

# Queensland Coastal Plan Coastal Hazards Guideline

Prepared by: Coastal Planning, Department of Environment and Resource Management

© The State of Queensland (Department of Environment and Resource Management) 2012

Copyright inquiries should be addressed to <copyright@derm.qld.gov.au> or the Department of Environment and Resource Management, 41 George Street, Brisbane QLD 4000

If you need to access this document in a language other than English, please call the Translating and Interpreting Service (TIS National) on 131 450 and ask them to telephone Library Services on +61 7 3224 8412.

This publication can be made available in an alternative format (e.g. large print or audiotape) on request for people with vision impairment; phone +61 7 3224 8412 or email <library@derm.qld.gov.au>.

January 2012

#29960

---

# Contents

<b>1</b>	<b>Purpose of the guideline</b>	<b>1</b>
<b>2</b>	<b>Scope of the guideline</b>	<b>1</b>
<b>3</b>	<b>The coast</b>	<b>2</b>
<b>4</b>	<b>Coastal hazards</b>	<b>2</b>
	Risk assessment factors	3
<b>5</b>	<b>Coastal erosion and its management</b>	<b>4</b>
	<b>Erosion and natural beach behaviour</b>	<b>4</b>
	Long-term and short-term erosion	4
	The beach erosion problem	4
	The buffer zone concept	5
	<b>Assessment of erosion prone area widths</b>	<b>5</b>
	Background	5
	Erosion prone area width assessment formula	6
	The planning period (N)	6
	Rate of long-term erosion (R)	7
	Short-term erosion	8
	Acceptable risk to the community – design storm event	8
	Selection of parameters for the design storm event	8
	Estimation of erosion distances	10
	Erosion due to sea-level rise (metres) (S)	10
	Factor of safety	11
	Dune scarp component (D)	11
	<b>Defined extent of the erosion prone area</b>	<b>11</b>
<b>6</b>	<b>Storm-tideinundation</b>	<b>13</b>
	<b>Key characteristics of storm-tide inundation in Queensland</b>	<b>13</b>
	<b>Determining the storm-tide inundation area</b>	<b>13</b>
	Options for determining a storm-tide inundation area	14
	Storm-tideinundation area assessment	14
	Assessment of extreme coastal water levels	14
	Hydrodynamic analysis	15
	<b>Determination of high and low risk areas within storm-tide inundation areas</b>	<b>16</b>
	<b>Updating existing storm-tide inundation area assessments to include climate change</b>	<b>17</b>
<b>7</b>	<b>Glossary</b>	<b>18</b>
<b>8</b>	<b>References</b>	<b>20</b>
	<b>Appendix 1—Useful references</b>	<b>21</b>

---

## List of figures

<b>Figure 1. Typical beach profile response to long-term erosion.</b>	8
<b>Figure 2. Estimated short-term beach profile response to a 1-in-100-year average recurrence interval storm event based on Vellinga (1983) – South Mission Beach</b>	10

## List of tables

<b>Table 1. Minimum assessment factors for determining erosion prone areas and storm-tide inundation areas</b>	3
<b>Table 3. Planning period for development subject to development commitment</b>	3
<b>Table 4. Projected sea-level rise for the year of the end of asset life as per Table 2</b>	3
<b>Table 5. Probability of occurrence of a storm-tide of particular return period over various periods of time (Patterson, C 1986).</b>	9
<b>Table 6. Recommended storm-tide event levels for essential community infrastructure</b>	17

# 1 Purpose of the guideline

- 1.1. The purpose of this guideline is to provide advice and information about the methodology used to determine coastal hazard areas under the State Coastal Management Plan—Queensland’s Coastal Policy 2001.
- 1.2. This guideline is to provide background information about coastal hazards (storm-tide inundation and coastal erosion, including potential climate change impacts such as sea-level rise) and guidance about determining areas at risk from coastal hazards.
- 1.3. This guideline is to be used to assist in achieving relevant policy outcomes of the Queensland Coastal Plan, incorporating the State Policy for Coastal Management and the State Planning Policy for Coastal Protection.
- 1.4. This guideline is 'extrinsic material' under the *Statutory Instruments Act 1992*, thereby giving it legal status in assisting in the interpretation of the Queensland Coastal Plan.
- 1.5. This guideline aims to ensure that coastal hazard areas are adequately considered when decisions about development are being made by ensuring the accurate determination of coastal hazard areas. In particular, coastal hazard areas are to be determined and included in local government planning schemes and considered during the development of regional plans; the assessment of development applications; and when land is designated for community infrastructure under the *Sustainable Planning Act 2009* (SPA).
- 1.6. The identification of coastal hazard areas is also required for the effective management of the coast, including the preparation of local area plans of management.

# 2 Scope of the guideline

- 2.1 The State Planning Policy for Coastal Protection (SPP) as part of the Queensland Coastal Plan, establishes the policy framework for making land-use decisions regarding coastal hazard risks.
- 2.2 Section 2.2 of the SPP outlines the factors for determining erosion prone areas and storm-tide inundation areas.
- 2.3 Annex 3, sections A3.1, A3.2 and A3.3 of the SPP provides the options for determining the storm-tide inundation areas.
- 2.4 This guideline does not address:
  - a) counter-disaster planning and operations. This is dealt with by the *Disaster Management Act 2003*
  - b) emergency response mapping to interpret storm tide warnings issued by the Bureau of Meteorology
  - c) coastal cliff erosion. Areas of potential cliff erosion are to be included in the landslide hazard management area maps that are required by State Planning Policy 1/03 and associated Guideline for Mitigating the Adverse Impacts of Flood, Bushfire and Landslide
  - d) riverine flooding which is also addressed by State Planning Policy 1/03
  - e) coastal hazards other than storm-tide inundation, coastal erosion and sea-level rise inundation (such as tsunami flooding).
- 2.5 This guideline is not intended to be a complete technical guide to the assessment and management of coastal hazards (coastal erosion, sea-level rise inundation and storm-tide inundation) as its scope is defined by the matters covered by the Queensland Coastal Plan.
- 2.6 The provisions within the Queensland Coastal Plan and this guideline should not restrict the use of broader or more stringent measures to address and plan for coastal hazards.

## 3 The coast

- 3.1 The coast is highly dynamic and complex. It is subject to continuous and extensive changes in response to variations in meteorological and oceanographic conditions. The nature of these changes depends on the way coastal processes interact with landforms, vegetation and sediment. Coastal processes include sediment transport; fluctuations in the location and physical characteristics of the foreshore, dune systems and associated ecosystems; tides; changes in sea level and coastal hazards; ecological processes (such as migration of plant and animal species) and the natural water cycle (for example, coastal wetlands' role in nutrient filtration and flood mitigation).

## 4 Coastal hazards

- 4.1 For the purpose of this guideline 'coastal hazards' is a term used to describe:
- coastal erosion—shoreline recession due to sea erosion causing a permanent loss of land
  - storm-tide inundation—temporary inundation of land by abnormally high ocean levels. Storm tide is the total water level obtained by adding the storm surge and wave set-up to the height of the astronomical tide; and
  - sea-level rise inundation—permanent inundation of land due to a rise in sea level. Sea-level rise is not treated as a separate hazard in this policy. It adds to and is combined with coastal erosion and storm-tide inundation.
- 4.2 Coastal erosion and storm-tide inundation are naturally occurring coastal processes that are referred to as coastal hazards because they can pose risks to life and development on the coast.
- 4.3 The Queensland Coastal Plan recognises the need to both avoid and minimise risk to people and property and to allow coastal processes to occur naturally. Decision makers need to be aware of the risks associated with coastal hazards when considering the use of resources within the coastal zone. Climate change, primarily by an increasing sea level, has the potential to increase the risk to development from existing coastal hazards and extend the effects further inland than is currently experienced, particularly in low-lying coastal areas of Queensland. Accurate assessment and determination of coastal hazard areas is critical for coastal development assessment, planning, and mitigation and response activities.
- 4.4 Climate change is projected to have a significant impact on the coastal zone, especially through sea-level rise and intensification of cyclone activity. Implications for the Queensland coastline include a progressive worsening of coastal hazards as detailed below.

