CHAPTER 7: CYCLONE RISKS

The Cyclone Threat

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

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

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

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

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

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

Table 7.1: Australian tropical cyclone category scale

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

In this chapter we concentrate on the destructive wind and storm tide inundation hazards and the risks that they pose. The consequences of intense rainfall have been addressed to varying degrees in **Chapter 5** (Landslide Risks) and **Chapter 6** (Flood Risks).

The Cairns Cyclone Experience

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

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

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

The Cyclone Phenomenon

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

> ***Tropical cyclones*** *are low pressure systems in the tropics which, in the southern hemisphere, have well-defined clockwise wind circulations with mean surface winds (averaged over ten minutes) exceeding gale force (63 km/hr) surrounding the centre. Short period* ***wind gusts*** *are often 50 per cent or more above the mean wind speed.*
>
> ***Severe tropical cyclones*** *(referred to as hurricanes or typhoons in other countries) have surface wind speeds in excess of 120 km/hr surrounding the centre. These are potentially the most dangerous of all meteorological phenomena.*

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

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

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

Severe Wind Risks

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

Most of the loss created by tropical cyclones globally comes from the damage inflicted by the strong winds that reach their peak in the eye wall. This damage can be caused directly by the wind and/or by the debris that is propelled, frequently with great force, by the wind.

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

Buildings: The construction, design, age and location of buildings each have an influence on their risk of damage. Metal roofs are more susceptible to wind damage than are tile roofs, though the latter is more susceptible to damage by wind-driven debris; brick and concrete block walls are resilient, however, fibro, metal cladding and even timber walls are susceptible to being penetrated by debris. Large areas of unprotected glass are even more susceptible to both wind and debris damage.

Roof shape and pitch are influential. In simple terms, gable ended roofs take the full force of the wind, whereas the wind flows more smoothly over hip ended roofs. Depending on wind direction, flat or low pitched roofs can experience greater levels of suction than do high pitched roofs. Hip ended roofs with a pitch of around 30° tend to perform the best. The fastening of roofing material to trusses and the fastening of roof members to walls and foundations are also important. These were key features addressed by the wind loading aspects of the Building Code (AS 1170.2-1989 *Wind loads*) introduced in 1975 and upgraded for domestic structures in 1989 and 1992.

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

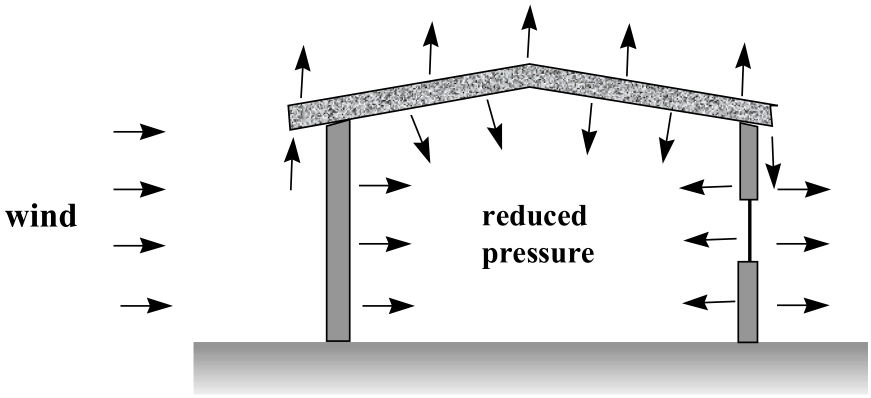

Figure 7.2: Wind forces working on a building with external integrity

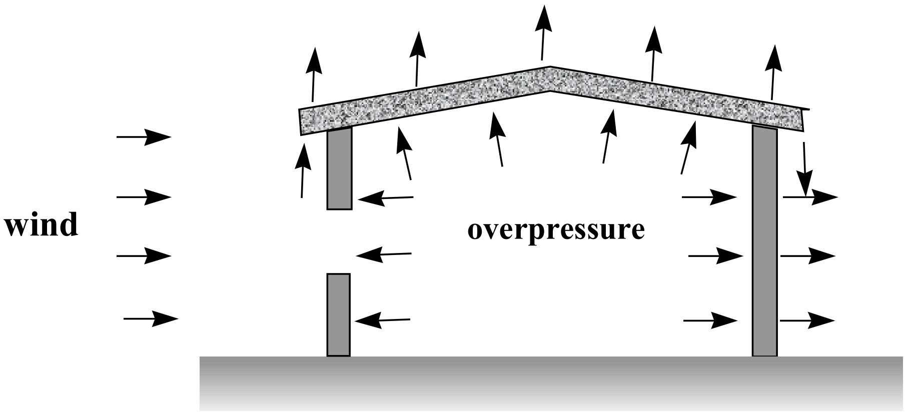

Figure 7.3: Wind forces working on a building where its external integrity is lost

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

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

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

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

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

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

Table 7.2: Severe wind risk exposure ranking for Cairns suburbs

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

Tree-fall also represents a significant threat to buildings and other assets such as cars. Trees will also block roads and may even dislocate underground utilities, such as water mains, if their root systems are extensive. The disposal of debris produced by wind damage to trees in cyclones inevitably presents Council’s waste managers with a major challenge.

