# CHAPTER 7: A MULTI-HAZARD RISK ASSESSMENT

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## Overview

Our approach in developing this multi-hazard risk assessment of Mackay has been consistent with the general risk management process outlined in *AS/NZS 4360:1999 Risk management* (see Figure 1.1 and Figure 1.2) and its evolving application in the emergency (or disaster) risk management field. So far in this report we have:

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

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

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

> ***Risk*** (i.e. 'total risk') *means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon…*
>
> (Fournier d'Albe, 1986)

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

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

## Risk Criteria

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

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

- for earthquake - the criteria established in *AS1170.4-1993* are the minima to prevent buildings suffering structural collapse under earthquake loads for which there is a 10% probability of exceedence in any 50 year period (i.e an ARI of around 500 years). More stringent design standards are required for structures used for what we have termed 'critical facilities';
- for flood - Council Guidelines require ground fill levels of new urban subdivision development to be above the level of the ARI = 50 years flood, and new building floor levels to lie above the level of the ARI = 100 years flood;
- for destructive winds - under the criteria established in *AS 1170.2-1989*, no building should fail unless exposed to wind loads greater than those for which there is a 5% probability of exceedence in any 50 year period (i.e. an ARI of around 1000 years);
- for storm tide - Council Guidelines require ground fill levels of new urban subdivision development to be above the level of the ARI = 50 years storm tide event (plus allowance for other factors), and new building floor levels to lie above the level of the ARI = 100 years storm tide (plus allowance for other factors).

