Department of Environment and Heritage Protection

Coastal hazard technical guide

Determining coastal hazard areas

Queensland Government

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Introduction

This guide provides information about coastal hazards (storm-tide inundation and coastal erosion), and guidance for determining areas at risk from coastal hazards, including future risks linked to projected sea level rise and an increase in cyclone intensity. The identification of coastal hazard areas is required for the effective management of the coast, including the preparation of local area plans of management.

Coastal erosion and storm tide inundation are naturally occurring coastal processes that are referred to as coastal hazards as they have the potential to impact on public safety and development along the coast. They are quite different processes and discussed separately in more detailed below.

The implications of projected sea level rise and an increase in cyclone intensity for Queensland's coast 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 land may 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 apparent severity and frequency 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.

As development is generally long lived and development rights are granted permanently, the effect of these factors on coastal hazard risks should be taken into account to guide sound land-use decisions.

Coastal erosion and its management

Erosion and natural beach behaviour

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.

It is likely that a number of these factors will be influenced by projected 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

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.

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

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.

It has been the intention of coastal policy in Queensland for many years to set aside the width of coast 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

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. It 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.

The future assessment of both short-term and long-term erosion may be affected by sea level rise. While future changes to sea level rise and storm intensity continue to be researched, current 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 (e.g. <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.

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 10m 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.

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

The formula adopted by the Department of Environment and Heritage Protection (EHP) for the calculation of the necessary erosion prone area width is as follows:

$E = [(N \times R) + C + S] \times (1 + F) + D$ (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).

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)

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.

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)

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.

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.

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:

- 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
- 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.

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

$Qe = (R \times h1) + 0.5(R \times h2)$ (equation 2)

$= R\,(h1 + 0.5h2)$

Therefore $R = Qe/(h1 + 0.5h2)$ (equation 3)

Where:

Qe = erosion quantity in cubic metres per metre length of beach per year (m^3/m/yr)

$h1$ = height of frontal beach ridge above low water mark (metres)

$h2$ = depth of closure (metres)

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

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.

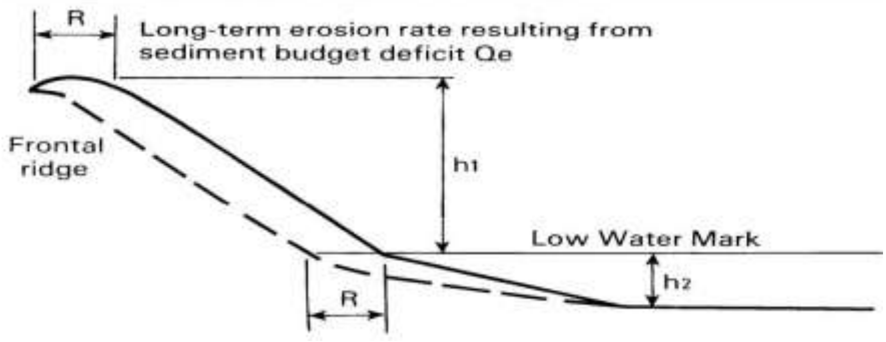

Figure 1: Typical beach profile response to long-term erosion.

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 (C)

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

1. Assessment of what the community considered an acceptable risk for assets under threat from a severe storm.
2. Selection of the relevant parameters of the design storm event.
3. Estimation of the horizontal recession of the beach associated with this storm event.

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% (see Table 1). 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 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 1 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 1: 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 (%) 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

The assessed probability of occurrence of the design storm can be calculated from return period data as in Table 1. Should 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.

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.

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).

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.

For a tide-dominated coast where storm tide levels can be large, the parameters adopted for the minimum design storm are:

(i) storm tide level corresponding to an average recurrence interval of 1-in-100 years

(ii) wave height for a moderate storm using the 1-in-20-year significant wave height (Hsig).

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.

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 last 10 years of such a planning period, there is only a 10% 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%.

For estimation of the horizontal recession of the beach associated with this storm event the techniques available 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.