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

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

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

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

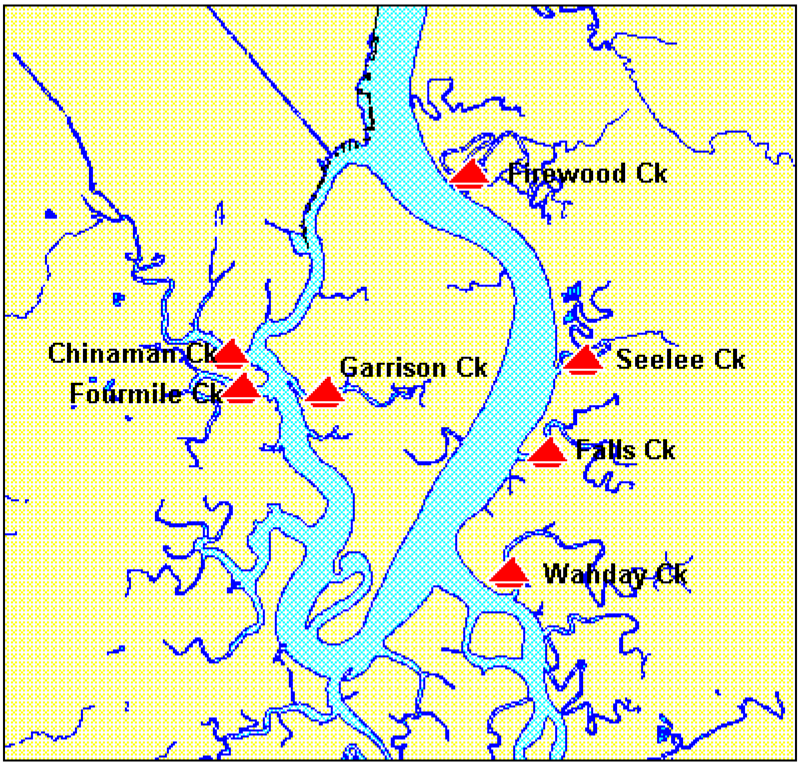

Figure 7.5: Cairns emergency boat shelters

The Storm Tide Phenomenon

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

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

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

The location of crossing is important given that the maximum surge height on the Queensland coast is in the south-west quadrant of the cyclone in the band of maximum onshore winds (i.e. in the eye wall). A cyclone crossing the coast 25 to 50 km to the north of Cairns, therefore, will produce a greater storm tide than a cyclone crossing directly over, or to the south of, the city. Areas to the north of the crossing point will typically experience a reduced sea level.

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

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

Most models and hazard maps of storm tide adopt a 'still water' inundation approach that simply delimits the area affected by the horizontal contour equivalent to the storm tide elevation. **Figure 7.6** is an example of a 'still water' storm tide hazard map of Cairns. It shows zones in increments of one metre above HAT, the current Queensland standard.

