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Information sheet

Coastal management

Coastal erosion and assessment of erosion prone area widths

1. Coastal erosion and its management

1.1 Erosion and natural beach behaviour

Sea 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 seaward of the intertidal zone. 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 nearshore sand bars. These changes are commonly temporary, as the beach never achieves 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 the greenhouse effect, which is associated with increasing levels of certain gases in the earth's atmosphere trapping heat and increasing the temperature of the earth. This has the potential to change the general circulation of the atmosphere, and elevate the sea level. While the likely impact of the greenhouse effect is unclear, and world opinion regarding the magnitude of the climatic changes and sea level rise varies widely, the greenhouse effect has the potential to increase the frequency and intensity of storms and cause coastal recession rates to accelerate.

1.2 Long-term and short-term erosion

Sea erosion can be classified as either long-term or short-term, depending on the time scale over which it occurs. Long-term erosion usually refers to a trend of erosion extending over several years 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 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, rather than years, 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 cyclones may last for decades and can result in relatively permanent features such as relocated tidal entrances.

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Figure 1 Slow but persistent erosion of the foreshore at Tinnanbar in Tiaro Shire has exposed ancient bleached dune sands

1.3 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 and improvements. The problem is not so much that the beach is eroding but that development has occurred within the zone of natural beach fluctuations.

Once such a problem becomes apparent, there are several means available of countering the erosion threat, including:

(a) 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 updrift side, resulting in accretion, but the associated sand starvation on the downdrift side merely transfers the original erosion problem to this area.

(b) Retreat

Where property is subjected to severe erosion, resuming property to create a development free zone where coastal fluctuations can occur naturally provides a means of overcoming an erosion problem without interfering with natural beach processes.

(c) 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.

The various means of combating erosion are all relatively 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.

1.4 The buffer zone concept

The high cost of property protection works can be avoided in future development proposals by providing an adequate buffer zone between the seaward boundaries of the development and the shoreline (as demonstrated in figure 2). 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.

Figure 2 Coastal development on the dunes at Bokarina in Caloundra City has been set back outside the erosion-prone area, creating a wide coastal buffer zone.

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 land owners 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 rights; or
- by not allowing any permanent development to be constructed within the erosion-prone area.

Application of the buffer zone concept can be extended into existing erosion problem areas by considering beach nourishment. Beach nourishment can establish or increase a suitable buffer zone between the property under threat and the beach.

The buffer zone concept has been an intrinsic part of Queensland's coastal management policy. It was recommended by the Queensland Beach Protection Authority from its establishment in 1968, and has continued through the *State Coastal Management Plan – Queensland Coastal Policy* developed under the Coastal Act. The intention of the plan is to set aside the width of coastline potentially affected by erosion over a design period (the erosion-prone area width) as a development free buffer zone.

2. Assessment of erosion-prone area widths

2.1 Background

Erosion-prone area widths must accommodate both short-term and long-term erosion over some specified 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) 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.

The future assessment of both short-term and long-term erosion may be affected by climatic changes caused by the greenhouse effect. While all the impacts of the greenhouse effect are currently being researched, indications are that it may cause changes in wind speed and direction, increase the frequency and intensity of storms, and raise 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 <10m) 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 and where it appears reasonable to assume that the wall location will stay fixed in the long-term in spite of possible damage from storms, the long-term component again can be deleted from the erosion-prone area width calculation. Seawalls cannot usually be considered as a barrier against short-term erosion during the planning period. Seawalls are inappropriate for sort-term erosion protection as the walls may be designed to partially fail during extreme events, or the standard of the wall may be incapable of withstanding storm wave attack in conjunction with a storm tide. Furthermore, walls built by private interests are not guaranteed to remain or be maintained to an adequate standard, as they may be removed, altered or poorly maintained by the landowner or subsequent owners.

2.2 Erosion-prone area width assessment

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

$$E = [(N \times R) + C + G] \times (1 + F) + D \quad \text{(Equation 1)}$$

Where:

E = Erosion-prone area width (metres)

N = Planning period (years)

R = Rate of long-term erosion (metres/year)

C = Short-term erosion from the "design" storm/cyclone (metres)

G = Erosion due to greenhouse effect (metres)

F = Factor of safety on short-term and long-term erosion estimates

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

In the above equation, the values of R, C, G and D can be determined for individual beaches based on collected data. 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.

2.3 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/accretion trends on the local beaches.

A period of 50 years has been adopted as the planning period for the assessment of erosion-prone area widths. However, it is recognised that as further information becomes available on the likely implications of the greenhouse effect, this planning period may have to be reviewed.

