# PEER REVIEW OF METHODS FOR REVIEW OF THE 1996 AHURIRI TO ESK COASTAL HAZARD ZONE

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## 1. SUMMARY & CONCLUSIONS

The purpose of this report is to review of methods used by Coastal Management Consultancy Ltd (CMCL) for Hazard Zone Assessment of the coast between Ahuriri Entrance and the Esk River mouth, Hawke Bay, New Zealand.

1. The CMCL method estimates future shoreline position taking into account rates of mean-trend shoreline recession, impacts due to the industrial Greenhouse Effect, and superimposed fluctuations in mean-high-tide shoreline due to storm erosion and subsequent beach recovery. The method does not account for the region of reduced foundation strength that occurs landward from an erosion scarp.
2. Overall, the basis of the CMCL method applied in the Napier study is used widely in coastal hazard assessment and therefore can be regarded as best practice in the absence of reasonable estimates of the littoral sediment budget. The method is tailored to site-specific conditions (i.e., mixed sand and gravel beach) through choice of parameter estimates for prediction of effects due to sea-level rise. In this regard the CMCL method departs from standard practice for sand beaches; but in the absence of established principles, the reasons underlying the novel approach seem sound.
3. The CMCL method is enhanced by incorporating a margin-of-safety factor, which acknowledges the uncertainty inherent in all predictions of the type required by the project objectives. Not all sources of uncertainty are included in the CMCL method, but the approach is consistent with deterministic methods widely applied in coastal-hazard assessment. In this respect, the method involves a trade off between margin of safety and opportunity costs of development restrictions in the hazard zone.

4. Assumptions underlying the CMCL method would benefit from the following additional analyses:
    a) cross check *R* estimates by evaluation of the littoral sediment budget (Sec. 4.1.1);
    b) obtain sub-surface sediment samples to evaluate the proportion of sand in the sand-gravel matrix, and hence to confirm adequacy of the predictions for beach response to sea-level rise (Sec. 4.2.3).

## 2. TERMS OF REFERENCE

This report was commissioned by Napier City Council (NCC) for peer review of methods employed by Coastal Management Consultancy Ltd (CMCL) in its Hazard Zone Assessment of the coast between Ahuriri Entrance and the Esk River mouth. More specifically, the report reviews CMCL methods for estimating the inland extent of the foreshore subject to the hazard of coastal recession on the 100 year time scale.

The review is circumscribed on the basis that the hazard-zone assessment is subject to the following practical constraints:

1. to provide conservative (safe) estimates that do not exaggerate the extent of the hazard zone (i.e., a trade off between safety and development-opportunity cost);
2. the need to use cost-efficient methods;
3. the desirability to keep the method as simple as possible
    a) to maintain transparency in procedures, and
    b) to reduce compounding of uncertainty inherent in complicated models (Cowell and Thom, 1994).

The review was undertaken through

a) critique of a preliminary methods paper provided by CMCL entitled *Brief for Peer Review of Methods for Review of the 1996 Ahuriri to Esk Coastal Hazard Zone*,
b) critique of an abbreviated final methods documented by CMCL entitled *2001 CHZ*,
c) 30 memorandums of clarification from CMCL via e-mail
d) 2 telephone conferences with CMCL regarding clarifications.

## 3. BASIC APPROACH USED BY CMCL

### 3.1. OVERVIEW OF GENERAL METHODOLOGY

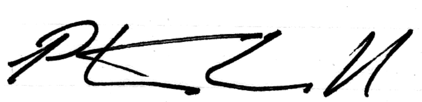
The approach used by CMCL defines the coastal hazard zone as the extent of foreshore that is likely be impacted directly by a shoreline-erosion event at any time during the next 100 years. The landward extent of such erosion is predicted in general as the combination of

- mean-trend shoreline change, and
- superimposed shoreline fluctuations due to storm events and subsequent beach recovery.

The mean-trend shoreline change is predicted by CMCL as the sum of

- the measured, time-averaged rate of shoreline change, and
- the theoretical shoreline recession associated with best-estimates of sea-level rise due to the industrial Greenhouse Effect (assuming no other source of change in relative sea level),

extrapolated 100 years into the future. The CMCL hazard-zone definition does not include the zone of reduced foundation strength for land adjacent to an erosion scarp.