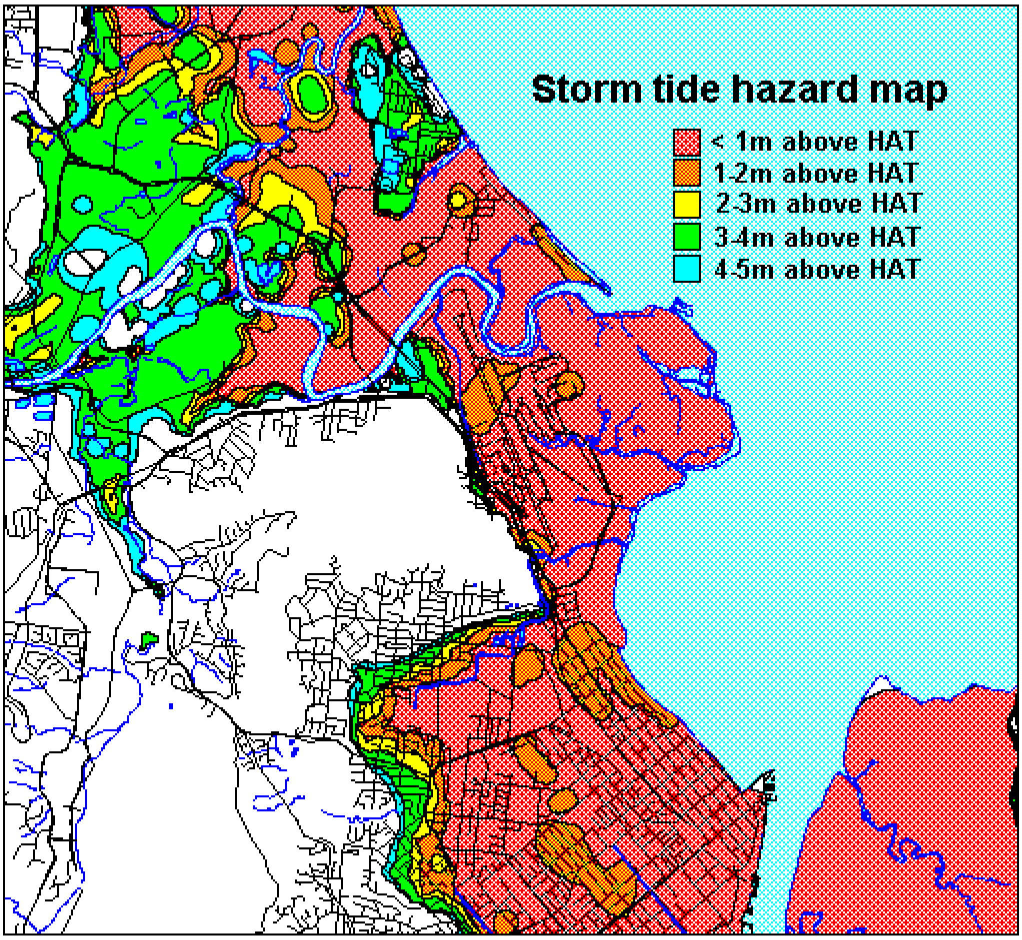

Figure 7.6: Cairns storm tide hazard zonation map

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

Vulnerability to Storm Tide

The 'still water' model does not take account of any wave setup or wave runup. Wind-generated waves of several metres in height can be anticipated with cyclones. These are on top of the surge. As waves enter the shallow waters of the coast, where their amplitude becomes limited by the sea bed, they will build in height to substantial levels. The combination of wave setup height and wave power (a combination of mass and velocity) can have a massive impact on the shore line and any structure that is exposed to those forces. Sea wave height and power, however, decay rapidly as the wave moves inland. Smith and Greenaway (1994), for example, provide a curve (their Figure 3.7) representing velocity decay, relative to distance from the shoreline, for Mackay. This curve was based on the North American experience of storm tide and shows that the velocity (and, by inference, the height) of sea waves, based on a wind speed of 130 km/hr, declines from 1.54 m/sec to 0.5 m/sec within 500 m of the shore.

Whilst the destructive potential of sea waves declines rapidly inland, shallow water, wind-driven waves will be present in all areas inundated by the storm tide. These waves can attain heights of about half as much again as the still water depth. Whilst they are likely to increase inundation levels, they will probably not add significantly to the destructive force of the storm tide. They will also slightly extend the area inundated, beyond the simple 'still water' contour level, because of wave runup.

Inundation depth is important, not only because of the damage caused by emersion, but also because of the stress placed on structures by moving water. Smith and Greenaway (*op cit*, p38) make the assumption that 'if the combination of still-water and wave height exceeded floor level by 1.0 m building failure will occur.' In the USA, the Federal Emergency Management Agency (FEMA) have adopted one metre above floor level as their 'base flood elevation' for calculations of planning constraints and flood insurance exposure. The significance of this elevation was demonstrated in coastal areas that experienced the impact of Hurricane *Hugo* in 1989. FEMA (1992), quoted by Smith and Greenaway *(ibid*), state that:

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

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

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

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

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

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

Storm Tide Risk Scenarios

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

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

Table 7.3: Comparison of published forecast storm tide height (above AHD) for various AEP

LOCALITY	2% AEP	1% AEP	0.2% AEP	0.1%AEP	0.01% AEP
Northern Beaches[1]	1.9 m	2.0 m	2.7 m	3.0 m	4.0 m
City[2]	2.2 m	2.5 m	3.2 m	3.5 m	4.5 m
Cairns general[3]	1.76 m	2.15 m	3.39 m	3.75 m	n/a

NOTES:

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

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

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

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

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

To model the likely impact of storm tides of 2%, 1%, 0.2%, 0.1% and 0.01% AEP scenarios (i.e. ARI of 50, 100, 500, 1 000 and 10 000 years respectively), the 'still water' inundation values adopted by Cairns City Council were used. The modelling is aimed at identifying the buildings that would be inundated to more than 1 m over floor; over the floor but less than 1 m in depth; water on the property but not over floor level, and properties that would be free of inundation. To take account of the wave setup, sea wave power and wind driven shallow water wave components, the following adjustments were made:

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

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

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

This conservative approach is consistent with the stated needs of emergency managers. The resulting figures should be seen as reflecting the upper level of impact estimates.

