# CHAPTER 4: TROPICAL CYCLONE RISKS

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## The Cyclone Threat

There is little doubt that tropical cyclones (TC) pose a significant threat to the urban communities of South-East Queensland. These spectacular meteorological phenomena are very large in scale, and have the potential to bring severe loss to the whole region. On long-term average, 1.2 cyclones pass within 500 km of Brisbane each year. The most active cyclone season on record (1962/1963) saw 7 cyclones passing into the region. In the past 92 years of detailed record, the centres of 15 of these storms have passed within 100 km of downtown Brisbane. An historical inventory of cyclones effecting the region is included in Appendix D, based largely on a listing of historical events compiled from many sources by the Bureau of Meteorology's Queensland Regional Office in Brisbane.

Perhaps the most significant regional impact by a tropical cyclone in recent history was the severe and widespread flooding caused by TC *Wanda* in January 1974 – the so-called 'Australia Day' floods that caused such devastation in Brisbane and elsewhere in the region.

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

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

**Table 4.1: Australian tropical cyclone category scale**

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

In this chapter we concentrate on the destructive wind and (where appropriate) storm tide inundation hazards and the risks that they pose. The closely related phenomenon of east coast lows is discussed in Chapter 5 (East Coast Low Risks) and the consequences of the intense rainfall associated with tropical cyclones are largely addressed in Chapter 9 (Flood Risks).

## The Cyclone Phenomenon

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

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

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

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

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

Thermodynamic parameters include:

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

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

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

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

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

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

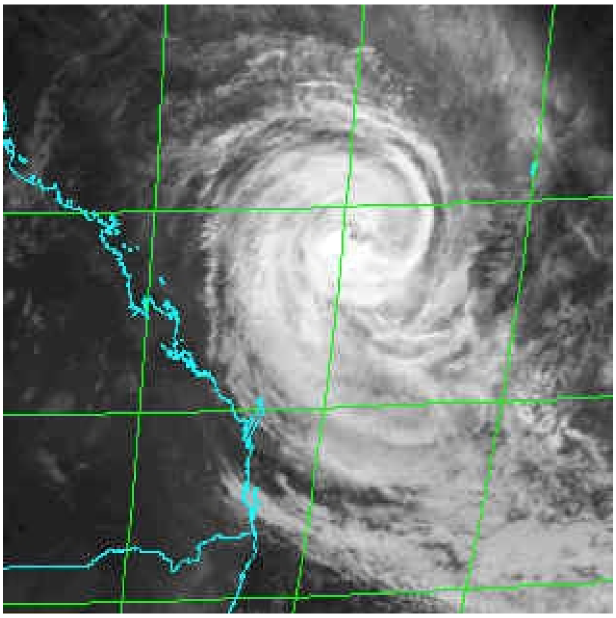
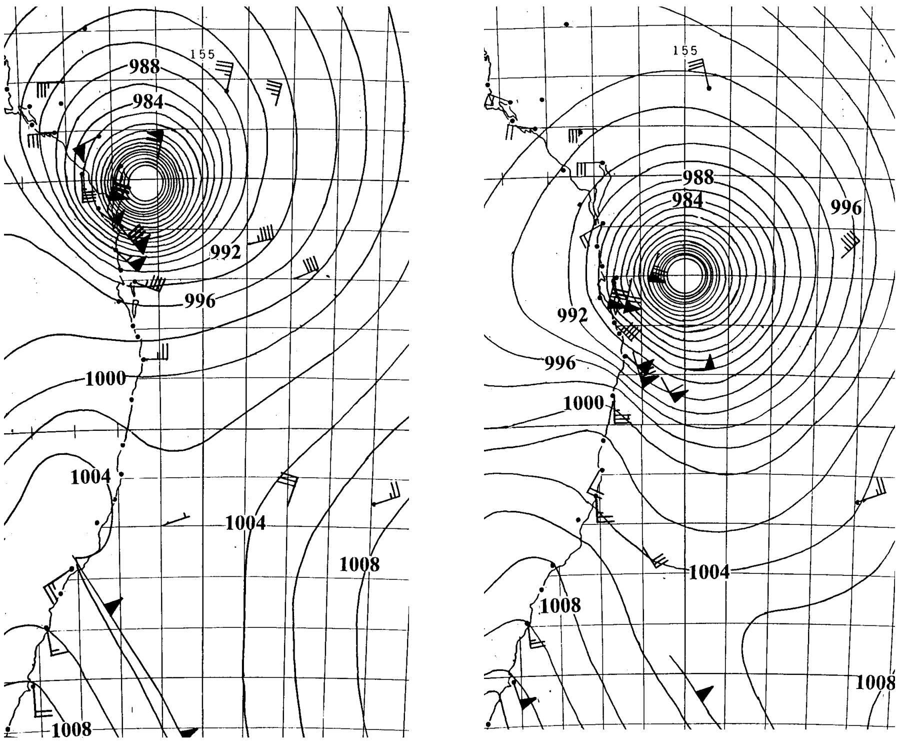


**Figure 4.1: TC *Fran* approaching the Queensland coast in March 1992**

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

Cyclonic winds circulate clockwise in the southern hemisphere. The windfield within a moving cyclone, however, is generally asymmetric so that, in the southern hemisphere, winds are stronger to the left of the direction of motion of the system (the 'track'). This is because on the left-hand side, the direction of cyclone movement and its circulation act together; on the right-hand side they are opposed. During a coast crossing in the southern hemisphere, the cyclonic wind direction is onshore to the left of the eye (seen from the cyclone) and offshore to the right. The large-scale surface pressure (isobar) fields of the mature TC *Dinah*, as it tracked south-south-east 150 km off the coast, are given in Figure 4.2. The strongest winds in this situation would be generally expected just to the left of the track (i.e. on the eastern side). The development of the intense pressure gradient (and gale to storm-force southerly winds) south-west of TC *Dinah*, as it interacted with the ridge pushing up the NSW coast, should be noted. At the time of closest approach, therefore, Brisbane was subjected to southerly winds. However, Brisbane experiences only light winds under the strong synoptic south-east-to-southerly flow, possibly created by shielding from the McPherson Ranges along the border with New South Wales.

For any given central pressure, the size of individual tropical cyclones can vary enormously. However, because it is difficult for a cyclone to form south of 25ºS (i.e. south of Bundaberg), the vast majority of cyclones affecting the South-East Queensland region have traveled from further north and are likely to be either mature, undergoing decay, or tending extra-tropical (similar to east coast lows). In those circumstances, small cyclones are relatively rare.




1100 UTC 29-Jan-1967 | 2300 UTC 29-Jan-1967

**Figure 4.2: Synoptic features of severe TC *Dinah*.**

Large cyclones can have impacts far from their track, especially with the generation of large waves and storm tide. For example, TC *David* crossed the coast near Yeppoon in 1976, and TC *Pam* passed 450 km offshore from Brisbane in 1974, but both caused significant coastal impacts in South-East Queensland.

<u>Climatology</u>: Historical searches for tropical cyclones affecting the South-East Queensland region have uncovered significant community impacts as early as the mid-1800s (see Appendix D) but the detailed record maintained by the Bureau of Meteorology's National Climate Centre begins in the 1907/08 season. An overview of this 92 year official record is given below, summarising cyclone activity within a radius of 500 km from Brisbane, which includes all cyclones which may have been capable of having an influence on the region within a nominal 24 hour period.

Figure 4.3 summarises the frequency of occurrence on an annual (or seasonal) basis. It includes 111 storms since 1902. This produces an average of 1.2 storms per year, but varies between 0 and 7 occurrences in any one season. While this is an extensive period of record, Holland (1981) advises caution in utilising records prior to 1959/60 in any detailed statistical analysis of the frequency of occurrence or intensity because of the major changes in observing technology, standards of reporting and increasing scientific understanding over that time. Experimental satellite imagery first became available in 1960, leading to the adoption of objective intensity estimating methods from 1968 onwards, with the later Dvorak technique (Dvorak, 1975) still in regular usage. While evidence of

incomplete detection is suggested in the record prior to the 1930s, restricting the data set to post-1959/60 results gives a total of 44 storms in the 40 year period, producing a slightly decreased average occurrence rate of 1.1 per season.

Figure 4.3 also shows the 5 year moving average of occurrences, which can be compared with the annual and 5 year averaged Southern Oscillation Index (SOI). Recent sustained negative SOI (*El Niño*) influences can be seen to be associated with a significant reduction in cyclone numbers across the region from 1975 onwards. Further discussion on these points is provided later in regard to climatic variability.

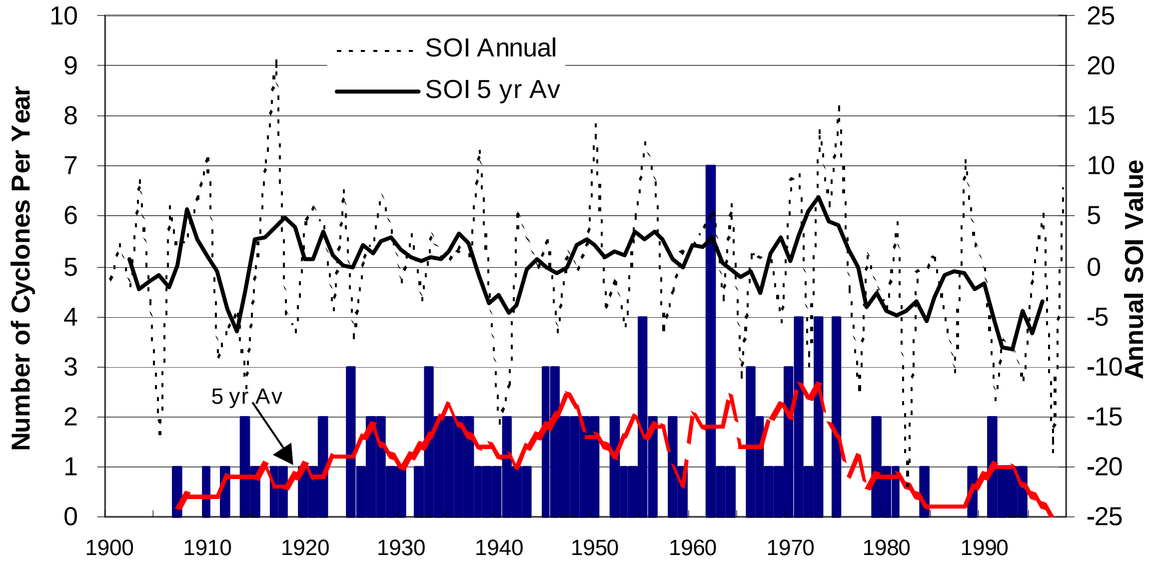



**Figure 4.3: Frequency of occurrence of tropical cyclones within 500 km of Brisbane.**

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

Some measure of the destructive power of cyclonic winds can be gauged from the following account of damage caused by the 1893 cyclone, reproduced in Caboolture Historical Society (1973) and taken from the account published in the *Telegraph* of 25th February 1893:

> *A recent visitor to Woody Point* (Redcliffe) *supplies the following account of the total destruction of Mrs. Bell's well known residence 'Klanger'. This place was caught in a tornado on February 17th* (1893) *at 7 a.m.*
>
> *The first intimation the occupants had of the strength of the wind was the front door bursting open. Mrs. Bell, who was in bed at the time, went to shut the door, when she was lifted bodily up and her head knocked against the ceiling of the hall. Mrs. Bell was found amongst the debris, apparently without a broken bone but severely bruised.*
>
> *Her daughter, Mrs. Hobbs, and the latter's two children, who were also in the house, had a miraculous escape from death, as the building fell in on them. In fact one child was under a wardrobe that took four persons to lift and the other had a hairpin knocked into her head. All of them were very much bruised, especially Mrs. Bell and her daughter.*

*The man servant was carried from the kitchen steps into a mulberry tree and hurt about the legs by falling timber.*

*The house and the 8 ft. 6 in. verandah appear to have been lifted bodily up, carried about five to ten yards and then crashed to pieces.*

*Nearly all the furniture is smashed to atoms and bedsteads are broken and twisted like so many twigs. At one time it was thought that a valuable piano, which had somehow escaped the weight of the falling building, was uninjured – but unfortunately that is not the case.*

*Perhaps the most remarkable incident is that a large box with a glass top containing birds eggs was not damaged in any way.*

*Parts of the galvanized iron roof were carried a long distance and wrapped around a big tree.*

*A light buggy belonging to Mr. Parry Okeden which was in a shed at the stable was lifted and carried into a fig tree. When taken down it appeared none the worse for its aerial flight, except that part of the ironwork was bent.*

*A poor horse, which had been feeding some distance away, must have been lifted up and dashed against a tree as the unfortunate animal was found almost cut in two.*

*Mrs. Boden, a daughter, says that when Mrs. Bell was found she was holding a silver tea pot which had been presented to her in appreciation of her hospitality.*

<u>Heavy Rainfall</u>: Before proceeding to discuss the risks associated with severe wind and the oceanic effects of storm tide and extreme waves in South-East Queensland, it is worth touching briefly on the climatology associated with the severe rainfall that frequently accompanies tropical cyclones. The consequences of this rainfall are dealt with more fully in Chapter 7 (Flood Risks).

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

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

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

Topography also affects the rainfall generation process due to coastal convergence and uplift effects. The presence of the mountainous areas of the Great Dividing and Border Ranges to the west are, therefore, important factors in delivering heavy rainfall events in South-East Queensland.

<u>Severe Waves</u>: The Queensland Beach Protection Authority (BPA - now within the Environment Protection Authority) has maintained a near-continuous record of wave heights dating, back to 1976, using moored buoy systems offshore from Point Lookout on North Stradbroke Island. A recent analysis of some 21 years of data (Allen and Callaghan, 2000) revealed the maximum recorded significant wave height of 7.4 m occurred during TC *Roger* in 1993. Based on their statistical

analyses, Table 4.2 indicates that the average recurrence interval (ARI) for significant wave heights at this location caused by tropical cyclones. The significant wave height (Hs) is an estimate of the average height of the highest one-third of waves in a 20 minute period, and is found to be similar to the visually estimated wave height made by an experienced observer. The single highest wave (Hmax) during the same period is typically around 1.8 times higher than Hs.

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

**Table 4.2: Predicted extreme wave heights due to tropical cyclones in South-East Queensland (after Allen and Callaghan, 2000).**

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

One of the principal impacts of severe waves is significant beach erosion, especially when combined with storm tide effects. Between late January and early April in 1967, a sequence of cyclones – TCs *Dinah*, *Barbara*, *Elaine* and *Glenda* – attacked the beaches of southern Queensland causing extensive erosion and economic loss to the tourist industry. This was followed in June by three east coast low events which, together with the earlier cyclones, were estimated to have removed more than 8 million cubic metres of sand from beaches between Point Danger and the Nerang River mouth (DHL, 1970). Extensive property damage occurred along the Gold Coast strip - houses fell into the sea at Mermaid Beach, Nobby's and Palm Beach (see Figure 4.4). Large sections of the esplanade collapsed at Surfers Paradise, Main Beach and Palm Beach. A volunteer army of 5000 people placed around 100 000 sandbags along the foreshore helping to prevent many other houses being lost to the sea. It then took two years for natural accretion to rebuild much of the region's beaches.

In some areas, unrestricted development within the active beach zones had robbed the beach of its natural buffer against storm attack and those areas remained chronically affected for many years. This and other significant coastal erosion events prompted State legislation to ensure the sustainable development of coastal areas and lead to the creation of the BPA in 1968. The BPA was instrumental in undertaking essential research and investigation into coastal management problems. Extensive artificial beach nourishment programs have also been conducted by Gold Coast City Council over a number of years to restore beach amenity and provide property protection. In 1994, the Queensland and New South Wales Governments agreed to jointly finance and build an artificial sand by-passing system to restore the natural northward progression of sand past the Tweed River entrance, which had been contributing to erosion of the southern Gold Coast beaches for many years. This system is expected to become operational in 2001 and will greatly enhance the ability of Gold Coast beaches to withstand future cyclone attack.

