this size can be damaging to structures built on sites that magnify their shaking. Fortunately, their epicentres were 200 km from Gladstone. All of the ML 4.0 or greater earthquakes in Table 5.2 were at least 75 km from Gladstone, and it is uncertain whether the city lies inside or outside the Wide Bay – Burnett earthquake zone.

While 15 small earthquakes, with magnitudes in the range ML 0.4-3.4, occurred within a 50 km radius of Gladstone, only one of these was less than 30 km from the city. It happened about 10 km from Gladstone on 6 December 1912, had a magnitude of ML 2.2, and was felt in the city with a Modified Mercalli intensity of III (Rynn, 2001).

Estimates of Earthquake Hazard

Earthquake hazard can be defined as the degree of earthquake shaking expected to be equalled or exceeded at a site in a given period of time. It can be expressed in terms of peak ground acceleration, peak ground velocity, or Modified Mercalli intensity. The earthquake hazard for Gladstone, although 'moderate' by global standards (Giardini and others, 1999), is relatively high for an urban centre in Australia, being only marginally lower than that for Newcastle or Adelaide.

Three estimates of earthquake hazard have been prepared for the Gladstone region. They give the reader an indication of the uncertainty in earthquake hazard assessment for this area. Each estimate relates to a 10% probability of exceedence in 50 years at 'rock' or 'firm' sites. This probability corresponds to an AEP of approximately 0.2% (an ARI of 475 years). The first of these estimates of hazard is found in *AS1170.4-1993* and its replacement, the draft *AS/NZS DR 00902* (Standards Australia, 2001). An 'acceleration coefficient' of 0.096 for Gladstone was read from the Queensland earthquake hazard map in the standard. This value is equivalent to a peak horizontal ground acceleration (PGA) of 0.096 g, where 'g' is the acceleration experienced at the earth's surface under gravity. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993* has an acceleration coefficient in the range 0.05 - 0.1. The coefficient values across Australia range from a minimum 0.03 ('low' globally) to highs of up to 0.22 ('moderate' globally) in 'bullseye' areas.

The second of these estimates originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). We estimate a higher PGA of around 0.12 g on rock from their hazard map, consistent with their estimates of PGA for Queensland being higher than previous estimates.

The third of these estimates is found in the work of Gaull and others (1990). The earthquake hazard maps in *AS1170.4-1993* were derived from this work. We estimate a PGA value of 0.07 g for Gladstone from their hazard map.

Effect of Site Conditions

Site factors: In addition to the regional earthquake hazard represented by, for instance, the state-wide hazard maps in *AS1170.4-1993*, earthquake hazard can vary considerably across a city, primarily because of local site geology. This effect has been responsible for the concentration of damage in many earthquakes, including the 1989 Newcastle earthquake, the 1989 Loma Prieta (California) earthquake and the 1995 Kobe (Japan) earthquake. In Kobe the focussing of seismic waves at the edge of a geological basin may also have had a significant role in producing the strongest shaking. Ground shaking recorded from these earthquakes and others indicates that the localised earthquake hazard can vary by a factor of two or more depending on site conditions, being higher on soft sediments than on rock.

The way in which amplification of earthquake shaking varies with the nature of the rock or soil is shown in Table 5.4. For example, if the amplification factor is 2.0 on site class D, then the shaking from an earthquake experienced on site class D will be double what it would have been on rock. The reason for the range of amplification factors on a single site class is that they vary with the strength of the earthquake shaking and speed of the vibration as well as with site class.

Table 5.4 Variation of amplification of earthquake shaking with softness of the rock or soil

Site class	Description	Amplification factors
A	Hard rock	0.8
B	Rock	1.0
C	Hard and /or stiff/very stiff soils; mostly gravels	1.1 – 1.7
D	Sands, silts and/or stiff/very stiff clays, some gravels	1.2 – 2.4
E	Profile containing at least 3 m of soft/medium stiff clay	1.2 – 3.5

Although there are some bore holes in Gladstone, there are insufficient geotechnical data to enable a site class map, based on surface geology and geotechnical data, to be produced for the study area at this stage. The rock in the study area, however, would be chiefly site class A or B. The soft sediments would be expected to be site classes C, D or E, but in certain areas they may be so thin that they would be removed for building construction, or have negligible effect. In this case, the site would behave as though it were a rock site. The soft sediments in the Gladstone area include varying proportions of sand, silt, mud and gravel, as land fill, alluvium, tidal flats, beach ridges, sand dunes, delta sands, sand spits, residual soil, and colluvium (clay, gravel, scree). The distribution of rock, naturally-occurring soft sediments and land fill in the study area is shown in Figure 5.2.

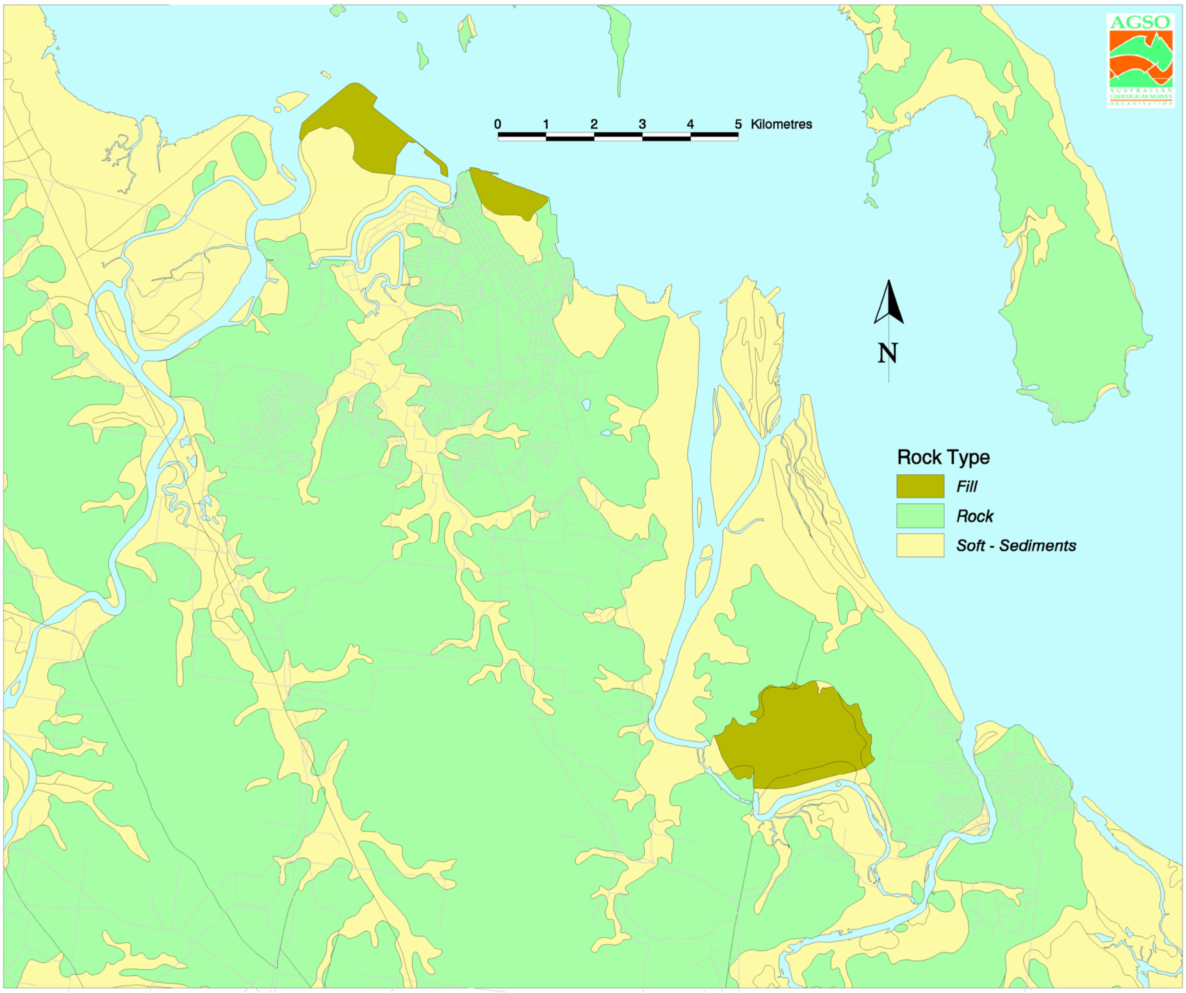

Figure 5.2 Gladstone earthquake site conditions

Microtremor measurements of natural period of vibration of the ground: A convenient way of assessing the likely behaviour of soils in various parts of a city during an earthquake is by recording microtremors - the ever present vibrations of the ground due to wind, surf, traffic, etc. The advantage of using microtremors is that you do not have to wait for an earthquake to record useful data. By analysing the microtremor recordings you can identify sites that will amplify earthquake shaking at a certain rate of vibration, and also the fundamental period of vibration at which this will happen. The period of a vibration is the time taken for one complete oscillation. A thin layer of alluvium overlying bedrock has a shorter period of vibration, for example, than a thick layer of alluvium. Similarly a low building generally has a shorter natural period of vibration than a tall building.

It is important to know the period of vibration of the ground. If it matches that of a building above it there is a resonant effect, much like a person pushing a swing higher and higher by matching the push to the moving swing. The resonance effect increases the likelihood of a building being damaged in an earthquake.

The microtremor measurements in this survey were made using a three-component seismometer and a digital recorder. Computer analysis was done using the Nakamura (1989) method. This involves computing the spectral ratios of each of the horizontal components (north-south and east-west) of ground motion relative to the vertical component. This technique has been found by many seismologists to give a realistic estimate of the dominant period of a site from microtremors, when compared with the results from earthquakes.

Figure 5.3 shows the sites at which measurements were made, and the natural period of the sediments and rock, contoured automatically from the natural period values at the microtremor sites. A value of 0.1 seconds was assigned arbitrarily to sites for which no natural period was obtained, so only values of 0.2 seconds or greater were contoured. Areas outside the 0.2 contour either have no natural period at all, or else one of less than 0.2 seconds.

A comparison of Figures 5.2 and 5.3 shows a broad correlation between areas interpreted as having natural periods of 0.2 seconds or more and areas of soft sediment, including fill. However, there are areas mapped as rock that appear to have a natural site period. This may be because of deep weathering of the rock, inappropriateness of the contouring of the natural period in that area, or discrepancies in the geological mapping. There are also isolated areas of soft sediment that do not seem to have a natural period. A possible explanation is that the sediment is very thin in that area. Another reason for anomalies in the microtremor results could be that the sediments are not in uniform horizontal layers, or that the upper surface of the underlying rock is not horizontal, as this type of layering is an assumption in the technique.

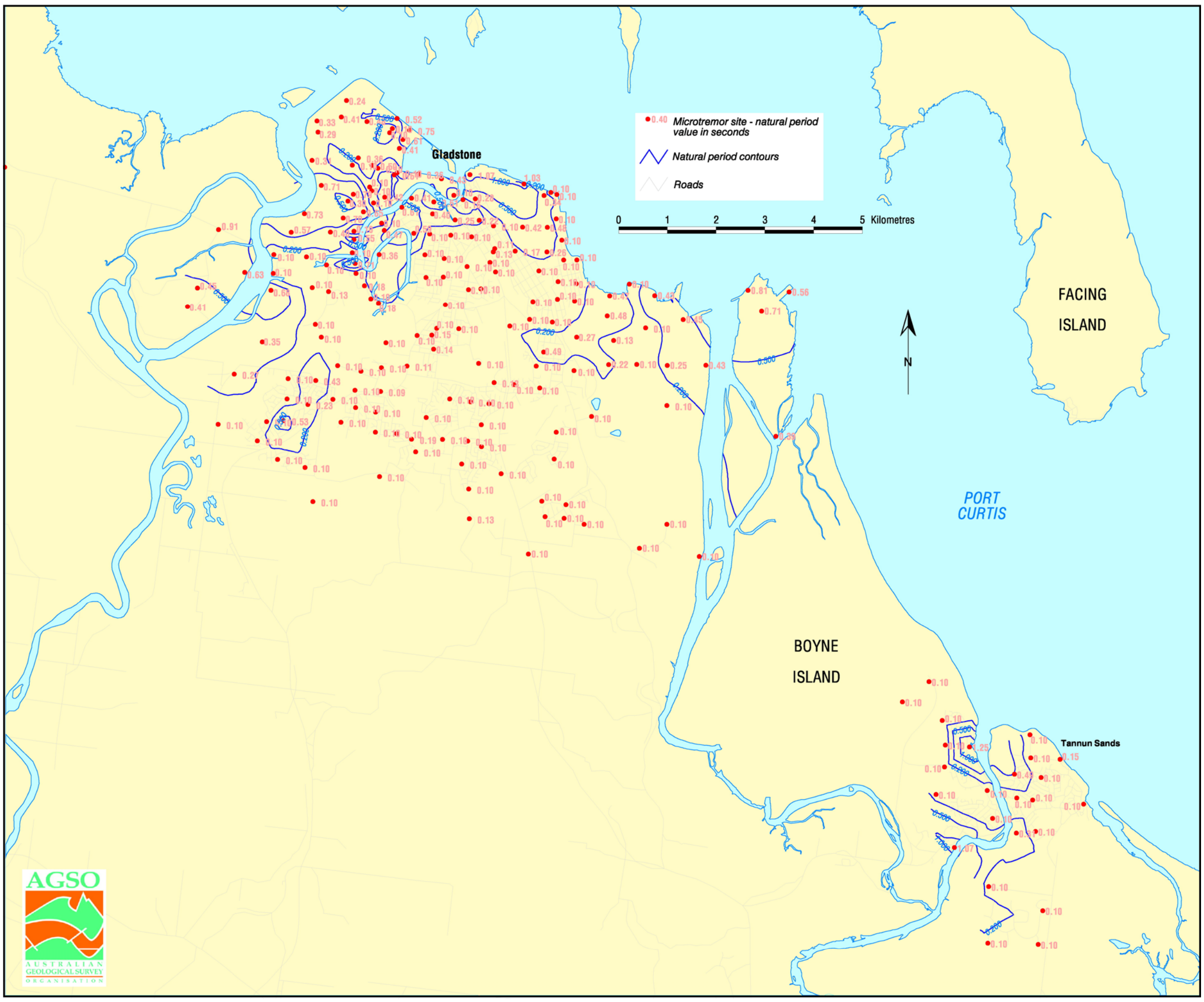

Figure 5.3 Gladstone microtremor recording sites and natural period

The measurements of natural period will also be useful in any future site investigations for earthquakes in Gladstone. First, the draft earthquake loading standard, DR 00902, proposes soil site classes that are categorised by natural period. Second, the measurements of natural period, when combined with data on the thickness of soils, can be used to estimate seismic shear wave velocities in the soils. Seismic shear wave velocity is a key parameter in models of site behaviour in earthquake shaking.

Earthquake Risk

Our approach to assessing risk is discussed in Chapter 1. In this approach we seek to assess the *total risk* faced by the community (i.e. the interaction between the hazard phenomenon, all of the elements at risk in the community and their respective levels of vulnerability). Total risk should encompass direct dollar losses, number of deaths, injuries or other trauma, and indirect losses, e.g. the costs to external communities from disruption to economic supply and demand. From an assessment of the type of critical facilities that may be damaged in an earthquake, the effect of the event on the entire community can also be gauged.

Unfortunately we have insufficient data at this stage to estimate earthquake risk for the study area. To do this, we would need to be able to produce a reliable earthquake hazard map, taking site conditions into account. The information that would need to be gathered for the earthquake hazard map includes:

- the nature of the soft sediments;
- the depth of the soft sediments;
- the amount and depth of weathering of rock; and
- more microtremor measurements.

Some comments relevant to risk follow, but they must ***not*** be construed as an earthquake risk assessment.

<u>Buildings/structures on potentially unfavourable sites</u>: From our building database and the geological map, it is possible to ascertain the number and percentage of existing buildings and structures on land that are situated on rock, land fill, or naturally-occurring soft sediments (Table 5.5). The soft sediments and fill would usually tend to amplify earthquake shaking, increasing the likelihood of damage to structures built on them.

Table 5.5 Number of buildings/structures on rock, fill and soft sediment

Foundation material	Number of buildings	Percentage of buildings
Rock	10624	93.6
Land fill	31	0.3
Soft sediments	692	6.1

While the microtremor measurements suggest that there is a minority of rock sites where amplification of earthquake shaking may take place, and also a small number of fill and soft sediment sites where there is no amplification of earthquake shaking, the statistics in Table 5.5 indicate that less than 10% of the buildings and structures in the study area would be expected to suffer amplification of earthquake shaking due to site effects.

The vulnerability of a community may depend not only on the number of buildings at risk but also on the proportion of buildings in certain categories that are likely to be adversely affected. Table 5.6 shows the number of buildings or facilities according to their function, situated on rock and on soft sediments or land fill. In terms of absolute numbers, detached houses and then businesses are the two most common categories on soft sediments or fill. The percentages on soft sediments or land fill are given in Table 5.7. The building function classifications are discussed in Chapter 3.

Table 5.6 Categories of buildings on rock and on soft sediments

Building category	Number situated on rock	Number situated on soft sediments or land fill
Houses	9359	469
Flats	414	9
Commercial accommodation	58	4
Business + industry	345	148
Logistics + storage & transport	112	51
Public safety + health	50	1
Education	98	2
Community + government + recreational facilities	124	30
Utilities (power + water)	38	8
Telecommunications	6	1

Table 5.7 Percentage of buildings/structures on soft sediments or land fill

Category	Percentage of that category on soft sediments or fill
Houses	5
Flats	2
Commercial accommodation	6
Business + industry	30
Logistics + storage & transport	31
Public safety + health	2
Education	2
Community + government + recreational facilities	19
Utilities (power + water)	17
Telecommunications	14

Structures vulnerable because of their construction: Some structures have an increased vulnerability to earthquake shaking because of their age, design, the way that they have been constructed or the materials used. They may not have been designed to survive the *horizontal* accelerations experienced in a earthquake, although design for wind loadings offers some protection..

In general, flexible structures, tied together properly at the edges and corners, fare better in earthquakes than brittle structures do. For example, a well-built weatherboard building with a corrugated iron roof will tend to do better in an earthquake than a similar building of unreinforced brick or masonry. A properly reinforced building will usually come through an earthquake better than an unreinforced building. For example, a brick veneer building will tend to fare better than a solid brick one of similar design, though the bricks may peel off the timber frame if the shaking is sufficiently intense. The many houses in Gladstone with fibro walls could also be expected to suffer more (superficial) damage that houses clad with timber or brick veneer.

If a vertical structure, anchored only at its base, is shaken, the amount of displacement in each oscillation is greater the higher you go up the structure. Thus, the shaking at the top of a column during an earthquake is much more extreme than at its base (the inverted pendulum effect). This phenomenon could have great significance in Gladstone. In all of the major power supply switching yards and substations, for example, there are many vertical ceramic insulators that are topped by a mass coil. Less significantly perhaps, but similarly, high set 'Queenslander' houses, especially if no longer tied properly on to their poles, or if their piles are not braced, could also suffer in an earthquake because of the inverted pendulum effect.