### **Coastal erosion:**

- Increased water levels will accelerate coastal erosion.
- Sediment transport patterns may be altered by shifts in wave direction triggering changes to the form and location of shorelines.
- Low-lying areas are more likely to be permanently inundated.
- Increased cyclone and storm activity will escalate the severity of coastal erosion events.

### **Storm-tide inundation:**

- Sea-level rise will increase the severity of storm-tide inundation and will cause inundation to occur further inland.
- Increased cyclone and storm intensity will add to the magnitude of storm-tide events and the extent of inundation.

## Risk assessment factors

4.5 In considering the impacts of coastal hazards on existing and proposed development (particularly urban development) in the coastal zone, the Department of Environment and Resource Management (DERM) has adopted the following assessment factors for Queensland:

**Table 1. Minimum assessment factors for determining erosion prone areas and storm-tide inundation areas**

For development subject to a development commitment	For development not subject to a development commitment
Planning period equivalent to expected asset life of the development as outlined in Table 2. Adoption of the 100-year average recurrence interval extreme storm event or water level. Projected sea-level rise of amount outlined in Table 3 based on expected asset life. Increase in cyclone maximum potential intensity by 10 per cent due to climate change.	Planning period of 100 years. Adoption of the 100-year average recurrence interval extreme storm event or water level. Projected sea-level rise of 0.8 m by 2100 due to climate change (relative to 1990 value). Increase in cyclone intensity by 10 per cent (relative to maximum potential intensity) due to climate change.

**Table 2. Planning period for development subject to development commitment**

Type of development	Planning period (based on anticipated asset life)
Short-term tourist accommodation	40 years
Residential dwelling, excluding unit blocks of less than seven units	50 years
Residential dwelling unit blocks of seven or more units	60 years
Industrial building	40 years
Commercial building (retail)	40 years
Commercial building (multiple storeys)	60 years

**Table 3. Projected sea-level rise for the year of the end of asset life as per Table 2**

Year of end of planning period	Projected sea-level rise
Year 2050	0.3 metres
Year 2060	0.4 metres
Year 2070	0.5 metres
Year 2080	0.6 metres
Year 2090	0.7 metres
Year 2100	0.8 metres

4.6 These assessment factors are based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report: Climate Change 2007 and more recent studies undertaken by the CSIRO in 2007.

4.7 Any coastal hazard risk assessment should consider these factors as the minimum standard to be used when considering permanent developments in the coastal zone.

## 5 Coastal erosion and its management

### Erosion and natural beach behaviour

- 5.1 Coastal erosion is a natural phenomenon of beaches. Beaches respond to environmental factors such as annual variations in the amount of sand washed down from rivers; changes in the geometry of river delta channels; and changes in the weather, especially prevailing winds, severe storms and tropical cyclones. The ‘active beach system’ extends from well back in the dune system to the seaward extent of wave influence on the seabed. As environmental conditions change, the beach profile changes as sand is moved onshore or offshore seeking an equilibrium profile. The movement of sand may appear as beach erosion, dune build-up or the formation of near-shore sand bars. Typically, beaches never achieve a stable profile due to ever-changing environmental conditions. However, in some cases there may be a trend of ongoing erosion resulting in long-term shoreline recession.
- 5.2 It is likely that a number of these factors will be influenced by climate change and associated sea-level rise. The impact of sea-level rise will most likely be experienced as more severe coastal erosion during extreme events. Eroded coastlines will increasingly fail to rebuild fully following these extreme events, resulting in permanent losses of land to the sea.

### Long-term and short-term erosion

- 5.3 Coastal erosion can be classified as either long-term or short-term. Long-term erosion usually refers to a trend of erosion extending over several decades and can be caused by a deficit in the annual sediment budget, or in the longshore transport rates along the beach. Such erosion can occur without any reduction in the value of the beach as a natural system or as a public asset, as the beach profile is not changed but merely shifted landwards.
- 5.4 Short-term erosion refers to erosion that occurs over a period of days, as a result of extreme weather events, such as severe storm or cyclone activity. Short-term erosion results in changes to the profile of the beach. During short-term erosion events, the main sand transport mechanisms occur offshore. After the storm passes normal beach processes usually produce onshore sand transport that restores the beach naturally. This natural restoration process may take many months or years. In most cases, intervention to restore the beach to its former condition is not required. The effect of severe storm systems (such as cyclones or east coast lows) may last for decades and can result in relatively permanent features, such as the relocation of river mouths and other tidal entrances.

### The beach erosion problem

- 5.5 Erosion from natural beach processes does not permanently affect the form of the beach and hence its value as a public asset. However, it does involve a landward shift in its location. The problems associated with beach erosion only occur once the shoreline recession threatens property. The problem is not so much that the beach is eroding, but that development has occurred within the zone of natural beach fluctuations.
- 5.6 Once such a problem becomes apparent, there are several means available of countering the erosion threat, including:
- Retreat**—where property is subjected to severe erosion, there may be an option of pursuing the development in a more appropriate alternative location. The *Coastal Protection and Management Act 1995* also provides for the surrender of land to the State for coastal management purposes to be imposed as a condition of a development approval in certain circumstances. This can be used to create a development-free zone where fluctuations in landform can be accommodated and managed on State land.
  - Beach nourishment**—the replenishment of beaches with imported sand allows the width of beach lost by erosion to be restored and natural beach processes to be maintained. Both this approach and the retreat option maintain the value of the beach as a public asset.
  - Coastline defence**—historically, the most commonly used method of coastline defence in Queensland has been the construction of seawalls. Depending on the quality of the design and the construction techniques

employed, such works may be effective in stabilising the horizontal recession of the shoreline. However, these works constitute major interference with natural beach processes and often result in deterioration of the original beach. In a similar manner, groynes may trap sand on the up-drift side, resulting in accretion, but the associated sand starvation on the down-drift side merely transfers the original erosion problem to this area.

- 5.7 The various means of combating erosion can all be costly to implement. Properly designed and constructed works usually involve large capital costs, whereas works of a low standard normally attract recurring maintenance costs and can be expected to fail during extreme weather events. A determination of whole-of-life cost is required in order to select the most appropriate management.

## The buffer zone concept

- 5.8 The high cost of property protection works can be avoided for future development proposals by providing an adequate buffer zone between the seaward boundaries of the development and the shoreline. This allows for future beach movements to be accommodated within this zone without the need for any direct intervention. Providing an adequate buffer zone does not impose artificial constraints on beach behaviour and ensures the continued existence and recreational value of a natural beach. An example of an effective buffer zone is available along various foreshores in Queensland where permanent development is separated from tidal waters by parkland or unused land that would not result in significant consequences if it were to erode.
- 5.9 Application of the buffer zone concept can be applied to existing erosion problem areas by considering beach nourishment. Beach nourishment can create or increase a suitable buffer zone between the property under threat and the beach.
- 5.10 The action of private property owners in protecting their property from erosion, usually by the construction of seawalls, can adversely affect the beach and other coastal resources and reduce the value of the beach as a public asset. Hence, the erosion issue can adversely affect all members of the community, not just affected property owners. In an informed community, it is likely that landholders seeking increases in development rights over land in an area vulnerable to erosion would incorporate adequate buffer zones to protect the beach and other coastal resources. This outcome can be achieved by:
- surrendering vulnerable land to the State when applying for development intensification; or
  - by not allowing any permanent development to be constructed within the erosion prone area.
- 5.11 It is the intention of the Queensland Coastal Plan to set aside the width of coastline potentially affected by erosion over a nominated planning period (the erosion prone area) as a development-free buffer zone.