2.4 Rate of long-term erosion (R)

The annual rate of long-term erosion (or accretion) occurring at any individual beach is not constant and will vary significantly depending on the period over which the average rate is assessed. Selection of the planning period for erosion-prone area width determination defines the time scale of interest. Hence the annual long-term erosion rate selected must be one considered likely to occur for at least the duration of the planning period. 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; and
- 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; and
- 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:

$Qe = (R \times h_1) + 0.5(R \times h_2)$ Equation 2

$= R(h_1 + 0.5h_2)$

Therefore $R = Qe/(h_l + 0.5h_2)$ Equation 3

Where:

Qe = erosion quantity in cubic metres per metre length of beach per year

h_1 = height of frontal beach ridge above low water mark in metres

h_2 = depth below low water mark to which changes occur in metres

R = long-term erosion rate in 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 3.

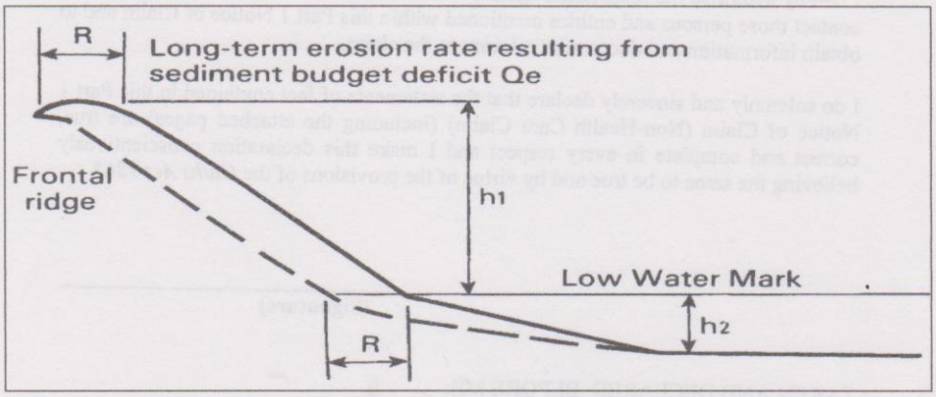

Figure 3 Typical beach profile response to long-term erosion

2.5 Short-term erosion

2.5.1 General

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

- selection of the relevant parameters of a severe storm event
- estimation of the horizontal recession of the beach associated with this storm event.

2.5.2 Selection of storm event

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 fifty-year planning period, based on an assumed Poisson distribution of occurrences of such events.

Average return interval (years)	Probability of one or more exceedances in 50 years
5	99.99%
10	99.3%
25	86.5%
50	63.2%
100	39.3%
250	18.1%
500	9.5%

Table 1 Probabilities of design storm event occurrence

The assessed probability of occurrence of the "design" storm in the above table was determined by projecting the results of a statistical analysis of water levels and storm intensities, which was based on data obtained from past meteorological records and recorded wave data. Should climatic changes and sea level rise due to the greenhouse effect become significant over the next ten to fifteen years, the parameters of the selected "design" storm may change substantially, resulting in increased storm erosion.

In order to select a design condition with a probability of occurrence of less than 40 percent (odds of 1 in 2.5), an event with an average return period of over 100 years must be selected. In the case of storm erosion, the design event involves the joint occurrence of high waves and a high storm tide for duration sufficient to cause substantial damage. However, because high waves and high storm tide are not always related phenomena, the probability of their joint occurrence cannot readily be assessed. For example, high winds, which produce high waves and high storm surges, will not produce high storm tides if the winds occur around the time of low tide. On the other hand, moderate waves produced by moderate winds may produce a high storm tide level if the winds occur around the time of high tide.

Of these two design parameters influencing storm erosion (i.e. storm tide and wave height), the storm tide level is more critical. Small increases in the storm tide level can result in large changes in beach recession, whereas similar changes in wave height do not affect beach erosion to the same degree. This trend is demonstrated in Table 2 where the effect of a 20 per cent increase in storm tide level is compared with a 20 per cent increase in wave height.