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

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

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

## Total Risk Assessments for Mackay Suburbs

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

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

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

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

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

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

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

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

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

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

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

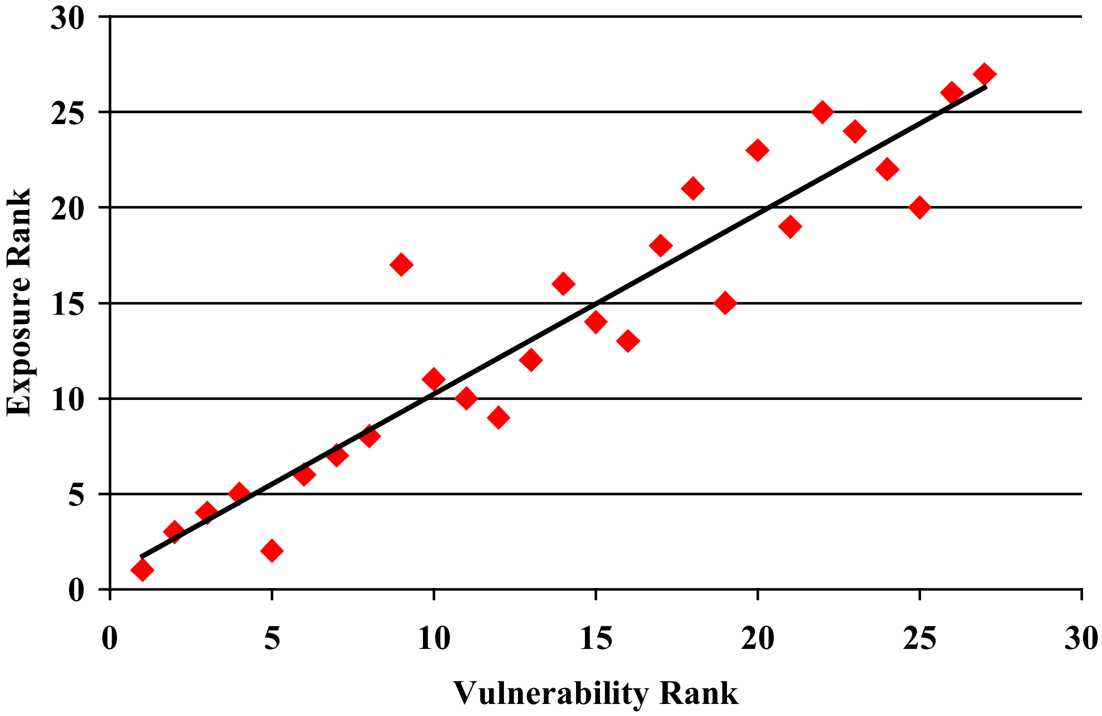

Figure 7.1: Mackay earthquake total risk relationship

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

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

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

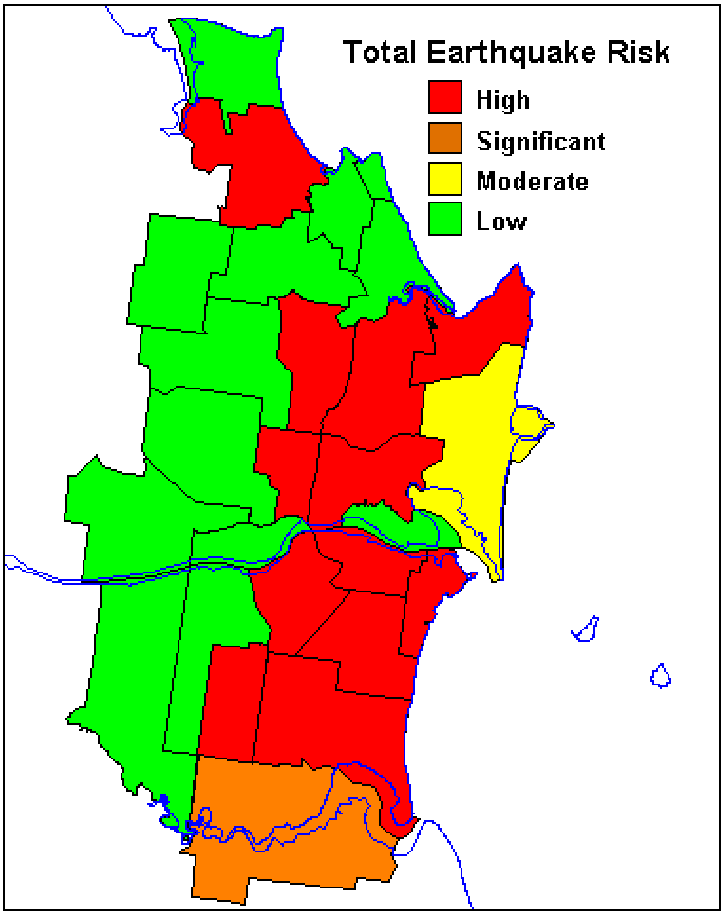

Figure 7.2: Distribution of total earthquake risk

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

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

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