Based on the above factors, the algorithm used to express the inland extent of the coastal hazard zone ($x_{chz}$) is

$$x_{chz} = (R + X)t + S + F \tag{1}$$

where $R$ is the background rate of coastal recession (due to factors such as alongshore gradients in littoral transport), $t$ is time at which the prediction is required ($t$ = 100 years for the purpose of the coastal-hazard zone definition), $S$ is the maximum expected shoreline fluctuation associated with extreme (IPO related) storms and recovery cycles, $X$ is the predicted recession distance due to a relative sea-level rise, and $F$ is a safety factor (i.e., accounting for some parameter and measurement uncertainties). The distance $x_{chz}$ is extended landward from a reference MHWS shoreline defined in 1995 surveys of the beach.

The sea-level rise component of shoreline recession is based on the standard Bruun Rule which is expressed as

$$X = \frac{al}{(d + h)} \tag{2}$$

where $a$ is the rate of sea-level rise, $l$ is the offshore extent (distance perpendicular to the shoreline) subject to morphological adjustment due to the change in sea level, $d$ is the water depth at distance $l$ from the erosion scarp, and $h$ is the height of the dune (in this case the ridge of the barrier elevated through co-seismic uplift). The denominator and numerator in equation 2 are sediment source and sink terms respectively. That is, the numerator expresses the sediment volume deposited on the sea bed in response to a relative sea-level rise, while the denominator relates to the volume, $X(d + h)$ of sediment supplied through erosional recession of the barrier and upper shoreface.

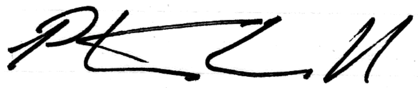
The shoreline fluctuation term $S$ was determined from maxima contained in data on excursion distances at 1.5m above MSL. The data were provided by HBRC to CMCL from 56 cross-shore transects within the study area, with surveys for different transects variously spanning the last the last 6 to 85 years.

The safety factor is given by

$$F = \sqrt{\varepsilon_R^2 + \varepsilon_X^2 + \varepsilon_S^2} \tag{3}$$

where $\varepsilon$ is a partial measure of uncertainty for each of the factors $R$, $X$, and $S$ in (equation 1) as signified by the subscripts. The uncertainties are derived in different ways for each factor and do not include all potential sources of uncertainty (hence they are partial measures).

The recession uncertainty $\varepsilon_{\underline{R}}$ is based on an estimate of measurement error but does not include any allowance for the possibility of future changes in rates (e.g., due to changes in wave climate) or the possibility that the measured trends occur within cycles longer than the measurement record. The $\varepsilon_{\underline{X}}$ uncertainty is based exclusively on the range of IPCC estimates for sea-level rise: it does not include uncertainty in estimation of closure depth and associated distance ($l$). The $\varepsilon_{\underline{S}}$ uncertainty is based on heuristic considerations by allowing for an error of roughly 100% due to possible limitations in the length of available record and the sampling frequency (i.e., time between successive surveys). Both these limitations mean that maximum shoreline excursions associated with the largest recovery phases are unlikely to be captured within the record. The erosion maxima are recorded in the position of the erosion scarp which remains visible even after accretion occurs in front of it.



## 3.2. CRITIQUE OF GENERAL METHODOLOGY

Principles underlying equation 1 are widely used by coastal managers in representation and prediction of shoreline change. At any location along a coast, the shoreline position is governed by gains and losses of sediments in the alongshore and across-shore directions (i.e., the local sediment budget), and by tendencies toward flooding or emergence of the backshore due to changes in sea level. Sea-level change also mediates across-shore sediment displacements, and can influence alongshore sediment budgets through effects on the hydrodynamic conditions caused by changes in the effective bathymetry experienced by nearshore wave and current fields.

All of these factors are taken into account in Equation 1 through a bulk representation. In general, derivation of estimates for each of the terms in the equation adopts different approaches, depending on the space and time scale over which predictions are required, and the financial constraints on the project. Estimates in the Napier project are derived from a mix of empirical (for $R$ and $S$) and theoretical methods (for $X$).

The overall approach is widely used and can be regarded as best practice, especially because it acknowledges the uncertainty inherent in deriving parameter estimates (Cowell and Thom, 1994) and incorporates a method ($F$) that allows for the uncertainty in predictions. Although $F$ does not include all sources uncertainty, the approach is consistent with deterministic methods widely applied in hazard assessment. To this extent, the method is cautious in not exaggerating the hazard zone: a trade off against reduced conservatism in margin of safety.