## Assessment of erosion prone area widths

### Background

- 5.12 Erosion prone area widths must accommodate both short-term and long-term erosion over the planning period. The procedure involved in determining the necessary erosion prone area width involves estimating long-term erosion rates, the extent of short-term erosion corresponding to a 'design' storm (cyclone or east coast low) event, and choosing a specific 'planning period'. The planning period affects the width of the long-term erosion component, which is usually based on assessed annual erosion rates, and also influences the calculated short-term erosion width, because the selection of the 'design' extreme event is based on the probability of occurrence over the specified period.
- 5.13 The future assessment of both short-term and long-term erosion may be affected by climate change. While all the impacts of climate change are currently being researched, projections indicate changes in wind speed and direction, increases in the frequency and intensity of storms, and a rise in sea levels. Clearly all of these factors are significant in the determination of erosion prone area widths. In cases where the net long-term trend appears to be one of accretion, which is expected to continue throughout the planning period, the erosion prone area width can be based on short-term erosion rates with a nominal provision (say < 10 m) for long-term erosion. In such cases, the first few years of the planning period will be the most critical for the occurrence of

storm erosion, as after that, the long-term accretion trend may reduce the net magnitude of any short-term erosion in relation to the original shoreline location.

- 5.14 In locations where seawalls exist, the erosion prone area calculation generally does not consider the wall in limiting erosion. This is due to the fact that seawalls may be damaged, or fail, during extreme storm events, and the area's vulnerability to erosion is returned. Erosion behind the wall may occur more quickly during future events if the wall is not maintained to the approved design. Reduction of an erosion-prone area width may be considered if it can be guaranteed that the seawall will be maintained to the approved design in perpetuity and that any such repairs required will be promptly addressed. Due to the access requirement for maintenance of the seawall, and slumping that may result from partial failure of the wall, the erosion prone area should not be reduced below 10 m and it would be prudent to set the minimum erosion prone area reduction to the short-term erosion component of the calculation. Generally, walls in private ownership cannot be guaranteed to be maintained in perpetuity due to the possibility of changes in ownership and the uncertainty of future management.
- 5.15 An erosion prone area width assessment formula (described below) has been developed for sandy coasts exposed to moderate to high wave energy. For low energy coasts dominated by fine sediments, or for estuarine coasts where the dominate erosion process is channel migration or tidal flow, then erosion hazard is to be assessed by a suitably qualified person. Default erosion prone area width values are generally set for these latter coastal areas.

### Erosion prone area width assessment formula

- 5.16 The formula adopted by DERM for the calculation of the necessary erosion prone area width is as follows:

$$E = [(N \times R) + C + S] \times (1 + F) + D \text{ (equation 1)}$$

Where:

E = erosion prone area width (metres)

N = planning period (years)

R = rate of long-term erosion (metres per year)

C = short-term erosion from the 'design' storm or cyclone (metres)

S = erosion due to sea-level rise (metres)

F = factor of safety (0.4 has been adopted)

D = dune scarp component to allow for slumping of the erosion scarp (metres)

- 5.17 In the above equation, the values of R, C, S and D can be determined for individual beaches based on collected data and site specific modelling or profile response. The choice of values for N and F, as well as the specifications of the storm used to determine C, are more subjective decisions that require reliance on accepted practices.

### The planning period (N)

- 5.18 The erosion prone area width varies directly with the duration of the planning period. There are no quantitative methods of determining the ideal duration of the planning period; however, the following considerations must be taken into account:
- If the planning period is too short, persistent long-term erosion will quickly remove the buffer zone completely and direct action will be required to counter the erosion threat. This completely negates the potential advantages of the planning concept and provides only a short-term postponement of existing problems.
  - If the planning period is too long, it will result in a buffer zone that is unrealistically large in terms of the public's perception of the magnitude of future erosion, and can be inconsistent with the time scale of alternating erosion and accretion trends on the local beaches.

5.19 The planning period only relates to the sea-level rise and the long-term erosion components, but this needs to be treated differently. A period of 100 years has been adopted as the planning period for the assessment of erosion due to sea-level rise. This recognises that the primary issue needing to be addressed is the placement of new urban development, which is permanent development and cannot be relocated. Hence it is assigned a design life or planning period of 100 years. The long-term erosion component (excluding sea-level rise) of the calculation is often cyclical in nature and typically of a decadal scale. For this reason, it is considered the estimated annual rate of long-term erosion is only applied for a 50-year period to avoid over-estimation, unless there is clear evidence to the contrary.

## Rate of long-term erosion (R)

5.20 The annual rate of long-term erosion occurring at any individual beach is not constant and will vary significantly depending on the period over which the average rate is assessed. Long-term erosion is often caused by sediment pulsing to the coast, related to extreme flood events, relocations of river and creek mouths, meandering of tidal channels and sand bar migrations onto the coast, but this erosion usually ceases after a period of time and may be followed by a long period of accretion. There are two basic approaches to obtaining an estimate of future long-term erosion:

- extrapolation of past trends deduced from the geological record or evidenced from surveys and aerial photographs
- calculation of the present local sediment budget for each beach. Any deficit (or surplus) is converted into a horizontal movement of the shoreline that can be extrapolated over the planning period.

5.21 Both approaches have limitations in the accuracy with which they can estimate the magnitude of the recent and present erosion rates and, more importantly, in the confidence with which these estimates can be projected into the future. In practice, calculations of sediment budgets are usually tested against recent recorded beach behaviour to check and calibrate the calculation procedures. In this manner, an acceptable estimate of the current annual erosion rate can be achieved.

5.22 Conversion of sediment losses into horizontal recessions requires certain assumptions about the distribution of losses across the beach and dune profile. The form of this distribution is based on the following assumptions:

- a) the average beach slope from the crest of the frontal beach ridge to a base level close to low water mark is assumed to be locally constant for any individual beach. This is supported by normal grain size/wave energy stability considerations; and
- b) below the base level close to low water mark, the profile is assumed to continue to a cut-off with the existing profile that will vary from beach to beach but can be identified from the form of the profile in most cases.

5.23 Based on the assumed distribution, the annual erosion quantity can be related to the annual recession rate by the following equation:

$$Q_e = (R \times h_1) + 0.5(R \times h_2) \text{ (equation 2)}$$

$$= R (h_1 + 0.5h_2)$$

$$\text{Therefore } R = Q_e / (h_1 + 0.5h_2) \text{ (equation 3)}$$

Where:

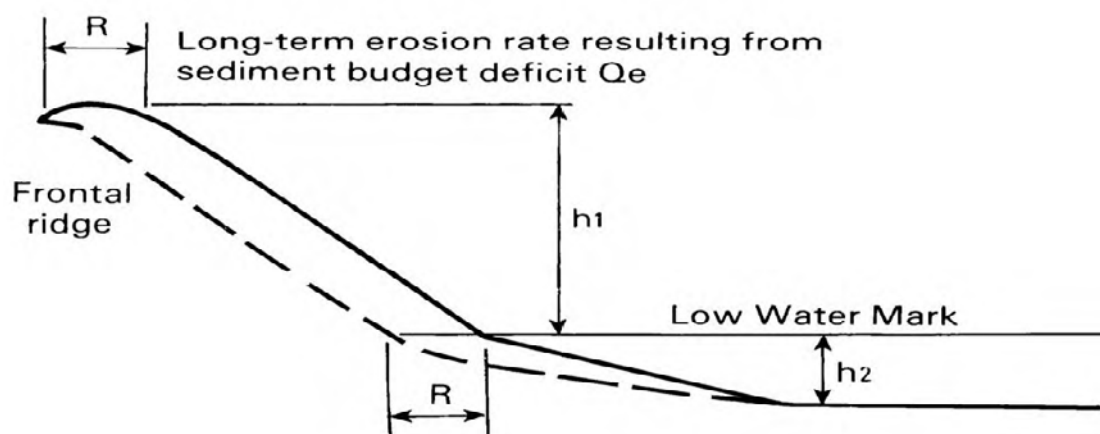
$Q_e$  = erosion quantity in cubic metres per metre length of beach per year (m<sup>3</sup>/m/yr)

$h_1$  = height of frontal beach ridge above low water mark (metres)

$h_2$  = depth of closure (metres)

$R$  = long-term erosion rate (metres per year)

5.24 Although the above calculation procedure has been developed for beach recession, it can also be applied to calculate the relationship between volumes and horizontal accretion for beach nourishment schemes with any necessary modifications for grain size variations between natural and nourishment sand. A typical beach profile response to long-term recession is shown in Figure 1.



**Figure 1. Typical beach profile response to long-term erosion.**

5.25 Care must also be taken when determining the long-term rate of erosion due to morphological or sediment supply processes that historical sea-level rise due to climate change is excluded. The variable  $S$  provides an estimate of erosion due to future sea-level rise and is discussed below.