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

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

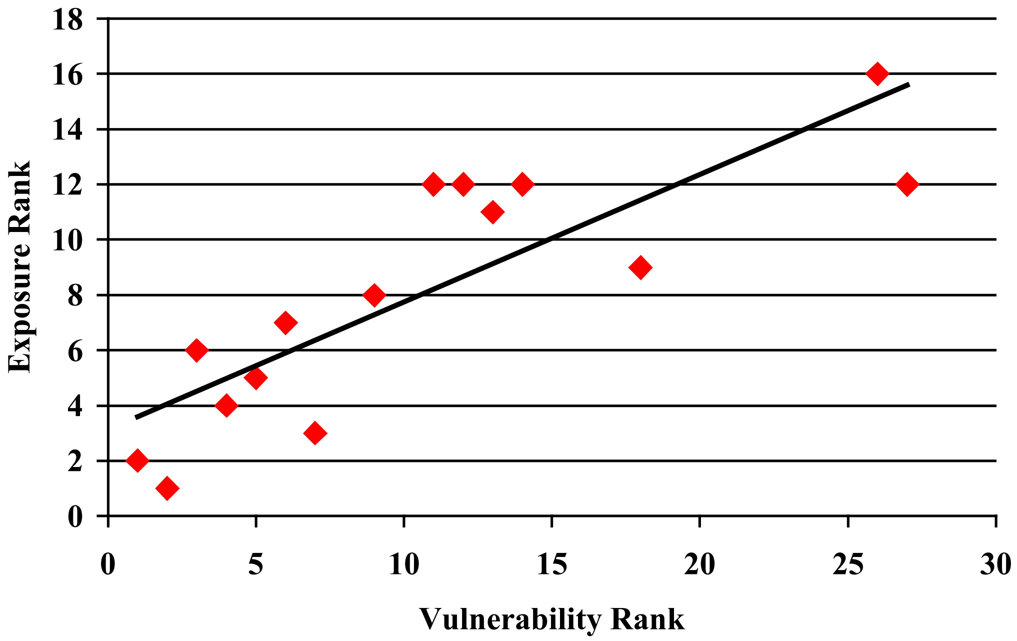

Figure 7.3: Mackay flood total risk relationship

Table 7.3: Mackay suburb rating for total flood risk

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

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

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

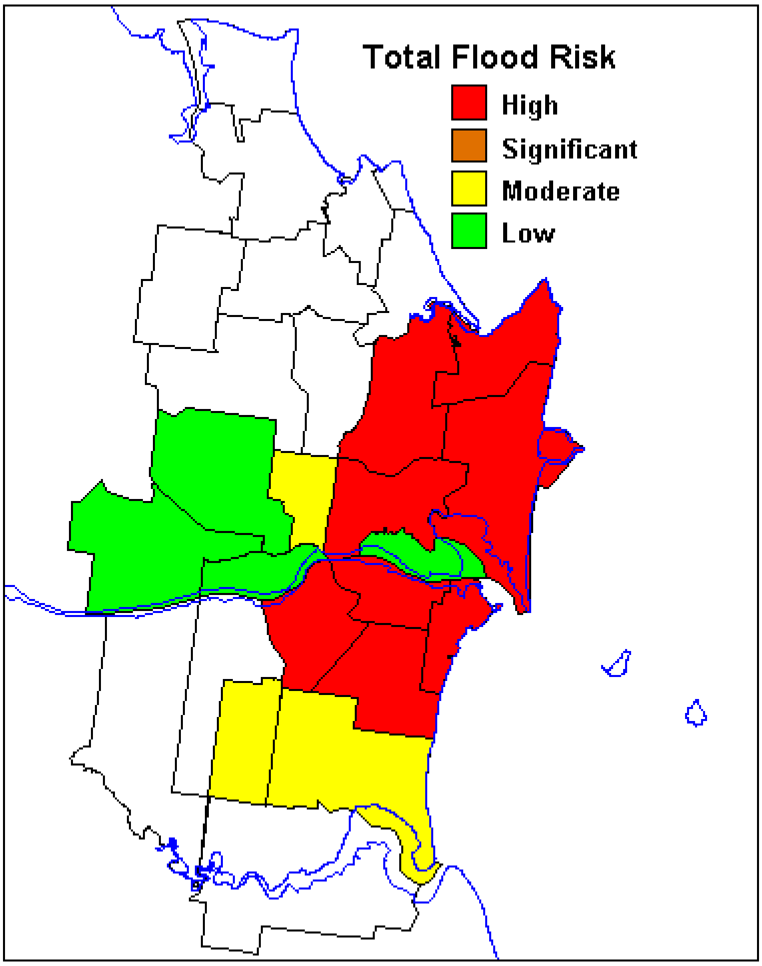

Figure 7.4: Distribution of total flood risk

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

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

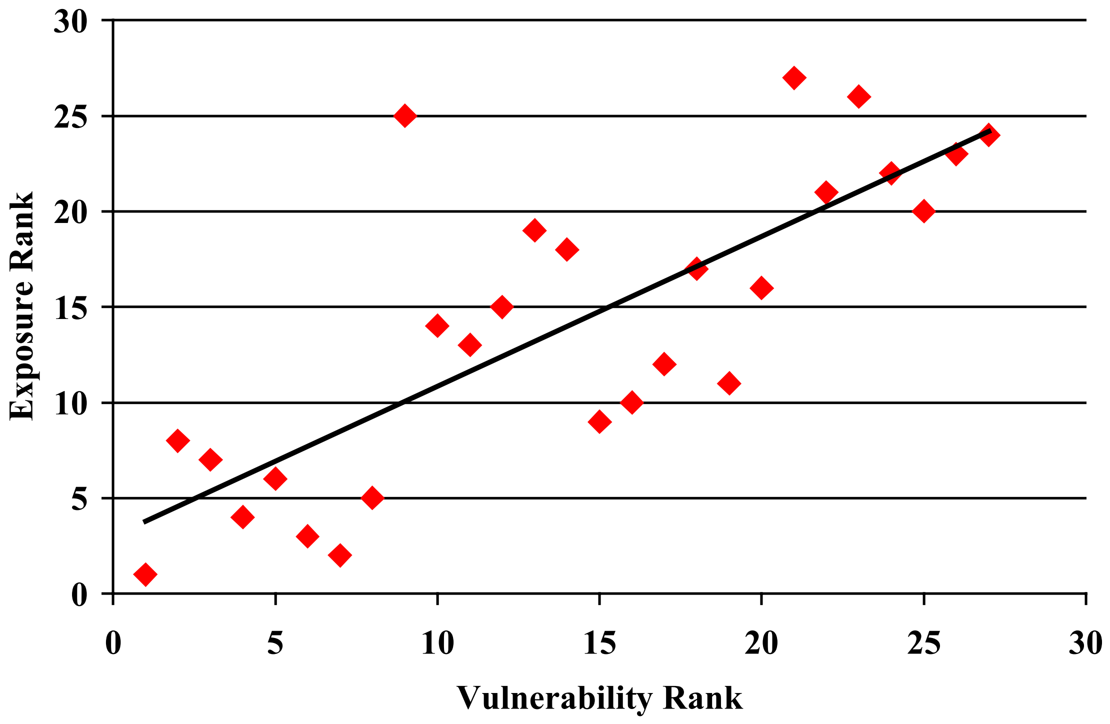

Figure 7.5: Mackay total severe wind risk relationship

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

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

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

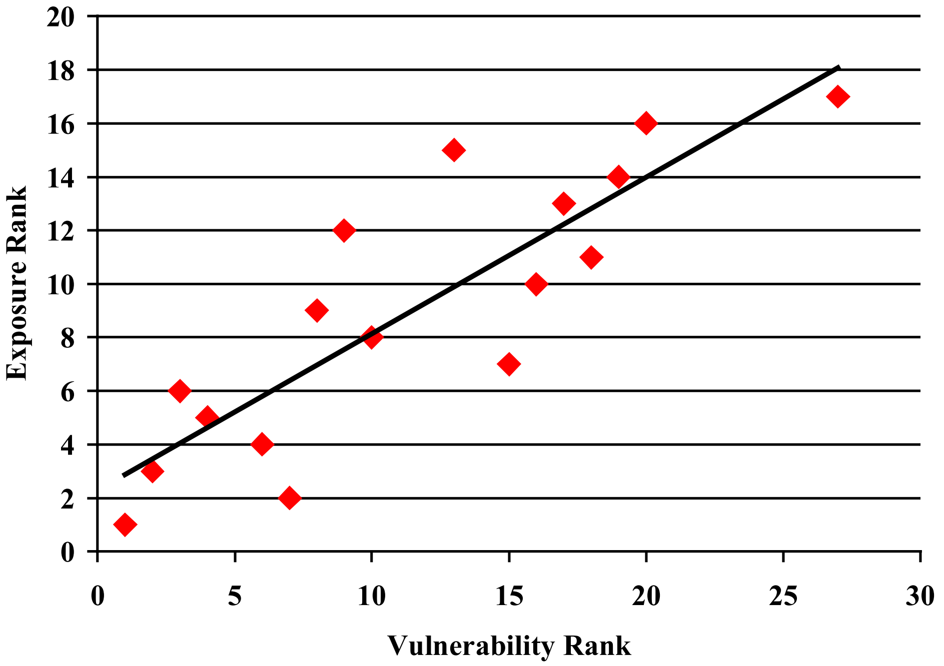

Figure 7.7: Mackay storm tide total risk relationship

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

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

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

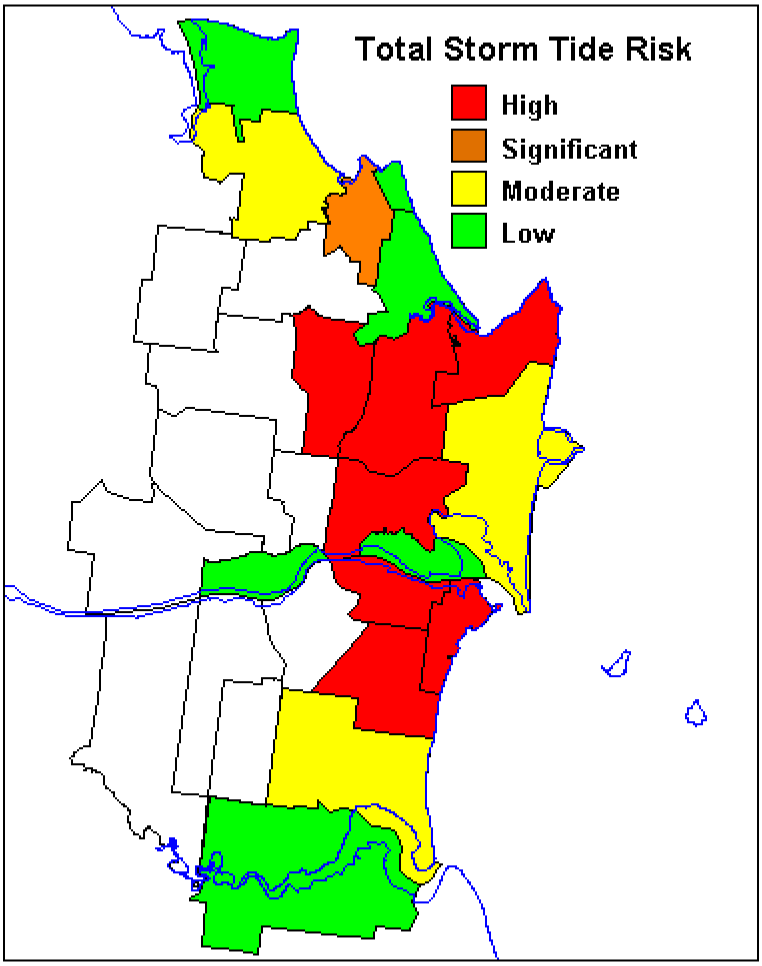

Figure 7.8: Distribution of storm tide total risk

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