**Figure 4.4: Severe beach erosion at Palm Beach during 1967 (EPA photograph).**

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

Figure 4.5 summarises the various components which work together to produce an extreme storm tide. Firstly, the storm surge is generated by the combined action of the severe surface winds circulating around the storm centre generating ocean currents, and the decreased atmospheric pressure causing a local rise in sea level (the so-called *inverted barometer* effect). The strong currents impinging against the coast are normally responsible for the greater proportion of the surge. As shown in Figure 4.5, the surge adds to the expected tide level at the time the storm makes landfall.

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

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

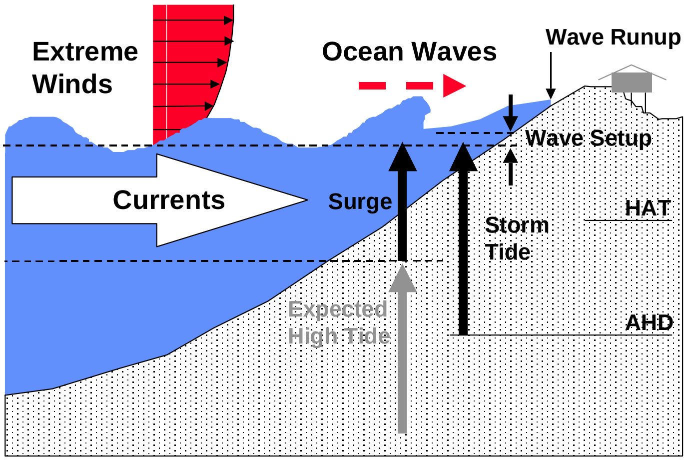



**Figure 4.5: Components of a storm tide (from Harper, 1998)**

Table 4.3, mainly extracted from Harper (1998), provides a summary of some recorded storm tide events in the study region. This list should be regarded as indicative only but shows that at least 29 separate surge events have occurred over the past 100 years. Of these, about half resulted in storm tide levels reaching above the HAT (Highest Astronomical Tide) level. Mostly the affected areas were within Moreton Bay, especially Beachmere, but parts of the Gold Coast such as South Stradbroke Island, McIntosh Island and Mermaid Beach have also been partly inundated at various times. The *Courier Mail* of Monday 22nd February 1954, for example, reported:

> *… 42 families were evacuated from areas swollen by the Nerang River. Twenty-two residents of McIntosh Island spent a nightmare eight hours before being rescued by police and lifesavers. At the first attempt … three men made the island (by) boat and took the residents into the biggest of the houses. But soon after the stumps supporting the house gave way, and the party rushed outside seconds before the building collapsed. Drenched to the skin the party, which included six small children, then moved into another house on the highest point of the island. There, waist high in water, they waited for rescue. 'Then the wind dropped and we were able to make it. Five minutes after we had completed the rescue, the wind started howling again.'.*

The open coasts of the South-East Queensland region are afforded some protection against extreme storm surge by the relatively narrow continental shelf (Harper,1998) but are open to severe wave attack and subject to high levels of wave setup. Conversely, the shallow waters of Moreton Bay are protected against serious wave attack but subject to wind stress effects which impact many low lying residential areas from Beachmere in the north to Bay Islands in the south. The extensive tidal estuaries of Moreton Bay and The Broadwater are also susceptible to storm tide, which can exacerbate the effect of river flooding.

The highest known water levels occurred during TC *Dinah* in 1967, eclipsing the previous 1954 event on the Gold Coast. TC *David* in 1976 also created significant impact, even though its centre was over 600 km to the north, near Yeppoon.

**Table 4.3: Historical storm tide record for South-East Queensland**

| Date | Place | Event | Storm Surge (m) | Storm Tide Level (m on AHD | Inundation Above HAT (m) |
|---|---|---|---|---|---|
| 08-Jun-1891 | Brisbane | | ? | 1.8 | 0.3 |
| 19-Feb-1894 | Brisbane | | 0.6 | 1.6 | 0.2 |
| 11-Feb-1915 | Brisbane | | 0.6 | | |
| 16-Jun-1928 | Brisbane | | ? | 1.7 | 0.2 |
| 05-Feb-1931 | Brisbane | | 1.1 | 2.0 | |
| 01-Feb-1934 | Brisbane | | 1.2 | ? | |
| 20-Jan-1938 | Brisbane | | 0.5 | 1.4 | |
| " | Gold Coast | | >0.5 | 1.8 | >0.5? |
| 25-Mar-1946 | Brisbane | | 0.6 | | |
| 23-Jan-1947 | Brisbane | | >0.5 | ? | |
| 28-Jan-1948 | Brisbane | | 0.5 | 1.8 | 0.3 |
| 18-Jan-1950 | Brisbane | | 0.6 | 1.8 | 0.3 |
| 25-Jan-1951 | Brisbane | | ? | | |
| 21-Feb-1954 | Brisbane | | 0.7 | 2? | ? |
| " | Coolangatta | | >1? | 2? | >0.5? |
| 17-Feb-1957 | Brisbane | TC *Clara?* | >0.5 | ? | |
| 01-Jan-1963 | Brisbane | TC *Annie* | 0.8 | ? | |
| 29-Jan-1967 | Moreton Bay | TC *Dinah* | 2? | 2.8? | 1.5? |
| " | Broadwater | " | 1.5? | 1.8? | 0.8? |
| 11-Feb-1972 | Fraser Island | TC *Daisy* | 3? | ? | ? |
| " | Bribie Island | " | 0.8? | | |
| " | Tweed Heads | " | 0.6? | | |
| 24-Jan-1974 | Brisbane | TC *Wanda* | 0.6 | | |
| " | Broadwater | " | 0.3 | | |
| 07-Feb-1974 | Brisbane | TC *Pam* | 0.7 | 1.9 | 0.4 |
| " | Broadwater | " | 0.6 | | |
| " | Kirra | " | 0.4 | | |
| 12-Mar-1974 | Brisbane | TC *Zoe* | 0.7 | | |
| " | Broadwater | " | 0.5 | | |
| 19-Jan-1976 | Moreton Bay | TC *David* | 0.8 | 1.9 | 1? |
| 14-Feb-1981 | Gold Coast | TC *Cliff* | 0.7 | | |
| 01-Feb-1988 | Beachmere | | 0.2 | 1.5 | 0.2 |
| 26-Apr-1989 | Beachmere | | 0.6 | 1.5 | 0.2 |
| 17-Mar-1993 | Gold Coast Seaway | TC *Roger* | 0.7 | 1.3 | |
| 04-Dec-1994 | Beachmere | | 0.1 | 1.5 | 0.2 |
| 02-May-1996 | Beachmere | | 0.7 | 1.8 | 0.4 |
| 26-Mar-1998 | Brisbane | ex TC *Yali* | 0.3 | 1.5 | |
| 13-Jul-1999 | Beachmere | | 0.2 | 1.5 | 0.2 |
| | | Total Events: | 29 | | 16 |

The Bureau of Meteorology has been concerned with forecasting storm tide effects in and around Moreton Bay for many years and Gourlay (1981) proposed a simplified method for estimating peak surges from individual storms based on the cyclone central pressure and its distance from Cape Moreton. At about the same time, a numerical modelling study was undertaken for setting the tarmac elevations for the new Brisbane Airport (BBW, 1979) which provided estimates of the combined surge plus tide. Shortly afterwards, the BPA funded further numerical modelling which was part of a comprehensive assessment of storm tide risks along the Queensland coastline (BPA, 1985a & b). The BPA analyses used a combination of numerical hydrodynamic modelling of individual model cyclones having a variety of intensities and tracks, and statistical modelling of the tidal variation. The selection of intensities and frequency of occurrence were based on the historical record of the time (circa 1980). The BPA study did not update estimates of storm tide within Moreton Bay but only provided estimates on the open coast between Cape Moreton and Point Danger.

Recently, a further update of storm tide levels was independently commissioned by Gold Coast City Council to assist in flood planning studies (H. Betts, Gold Coast City Council, personal communication, 2000). The predictions from these various studies are summarised in Table 4.4, where the indicated storm tide level considers the **combined effects of tide, storm surge and wave setup** as recommended by the various studies listed. Levels are given relative to AHD and the highest expected tidal level (HAT) is also indicated (from Queensland Transport, 1999).

**Table 4.4: Predicted total storm tide levels for the South-East Queensland region**

| Site | Highest Astronomical Tide | Average Recurrence Interval (ARI) years | | | | |
|---|---|---|---|---|---|---|
| | | 50 | 100 | 500 | 1000 | Reference |
| | m above AHD | m on AHD | m on AHD | m on AHD | m on AHD | |
| Moreton Bay | 1.47 | 2.3 | 2.5 | 3.2 | 3.5 | BBW (1979) |
| Cape Moreton | 1.20 | 2.0 | 2.0 | 2.2 | 2.2 | BPA (1985b) |
| Point Lookout | 1.18 | 2.0 | 2.0 | 2.2 | 2.2 | " |
| Jumpinpin | 1.13 | 2.0 | 2.1 | 2.2 | 2.3 | " |
| Surfers Paradise | 1.13 | 2.0 | 2.0 | 2.2 | 2.2 | " |
| Point Danger | 1.11 | 2.0 | 2.0 | 2.1 | 2.2 | " |
| Gold Coast Seaway | 1.13 | 1.9 | 2.1 | | | GCCC(2000) |
| Coomera River Mouth | 1.03 | 1.8 | 2.0 | | | " |

Harper (1998, Appendix 2) uses the same data and extends the scenario range to the 10 000 year ARI event for all areas other than the Gold Coast Seaway and Coomera River mouth.

It can be seen that only very slight variation in total storm tide levels is expected along the open exposed coastline. Within The Broadwater (e.g. Coomera River) slightly lower levels are predicted for the more frequently occurring scenarios, whereas in Moreton Bay (including Deception Bay) significantly higher levels are indicated.

Climatic Variability: Figure 4.3 shows that the incidence of tropical cyclones can be quite variable from one year to the next. This is because of the complex set of factors which influence their genesis. For many years, one of the most frequently used indicators of seasonal cyclonic activity has been the so-called *El Niño*-Southern Oscillation (ENSO) phenomenon (Nicholls, 1992). This is the name given to a near-periodic (between one and three year) cycle of alternating cold and warm ocean temperatures between one side of the Pacific Ocean and the other. The *El Niño* phase sees abnormally warm ocean temperatures off the coast of South America and along the central and eastern Pacific equatorial zone, and simultaneously cooler ocean temperatures in the western Pacific and the Coral Sea. During the reverse cycle, or *La Niña*, ocean temperatures near the Queensland coast are typically above average. Ocean temperature is not the only factor causing cyclone variability but it is a prime contributor. When combined with associated shifts in large-scale zones of atmospheric convergence (Basher and Zheng, 1995), the regions of tropical cyclone genesis in the South Pacific tend, as a result, to move further towards the east (*El Niño*) or the west (*La Niña*).

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

Another common method is to use sea surface temperature readings (SSTs) from various zones in the Pacific. These data have become routinely available from satellites as well as from ships, drifting buoys and from moored buoy networks positioned along the equator. Using an accepted SST-based sequence from 1959 to 1997 (e.g. from Pielke and Landsea, 1999), Figure 4.6 shows that when the historical record is separated into *El Niño* and *La Niña* periods, there is a quite noticeable effect on the tracks of tropical cyclones in the Coral Sea. During *La Niña* (the positive SOI phase), cyclone activity tends to be located closer to the east coast of Queensland and further south than during the *El Niño* (negative SOI) phase. While the ENSO phenomenon appears to be somewhat random, *El Niño* years have outnumbered *La Niña* years by about a factor of 3 since the mid-1970s. This has been reflected along much of the east coast of Queensland by a corresponding reduction in the frequency of cyclone occurrence and Figure 4.3 indicates this effect from about 1975 onwards within 500 km of Brisbane. Exactly why this preference for *El Niño* episodes has persisted during this period is not entirely clear but it may be related to longer period climatic variability as discussed below, or even global climate change. From 1998 to early 2000 there was a return to mild *La Niña* and near-neutral conditions.

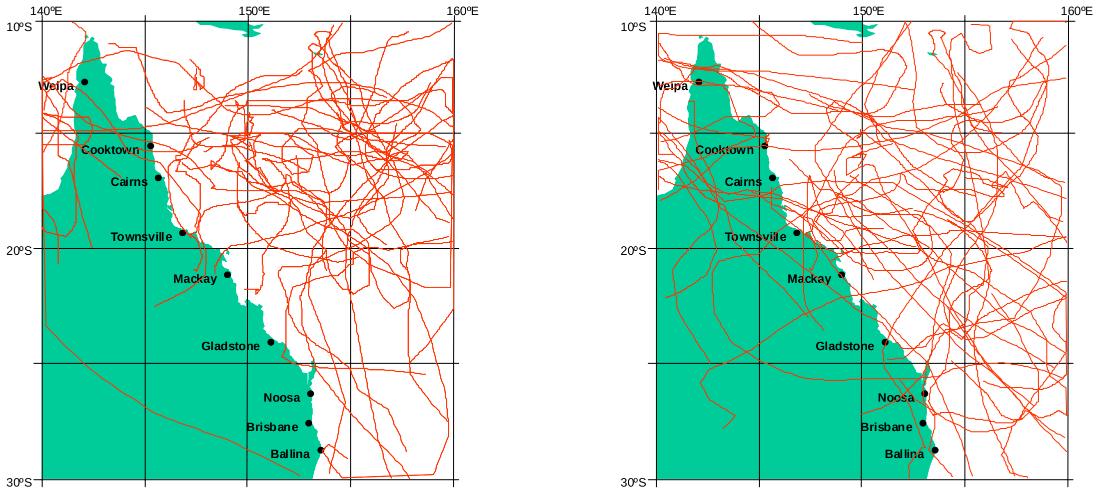



**Figure 4.6: Differences in tropical cyclone tracks between *El Niño* (left) and *La Niña* (right) years.**

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

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

**The South-East Queensland cyclone experience**

Most tropical cyclones in the region occur during the period between December and March, although prior to the 1960s, some east coast lows (so-called 'winter cyclones') were also classified as tropical cyclones and appear in the archive during other months (see Chapter 5). Figure 4.7 shows the recorded monthly occurrences, combined with a closest approach analysis. February can be seen to have the highest incidence, with 34 cyclones, followed by March with 31, and January with 13. December and April are equal with 10 cyclones each. In terms of closest distance to Brisbane, February and March have similar proportions of about 15% being within 100 km. Half the storms have been at least 300 km distant.