Data uncertainty: In this model, the key values of floor height and ground height were taken from the detailed building database described in **Chapter 3** and **Appendix D**. Floor heights were estimated in the field for most buildings and are, in at least 90% of observed cases, accurate to within 0.25 metre. Where buildings were not observed in the field, a default value of 0.3 metre (i.e. slab-on-ground construction) was used.

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

The use of such ‘imprecise’ data may seem to introduce potentially significant error or uncertainty in the outcome. It should be recognised, however, that the error estimates for the DEM produced by Zerger are substantially less than those published for the original topographic data. In the original source, 90% of values of less than 5.0 m above AHD were accurate to within 1.25 m and for the values 5.0 to 10.0 m above AHD zone, 90% were accurate to within 2.5 m.

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

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

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

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

where:

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

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

Similar models have also used to identify the road segments and cane fields at risk in the various scenarios. These results are summarised in the following discussions of each of the five scenarios. A comparison of the outcomes for the five scenarios is also provided to illustrate the incremental growth of risk as the probability decreases.

Assumptions: In the following scenarios two key assumptions have been made. First, that there will be no significant land-based flooding prior to the storm tide impact. We feel that this is a reasonable assumption given that significant storm surges are more likely to be associated with cyclones that move rapidly over the ocean and approach the coast at close to right angles. Such cyclones are less likely than slow moving cyclones to be preceded with substantial rainfall. Even if peak rainfall were to coincide with cyclone landfall, it would typically take at least 12 hours for that rainfall to produce flooding on the Barron River delta. This assumption is consistent with the engineering flood models of the Barron River undertaken for the former Mulgrave Shire Council and the Cairns Port Authority in 1988 (Macdonald Wagner, 1988).

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

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

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

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

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

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

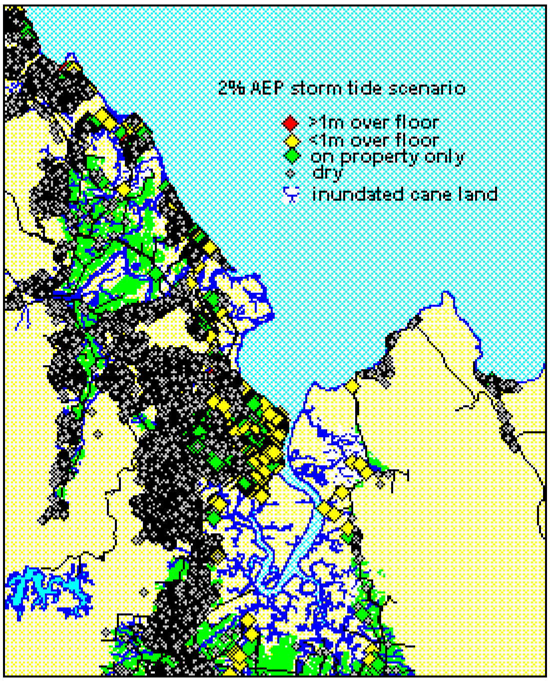

Figure 7.7 Modelled impact of a 2% AEP storm tide scenario

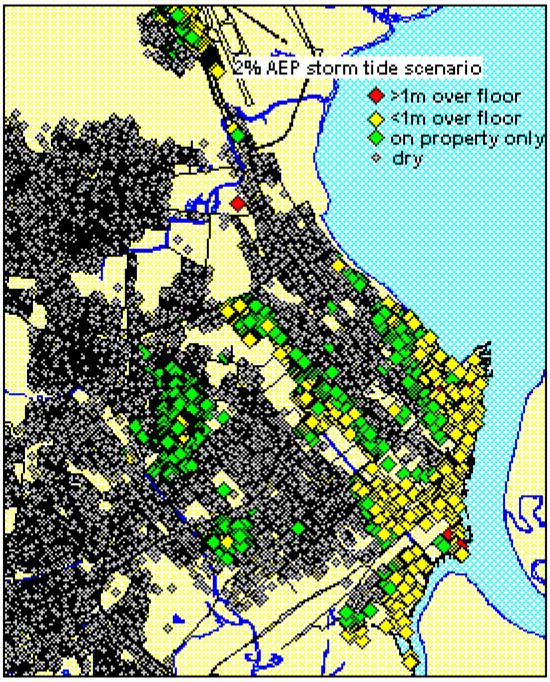

Figure 7.8: Modelled impact of a2% AEP storm tide (detail)