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

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

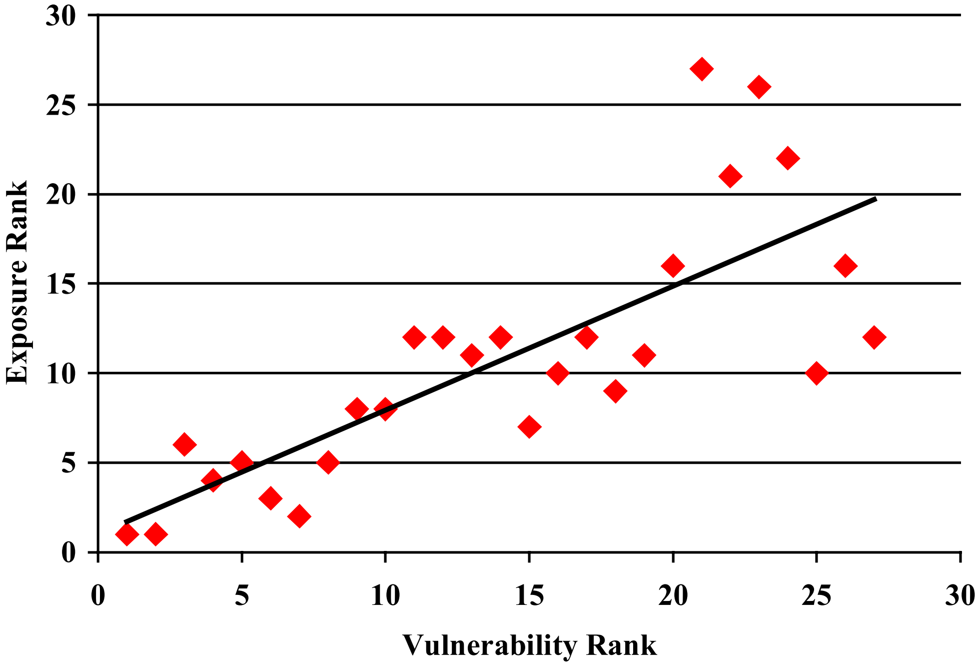

Figure 7.9: Mackay cyclone (combined) total risk relationship

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

### Risk Evaluation and Prioritisation

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

**S**eriousness, **M**anageability, **A**cceptability, **U**rgency and **G**rowth

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

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

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

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

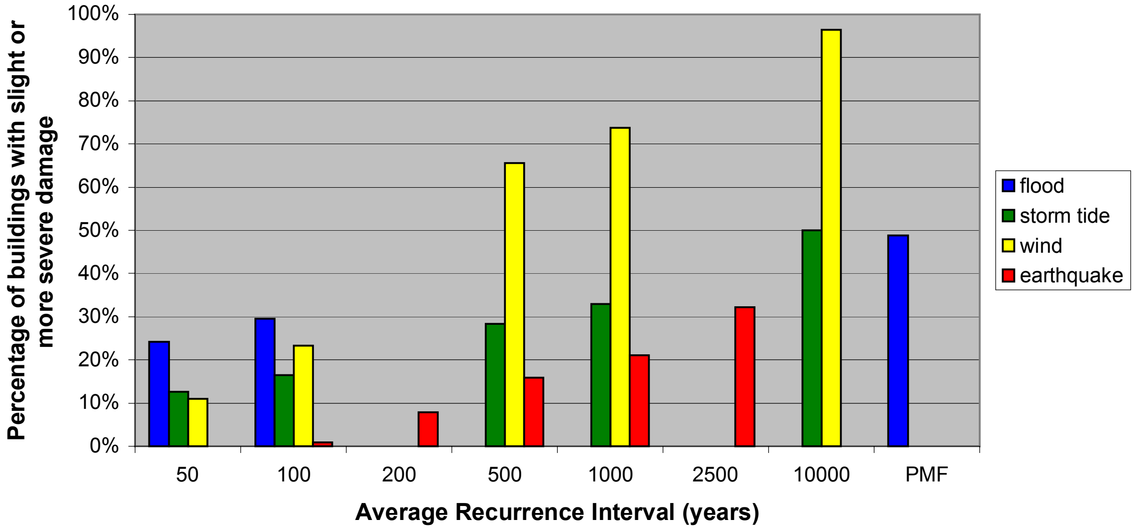

Figure 7.11: Slight or more severe damage for all hazard scenarios considered

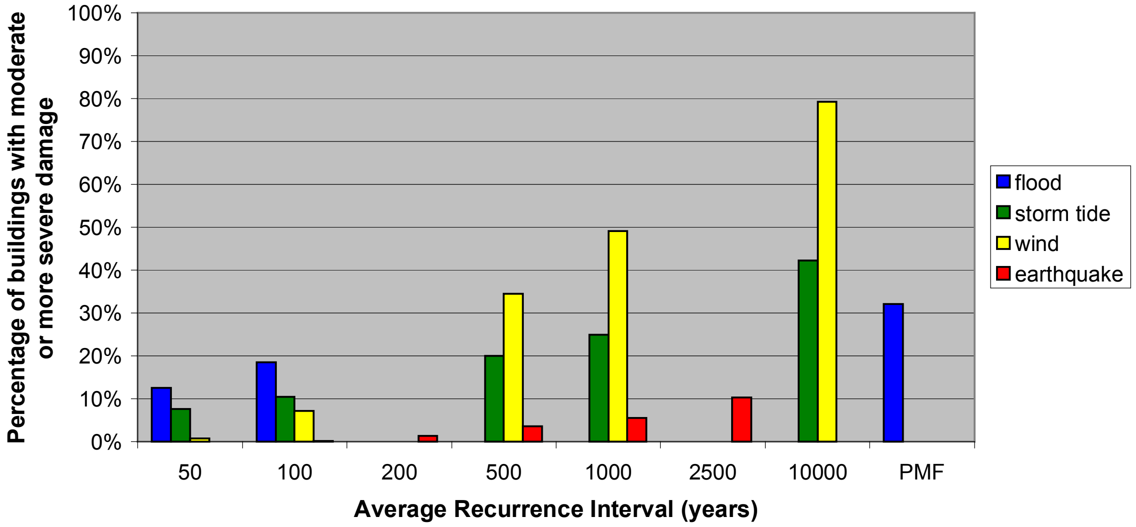

Figure 7.12: Moderate or more severe damage for all hazard scenarios considered

Although the absolute levels of predicted damage may have bias or significant associated uncertainty, the relative risks are, we believe, more robust.

Although we have attempted to compare damage from the different hazards as closely as possible, there are some differences in the assessments. For earthquakes and severe winds, residential buildings only were considered, whereas for storm tide and floods all