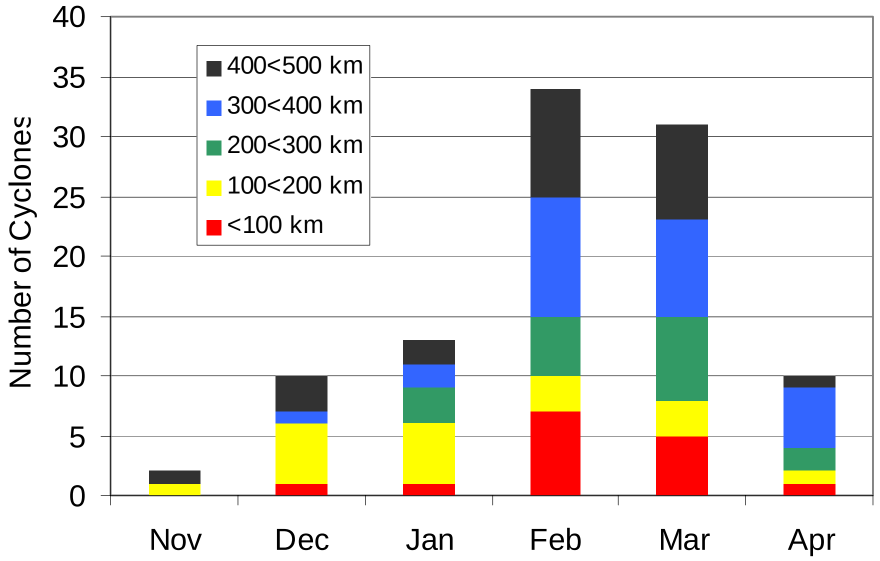
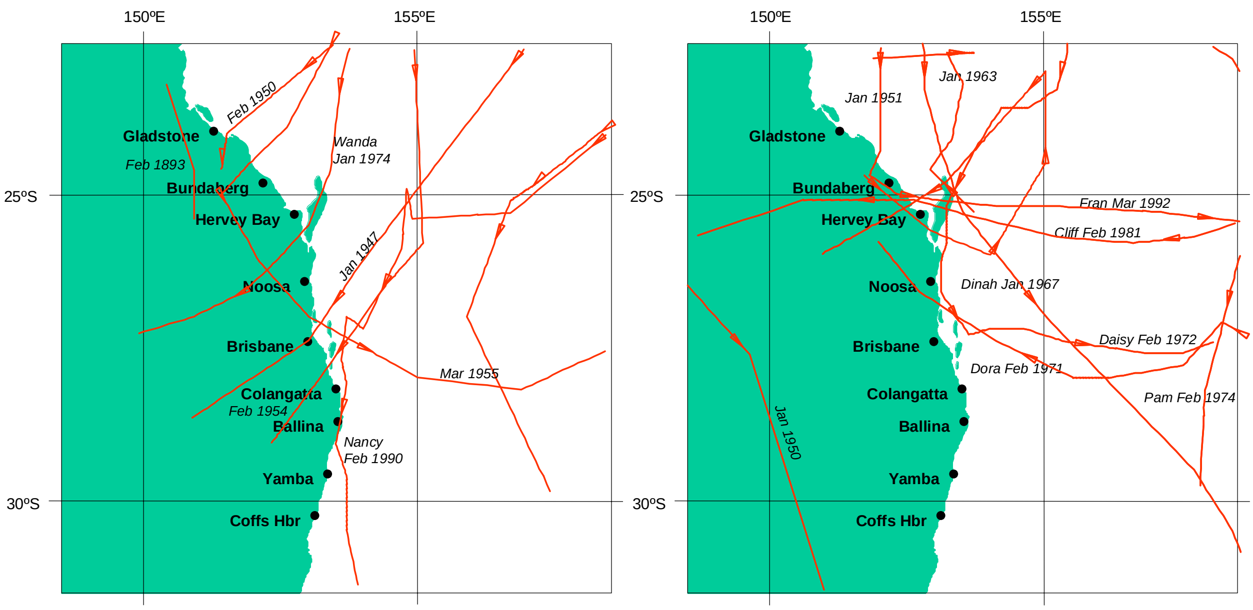



**Figure 4.7: Seasonal distribution of tropical cyclones and closest approach analysis.**

Individual tropical cyclone tracks can be quite variable and, when combined with their overall size and intensity, their impacts can also vary enormously. Figure 4.8 provides a selection of tracks of cyclones which have resulted in significant impacts in the South-East Queensland region. Figure 4.8a presents the tracks of 7 cyclones which caused severe flooding impacts. These include the infamous Brisbane River floods of February 1893 (907 mm rainfall at Crohamhurst north of Caboolture in 24 hours) and January 1974 (TC *Wanda)*, as well as a number of smaller but still significant events. Typically, these cyclones either crossed the coast and decayed inland or spent considerable time near the coast creating strong, moist, onshore flows. Figure 4.8b presents a selection of 9 cyclones whose impacts were more concentrated on the coast or caused significant wind damage. These include the January 1950 cyclone which originated in the Gulf of Carpentaria and actually passed 300 km inland but was accompanied by a strong and extensive circulation which created a 0.58 m storm surge in Moreton Bay.




(a) Flood impacts

(b) Wind, wave and surge impacts

**Figure 4.8: Selected tracks of tropical cyclones impacting South-East Queensland**.

As tropical cyclones move into temperate latitudes they begin to interact with troughs in the middle to upper westerlies. There are three possible outcomes in South-East Queensland as a result of this interaction:

- the cyclone may remain far enough removed from these westerlies to retain tropical cyclone characteristics (e.g. TC *Dinah*);
- the westerlies may interfere destructively with the cyclone circulation and weaken it (e.g. TC *Nancy*); or,
- the cyclone may interact favourably with an upper trough to form an intense temperate latitude cyclone – collectively termed 'extra-tropical cyclones' in the literature.

This latter interaction is called *extra-tropical transition* and globally has been associated with some extreme tropical cyclone impacts in high latitudes. The 1938 'New England' Hurricane in the United States is listed 4th on the list of all-time greatest US hurricane disasters (Pielke and Landsea 1998) and in 1968, TC *Gisselle* caused widespread destruction in New Zealand, sinking the *Wahine* in Wellington Harbour.

A recent Queensland example of a tropical system undergoing this type of potentially destructive transition at higher latitudes is TC *Lance* in April 1984. History now also records *Lance* as an east coast low in terms of its impact on South-East Queensland. Figure 4.9 illustrates the sequence of development of this system whereby *Lance* had decayed into a low pressure system east of Proserpine late on April 6th, losing its 'tropical cyclone' status. However, as it drifted south, its remnant circulation underwent rapid extra-tropical transition to the north and offshore of Brisbane, buffeting parts of the southern coast with 110 km/h winds over the next three days. Fortunately it maintained its distance from the coast, thus avoiding more major impact.

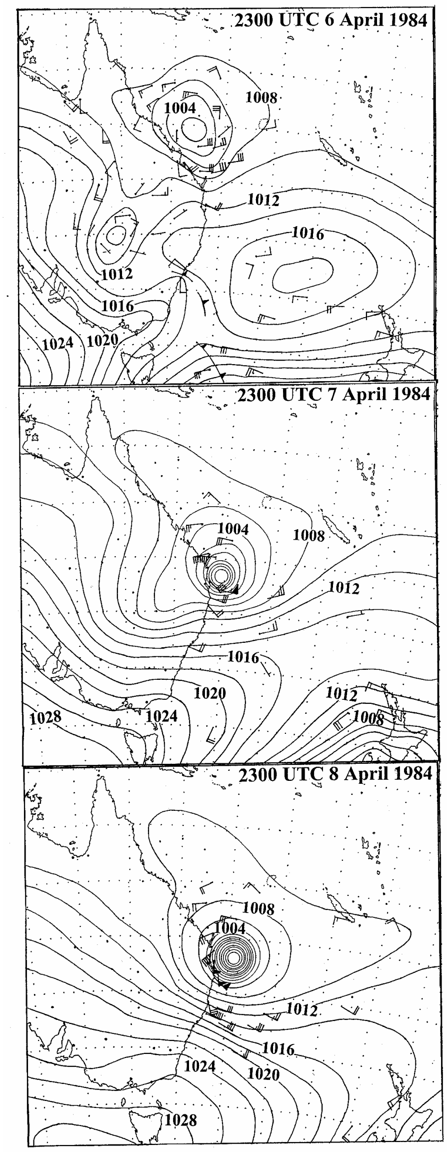



**Figure 4.9: Extra-tropical transition of TC *Lance* in April 1984.**

### The severe wind threat

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

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

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

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

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

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

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

Some of the key forces on buildings are illustrated in Figure 4.10 and Figure 4.11. The first figure shows the way in which the suction forces generated on low pitched roofs may be countered by a reduced pressure inside the building where the integrity of the windward walls and windows are maintained and there is a predominance of openings on the leeward side. The second figure shows how an overpressure inside the building is created when that integrity is compromised by a window being broken on the windward side. The additional force can destroy the roof, if not the whole structure.

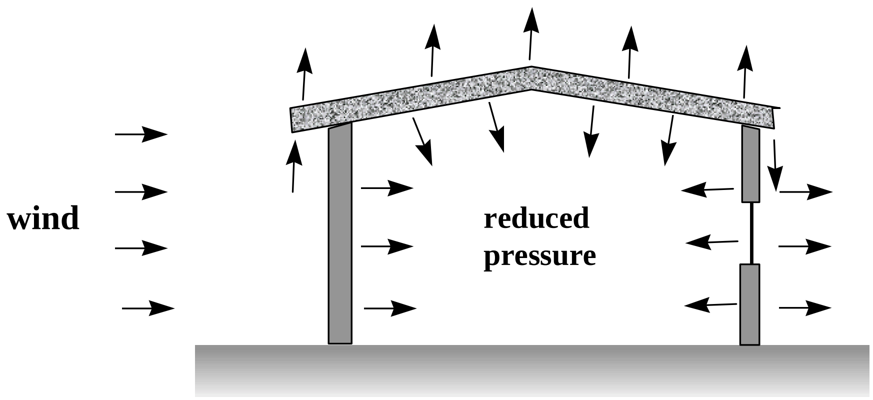



**Figure 4.10 Wind forces working on a building with external integrity**

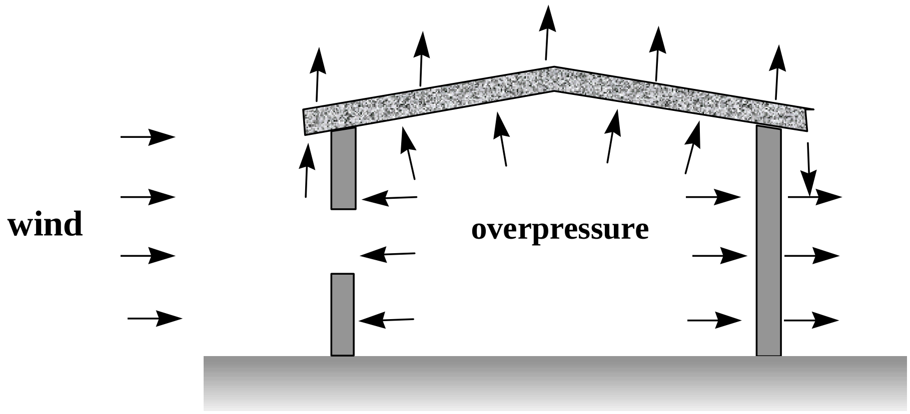



**Figure 4.11 Wind forces working on a building where its external integrity is lost**

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

**Severe Wind Risk Assessment**

Methodology:

The impact of severe winds in tropical cyclones will vary considerably from site to site because of the influences of local terrain and topographic factors. These relate primarily to:

- terrain 'roughness' (e.g. open sea, fields, trees, houses, etc);
- shielding or interference from adjacent objects (e.g. other buildings); and,
- topographic effects on slopes and the near the tops of hills.

The wind loading code makes significant allowance for these site factors. These site factors have been determined on a property-by-property basis. Terrain and shielding effects have been accounted for by categorisation of properties into five groups; "Foreshore", "Inland", "Town", "Town Centre" and "Foreshore Town", as illustrated in Figure 4.12. The site classes and site nomenclature were derived in part from the approach of Harper (1999a).The relevant terrain and shielding factors, which allow a reduction of the basic wind speed under *AS1170.2-1989* rules, are given in Table 4.5. Although the categories are few and broad in nature, they are considered to be sufficient for risk assessment on a broad scale. Local variations in terrain roughness due to the existence of open spaces within urban areas, variations in vegetation types, or local shielding effects from nearby buildings, for example, are not considered, although a more detailed analysis would require this.

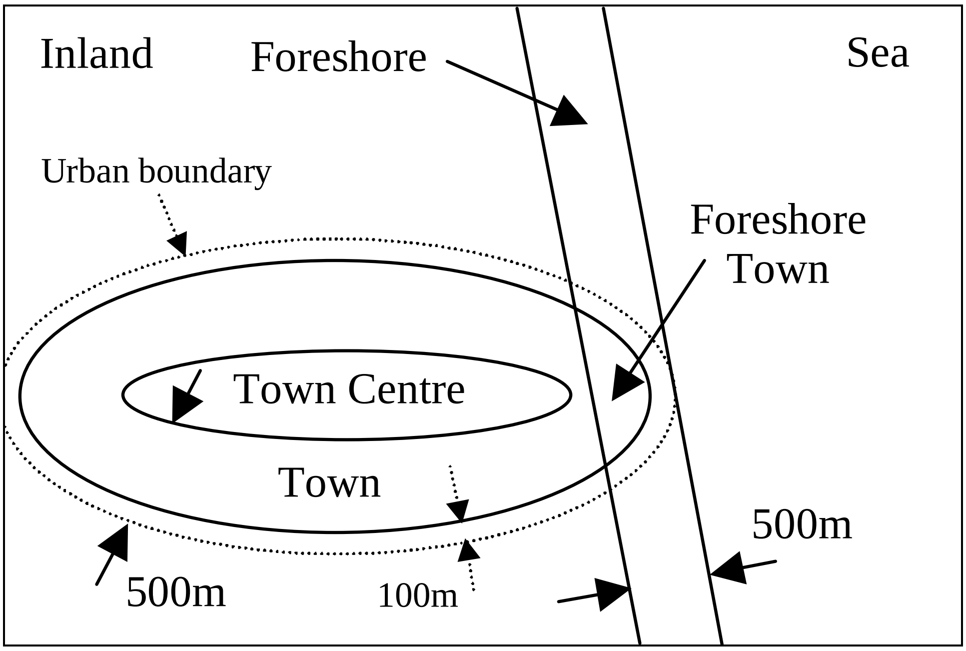



**Figure 4.12 Classification scheme for the five terrain/shielding categories**

**Table 4.5 Terrain and shielding multipliers**

| Category | AS1170.2 Terrain Category | Building Height, z (m) | Terrain multiplier, $M_{z,cat}$ | Shielding multiplier, $M_s$ |
|---|---|---|---|---|
| Foreshore | 2.0 | 7 | 0.946 | 1.0 |
| Town | 2.5 | 7 | 0.864 | 0.85 |
| Inland | 2.5 | 7 | 0.864 | 1.0 |
| Foreshore Town | 2.0 | 7 | 0.946 | 0.85 |
| Town Centre | 3.0 | 7 | 0.782 | 0.85 |

Topographic effects were calculated for north, south, east and west wind directions, on a 200 m grid, with elevation derived from a 10 m grid Digital Elevation Model (DEM). In some parts of the region, the DEM was coarser because detailed topographic information was not available. The effect of using a coarser DEM grid is that wind risk will be slightly underestimated because topographic 'highs' and 'lows' are smoothed out. The affected areas are in minor parts of Caboolture Shire and all of Pine

Rivers, where AUSLIG's Three Second DEM was used (grid cell approximately 100 m), and Brisbane City, where a 20 m grid cell was used.

The method used is in accordance with *AS1170.2*. An example of how the topographic factor varies along a surface profile is shown in Figure 4.13. The topographic factor increases the basic wind speed, which is referenced to flat, open terrain.

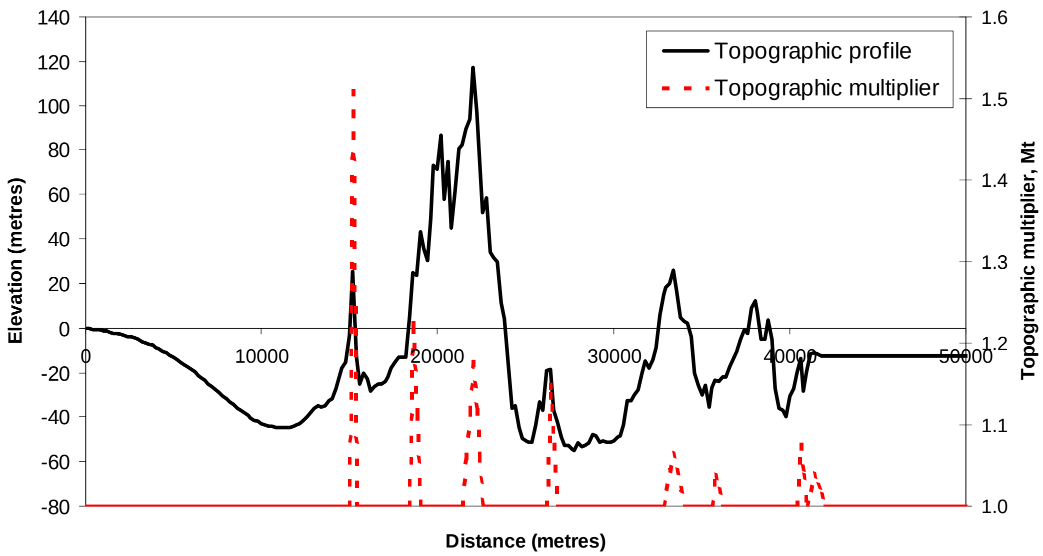



**Figure 4.13 An example of variation in the topographic multiplier for a single surface profile**

Although South-East Queensland has some hilly terrain, topographic effects are generally not important because most of the urban development is located on flat areas. High values for the topographic factor, which can reach a maximum of 1.54, apply to only a very small percentage of properties.