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

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

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

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

Of the 240 buildings at greatest risk:

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

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

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

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

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

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

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

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

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

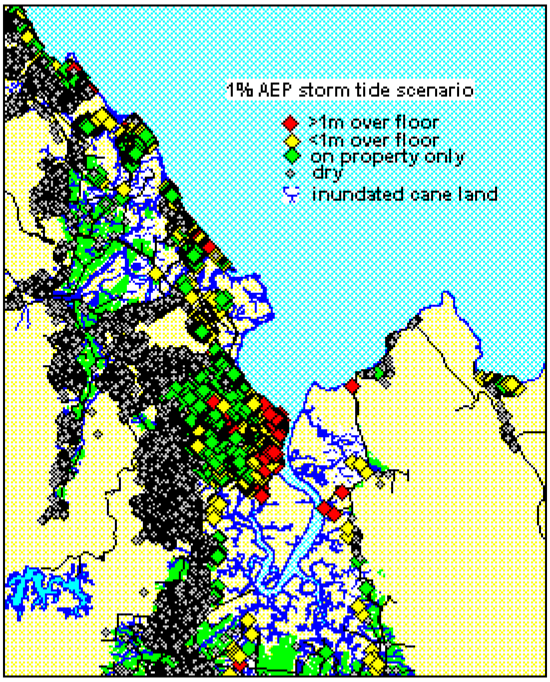

Figure 7.9: Modelled impact of a 1% AEP storm tide event on Cairns

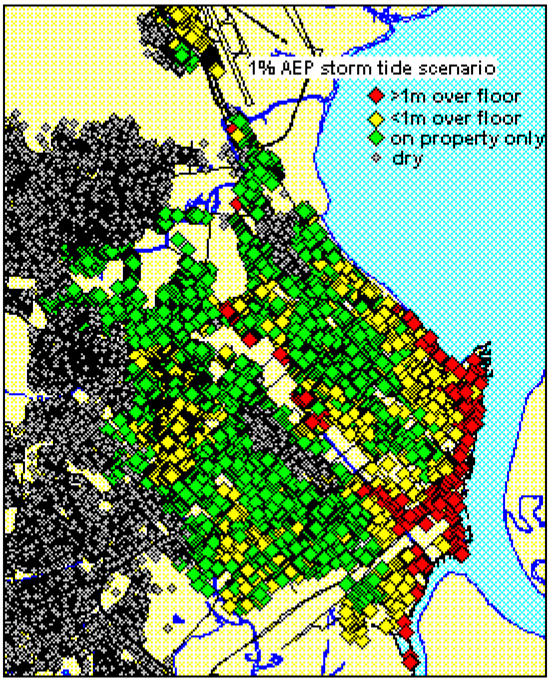

Figure 7.10: Modelled impact of a 1% AEP storm tide event on Cairns (detail)

Of the 2 200 buildings at greatest risk:

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

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

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

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

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

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

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

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

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

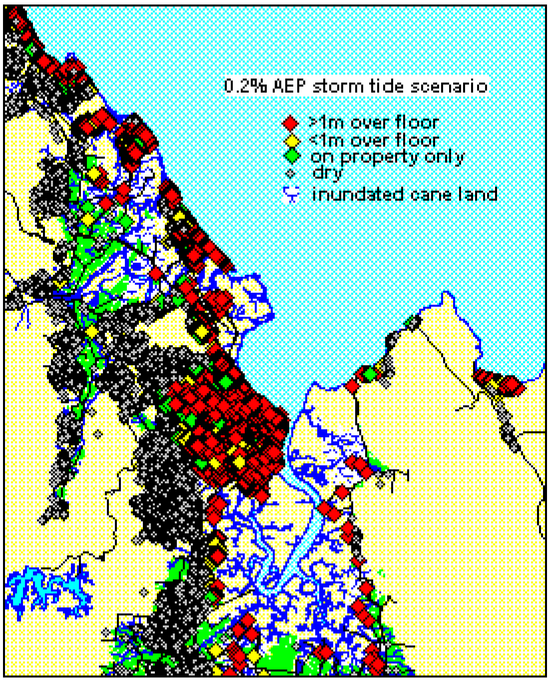

Figure 7.11: Modelled impact of a 0.2% AEP storm tide scenario

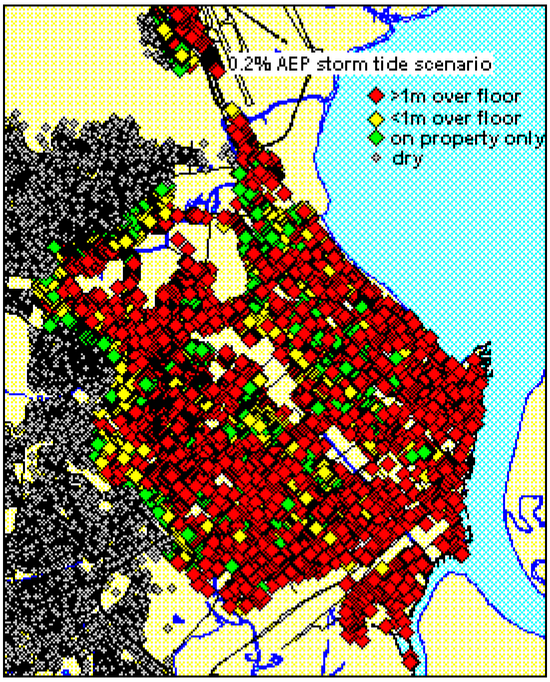

Figure 7.12: Modelled impact of a 0.2% AEP storm tide scenario (detail)

Of the 2 490 buildings at greatest risk:

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

- 140 are community facilities.

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

Approximately 5 250 people would need to be evacuated from the houses and flats at very great risk of destruction. A further 12 800 people would probably need to be evacuated from the houses and flats with more than 1 m over floor level but further than 750 m from the shore. Most of these are in Manunda and Westcourt. Assuming an average occupancy of 1.5 persons per room in the commercial accommodation at significant risk, a further 6 400 people could require evacuation to managed shelters ahead of the cyclone crossing the coast. Activation of designated evacuation shelters across the city would be required to cope with the numbers of evacuees that were unable to take refuge with friends or relatives elsewhere in the city.

The impact of a 0.1% AEP (ARI of 1 000 years) storm tide event would be catastrophic. As many as 24 500 people could be at considerable risk of serious harm. Some 8 000 buildings would be at risk of destruction or significant damage and as many as 1 750 further buildings would suffer substantial contents damage. Around 24 200 ha of cane lands would also be inundated by sea water. Thirty-nine of the 60 critical facilities would be at significant risk of severe damage if not destruction. These are detailed in **Table K1**. The extent of the area affected is illustrated in **Figure 7.13**, whilst **Figure 7.14** provides a larger scale view of the central city area. Table K5 provides the key statistics for each of the suburbs affected.

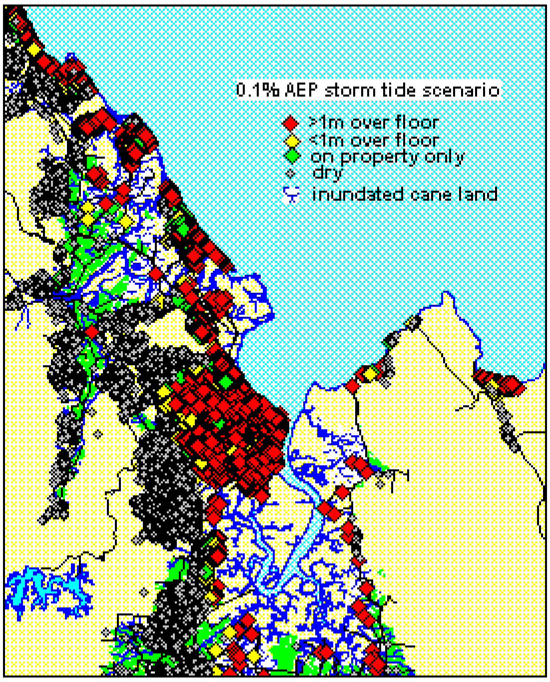

Figure 7.13: Modelled impact of a 0.1% AEP storm tide scenario

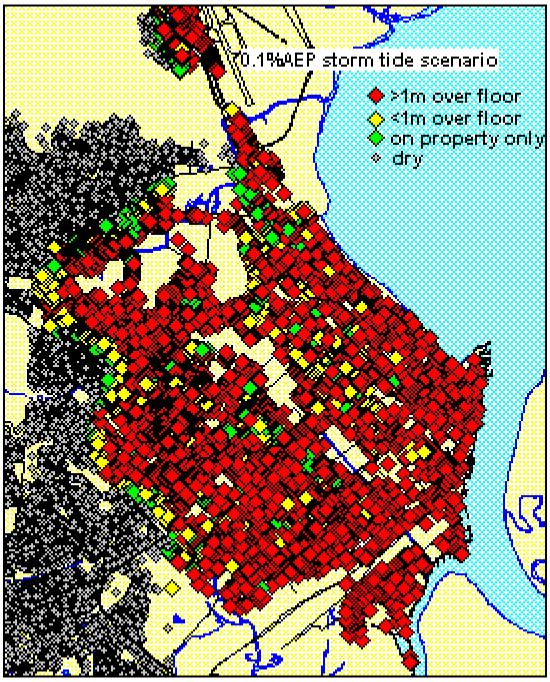

Figure 7.14: Modelled impact of a 0.1% AEP storm tide scenario (detail)