buildings were considered. For storm tide, floods and severe wind, damage to buildings and building contents was included whereas for earthquakes, building damage only was considered. These differences are considered relatively minor in comparison to other uncertainties in the risk evaluation.

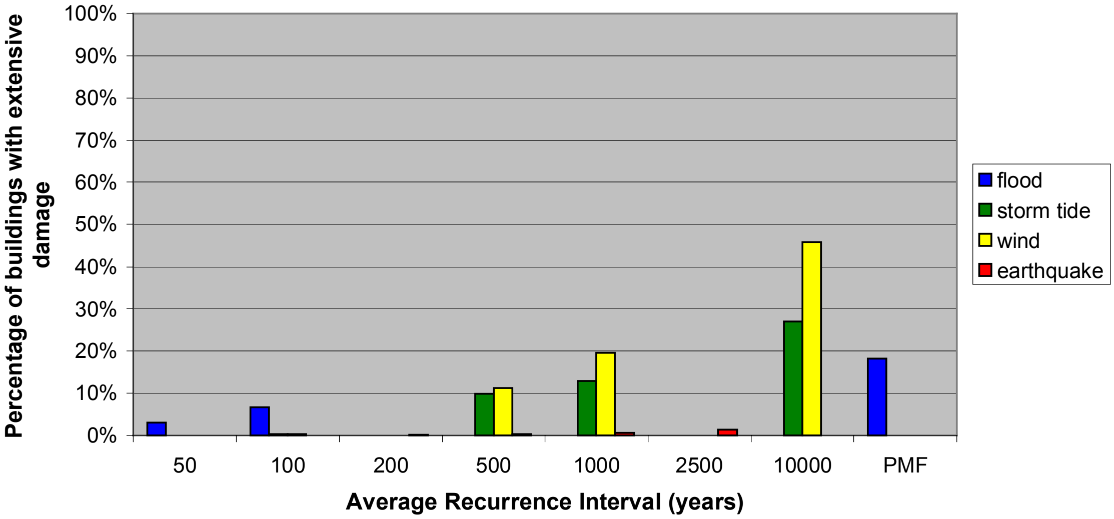

Figure 7.13: Extensive damage for all hazard scenarios considered

Notwithstanding the many uncertainties inherent in the risk evaluation, the results indicate that the single geohazard **Floods in the Pioneer River pose the greatest risk to Mackay.** Major flood levels in the Pioneer River have been reached 20 times since 1884. If the risks associated with local storm water surcharge from the same rainfall episode that caused the riverine flooding were added (a very significant issue for Gooseponds Creek), the potential damage from floods would be greater than indicated.

The relatively frequent major flooding events make floods the greatest risk to Mackay. In scenarios with ARIs of 50 years and 100 years, more than 10% of Mackay buildings will be moderately or more severely damaged (Figure 7.12). However, extreme floods will not affect all parts of Mackay, unlike extreme earthquakes and winds from tropical cyclones, which could cause damage across all suburbs.