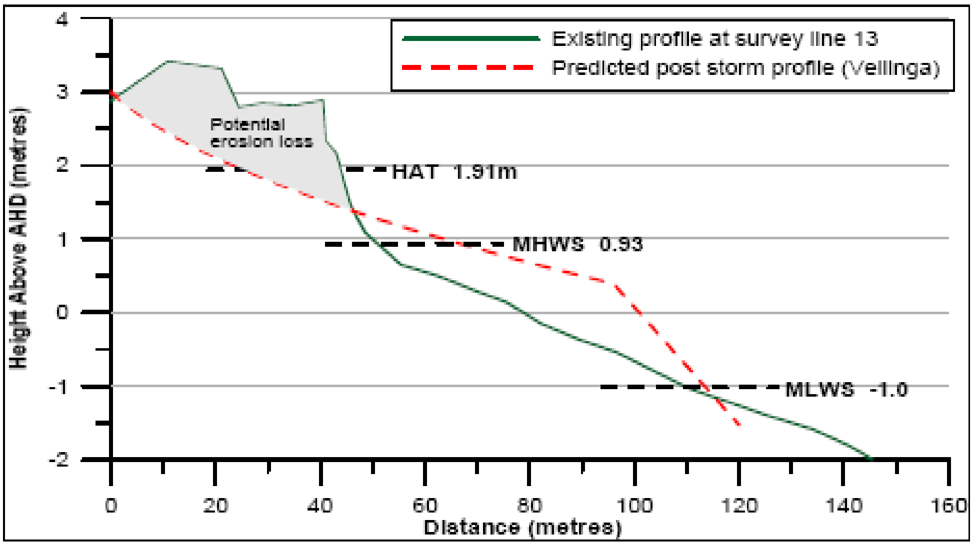

Figure 2: Estimated short-term beach profile response to a 1-in-100-year average recurrence interval storm event based on Vellinga (1983)—South Mission Beach

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.

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)

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 such as the accelerated rate of sea level rise.

Considering the significant body of evidence supporting the projected sea level rise of around 0.8 metres by 2100, 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.

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 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. 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.

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 0.8m by the year 2100. This value was based on the 2007 Forth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) sea level rise projections to 2100 relative to the 1990 level, however the preference is to adopt a 100 year planning period. Therefore a sea level rise value of 0.8m from present day to 2100 was adopted rather than the strict scientific value of 0.84m from 1990 to 2100 to simplify determinations and prevent inaccuracies from using older (1990) tidal plane estimates. As the sea level rise value is updated in line with future IPCC projections, errors from a diminishing time period with a fixed sea level rise will be minimised.

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.

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 (F)

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% factor of safety has been adopted.

Dune scarp component (D)

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

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.

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:

1. 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.
2. Erosion prone areas include areas subject to inundation by the highest astronomical tides (HAT) by the year 2100 or at risk from sea erosion.

3. On land adjacent to tidal water 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 40m landward of the plan position of the present day HAT level except where approved revetments exist in which case the line is measured 10m landward of the upper seaward edge of the revetment, irrespective of the presence of outcropping bedrock;
   b. a line located by the Erosion Prone Area Width Assessment Formula and 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 HAT plus 0.8m vertical elevation.

   Except:

   i where the linear distance specified in 3b is less than 40m, in which case section 3a does not apply and the erosion prone area width will be the greater of 3b and 3c; or

   ii 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; or

   iii in approved canals in which case the line of present day HAT applies, irrespective of the presence of approved revetments or outcropping bedrock.

'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 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' 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 0.8m 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 that may not persist to 2100 with coastline response to sea level rise.

For erosion prone areas defined 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.

Due to likely improvement in the certainty of 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.

Storm tide inundation

A storm tide is the combination of a storm surge and the normal astronomical tide. A storm surge is an increase (or decrease) in water level associated with some significant meteorological event (for example, a change in atmospheric pressure such as a low pressure system associated with a tropical cyclone). Combined with a normal astronomical tide, this can result 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 of the storm surge in coastal areas. In some situations, such as when winds blow offshore, the actual tide level can be lower than that predicted. In Queensland, most large surges are caused by tropical cyclones.