Design storm tide Level (metres above AHD)	Significant wave height (m)	Calculated beach erosion (m)
2.3	2.8	10
2.76 (20% increase in storm tide level)	2.8	17
2.3	3.36 (20% increase in wave height)	11.5

Table 2 Effect of storm tidal level and wave height on beach erosion - Moore Park, Burnett Shire

(Extracted from: the Hervey Bay Beaches Report)

Because beach erosion is much more sensitive to storm tide level than to significant wave height, it is appropriate to adopt a storm tide level corresponding to a particular probability of occurrence, and estimate an associated wave height corresponding to a moderate storm. The parameters adopted for the design event were:

- storm tide level corresponding to a 40 per cent probability of exceedance within 50 years (i.e. a recurrence interval of 1 in 100 years)
- wave height for a severe storm (i.e. a recurrence interval of 1 in 50 years)

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 is sufficiently wide to accommodate the "design" storm erosion in fifty years time, when all of the "design" long-term erosion has occurred. It also follows therefore that for much of the fifty-year planning period, the erosion-prone area is sufficiently wide to accommodate a larger storm than the one selected for design purposes. In fact, in the most critical last ten 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 50-year period will be significantly less than 40 per cent.

2.5.3 Estimation of erosion distance

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.

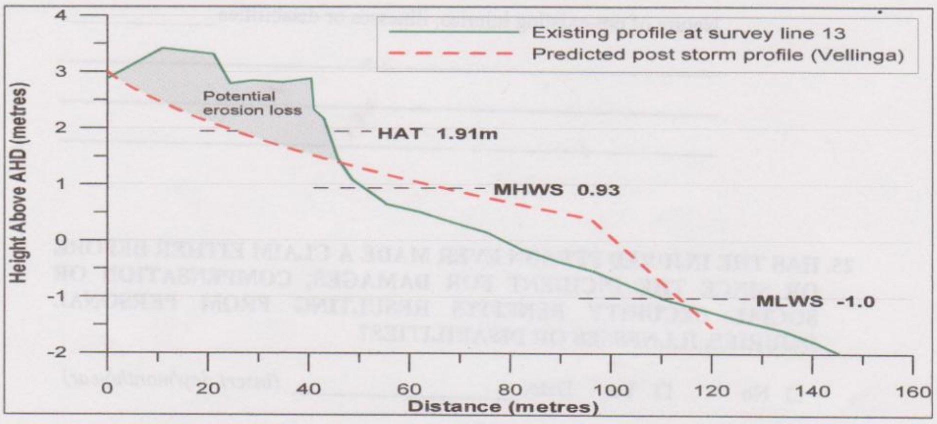

Figure 4 Estimated short-term beach profile response to a 1 in 100 year average return interval storm event based on Vellinga (1983) – South Mission Beach

Experience at sites along the Queensland coast indicates that the empirical Edelman (1972) method predicts a characteristic storm profile that is very similar to the post-storm surveys. The method was originally calibrated for beach profiles along the Dutch coast with sand of median size of about 0.2mm. The Edelman profile was modified using the storm erosion profile documented by Vellinga (1983). The method used to evaluate the erosion distance assumes a fully developed equilibrium profile. 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. The phenomenon of overtopping of the frontal dunes is also considered by assuming that part of the overtopped dune is washed back into the adjacent dune swale (Leatherman, 1979). Because of the relatively low dune height along much of the central and northern Queensland coasts, overtopping is expected to occur quite often under storm conditions.

2.6 Erosion due to the greenhouse effect (G)

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 accelerated rates of sea level rise and climatic changes due to the greenhouse effect.

Despite the lack of quantitative data on the likely impacts of the greenhouse effect, it is essential to make provision 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 of an equilibrium beach profile which is maintained during a sea level rise by transferring material removed during shoreline retreat onto the adjacent inner shelf, thus maintaining both the original beach profile and nearshore shallow water conditions.

This rule is applied to beaches to assess the response of the shore to sea level rise. The physical characteristics of the coastline, such as the presence of seawalls or creek mouths, must also be considered and together with the results of the Bruun Rule calculations are used to obtain the recession G in Equation 1. G thus represents the erosion component of erosion due to the rise in sea level caused by the greenhouse effect. Climatic changes due to the greenhouse effect such as increased storm activity and changes in wind patterns do not form part of the determination of G. It is important to note that the "Bruun Rule" is not strictly applicable on tidally dependant beaches, where tidal energy has a greater impact on beach morphology than wave energy. On these beaches wide gently sloping intertidal often exist and sediments are not well sorted.

The estimated sea level rise is based on the best information currently available, and the current value adopted for use in erosion-prone area determination over a 50-year planning period is 0.3m. Should it become apparent in the future that the rate of sea level rise is significantly different to the current estimate, and then the value of G would need to be reviewed accordingly.

2.7 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 a 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 safety factor of 40 percent has been selected.

2.8 Dune scarp component (D)

The Edelman method of 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 ridge beyond this design run-up level and the possible undermining and collapse of structures founded on the beach ridge, a dune scarp component should be included in the erosion-prone area width.

3. References

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Further Information

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