A major flood, beyond the 50 year ARI level, has not been experienced in Mackay since settlement. Given that the flood structural mitigation works in place in Mackay have been set at what was thought to be the 50 year ARI level, but in fact may be the level for events with an ARI of less than 50 years, is likely that events with an ARI of 100 years or more will cause major loss. Under such a major flood scenario (ARI ≥ 100 years), Mackay would be isolated for some time, given that all road and rail links would be cut and the Mackay airport would also be closed by flood waters. The isolation would be, in part due to flooding of creeks and rivers to the north and south of the Pioneer. Such an event could also pose significant environmental risks, including the potential for the mouth and course of the Pioneer River to change significantly. It is estimated that the Probable Maximum Flood will cause moderate or more severe damage to about 30% of Mackay buildings.

A program of levee construction began in the 1960s and is nearing completion. Planning constraints for development in the flood-prone areas of the estuary were not introduced until the early 1990s, though much of the urban area at risk had already been established by that time. Flooding is, however, generally of short duration and the warning systems operated by the Bureau of Meteorology provide sufficient time for residents to take steps to protect their property and for emergency services to conduct precautionary evacuations if that course of action is indicated.

The risk of fatalities in any flood event is significant, especially where people ignore warnings to evacuate, or indulge in irresponsible behaviour such as 'surfing' in the floodwaters or attempting to negotiate flooded roads. Drownings through this kind of behaviour and building failure have been demonstrated by the 1958 flood.

The geohazards **severe wind from tropical cyclone and storm tide are equal second in the threats they pose to Mackay**. In relatively frequent events (e.g., ARI = 50 or 100 years), wind will cause less damage than floods and possibly less than storm tide also. However, wind has the potential to inflict damage over a large geographical area, whereas the impact of storm tide and flood is restricted to low lying and coastal areas. In events that are unlikely to occur (e.g, ARI = 500 or 1000 years), wind will damage more Mackay buildings than any other geohazard (Figure 7.12).

It should be noted, also, that predictions of wind damage from the wind speeds in *AS1170.2-1989* are higher than the levels predicted in this study, for events with any probability of occurrence. In fact, the wind model based on *AS1170.2-1989* leads to the result that wind is the geohazard that causes the greatest risk to Mackay. We have compared the damage from the two wind models in Chapter 6.

Design practice aimed at making buildings more resilient to strong winds came into use in the 1950s. The cyclone resistance of major buildings was formalised in 1975 through the Queensland Building Act. The resistance of some classes of buildings was significantly upgraded in 1982 with the introduction of Appendix 4 of the Act which also introduced requirements for domestic structures. These appear to provide an effective form of mitigation. However, older buildings in Mackay (about two-thirds of all buildings) were not constructed in accordance with these standards.

Given the capacity of the cyclone monitoring and warning system operated by the Bureau of Meteorology, it is now highly unlikely that the Mackay community will be caught by surprise by tropical cyclone. Thanks to the annual community awareness campaign mounted jointly by the Bureau, the DES and Mackay City Council, there is a high level of community awareness of the risk and how to cope with it. The level of awareness has been reinforced by the community's experience of Cyclone *Justin* in 1997. The risk to life from destructive cyclone winds, therefore, should be low and confined to the foolhardy who ignore the warnings and advice, or those who do not hear or understand the warnings.

Mackay holds the dubious distinction of being the only significant urban population in Australia to have suffered a significant **storm tide** impact. That 1918 experience has clearly remained strong in the community's consciousness.

For the more frequently occurring events (ARI ≤ 100 years), storm tides have a lesser potential for loss than floods and this is the reason why storm tide risk is less than flood risk. Storm tides and floods will cause moderate damage to similar numbers of buildings, but floods will also cause extensive damage to significant numbers of buildings (Figure 7.13).

For rarer, more extreme events, the situation is reversed and storm tide has the potential for greater destruction than floods in these rare events (Figure 7.12).

The potential for destruction by storm tide is derived not only from the large numbers of people, buildings and critical facilities that are located within the area in which storm tide impact would be greatest but also from the extremely limited options available in Mackay for safe evacuation ahead of a storm tide impact. A significant storm tide also carries with it the threat of major environmental impacts. These include major levels of coastal erosion and/or deposition that would, in turn, pose a threat to beachside suburbs. A small sampling of the damage potential of storm tide and associated high seas in Mackay was provided by Cyclone Justin in 1997.

Although earthquakes are not widely recognised as a significant threat to Mackay, our research leads us to conclude that **earthquakes pose the fourth geohazard risk to the Mackay community**. **The level of earthquake risk in Mackay is certainly significant and earthquakes should be considered in risk management strategies for the city.** For more frequently occurring events, damage will be low. However, like severe winds, earthquakes have the potential to impact upon the entire Mackay community, and strong but rare events (e.g., ARI ≥ 1000 years) will cause damage to many buildings (Figure 7.12).

The probability of death is low in any of the earthquake scenarios considered. However, the possibility of casualties or deaths in Mackay from earthquakes cannot be excluded.

The economic risk posed by earthquake in Mackay is substantial, especially in the older parts of the city. In addition to losses from building damage, old and brittle underground utilities such as water and sewerage networks will be especially susceptible to damage.

## Risk Mitigation Options

The development and implementation of risk mitigation strategies for Mackay lies outside the remit of the *Cities Project*. Our experience in working with emergency managers and others, in Mackay and elsewhere, has, however, given us some insight into key aspects of risk mitigation that are offered here as observations, rather than as suggestions, let alone recommendations.