Interpretation

Because we have insufficient information at present to undertake an earthquake hazard and risk assessment of the study area, it is not possible to estimate the effects on the community of various earthquake scenarios. Table 5.3 indicated that reasonably strong shaking was experienced from the ML 6.0 'Bundaberg' earthquake in 1918, even though it was 125 km away. An earthquake of similar magnitude close to Gladstone would probably cause some damage and economic disruption.

Fortunately, less than 10% of the structures in the study area are built on soft sediment or land fill, both of which *may* amplify earthquake shaking. Most of the existing major industrial facilities are located on rock foundations. These include the Boyne Smelters, and nearly all structures of the Queensland Alumina Refinery. The major NRG electric power generation plant is also located on a rock foundation.

The scope of this report does not permit an exhaustive or detailed discussion of individual facilities that may be on sites where amplification of earthquake shaking could take place. However, the following paragraphs allude to some facilities and categories of facilities where this *may* be a problem.

The categories that have the highest percentages on fill or soft sediments are the logistics, storage and transport group (31%) and the business and industry group (30%). These are mostly concentrated on the reclaimed land along Auckland Creek, in the marina area or in the Barney Point port area. Given their age, most of the facilities may have been constructed to the requirements of the Australian Building Code for earthquake loads.
The absolute number of buildings is also high; 148 business and industry and 51 logistic, storage and transport facilities are on fill or soft sediment.

The logistics category includes the bulk fuel and gas depots concentrated in the Port area. These supply consumers in a region extending beyond the study area, so earthquake damage could have regional repercussions. Also in this group are the bulk handling facilities, such as the coal, bauxite and alumina loaders. Should these structures be damaged in an earthquake the impact on the Gladstone industries (and consequently the economy) would be significant, even if the industrial facilities themselves, such as the alumina refinery, were unaffected. A similar impact could be experienced if the rail lines from the coal fields were damaged or the power reticulation infrastructure were damaged. In the Newcastle earthquake, for example, the power supply was disrupted for 3 hours and in that time one pot in the Tomago aluminium smelter was lost.

A much more detailed investigation, than is possible within the scope of this report, would be necessary to assess the effect on the Gladstone region's economy, and the economics of its suppliers and customers, if the businesses on soft sediments or fill were unable to operate due to earthquake damage.

Given that the vast majority of dwellings are located on firm ground and are of flexible, timber frame construction, the likelihood of casualties, even in a strong earthquake, is probably quite low. An earthquake that struck during a working day, however, could produce casualties because many of the businesses in the CBD area and some of the older schools are of a solid brick construction that would be more susceptible to damage. However, it is fortunate that the CBD and most educational facilities are situated on rock.

Limitations and Uncertainties

There is an inadequate coverage of microtremor recordings and borehole data over the study area by which to produce a natural period map of the entire area, or a reliable earthquake shaking amplification factor map. It is not possible at this stage, therefore, to undertake an adequate earthquake hazard and risk assessment of the study area. This is especially the case in the important areas of fill on which much of the industrial and port facilities have been built.

We have not conducted any investigations in the Yarwun and Aldoga areas into which the future growth of industry will be concentrated. It would be prudent for such an investigation to be carried out as part of the development planning process.

Community Preparedness

It is not possible at present to forecast earthquakes in the study area. The most useful aid to preparedness would be

- a reliable earthquake hazard and risk assessment;
- assessment of the earthquake resistance of critical and hazardous facilities, and retrofitting if necessary; and
- education of the community in what to do before, during and after an earthquake (see the Earthquake Action Guide - Appendix E).

Community awareness is an important tool in mitigating the effects of an earthquake. Earthquake drills are quick and inexpensive. If school children were given earthquake drill on a regular basis, then they would know as a reflex action what to do in an earthquake. It could save their life, should they get caught in an earthquake anywhere in the World.

Future Research Needs

More data would be needed, than we have at present, to produce a reliable earthquake microzonation map for Gladstone and surrounds akin to those produced by AGSO for Launceston (Michael-Leiba and Jensen, 1997), Cairns (Granger and others, 1999), the ACT (Jones and others, 1999) and Mackay (Middelmann and Granger, 2000). A copy of the Launceston material, for example, is included as Appendix F. Such mapping would be useful in enabling planning authorities to identify areas in which site specific geotechnical investigations are required to ensure that engineering designs take adequate account of the potential earthquake loads.

A lot more work is required to ascertain the vulnerability of lifeline infrastructure in Gladstone. Of particular concern are the power and water reticulation networks. Dislocation of either for an extended period would have very serious consequences. Such a study would require detailed engineering investigation at the facility level. Such detailed work was not possible under this reconnaissance-level study.

CHAPTER 6: MINOR HAZARDS

Ken Granger, Bruce Harper and Marion Michael-Leiba

Introduction

The Gladstone community faces a range of natural hazards other than tropical cyclones and earthquakes. These hazards, however, pose only a limited threat to people and property. The following discussions, however, will provide an overview of the risks posed to the Gladstone community by severe thunderstorms, flood, landslide, heat wave and bushfire.

Severe Thunderstorms

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

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

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

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

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

<u>Genesis</u>: Thunderstorms typically occur when dense cold air overlies warm moist air and uplift is initiated by one of several possible factors such as solar heating, orographic (topographic) effects or fronts and troughs (BoM, 1995a). Strong localised upward currents of air can develop as the heat energy stored in the moist warm air is converted to kinetic energy high in the clouds. During this process, condensation of the moist air occurs at altitude, together with separation of positive and negative electrical charges, leading to the generation of lightning. Hail is formed by the freezing of raindrops at very high levels. These are then thought to grow steadily in size while being recirculated

throughout the storm by powerful updrafts and downdrafts. When the weight of the circulating water and ice can no longer be supported by the updrafts, they fall to earth in concentrated shafts, dragging the surrounding air downwards and causing strong 'downburst' winds at the surface. When conditions are favourable, mature thunderstorms can form in very short periods of time and have highly organised motion comprising complementary up- and down-drafts. Sometimes, practical warnings for such events are not possible.

The most common type of thunderstorm is termed the *ordinary* cell, which is limited in size and lifetime, but can produce short bursts of severe weather. *Multi-cellular* storms are more persistent and larger in impact, formed by successive cell generation on the forward left flank, allowing them to move transverse to the prevailing wind and to present a broader impact front. Several other variants also exist, but the most dangerous form is termed the *supercell* thunderstorm, which is schematically illustrated in Figure 6.1 (BoM, 1995b).

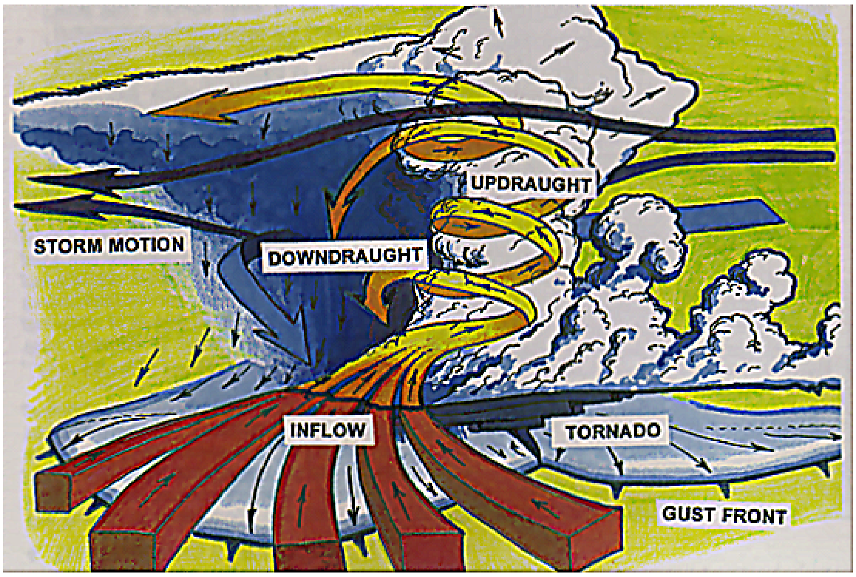

Figure 6.1 Schematic illustration of a *supercell* severe thunderstorm (BoM diagram)

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

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

Destructive Winds: The structure of severe winds in thunderstorms is significantly different from those in tropical cyclones. Instead of the wind being essentially horizontal, driven by the large scale pressure gradient, it originates as a vertical 'downburst' from high within the thunderstorm cloud structure, as schematised in Figure 6.2. The descent time may be several minutes, depending on the height of the storm. The downburst consists of a mass of colder air which, when it impacts the ground, spreads radially and horizontally, creating very sharp increases in wind speed. The forward speed of the storm then adds to the downburst speed, creating an elongated 'footprint' of damage which may be a few kilometres wide and about three times its width in length. The increase in wind speed and change in direction is often particularly rapid, typically reaching a maximum within a minute or less of initially calm starting conditions.

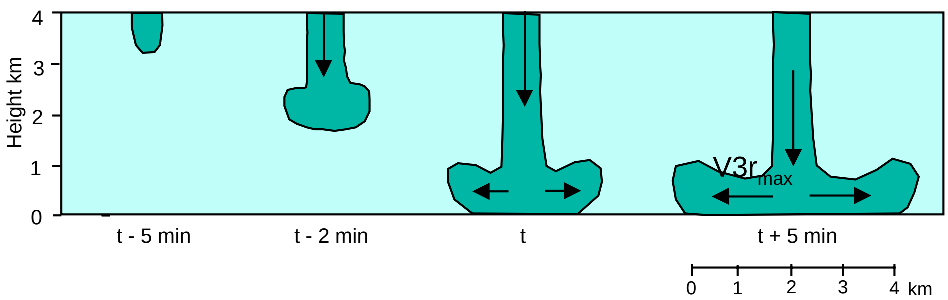

Figure 6.2 Schematic example of a thunderstorm 'downburst' (after Hjelmfelt, 1988)

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

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

Hail: Bureau of Meteorology records suggest that approximately 30% of all severe thunderstorms produce damaging hail, with actual sizes varying depending on the strength of the recirculating updrafts in the storm system. Hail is thought to grow by the accumulation of super-cooled water droplets as the hail nucleus is supported by the strong updrafts. Eventually, the mass of ice particles cannot be maintained and the hailstones typically fall in intermittent 'shafts' which form damage swaths at ground level due to the forward movement of the storm. These swaths are typically from a few kilometres in width and vary from 10 kilometres to 100 km or more in length. However, the formation of hail (and lightning) is not completely understood. For example, the extremely rapid development of the hailstorm depicted in Figure 6.2 tends to question the simple recirculating theory and suggests a shorter and more direct mechanism for hail generation is possible.

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

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

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

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

Traditionally, the collection of ‘thunder day’ statistics at observing stations has been used to estimate the occurrence and distribution of lightning across the state. However, this leads to fairly inaccurate sampling of the true occurrence. Following a period of development of remote sensing techniques for lightning detection in the late 1970s, magnetic direction-finding systems were established and have been operating in Queensland for more than 15 years. The first system was jointly operated by (now) Telstra and Energex. Recently, more accurate time-of-arrival lightning tracking systems have been commercially developed and their information is able to be purchased by lightning sensitive industry sectors, including sporting bodies. Each year in Australia, lightning claims up to 10 lives and causes over 100 injuries.

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

Storms have six main adverse impacts:

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

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

When roof integrity is lost, significant rainwater entry occurs and content damage rapidly rises. As has been witnessed with the recent Sydney event, estimated to exceed $1.7 billion in damage, delays in roofing repair can severely exacerbate the consequential losses. In past events involving hail sizes in the order of 80 mm, some insurance losses in Queensland have reached 25% of the insured value of the property (SEA, 1999b). Motor vehicle damage can also be very extensive when hail sizes exceed 40 mm. Because many severe thunderstorms cross the metropolitan area around 6 pm, they coincide with weekly peak traffic periods and can cause significant road chaos. It should also be remembered that large hail is a significant public hazard and serious injuries can be sustained by persons (or animals) unable to gain shelter.

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

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

Whilst it can be anticipated that at least one damaging thunderstorm could have an impact in the Gladstone area in any given year, and that their impact could be both lethal and destructive, their impacts will tend to be localised and somewhat random in their distribution. They are such common events that most of the population now take the warnings of severe storms issued by the Bureau of Meteorology quite seriously and attempt to get themselves and/or their cars at least under cover.

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

Forecasting and Warnings: The Bureau of Meteorology (BoM, 2000) is responsible for issuing warnings for all severe weather events. Operational procedures for the issuing of severe thunderstorm warnings from the Brisbane office of the Bureau detail three distinct phases: (a) Monitoring Phase, (b) Advice Phase and (c) Warning Phase.

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

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

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

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

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

The final role of the Bureau of Meteorology is to undertake assessment of its own performance and to document the outcomes from the severe weather event. It does this by compiling annual verification statistics and maintaining a database of events. The aim of the Severe Thunderstorm Warning Service is to provide a probability of detection of 70% or greater of severe events, a false alarm ratio of 40%

or less, and at least thirty minutes lead time (i.e. time between the issue of a warning and the occurrence of the severe phenomena) on 70% of occasions.

Flood

A simple definition of flooding is *water where it is not wanted* (Chapman, 1994) and such water 'out of place' has accounted for the third greatest loss of life in natural disasters in Australia. Flooding occurs when the amount of water reaching the drainage network exceeds the amount of water which can be contained by the drainage channels, and overflows out onto the floodplain. Several factors influence whether or not a flood occurs:

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

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

Localised and/or flash flooding typically occurs where there is intense rainfall over a small sub-catchment which responds to rainfall in six hours or less. In urban or rural areas where drainage is poor, the risk of localised flooding is high under such circumstances. Widespread flooding and/or non-flash flooding (lasting for more than 24 hours), occurs following rainfall of high intensity or long duration over the whole or a large proportion of the catchment. Runoff is typically low in areas where the percentage of vegetation cover is high, as vegetated areas allow high infiltration until the earth is saturated. Where the ground is pre-saturated, such as following a long wet period, medium rainfall events can cause flooding as runoff begins almost immediately. Flood levels in urban areas quickly rise where the percentage of impermeable surfaces on the floodplain, such as buildings, roads and car parks, is high. On sloping concrete and bitumen surfaces, for example, runoff is immediate.

In the Gladstone area flash flooding is evident in many of the smaller creeks and streams. Of these, Auckland Creek probably has the greatest potential for causing damage and/or loss of life. Modelling of the flood potential of Auckland Creek has been undertaken to the 1.0% AEP level. That modelling indicates that there are no developed properties directly affected.

Evidence of major flooding was recorded by Oxley in his exploration of the Boyne River in 1823, reinforcing his rather jaundiced view of the suitability of the Port Curtis area for settlement. Whilst neither the Boyne River or the Calliope River pose a direct threat to the urban areas of Gladstone, they have caused dislocation to transport and set back development in the past. In 1875, for example, one of the early sawmills established along the Calliope River was washed away; in 1911, flash flooding washed away a eucalypt distillery located on Clyde Creek; and in 1966, flash flooding in the Boyne River twice destroyed a large temporary dam built as part of the construction of the Awoonga Weir (McDonald, 1988).

The greatest threat posed by flooding in Gladstone is probably to the lives of those people who do not appreciate the power of flood waters and try to cross flooded roads or 'surf' in the flood waters. Such behaviour accounts for many flood fatalities. There are no flood warning systems established on either the Boyne or Calliope Rivers. Both have relatively small catchments and warning times would probably be close to or less than six hours.

Landslide

In Australia, 56 landslides are known to have caused injury or death during the period from 1842 to May 2001. At least 88 people have been killed and 118 injured. The events which caused death varied from the topple or fall of a single rock, to a spectacular debris flow. Some were the result of human activity, while others were naturally occurring events. Because of the scarcity of readily available data, it is not possible to estimate the total economic loss due to landslides, but most of the loss has resulted from damage to infrastructure such as roads and railways. Fifty-eight landslides throughout Australia are known to have caused damage to a total of over 200 buildings, many of which were destroyed.

The landslide phenomenon: 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.

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

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

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

The Gladstone landslide experience: We have two records of landslides in Gladstone. The first was a rock fall from the face of Auckland Hill in the early 1960's, preceded by a visible fracture (McDonald, 1988). In 1965, the GPA agreed to accept responsibility for future landslides on the hill, to repair the rock fall, and to erect a safety fence above it.

The other record of landslides was in 1988. *The Gladstone Observer* of Tuesday, 20 December, 1988 reported the following:

> *Shopkeepers, home owners and Gladstone City Council crews spent yesterday mopping up after a weekend of torrential rain caused an estimated $1 million damage in Gladstone…..*
>
> *Gladstone City Council engineering staff are still assessing damage to council property, which includes landslides, road damage and blocked drains.*

Alderman Brown said a conservative estimate of damage would be $150,000.

'If restoration has to be carried out to stabilise places that had landslides then that figure would sky rocket.'

On Thursday, 22 December, 1988 the *Gladstone Observer* added that:

The mayor said a Brisbane engineer would arrive in Gladstone tomorrow to advise on the best method to secure Auckland Point Hill from future landslides.

From these newspaper reports we deduce that two days of torrential rain triggered a number of landslides in Gladstone. Auckland Hill was involved again, but we are not told where the others happened.

Landslide risk: Auckland Hill, which has been subject to landsliding in the 1960's and in 1988, is one of the lower hills in the study area. There are a number of other hills that may perhaps also experience slope instability in torrential or prolonged heavy rain. Three prominent ones in the urban area are Radar Hill, Round Hill and Biondello. They have been largely left with natural vegetation, which would improve their stability. Because of the lack of information about landslides in the study area, we do not know which hills may be susceptible to landslides.

Because Gladstone is hilly, some development has taken place on sloping land, and there are some cuts along roads and railways. Slopes developed using cut and fill tend to be more susceptible to landslide than uncut slopes because of:

- artificially steepening the slope with batters;
- potentially weakening the site with fill;
- loading the upper part of the slope;
- removing support from the base of the slope;
- clearing vegetation during development; and,
- watering developed land.

However, the risks can be, and frequently are, mitigated by carrying out the development with appropriate geotechnical advice.

Debris flows are a type of landslide triggered by the action of torrential rain on loose material (rocks and finer material) on a mountain side or escarpment. The boulders and finer material, mixed with water, flow as a torrent down the slope. The boulders and some of the finer material are deposited first, while the remainder of the mud travels further as a flash flood. When assessing the risk to buildings, roads and railways near the base of a slope, one needs to take into account the fact that material from debris flows and flash floods runs out down-slope from the area of slippage. However, because the hills in the urban parts of the study area are low, any debris flows would be small and would not run out far. We do not know whether debris flows occur in the Gladstone area.