For the modelling of building vulnerability to wind, two age classes have been established, that is, nominally pre- and post-1980. Damage loss curves for these two age classes were previously developed by Walker (1994), based on insurance industry experience in Australia, and are shown in Figure 4.14. The high level of uncertainty associated with these curves should be recognised.

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

> *The problem in estimating domestic quality building behaviour in strong winds stems from a number of issues:*
>
> - *relatively few instances of severe damage being available;*
> - *a lack of accurate wind measurements at, or near building exposure conditions;*
> - *structural redundancy, variable load paths and variety of fixings;*
> - *wide variations in building style and quality of construction; and,*
> - *second-order effects such as debris damage.*
>
> *Based on damage assessments undertaken primarily for the insurance industry* (since 1971) *it has been possible to develop indicative 'damage curves' for Australian domestic construction (Walker 1994, Harper and Holland 1998) which are also deemed consistent with US experience in Hurricane* 'Andrew' *(Sparkes 1993).*

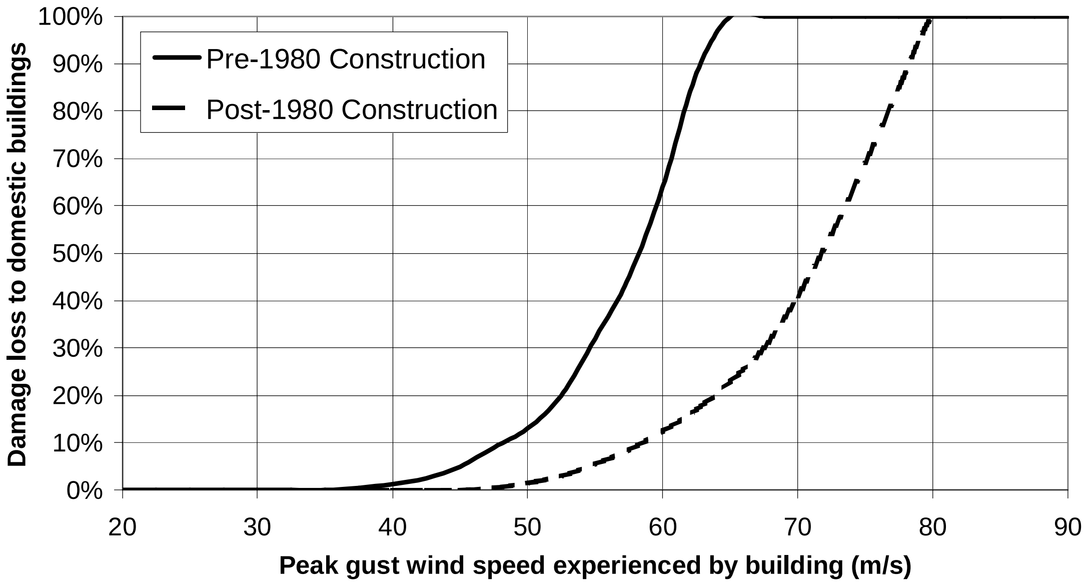



**Figure 4.14 'Damage loss curves' (adapted from Harper, 1999a; originally developed by Walker, 1994)**

The damage loss curves presented by Harper (1999a), and reproduced here in Figure 4.14, clearly illustrate the significance of the introduction of mandatory building standards in the 1980s. This point was evident in the experience of the impact of TC *Winifred* near Innisfail in 1986 and most recently with TC *Vance* at Onslow in Western Australia in 1999 (Reardon, Henderson and Ginger, 1999). The percent damage loss values shown are relative to the nominal insured value of a single, 'typical' dwelling and associated assets, or, when aggregated, the total residential building stock. Industrial and commercial buildings, where individual engineering design and inspection have been applied, may be expected to suffer significantly less damage than dwellings in similar conditions. This is not always the case, however, as was observed in the damage to Dubbo caused by a severe thunderstorm on 6 January, 2001 (Stehle and Henderson, in prep.). Nonetheless, the percentage losses assessed here, for residential properties only, are considered to be indicative of the total urban losses.

Although *AS1170.2-1989* presents guidance on the estimated peak gust wind speed for Brisbane as a function of ARI, application of point wind speed estimates across an entire urban community is not appropriate because it will overestimate the potential damage to the community. This is due to the complex spatial variation in tropical cyclones (especially near the eye, etc.) and the likelihood of decay of the wind strength with increasing radius from the centre of a cyclone, and decay of wind strength as a cyclone moves inland. It has also been suggested that the tropical cyclone wind hazard, as represented by *AS1170.2*, is more conservative than recorded tropical cyclone wind data and advanced numerical modelling suggests (Harper, 1999b).

Hence, to explore the community-wide wind hazard potential in Southeast Queensland, a series of synthetically generated tropical cyclone wind fields have been supplied by Dr Harper at Systems Engineering Australia Pty Ltd (SEA), expressly for use in this study. These modelled maximum envelope wind gust data have wind speeds that approximate the return period wind speed for ARIs 100, 200, 500, 1000, 2000 and 5000 years at one of three reference sites according to the model of Harper (1999b). The three reference sites are Brisbane GPO, Caboolture GPO and Bundall in Gold Coast. For each ARI being considered, the potentially high spatial variability of the cyclonic winds (due to track, speed, size, etc.) has been approximated by taking 30 sample scenarios, each of which produces a similar peak wind speed at a reference point but not necessarily at any other point. For each ARI, ten scenario events have return period wind speeds referred to the Caboolture site, 10 events have return period wind speeds referred to the Brisbane site, and 10 have return period wind speeds referred to the Gold Coast site. A single scenario representing a maximum credible (simulated 50 000 year return period) wind speed at each of the three reference sites was also supplied. A total of 180 synthetic storms were generated, excluding the 50 000 year ARI events. These events are intended to be a representative sample of the broad range of possible scenario cyclonic events that could impact on the region in all time frames.

The wind swath for each scenario event consists of values of peak wind gust speed and direction on a uniform grid. These values were then interpolated to values at the centroid of each CCD for damage calculations. The damage level to houses and flats was calculated for each CCD, for each scenario event. Damage to the flats and houses in the entire South-East Queensland region was also calculated for each scenario event.

Each loss scenario was associated with a probability of occurrence equal to one-thirtieth of the probability of an individual scenario storm for a given ARI. For example, a particular storm that has a 100-year ARI wind speed at Brisbane GPO is assigned a probability of occurrence of 1 ÷ 100 ÷ 30 = 0.033%. The losses associated with this storm have the same probability of occurrence as the storm.

Cumulative loss curves for each CCD, and for the entire South-East Queensland region, were prepared by aggregating the probabilities of exceedence of various loss levels for all 180 scenario storms. A relationship describing the ARIs at which various levels of damage were exceeded was developed from the loss curve.

Results:

**Before the results of the wind and storm tide loss assessments are presented, it must be pointed out that very significant uncertainties are associated with the estimates of damage losses presented here for severe wind and storm tide. Therefore, the reader should treat the estimates of damage losses as indicative only. Refer to the comments on limits and uncertainties in this chapter.**

Limits and uncertainties in the wind risk assessment include, but are not confined to:

- uncertainty in the hazard model. Uncertainties originate from the inherent variability of cyclonic wind fields, from uncertainties due to assumptions made in the parametric hazard model, from the incomplete sampling of the total probability space of synthetic cyclone events, from assumptions made about the probabilities of events selected from the synthetic catalogue, and from the short and incomplete historical record of cyclonic winds in Southeast Queensland that is used as a reference for the hazard model;
- uncertainty in the terrain model. AGSO's GIS-based approach of developing the terrain model is innovative. However, the terrain model was developed for a broad-scale study and it will contain inaccuracies at the individual parcel level. Uncertainties in the terrain factors will arise from assumptions made in *AS1170.2*. The time-dependent interaction of the cyclones with the terrain and built environment is not modelled;
- uncertainty in the building damage loss model. Some of these uncertainties have been mentioned earlier in this chapter. Additionally, although the building damage loss model is based on Australian data, the data refer to dwellings constructed in cyclonic areas. Dwellings constructed in Region B of *AS1170.2* will have different performance characteristics from modern dwellings constructed to wind codes in cyclonic areas;
- uncertainties and incompleteness of the property inventory for information such as building age, condition, and compliance with wind loading standards; and
- limitation on the scope of the risk assessment. The analysis does not consider non-residential structures such as commercial, industrial and infrastructure facilities. Nor does it consider direct or indirect economic or social losses, or casualties, that are a consequence of building

damage. Hence, significant further analysis is required to develop a more comprehensive understanding of how the community could be affected.

A more rigorous analysis would account for all of these uncertainties and limitations, although it would entail considerable additional effort.

A summary of the tropical cyclone severe wind damage losses in the South-East Queensland region is given in Table 4.6 and plotted in Figure 4.15. Damage losses are expressed as a percentage of the total insured value of a 'typical' residential building and its contents. Alternatively, the damage losses can be considered as a percentage of the total insured value of all of the residential buildings and their contents. The losses are the minimum losses expected for the probability associated with that loss. For example, there is an annual probability of 0.2% that damage losses will be 0.23% of the total insured value, or higher than 0.23% (Table 4.6).

For an annual probability of 0.1%, damage losses are calculated to be equivalent to the repair or replacement cost of at least 1500 dwellings, or approximately 0.23% of the total residential building stock. This AEP corresponds approximately to the likelihood of the design event in *AS1170.2-1989*.

**Table 4.6 Residential damage losses for cyclonic winds in South-East Queensland**

| ARI (years) | AEP | Damage (insured value of building and contents – equivalent number of houses and flats) | Damage (% of total insured value of building and contents for houses and flats) |
|---|---|---|---|
| 100 | 1.0% | 150 | 0.024% |
| 200 | 0.5% | 500 | 0.078% |
| 500 | 0.2% | 1050 | 0.16% |
| 1000 | 0.1% | 1500 | 0.23% |
| 2000 | 0.050% | 1800 | 0.28% |
| 5000 | 0.020% | 2500 | 0.38% |

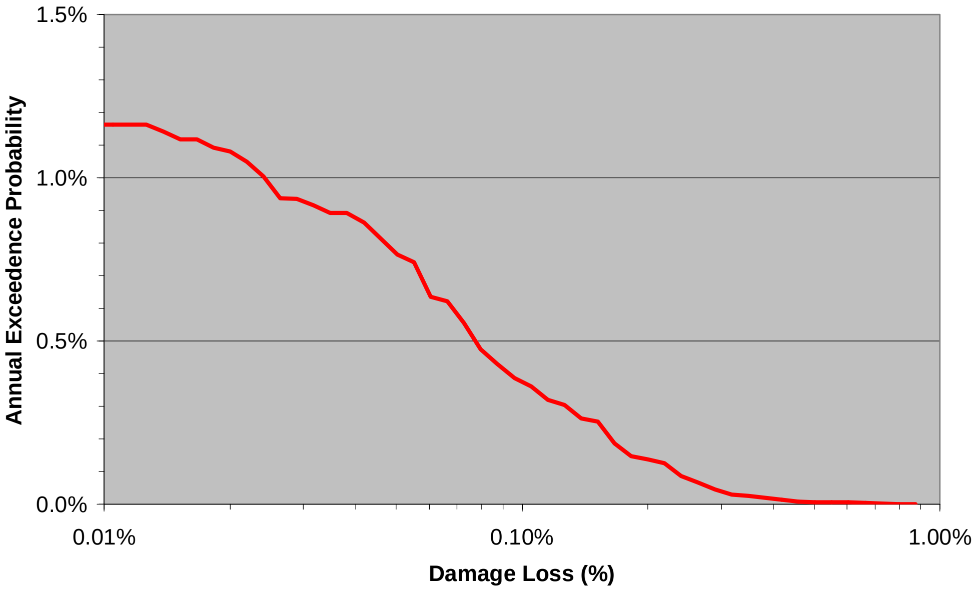



**Figure 4.15 Cumulative tropical cyclone wind damage losses for residential buildings in South-East Queensland**

The reader should note that, typically, the South-East Queensland region is larger than the spatial extent of damaging winds from the synthetic windfields of the scenario cyclones. For example, a scenario cyclone selected for its damaging windspeeds in the Gold Coast may have windspeeds at Caboolture that would cause little or no damage. Similarly, a scenario cyclone selected for its potentially damaging winds in Caboolture may have lesser windspeeds in Logan and Gold Coast. The estimates of damage losses to the South-East Queensland region, in its entirety, are therefore reduced compared to estimates of damage to individual LGAs with scenario cyclones that pass close to those individual LGAs.

A probabilistic distribution of potential tropical cyclone wind damage risk across the South-East Queensland region is shown in Figure 4.16. The annual risk to each CCD is shown. The risk is defined in terms of the percentage loss of the insured value of a 'typical' residence including contents or, alternatively, the percentage loss of the insured value of the residential building stock and contents (multiplied by an annual probability of one). The percentages in the legend of Figure 4.16 must be multiplied by $10^{-6}$. All of the scenario storms were used to prepare the map.

The damage patterns, and the severity of damage, will be different for each individual scenario event (and each real event), and each of these will be different from the probabilistic map shown in Figure 4.16. The level of damage in each CCD from individual scenarios ranges from negligible upwards, depending on the spatial patterns of wind gust velocities, and their interaction with the terrain and topography model.

The spatial pattern of damage losses strongly indicates areas of older construction, exposed terrain (especially adjacent to the coast and major waterways) and steep topography, according to the assumptions of the analytical model. Settlements having more than one of these attributes are particularly at risk of above-average wind damage levels.

Areas of relatively old (pre-1980) settlement are expected to suffer stronger damage than newer areas. These affected areas of older settlements include parts of Redcliffe, older suburbs in Ipswich such as Ipswich and Leichhardt, older suburbs in Logan such as Loganholme and Slacks Creek, and older suburbs of Brisbane including Hendra, Pinkenba, and parts of Hamilton, Bowen Hills, Mansfield and Nundah.

The expected damage to older settlements near the coast is estimated to be almost 100 times greater than the average residential damage across the entire region. Brighton, Sandgate, Shorncliffe, Wynnum, Manly, and Lota are examples of those suburbs most at risk of damage. Coolangatta, Surfers Paradise and Burleigh Heads are also expected to suffer significantly higher wind damage than the regional average.

On the other hand, large areas of urbanisation offer significant shielding from severe winds and, in these areas, modelled damage is reduced compared to damage in areas where urbanisation is less dense. This is the case in a very large area of Brisbane, extending South from Zillmere and Apsley to the Brisbane River, and South from Brisbane City to suburbs such as Coorparoo, Greenslopes and Camp Hill.

Residences that are not shielded by other buildings, such as those in semi rural areas, are also expected to suffer higher damage rates than residences of similar age in more densely urbanised settlements. However, the numbers of dwellings in such areas are relatively small compared to those in the main urban areas, although this may be little satisfaction to those potentially affected. Such areas include Gumdale and Chandler in South-East Brisbane, and the northern parts of Caboolture Shire such as Elimbah.