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

Unlike many other local governments in Queensland, risk management has clearly taken root in Mackay City Council, though it is still at an early and fragile stage of development. This commitment can be largely attributed to the pioneering efforts of successive city engineers since the early 1990s and most recently through the Council's active involvement in the Queensland *Local Government Disaster Mitigation Project* sponsored by the DES. Indeed Mackay Mayor Julie Boyde has been actively involved in that project. The lead shown by Mackay City Council is clearly underpinned by the development and promotion, by the DES, of practical guidelines for local governments to follow in pursuing 'disaster risk management' (Zamecka and Buchanan, 1999).

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

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

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

- historical information: whilst the Bureau of Meteorology, QUAKES and AGSO maintain their own information on hazard history, and other bodies in the community such as the Historical Society and the *Mackay Mercury* each maintain collections on the community experience of disaster, there is no consolidated index or coordination of information about the Mackay history of disasters and their impact on the community, other than for the 1918 cyclone and, perhaps, the 1958 flood;

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

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

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

Monitoring and warning systems: For all of the hazards considered in this study, with the exception of earthquake, warnings of impending impact are already provided. Whilst there is some scope to improve their timeliness and accuracy, their value will only be increased when individuals are able to relate warning information to their own circumstances and translate that information into risk reduction action. To achieve this it is necessary to increase public awareness by combining appropriate risk information and warning information.

A report produced by the Institution of Engineers, Australia (Institution of Engineers, 1993) provides a useful hypothetical example of the benefits of this approach in the following terms:

> *Flood warning systems now feature real time data collection networks linked to computer based flood models. These systems not only identify and track floods down a river but also*

> *enable emergency services to quickly assess the impact of various scenarios of increased or decreased rainfall, changing tidal conditions in the lower reaches of the river and varying tailwater effects at the river mouth due to storm surge and wave setup. Based on these scenarios, authorities can take more effective action to save lives and minimise damage to property. Even in a catchment with only one thousand flood prone homes, accurate advanced information on flood levels which enables residents to move contents and motor vehicles to locations above flood waters can result in a saving of $10 000 per household.* ***This $10M savings is a direct benefit to the community every time such a flood occurs.***
>
> (emphasis in original)

Nonetheless, warning systems will be much more effective if the community is aware of their existence and of the implications of warnings.

Community awareness: It is widely recognised by emergency managers that 'an aware community is a prepared community'. To put the reverse argument, all of the investment in risk information, warning systems, risk science and emergency planning is completely wasted unless it also influences the community to adopt risk reduction strategies. An effective strategy of risk communication is, therefore, essential. For example, a typical public flood warning will be expressed in terms of a height on the reference flood gauge (e.g. the Forgan Bridge gauge). Few people could translate that level to their own property in terms of how high the water would reach, with any certainty, consequently the value of the warning is diminished because few individuals would know what action they should take in response.

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

> Rule 1 – accept and involve the public as a legitimate partner: *the goal of risk communication in a democracy should be to produce an informed public that is involved, interested, reasonable, thoughtful, solution-oriented, and collaborative; it should not be to diffuse public concerns or replace action.*
>
> Rule 2 – plan carefully and evaluate your efforts: *there is no such entity as "the public"; instead, there are many publics, each with its own interests, needs, concerns, priorities, preferences, and organisations.*
>
> Rule 3 – listen to the public's specific concerns: *people in the community are often more concerned about such issues as trust, credibility, competence, control, voluntariness, fairness, caring, and compassion than about mortality statistics and the details of quantitative risk assessment.*
>
> Rule 4 – be honest, frank and open: *trust and credibility are difficult to obtain. Once lost they are almost impossible to regain completely.*
>
> Rule 5 – coordinate and collaborate with other credible sources: *few things make risk communication more difficult than conflicts or public disagreements with other credible sources.*
>
> Rule 6 – meet the needs of the media: *the media are frequently more interested in politics than in risk; more interested in simplicity than in complexity; more interested in danger than in safety.*

> Rule 7 – speak clearly and with compassion: *tell people what you cannot do; promise only what you can do, and be sure to do what you promise.*

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

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

Building and planning codes: Building codes and planning regulations are rightly seen as being very effective strategies for risk reduction. The simplest way to reduce risk is obviously to prevent development in areas that are prone to regular and/or significant hazard impact such as floods. Such an approach has already been adopted in Mackay with the Council's inundation policy for new development. It requires immunity to the 50 year ARI flood and storm tide event for fill levels for buildings, and floor levels for all habitable rooms above the 100 year ARI flood and storm tide levels.

If planning constraints are not a viable option (as is the case with earthquakes and destructive winds), the best option is to ensure that the buildings and infrastructure that provide the community with shelter, sustenance, security and social viability are built to withstand reasonable degrees of hazard impact.

Mackay City Council enforces the provisions of the Australian Building Code, which established minimum standards for construction to safely withstand established levels of earthquake and wind risk. Whilst these standards reduce the risk to new buildings, standards and guidelines have also been developed to 'retrofit' older buildings to similar levels of safety against earthquake and wind loads. Preliminary consideration is also being given to the development of comparable standards for design and construction in areas prone to landslide and to inundation hazards such as flood and storm tide.

However, by no means is all geohazard risk in Mackay treated by building and planning regulations. The rarer, more severe geohazard events make a secondary but substantial contribution to the total geohazard risks in Mackay. In the case of flood and storm tide, for example, this means that new buildings complying with the Council's Guidelines are protected from most of the flood and storm tide risk in Mackay, but they still face the risk of inundation from more severe events than those addressed by the Guidelines.

In contrast, the design event for the wind loading standard *AS1170.2-1989* has an ARI of 1000 years such that the adoption of the wind standard is a conservative measure in comparison with the flood and storm tide risk criteria. The standard may be even more conservative than it appears, and the community additionally protected, because recent research suggests that wind gust speeds for Mackay may not be as high as described by the standard.