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

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

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

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

Of the 3 110 buildings at greatest risk:

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

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

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

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

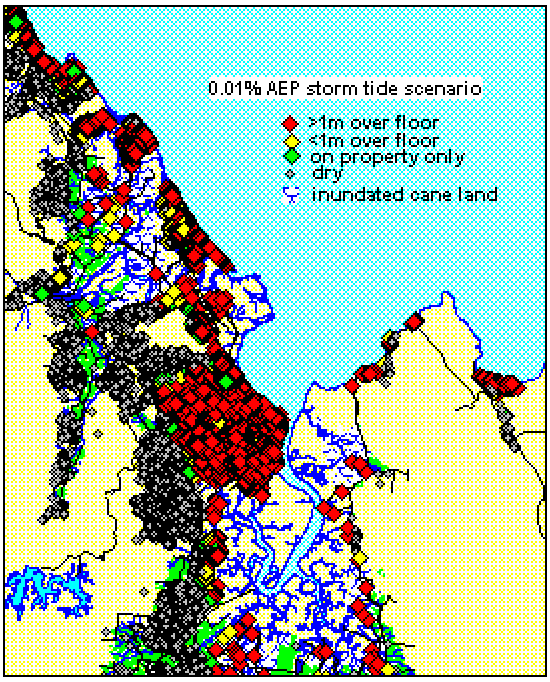

Figure 7.15: Modelled impact of a 0.01% AEP AEP tide scenario

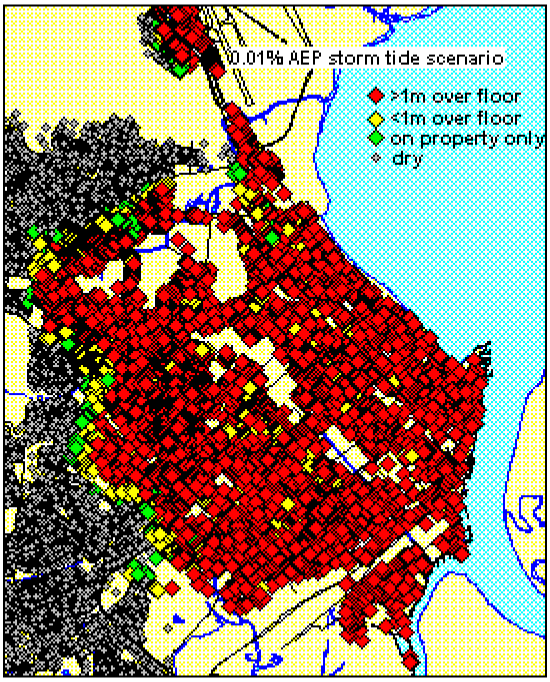

Figure 7.16: Modelled impact of a 0.01% storm storm tide scenario

Comparative Storm Tide Risk

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

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

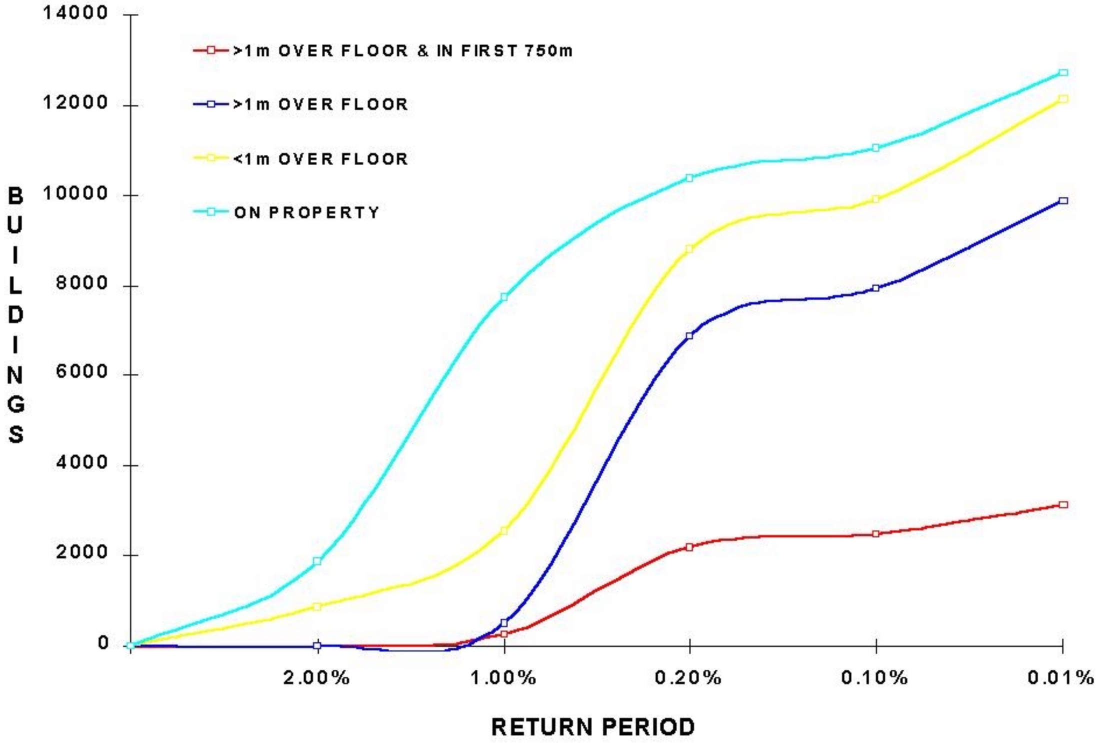

Figure 7.17: Cumulative impact on buildings of storm tide in Cairns

Table 7.4: Percent of buildings, by function, affected by over-floor inundation in each scenario

FUNCTION	2% AEP	1% AEP	0.2% AEP	0.1% AEP	0.01% AEP
Houses	0.9	3.5	17.3	20.3	25.5
Flats	3.1	14.2	48.6	50.2	57.1
Commercial accommodation	9.5	21.4	66.9	68.2	71.3
Business & industry	17.7	41.7	83.6	84.3	85.7
Logistic, transport & storage	30.3	50.1	80.2	80.5	81.7
Public safety & health	10.7	33.2	63.6	64.0	65.0
Community, education & sport	8.3	17.7	58.1	58.8	60.7
Utilities	4.6	14.9	56.3	57.5	59.8

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

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

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

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

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

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

- there is a high degree of concentration of these facilities in storm tide-prone areas;
- for scenarios of 0.2% AEP or greater rarity, significant relocation of residents of commercial accommodation could be required. Most of these would need to be provided with shelter in public centres because there would be inadequate alternative commercial accommodation available in ‘safe’ areas;
- for the lower intensity scenarios there should be sufficient alternative commercial accommodation to house those who would need to be relocated. The option of ‘vertical evacuation’ could be viable in commercial accommodation other than those along the ‘front row’;
- caravan parks (of which there are 20) would need to be evacuated or adequately secured for all but the lowest intensity cyclones because of the strong wind hazard threat to caravans.

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

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

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

- these facilities are strongly concentrated in storm tide-prone areas;