Forecasting and warnings: The rainfall threshold values for slope failure in various parts of the world are in the range 8 to 20 mm over one hour, or 50 to 120 mm over a day depending on geology and slope conditions. We do not know the threshold for landsliding in the Gladstone area but, because the risk is low, it would be advisable to issue warnings probably only near the upper limit of those ranges.
The Bureau of Meteorology routinely includes a generic caution regarding the possibility of landslides during periods of heavy rain, such as those associated with cyclones. Given the very low probability and non-specific nature of the landslide threat in Gladstone, such warnings are probably adequate. There does not appear to be any justification for the establishment of an automated landslide monitoring system in Gladstone.

Heat Wave

According to Coates (1996), heat waves kill more people than any other natural hazard experienced in Australia. She reported that in the period between 1803 and 1992 at least 4287 people had died in Australia as a direct result of heat waves. This was almost twice the number of fatalities attributed to either tropical cyclones or floods over much the same time-frame. Coates' figures are not broken down according to the state or territory in which the deaths occurred. However, a database developed by her colleague at the Natural Hazards Research Centre at Macquarie University, Kylie Andrews, based on press reports covering the period between 1907 and 1992, indicated that about 18% of the national heat wave deaths occurred in Queensland – 681 deaths out of a national total of 3843 (Russell Blong, personal communication, 2000). NSW, with 33% of the total, suffered the greatest number of deaths. Interestingly, the Andrews data indicates that males are significantly more at risk than females (449 male deaths to 222 female deaths) though this trend has been significantly less marked in the past few decades as the number of men engaging in hard physical labour out of doors has decreased. Regardless of these statistics, heat wave is probably the most under-rated of all natural hazards.

As well as loss of life, heat waves can also have significant economic impact through livestock/crop losses and damage to roads, railways, bridges, power reticulation infrastructure, electrical equipment, and so on (EMA, 1998). Heat wave conditions also lead directly to significant increases in demand for electricity to power domestic air conditioners. This demand can exceed the available capacity of the generating system, leading to load shedding – which in turn exacerbates the heat wave impact on people.

There appears to be no official Australian definition of a heat wave, however, the American Red Cross (*www.redcross.org/disaster/safety/heat.html*) define it simply as a 'prolonged period of excessive heat and humidity'. This is a useful definition because it emphasizes the combined effects of both air temperature and humidity.

Temperatures that would indicate whether a specific location was under the effect of a heat wave would be in the top 5% for a continuous three-day period. In Gladstone, heat waves typically occur between November and February, but days of excessive heat can occur between October and March. During these events the predominant wind is generally from the south-west to the north-west, i.e. from the interior of the Continent. Winds from these quarters have the potential to nullify the cooling effects of any sea breeze.

Using a threshold for temperature that is within the top 5% of daily maximum temperatures for a continuous three-day period in the South-East Queensland area – which are likely to be very similar for Gladstone - at least 18 heat wave events have been identified since 1899 giving an ARI of, at most, 5 to 6 years. January is clearly the most common month in which to experience a heat wave episode.

<u>The heatwave threat</u>: The level of discomfort experienced in warm, moist tropical and sub-tropical conditions is determined by a range of climatic variables, principally air temperature, humidity and wind; as well as cultural variables including clothing, occupation and accommodation; and physiological variables such as health, fitness, age and the level of acclimatisation. The main factor involved in the degree to which we feel uncomfortable in such conditions is not so much because we feel hot, but rather we sense how difficult it has become for us to lose body heat at the rate necessary to keep our inner body temperature close to $37^{o}C$. Put simply, in still air the higher the humidity, the less effective are the body's mechanisms for evaporative cooling through sweat.

The body responds to this stress progressively through three stages:

- **heat cramps** – muscular pains and spasms caused by heavy exertion. Although heat cramps are the least severe stage they are an early signal that the body is having trouble with the heat;
- **heat exhaustion** – typically occurs when people exercise heavily or work in a hot, humid place where body fluids are lost through heavy sweating. Blood flow to the skin increases causing a decrease of flow to vital organs. This results in mild shock with the symptoms of cold, clammy and pale skin together with fainting and vomiting. If not treated the victim may suffer heat stroke;
- **heat stroke** – is life threatening. The victim's temperature control system, which produces sweating to cool the body, stops working. The body temperature may exceed 40.6^{o}C potentially causing brain damage and death if the body is not cooled quickly.

(based on material from the American Red Cross web site)

The suggested responses to heat wave conditions include:

- slow down – avoid strenuous activity. If this cannot be avoided, do it during the cooler parts of the day, e.g. between 4.00 and 7.00 am;
- stay indoors as much as possible and stay out of the sun. If air conditioning is not available, stay on the lowest floor. Try to go to a public building with air conditioning, such as a shopping centre, each day for several hours. Whilst electric fans do not cool the air, they do help sweat to evaporate, which in turn cools the body. Ensure that the building you are in has adequate ventilation;
- wear lightweight, loose fitting, light coloured clothes;
- drink plenty of water regularly. Avoid drinks with alcohol or caffeine in them. They may make you feel good briefly, but they make the effects of the heat on the body worse. This is especially true of beer which dehydrates the body;
- eat small meals and eat more often. Avoid foods that are high in protein which increase metabolic heat; and,
- check on elderly relatives or neighbours, especially if they are living alone, and ensure that they also follow these risk mitigation measures.

(also based on material from the American Red Cross web site)

Given the lack of detailed information about the incidence of heat wave in the Gladstone region, it is not possible to provide a specific risk assessment. It is clear, however, that whilst such a weather sequence will be felt across the entire area, its impact will be greatest on those who are most susceptible. The elderly, especially those living alone, are a particularly susceptible group.

The distribution of people over 65 and living alone, based on the proportion they represent of the total population in 1996, is shown in Figure 3.17. In absolute terms, however, it should be noted that in the Gladstone study area there were 531 people that were within this group in 1996. They were present in 49 of the 53 CCD in the study area, with the largest number (38) in a CCD located in South Gladstone.

The very young also constitute a susceptible group, however, it is likely that they will have a parent or other carer to look after their well being. We do not have any information on the distribution or numbers of other susceptible groups such as the homeless and the physically or mentally disabled.

The anecdotal evidence of the heat wave event that killed 23 elderly in Brisbane in January 2000 indicates that many elderly people, and indeed many people in other susceptible groups of the population, are largely ignorant of the risk posed by heat waves, or of the simple steps that can be taken to reduce that risk. There is clearly a need to improve public awareness of the risks associated with heat wave. There is also a need to actively involve those community agencies, such as Meals on Wheels and Blue Nurses, that have regular contact with some of the more susceptible individuals, to promote the awareness message.

Bushfire

Whilst bushfires in Gladstone have never been as severe as the worst fires that have occurred in the southern states, (such as the 'Ash Wednesday' fires that claimed 75 lives in South Australia and Victoria in 1983,) serious fires have occurred in the region during most months of the year. Contrary to the widely held belief, bushfires do destroy property (including urban property) and they do kill people in Queensland.

The bushfire season for Queensland typically extends from mid to late winter through to early summer. The greatest danger occurs in the period towards the end of winter and into spring, especially if a good summer 'wet' season, which produced abundant growth of grass and other fuel, is followed by a winter of low rainfall and lengthy periods of dry westerly winds. The risk generally eases following the first rains of the spring thunderstorm season and is largely absent during the summer 'wet' season. The 'wet', however, produces the conditions for lush growth that will, by the following winter, provide the fuel for the next fire season – and so the cycle continues.

Unlike most of the other hazard phenomena dealt with in this study, with bushfires there is a clearly defined philosophy of responsibility, namely, that if you own the fuel, you own the fire. According to the 'basic philosophy of operation' of the Queensland Fire and Rescue Authority (QFRA) Rural Fire Service (Rural Fire, 1999):

> *Fire control is a property owner's responsibility, supported in an organised manner by the community through the Rural Fire Brigades.*

Queensland rural fire authorities (including Rural Fire Brigades, National Parks Service, Forestry Service and local governments) have always supported a regime of fuel management in bush areas under a system of permits issued by local Fire Wardens. These permits are aimed at:

> *encouraging hazard reduction burning through the provision of legal protection for responsible users of fire and punitive action for irresponsible users*. (Rural Fire, 1999)

In the most urban areas there had been significant pressure to minimise, if not curtail, hazard reduction burning and/or pasture management fire activities. These pressures came largely from lobby groups including environmentalists (who have argued that any fire is destructive) and those whose medical conditions could be aggravated by the smoke from fuel reduction burn-offs. This pressure has eased somewhat since the destructive fires in South-East Queensland and elsewhere in late 1994 (and the fatal fires in NSW earlier in that same year).

<u>The bushfire phenomenon</u>: For a bushfire to start and to be sustained, three things are needed:

- there must be fuel available to burn;
- there must be sufficient heat to cause and maintain ignition; and
- there must be sufficient oxygen to sustain combustion.

If any one of these is absent or inadequate the fire will either not start in the first place, or will not spread.

The fuel for a bushfire is made up of the available vegetation, together with any other combustible materials (such as houses) that become involved. Most of the natural vegetation communities of the region are 'fire climax' types that have evolved to the point where they rely, to varying degrees, on fire for regeneration.

The heat needed to start a bushfire can be provided by something as simple as a match or cigarette butt, or by something as dramatic as a lightning strike. Of course, the higher the atmospheric temperature is in the first place, the easier it is for these sources to get things going. In the Gladstone region, in spite of its reputation for spectacular thunderstorms, the vast majority of bushfires are started either by human carelessness (e.g. a discarded cigarette butt or a poorly supervised burn-off) or human stupidity and wanton criminality (the fire deliberately lit by car thieves or bored children). Once the bushfire is established it generates its own heat.

The oxygen required for combustion is provided by the atmosphere and is constantly being replenished by the winds, either created by the fire itself, or by the atmospheric winds. Higher winds mean more oxygen and more intense flames.

The intensity of a bushfire, and thus its destructive potential, is determined by three factors that are related to these three basic elements. The first is heat yield. The heat yield of most native vegetation types in Australia is extremely high. Eucalypt trees and regrowth scrub and the exotic pines in plantations, all produce naturally volatile substances. These fuels invariably produce more intense fires and yield more heat than does grass. The greater heat energy released by scrub and forest fires make them potentially more damaging to houses and other buildings than are grass fires. They also produce airborne embers and firebrands which can start spot fires well ahead of the fire front. Grass fires, by comparison, consume the available fuel much more quickly and produce few embers.

The second factor is the rate of spread. This can be influenced by two main conditions – terrain and weather. Fires burn more rapidly and with greater intensity on up-slopes than they do on down-slopes or on the flat. Generally, the steeper the up-slope, the greater the speed and intensity of the fire. Rising temperatures and wind velocities and decreasing humidity directly contribute to an increase in both the rate of fire spread and its intensity. As fuels dry out, ignition becomes easier and the rate of spread increases. Winds can also assist the spread of fire by carrying heat and burning embers to new fuels (causing spot fires ahead of the fire front) and by bending the flames closer to unburned fuels ahead of the fire. Doubling the wind speed will quadruple the rate of spread of the fire.

Preliminary findings from *Project Vesta*, a joint CSIRO – WA Department of Conservation and Land Management research program, indicate that fire spread can be significantly greater than previously estimated where there is a developed shrub layer taller than one metre and wind speed exceed 15 km/hour; there appears to be a wind speed threshold at around 12 to 15 km/h, below which fire can spread relatively slowly, but a slight increase in wind speed can result in large increases in the rate of fire spread . It has also been found that wind speeds within forest areas can be highly variable, giving rise to significant variability in fire spread rates (CSIRO, 2000).

Hot, dry air can lower the moisture content of forests and grasslands to around 5% (and in extreme cases to 2-3%,) greatly increasing the spread of fire. The worst fire weather conditions in the Gladstone area (high temperatures, low humidity and strong winds) tend to occur when deep low pressure systems develop over southern Australia, bringing strong dry westerly winds from the continental interior to the coast.

The third factor is the amount and nature of the fuel available. This can be influenced by the nature of the preceding growth season – a wet summer will give rise to much more growth than will a dry summer; the length of time since the area was last burnt (either by a previous bushfire or by fuel reduction burning); and by other land management practices such as cultivation, slashing, irrigation and so on.

It should be recognised that under some situations, the intensity of a bushfire can reach such a level that it simply can not be put out by currently available or practical suppression measures. Fire authorities in Australia acknowledge that this situation is unlikely to change in the foreseeable future.

Bushfire risks: In the context of this study, which has an emphasis on the urban environment, the primary risks posed by bushfires are to those areas on the urban fringe, or at the interface between the 'bush' and built up areas. The key risk is to buildings and to those elements of infrastructure that are either flammable (e.g. timber power poles and wooden bridges) or susceptible to the heat generated by bushfires (e.g. power supply switching gear and electronic equipment). People are also at significant risk, especially if they are caught in the open or in vehicles that are inadequately protected. This is a particular risk where rapid shifts in wind direction and speed cause the fire to change direction and speed without warning.

When considering the risk to people, the risks faced by fire fighters, most of whom are volunteers, should not be overlooked. This risk was highlighted recently by the deaths of several firefighters in other states and the serious injuries suffered by nine volunteer firefighters near Beerwah (the so-called 'Bell's Creek fire') in November 1994. These fatalities and serious injuries can, in virtually all instances, be attributed to a lack of appropriate hazard mitigation (i.e. fuel reduction) prior to the dangerous fire conditions occurring.

There are four main mechanisms by which bushfires cause damage. The first, and most obvious, is direct exposure to flames. Exposure to flames is typically only a threat where vegetation or other fuel is allowed to accumulate under, against, or on the exposed building. Similarly with infrastructure elements, fuel must be present close to the pole, bridge timbers and so on, for it to be affected directly by flames.

The second mechanism is burning debris. Buildings are at risk from wind-blown sparks and embers that can be carried significant distances from the fire front. They can also be propelled at great speed by the strong winds generated by the fire and be of a size large enough to smash unprotected windows. Sparks and embers can enter the building through openings such as open or broken windows or unlined eaves, thus introducing a source of ignition to the interior of the building. Sparks can start small fires in curtains, carpets and other interior furnishings. These can develop rapidly and destroy the building from the inside. Similarly, sparks can lodge in combustible material close to, on the roof of, or even under the building, thus causing exterior fires that can quickly envelop the building.

The third mechanism is radiant heat. Bushfires generate extreme heat levels at their active front. As the fire travels forward, this extreme heat lasts for only a few minutes, however, it is sufficient to fracture glass or cause combustible items inside the building, such as fabric and paper, to burst into flame. Radiant heat is also a significant threat to heat-sensitive power supply and other electronic equipment.

The fourth mechanism is the strong winds generated by the fire. Wind speeds in excess of 42 m/s (120 km/h) can be experienced in fires. This is the wind speed threshold contained in the wind loading standard applicable to most urban buildings in the area, other than those on the coastline. Such winds can cause direct damage, e.g. by unroofing buildings; it can cause impact damage by propelling debris, including burning debris, at considerable velocity; trees or power poles may be toppled, especially if weakened by the fire.

A significant secondary bushfire hazard is smoke. Fire smoke can produce direct physical effects in people, especially in those with respiratory illnesses such as asthma and emphysema, as well as psychological effects. Stress and anxiety levels in many people can be raised simply by the smell of fire smoke on the air. Smoke can also reduce visibility to the extent that roads, and even airports, may need to be closed temporarily.

There is perhaps a perception that only buildings in rural areas are at risk from bushfires. There is little doubt that they make up the bulk of buildings destroyed, however, buildings in urban areas are also at risk – as was demonstrated on Bribie Island and elsewhere during the 1994 fires. Ahern and Chladil (1999), using data from three severe historic fires in which urban houses were destroyed (the 1967 'Black Tuesday' fires in Hobart, the 'Ash Wednesday' fires in the Otway area of Victoria in 1983 and the Como-Jannali fires of 1994 in NSW), have calculated that 95% of all urban buildings destroyed in bushfires were within 100 m of the bush interface. Buildings destroyed beyond that range were almost universally victims of ember spotting. The greatest distance recorded (in the 1967 Hobart fires) was 684 m from the vegetation boundary. Ahern and Chladil observe:

> *Consider also, the case of common suburban lot dimensions. Assuming an average lot depth of 40m, we can account for about 64% of all houses burnt* [as] *actually being adjacent to the vegetation boundary. If one allows 30m for a road reservation we are 70m from the vegetation boundary and have accounted for about 75% of all burnt houses. Only 13% of all houses burnt were beyond a distance equivalent to a house lot, a road reservation and another house lot.*

It should be noted that 'vegetation boundary' relates to 'bush' rather than grassland vegetation.

The potential for bushfire spread has, since the 1960's, been measured using the various versions of the McArthur Forest Fire Danger Meter and the McArthur Grassland Fire Danger Meter. The 'fire danger', based on input including weather variables and fuel variables, is rated from low to extreme. These ratings form the basis for public warnings and govern the introduction of fire bans and other restrictions on the use of fire.

Under the *Queensland Building Act*, which calls up the Building Code of Australia, all buildings constructed since 1993 in those areas so designated by each local government authority as being bushfire prone, must comply with standard AS 3959-1991 *Construction of buildings in bushfire-prone areas* (Standards Australia, 1991). AS 3959-1991 specifies only minimum standards that are intended to improve the performance of buildings against burning debris. Other passive risk reduction measures, such as correct siting of the building, the provision of suitable landscaping to act as a barrier to the oncoming fire, and the protection of windows, should also be considered. Guidance on the siting and design of residential buildings in bushfire prone areas of Queensland is provided in DHLGP & QFS (undated).

More recently, a national position on development and building in bushfire prone areas has been developed. The relevant codes and standards to give effect to this agreed position will be published in late 2001. The objective is to produce developments that are designed to minimise the impact of bushfire on the community and the built environment. They will be performance-based and allow for regional variation. Risk reduction will be achieved by limiting development to areas with 'acceptable bushfire risk' and by imposing standards which embrace the survivability of structures and their occupants if subject to bushfire attack. Included will be the concept of 'defensible space' which aims to maximize the opportunity for interventions by property owners and suppression agencies to further improve survivability of structures and their occupants.

Guidelines have also been published that are designed to assist local governments identify those areas under their jurisdiction that are bushfire prone, and consequently subject to the provisions of the Building Code; and to establish standards for the planning of subdivisions in bushfire prone areas (QFRA,1998). These guidelines encourage local governments to prepare fire hazard maps based on 'fire loading factors' derived from an assessment of the topography, aspect, fire history and vegetation cover of the area. Fire hazard mapping, employing the recommended fire loading factor methodology has been undertaken by the Rural Fire Service using GIS.

These risks can, to a degree, be balanced by the provision of fire services. These are provided either by urban brigades, rural brigades or by agencies such as the Forest Service (in State Forests) and National Parks Service (in National Parks).