### Short-term erosion

5.26 Determination of the short-term erosion component ( $C$  in equation 1) involves three separate steps:

- assessment of what the community considered an acceptable risk for assets under threat from a severe storm
- selection of the relevant parameters of the ‘design’ storm event
- estimation of the horizontal recession of the beach associated with this storm event.

### Acceptable risk to the community – design storm event

5.27 For this calculation an acceptable risk is considered to be a storm event of a severity that only occurs on average once in 100 years. For a 100-year planning period, the risk that the coast will be affected by a storm of this intensity is 63 per cent (see Table 4). However, the risk that assets will be affected by erosion from such an event is moderated somewhat by the safety factor in the calculation.

### Selection of parameters for the design storm event

5.28 Selection of parameters for a ‘design’ storm is not a simple matter. Data on probabilities of various storm-tide levels and average return intervals of various storm wave heights and persistence are available. However, for any set of conditions adopted, there is always a risk that a much more severe event will occur. Table 4 summarises the probability of occurrence for events with various average return periods within the adopted 100-year planning period, based on an assumed Poisson distribution of occurrences of such events.

**Table 4. Probability of occurrence of a storm-tide of particular return period over various periods of time (Patterson, C 1986).**

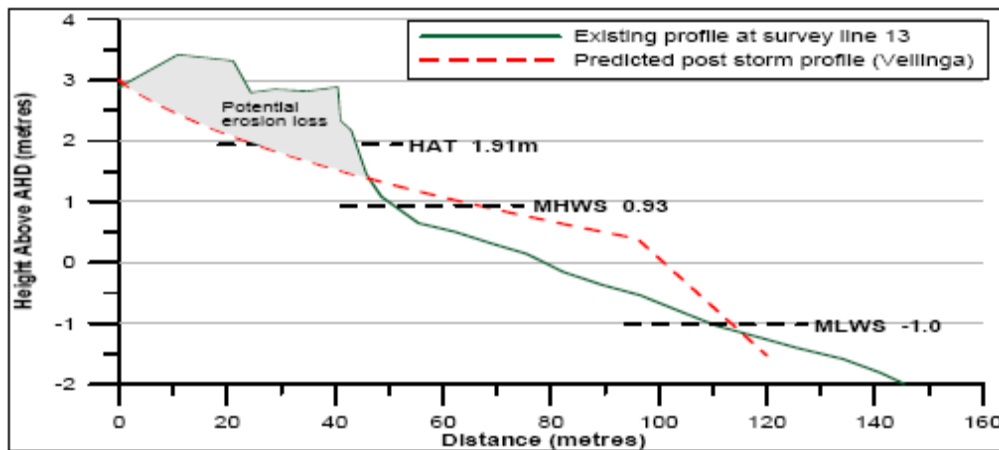
Return period of storm (years)	Probability of occurrence (per cent) for the period (years) shown				
	25 years	50 years	100 years	200 years	500 years
50	39	63	87	98	99.9
100	22	39	63	87	99.3
200	12	22	39	63	92
500	5	9.5	18	33	63
1000	2.5	5	9.5	18	39
5000	0.5	1	2	4	9.5

- 5.29 The assessed probability of occurrence of the ‘design’ storm can be calculated from return period data as in Table 4. Should climate change and associated sea-level rise become significant over the next 10 to 15 years, the parameters of the selected ‘design’ storm may change, resulting in increased storm erosion. Section 4.7 provides for this to be considered by increasing cyclone maximum potential intensity by 10 per cent.
- 5.30 In order to select design storm conditions, it is necessary to break down the ‘design storm’ into the design wave and water level (storm surge) conditions and analyse the probability and risk of each component. The likelihood of peak surge and peak wave conditions influencing a particular area at the same time is statistically very unlikely and the probability of their joint occurrence cannot be readily assessed. As a cyclone approaches the coastline, the length of fetch available for wave generation is reduced which results in an effective reduction in wave height by the time the peak storm surge is observed.
- 5.31 The Queensland coastline exhibits a diverse range of beach profiles from high energy, wave-dominated profiles, to low energy, tide-dominated beach profiles with each profile being influenced differently by external forces. The rate at which coastal erosion occurs is dependent on how external forcing mechanisms, such as the storm-tide level and significant wave height, are allowed to influence the coastline. During a storm event, these two factors interact with the coastline for a length of time (duration).
- 5.32 For the selection of a 100-year average recurrence interval (ARI) storm event, it is appropriate to consider the relative impacts of waves and storm-tide level for a particular coast and adopt a storm-tide level corresponding to a particular probability of occurrence, and an estimated wave height corresponding to a moderate storm.
- 5.33 For a tide-dominated coast where storm-tide levels can be large, the parameters adopted for the minimum design storm are:
- storm-tide level corresponding to an average recurrence interval of 1-in-100 years
  - wave height for a moderate storm using the 1-in-20-year significant wave height ( $H_{sig}$ ).
- 5.34 However, for wave-dominated coastlines where extreme storm-tide levels can be relatively minor, such as the Gold Coast, the significant wave height and duration of the storm event are major factors influencing short term erosion, rather than storm tide. Hence it may be necessary to consider a larger wave event (for example, a storm event with a 1-in-100 ARI) and a moderate storm-tide level. Decisions on appropriate parameters to be used must be based on local conditions and the experience of the coastal engineer undertaking the assessment.
- 5.35 Although the abovementioned probability of occurrence may appear to be fairly high, it is considered that this choice is reasonable when considered in conjunction with the method used to determine erosion prone area widths. This method implies that the erosion prone area has sufficient width to accommodate the ‘design’ storm erosion in 100 years time, when all of the estimated long-term erosion has occurred. Therefore, it also

follows that for much of the 100-year planning period, the erosion prone area is sufficient to accommodate a larger storm than the one selected for design purposes. In fact, in the most critical past 10 years of such a planning period, there is only a 10 per cent probability of occurrence of the ‘design’ storm. Thus the risk of a storm breaching the entire erosion prone area at some time during the 100-year period will be significantly less than 63 per cent.

## Estimation of erosion distances

5.36 The techniques available for estimating storm recession vary from purely empirical procedures to those employing various combinations of empirical and theoretical considerations. The common link is the assumption that a characteristic beach profile is developed during storm wave attack, and that this characteristic profile provides a volume balance between the material eroded from the frontal dune and upper beach with the material deposited further down the new profile in the nearshore zone, as shown in Figure 2.



**Figure 2. Estimated short-term beach profile response to a 1-in-100-year average recurrence interval storm event based on Vellinga (1983) – South Mission Beach**

- 5.37 Vellinga 1983, developed a predictive computational model for beach and dune erosion during storm surges. This method is used to evaluate the erosion distance assuming a fully developed equilibrium profile is reached. It should be noted that the development of an equilibrium profile is a gradual process that for any given storm conditions may not be reached, thus providing an additional factor of safety on the calculations.
- 5.38 Modelling programs, such as the Storm-induced BEACH CHANGE model (SBEACH), provide a one-dimensional model that simulates cross-shore beach, berm and dune erosion produced by storm waves and water levels for the assessment of short-term storm erosion cut. Further information regarding SBEACH can be obtained from the VeriTech website.

## Erosion due to sea-level rise (metres) (S)

- 5.39 As discussed previously, the assessment of the planning period (N), the rate of long-term erosion (R) and storm (cyclone erosion) (C) is based on the extrapolation of either past or present trends, and therefore does not consider the effects of climate change including the accelerated rate of sea-level rise.
- 5.40 Considering the significant body of evidence on the impacts of climate change, it is essential to make provisions for it in the assessment of erosion prone area widths. Techniques are available for modelling shoreline response to a rise in sea level. The so called ‘Bruun Rule’ (Bruun 1962) is a popular approach based on the concept that an equilibrium beach profile is maintained during a sea-level rise, but is translated up and landward. Sediment is removed from the upper beach and dune during shoreline retreat (erosion) and deposited onto the adjacent nearshore zone, thus maintaining both the original beach profile and nearshore shallow water conditions.
- 5.41 This rule is applied to uniform sandy beaches to assess the response of the shore to sea-level rise. The physical characteristics of the coastline, such as the presence of seawalls, inlets, delta mouths and varying sediment size in the beach system, will affect beach response and must also be considered. Results of the Bruun Rule calculations are used to obtain the recession S in equation 1. S thus represents the erosion component due to

the predicted vertical increase in sea level. Impacts of climatic change, such as increased storm activity and changes in wind patterns, do not form part of the determination of S. It is important to note that the Bruun Rule is not strictly applicable on tidally-dependent beaches, where tidal energy has a greater impact on beach morphology than wave energy and sediment grading can be wide and sediments poorly sorted. A simple inundation calculation based on slope may be considered but best practice methodology should be used.