- the sustainability of Cairns would be under significant stress with a 2% AEP event, but would probably be untenable under any of the high intensity events. The loss of food, fuel and other essential commodities would place the Cairns community at extreme peril. The most likely response option under those circumstances would probably involve the evacuation of substantial numbers of people to other centres in Queensland, or further afield, until those services could be restored;
- damage and loss of these facilities, under all scenarios, would be greatly exacerbated by the likely dislocation of power, water and telecommunications lifelines as a result of the strong winds.

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

- these facilities are reasonably well disbursed throughout the community;

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

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

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

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

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

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

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

where:

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

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

Table 7.5: Storm tide risk exposure of Cairns suburbs

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

Interpretation

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

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

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

Whilst the direct impact of a severe cyclone on Cairns will have a major immediate impact with potentially significant loss of life and massive damage, the long term impact will also be catastrophic. In an extreme event, a major proportion of the survivors would need to be evacuated to centres as far away as Brisbane and Sydney (as was the experience of Darwin following the impact of Cyclone *Tracy* in 1974). The loss of facilities on which the community relies would be such that the city would be virtually uninhabitable for an extended period.

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

Limitations and Uncertainties

We have already discussed at some lengths the key concerns we have with data and model limitations and uncertainties. Given the generalised assessment that we have undertaken, however, we are confident that the results are realistic.

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

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

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

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

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

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

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

NOTES:

* Water on the property but not over floor level

1. Model 1 = the ‘still water’ model.
2. Model 2 = the ‘still water’ model plus an allowance for shallow water wind waves.
3. Model 3 = the ‘0.5 m wave setup model + shallow water wind wave’ model.
4. Model 4 = the *Cities Project* model which includes allowance for sea wave impact.