The management of bushfire is underpinned by a predominantly volunteer network of fire wardens. Their role is to manage the Permit to Light Fire system. Fire wardens are regarded as the pre-fire experts and the effect of the permit system is to promote the responsible use of fire as a land management and hazard reduction tool. The universal application of this system throughout Queensland provides the legal mechanism by which to substantially control ignition from man made sources

The role of the fire warden is to consider applications for Permits to Light Fire and issue, or refuse to issue, permits. Permits issued are conditioned so as to require the permittee to ensure that fire is used and maintained in a safe and responsible manner. An added incentive for compliance with the permit system is the provision of relief from civil liability to permittees.

Community awareness: In spite of the experience of the widespread fires in the region in 1994 there appears to be a persistent view in the community at large that Queensland does not have a significant bushfire risk. There seems to be many reasons for this false perception, not least of which is the view that coastal areas of Queensland are ‘too wet’ for serious fires, that bushfires are only a problem in the southern states such as Victoria, or that bushfires only occur in rural areas.

Even amongst people in the higher risk urban fringe areas, there has been a general decline in experience and knowledge of bushfire and fuel management. The popularity of rural residential development and the increased number of properties now managed by ‘weekend’ farmers has taken large areas of rural land out of ongoing management. Many residents of these areas also have a strong attachment to what they see as the ‘natural’ environment. One outcome of these changes in land use and land management has been that regrowth, scrub and litter fuels are allowed to build up in a haphazard manner – often because of the landholder’s mistaken view that the use of fire as a land management tool is ‘wrong’, even ‘environmental vandalism’.

Perhaps as potentially dangerous is a general lack of awareness as to what to do should a bushfire threaten, especially in urban/rural interface areas. A common (and natural) response is to flee or, in the case of most police officers, to order people to evacuate their homes. Experience in South-East Queensland and elsewhere has shown repeatedly that this type of response increases the risk of both fatalities (people caught in the open or in their cars during an evacuation) and the loss of property (if there is nobody there to douse small spot fires in or around the house before they grow to an uncontrollable degree).

Rural fire brigade volunteers throughout the rural areas, however, play an important part in educating and assisting people in these areas, whilst rural-based councils are taking an active part in requiring landholders to better manage potential bushfire fuel loads.

Warnings and forecasts: The fire danger rating system in common use throughout eastern Australia has come to be known as the McArthur Fire Danger Rating System after the late A. G. McArthur who developed the system. The McArthur Fire Danger Rating System is based on a large amount of experimental work that has been carried out over the years and continues to be revised and refined through ongoing research. The system provides a means of estimating fire behaviour across a wide range of common fuel types and is currently available in both circular slide rule and electronic forms. They integrate the combined effects of fuel moisture content and wind velocity to calculate a basic fire danger index. The resultant indices can be related to fuel quantity and slope to predict head fire spread rates and other fire behaviour characteristics such as flame heights and spotting potential.

The indices are also directly related to rates of forward spread on a scale of 1 to 100. An index of 100 represents the near-worst possible fire weather conditions that are likely to be experienced in Australia. They are also divided into five fire danger classifications of low, moderate, high, very high and extreme. The index number is directly related to rate of spread, ignition probability and suppression difficulty. At an index of 1 fires are virtually self-extinguishing, whilst at an index of 100 fires will burn so rapidly and intensely that control is virtually impossible.

When fire danger conditions are expected to become very high to extreme, corresponding to a Fire Danger Index of 40 or above on the McArthur Mark IV Grassland Fire Danger Meter, the Bureau of

Meteorology issues Fire Weather Warnings. Warnings are broadcast to the general public via radio and television. Fire authorities will respond as required when Fire Weather Warnings are received and in most instances implement fire restrictions over the affected region.

The Bureau of Meteorology issues fire weather forecasts for South-East Queensland each day throughout the fire season. These forecasts contain information about expected temperatures, atmospheric moisture, wind speeds and direction and the corresponding fire danger rating for the following three days. During an ongoing major fire event, the Bureau of Meteorology issues special spot forecasts detailing current and expected conditions in the area of the fire.

Recent developments in the use of AVHRR satellite imagery and its analysis have enabled the development of map products that provide information about the quantity, condition and distribution of available fuel across Queensland. This information is now available on the rural fire service website (www.ruralfire.qld.gov.au) and is a valuable tool for planning and monitoring fire management, particularly in broad acre areas.

CHAPTER 7: A MULTI-HAZARD RISK ASSESSMENT

Ken Granger and Marion Michael-Leiba

Overview

On a global scale, Australia, as a whole, is a very safe place. We do not suffer the losses from cyclones and floods experienced in countries such as China or Bangladesh, nor are we exposed to the threat of great earthquakes, like those experienced in recent times in Chile, the west coast of the USA, Japan, Taiwan and Turkey. Australia, however, is far from immune from the impact of significant natural disasters, given that such events cost the Australian community around $1.14 billion annually. The recent Bureau of Transport Economics (BTE) study into the economic costs of natural disasters in Australia (BTE, 2001) shows that over the period 1967 to 1999, Queensland experienced 71 major disasters with a total estimated cost of $7.9 billion (1999 dollar value), second only to the NSW total of $16.0 billion from 83 major disasters. It should be remembered, however, that for the last 24 years of this 34 year period Queensland has been relatively free of major cyclone and flood disasters.

The risks posed by natural hazards in the region are clearly significant, though perhaps not as widely recognised as they deserve to be given the region's disaster history. A multi-hazard risk assessment is, therefore, clearly required.

Our approach in developing this multi-hazard risk assessment has been consistent with the general risk management process outlined in *AS/NZS 4360:1999 Risk management* (see Figure 1.1) and its evolving application in the emergency (or disaster) risk management field. So far in this report we have:

- established the risk study context and process;
- identified the key risks faced by the Gladstone community that are posed by a range of natural hazards; and,
- analysed and characterised those risks.

In this chapter we evaluate these risks and prioritise their significance to the Gladstone community.

Risk Evaluation and Prioritisation

Several methodologies have been described in the literature for evaluating and prioritising risk as the first step towards establishing treatment priorities and strategies. The method that has gained wide recognition amongst Australian emergency managers is the 'SMAUG' approach based on the work of Kepler and Tregoe (1981). In this instance, SMAUG is not J.R.R. Tolkien's dreaded dragon, but an acronym standing for:

Seriousness, **M**anageability, **A**cceptability, **U**rgency and **G**rowth

The method involves rating each risk in relation to these criteria as being high, medium or low (see, for example, the discussion of this approach in Salter, 1997). The risk management standard (*AS/NZS 4360:1999*) provides a similar approach based on a matrix to rate risk likelihood qualitatively against its consequences (see Standards Australia, 1999, Appendix D).

Whilst both of these approaches provide a useful method for reaching a qualitative (and subjective) evaluation of risk, especially for a single hazard impact on a relatively small community, they are significantly less useful when applied to a multi-hazard risk evaluation and prioritisation for very large and complex communities such as that covered in this study. The quantitatively-based total risk approach that we have adopted in this study provides a more objective means of identifying the risks that pose the greatest threat to the Gladstone community and to its constituent neighbourhoods. To achieve this we have measured the input of the three key variables in the total risk relationship described in Chapter 1 and illustrated in Figure 1.2 – namely the hazards, the community elements exposed to those hazards and the relative vulnerability of those elements.

Risks compared: Whilst there is still some way to go before we can produce a single statistic that is able to measure total risk across all hazards, we have been able to produce statistics that do provide a direct comparison of the community's exposure to the more significant hazards. The statistics used for this comparison are the estimated annual average damage (AAD) to buildings modelled across a wide range of AEP for flood, cyclonic wind, storm tide and earthquake across the region.

Average annual damage or average annual cost figures are commonly used in the insurance industry and other areas with an interest in the cost of disasters. The BTE (2001) study, for example, shows that Queensland's average annual cost of natural disasters over the 1967 to 1999 time frame was $239 million, of which 46.7% was contributed by floods, 37.5% by cyclones and 15.6% by severe storms. There were no damaging earthquakes in Queensland during the time frame, however, the proportion of the NSW average annual damage bill of $484.1 million contributed by the Newcastle earthquake is 29.1%, compared with 26.5% for flood, 40.0% for severe storm and 3% for bushfires.

The use of building damage as a surrogate indicator for exposure across all elements at risk clearly imposes limits, however, it is clear from the BTE study that in Australian urban areas, damage to buildings is the largest component of both direct and indirect damage in natural disasters. The contribution of building damage to the total estimated costs in four Australian natural disasters are shown in Table 7.1.

Table 7.1 Contribution of building damage to costs associated with four disasters (based on data from Tables 5.1, 5.2, 5.3 & 5.5 in BTE, 2001)

	Lismore flood 1974	Cyclone *Tracy* 1974	Ash Wednesday bushfires 1983	Nyngan flood 1990
% of direct costs	49	91	61	72
% of indirect costs	26	71	32	45
% of total costs	44	88	59	65

It should be noted that in the 1974 Lismore flood, the losses incurred by agriculture amounted to 55% of the total cost, whilst in the Ash Wednesday fires 15% of the total cost was represented by agricultural losses. The estimated intangible costs (e.g. from fatalities and injuries to people) have been excluded from the totals.

Based on our estimates of AAD, therefore, tropical cyclone wind poses by far the greatest risk to Gladstone. We calculate the AAD for severe wind to be the equivalent of **2.19 dwellings destroyed each year.** By comparison, the AAD for storm tide is calculated to be **0.38 dwellings destroyed each year.** Unfortunately we have not been able to calculate the AAD for earthquake risk, however, it is likely to be less than either of the cyclone-caused risks.

These AAD values have been calculated across a range of hazard incidence probabilities, including the one which represents the criteria against which the level of risk performance or 'acceptability' may be measured.

Risk Thresholds

It is difficult, if not impossible, to be categorical about levels of acceptable or tolerable risk. Such risk criteria vary greatly over time, from circumstance to circumstance and from the different perspectives of each individual member of the community. For example, many people will tolerate the minor levels of flooding that might occur once every five or so years, especially if it affects few properties. The community generally will be less tolerant of moderate to major flooding that causes widespread dislocation and does damage. Major levels of inundation or wind damage that kill people and produce massive economic loss are typically 'unacceptable'. Whilst this seems to be an eminently reasonable approach, it can also be viewed as being unrealistic, especially where the event that creates tragic losses is very rare.

It is relatively easy and inexpensive to control, or even eliminate, the nuisance levels of flooding that most people tend to tolerate. It is, however, economically impractical, if not physically impossible, to eliminate the risk of rare but catastrophic levels of riverine or storm tide inundation. Similarly, it would be prohibitively expensive to build structures to withstand the impact of the largest likely earthquake or the strongest likely wind. There is clearly an inverse relationship between risk acceptability and risk controllability. The widely adopted response to this paradox is to establish thresholds of risk that are economically viable to implement and socially acceptable. Events that exceed those thresholds are coped with, if, and when they occur. In Gladstone the following thresholds, based on local government planning thresholds or Australian Standards, are either explicitly or implicitly accepted, probably with minimal community input:

- for destructive winds - under the criteria established in *AS 1170.2-1989*, no building should fail unless exposed to wind loads greater than those for which there is a 5% probability of exceedence in any 50 year period (i.e. an ARI of around 1000 years);
- for storm tide – none appear to have been formally adopted, however, new urban subdivision development appears to be above the level of the 100 year ARI storm tide event (plus allowance for other factors), and new building floor levels are to lie above the level of the 100 year ARI storm tide plus 0.3 m;
- for flood – again none appear to have been established though it is likely that should development move into the flood plains of either the Calliope or Boyne Rivers ground fill levels of new urban subdivision development will need to be above the level of the 100 year ARI flood, and new building floor levels to lie above the level of the 100 year ARI flood plus 0.3 m;
- for earthquake - the criteria established in *AS1170.4-1993* are the minima to prevent buildings suffering structural collapse under earthquake loads for which there is a 10% probability of exceedence in any 50 year period (i.e. an ARI of around 500 years). More stringent design standards are required for structures used for what we have termed 'critical facilities';

This approach would seem to set inconsistent standards of 'risk acceptance' and is certainly not unique to Gladstone. The thresholds for earthquake and severe wind have largely been set by agencies outside Gladstone, especially those involved in establishing the various standards for structures under the Australian Building Code. For hazards for which no Australian standards exist (flood and storm tide), local government planning guidelines play a larger part in setting thresholds.

These thresholds do not generally address the risks to structures (and consequently people) built before their introduction. The vulnerability of older structures to earthquake loads, for example, has, as a result of the losses experienced in the 1989 earthquake in Newcastle, been addressed through the publication of *AS 3826-1998 Strengthening existing buildings for earthquake* (Standards Australia, 1998). A similar engineering guideline (rather than a standard) for upgrading older houses in high wind areas has also been published for both non-cyclone areas (Standards Australia and ICA, 1999a) and cyclone areas (Standards Australia and ICA, 1999b). These documents, which provide guidance relating to the improvement of older buildings, are not mandatory in their application. No equivalent document exists for storm tide or flood.

Is Gladstone a Risky Place?

Our analysis enables us to make the following judgements regarding the 'riskiness' of Gladstone **at threshold levels**:

- the risk posed by tropical cyclone severe wind is low to moderate across the region. There are, undoubtedly, localised areas in which the combination of building age, construction and site conditions could produce high damage levels. The amount of damage likely to occur as the result of a design level event (a 0.1% AEP wind) would equate to the total damage to 700 dwellings. Strong winds also pose a threat to power reticulation which in turn could pose a very serious threat to industry, especially the aluminium smelter. Unless there was at least 24 hours warning by which to enable the pot lines to be closed down safely any loss of power for more than 6 hours would lead to the aluminium in the pot line solidifying, with the resulting destruction of the plant. The economic consequences would be extremely great given the smelter's capacity of almost 500 000 tonnes of aluminium annually;

- across the area as a whole there is a low risk from storm tide inundation, however, the aggregate potential at the 1% AEP level is significant with as many as 247 buildings or facilities likely to experience over-floor inundation. The nature of the facilities that have a storm tide risk exposure, however, significantly magnifies the importance of this hazard. The viability of Gladstone rests on its port and the port facilities, including the coal loader, the bauxite import and alumina export facilities are all likely to be made inoperative for a period because of storm tide damage;

- the risk posed by earthquakes is probably low to moderate across most of the region. As with cyclone winds, there are, undoubtedly, localised areas in which the combination of building age, construction and site conditions could produce high damage levels. We have not been able to calculate a level of risk, however, the earthquake threat must be taken into account given the historic evidence of the region's seismicity. A high magnitude earthquake close to Gladstone could cause damage to the power reticulation network as well as to buildings and other infrastructure. Much of the domestic water reticulation, for example, consists of brittle, and consequently fragile, pipes. Unlike cyclones, there would be no warning of an earthquake by which to shut down plant in a safe and timely manner;

- flood, urban stormwater and flash flooding caused by cyclones, east coast lows or severe storms pose a significant threat of both fatalities and economic loss in localised areas. There is currently, however, insufficient information available on which to base a risk assessment;

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

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

- across the region there is a low to very low risk from landslides;

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

There will undoubtedly be environmental impacts from most of the natural hazards described in this study. Perhaps the scenario of greatest concern would be the impact of a significant storm tide that caused material from the coal, bauxite, alumina and other material stockpiles that are located along the foreshore area to be washed into and beyond Port Curtis. Whilst we have not investigated the likely consequences of such an event, the anecdotal evidence suggests that it could have profound effects on marine life, including sea grass and corals. This is clearly an area that requires further detailed investigation and risk assessment.

The warning systems and other mitigation strategies already in place in the region for atmospheric hazards should help to minimise both loss of life and economic harm <u>if the warnings issued are acted upon in an appropriate and timely manner</u>. For this to be achieved, however, the community must be aware of the risks they face and understand the warnings and their significance to them.

Reducing Risk

The development and implementation of risk management strategies for Gladstone lies outside the remit of the *Cities Project*. Our experience in working with people involved in emergency risk management in Queensland and elsewhere, has, however, given us some insight into key aspects of risk reduction that are offered here as observations, rather than as suggestions. They are certainly not put forward as recommendations.

As has been emphasised at several stages in this study, the only way to reduce or eliminate risks posed by natural hazards is to reduce or eliminate one or more of the three risk variables – the hazard, the elements exposed to the impact of that hazard and the vulnerability of those elements. For any tangible steps to be taken, however, a strong risk culture and the information to sustain it must be developed.

<u>Risk culture</u>: At a philosophical level at least, one of the most potent forms of risk minimisation is the development and nurturing of a strong risk management culture across the community. It has, for example, been frequently observed that emergency risk management is most effective where it is an integral part of overall community risk management. Similarly, disaster planning is most effective where it is managed as an integral part of total community planning. In the vast majority of cases, however, these processes and activities tend to be divorced from the mainstream of community governance, even within organisations that are clearly committed to public safety, as are both of the LGA in the study area. The compartmentation and isolation of emergency risk management from the mainstream of community governance can best be attributed to the lack of a broadly-based culture of risk management.

Risk management has clearly taken root in both Gladstone City and Calliope Shire Councils, though it is still at an early, and perhaps, fragile stage of development. This commitment can be largely attributed to the pioneering efforts of various council engineers and planners since the 1980s. The activity is clearly underpinned by the development and promotion, by the DES, of practical guidelines for local governments to follow in pursuing 'disaster risk management' (Zamecka and Buchanan, 1999).

A mature risk management culture will see the decisions made by the executive, administrative, public health, planning, environmental, engineering, fiscal, legal and emergency management elements become more integrated, consistent and coordinated. The outcome would see the interdependencies of strategic decisions in each of those areas acknowledged and their consequences taken into account in a more transparent and seamless process. Such an approach would also tend to widen the planning timeframe from the current two or three year, electorally constrained, horizon to one of 10, 20 or even 50 years.

Risk information: For a comprehensive risk management culture to flourish, it is necessary for it to be underpinned by a strong and effective information infrastructure. We see the development of such an infrastructure as being the most fundamental of all risk reduction strategies. It is also one of the most cost effective strategies, given that most of the information required is already collected, maintained and used by both councils and the other authorities that have a role in community risk management. This aspect is considered in detail in a report on the *Cities Project's* experience of implementing key aspects of the Australian Spatial Data Infrastructure (ASDI) in the Cairns case study (Granger, 1998). A similar strategy was adopted for this study.

Whilst much of the basic information required for risk management, such as street layout, property information, land use and demographic aspects, is already available, there are several themes that we have found to be poorly addressed. Three themes stand out:

- historical information: whilst the Bureau of Meteorology, QUAKES and AGSO maintain their own information on hazard history, and other bodies in the community such as local historical societies, libraries and media outlets each maintain collections on the community's experience of disaster, there is no consolidated index or coordination of information about the history of disasters and their impact on the Gladstone community;

- modern event experience: Gladstone has not experienced any significant disaster impacts for several years so there has been little need for post-event research to be conducted, as has been the case in Cairns, for example, following Cyclones *Justin*, *Rona* and *Steve*. Much of this post-event information, such as the recording of earthquake aftershocks or the nature of flood damage, is highly perishable – if it is not collected during the event it will be lost forever. Without such detail of real events it is not possible to reduce the uncertainty that exists in our models and basic information. The requirement to collect key event information needs to be entrenched in the doctrine of disaster response, with appropriate resources identified in disaster plans and made available to undertake the collection and management of that information; and,

- technical information: much background technical information is being routinely collected by commercial consultancies to meet the requirements of various standards such as the Australian Building Code. The collection and analysis of geotechnical information on which to base the design of building foundations is a case in point. This information is of great significance to improving the accuracy and relevance of risk assessments. Whilst there are obvious commercial (and possibly legal) sensitivities concerning such information, its value to the wider aspects of community safety is not being realised because there is no central inventory of the existence of such information – let alone an archive of the detail.