The hazard zone is mapped relative to the MHWS shoreline determined by survey in 1995 as a horizontal distance landward given by equation 1. The hazard zone is georeferenced accordingly and no cadastral ambiguity should exist in delineation of the hazard zone.

Two sets of predictions are required by NCC for the Westshore-The Esplanade shoreline, where a beach nourishment programme has operated since 1987 (involving a total sediment volume of 240,000 $m^3$ placed on 20 occasions at an average of 12,000 $m^3$ per replenishment event). Predictions are required for scenarios with and without continuation of the nourishment programme. The CMCL method accounts for the respective scenarios by applying the following values of $R$ in equation 1:

a) $R$ estimates from data obtained before commencement of nourishment in 1987 (without nourishment scenario); and
b) $R = 0$ (with nourishment scenario).

Although the approach is reasonable, it entails a reduced length of record for estimating $R$ compared to data for other parts of the study area. The estimate could be improved by including $R$ values calculated from nourishment volumes: i.e. the recession that would have occurred had the beach not been nourished. Such an estimate would thus gauge more contemporary trends than contained in the pre-1987 data. The additional analysis would however reduce the cost effectiveness of the CMCL method.

The CMCL method for with-nourishment estimates retains the $R$-related component of the $F$ factor. Since evaluation of $R = 0$ conditions is based on available data from the Westshore-Esplanade shoreline, inclusion of the uncertainty measure in full is appropriate (i.e., $\varepsilon_{\underline{R}}$ derived from the 1962-1982 data).

# 4. PROCESS-PARAMETER ESTIMATION

## 4.1. MEAN-TREND RECESSION: FACTOR *R*

The *R* term incorporates the effects of alongshore and across-shore sediment movements. It may also include other effects such as losses due sand mining, gains from beach nourishment, and effects of historical (background) relative sea-level change. Background relative sea-level changes are due to tectonics, isostasy and compaction of coastal sediments. The background relative rise within the study area is estimated at 0.03 to 0.60 mm/year since 1959 due to ground subsidence, plus 1.7mm/year regional SLR around New Zealand (CMCL *Brief for Peer Review of Methods)*.

If the effects of historical sea-level rise are included in *R* then this component of sea-level rise should not be included in factor *X* (i.e., via *a*). Otherwise, the sum of the extrapolated-historical and predicted-Bruun recessions account twice the effects of background sea-level: i.e., an over prediction of recession rates. CMCL therefore has excluded background sea-level rise from Factor *X* and included residual sea-level rise implicitly through bulk measurements of *R* .

The *R* term can be estimated from analysis of sediment budgets or historical changes in shoreline position. Either way, *R* estimates can be extrapolated to predict future shoreline position. Reliability of the extrapolation however, depends on whether *R* is likely to vary through time. Possible sources for such variation therefore must be evaluated. For example, at least three events causing change in *R* have occurred in the study area: 1) construction of harbour walls updrift of the study site between 1876 and 1890 at the Ports of Ahuriri and Napier that blocked the supply of beach gravel; 2) co-seismic emergence of 1.8-2.1 m in 1931); and 3) commencement of the beach nourishment programme in 1987 along Westshore-The Esplanade. Different *R* conditions therefore have prevailed at varies times.

The method has taken these differences into account by choosing segments of shoreline time series that provide the most appropriate conditions for extrapolation of *R* within the limits of available data. More specifically, *R* is quantified in the CMCL method from barrier-edge movements after the isostatic effects stemming from the 1931 co-seismic uplift had abated: assumed by CMCL to have occurred by 1962. This procedure reduces the length of record and number of samples upon which the extrapolation is based. The confidence of the prediction is reduced accordingly.

### *4.1.1. Alongshore sediment-transport patterns*

Although determination of *R* from long-term records of shoreline position is the most common method for assessing coastal change, it is worth cross-checking the results at least qualitatively through an assessment of the littoral transport budget. In general, if *R* is non-zero on a multi-decade time scale, the most likely cause is systematic convergences and divergences in littoral transport. Systematic shoreline migration is more sensitive to imbalance in littoral-drift budgets than to sea-level anticipated with the industrial Greenhouse Effect (Cowell and Thom, 1994; Cowell *et al*., 1995).