Areas of predominantly new dwellings (post-1980) are expected to fare relatively well in future strong winds. Redland is a good example, where about 62% of all buildings were constructed after 1980. Cyclonic wind risk is relatively low, despite Redland's coastal location.

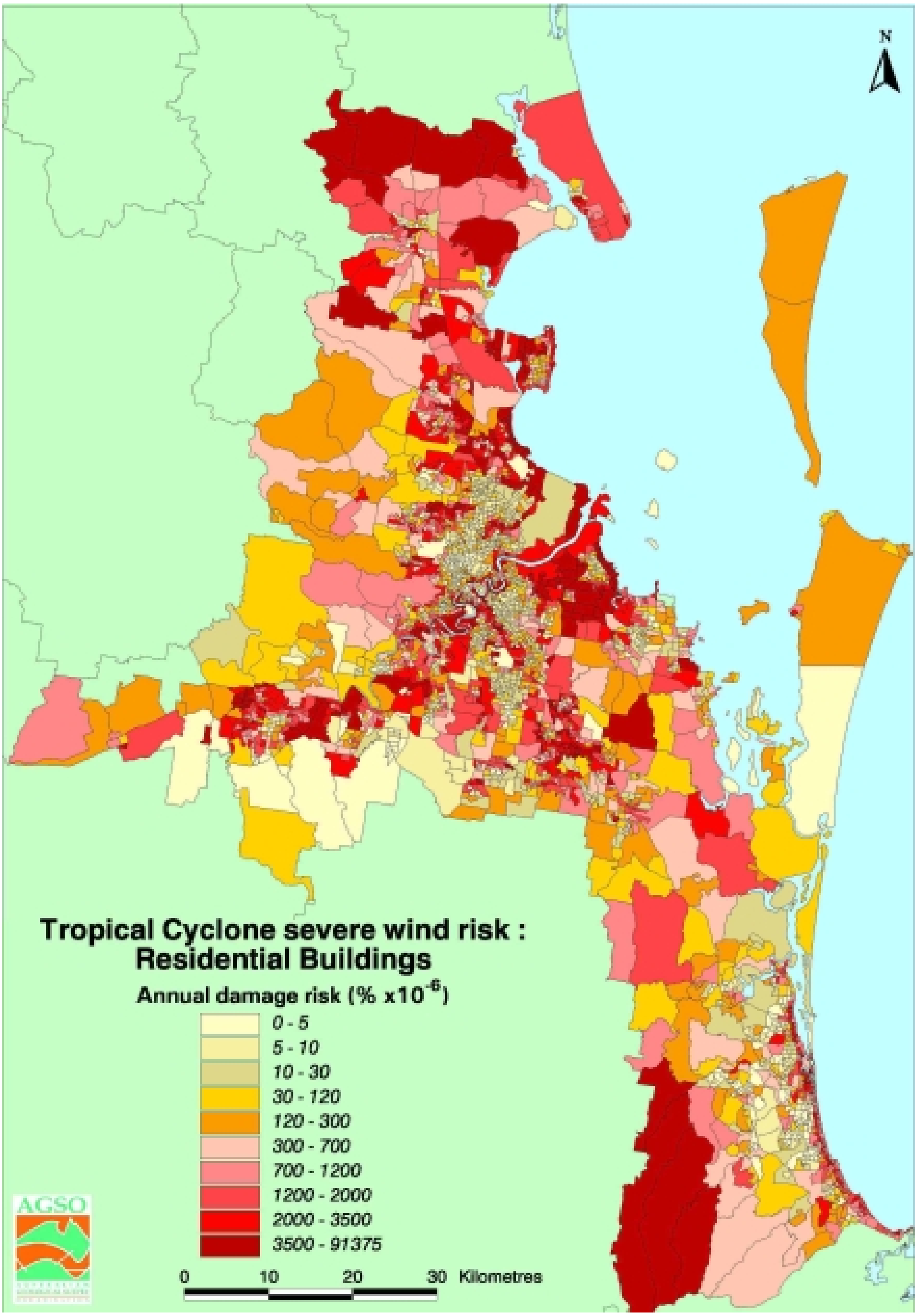



**Figure 4.16 Annual tropical cyclone severe wind risk to residential buildings. Units are the percentage of the insured value of a 'typical' residence including contents, multiplied by $10^{-6}$ (see text)**

<u>Comments on risk to lifelines and other assets</u>: With most cyclones that approach to within the radius of maximum winds, the greatest amount of inconvenience has been caused by damage to the power reticulation infrastructure. Power lines are often brought down by tree branches, palm fronds and other wind-blown debris. Electricity authorities in coastal areas of Queensland tend to maintain good clearance of trees from power lines and the more critical areas tend to be serviced by underground mains. Power poles and pylons may be brought down by high winds. In the Brisbane Valley, near Esk, in 1999, for example, several transmission line pylons were brought down in extreme wind gusts associated with a local storm . Also, in TC *Steve* in Cairns (late February 2000), several poles were pushed out of the vertical because their foundations had been saturated by up to four weeks of repeated heavy rainfall.

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

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

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

**Storm Tide Risk**

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

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

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

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

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

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

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

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

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

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

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

**Storm Tide Scenarios**

The total storm tide height (i.e. the combined total of storm surge, atmospheric tide and wave setup above AHD) annual exceedence probabilities cited in Table 4.4 and Appendix 2 in Harper (1998), have been used to model the impact of storm tide inundation for 2%, 1%, 0.2%, 0.1% and 0.01% AEP scenarios (i.e. ARI of 50, 100, 500, 1000 and 10 000 years respectively) on developed properties in South-East Queensland. The modelling was aimed at identifying:

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

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

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

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

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

Data uncertainty: In this model, the key values of floor height and ground height were taken from the detailed property database described in Chapter 3. Floor heights have been estimated on the basis of building age rather than field survey, as was done by the *Cities Project* in Cairns, Mackay and Gladstone. A broad generalisation has been adopted where houses built before 1980 will have a suspended floor at least 0.8 m above ground level and houses built after 1980 will be on a slab (0.3 m above ground level). No allowance has been made for the high-set 'Queenslander' style house so common in northern Queensland. Observation of high set houses in coastal areas of South-East Queensland indicates that where such houses exist, the under-house areas have almost all been enclosed, thus making them two story houses with floor heights at 0.3 m. Again these are perhaps conservative assumptions. Non-residential buildings are all assumed to have a floor height of 0.3 m above ground level.

The ground height for each property was interpolated in the GIS from the Digital Elevation Model (DEM) developed by AGSO from a range of sources. In the low lying coastal areas at risk from storm tide inundation, the accuracy of the DEM is, at best, in the plus-or-minus 0.3 to 0.5 m range. The use of such 'imprecise' data may seem to introduce potentially significant error or uncertainty in the outcome. It should be recognised, however, that the error estimates for the AGSO DEM are substantially less than those published for the original topographic data and are the very best available. Unfortunately, DEM data covering the coastal areas of Caboolture Shire (e.g. Bribie Island, Beachmere and Deception Bay) were not available at an appropriate resolution for this study. In these areas we have resorted to making ‘best guess’ estimates based on the network of permanent survey marks (PSM) maintained by the Department of Natural Resources, local knowledge and reports of historic events. The DEM data for Brisbane pre-dates the development of the current international airport and much of the Fisherman Island port area, both of which have been subject to significant filling since that time. Where possible, allowance for that work has been taken into account.

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

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

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

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

where:

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

Modelling results are presented separately for the area inside Moreton Bay and for the Gold Coast area facing the Coral Sea. This is to take account of the different estimated storm tide heights likely to be experienced in each area, as outlined in Table 4.4. Whilst the damage estimates for the Gold Coast area could be generated by a single tropical cyclone, it is unlikely, given its much greater spatial extent, that a single cyclone would have an equal impact throughout Moreton Bay. The estimates for the area inside Moreton Bay, therefore, represent the aggregate damage for the range of cyclones that would be experienced for the given AEP. Given the significant unpredictability of cyclone behaviour, however, it would be prudent, from both personal and public safety perspectives, to assume that the effects modelled **could** be produced by a single cyclone event.

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

The second assumption is that the population will be concentrated at their place of residence at the time of impact. We feel that this is also a reasonable assumption, given that there would be 24 and 48 hours warning of the impending cyclone impact and that families would seek shelter together at home wherever possible. This is in contrast to the situation with earthquakes (see Chapter 8), where a range of population distribution scenarios (e.g. day, night, weekend, holiday period, etc.) needs to be considered.

It should be noted that the numbers of properties identified as 'not affected' in each of the following scenario include those in Ipswich and Logan Cities and Pine Rivers Shire where there is no exposure to storm tide.

The 2.0% AEP scenario: Under this scenario a total storm tide elevation above AHD of 2.3 m would be experienced inside Moreton Bay (i.e. roughly 1.5 m above mean high water spring tides (MHWS) or 0.9 m above HAT); a 2.0 m elevation would be experienced along the open Coral Sea coast (1.35 m above MHWS and 0.9 m above HAT); and 1.8 m inside The Broadwater. The modelled impact (with all the caveats outlined above), in terms of the inundation of developed properties is summarised in Table 4.7.

**Table 4.7 Developed properties affected by a 2.0% AEP storm tide**

| Level of Inundation | Moreton Bay | Coral Sea | Region |
|---|---:|---:|---:|
| >1m over floor | 350 | 50 | 400 |
| <1m over floor | 5350 | 1200 | 6750 |
| on property but below floor level | 10 250 | 4050 | 14 300 |
| not affected | 548 850 | 114 300 | 663 150 |

Overall, the impact of a 2.0% AEP (ARI of 50 years) storm tide event would have minimal impact on a regional basis with only 1.0% of all developed properties likely to be affected by over-floor inundation. Such an event would, however, certainly cause damage to buildings and short-term dislocation in a few localised areas. Inside Moreton Bay, the main areas of concern would be those facing Pumicestone Passage (notably Donnybrook, Toorbul, Bellara and Bongaree), Deception Bay (Godwin Beach, Beachmere, Deception Bay and Scarborough) and Bramble Bay (Woody Point, Clontarf, Brighton, Sandgate, Shorncliffe and Nudgee Beach) in the northern section; along the Brisbane River and its major tributaries (especially along Bulimba Creek, Breakfast Creek and Norman Creek) and the north-facing coastal areas such as Birkdale, Cleveland and Victoria Point as well as the low lying areas of the Bay Islands (such as Coochiemudlo, Macleay and Russell), in the south of the Bay. In all, 15 950 properties would suffer some degree of impact within Moreton Bay, of which 35.7% would have over-floor flooding.

In the areas along the Coral Sea coast, the greatest impact would be felt in the low lying areas facing The Broadwater and the tidal estuaries that enter it, and along Currumbin and Tallebudgera Creeks. Levels of inundation in this area, however, would be significantly less than experienced inside Moreton Bay for a scenario of the same ARI. Around 5300 properties would be affected, of which 23.5% would have over-floor flooding.

Most of the properties identified as having more than a metre of water over floor level would be facilities such as boat ramps, wharves and similar features that are, by their very function, on the water. None-the-less, around 15 700 people would be directly affected in dwelling which would have water over floor level. Some precautionary evacuations may need to be considered. These would need to have been completed before the winds of the cyclone reach 75 km/h, the speed above which it is considered to be unsafe to be outside shelter. This wind speed is typically reached about 6 hours before the eye of the cyclone actually reaches the area.

Very few key facilities would be affected by storm tide inundation under this scenario, though there are likely to be some roads closed by sea water flooding.

The modelled impact of the study area is shown in Figure 4.17 (northern Moreton Bay) Figure 4.18 (southern Moreton Bay) and 4.19 (Coral Sea coast).

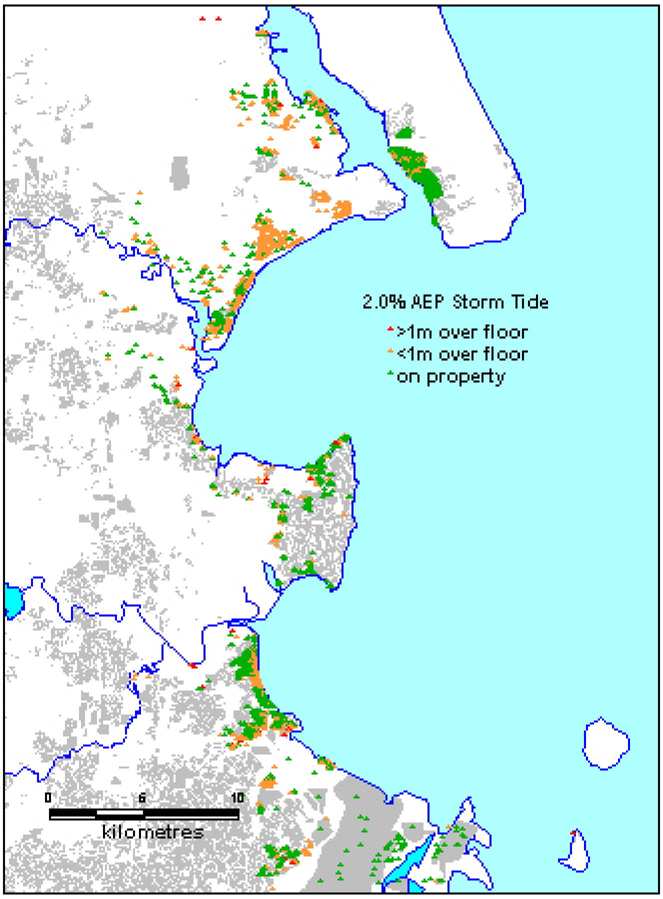



**Figure 4.17 Modelled impact of a 2.0% AEP Storm tide in northern Moreton Bay**

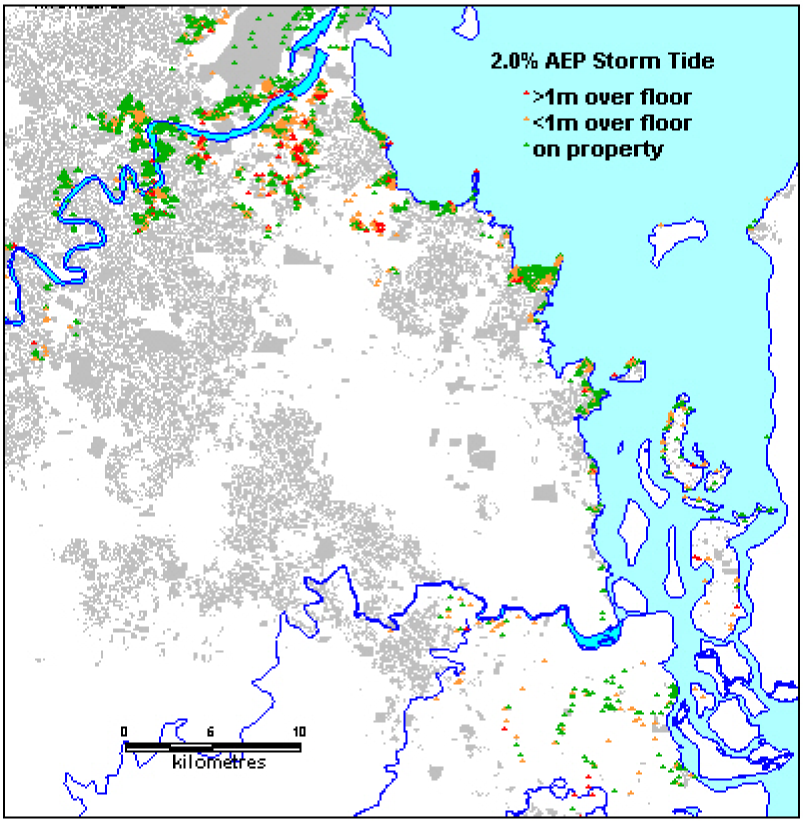



**Figure 4.18 Modelled impact of a 2.0% AEP storm tide in southern Moreton Bay**

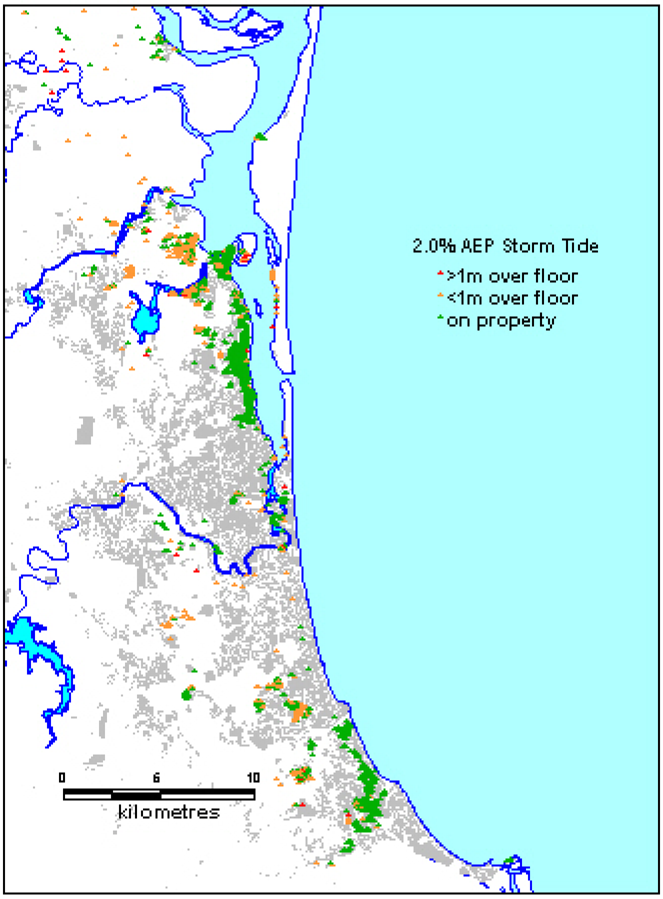



**Figure 4.19 Modelled impact of a 2.0% storm tide along the Coral Sea coast**

The 1% AEP scenario: Under this scenario a total storm tide elevation above AHD of 2.5 m would be experienced inside Moreton Bay (about 1.7 m above MHWS or 1.1 m above HAT) and 2.0 m would be experienced along the open Coral Sea coast and inside The Broadwater (about 1.35 m above MHWS or 0.85 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.8.