- 5.42 The estimated sea-level rise is based on the best information currently available, with the current projected rise adopted for calculating the erosion prone area being 0.8 m by 2100. This value was based on IPCC sea-level rise projections to 2100 relative to the 1990 level, however the Queensland Coastal Plan adopted a 100-year planning period. Therefore a sea-level rise value of 0.8 m from present day to 2100 was adopted rather than the strict scientific value of 0.84 m from 1990 to 2100 to simplify determinations and prevent inaccuracies from using older (1990) tidal plane estimates. As it is assumed from the policy that the sea-level rise value will be regularly updated in line with IPCC projections, errors from an diminishing time period with a fixed sea-level rise will be minimised.
- 5.43 For beaches in moderate wave energy environments where the tide has a greater effect on beach morphology, a modified Bruun Rule approach may need to be adopted. These beaches are typified by a steep sandy upper beach and wide flat intertidal zone comprised of finer sediment. The Bruun Rule is not applicable over the entire profile of these beaches but can be used on the upper beach profile. It is considered that sea-level rise will predominately impact on the upper beach and dune area and this component of the profile will control the shoreline response to sea-level rise.
- 5.44 On low energy coasts, such as estuarine areas, the shoreline response to sea-level rise is expected to be dominated by inundation, with minimal morphological response. This is due to the low available wave energy to redistribute sediment, but an assessment must be made on a site-by-site basis.

## Factor of safety

- 5.45 The calculation procedures adopted for erosion prone area width determinations are consistent with current engineering practice in this field, but are subject to uncertainties and limitations. For example, the calculation of storm erosion considers beaches as two dimensional and therefore does not incorporate changes in conditions along the beach. In the process of determining values for these various terms, no conscious attempt has been made to select conservative values. Therefore, in accordance with normal engineering practice, a factor of safety should be applied to these calculations. For this purpose, a 40 per cent factor of safety has been adopted.

## Dune scarp component (D)

- 5.46 The short-term erosion calculation permits the assessment of shoreline recession as far as the limit of wave run-up for those cases where the frontal beach ridge is not overtopped. To allow for slumping of the frontal dune beyond this design run-up level, and the possible undermining and collapse of structures founded on the dune, a dune scarp component should be included in the erosion prone area width.

## Defined extent of the erosion prone area

- 5.47 Erosion prone areas are deemed to exist over all tidal water to the extent of Queensland coastal waters and on all land adjacent to tidal water.
- 5.48 On land adjacent to coastal waters the landward boundary of the erosion prone area shall be defined by whichever of the following methods gives the greater erosion prone area width:
- a) a line measured 40 metres landward of the plan position of the present day highest astronomical tide (HAT) level except where approved revetments exist in which case the line is measured 10 metres landward of the upper seaward edge of the revetment, irrespective of the presence of outcropping bedrock;
  - b) a line located by the linear distance (as calculated in section 5.16) specified on an approved erosion prone area plan measured, unless specified otherwise, inland from:

- i) the seaward toe of the frontal dune (the seaward toe of the frontal dune is normally approximated by the seaward limit of terrestrial vegetation or, where this cannot be determined, the level of present day HAT); or
- ii) a straight line drawn across the mouth of a waterway between the alignment of the seaward toe of the frontal dune on either side of the mouth
- c) the plan position of the level of present day HAT plus 0.8 m, being the projected elevation of HAT in 2100 with a 0.8 m rise in sea level.

Exceptions to the above methodology for defining the landward boundary are:

- where the linear distance specified on the erosion prone area plan under 5.48 b) is less than 40 metres, in which case section 5.48 a) does not apply; and the erosion prone area width will be the greater of 5.48 b) and 5.48 c);
- where outcropping bedrock is present and no approved revetments exist, in which case the line is defined as being coincident with the most seaward bedrock outcrop at the plan position of present day HAT plus 0.8m;
- in approved canals, in which case the line of present day HAT applies, irrespective of the presence of approved revetments or outcropping bedrock.

5.49 Erosion prone areas defined in accordance with the above methodology are deemed to exist throughout all local government areas, irrespective of whether the entire local government area is depicted on erosion prone area plans for the area.

5.50 'Present day HAT' in the definition is always taken to be the present day level of HAT for the coastline as defined in the Queensland Tide Tables for that year or as defined by empirical methodology at the site. In this way the landward boundary of the erosion prone area defined by 5.48(i) and 5.48(iii) above will continue to move landward over time as sea-level rises in the future. The current extent of the erosion prone area where it is defined by 'HAT plus 0.8m' under 5.48c) is the projected HAT coastline at the year 2100. It is determined by the area of land inundated to the HAT level of the nearest adjacent open coast or river tide gauge, plus 0.8 m vertical elevation for projected sea-level rise to that time. Site based HAT is not to be used as present day attenuation of inland HAT level due to flow constraints may not persist to 2100 with coastline response to sea-level rise.

5.51 For erosion prone areas defined by 5.48 b) above, each segment of beach which has a different width calculation by equation 1, has a start and end point defined by latitude and longitude. A projection of each point to the nearest actual coastline and continuing inland perpendicular to the coast defines the erosion prone area contained within the segment.

5.52 Due to likely developments in the climate change projections, not only of sea-level rise but also storm intensity, and the possible advancements in the modelling of impacts (e.g. developments to the 'Bruun Rule'), the width of the erosion prone areas will be reviewed and updated as required in the future.

## 6 Storm-tide inundation

6.1 A storm-tide is the combination of a storm surge and the normal astronomical tide. A storm surge is an increase in water level associated with some significant meteorological event (for example, low pressure systems) resulting in a recorded water level higher than the predicted tide. The magnitude of the storm surge is dependent on the severity and duration of the meteorological event, the seabed shape and the proximity of bays, headlands and islands. Large waves can also be generated by winds associated with the meteorological event increasing the risk in coastal areas.

A storm surge is an increase (or decrease) in water level associated with some significant meteorological event, for example, persistent strong winds and change in atmospheric pressure, or tropical cyclone. Its typical effect is to raise the level of the tide above the predicted level. In some situations, such as when winds blow offshore, the actual tide level can be lower than that predicted. The magnitude of the storm surge is dependent on the severity and duration of the event and the seabed topography at the site. In Queensland, most large surges are caused by tropical cyclones.

6.2 A storm surge results in large volumes of water being pushed against the coast. This causes flooding of low-lying coastal areas referred to as storm-tide inundation. The worst impacts occur when the storm surge coincides with a normal high tide. When this happens, the storm tide can inundate areas within a time period of several hours that might otherwise have been safe. Storm-tide inundation results in the erosion of dunes and damage to property and infrastructure from inundation that is not normally subject to flooding by sea water, and therefore can pose risk to life.

### Key characteristics of storm-tide inundation in Queensland

6.3 The key characteristics of storm-tide inundation in Queensland are listed below:

- A storm tide is the effect on coastal water of a storm surge combined with wave set-up and normally occurring astronomical tide.
- The actual level reached by a storm tide is dependent on the height and the relative timing of the local astronomical tide together with the characteristics of the meteorological event. If a storm surge coincides with a moderate or high tide, there is potential for very dangerous flooding of low-lying coastal land.
- Storm-tide inundation is likely to occur when the total water level exceeds the HAT. The mechanism of inundation includes the breaching of dunes or coastal protection structures and overbank flows from watercourses and/or storm water drains.
- The inundation effects of a storm tide may worsen terrestrial flooding from intense rainfall if the two events coincide.
- Wave set-up and run-up also contribute to the overall hazard at exposed coastal locations. Damage to infrastructure and/or beach erosion, including loss of private property, can be caused by wave overtopping of coastal defences during extreme water levels associated with severe events.
- In northern Queensland, large storm-tide events are generally associated with cyclones. However, in southern Queensland, storm-tide events can also be caused by severe storms and east coast lows.