There has been significant public investment in the development of systems to monitor hazard phenomena and to provide warnings of an impending impact. This important investment has not, however, been matched by the level of investment in information that enables the warnings or risk forecasts to be translated into information of relevance to members of the community. There is clearly a need for a greater level of investment in risk information.

Emergency management: The emergency management process has been based on consideration of the prevention, preparedness, response and recovery phases of disasters (known as PPRR). Under the adaptation of *AS/NZS 4360:1999* to emergency risk management, these traditional components of emergency management can be seen as risk treatment options. The emphasis is on the treatment of residual risks (i.e. the risks that can not be eliminated or reduced by other means), especially in the preparedness, response and recovery phases. Most risk reduction options, however, clearly focus on prevention.

The preparedness phase emphasises disaster planning, community awareness, training and exercising and the provision of appropriate resources such as communications equipment (see EMA, 1993). It is important, therefore, for emergency planning to be based on sound risk assessments and realistic risk scenarios, otherwise plans may be inappropriate, awareness will be inadequate, training and exercises will not be based on realistic scenarios and resources may not be appropriate. Evacuation planning provides a good example. If such plans are based on an assessment that badly underestimates the numbers of people at risk and the timing for an evacuation, many people could be placed in serious jeopardy by reacting too late and with too few resources. Conversely, if the estimates are too conservative, large numbers of people who did not need to be evacuated could easily overwhelm evacuation resources and shelters.

The detailed information and decision support tools provided to the two councils as a result of this study can be used to produce threat-specific plans on which to base all aspects of the preparedness phase. They enable, for example, the development of disaster response and recovery plans for specific levels of cyclone or flood risk, well in advance of any event, and to use the scenarios on which they are based to run realistic exercises and training serials.

The risk scenarios also provide a capacity to model and forecast impact consequences so that the response phase can be managed more effectively. In Cairns in 1999, for example, the data developed under the *Cities Project's* Cairns multi-hazard risk assessment was used by the local counter disaster staff together with the Cairns City Council's own flood model data to forecast the likely impact of the flood that was developing in the Barron River following the passage of Cyclone *Rona*. The information derived from this scenario modelling was then used to successfully plan and carry out the evacuation of more than 1500 people, assessed as being at risk, before the flood peak was reached. That evacuation was conducted at 2.00 am!

The same modelling is also appropriate for rehearsing and planning for the recovery phase. There are examples in the literature of GIS being used to model the impact of a damaging earthquake and to forecast the requirements for short term and long term post-event shelter. Similarly it is possible to model the physical impact on lifelines and the consequences of their loss on the community.

Use of the scenario analysis technique develops 'future memory', i.e. disaster responders develop an understanding of what will happen when such an eventuality occurs so that their actions are based on 'experience' when it eventually does happen. This process could be reinforced by the development of role-play simulation 'games', such as *SimCity*, designed around Gladstone.

Reducing hazards: Apart from reducing or eliminating bushfire fuels, and stabilising some slopes to prevent landslide occurrence, we have no capacity to reduce the magnitude or severity of any natural hazard phenomenon. On present indications, however, over the next 50 years at least, climate change and an associated rise in sea level are likely to increase both the incidence and severity of most hazards that have an atmospheric origin, including tropical cyclones, storm tide, floods, storms and landslides. Climate change may also increase the incidence and/or severity of heat waves and bushfire. Such changes should obviously be taken into account in planning decisions being taken now to ensure that future risk is at least minimised. It is also important that this process of change is effectively and closely monitored.

Monitoring and warning systems: For all of the hazards considered in this study, with the exception of earthquake, warnings of impending impact are already provided in one form or another. A report produced by the Institution of Engineers, Australia (Institution of Engineers, 1993) provides a useful hypothetical example of the benefits of this approach in the following terms:

> *Flood warning systems now feature real time data collection networks linked to computer based flood models. These systems not only identify and track floods down a river but also enable emergency services to quickly assess the impact of various scenarios of increased or decreased rainfall, changing tidal conditions in the lower reaches of the river and varying tailwater effects at the river mouth due to storm surge and wave setup. Based on these scenarios, authorities can take more effective action to save lives and minimise damage to property. Even in a catchment with only one thousand flood prone homes, accurate advanced information on flood levels which enables residents to move contents and motor vehicles to locations above flood waters can result in a saving of $10 000 per household.* ***This $10M savings is a direct benefit to the community every time such a flood occurs.***
>
> (emphasis in original)

The coverage and sophistication of most of the monitoring and surveillance systems is constantly improving. There are plans, for example, to introduce Doppler radar to measure wind speed in storms and cyclones and thus improve both warnings and our knowledge of extreme wind speeds. There is also significant scope to improve on the existing seismic monitoring network in the Queensland region so that instrumental recording of the smaller and more frequent events can help build up our knowledge of the region's seismic environment.

Nonetheless, warning systems will be much more effective if the community is aware of their existence and of the implications of warnings. Whilst there is some scope to improve the timeliness and accuracy of warnings, their value will only be increased when individuals are able to relate warning information to their own circumstances and translate that information into risk reduction action. To achieve this it is necessary to increase public awareness by combining appropriate risk information and warning information.

Reducing vulnerability: It is widely recognised by emergency managers that 'an aware community is a prepared community'. To put the reverse argument, all of the investment in risk information, warning systems, risk science and emergency planning is completely wasted unless it also influences the community to adopt risk reduction strategies.

Risk communication: An effective strategy of risk communication is essential. For example, a typical public flood warning will be expressed in terms of a height on the reference flood gauge. Few people in urban areas can translate that level, with any certainty, to their own property in terms of how high the water would reach. The value of the warning is consequently diminished because few individuals know what action they should take in response.

A considerable literature on risk communication has emerged over the past decade or so (see, for example, the review by Marra, 1998). One of the most coherent examples we have encountered is that promoted by the US Environmental Protection Agency (EPA). Their approach devolves from the basic tenet that, in a democracy, people and communities have a right to participate in decisions that affect their lives, their property, and the things they value. The EPA approach is based on the following 'seven cardinal rules' (word in italics are quoted from EPA, 1988):

> Rule 1 – accept and involve the public as a legitimate partner: *the goal of risk communication in a democracy should be to produce an informed public that is involved, interested, reasonable, thoughtful, solution-oriented, and collaborative; it should not be to diffuse public concerns or replace action.*
>
> Rule 2 – plan carefully and evaluate your efforts: *there is no such entity as "the public"; instead, there are many publics, each with its own interests, needs, concerns, priorities, preferences, and organisations.*
>
> Rule 3 – listen to the public's specific concerns: *people in the community are often more concerned about such issues as trust, credibility, competence, control, voluntariness, fairness, caring, and compassion than about mortality statistics and the details of quantitative risk assessment.*
>
> Rule 4 – be honest, frank and open: *trust and credibility are difficult to obtain. Once lost they are almost impossible to regain completely.*
>
> Rule 5 – coordinate and collaborate with other credible sources: *few things make risk communication more difficult than conflicts or public disagreements with other credible sources.*

> Rule 6 – meet the needs of the media: *the media are frequently more interested in politics than in risk; more interested in simplicity than in complexity; more interested in danger than in safety*.
>
> Rule 7 – speak clearly and with compassion: *tell people what you cannot do; promise only what you can do, and be sure to do what you promise.*

Governments, at any level, can only hope to reduce risk if their risk reduction strategies are accepted and supported by the community. Risk communication is the most democratic way of achieving that support.

Efforts to inform the community about risks are not always viewed with the same passion and altruistic values as those held by risk communicators. They are often met with opposition from small, but influential, sectors. The most common negative reactions relate to the belief that such information will have a negative impact on real estate values, and/or, will 'scare away' tourists or investment. Whilst there has been only limited research into the overall economic impact of risk communication, the anecdotal information that we have seen indicates that such negative beliefs are wrong. They do, nevertheless, excite levels of passion and political 'outrage' that typically leads to the dilution, if not termination, of public awareness efforts.

Strengthening buildings: Adherence to building codes is rightly seen as being a very effective strategy for risk reduction, given that much of the losses encountered in disasters come from damage to buildings. All Queensland LGAs enforce the provisions of the Australian Building Code which established minimum standards for construction to safely withstand established levels of earthquake and wind risk. A standard for construction and subdivisional design in bushfire prone areas is also close to publication. Whilst these standards reduce the risk to new buildings, standards and guidelines have also been developed to 'retrofit' older buildings to similar levels of safety against earthquake and wind loads, as described above. Preliminary consideration is also being given to the development of comparable standards for design and construction in areas prone to landslide and to inundation hazards such as flood and storm tide.

It is clear that many existing buildings in Gladstone are susceptible to wind, in particular, and to earthquake damage. Councils could compile local databases of these buildings and assess whether mitigating action is necessary. Mitigation schemes could include elements of:

- regulations that make wind or seismic upgrade mandatory when any major renovation, alteration, addition or change of use is undertaken by the owner. *SAA HB132.1* and *SAA HB132.2* (Standards Australia & Insurance Council of Australia, 1999a and 1999b) contain recommendations for structural upgrade of dwellings for severe wind. *AS3826-1998*, (Standards Australia, 1998) contains recommendations for retrofit of buildings for earthquake;
- incentives through rating reductions for buildings that have undergone retrofitting;
- alternatively, disincentives through rating rises that increase over time if no mitigating action is taken;
- incentives to rebuild rather than renovate, alter or add; and,
- a broader State or National mitigation scheme that consults the insurance industry.

Critical facility protection: The loss or isolation of critical facilities such as hospitals, airports, fuel depots, power substations, cold stores and emergency service facilities, will greatly magnify the impact of disaster on the community. Whilst such facilities remain exposed to disaster impact, plans to protect them are called for. Such protection may be as simple as ensuring the priority allocation of sandbags to the facility. It may be as routine as ensuring that the facility has an adequate uninterruptible power supply (UPS) or a stand-by generator with adequate fuel to cover the loss of reticulated power supply. Or it may embrace costly structural defences such as the construction of permanent protective berms or levees and the development of redundant capacity at other facilities that could cope with the potential loss of one component in a critical system.

Such mitigation efforts are targeted to maximise community protection with a minimum of effort and cost.

Reducing exposure: The simplest way to reduce risk is obviously to keep people and development out of areas that are prone to regular and/or significant hazard impact such as floods. Such an approach has already been adopted in Gladstone with the various council inundation policies for new development.

Queensland's *Integrated Planning Act* (IPA), which came into force in 1998, also has the potential to be used to reduce community risk. This legislation enables local governments to include, within their urban planning schemes, specific constraints on development that are aimed at managing risk. The IPA does not establish levels of constraint for different hazards, such as an ARI of 100 years as the State-wide constraint for development in floodplains, but leaves the setting of such thresholds to the individual local government.

The IPA also contains provisions that enable councils to change past planning decisions that did not take into account community safety issues. A land use approved under a previous planning scheme can, for example, now be changed without compensation to the owner, but only after the owner has been allowed two years to substantially commence redevelopment on a site with a previous use.

To be effective, however, planning policy must take both a long-term view (preferably with at least a 20-year horizon), and a holistic perspective, especially as the centre of development moves away from historical urban centres as the community expands. This study, for example, has provided new earthquake hazard information. Councils could use that information to lessen the probability of new development introducing unnecessary risk. If more work were done to produce a reliable earthquake hazard map, councils could, for example, adopt the map to inform developers and their engineers of ground conditions with regard to earthquake.

The planning regulation corollary to the 'retrofit' codes for existing buildings is the policy of relocation or compulsory acquisition of properties with an unacceptably high degree of exposure. Such programs are usually expensive and marked by controversy, however, they are clearly effective in reducing risk.

Engineered defences for inundation: The classic response to inundation risk mitigation has been to turn to structural defences such as levees, dams, flood detention basins and fill that are designed to reduce or eliminate exposure to the hazard. There is a view, however, that:

- they are invariably expensive;
- they frequently fail to provide the levels of protection that are attributed to them because of inadequate design and/or poor maintenance;
- they foster a false sense of security in the community that they are supposed to protect, with the result that when they fail, the community is exposed to a much greater degree of loss; and,
- the levels on which they are based (e.g. the modelled Q100 flood line) can change dramatically (either up and down) as better science, modelling techniques and information is applied, and as external factors, such as vegetation protection regulations, take effect.

There is an increasing tendency to emphasise non-structural mitigation measures (such as those discussed above) and to regard structural defences as the risk reduction strategy of last resort. Where structural mitigation is being considered, however, the risk assessment methodology we have employed in this study provides the basis on which to undertake a cost-benefit study. The risk assessment approach also enables proposed risk reduction strategies to be modelled and their effects tested against the criteria that they aim to meet.

The Wider Picture

This study has concentrated on the risks posed directly to the Gladstone community. Where appropriate, however, attention has been drawn to factors that lie outside the control or influence of that community that may exacerbate those risks. Attention has also been drawn to facilities located within Gladstone, the loss or isolation of which could have significant consequences beyond the borders of the study area in which they are sited. It is appropriate, therefore, to consider the risks to Gladstone in a wider geographic context.

Clearly, the most significant factor that influences the vulnerability of the Gladstone community is its reliance on external sources for all of its fuel, most of its food, water and personal requisites. The dislocation of any or all of these services, or their isolation from Gladstone, would have a very significant impact on the community, even if it were not directly affected by the particular hazard impact.

Given that it is many years since the last significant disaster event in Gladstone, there is a significant degree of ignorance and complacency in the wider community regarding risk. A concomitant reluctance on the part of policy makers to commit to community safety has also been evident, especially if it is perceived to be at the expense of ‘development’. There are indications, however, that this situation is changing. This wind-shift is, in no small way, attributable to the publication of *AS/NZS 4360* and its adoption by DES as the basis for emergency risk management throughout the State. It has also been given some additional focus by changes to the guidelines that govern the Natural Disaster Relief Arrangements (NDRA) payments from the Commonwealth.

The Commonwealth Government revised its NDRA guidelines in 1998. The continued payment of the Commonwealth funding contribution to the restoration of public assets following disasters has been made explicitly conditional on there being evidence that the receiving public body (State or local government) can demonstrate that they have taken steps towards reducing the risks posed by recurrent hazards in the area that was affected. It should be noted that NDRA payments are only designed to return damaged assets to their pre-disaster state – it does not cover the costs of upgrading the assets to reduce their risk exposure. It is important to note that if mitigation measures are not increased in Queensland, the State risks not only recurring damage from disasters but also an increased shift in the NDRA cost burden from the Commonwealth Treasury to the State Treasury.

Queensland authorities see the principal challenge for the continued success of this ‘wind shift’, from an emphasis on response and recovery, to one of mitigation and risk reduction, as being one of securing the necessary funding through the establishment of a ‘National Disaster Mitigation Fund’. Queensland has been an advocate of such a fund, with the Premier writing to the Prime Minister in 1999 seeking the Commonwealth’s support. To date no progress has been made (Lesley Galloway, DES, personal communication, 2000).

Queensland authorities have also begun to develop a strategic view of risk mitigation at the State level. In December 1998, the Queensland Cabinet established the State Disaster Mitigation Committee (SDMC) to improve disaster mitigation in Queensland. The SDMC is a whole-of-Government committee, with representatives from ten State Government Departments (chaired by the Director-General, Department of Emergency Services), two Local Governments and the Local Government Association of Queensland (LGAQ).

From material provided by DES, the role of the SDMC is:

To provide advice to the Minister for Emergency Services on disaster mitigation issues through the Central Control Group of the State Counter Disaster Organisation (chaired by the Director General, Department of State Development).

The efforts of the SDMC are designed to assist LGA with planning for disaster mitigation, together with developing whole-of-Government strategies to incorporate disaster mitigation considerations in the full range of legislative and planning frameworks. These include a State Planning Policy on land use planning for disaster mitigation (under the *Integrated Planning Act*); the proposed State Infrastructure Plan (being developed by Department of State Development); and the State's capital works programs.

The SDMC has:

- defined disaster mitigation as 'the process of identification and analysis of potential hazards with a view to formulating options and strategies designed to reduce risk and minimise the effects when disasters occur';
- established the parameters of an all-hazard risk management approach by developing a comprehensive reference book, *Disaster Risk Management* (Zamecka and Buchanan, 1999), which is based on the practical application of the *AS/NZS 4360:1999.* A companion guide, *The Disaster Risk Management Guide: A How–To Manual for Local Government*, has also been developed by DES;
- commenced the determination of criteria to be used in setting priorities for disaster mitigation across the State;
- evaluated existing Commonwealth and State programs' abilities to fund disaster mitigation activities;
- developed funding criteria for the $3 million Natural Disaster Risk Management Studies Program (NDRMSP) which was formally released by the Commonwealth Minister for Finance and Administration in March 2000; and
- conducted a broad disaster awareness and education program directed at Local Governments and the community.

Where to From Here?

At the beginning of this multi-hazard risk assessment of Gladstone we stated that it was 'a starting point, rather than an end in itself'. This needs to be restated at the conclusion.

There is opportunity to build on this assessment. For example, there has been a deliberate avoidance of undertaking economic assessments of potential loss as there are not the sufficiently complex models and data on which to base such an assessment at this time. It is clear that to enhance this assessment with a soundly based economic dimension would be a relatively minor undertaking with major advantages. We have also confined our assessments to scenarios that are based on present-day climatic conditions. Further work is required to understand the longer term risks associated with climate change, especially where it relates to sea level rise and the possible increase in the frequency and/or severity of cyclones and intense rainfall episodes. Further work is also required to produce a reliable earthquake hazard and risk assessment.

A general lack of data has limited our consideration of the risks to lifelines such as power and water supply and their interdependencies. We are confident that those data will become available in the future and when they do, this study should be updated and its assessments re-evaluated.

Turning the information and the risk assessments provided here into risk reduction strategies is a task for others, particularly the two local governments and their respective communities.

We are greatly encouraged by the action that has already become evident in the area and elsewhere. A strong level of commitment to risk management is beginning to emerge. We are confident that Gladstone is well on the way to becoming a much safer, more sustainable and prosperous community.