**Table 4.8 Developed properties affected by a 1.0% AEP storm tide**

| Level of Inundation | Moreton Bay | Coral Sea | Region |
|---|---|---|---|
| >1m over floor | 850 | 100 | 950 |
| <1m over floor | 6750 | 1850 | 8600 |
| on property but below floor level | 11 950 | 5200 | 25 750 |
| not affected | 545 300 | 112 500 | 657 800 |

Overall, the impact of a 1.0% AEP (ARI of 100 years) storm tide event would affect only 1.5% of the region's developed properties having water over floor level. It would, however, certainly cause significant damage to buildings and their contents and cause short-term dislocation in localised areas. The horizontal extent and depth of inundation experienced in a 2.0% AEP event would increase slightly under a 1.0% AEP scenario. For example, the suburb of Banksia Beach on Bribie Island, which is built around a large canal estate, would be affected for the first time. Within Moreton Bay a total of 19 550 properties would be affected to some degree, of which 38.8% would have water over the floor; along the Coral Sea coast, 7150 properties would be affected, with 27.2% having over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 22 000 and the need to consider precautionary evacuations would also increase. Up to 1500 people could be at significant risk in dwellings that would have more than 1 m of sea water over floor level. Certainly seaside caravan parks at risk of inundation would need to be evacuated ahead of cyclone impact. As many as 520 commercial properties and 230 logistic and transport facilities would be subject to over-floor flooding, together with a small number of key facilities, including telephone exchanges and power substations.

The modelled impact of the study area is shown in Figure 4.20 (northern Moreton Bay) Figure 4.21 (southern Moreton Bay) and 4.22 (Coral Sea coast).

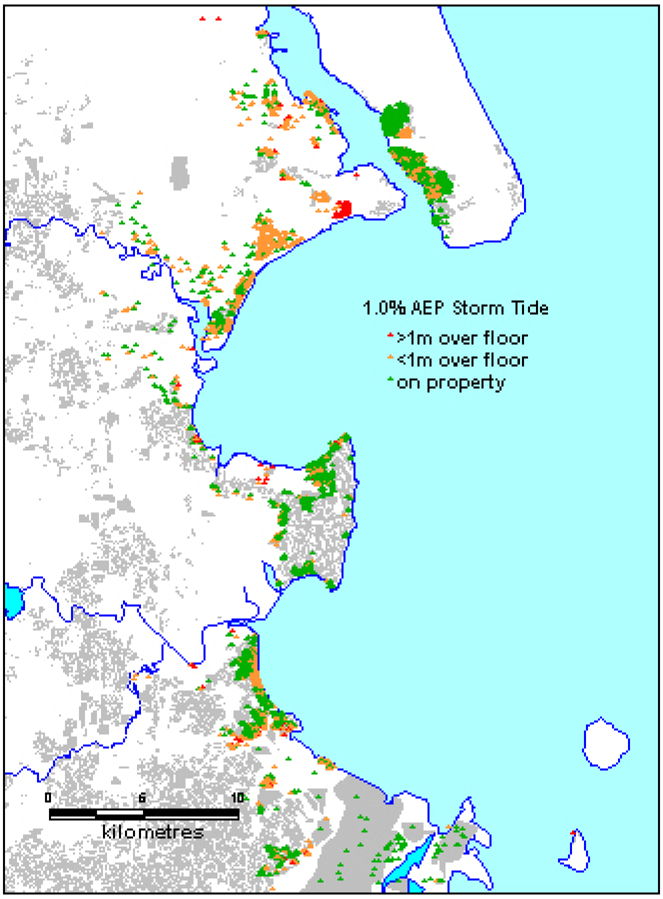



**Figure 4.20 Modelled impact of a 1.0% storm tide in northern Moreton Bay**

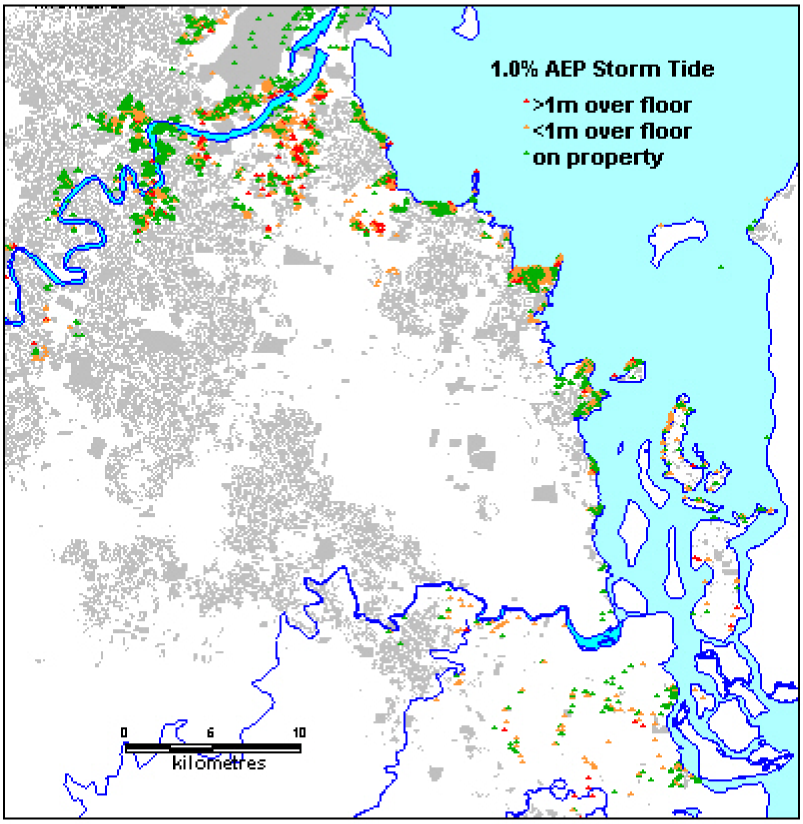



Figure 4.21 Modelled impact of a 1.0% storm tide in southern Moreton Bay

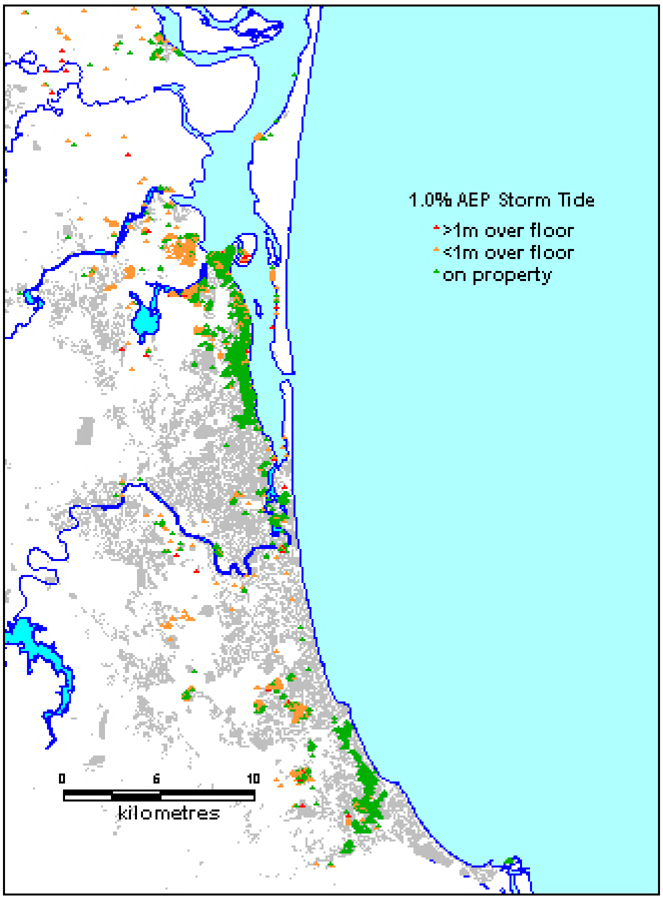



Figure 4.22 Modelled impact of a 1.0% storm tide along the Coral Sea coast

The 0.2% AEP scenario: Under this scenario a total storm tide elevation above AHD of 3.2 m would be experienced inside Moreton Bay (about 2.4 m above MHWS or 1.8 m above HAT) and 2.2 m along the open Coral Sea coast and in The Broadwater (1.55 above MHWS or 1.05 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.9.

**Table 4.9 Developed properties affected by a 0.2% AEP storm tide**

| Level of Inundation | Moreton Bay | Coral Sea | Region |
|---|---|---|---|
| >1m over floor | 6550 | 200 | 6750 |
| <1m over floor | 15 100 | 3000 | 18 100 |
| on property but below floor level | 7350 | 6550 | 13 900 |
| not affected | 535 800 | 109 900 | 645 700 |

Overall, the impact of a 0.2% AEP (ARI of 500 years) storm tide event would affect only 2.2% of the region's developed properties with over floor inundation. It would, however, certainly cause very significant damage to a large number of buildings and their contents and cause short-term dislocation in localised areas. The horizontal extent and depth of inundation experienced in a 0.2% AEP event would be greater than that for the 1.0% AEP scenario and the depth of inundation would be significantly increased leading to a much greater proportion of properties with over-floor flooding. Within Moreton Bay a total of 29 000 properties would be affected to some degree, of which 74.6% would have water over the floor, whilst along the Coral Sea coast, 9750 properties would be affected, with 32.8% having over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 57 500 of whom at least 20 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. Consideration may need to be given to the total evacuation of some Bay Island communities given the ease with which they would be isolated and because their ability to handle internal evacuations would probably be inadequate. As many as 1300 commercial properties and 630 logistic and transport facilities would be subject to over-floor flooding, together with 34 public safety facilities and 66 lifeline facilities, including water supply, power supply, sewerage and telecommunications facilities.

The modelled impact of the study area is shown in Figure 4.23 (northern Moreton Bay) Figure 4.24 (southern Moreton Bay) and 4.25 (Coral Sea coast).