Under present conditions within the study area (i.e., post harbour construction), if northward dispersal of gravels persists, but the supply from the south ceased following harbour construction, then a volume deficit in the sediment budget results in shoreline recession (which may be enhanced by losses through gravel abrasion). This volume deficit in the littoral sediment budget presumably stimulated the management response now in effect: i.e., beach nourishment. Comparison of nourishment volumes (applied since 1987) against movements in the time-average shoreline position during this time (taking into account effects of any relative sea-level rise evident in local tide gauge records) provides a means of evaluating the background sediment budget.

Such cross-checking was beyond the scope (budget) of the study. Additional work involving such a cross check is however recommended.

#### *4.1.2. Across-shore transport and shoreline fluctuations*

Although *R* relates to systematic (mean-trend) movement of the shoreline, care needs to be taken that the fluctuating component of shoreline change (measured by *S*) does not contaminate the *R* signal. This contamination can occur, in addition to measurement uncertainty, when shoreline histories comprise long intervals (years) between samples (based on measured transects, aerial photographs and old maps). Aliasing can introduce false trends or cycles that are statistical artefacts of higher frequency movements in the shoreline (e.g., seasonal shoreline changes). These high frequency movements most commonly relate to temporary across-shore sediment displacements during storms and subsequent beach-recovery cycles.

The risk of aliasing is reduced in the methods by focusing on the maximum-erosion scarp (i.e., located furthest inland). This reference point is referred to as the ‘barrier edge’ by CMCL in its documentation of the method. The approach however assumes that *S* has been constant throughout the period over which topographic data area available. Constant *S* is hardly ever occurs, so the nature and degree of variation also requires at least qualitative assessment based on the following considerations. For longer records of shoreline and scarp positions, the likelihood increases that the record will include larger but rarer storm-erosion events, and more pronounced recovery phases.

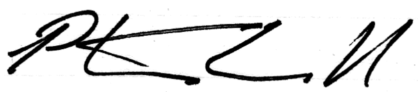
Although full recovery can be expected from the even largest erosion events (e.g., 1:100 year storm or exceptional IPO events), the extreme landward position of the scarp may be interpreted erroneously as a coastal recession signal (i.e., *R*). Unfortunately, no universal generalisation can be made about this possibility (unless storm records are available) because the largest erosion events can occur fortuitously at any time in the measurement record.

### 4.2. RECESSION DUE TO SEA-LEVEL RISE: FACTOR ***X***

Contemporary best practice in coastal prediction for planning purposes demands inclusion of shoreline recession due to sea-level rise associated with the industrial Greenhouse Effect. Best practice (due diligence) requires use of latest IPCC best-estimates for sea-level rise (*a* in equation 2) adjusted for local changes in relative sea level evident in tide-gauge records or from regional studies of tectonics and isostasy. Since the CMCL method already includes effects of background sea-level rise empirically through *R*, only the effects of the enhanced Greenhouse Effect are included by the CMCL method in Factor *X*.

#### *4.2.1. Bruun model*

Equation 2 expresses the Bruun Rule (Bruun, 1962) which is the simplest (hence cost-effective) and most widely used method for predicting shoreline response to sea-level rise, although it also attracts the most controversy (SCOR, 1991; Pilkey, 1993). Nevertheless, detractors offer no alternative for quantifying the geomorphic effects of sea-level rise. Although equation 2 provides first-order approximation, higher order approximations give no guarantee of greater reliability (SCOR, 1991; Cowell and Thom, 1994).



As formalised in equation 2 for application in the study area, the erosion volume is taken into account through the product $X(h + d)$, where $h$ is the elevation at the crest of the uplifted barrier. This relation is reasonable provided the following assumptions are satisfied to a reasonable degree.

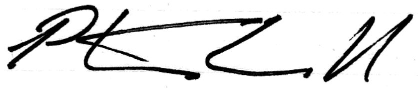
1. The active profile (i.e., within the $x$ domain of $l$) maintains a constant form with respect to sea level at any time. Generally this further assumes
   a) a time-averaged equilibrium form on the decade time scale, and
   b) the absence of anything to inhibit redistribution of sediments along the active profile.

2. The uplifted barrier face is steep or 100 year recession places the erosion scarp near to the uplifted barrier crest in the horizontal. That is, since the elevation of the barrier ridge is used as a surrogate for $h$ in the Bruun Rule, the assumption is that the erosion scarp extends upward to the barrier-ridge elevation. If recession occurs only to some distance seaward of the barrier crest (as in Figure 1), $h$ will be an over estimate. The onshore segment of $l$ is similarly affected.