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APPENDIX A: ACRONYMS AND ABBREVIATIONS

AAD	annual average damage
ABS	Australian Bureau of Statistics
AC	asbestos cement (aka ‘fibro’)
AEMI	Australian Emergency Management Institute
AEP	annual exceedence probability
AGSO	AGSO – Geoscience Australia (formerly Australian Geological Survey Organisation)
AHD	Australian height datum
ANU	Australian National University
ARI	average recurrence interval
ASDI	Australian Spatial Data Infrastructure
AVHRR	Advanced Very High Resolution Radiometer
AWS	automatic weather stations
BoM	Bureau of Meteorology
BPA	Beach Protection Authority
BTE	Bureau of Transport Economics
C	Celsius
CBD	central business district
CCD	census collection district
Comms	telecommunications
CQU	Central Queensland University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCILGP	Department of Communication and Information, Local Government and Planning
DDC	disaster district coordinator
DEM	digital elevation model
DES	(Queensland) Department of Emergency Services
DME	(Queensland) Department of Mines and Energy
DMR	(Queensland) Department of Main Roads
EDRI	earthquake disaster risk index
e.g.	for example
ENSO	El Niño / Southern Oscillation
EPA	Environmental Protection Agency
EPR	earth potential rise
FEMA	(US) Federal Emergency Management Agency
GAWB	Gladstone Area Water Board
GIS	geographic information system
GMS	geostationary meteorological satellite
GPA	Gladstone Port Authority
h(s)	hour(s)
ha	hectares
HAT	highest astronomical tide
HNFY	historical no failure yield
hPa	hecto-pascals
HQ	headquarters
ICA	Insurance Council of Australia
IDNDR	International Decade for Natural Disaster Reduction
IPA	*Integrated Planning Act*
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
km	kilometres
km/h	kilometres per hour
Kv	kilovolt

LAT	lowest astronomical tide
LDC	local disaster committee
LGA	local government authority
LGAQ	Local Government Association of Queensland
LPG	liquid petroleum gas
m	metres
max	maximum
min	minimum
ML	local (Richter) magnitude
MM	Modified Mercalli intensity
mm	millimetres
MPI	maximum potential intensity
m/s	metres per second
NHRC	Natural Hazards Research Centre (Macquarie University)
NDRA	Natural Disaster Relief Arrangements
NDRMSP	National Natural Disaster Risk Management Studies Program
NOAA	(US) National Oceanographic and Atmospheric Administration
NSW	New South Wales
PGA	peak ground acceleration
PPRR	prevention, preparedness, response and recovery
QAL	Queensland Alumina Limited
QFRA	Queensland Fire and Rescue Authority
QPS	Queensland Police Service
QUAKES	Queensland Advanced Centre for Earthquake Studies
SCDO	State Counter Disaster Organisation
SDMS	State Disaster Mitigation Committee
SEA	Systems Engineering Australia
SEIFA	Socio-Economic Indexes for Areas
SES	State Emergency Service
SEWS	Standard Emergency Warning Signal
SLA	statistical local area
SOI	Southern Oscillation Index
SST	sea surface temperature
TAFE	Technical and Further Education
YC	tropical cyclone
TCCIP	Tropical Cyclone Coastal Impacts Program
TCWC	Tropical Cyclone Warning Centre
temp	temperature
TPM	Thiess Peabody Mitsui
UHF	ultra high frequency
UNDRO	United Nations Disaster Relief Organisation
UNEP	United Nations Environment Program
UPS	uninteruptable power supply
VHF	very high frequency
WA	Western Australia
WMO	World Meteorological Organisation

APPENDIX B: THE SEIFA INDEXES

The following tables list the variables used by the Australian Bureau of Statistics the produce the Socio-Economic Index for Areas (SEIFA) index values used in this study. For further details of the SEIFA indexes and the methodology used to construct the most appropriate reference is ABS (1998b).

Table B1: Variables used in the SEIFA *Index of Socio-Economic Disadvantage*

Variables with weights between 0.2 and 0.3

persons aged 15 and over with no qualifications (%)
families with income less than $15,000 (%)
families with offspring having parental income less than $15,600 (%)
females (in labour force) unemployed (%)
males (in labour force) unemployed (%)
employed females classified as ‘Labourer & Related Workers’ (%)
employed males classified as ‘Labourer & Related Workers’ (%)
employed males classified as ‘Intermediate Production and Transport Workers’ (%)
persons aged 15 and over who left school at or under 15 years of age (%)
one parent families with dependent offspring only (%)
households renting (government authority) (%)

Variables with weights between 0.1 and 0.2

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

Table B2: Variables used in the SEIFA *Index of Economic Resources*

Variables with weights between 0.2 and 0.4

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

Variables with weights between 0 and 0.2

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

Variables with weights between -0.2 and 0

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

Variables with weights between -0.3 and -0.2

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

Table B3: Variables used in the SEIFA *Index of Education and Occupation* (ABS, 1998b)

Variables with weights between 0.2 and 0.4

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

Variables with weights between 0 and 0.2

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

Variables with weights between -0.2 and 0

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

Variables with weights between -0.4 and -0.2

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

APPENDIX C: METHODOLOGY FOR ASSESSING RELATIVE COMMUNITY VULNERABILITY IN GLADSTONE

Ken Granger

In Chapter 1 we described the approach adopted by the *Cities Project* to assess community risk. At the heart of that approach is the view of total risk as being the outcome of the interaction between a hazard phenomenon, the elements at risk in the community and their degree of vulnerability to that impact. The relationship was summarised in the expression:

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

In Chapters 2 and 3 we describe individual aspects of the specific community under study and the contribution they make to community vulnerability. We also present an assessment of their relative contribution to the overall vulnerability of that community. In this Appendix we describe the methodology we have developed to produce that relative assessment and the philosophy that underpins it.

The Challenge

A large amount of high resolution data has been accumulated on the hazard phenomena, properties, infrastructure and people in Gladstone. The resolution and scope of this information varies between the eight local governments included in the Gladstone project area, however, there is a broad range of information that is common and consistent across the region. Whilst those data provide a detailed quantitative description of <u>specific</u> aspects of the each community'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 community. We considered it to be highly desirable, however, to be able to identify those parts of the community under study that would provide a potentially disproportionate contribution to community risk, regardless of the hazard involved, because of the number and nature of the elements at risk they contained.

The challenge, then, is to develop a measure, or index, that enables us to rate neighbourhoods (as represented by CCDs) on the basis of their contribution to overall risk.

Vulnerability Indexes

There is little in the risk management or disaster management literature to use as a guide to construct such an index. Whilst the two workshops held at the Australian Emergency Management Institute (AEMI) at Mount Macedon in April and September 1995 contributed significantly to our understanding of vulnerability as a concept, they were not conclusive where the development of a 'vulnerability index' was concerned.

One of the few worked-through examples of a 'risk index' we have found is the Earthquake Disaster Risk Index (EDRI) approach developed by Dr Rachel Davidson (1997), now at the University of North Carolina at Charlotte. EDRI has been used recently to compare the earthquake risk in some 72 cities around the world as part of the *Understanding Urban Seismic Risk Around the World* Project.

The philosophy behind EDRI is similar to that which underpins the *Cities Project*. It is summarised by Davidson and Shah (1998) in the following terms:

> *Using a holistic approach, the EDRI attempts to measure the risk of an urban earthquake disaster. This is a broader concept than just the expected frequency of future earthquakes, or even their expected impact in terms of the number of deaths, injuries, or damaged buildings. In assessing earthquake disaster risk, the economic, social, political, and cultural context of the earthquake hazard plays a role too. An earthquake disaster is considered to be a function of not only the expected physical impact of future earthquakes, but also the capacity of the affected city to sustain that impact, and the implications of that impact to the city and to world affairs.*

EDRI is based on data considered to 'measure' the contribution to overall risk under five factors described as follows:

- ***Hazard*** **-** *Severity, extent, and frequency of the geological trigger phenomenon to which the city may be subject.*
- ***Exposure*** **-** *Size of the city. Number of people and physical objects, and the amount and type of activities they support.*
- ***Vulnerability*** - *How easily the exposed people, physical objects, and activities may be affected in the short or long-term.*
- ***External Context*** **-** *How impact within a city affects people and activities outside the city.*
- ***Emergency Response and Recovery Capability*** - *How effectively and efficiently a city can reduce the impact of an earthquake through formal, organised efforts made specifically for that purpose.*

Davidson's index is built on a range of weighted 'indicator' values that are combined to provide a standard measure by which to compare 'earthquake disaster risk' of individual cities.

The urban geography literature of the 1960's also contains examples of research aimed at classifying areas within cities to reflect particular features such as socio-economic status. Berry and Horton (1970), for example, provide a good overview of this research. Most of these examples, however, rely on sophisticated statistical analysis such as factor analysis and analysis of variance.

The approach we have developed here is similar in most basic respects to both EDRI and the classic geographic numerical taxonomy studies. It differs from EDRI, however, in two main ways. First, it is being used to assess the risk to a range of hazards across a single city, and second, we have not been constrained by selecting indicators that are available 'universally'. It differs from the sophisticated multi-variate statistical techniques in that it was undertaken using the analytical tools of the MapInfo GIS and Microsoft Excel software products rather than specialised and sophisticated statistical analysis software. This computationally less demanding approach was felt to be important given that our methodology is intended for use by local governments and others responsible for undertaking risk assessments at the local level who would not necessarily have access to the more sophisticated tools.

We have also constructed it to better 'fit' our risk assessment process described in Chapter 1, especially the 'five esses' approach to the analysis of vulnerability.

The approach we have developed was first used in the Cairns case study (Granger and others, 1999). In the Cairns study we chose to present our analyses at the suburb level given that most members of the community already identify themselves at home and at work with a suburban locality. For the Gladstone study, however, we have adopted a different strategy, namely constructing the analysis at the level of the CCDs used in the 1996 national census. There are 52 CCD covering the full area under study. These units typically contain approximately 200 households.

We have chosen this approach for two reasons. First, suburb boundaries do not match well with CCD boundaries across the region, so it was difficult to adequately translate the census-derived statistics to the suburban level. Second, the variation in suburb size would significantly distort the statistics to such an extent that the results would have been largely meaningless.

Assumptions

Because we are interested in showing the relative importance of each CCD to overall community vulnerability it was assumed that the most appropriate statistic to use would be the rank of the CCD in each measure. The use of rank is not without its problems. Inclusion of several variables that are highly correlated, or indeed derived from the same basic statistic, will obviously bias the outcome. Similarly, the inclusion of variables that have little, if any, bearing on community vulnerability could also distort the results. We feel, however, that with the careful selection of variables, rank is an appropriate statistic to reflect the relative significance of CCDs.

A systematic sensitivity analysis of the Cairns methodology was undertaken for AGSO by the James Cook University Centre for Disaster Studies (King, Moloney and MacGregor, 2000). This analysis broadly verified the statistical integrity of the method. It also endorsed the philosophical basis of the method.

The Setting

Given that the 'setting' group of variables relates mainly to external factors (e.g. the source of power supply), or to factors that apply equally across all suburbs (e.g. jurisdictions), only four variables were selected.

Population: Clearly the most significant element at risk is the population of the community. CCDs were ranked on the basis of their total population ranging from highest value to lowest value. The reasoning is that the larger the population, the greater the number of elements at risk and thus the greater the level of vulnerability.

Population density: CCD boundary design aims to encompass neighbourhoods of roughly equal size. To balance the absolute population figures, which are sensitive to CCD boundaries, we have also included population density, taken as the number of people per square kilometre. CCDs are ranked from the most densely populated to the least densely populated on the assumption that more densely populated areas carry a higher level of vulnerability.

Gender: The gender ratio measured in terms of the number of males for every 100 females provides a crude measure of the structure of the population. At the CCD level, it appears sensitive to the presence of institutions such as nursing homes, boarding schools and prisons where highly skewed gender ratios can be expected. CCDs were ranked from lowest value (least masculine) to highest value (most masculine) on the possibly questionable, but widely held assumption, that males are more resilient than females.

CCD-level composite: A composite view of the setting group of variables at the CCD level was produced by simply adding the ranks for each CCD for each setting variable and standardising the sum by expressing it as a percentage of the maximum possible setting rank sum (i.e. the number of CCDs times 3 – the number of variables in the 'setting' group). This is the 'setting vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the setting category.

Shelter

Seven variables were selected to represent the shelter group of elements at risk.

Houses: Houses provide the most widespread form of shelter in the community and, consequently, they are considered to make a specific contribution to community vulnerability. CCDs were ranked on the number of houses included in the 1996 census data provided in ABS (1998a) even though it is now four years out of date. This is clearly a problem in an area like Gladstone where growth since 1996 has been significant. It was considered preferable to use this source, rather than sources such as local government land use data, for consistency across the region. CCDs are ranked from largest number of houses to smallest, on the assumption that more houses equate to higher levels of vulnerability.

Average house occupancy: CCDs were ranked on the average number of people living in separate houses at the 1996 census. This is a reasonable measure of household size. CCDs were ranked from highest value to lowest value on the basis that larger households are more vulnerable than small households.

Flats: Flats are the second most significant form of shelter. The census data provides tallies of the number of individual dwelling units rather than buildings. CCDs were ranked from highest value to lowest value on the same basis as used for houses.

Average flat occupancy: Household size in flats was assessed from the average number of people living in flats in each CCD. These data were also taken from the 1996 census and relate to the occupancy of individual flats. CCDs were ranked from largest average household to smallest average household.

Residential ratio: The proportion of properties used for residential purposes to the total number of properties provides a measure of relative dominance of residential land use. Residential buildings were taken to include houses and flats and were based on land use data provided by each of the local governments in the region. The strategy of ranking CCDs from highest residential ratio value to lowest ratio value reflects the disaster management priority given to people before other elements at risk. This variable also provides some degree of update on the population distribution changes since the 1996 census.

Cars: Private cars are clearly amongst the most important assets owned by households. They are also susceptible to damage or loss from a wide range of hazards. CCDs were ranked on the estimated total number of cars to which households had access. This figure was derived from the statistics provided in the 1996 census data for household access to vehicles. Whilst it may not be a completely accurate absolute measure, it is felt to be a good relative measure. CCDs were ranked from most cars to least cars as simple measure of the number of elements-at-risk present.

Households with no car: This variable has both socio-economic significance and great relevance for emergency managers should evacuations be required. The value used here is the proportion of households within each CCD that do not have access to a car according to the 1996 census. CCDs are ranked from greatest proportion of car-less households to lowest proportion on the assumption that households with limited independent mobility are more vulnerable.

CCD-level composite: A composite view of the shelter group of variables at the CCD level was produced by simply adding the ranks for each CCD for each shelter variable and standardising the sum by expressing it as a percentage of the maximum possible shelter rank sum (ie the number of

CCDs times 7 – the number of variables in the 'shelter' group). This is the 'shelter vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the shelter category.

Sustenance

The variables potentially available for use to assess the vulnerability derived from the facilities that sustain the community differ from local government to local government across the region because of the wide disparity in available relevant data. Five variables were available consistently for each area and these were adopted as the standard measures for the sustenance group of elements at risk.

<u>Logistic facilities</u>: These facilities contribute significantly to the sustainability of the community given that they handle, store or distribute food, fuel and other essential commodities. Their loss or dislocation would significantly limit the viability of the community. The total number of properties classified as having a logistic or transport and storage function, based on council land use data, are tallied for each CCD. CCDs are ranked from largest number of logistic facilities to the lowest. No attempt is made to weight facilities on the basis of their size or function though this may be considered as a future refinement.

<u>Water supply facilities</u>: The number of above-ground facilities supporting the water supply and sewerage systems, such as treatment plants, pumping stations and reservoirs, have been tallied for each CCDs. These data are based on council land use data and other sources, including field inspections and the UBD. Again, CCDs were ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

<u>Power supply facilities</u>: The number of above-ground facilities supporting the power reticulation system, especially power substations and switching yards, have been tallied for each CCD. These data are based on council land use data and details provided by both Energex and Powerlink. Again, CCDs were ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

<u>Telecommunications facilities</u>: The number of telephone exchanges, as identified by Telstra, were tallied for each CCD. CCDs were again ranked from greatest number to smallest number on the basis that the more facilities exposed, the greater the risk to the community.

<u>Lifeline length</u>: Unfortunately data on the actual lengths of the various lifeline reticulation networks was not available for this study. It was considered that the total length of road in each CCD, however, would be a suitable (and available) surrogate. We feel that this is reasonable because lifelines such as water supply, sewerage, power supply and telephone cabling are closely related spatially to the road network. CCDs are ranked on from the highest value(s) to the lowest.

<u>CCD-level composite</u>: A composite view of the sustenance group of variables at the CCD level was produced by simply adding the ranks for each CCD for each sustenance variable and standardising the sum by expressing it as a percentage of the maximum possible sustenance rank sum (ie the number of CCDs time 5 – the number of variables in the 'sustenance' group). This is the 'sustenance vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the sustenance category.

Security

Eight variables were selected to represent the elements at risk that influence community security. In this context security is seen as including health, wealth and the protective services provided. Two of the variables used here have been derived from the *Socio-Economic Indexes for Areas* (SEIFA) produced by the Australian Bureau of Statistics from the 1996 census. The SEIFA methodology is described in detail in ABS Information Paper 2039.0 (ABS, 1998b).

<u>Public safety</u>: Ambulance, fire, defence force, police, SES, life saving and coast guard facilities, together with hospitals and other medical facilities, provide the bulk of the protective services required by the community. Their loss or dislocation would have a disproportionately large impact on overall public safety. The tally of these facilities in each CCD, based on council land use data and other collateral sources (including the Department of Emergency Services, the College of General Practice and the Department of Health) is used. CCDs are ranked from the largest number of facilities to the smallest number. No attempt has been made to weight the tally on the basis of the size or importance of each facility.

<u>Commercial ratio</u>: The ratio of commercial premise (including businesses, industry, commercial accommodation and transport and logistic services) to the total building stock was calculated. Again, CCDs were ranked from largest proportion to smallest proportion without weighting.

<u>Relative Socio-Economic Disadvantage</u>: 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 B1). The resulting index has been standardised to have a mean of 1000 and a standard deviation of 100 across all CCDs in Australia. This means that around 95% of index scores across Australia are between 800 and 1200. A value above 1200 reflects a significantly high degree of advantage, whilst a value of less than 800 reflects a significantly high level of disadvantage. CCDs are ranked from lowest index value (most disadvantaged) to highest (least disadvantaged).

<u>Economic Resources</u>: 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 B2). This index is also standardised with a national mean of 1000 and a standard deviation of 100. Again CCDs were ranked from lowest index value (lowest resource levels) to highest value (greatest resources).

<u>People under 5 years of age</u>: The very young are felt to be physically less resilient in the face of disaster impacts than older children and adults. For this attribute, we have taken the proportion of the total CCD population at the 1996 census that was under five years of age. CCDs are ranked from greatest proportion to smallest proportion.

<u>People over 65 years of age</u>: The vulnerability of the elderly to disaster impact is similar to that of the very young. Here we have taken the proportion of the total CCD population at the 1996 census that was over 65 years of age. Again, CCDs are ranked from greatest proportion to smallest proportion.

<u>Households renting</u>: The proportion of households that were renting their accommodation is also seen as an indicator of economic susceptibility. The statistic is calculated as the proportion of all households that are renting their accommodation. CCDs are ranked from largest proportion to smallest proportion.