### Determining the storm-tide inundation area

6.4 All activities and development on land higher than 1.5 m above HAT in areas with a development commitment or in south-east Queensland, and 2 m above HAT in the rest of Queensland are considered to be at very low risk to storm-tide inundation over the next 100 years. Below this level the risk increases according to a complex set of factors which include regionally and locally specific elements. A regional or local assessment needs to be undertaken to identify such risks. Factors contributing to storm-tide height include:

- the inverted barometer effect, which is the adjustment of sea level to changes in barometric pressure
- surface wind stress
- near-shore breaking wave set-up

- storm characteristics, including speed and track
- wave height and period
- the state of the astronomical tide
- morphological conditions, including bathymetry and coastal configuration.

## Options for determining a storm-tide inundation area

- 6.5 A registered professional engineer of Queensland, or equivalent, with expertise in physical coastal processes may determine the storm-tide inundation area relevant to a proposed development by undertaking a storm-tide inundation assessment consistent with the risk assessment factors discussed in section 4.5 of this guideline. Guidance on how to conduct a storm-tide inundation assessment is provided in the storm-tide inundation area assessment section of this guideline.
- 6.6 If a relevant storm-tide inundation assessment referred to in section 6.5 has not been completed in relation to a proposed development, then a default storm-tide inundation area is taken to be all land between high water mark and a defined storm-tide event (DSTE) level of:
- 1.5 m above the level of HAT in south-east Queensland; or
  - 2 m above the level of HAT in the rest of Queensland.

## Storm-tide inundation area assessment

- 6.7 The objective of a storm-tide inundation area assessment is to define the nature and extent (severity) of potential storm-tide hazards across all potentially affected areas. The assessment is a specialist task and is to be conducted by a registered professional engineer of Queensland, or equivalent, with expertise in physical coastal processes. To determine the nature of the storm-tide hazard, a storm-tide inundation area assessment would generally comprise the following two components:
- a) assessment of extreme coastal water levels
  - b) inundation modelling and mapping.
- 6.8 It is noted that the two components may be interrelated. It is common practice to consider the two separately; however, there may be some advantages in the integration of the modelling of coastal hydrodynamics and the overland flooding.
- 6.9 Any mapping products for emergency purposes produced by a storm-tide inundation assessment should be consistent with the National Storm Tide Mapping Model for Emergency Response (see useful references). Further information is available from the Department of Community Safety. Mapping for planning purposes should consider key requirements on the local government planning scheme and State policies.

## Assessment of extreme coastal water levels

- 6.10 Historical records of storm-tide events for a particular locality are generally either not available or very limited. Accordingly, a statistical description of water levels utilising extreme value analysis of recorded data is generally not possible.
- 6.11 The assessment normally requires the simulation of the storm-tide characteristics through numerical modelling techniques. The modelling will incorporate the following:
- assessment of appropriate climatology
  - a representation of tropical cyclone wind fields
  - simulation of the coastal hydrodynamics forced by the storm including storm surge, wind and waves
  - simulation of near shore processes, particularly the generation of wave set-up
  - the variation of the normal astronomical tide
  - the random occurrence of storm events over an extended period of time in accordance with the storm climatology of the region. Assessment of the storm climatology should consider all available data sources
  - a statistical analysis of extreme coastal water levels.

- 6.12 A detailed discussion of aspects of this type of numerical modelling study is provided by Systems Engineering Australia, 2001: Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Ocean Hazards Assessment—Stage 1, and is available at <[www.longpaddock.qld.gov.au](http://www.longpaddock.qld.gov.au)>.
- 6.13 In open coast areas, the effect of wave set-up should be incorporated into the assessment. Depending on its relative importance and the resources available to the assessment, this may be done by:
- wave and wave set-up modelling added into the storm-tide characteristic modelling as outlined above; or
  - adding a constant value allowance.
- 6.14 Wave run-up and overtopping can also potentially contribute to flooding effects and property damage. It is possible that, where extreme wave conditions are generated, considerable coastal flooding could occur without a storm-tide actually exceeding the height of the frontal dune or barrier. The United States Federal Emergency Management Agency Guideline (April 2003) provides guidance on the consideration of wave run-up and overtopping and is available at <[www.fema.gov](http://www.fema.gov)>.
- 6.15 For planning purposes, an allowance for future sea-level rise, in accordance with the assessment factors outlined in 4.5 of this guideline, should be included in the determination of the design storm-tide area. In addition, it may be appropriate to consider climate change effects on the future storm climatology. Little is known about the likely effects of climate change on the frequency and intensity of extreme storm events. It is prudent to adopt some appropriate assumptions, such as:
- a southward latitude shift in the tropical cyclone climate of approximately 1.3 degrees
  - an increased frequency of events; and/or
  - an increase in cyclone intensity of 10 per cent (relative to maximum potential intensity for tropical cyclones in the region).
- 6.16 A number of studies have been undertaken by local government and are available to enable reasonable estimation of appropriate levels for many affected localities. Refer to Appendix 1: Useful references, for a sample of existing studies.
- 6.17 Outcomes of this phase of the assessment would include:
- storm-tide statistics for a series of locations within the assessment area
  - an estimate of the joint probability of extreme waves and storm-tide water levels (at the very least the assessment should estimate a design near-shore wave height condition for the design storm-tide area)
  - the relative contribution to the total water level from climate change and wave set-up components
  - an estimate of wave run-up in the assessment area for design purposes.

## Hydrodynamic analysis

- 6.18 Storm-tide inundation is expected to occur in two modes:
- foreshore inundation (such as breaching of the frontal dune, overtopping of protection structures)
  - overbank flows from tidal watercourses.

## Numerical modelling

- 6.19 Assessment requires a good understanding of the hydraulic behaviour of the overland flow. This in turn requires detailed knowledge of the local topography and potential flow paths. Assessment (numerical modelling) should take into account:
- the effects of blockages and roughness elements, for example, houses, vegetation, fencing
  - the propagation of waves across inundated land
  - local stormwater flows
  - allowance for dune breach and erosion processes
  - additional discharge due to wave overtopping.

- 6.20 As a starting point, accurate topographic information within critical coastal areas should be collected. This should allow mapping of local contours to a resolution of 0.25 m, or better, and include tidally connected watercourses.
- 6.21 The theoretical modelling would examine a range of events from the design storm-tide area, or lower, through to the probable maximum storm-tide event. Outcomes of the modelling should include:
- the extent of inundation
  - flow velocities and depths of inundation through the assessment area
  - information on breaking wave heights in areas close to the open coast.

### Alternatives to numerical modelling

- 6.22 Some local governments may not be able to justify the effort and expense of a fully detailed storm-tide inundation assessment. A simplified approach may provide a reasonable approximation for planning purposes.
- 6.23 Storm-tide statistics for a particular locality can be interpolated from published study data. These include Harper (1999) and James Cook University (2004). These sources also provide estimates of appropriate wave set up values, however, generally lack detailed information on wave conditions expected in conjunction with the DSTE.
- 6.24 As a first approximation, the area of inundation expected during a storm-tide event can be determined from topographic data by simply assuming horizontal water level from the coast. For example, a 4 m AHD storm tide would inundate all land up to the 4 m contour. Care should be taken to ensure that all areas below the selected level would actually flood—some low-lying regions may not be directly connected to the storm-tide, either from the coast or tidal waterways.