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 free of inundation. Storm tide inundation results in the accelerated erosion of dunes. It can also damage property and infrastructure that is not normally subject to flooding by sea water, and therefore can pose risks to life.

Key characteristics of storm tide inundation in Queensland

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

All activities and development on land higher than 1.5m above HAT in south-east Queensland, and 2m 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 inverse 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

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. Guidance on how to conduct a storm tide inundation assessment is provided in the next section.

If a storm tide inundation assessment 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:

- 1.5m above the level of HAT in south-east Queensland, or
- 2m above the level of HAT in the rest of Queensland.

Storm tide inundation area assessment

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:

- assessment of extreme coastal water levels
- inundation modelling and mapping.

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.

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 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

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.

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.

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.

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.

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.

For planning purposes, and based on current science it is appropriate to assume the following impacts at 2100:

- a rise in sea level of 0.8m
- a southward latitude shift in the tropical cyclone climate of approximately 1.3 degrees
- an increase in cyclone maximum potential intensity of 10%.

However, the above assumptions should be replaced by current Queensland Government policy direction where available.

A number of studies have been undertaken by local government and are available to enable reasonable estimation of appropriate levels for many affected localities. This information is generally available on council web sites.

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 projected sea level rise and wave set-up components
- an estimate of wave run-up in the assessment area for design purposes.

Hydrodynamic analysis

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

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.

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 0.25m, or better, and include tidally connected watercourses. Topographic information for Queensland coastal areas may be available from the Department of Environment and Heritage Protection or from the Queensland Government's, Queensland Spatial website.

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

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.

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.

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 4m AHD storm tide would inundate all land up to the 4m 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, medium and low risk areas within storm tide inundation areas

Within a determined storm tide inundation area, medium and high-risk zones should also be defined and by default low-risk areas identified. 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.

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.

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—there is no anticipated inundation depth for a 0.1% AEP defined storm tide event.

Medium—the inundation depth is less than 1m with wave heights less than 0.9m, and the product of depth x velocity is less than 0.3m/s.

High—most residential structures will incur moderate to severe damage. The inundation depth is 1m or more with braking waves of 0.9m or higher, and/or peak flows with a product of depth x velocity of 0.3m/s or greater.

Table 2 shows the recommended storm tide event levels (RSTEL) for vulnerable land uses such as essential community service infrastructure.

Table 2. Recommended storm-tide event levels for vulnerable land uses.

Land use or infrastructure	Recommended storm-tide event level (RSTEL)
Emergency service facilities *	0.2% annual exceedance probability (AEP)
Emergency shelters	see reference 1*
Hospitals and associated facilities	0.2% AEP
Major switch yards and substations *	0.5% AEP
Police facilities *	0.5% AEP
Power stations	0.2% AEP
Sewerage treatment plants *	0.5% AEP

School facilities	0.5% AEP
Stores of valuable records or items of historic or cultural significance (e.g. galleries and libraries).	0.5% AEP
Water treatment plants *	0.5% AEP
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.
* The RSTEL applies only to electrical and other equipment that, if damaged by floodwater or debris, would prevent the infrastructure from functioning or being safe. 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 Shelters is available at www.works.qld.gov.au.	

A 0.5% AEP is approximately equivalent to a 200-year average recurrence interval (ARI); and a 0.2% AEP is approximately equivalent to a 500-year ARI.

Updating existing storm tide inundation area assessments

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 projected sea level rise and increased cyclone intensity on storm tide levels. It is acknowledged that undertaking a storm tide inundation area assessment may pose 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 0.8m rise in mean sea level by 2100 to save repeating the study.

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 1% AEP event (100-year ARI event) and the rise in mean sea level is essentially additive to the storm tide level.

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 exceedance of a given storm tide level. It is implicit in this definition that the periods between each exceedance 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 dune 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 1% 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, boulder walls, 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 (or decrease) 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.

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