Unemployment: A widely used indicator of economic vulnerability is the rate of unemployment. The rate for each CCD is included in the 1996 census data and was used here because of its availability and consistency with other measures. We have assumed that whilst the actual rates of unemployment may have changed since 1996, the relative distribution probably has not. CCDs are ranked from highest unemployment rate to the lowest.

CCD-level composite: A composite view of the security group of variables at the CCD level was produced by simply adding the ranks for each CCD for each security variable and standardising the sum by expressing it as a percentage of the maximum possible security rank sum (ie the number of CCDs time 8 – the number of variables in the 'security' group). This is the 'security vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the security category.

Society

Eight variables are used to reflect the social elements at risk.

Community facilities: A wide range of practical, social and cultural services support the community. These range from schools, churches and libraries, to sporting and social clubs, and from public toilets to government offices. The number of such facilities in each CCD, based on council land use data and collateral information, was tallied and CCDs ranked from greatest number to least number.

Large families: In a disaster situation, especially where evacuations are involved, larger families are frequently at a disadvantage. In this context 'large' families were taken to be those with three or more children or other dependants living at home. The proportion of the total number of families that are classed as 'large' in each CCD was calculated from the 1996 census data. CCDs are ranked from greatest proportion to lowest proportion.

Single parent families: Single parent families, especially those who are 'women-led', are also felt to be particularly vulnerable, both socially and economically. The 1996 census data does not permit women-led single parent families to be separately identified from the total, though it seems safe to assume that the majority of such families will have a female as the sole adult. This is supported by the fairly strong correlation between high values of single parent households and high femininity values from the 'setting' group. The proportion of all families which have only a single parent present was calculated and CCDs ranked from largest proportion to smallest proportion.

Visitors: Visitors are considered to have a greater inherent level of vulnerability than do residents because of their lack of familiarity with the local environment and their relative isolation from the general community. In many tourist destinations they are also the group that has the greatest concentration of non-English speakers. The percentage of visitors (both overseas and domestic) in the total CCD population in the 1996 census is used. CCDs are ranked from greatest proportion of visitors to lowest.

Education and Occupation: The third SEIFA index included in this study is the *Index of Education and Occupation*. This index is based on an analysis of 18 weighted variables selected to reflect the educational and occupation structures of communities (see Table B3). High scores reflect communities with high concentrations of people with higher education or undergoing further education and with people employed in higher skilled occupations; conversely low index values indicate low educational levels and largely unskilled employment categories. CCDs are ranked from lowest index value (low education and occupation status) to largest index value (high education and occupation status).

New residents: People who had lived at their census address for less than five years have been included as an indicator of the potential lack of awareness of the local disaster environment and of potentially low levels of community coherence. Whilst the census data on these 'new residents' include longer-term residents who have simply moved residence within the area, the great majority have moved from other statistical local areas (SLA). CCDs are ranked on the proportion of the total population that were living at a different address to that at the 1991 census with ranking from greatest proportion to least proportion.

No religious adherence: Lack of strong social links, such as adherence to a religion, is seen as an indicator of weaker community ties, and thus susceptibility. CCDs were ranked on the proportion of the total population who indicated in their response to the 1996 census that that they had 'no religion', from greatest proportion to least proportion.

Elderly living alone: Experience with evacuations and disaster response, and with hazards such as heat wave, suggests that elderly people who are living alone represent a special category of people in the community who are especially susceptible. Not only do they have general lower mobility, they tend to be somewhat isolated, apart from support by services such as home nursing and meals on wheels. The proportion of the total population who are over 65 years of age and living alone in each CCD at the 1996 census is the statistic used. CCDs are ranked from largest proportion to smallest proportion.

CCD-level composite: A composite view of the societal group of variables at the CCD level was produced by simply adding the ranks for each CCD for each societal variable and standardising the sum by expressing it as a percentage of the maximum possible societal rank sum (ie the number of CCDs time 8). This is the 'societal vulnerability index' used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability within the societal category.

Composite Ranking

To provide a composite rating of the **relative contribution of each CCD to overall community vulnerability**, the ranks for all variables for each CCD are summed and standardised by expressing them as a percentage of the maximum possible total rank sum (ie the number of CCDs time 31). This produces the composite index used in Chapter 3 in which the lower the index value, the higher is the assumed level of that CCD's contribution to overall community vulnerability.

Ranking Strategy

Where values of a given variable were equal in two or more CCDs, the same rank was applied to each. Where there were multiple CCDs with no value recorded (e.g. no power supply facilities present) a strategy was adopted to rank the zero-value CCDs with the median value of remaining ranks so as to maximise the difference between low and no values. For example, in a set of 50 CCDs where only the first 10 had values, rather than giving all the zero values a rank of 11, they were given the rank of 30 (i.e. the mid point of the remaining values).

Further Development

It is clear that this methodology is still evolving and that it requires further work. We would welcome any suggestions, comments and/or advice, that readers may have to further improve it.

Weighting: No attempt has been made to weight the individual variables within each group. Our research has not reached the stage where we can confidently judge the relative significance of, for example, houses as opposed to flats, as opposed to the road network, in the shelter group; nor can we yet judge the relative contribution of each group to the overall evaluation.

There is, none-the-less, a weight inferred by simply including the attribute in the assessment.

Facility importance: By contrast, the importance of individual facilities such as airports, hospitals, rail terminals, ports and police headquarters to overall community vulnerability are probably under-stated because they are each simply dealt with as a single facility. This is particularly an issue for those facilities, such as airports and police stations that have only limited distribution, but service a wide area. Further research is needed to incorporate their catchment or service areas in addition to the neighbourhoods in which they actually are located. Established geographic techniques, including distance decay and nearest neighbour analysis, are likely to hold potential.

A similar problem arises with facilities that have dual or multiple functions - should they be counted in more than one attribute? Where we have adequate information we have added ‘facilities’ to reflect those additional functions. For example, where the local counter disaster coordination centre is housed in the council offices, a ‘public safety’ facility has been added.

Further consideration is also needed to take account of the functional significance of facilities and the degree to which the functions they provide can be taken up by other facilities in the event of loss or isolation. Functional significance can be measured in terms of the extent of the impact of a facility being lost. A local ‘corner store’, for example, has a relatively localised catchment and people who rely on it can easily find an alternate source of the same services in an adjacent neighbourhood or at a higher order facility such as the suburban supermarket or regional shopping plaza. It has a low order of functional significance and a high degree of redundancy. A fuel refinery, power station or an international airport, by contrast, have at least international, national and State-level significance, in addition to their local significance. The loss of those facilities would cause a significant dislocation to the local, state and national economies, especially if alternate facilities within the region did not have the capacity to easily handle the extra demand. Such facilities have a high order of functional significance and a low degree of redundancy.

Conclusion

Regardless of the obvious limitations in the methodology employed here to provide a measure of the relative contribution each neighbourhood makes to overall community vulnerability, we do not believe they invalidate it, or the assessment it has produced. Whilst it is hardly a scientific test, the assessment fits our intuitive assessment fairly well - it contains no surprises. Its application in other centres will undoubtedly produce further refinements. We are none-the-less encouraged by the endorsement of our methodology by King and MacGregor (2000) who make the comment:

> *The selection of the social indicators is based on the definitions of the elements of vulnerability in the model. Thus rather than debate the pros and cons of different variables, or attempt to weight some of the indicators, which we know will change the ranking of individual communities, it is worthwhile refining the (*AGSO*) model towards adoption as a standard for measuring vulnerability. If we use a standard in all locations as a basis for* (measuring) *vulnerability to multiple hazards, measurements can be recalculated and added to relatively easily, thereby maintaining a continually available classification of community vulnerability for all communities.*

We certainly see our the method described here as the first step on what will hopefully be a fruitful journey.

APPENDIX D: MODIFIED MERCALLI(MM) SCALE OF EARTHQUAKE INTENSITY (after Eiby, 1966)

MM I Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than ten storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MMI may be more noticeable.

MM III Felt indoors, but not identified as an earthquake by everyone. Vibrations may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors, but not outside. Very 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. Walls and frame of building are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.

MM V Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows crack. A few earthenware toilet fixtures crack. Hanging pictures move. Doors and shutters swing. Pendulum clocks stop, start, or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moves. Unstable furniture overturns. Small school bells ring. Trees and bushes shake, or are heard to rustle. Material may be dislodged from existing slips, talus slopes, or slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls crack. Weak chimneys break, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motor cars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles break. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shift off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well-built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes, and canals thrown up on the banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines. Great damage to underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of slight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

Categories of non-wooden construction

Masonry A Structures designed to resist lateral forces of about 0.1g, such as those satisfying the New Zealand Model Building By-law, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality and the design and workmanship are good. Few buildings erected prior to 1935 can be regarded as Masonry A.

Masonry B Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces.

Masonry C 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.

Masonry D Buildings with low standards of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

APPENDIX E: EARTHQUAKE ACTION GUIDE

This information is provided by courtesy of the Disaster Awareness Program, Emergency Management Australia.

If your area has an earthquake history or potential, this advice could help save you injury and distress.

Know your local earthquake risk.

Ask your State/Territory Emergency Service (S/TES), council and insurance company for this information:

• Whether tremors or earthquakes have ever occurred in your area and what damage resulted.

• Ask your S/TES for a free pamphlet and/or poster which show Australia's earthquake risk zones.

• Study that information and ask your council about ways to make your house safer in an earthquake.

• Check that your insurance covers earthquake damage.

Emergency kit and check list

During and after an earthquake you will need:

• A portable radio and torch with fresh batteries.

• Candles, matches and containers of fresh water.

• A first aid kit and basic first aid knowledge.

• Plan together where your family will meet if separated.

• Know your safe areas during an earthquake *(see below)*.

• Your emergency contact numbers. For **life threatening situations** (police, fire, ambulance) **000**. For other emergency numbers, see your phone book.

Watch for possible warning signs

• Erratic animal behaviour - Scared, confused pets running about, or bird calls not usually heard at night.

• Ground water levels - Watch for sudden water level changes in wells or artesian bores.

During the earthquake

• If **indoors**, stay there (clear of falling debris outside). Keep clear of windows, chimneys and overhead fittings. Shelter under and hold a door frame, table, bench etc.

• In **high rise buildings**, stay clear of windows and outer walls. Get under a desk near a pillar or internal wall.

• Do **not** use elevators.

• In **crowded areas or stores**, do not rush for doors. Move clear of overhead fittings and shelves.

• If **outside**, keep well clear of buildings, overhead structures, walls, bridges, power lines, trees, etc.

• In a **city street**, shelter from falling debris under strong archways or doorways of buildings. Don't go under awnings or parapets as they may collapse.

• If in a **vehicle**, stop in an open area until shaking stops. Beware of 'downed' power lines and road damage, including overpasses and bridges. Listen to your car radio for warnings before moving.

After the earthquake

Watch for hazards and tend injuries as follows:

• Turn off electricity, gas, water. Do **not** light matches until you have checked for gas or fuel leaks.

• Check for injuries. Apply first aid. Do **not** move the seriously injured unless in immediate danger.
• Check for broken water, sewerage or electrical mains.
• Do **not** use the telephone immediately (to avoid congestion) unless there is a serious injury or fire etc.
• Check for cracks/damage, in roof, walls, chimneys etc.
• Evacuate if badly damaged. Be prepared for aftershocks.
• Do **not** waste food and water as supplies may be interrupted. Collect emergency water from heaters, ice cubes, toilet tanks and canned foods.
• Listen to local radio and heed warnings and advice on damage and service disruptions.
• Avoid driving unless for emergency (keep streets free).
• Do not go sight-seeing or enter damaged buildings.
• Stay calm and help others if possible.

SEISMIC MICROZONATION OF LAUNCESTON, TASMANIA

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Introduction

Buildings in the city of Launceston have been damaged by five earthquakes with epicentres in the west Tasman Sea, since 1884. While the damage detailed later in this paper was not extensive, some of the reported cases had the potential to cause injury or loss of life. All of the events listed in Table 1 occurred in a zone off the north-eastern tip of Tasmania. Over 2000 earthquakes in this zone were felt during the period 1883–1892, and the cluster of epicentres can be seen in Figure 1. The January 1892 event has the same magnitude as the highly damaging 1968 Meckering, Western Australia, and January 1995 Kobe, Japan, earthquakes. The magnitude of the smallest earthquake in Table 1 is the same as that of the very destructive 1989 Newcastle earthquake.

Why should earthquakes at such large distances from Launceston be a problem? The most likely explanation lies in its complicated geology, with earthquake shaking being amplified by sediments which filled at least one ancient rift valley under the city.

As the earthquake damage in Launceston was thought to be due to amplification of earthquake waves by sediments, the Launceston City Council asked AGSO to prepare a zoning map of Launceston with zones related to the requirements of Australian Standard AS 1170.4–1993. This was accomplished by carrying out a microtremor survey of the city. Measurements were made by University of Tasmania and AGSO staff and the data were analysed and zoning maps produced by AGSO.

As the geology of Launceston was not well understood, a detailed gravity survey with 400 data points was undertaken by Mineral Resources Tasmania and the data analysed by Leaman Geophysics. It revealed a complex geology involving at least two deep NNW–SSE trending valleys filled with sediments of varying degrees of consolidation. One of these extends along the Tamar River axis from north of Trevallyn to Kings Meadows and attains a maximum sediment thickness of over 250 metres. The other lies along the North Esk valley and may be less continuous. It has a maximum sediment thickness of approximately 130 metres. The rivers are shown in Figure 2. The deeper part of the former valley along the Tamar axis in Figure 3 is marked by the elongated area of Zone 4+ following the course of the Tamar and continuing SSE of the river, in the western part of the map.

Date (UTC) dy	mo	year	Time (UTC) hr	mn	sec	LAT(°S)	LONG(°E)	Magnitude (ML)	Distance (km) from Launceston
13.	7.	1884	03	55	00	40.5	148.5	6.4*	150
12.	5.	1885	23	37	00	39.9	148.9	6.8*	220
26.	1.	1892	16	48	00	40.4	149.5	6.9*	220
28.	12.	1929	01	22	45	40.75	148.65	5.6*	140
14.	9.	1946	19	48	50	39.97	149.35	6.0	240

**Intensity-based estimate of Richter magnitude*

Table 1. Earthquakes which have caused damage in Launceston.

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Method

During the 1989 Newcastle earthquake, the area of highest seismic intensity and damage was that underlain by alluvium or fill (Somerville et al, 1993). A convenient way of assessing the likely behaviour of soils in various parts of a city during an earthquake is by recording microtremors — the ever present vibrations of the ground due to wind, surf, traffic, etc. The advantage of using microtremors is that you do not have to wait for an earthquake to record useful data, and by analysing the data on a computer you can determine which sites will amplify the earthquake vibrations, and also the fundamental period of vibration at which this will happen. The period of a vibration is the time taken for one complete oscillation. A thin layer of alluvium overlying bedrock has a shorter period of vibration than a thick layer. Similarly a low building generally has a shorter natural period of vibration than a tall building.

It is important to know the period of vibration of the ground. If it matches that of a building above it there is a resonance effect, much like a person pushing a swing higher and higher by matching the push to the moving swing. The resonance effect increases the likelihood of a building being damaged in an earthquake.

By doing a microtremor survey of a city to measure the site periods, a zoning map can be produced and used for town planning. One can lessen the chance of earthquake damage by avoiding erecting a building with a certain resonant period on a site with the same period, and pre-existing buildings with periods which match that of the site can be strengthened if necessary. The zoning map will also be useful in planning the placement of essential services to maximise their probability of being operational following an earthquake.

The microtremor measurements in this survey were made using a three-component seismometer and a digital recorder. Computer analysis was done using the Nakamura (1989) method. This involves computing the spectral ratios of each of the horizontal components (N–S and E–W) of ground motion relative to the vertical component. This technique has been found by many seismologists to give a realistic estimate of the dominant period of a site from microtremors, when compared with the results from earthquakes.

Results and Discussion

The microtremor sites are shown in Figure 2. Long natural site periods (0.7 to more than 1 second) were observed on the very deep sediments of the Tamar axis valley and also on the North Esk trough axis. Relatively short natural periods (0.1–0.5 seconds) were measured on the very shallow sediments overlying

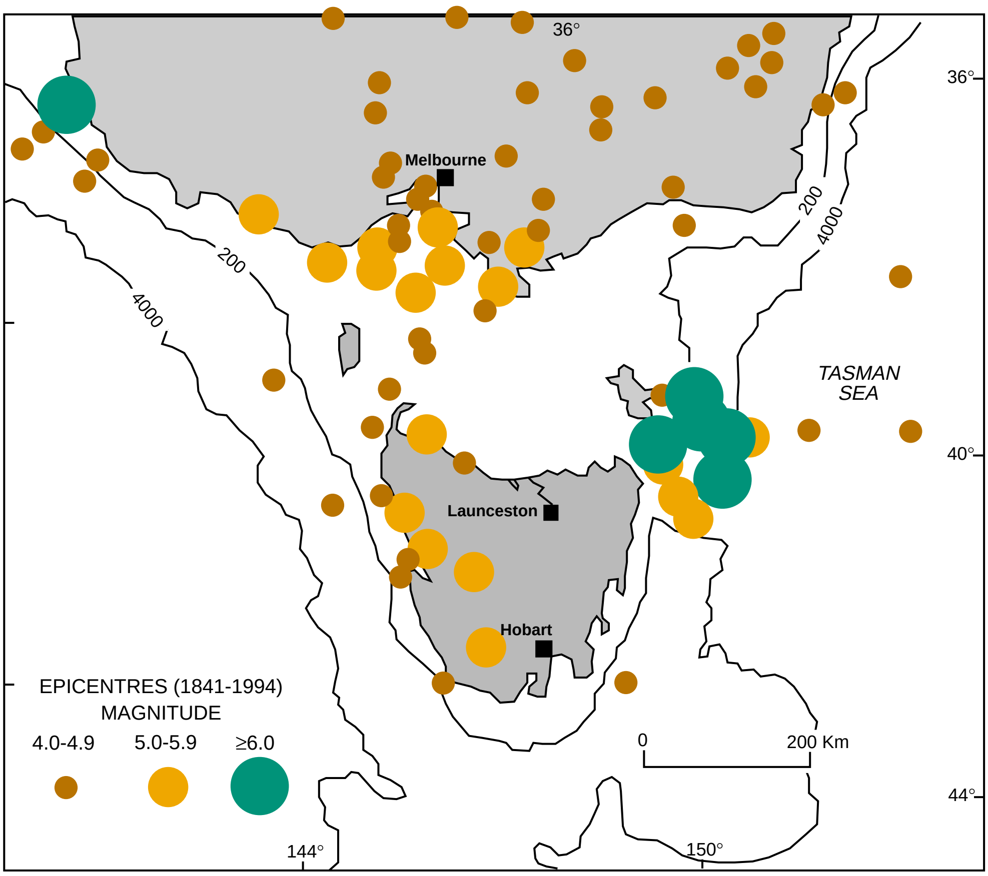

Figure1. Earthquake epicentre map of the Tasmanian region, showing magnitude 4.0 or greater earthquakes.