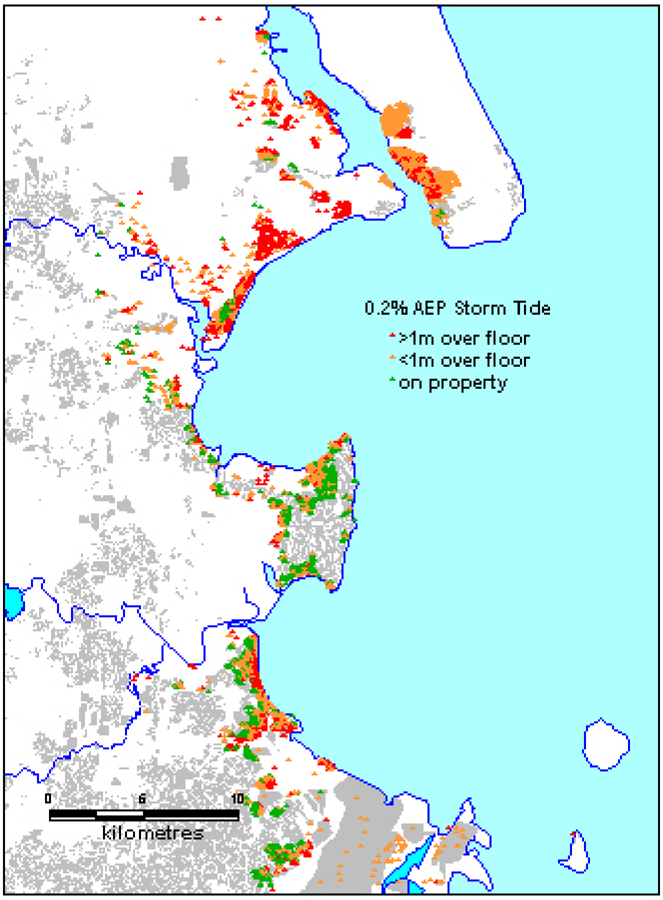



**Figure 4.23 Modelled impact of a 0.2% storm tide in northern Moreton Bay**

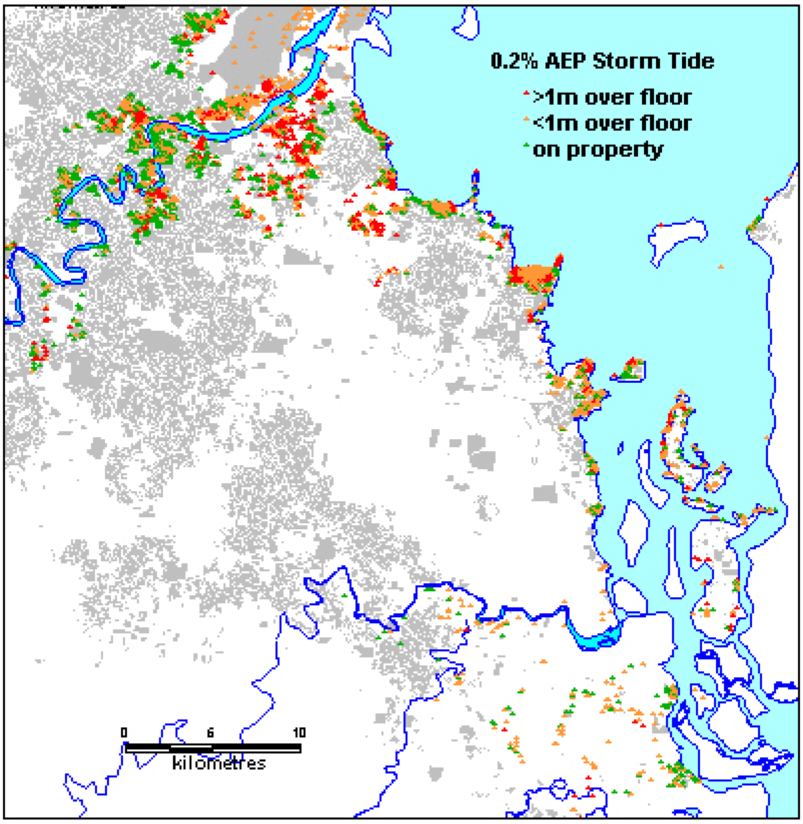



**Figure 4.24 Modelled impact of a 0.2% storm tide in southern Moreton Bay**

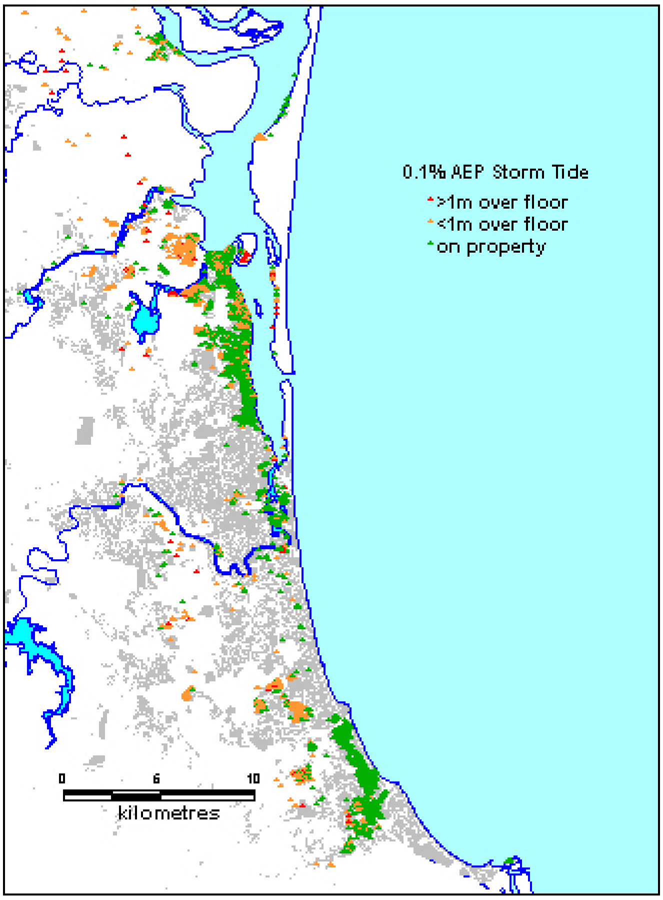



**Figure 4.25 Modelled impact of a 0.2% storm tide along the Coral Sea coast**

The 0.1% AEP scenario: Under this scenario a total storm tide elevation above AHD of 3.5 m would be experienced inside Moreton Bay (2.65 m above MHWS or 2.1 m above HAT) and 2.2 m along the open Coral Sea coast and in The Broadwater (1.55 above MHWS or 1.05 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.10.

**Table 4.10 Developed properties affected by a 0.1% AEP storm tide**

| Level of Inundation | Moreton Bay | Coral Sea | Region |
|---|---|---|---|
| >1m over floor | 15 550 | 200 | 15 750 |
| <1m over floor | 11 000 | 3000 | 14 000 |
| on property but below floor level | 5450 | 6550 | 12 000 |
| not affected | 532 750 | 109 900 | 642 650 |

Overall, the impact of a 0.1% AEP (ARI of 1000 years) storm tide event would affect 4.3% of the region's developed properties with over-floor flooding. It would certainly cause very serious damage, including total destruction, to a large number of buildings and their contents and cause significant short-term dislocation in all coastal areas. In Moreton Bay the horizontal extent and depth of inundation experienced in a 0.1% AEP event would not be much greater than that for the 0.2% AEP scenario, whilst along the Coral Sea coast there would be virtually no difference in the level of impact. Within Moreton Bay a total of 32 000 properties would be affected, of which 83.0% would have water over the floor.

The number of people directly affected in their dwellings with water over floor level would increase to around 68 000 of whom at least 40 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. It would be very prudent to evacuate all of

Bay Island communities well ahead of the cyclone's arrival. As many as 1780 commercial properties and 870 logistic and transport facilities would be subject to over-floor flooding, thus producing significant long-term economic consequences. At least 39 public safety facilities (including medical facilities) and 77 lifeline facilities (water supply, power supply, sewerage and telecommunications facilities) would also be flooded.

The modelled impact of the study area is shown in Figure 4.26 (northern Moreton Bay) Figure 4.27 (southern Moreton Bay) and 4.28 (Coral Sea coast).

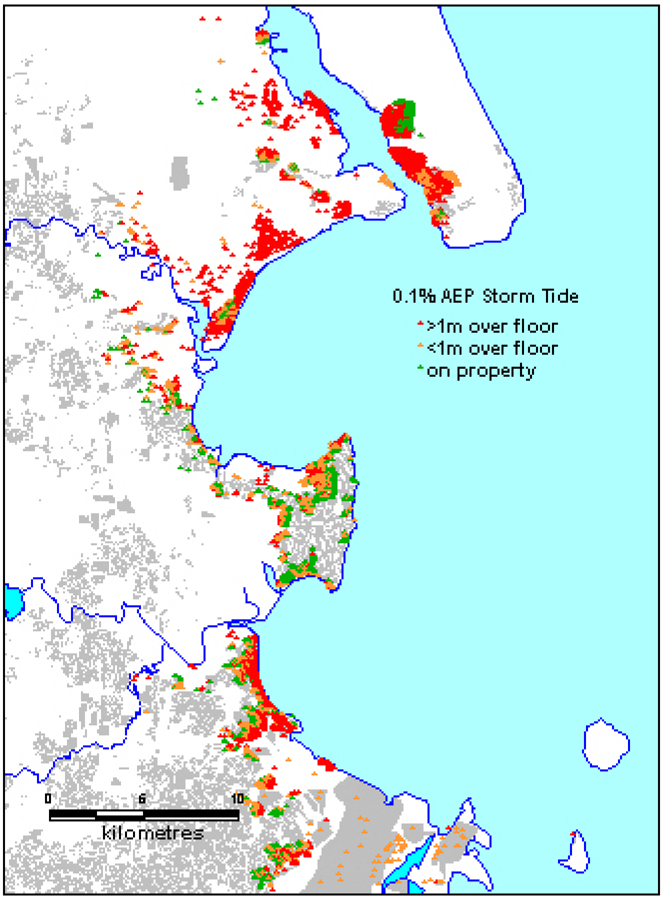



**Figure 4.26 Modelled impact of a 0.1% storm tide in northern Moreton Bay**

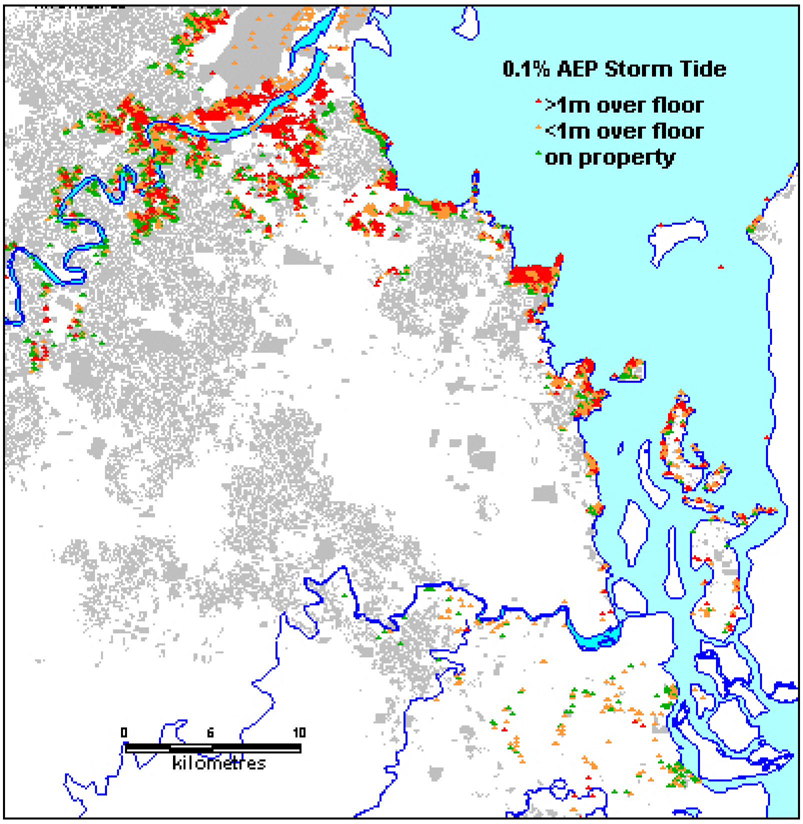



**Figure 4.27 Modelled impact of a 0.1% storm tide in southern Moreton Bay**

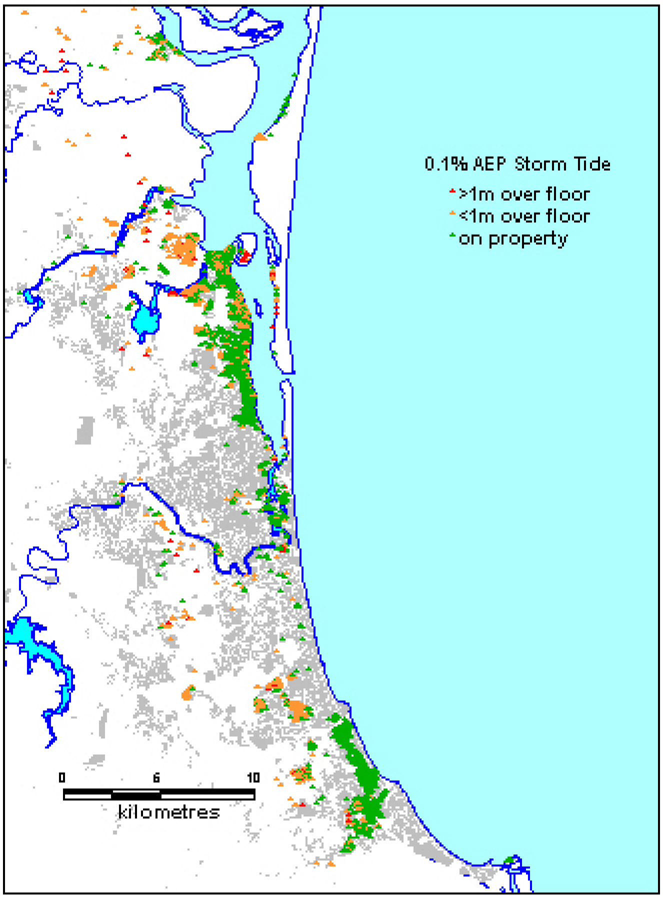



**Figure 4.28 Modelled impact of a 0.1% storm tide along the Coral Sea coast**

The 0.01% AEP scenario: Under this most extreme scenario a total storm tide elevation above AHD of 4.4 m would be experienced inside Moreton Bay ( 3.55 m above MHWS or 3.0 m above HAT) and 2.4 m along the open Coral Sea coast and Broadwater (1.75 m above MHWS or 1.25 m above HAT). The modelled impact, in terms of the inundation of developed properties is summarised in Table 4.11.

**Table 4.11 Developed properties affected by a 0.01% AEP storm tide**

| Level of Inundation | Moreton Bay | Coral Sea | Region |
|---|---|---|---|
| >1m over floor | 27 650 | 500 | 28 150 |
| <1m over floor | 10 150 | 4950 | 15 100 |
| on property but below floor level | 5250 | 7400 | 12 650 |
| not affected | 520 750 | 106 800 | 627 550 |

Overall, the impact of a 0.01% AEP (ARI of 10 000 years) storm tide event would affect 6.3% of the region's developed properties with over-floor flooding by sea water. It would, none-the-less, be devastating in all low lying coastal areas. The likelihood of significant loss of life would also be great unless an effective evacuation were conducted from the areas of likely impact well ahead of the impact of the cyclone. Both the horizontal extent and depth of inundation experienced in a 0.01% AEP event would significantly greater than that for the 0.1% AEP scenario. For example, the seaside suburb of Woorim, on Bribie Island, that would probably be immune to lesser levels of inundation, would be seriously affected and the Redcliffe Peninsula would be effectively isolated from the mainland for a short period. Within Moreton Bay a total of 43 050 properties would be affected, of which 87.8% would have water over the floor. Along the Coral Sea coast, 12 850 properties would be affected, of which 42.4% would have over-floor flooding.

The number of people directly affected in their dwellings with water over floor level would increase to around 101 800 of whom at least 80 000 should be evacuated ahead of the cyclone from dwellings that would have more than 1 m of sea water over floor level. Bribie Island and all of Bay Island communities would have to be evacuated well ahead of the cyclone's arrival to minimise the risk of major community trauma and serious loss of life and. The economy of the region would also suffer serious impact with as many as 2500 commercial properties and 1180 logistic and transport facilities subject to over-floor flooding. At least 66 public safety facilities (including medical facilities) and 100 lifeline facilities (water supply, power supply, sewerage and telecommunications facilities) would also be flooded.

The modelled impact of the study area is shown in Figure 4.29 (northern Moreton Bay) Figure 4.30 (southern Moreton Bay) and 4.31 (Coral Sea coast).