## Determination of high and low risk areas within storm-tide inundation areas

- 6.25 Within a determined storm-tide inundation area, low and high risk zones should also be defined. The intent of defining the high risk zone is to recognise the increased threat to public safety and the potential loss or damage to property and structures caused by wave impacts and/or high velocity flows. The high risk area is where a significant discharge of water and/or dangerous breaking waves occurs during a DSTE. Determination of this zone requires considerable detailed information on the predicted characteristics and likely effects of a storm-tide inundation event within a particular locality.
- 6.26 Determination of the extent and severity of a storm-tide hazard is of considerable significance in relation to land use, in relation to maximising the benefits of coastal lands while minimising the risks to people and property. The degree of storm-tide hazard varies across the affected area in response to the following factors:
- depths of inundation
  - flow velocities
  - wave heights.
- 6.27 The severity for a storm-tide hazard should focus on the effects of high flow velocities and breaking waves on the stability of structures. Suggested storm-tide hazard severity zones are defined as follows:
- Low – the inundation depth is less than 1 m with wave heights less than 0.9 m, and the product of depth x velocity is less than 0.3 m<sup>2</sup>/s.
  - High – most residential structures will incur moderate to severe damage. The inundation depth is 1 m or more with braking waves of 0.9 m or higher, and/or peak flows with a product of depth x velocity of 0.3 m<sup>2</sup>/s or greater.
- 6.28 Table 5 shows the recommended storm-tide event levels (RSTEL) for essential community service infrastructure.

**Table 5. Recommended storm-tide event levels for essential community infrastructure**

Type of infrastructure	Recommended storm-tide event level
Emergency services	0.2 % annual exceedance probability (AEP)
Emergency shelters	see reference 1*
Hospitals and associated facilities	0.2 % AEP
Major switch yards	0.2 % AEP
Police facilities	0.5 % AEP
Power stations	0.2 % AEP
Sewerage treatment plants	Storm-tide inundation area
School facilities	0.5 % AEP
Stores of valuable records or items of historic or cultural significance (e.g. galleries and libraries)	0.5 % AEP
Substations	0.5 % AEP
Water treatment plants	0.5 % AEP
State controlled roads, railway lines, stations and associated facilities Aeronautical facilities Works of an electricity entity not otherwise listed in this table Communication network facilities	No specific recommended storm-tide event level but development proponents should ensure that the infrastructure is optimally located and designed to achieve suitable levels of service, having regard to the processes and policies of the administering government agency.
For sewage treatment plants, major switch yards, substations and water treatment plants, the RSTEL applies only to electrical and other equipment that, if damaged by floodwater or debris, would prevent the plant or infrastructure from functioning. This equipment should either be protected from damage or designed to withstand inundation. Also some police and emergency services facilities (e.g. water police and search and rescue operations) are dependent on direct water access. The RSTELs do not apply to these aspects but other operational areas should be located above the RSTEL to the greatest extent feasible. Reference 1*: Design guidelines for Queensland public cyclone shelter posted at < <a href="http://www.distaster.qld.gov.au">www.distaster.qld.gov.au</a> >.	

## Updating existing storm-tide inundation area assessments to include climate change

- 6.29 There are a number of existing storm-tide inundation area assessments and storm-tide studies that have been undertaken for various sections of the Queensland coast. These existing studies may or may not have considered the impact of climate change on storm-tide levels. It is acknowledged that undertaking a storm-tide inundation area assessment poses an appreciable cost burden on local authorities. Where there is an existing study there may be scope to update the storm-tide statistics to account for the projected 0.8 m rise in mean sea level by 2100.
- 6.30 A review of the effect of climate change scenarios on storm-tide statistics has been provided by James Cook University (2004): Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Ocean Hazards Assessment – Stage 2. The review found that the rise in mean sea level is the most important effect in relation to storm-tide statistics especially for events up to the one per cent AEP event (100-year ARI event) and the rise in mean sea level is essentially additive to the storm-tide level.

## 7 Glossary

**Accretion**—the gradual addition of sand to a beach or shoreline generally during periods of light on-shore wind or following storm erosion.

**Astronomical tide**—the periodic rising and falling of the oceans, resulting from the gravitational attraction of the moon, sun and other astronomical bodies acting upon the rotating earth.

**Australian height datum (AHD)**—Australian height datum is the datum (adopted by the National Mapping Council of Australia) to which all vertical control for topographic mapping is to be referred.

**Average recurrence interval (ARI)**—the average, or expected, value of the periods between exceedances of a given storm-tide level. It is implicit in this definition that the periods between exceedances are generally random.

**Bathymetry**—the measurement of depths of water in oceans, seas and lakes; also information derived from such measurements.

**Beach nourishment**—the replenishment of a beach system using imported sediment to balance erosion losses or to re-establish a wider dunal buffer zone.

**Climate change**—a change in the state of the climate that can be identified by changes in the mean (and/or the variability) and that persists for an extended period, typically decades or longer. It can be due to natural variability or as a result of human activity (Intergovernmental Panel on Climate Change).

**Coastal erosion**—the wearing away of land or the removal of beach or dune sediments by wave or wind action, tidal currents, wave currents, or drainage.

**Coastal processes**—natural processes of the coast including sediment transport; fluctuations in the location and form of the foreshore, dune systems and associated ecosystems; tides; changes in sea level and coastal hazards (for example, storm-tide surge); ecological processes (such as migration of plant and animal species) and the natural water cycle (for example, coastal wetlands' role in nutrient filtration and flood mitigation).

**Defined storm-tide event (DSTE)**—the event (measured in terms of likelihood of recurrence) and associated inundation level adopted to manage the development of a particular area. The defined storm-tide event is the one per cent annual exceedance probability (AEP) storm-tide—equivalent to 1-in-100-year ARI unless otherwise indicated for essential community service infrastructure.

**Erosion prone area**—an area subject to coastal erosion or tidal inundation and declared to be erosion prone under section 70(1) of the *Coastal Protection and Management Act 1995*.

**Highest astronomical tide (HAT)**—the highest water level that can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.

**Inverse barometer effect**—the proportional rise in water level due to the hydrostatic pressure deficit beneath a tropical cyclone.

**Maximum potential intensity**—the theoretical limit of the strength of a tropical cyclone and a measure of its central pressure. Tropical cyclone intensity is calculated using sea surface temperature and atmospheric thermodynamic.

**Registered professional engineer (RPE)**—a person registered under the Professional Engineers Act 2002 by the Board of Registered Professional Engineers Queensland who holds a registration approved by Engineers Australia or the Australian Institute of Mining and Metallurgy (AusIMM) as fit to practice as a professional engineer, with approved competencies in the areas of structural, geotechnical or geological and environmental engineering.

**Revetment**—a protective layer of erosion-resistant material, either permanent or temporary, placed along the edge of a shoreline to stabilise and protect the shoreline from the erosive action of water. Revetment includes seawalls, boulderwalls, rip-rap and gabions.

**Sediment**—sand, clay, silt, pebbles, organic material and minerals carried and deposited by water or wind.

**Storm surge**—a localised increase in ocean water levels caused by high winds and reduced atmospheric pressures associated with a storm event.

**Storm tide**—the effect on coastal water of a storm surge combined with the normally occurring astronomical tide.

**Storm-tide inundation area**—the area of land determined to be at risk from inundation associated with a storm-tide.

**Wave run-up**—the rush of water up against a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level to which the rush of water reaches.

**Wave set-up**—an increase in the mean water level towards the shoreline caused by wave action. It can be very important during storm events as it results in a further increase in water level above the tide and surge levels.

## 8 References

Bruun, P 1962, Sea level rise as a cause of shore erosion, *ASCE Journal, Waters and Harbours Division*, vol. 188, pp. 117–130.

CSIRO 2007, *Climate Change in Australia – Technical Report 2007*, CSIRO, Australia. Ch. 6.

Harper, BA 1999, Storm tide threat in Queensland: History, prediction and relative risk, *Conservation Technical Report No.10*, Department of Environment and Heritage, Jan, ISSN 1037-4701.

Intergovernmental Panel on Climate Change 2007, *IPCC Fourth Assessment Report: Climate Change 2007*.

James Cook University 2004, Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Oceans Hazards Assessment – The Frequency of Surge Plus Tide During Tropical Cyclones for Selected Open Coast Locations Along the Queensland East Coast and Tropical Cyclone-Induced Water Levels and Waves: Harvey Bay and Sunshine Coast.

Patterson, C 1986, Storm tide statistics, *Beach Conservation*, Issue No.62, January 1986, Beach Protection Authority of Queensland.