Figure 2. Airphoto of Launceston showing microtremor sites as dots.

dolerite in the eastern and central parts of the central business district of Launceston. These results could be anticipated from sediment thickness. There was no site amplification on dolerite because it is bedrock in the area. What was not predicted is the wide range of periods at which we assessed site amplification would occur at most other sedimentary sites. This is because the sediments were not in the uniform horizontal elastic layers assumed in theoretical calculations.

Seismic Microzonation of Launceston

Based on the microtremor measurements, the soils map (Forsyth, 1995), the gravity results (Leaman, 1994), and unpublished drillhole information provided by Mineral Resources Tasmania, we have prepared 1:10 000 building height zoning maps of the northern and southern parts of Launceston showing areas where resonance may occur for low, medium or high rise buildings in various parts of the city. The zones are consistent with the microtremor measurements and with most reports of damage in earthquakes. We have also prepared a 1:25 000 map of the site factor (S) in Table 2.4(a) of Australian Standard AS 1170.4–1993 (Standards Australia, 1993). The site factor is an estimate of the amplification of earthquake shaking due to varying foundation conditions. It ranges from 0.67 for solid rock to 2.0 for more than 12 m of soft clays, loose sands, silts or uncontrolled fill. A site factor of 2.0 assumes that the earthquake shaking will be three times greater on these soft sediments than it would have been on solid rock (2.0 = 3 times 0.67). Similarly, the shaking on a material with a site factor of 1.25 will be 1.9 times greater than that on solid rock. Figures 3 and 4 are small scale versions of these zonation maps. They have been put up on a GIS together with infrastructure information provided by the Launceston City Council.

It is assumed for the purposes of the microzonation that a single storey building has a period of 0.1 seconds, a two storey 0.2 seconds and so on, generalising to an N storey building having a period of 0.1 * N seconds. Three groups of buildings are considered for the map: low rise (1-3 storeys), medium rise (4–9 storeys) and high rise (10+ storeys). If the natural period of the ground matches the period of the building, then resonance may occur in an earthquake and this increases the probability of damage to the building. More sophisticated methods are available for computing the period of the building, in which case the building period rather than the height should be used as the relevant factor. Soil-structure interaction could also modify the period but is not considered in this report.

Using this system, a total of seven zones has been marked on the building height maps. The number of zones could have been increased considerably by considering individual building heights instead of dividing them into the three groups (1–3, 4–9 and 10+ storeys), but the maps would have become very unwieldy and the Launceston City Council had requested that the number of zones be kept small for ease of comprehension.

The seven zones on the building heights maps are as follows:

ZONE 0. No site resonance, all buildings: *Dolerite, weathered dolerite, dolerite soils, bauxite, laterite, dolerite conglomerate. Care should be taken when applying this to dolerite conglomerate, as some of it may be underlain by thick Tertiary sediments and, in this case, its response would be unknown.*

ZONE 1–3. Possible resonance for 1–3 storey (low rise) buildings: *Shallow stiff sediments over dolerite; high gravity values. Site periods in the range 0.1–0.3 seconds measured at some sites.*

ZONE 1–5. Possible resonance for 1–5 storey buildings: *This is a narrow NNW–SSE trending zone along the eastern side of the Tamar axis valley. It was delimited by microtremor measurements which showed a tight range of periods, hence this exception to the three groups of buildings rule.*

ZONE 1–9. Possible resonance for 1–9 storey (low and medium rise) buildings: *Small zones on Tertiary sediments on Windmill Hill and near Coronation Park.*

ZONE ALL. Possible resonance for all buildings: *Microtremor measurements show amplification for a broad range of periods. The sites are often Tertiary sediments, not at the axis of deep valleys. Also, zone inferred from gravity and the soils map, in the NE part of the North Esk axis and, from microtremors, as a small area of floodplain.*

ZONE 4+. Possible resonance for 4 or more storey (medium and high rise) buildings: *Mainly deep sediment fill in the Tamar and North Esk axis valleys and the Norwood area. Also a zone on shallow floodplain sediments, including most of old railway yard.*

ZONE 10+. Possible resonance for 10 or more storey (high rise) buildings: *Zone, inferred from gravity and soils map, to east of old railway yard.*

On the site factor map the zones are as follows:

ZONE S=0.67–1.0: *Dolerite, weathered dolerite, dolerite soils, bauxite, laterite, dolerite conglomerate. S=0.67 should be used for fresh dolerite, S=1.0 for the rest. Care should be taken when applying this to dolerite* *conglomerate, as some of it may be underlain by thick Tertiary sediments and, in this case, its response would be unknown.*

ZONE S=1.0–1.25: *Shallow stiff sediments over dolerite; high gravity values. Site periods in the range 0.1–0.3 seconds measured at some sites.*

ZONE S=1.25: *Tertiary sediments.*

ZONE S=1.5: *Zone, inferred from gravity and the soils map, in the NE part of the North Esk axis and, from microtremors, as a small area of floodplain.*

ZONE S=1.5–2.0: *Zone on shallow floodplain sediments, including most of old railway yard. Also northern part of Tamar axis valley. A drillhole in the neighbourhood of Riverside revealed 40 metres of Quaternary overlying 120 metres of Tertiary sediments.*

ZONE S=2.0: Zone, inferred from gravity and soils map, to east of old railway yard.

Figure 4 also shows the city's infrastructure from the Launceston City Council GIS.

Earthquake Damage and its Relationship to Zones

In contemporary newspapers, particularly the *Examiner* and *Mercury*, there have been a number of reports of damage to buildings in Launceston from the earthquakes in Table 1. Not all locations were described precisely enough to be able to be pinpointed on a map, but 14 of them were. These are marked in Figure 3.

The damage at these 14 sites is noted below.

Richard Gee's house, Cataract Hill: Footstep split in 1892 earthquake. This earthquake was felt more severely by residents on the hills. The site was a dolerite hill, so this damage was probably a topographic effect, due to shaking being greater at the tops of tall structures and hills — like an inverted pendulum. *S=0.67, Zone 0.*

Shop on the corner of Frederick and Bathurst Streets: Ceilings cracked in 1884 earthquake. *S=1.25, Zone 4+.*

Bakehouse in Charles Street: New chimney collapsed in 1884 earthquake. *S=1.25, Zone 1–5.*

St Andrews Church, corner of St John and Paterson Streets: Top of pinnacle broken off and at least one more put out of perpendicular in 1884 earthquake. Finial of a pinnacle fell in 1885 earthquake. Stone ornament at top of spire fell in 1929 earthquake. *S=1.25, Zone 1–5.*

Margaret Street Wesleyan Church: Large patch of ceiling shaken down in 1884 earthquake. *S=1.25, Zone 4+.*

Railway Boarding House, corner of Cameron and Tamar Streets: Damaged in 1884 earthquake but already had slight cracks. *S=1.25, Zone 1–3.*

Mr Dunning's drapery establishment, Brisbane Street: Plate glass window split in two places in 1885 earthquake. *S=1.25, Zone 1–5.*

Dempster Pearce's establishment, Brisbane Street: Chimney fell in 1885 earthquake. *S=1.25, Zone 1–5.*

Roman Catholic Church, Margaret Street: Large pieces of plaster fell in 1885 earthquake. *S=1.25, Zone 4+.*

House at 147 York Street: Half of chimney fell in 1885 earthquake. *S=1.25, Zone 4+.*

General Hospital, corner of Charles and Howick Streets: Chimney fell in 1892 earthquake. Twelve feet of brick fell off top of chimney over laboratory, coping slab weighing about 3 cwt fell off chimney over operating theatre, and plaster came down in one of rooms of nurses' home in 1929 earthquake. *S=1.25, Zone ALL.*

Terminus Hotel, corner of William and Tamar Streets: Crack 9 foot long across a wall in 1946 earthquake. *S=1.25, Zone 1–3.*

Court House Hotel, corner of Wellington and Paterson Streets: 5 ft x 18 inch piece of plaster fell from ceiling in 1946 earthquake. *S=1.25, Zone ALL.*

House at 40 Welman Street: Pane of glass shattered in 1946 earthquake. Also happened in house opposite. *S=1.25, Zone ALL.*

The buildings in the 14 instances of damage outlined above were probably all 1–3 storey (low rise) structures, though it is not known how the presence of a steeple and other architectural features would modify the period of vibration of the three churches. It is also not known to what extent the state of repair of each of the 14 buildings influenced the ease with they became damaged in an earthquake.

Nine of the 14 buildings were situated on sediments (Zones 1–3, 1–5 and ALL), the natural periods of vibration of which may have matched that of the structure. In these nine cases, the damage may have been caused by the enhanced shaking due to resonance. The four buildings situated in the Zone 4+ are built on old lake sediments up to 250 m deep, in a valley bounded by a fault with relatively solid rock on the western side. Here, the damage may be the result of earthquake shaking being amplified because the earthquake waves travel slower in the sediments, or their energy being concentrated in certain areas by the asymmetric geology, or both.

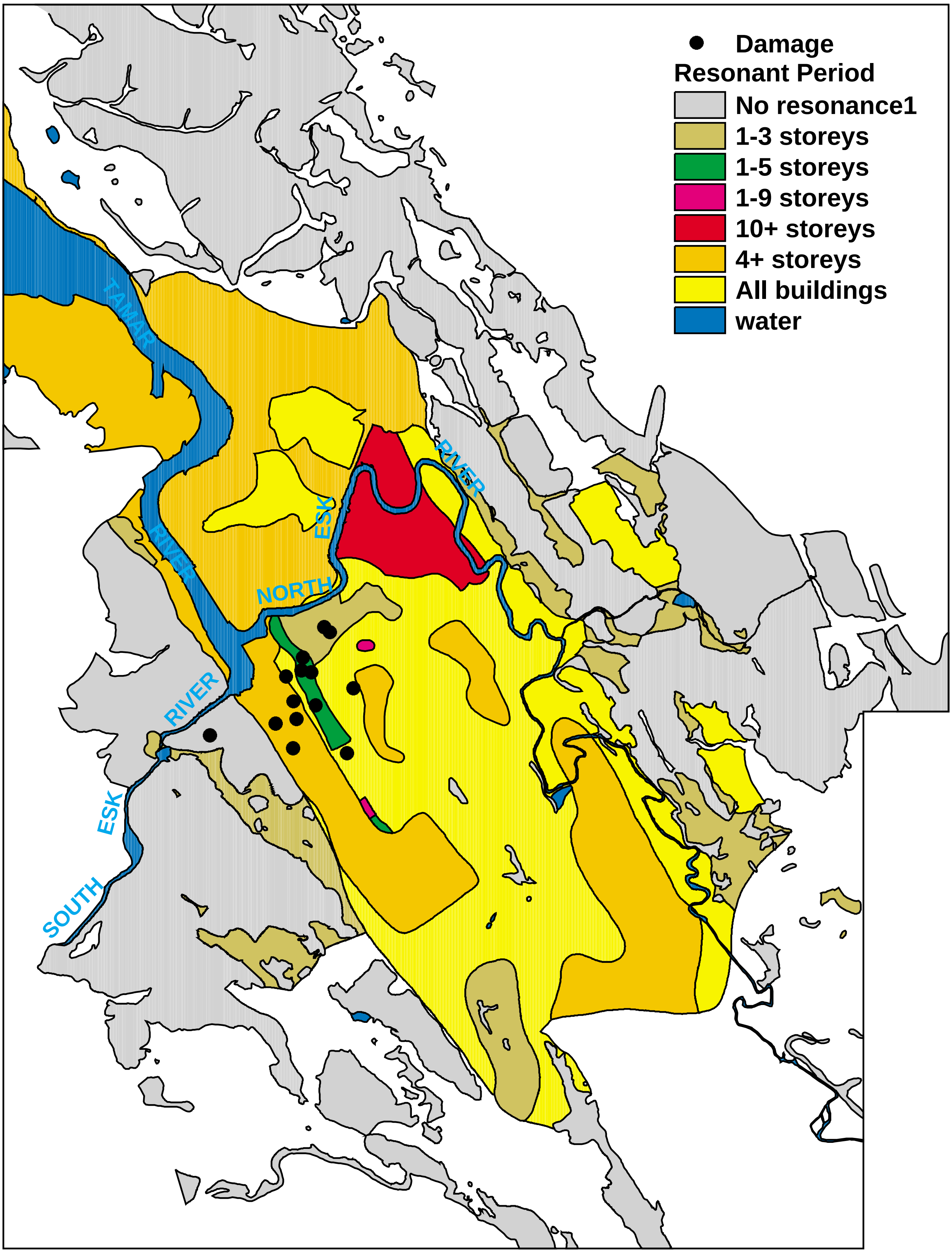

Figure 3. Building height zoning of Launceston, showing locations of damage sites as dots.

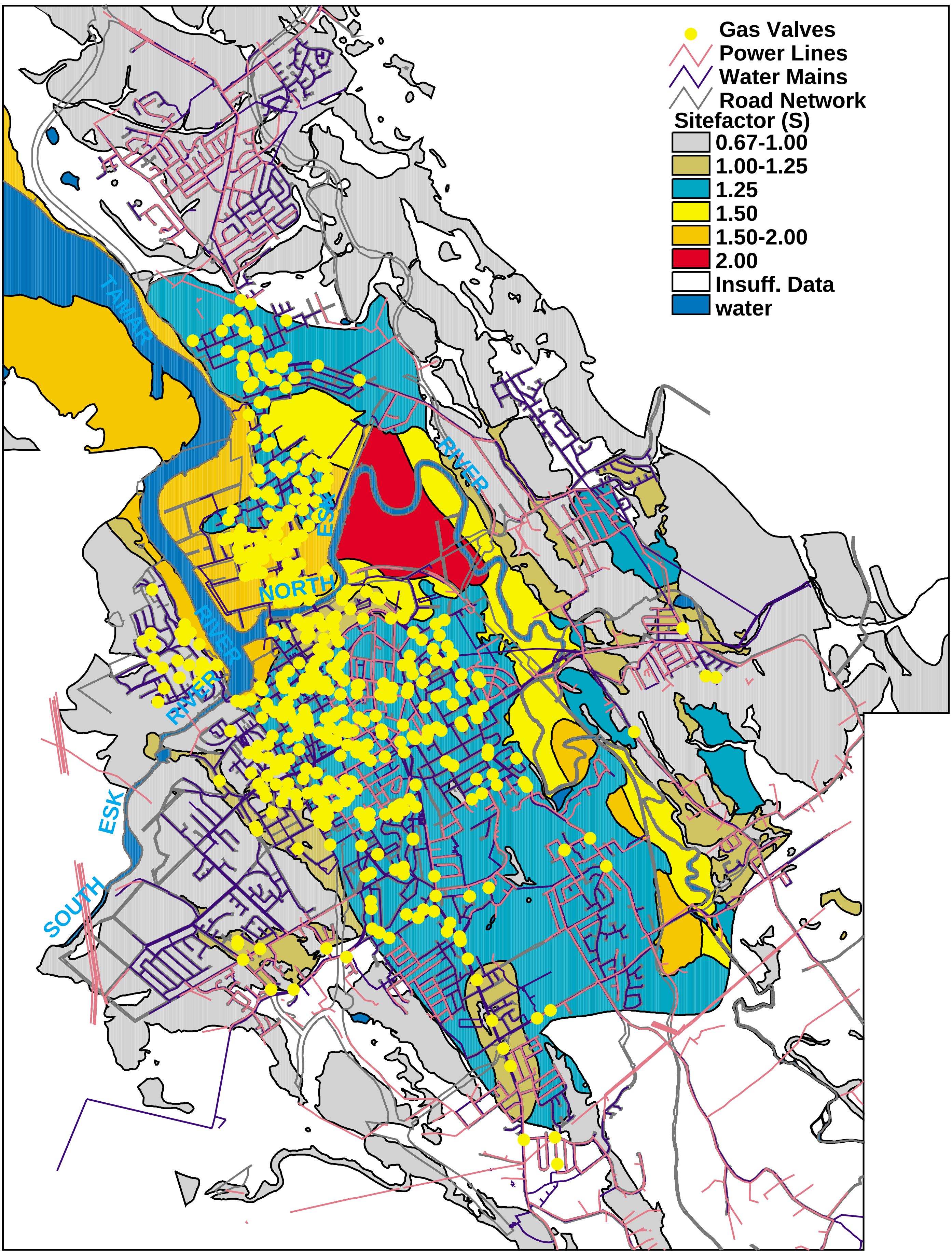

Figure 4. Site factor zoning map of Launceston, showing infrastructure.

What is the Probability of Extensive Earthquake Damage In Launceston?

Earthquake Zones. The epicentres of earthquakes with Richter magnitudes of 4.0 or more in the Tasmanian region are shown in Figure 1. All the events which caused damage in Launceston were in the west Tasman Sea off the northeastern tip of Tasmania. In this zone, the average time interval between large (Richter magnitude 6.0 or greater) earthquakes is about 70 years (Michael-Leiba & Gaull, 1989). At its closest point, this zone is still 150 km from Launceston and, as shaking decreases with distance from an earthquake, the probability of an event in this zone causing extensive serious structural damage to buildings on sediments in Launceston is negligible.

The other seismic zone from which earthquakes could cause damage in Launceston is western Tasmania. The average time interval between large earthquakes in this zone is estimated to be 290 years and the largest known event was of Richter magnitude 5.5 in South West Tasmania in February 1880, slightly smaller than the 1989 Newcastle, New South Wales earthquake.

Launceston itself does not lie in an earthquake zone, and the probability of an event the size of the 1989 Newcastle earthquake, Richter magnitude 5.6, happening within 20 km of the Launceston GPO in a year is estimated to be only about 1 in 70 000.

Launceston Earthquake Hazard. As the instances of recorded earthquake damage in Launceston were slight and isolated, the Launceston City Council asked us to estimate the probability of the city sustaining extensive damage from earthquakes off the northeastern tip of Tasmania, those in western Tasmania, and those in the immediate vicinity of Launceston. The first baseline for our calculations is widespread minor damage to structures on firm ground, but amplification by sediments combined with resonance effects may produce moderate to serious damage to many structures on sediments. Because of distance, the probability of an earthquake off the northeastern tip of Tasmania causing this damage in a year is negligible. From a western Tasmanian earthquake, the probability is about 1 in 95 000; and from an earthquake within 22 km of Launceston, about 1 in 23 000. The combined probability of this happening in Launceston in a year is estimated to be about 1 in 18 000.

The second baseline is a level of shaking on firm ground at which windows and crockery are broken, there is some plaster damage, and there are isolated cases of damage to chimneys and weak buildings. This could give rise to minor to serious structural damage on sediments.

The probability of this ground motion in any one year in Launceston from an earthquake off northeastern Tasmania is about 1 in 1600, from western Tasmania 1 in 6100, and from an event within 43 km of Launceston 1 in 3000. This gives a combined probability from these sources of 1 in 880 of Launceston experiencing this level of shaking in a year.

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