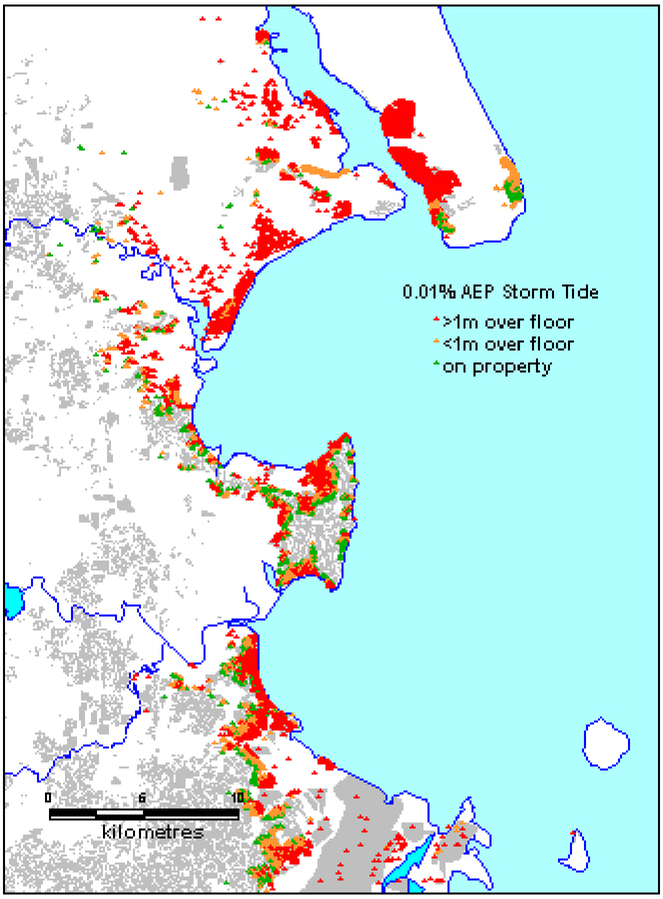



**Figure 4.29 Modelled impact of a 0.01% storm tide in northern Moreton Bay**

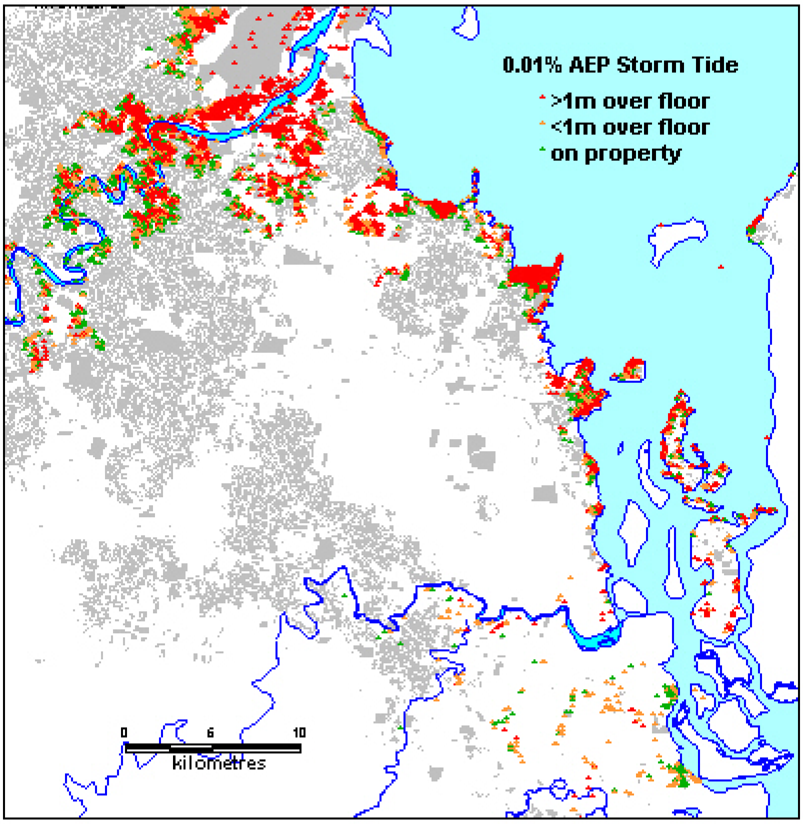



**Figure 4.30 Modelled impact of a 0.01% storm tide in southern Moreton Bay**

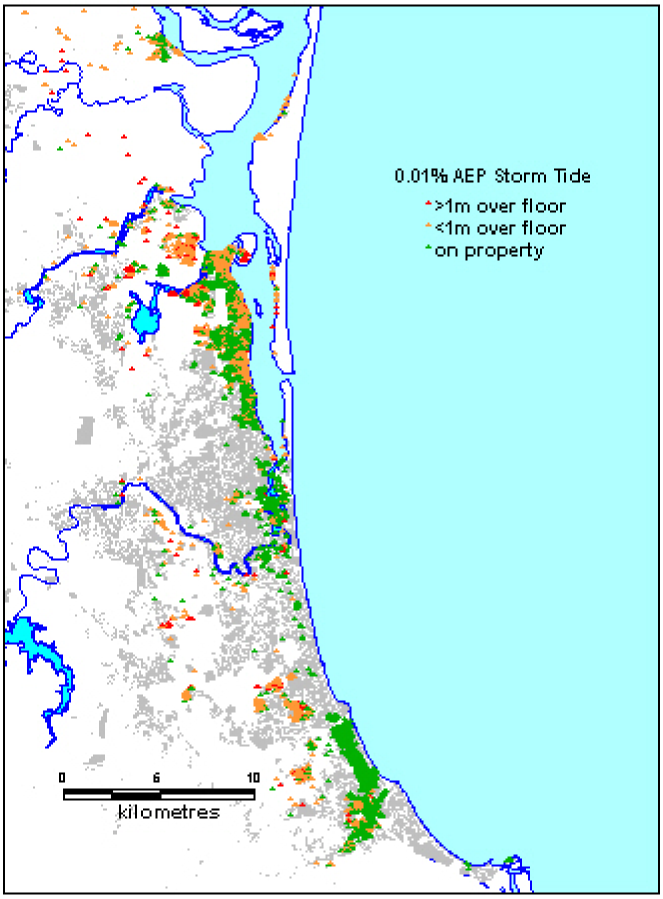



**Figure 4.31 Modelled impact of a 0.01% storm tide along the Coral Sea coast**

Comparative storm tide risk: It is clear that the impact of storm tide on South-East Queensland is potentially very serious, as has been demonstrated by the impacts of cyclones such as TC *Dinah* (1967) and TC *Dora* (1971) when developments close to the coast, such as the major canal estates, were significantly less extensive than they are today.

An analysis of the function of properties affected under each scenario reveals that the transport and storage facilities have the greatest per capita exposure at the more likely event levels. This can, to some extent, be accounted for by the number of facilities such as marinas and port facilities that are at the water's edge. Community facilities also carry a relatively high exposure. This is largely accounted for by the numbers of recreational facilities, such as golf and other sporting clubs, being located on the more inundation-prone land. The figures provided in Table 4.12 for each class of function are the percentages of all developed properties in South-East Queensland, within each functional class, that would have water of any depth over floor level.

**Table 4.12: Percent of properties, by function, affected by over-floor inundation in each scenario**

| Function | 2% AEP | 1% AEP | 0.2% AEP | 0.1% AEP | 0.01% AEP |
|---|---|---|---|---|---|
| Houses | 0.9 | 1.3 | 3.4 | 4.1 | 6.0 |
| Flats | 1.0 | 1.5 | 3.7 | 4.3 | 6.7 |
| Commercial accommodation | 0.9 | 1.3 | 3.5 | 4.6 | 7.0 |
| Business & industry | 1.9 | 2.3 | 5.9 | 8.0 | 11.2 |
| Logistic, transport & storage | 3.5 | 4.0 | 11.0 | 15.3 | 20.8 |
| Public safety & health | 1.4 | 1.6 | 4.4 | 5.1 | 8.7 |
| Community, education & sport | 2.4 | 3.0 | 5.4 | 6.3 | 8.8 |
| Utilities | 1.6 | 2.0 | 5.0 | 5.9 | 7.9 |

The low per capita proportions of houses and flats masks the fact that domestic properties would be, by far and away, the largest numbers of properties, in absolute numbers, that would be inundated above floor level. The percentage of all properties inundated over floor level that are either houses or flats for the 50, 100 and 500 year ARI scenarios are 85.9%, 89.4% and 90.0% respectively.

Climate change and sea level rise: All of the statistics contained in the above scenarios are based on current sea levels and climate. As indicated earlier in this chapter, the climate change models developed since the mid 1980s indicate that global warming and consequent sea level rise will occur as the result of the so-called 'Greenhouse' effect. The most recent estimates published by the IPCC indicate that, under 'business as usual' Greenhouse gas regimes, by 2100, sea level globally will have risen by between 20 cm and 86 cm, with a best estimate of 50 cm. There is some suggestion in the international literature, however, that the Australian region will be at the lower end of this scale. The impact of an increase in sea level on storm tide inundation in South-East Queensland, based on the current extent of development and assuming that there is no change to cyclone recurrence and intensity, is shown in Table 4.13.

**Table 4.13: South-East Queensland properties affected by over-floor inundation under different sea level estimates**

| Sea Level | 2% AEP | 1% AEP | 0.2% AEP | 0.1% AEP | 0.01% AEP |
|---|---|---|---|---|---|
| Current sea level | 7150 | 9550 | 14 850 | 29 750 | 43 250 |
| Low estimate (+0.2 cm) | 10 800 | 19 150 | 28 550 | 34 500 | 48 400 |
| Best estimate (+0.5 cm) | 23 650 | 25 350 | 38 350 | 41 350 | 55 850 |
| High estimate (+0.86 cm) | 32 300 | 34 400 | 45 550 | 50 300 | 65 150 |

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

## Storm Tide Risk Assessment

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

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

Inundation hazards are, by their very nature, limited by topography. This is particularly evident with storm tide which is, in effect, inundation caused by a temporary increase in sea level. The level of storm tide exposure is shown in Figure 4.32 which indicates the degree to which exposure increases as the probability of a storm tide impact decreases. The indicator used to quantify exposure is the number of properties that would have water over floor level under each AEP scenario.

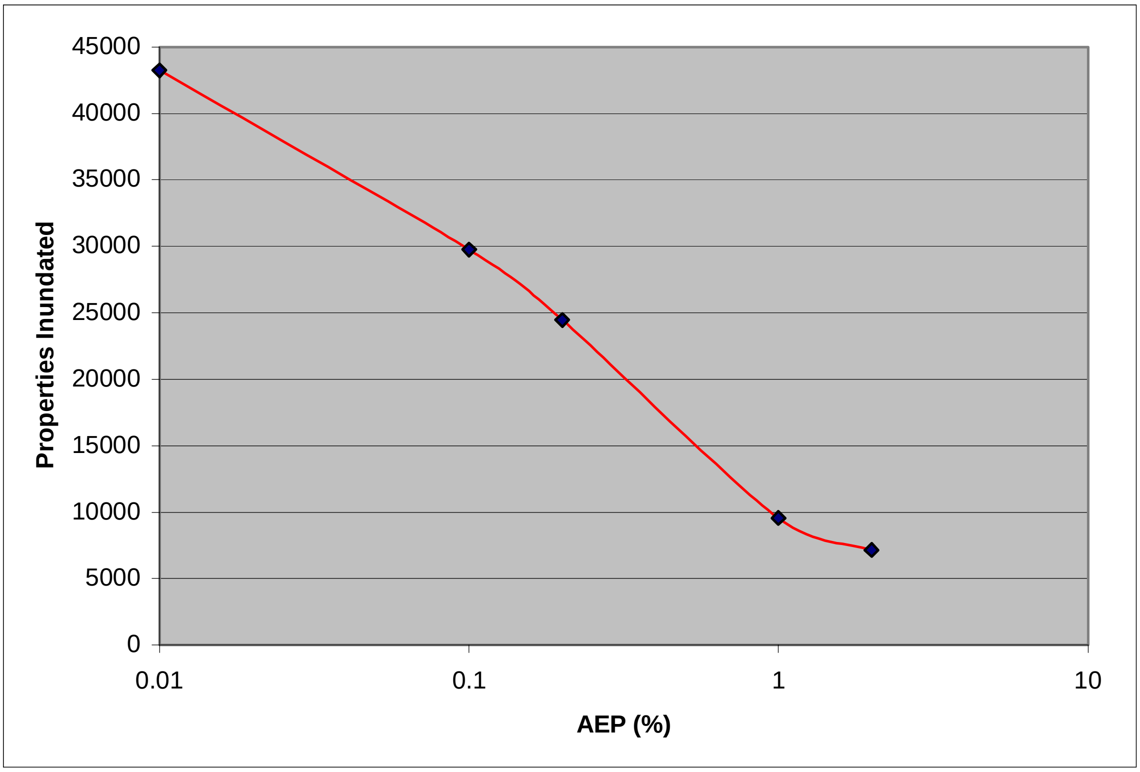



**Figure 4.32 Cumulative storm tide impact across all scenarios**

It is apparent that most of the LGA that have a recognised storm tide risk in the region have established, or are moving to establish, the 100 year ARI storm tide level for their planning threshold. This, then can be used as the 'design' level against which community risk can be measured. There are 9550 developed properties across the region that would be exposed to over-floor inundation in a 1.0% AEP storm tide event. Whilst this represents only 1.5% of all developed properties, it is still a relatively high number exposed at the 'design' level. This can be explained, at least in part, by two factors:

- the extent of residential development in areas potentially exposed to storm tide inundation that had occurred prior to the introduction of that threshold, especially over the past 25 years; and,
- the number of non-residential developments that, because of their function (e.g. marinas, port facilities, slipways, etc), have to be located by the water.

The 1.0% AEP urban storm tide risk index is shown in Figure 4.33. The risk index represents the product of the number of properties exposed and the vulnerability index, therefore, the higher the index number, the greater the degree of overall risk at the 'design' level of exposure. The risk in rural areas, such as on Bribie and Moreton Islands have been excluded.

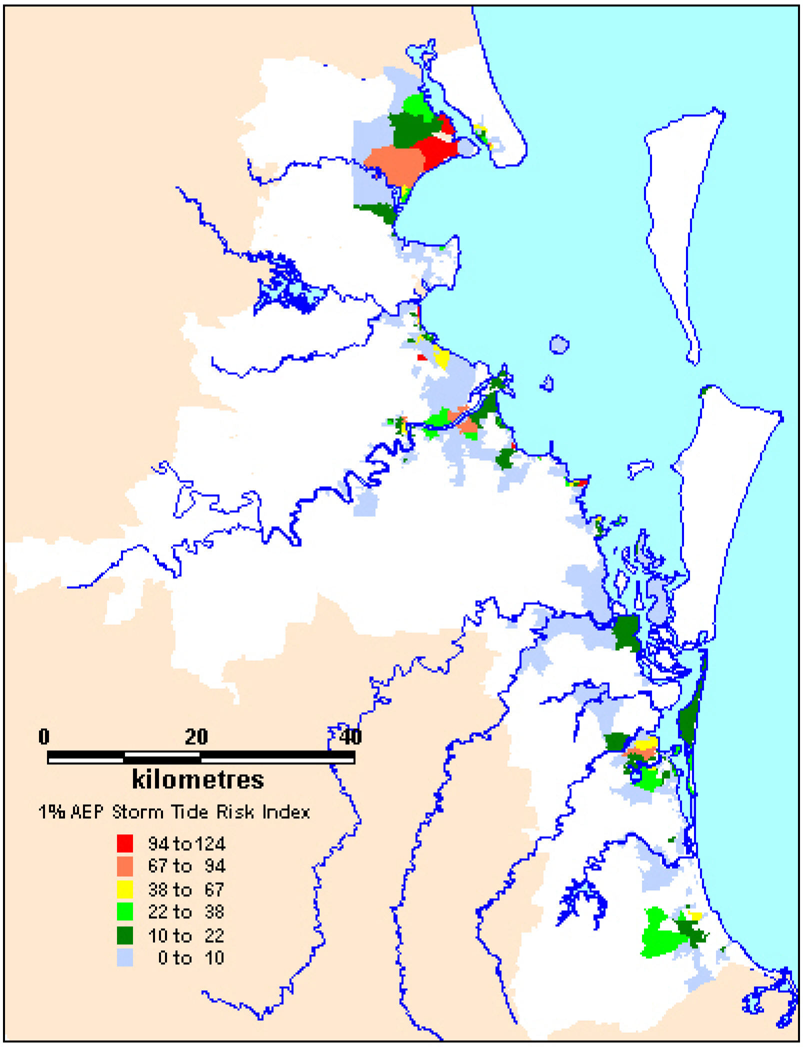



**Figure 4.33 1.0% AEP storm tide risk index**

The areas that carry the greatest level of exposure tend to be those that are perceived to be the most desirable residential locations, that is, close to the coast, in canal estates or along the lower reaches of the Brisbane River. They are the properties that carry a significant value premium because of this high level of desirability. As a broad generalization, therefore, whilst these communities are significantly exposed to the threat of storm tide inundation, they also tend to be the most economically resilient. Indeed, 82.4% of the 375 CCD with a storm tide exposure fall within the bottom half of the vulnerability index range.

The neighborhoods that do have a high storm tide risk index tend to be in the areas of older residential coastal development (particularly Bongaree, Brighton, Lota and Sandgate); rural or rural village-type communities (e.g. Beachmere, Boondall, Ningi, Nudgee Beach and Toorbul); some of the more modern canal estates (most notably Birkdale, Cleveland and Hope Island); and some of the more commercial/industrial areas on the lower reaches of the Brisbane River (e.g. Albion, Hemmant and Pinkenba). These are neighborhoods in which there tend to be more elderly people and/or people in the lower socio-economic ranges.

The main cautionary note that should be made here, however, is that **sea water inundation is not** (as a general rule) **an insurable risk** and even the residents of the more expensive neighborhoods at risk of storm tide inundation could suffer a significant economic loss.

**Community Awareness**

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

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

The poor level of awareness of cyclone risk in South-East Queensland is not surprising given:

- that it has been more than 25 years since the last significant cyclone impact (see Figure 4.3);
- that a significant proportion of the population has migrated from southern states where cyclones do not occur;
- the tendency by some representatives of disaster-sensitive industries, such as real estate and tourism, and some local government councillors in the region, to decry public information relating to natural hazards risks as being 'bad for business'; and,
- the tendency for the media to sensationalise research reports, such as the recent IPCC climate change report, to the extent that the information they contain loses relevance and/or credibility.

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

**Cyclone Forecasting and Warnings**

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

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

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

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

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

**Further Information**

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