Vellinga, P 1983, Predictive computation model for beach and dune erosion during storm surges, *Delft Hydraulics Laboratory*, Publication No.294.

## Appendix 1—Useful references

- Beach Protection Authority Queensland 1979, Capricorn Coast Beaches: Chapter 8 – Water Level Variations, p.12.
- Beach Protection Authority Queensland 1989, Hervey Bay Beaches: Chapter 7 – Water Level Variations, p. 14.
- Beach Protection Authority Queensland 1984, Mulgrave Shire Northern Beaches: Chapter 7 – Water Level Variations, Queensland Government, p. 17.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Bowen, Beach Protection Authority Queensland, p. 53.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Cooktown, Beach Protection Authority Queensland, p. 51.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Lucinda, Beach Protection Authority Queensland, p. 51.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Mackay, Beach Protection Authority Queensland, p. 52.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Mourilyan, Beach Protection Authority Queensland, p. 52.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Surfers Paradise, Beach Protection Authority Queensland, p. 50.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Townsville, Beach Protection Authority Queensland, p. 51.
- Blain, Blemner and Williams Pty Ltd 1985, Storm Tide Statistics: Yeppoon, Beach Protection Authority Queensland, p. 53.
- Burnett Shire Council, (1997), Burnett Coast Storm Tide Plan, p. 62.
- Connell Wagner, Lawson and Treloar 2004, Bowen Shire Storm Tide Study, Bowen Shire Council, p. 95.
- Connell Wagner, Lawson and Treloar 2003, Caloundra City Council Storm Tide Study – Counter Disaster Planning Report, Caloundra City Council, p. 48.
- Connell Wagner, Lawson and Treloar 2003, Caloundra City Council Storm Tide Study – Development Report, Caloundra City Council, p. 140.
- Connell Wagner, Lawson and Treloar 2003, Capricorn Coast Storm Tide Hazard Investigation, Livingstone Shire Council, p. 53.
- Connell Wagner, Lawson and Treloar 2004, Hinchinbrook Storm Surge Study, Hinchinbrook Shire Council, p. 85.
- Connell Wagner, Lawson and Treloar 2005, Maroochy Shire Storm Tide Study – Counter Disaster Planning Report, Maroochy Shire Council, p. 47.
- Connell Wagner, Lawson and Treloar 2005, Maroochy Shire Storm Tide Study – Development Report, Maroochy Shire Council, p. 146.
- Connell Wagner, Lawson and Treloar, WS Group 2003, Storm Tide Risk Management Study for Broadsound Shire Council and Sarina Shire Council, Broadsound Shire Council, Sarina Shire Council, p. 93.
- Department of Public Lands 1975, Storm Tide Inundation Map: Bowen, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Bundaberg Coast, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Cairns (1), Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Cairns (2), Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Emu Park, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Gladstone, Survey Office, Brisbane, Queensland.

- Department of Public Lands 1975, Storm Tide Inundation Map: Hervey Bay, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Innisfail, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Mackay (1), Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Mackay (2), Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Townsville, Survey Office, Brisbane, Queensland.
- Department of Public Lands 1975, Storm Tide Inundation Map: Yeppoon, Survey Office, Brisbane, Queensland.
- Douglas Shire Council, (2006), Emergency Action Guide, Maps 1–6, pp. 18–23.
- Granger, K, Jones, T, Leiba, M, Scott, G 1999, Community Risk in Cairns – A Multi-Hazard Assessment, Cities Project, Australian Geological Survey Organisation – Geoscience Australia, p. 231.
- Granger, K, Micheal-Leiba, M (editors) 2001, Community Risk in Gladstone – A Multi-Hazard Risk Assessment, Cities Project, Australian Geological Survey Organisation – Geoscience Australia, p. 169.
- Granger, K, Hayne, M (editors) 2001, Natural Hazards and the Risks They Pose to South-East Queensland, Cities Project, Australian Geological Survey Organisation – Geoscience Australia, p. 403.
- GHD, Systems Engineering Australia Pty Ltd 2004, Storm Surge Study – Rainbow Beach, Rainbow Shores, Coolooloolo Cove and Tin Can Bay, Coolooloolo Shire Council, p. 36.
- GHD and Systems Engineering Australia Pty Ltd 2003, Storm Tide Modelling Study of the Whitsunday Coast and Resort Islands, Whitsunday Shire Council, p. 166.
- GHD and Systems Engineering Australia Pty Ltd 2007, Townsville – Thuringowa Storm Tide Study, Townsville City Council, Thuringowa City Council, p. 251.
- Hardy, T, Mason, L, Astorquia, A 2004, The Frequency of Surge Plus Tide During Tropical Cyclones for Selected Open Coast Locations Along the Queensland East Coast, Marine Modelling Unit Report to Australian Bureau of Meteorology and Queensland Environmental Protection Agency, School of Engineering James Cook University, Townsville, Queensland, p. 60.
- Hardy, TA, Mason, LB, Astorquia, A and Harper, BA 2003, Tropical Cyclone-Induced Water Levels and Waves: Hervey Bay and Sunshine Coast, Marine Modelling Unit Report to Australian Bureau of Meteorology and Queensland Environmental Protection Agency, School of Engineering James Cook University, Townsville, Queensland, p. 78.
- Harper, BA 1998, Storm Tide Threat in Queensland: History, Prediction and Relative Risks, Conservation Technical Report No.10, Department of Environment and Heritage, Queensland Government, p. 26.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Bowen, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 100.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Cairns, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 24.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Cooktown, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 93.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Gold Coast, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 102.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Ingham, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 100.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Innisfail, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 100.

- Harper, BA, Sobey, RJ, and Stark, KP, 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Mackay, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 100.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Rockhampton, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 97.
- Harper, BA, Sobey, RJ, and Stark, KP 1977, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Townsville, Department of Civil and Systems Engineering, James Cook University of North Queensland, p. 98.
- John Wilson and Partners, Lawson and Treloar 2004, Pine River/Hays Inlet Storm Surge Study, Pine Rivers Shire Council, p. 56.
- Lawson and Treloar 2002, Hervey Bay Storm Tide Study, Hervey Bay City Council, p. 76.
- Maunsell Australia Pty Ltd, DHI Water and Environment 2003, Burdekin Shire Storm Surge Study – Volume 1, Burdekin Shire Council, p. 236.
- Maunsell Australia Pty Ltd, DHI Water and Environment 2003, Burdekin Shire Storm Surge Study – Volume 2 Surge Inundation Mapping, Burdekin Shire Council, p. 108.
- McInnes, K, Hubbert, G, Oliver, S, Abs, D 2000, Gold Coast Broadwater Study: Storm Tide Return Periods and 1974 Floodwater Modelling, prepared by CSIRO, Global Environmental Modelling Systems for Gold Coast City Council, p. 45.
- Middelmann, M, Granger, K (editors) 2000, Community Risk in Mackay - A Multi-Hazard Risk Assessment, Cities Project, Australian Geological Survey Organisation – Geoscience Australia, p. 270.
- Mirfenderesk, H 2008, Investigation of Possible Flooding on the Gold Coast Due to Storm Tide, Gold Coast City Council, p. 14.
- Queensland Government, Maritime Safety Queensland 2010, The Official Tide Tables and Boating Safety Guide 2007, Maritime Safety Queensland, Mineral House, Australia Queensland Risk Management Consultants Pty Ltd, Kellogg, Brown and Root Pty Ltd 2005, Report on Other Water Bases Hazards Phase (Severe Storm, East Coast Low and Storm Tide), Brisbane City Council, p. 143.
- State of Queensland and Commonwealth of Australia 2002, National Storm Tide Mapping Model for Emergency Response, State of Queensland and Commonwealth of Australia.
- Rusk PPK Pty Ltd, 1995, Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast: Cardwell, Beach Protection Authority Queensland, p. 208.
- Rusk PPK Pty Ltd 1995, Storm Tide Statistics: Cardwell, Beach Protection Authority Queensland, p. 53.
- Water Studies Pty Ltd, John Wilson and Partners, Lawson and Treloar, 1995 (updated 2000, 2001), Flooding in the Noosa River Catchment, prepared for Noosa Shire Council, p. 46.