This study has provided new earthquake hazard information. Mackay City Council could use the information to ensure that development does not introduce unnecessary risk. The Council could, for example, adopt the Mackay earthquake hazard map to inform developers and their engineers of ground conditions with regard to earthquake.

Many existing buildings in Mackay are susceptible to wind, in particular, and earthquake. The Mackay City Council could compile a database of these buildings and assess whether mitigating action is necessary. Mitigation schemes could include elements of:

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

The planning regulation corollary to the ‘retrofit’ codes for existing buildings is the policy of relocation or compulsory acquisition of properties with an unacceptably high degree of exposure. Such a policy was implemented in Foulden following the 1958 flood when several houses were lost and roads and land was buried under deep deposits of sand and gravel. Consideration has also been periodically given by Council to buying out the properties in Cremorne. Such programs are usually expensive and marked by controversy, however, they are clearly effective in reducing risk.

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

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

To be effective, however, planning policy must take both a long-term view (preferably with at least a 20-year horizon), and a holistic perspective, especially as the centre of development moves away from the historical centre as the community expands.

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

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

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

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

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

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

Engineered defences for flood: The classic response to risk mitigation has been to turn to structural defences such as levees, dams, flood detention basins and fill. There is a view, however, that:

- they are invariably expensive;
- they frequently fail to provide the levels of protection that are attributed to them because of inadequate design and/or poor maintenance;
- they foster a false sense of security in the community that they are supposed to protect, with the result that when they fail, the community is exposed to a much greater degree of loss.

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

## Conclusion: Is Mackay a Risky Place?

The Mackay study area has a relatively high level of risk exposure to most geohazards above the 2% AEP range (i.e. an ARI of 50 years or less). Events within this range will cause some loss **and put lives at risk** however the warning systems and other mitigation strategies already in place should keep loss of life to virtually zero and economic loss to nuisance, or at least tolerable levels. This will only be possible if the local community **is aware and prepared**. There are, however, a few suggestions to reduce the current level of risk in a more pro active way.

Despite this being a period of sustained population growth, there have been no fatalities directly attributable to the impact of a natural hazard in the Mackay community in the past two decades. This is due to the fact that there have been no significant earthquakes and very few major cyclone or flood impacts during that time. It can also be attributed to the Council's program to implement hazard-based planning constraints, to introduce and enforce building codes and maintain an effective local emergency management capability.

These risk mitigation strategies have greatly reduced the exposure of new developments to hazards and maximised resilience of structures to the more common hazard impacts. This study and other recent studies have provided the Mackay City Council with new information on the level of this risk which may lead to a reappraisal of mitigation measures. **Overall, we would assess Mackay as having a moderate level of risk exposure to the more frequently occurring hazard events.** It should also be recognised that the climate of the region, that is the source of these hazards, is also the source of the community's wealth in agriculture. A tolerably low level of risk, in exchange for community wealth, is perhaps not such a bad deal!

**The Mackay community has a high level of residual risk exposure to flood, severe wind and storm tide. Mackay has a much less, but significant, residual risk exposure to earthquakes.** Flood and cyclonic wind and storm tide events with an AEP of 1.0% or less (an ARI of 100 years or more) will inevitably cause significant economic harm and potentially some (and possibly significant) loss of life. In these rarer and more extreme events, the loss of critical facilities and the impact on specific community functions such as business activity, especially in Central Mackay, North Mackay, Mackay Harbour, Paget and West Mackay, will add to the magnitude of the risk posed directly by the hazard event itself. These secondary risks are likely to have an effect for a considerable period of time after the initial impact and will significantly increase the direct economic and social costs. Consequently, the community will be faced with a long recovery and restoration period. This is especially significant given the Mackay community's heavy reliance on disaster-sensitive industries such as agriculture, the provision of services such as education, and tourism.

It is clearly not possible, economic, or rational to attempt to eliminate all risk. It is, however, feasible and economic to reduce the residual risk by implementing long-term planning strategies (such as the relocation of critical facilities, the 'retrofit' of key buildings and the 'flood proofing' of roads) and by maintaining a vigorous campaign of community awareness and involvement in the community risk management process. The sooner that process is started, the sooner the risk will be reduced to an even more acceptable level.

It is also important to recognise that Mackay is a growing community and that the planning of future urban development should be done in such a way to not increase the community's exposure to risk. Table 7.7 shows the population projections for the period 1996 to 2016 produced by the Department of Communications, Local Government and Planning. The Mackay (Part A) statistical area is the urban area that is essentially the same as our study area, whilst the Mackay (Part B) statistical area is the rural area not included in this study.

Table 7.7: Mackay population projections 1996 to 2016

| AREA | 1996 | 2001 | 2006 | 2011 | 2016 |
|---|---|---|---|---|---|
| Mackay (Part A) | 61 080 | 65 950 | 70 650 | 74 870 | 78 410 |
| Mackay (Part B) | 10 370 | 11 430 | 12 590 | 13 830 | 15 230 |
| Mackay City (total) | 71 450 | 77 380 | 83 240 | 88 700 | 93 640 |

Much of the new development is likely to be in the 'safer' areas more distant from the coast, the Pioneer River and the softer sediments, such as Rural View.

## Where to From Here?

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

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

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

Turning the information and the risk assessments provided here into risk mitigation strategies is a task for others, particularly Mackay City Council and the Mackay community. This process will be significantly enhanced by the work being undertaken in parallel with this study under the DES *Local Government Disaster Mitigation Project*. It is also up to them to keep the information base we have established up to date. If it is not kept current it will rapidly move from being an asset to being a liability.

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