3. Terrain does not vary much along transects further inland.
   a) If ground falls away rapidly beyond the uplifted barrier crest (Fig. 1), the supply erosion volume $X(h + d)$ will be too small to offset the offshore deposition volume (since the real elevation will diminish from its maximum, $d$, beyond the barrier crest). Bruun-induced recession would then be greater than predicted.
   b) Similarly, if the ground rises further to landward of the crest (i.e., if the crest were to be defined as a morphological feature rather than a maximum elevation), then the Bruun recession will be over predicted.

Assumption 1 is considered further in the next sub section (Sec. 4.2.2). The barrier-ridge assumptions (Assumptions 2 and 3) are of considerable benefit because they allow practical simplification. The assumptions should however be assessed in documentation of the methods.

Where irregularities occur alongshore such that $l$, $d$ or $h$ vary significantly, the resulting shoreline protrusions and bays in reality would be evened out by the effects induced in littoral drift: i.e., divergences and convergences induced in the littoral drift by shoreline protrusions and bays respectively. These effects may be superimposed upon on larger scale variations along the coast (e.g., unidirectional net transport).



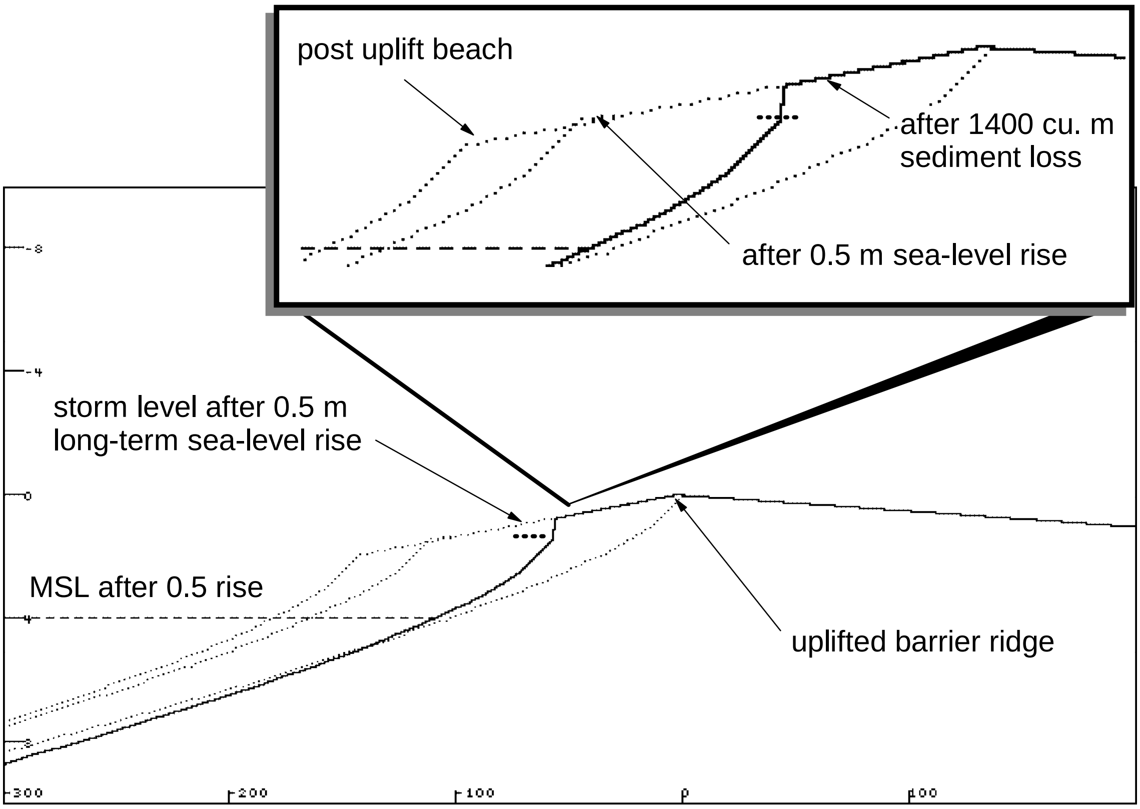


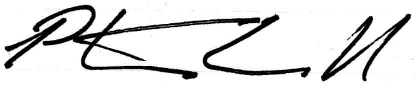

Figure 1. Shoreface recession on an barrier uplifted initially by 2 m, followed 1) by a sea-level rise of 0.5 m, and 2) a sediment loss from the beach of 1400 $m^3$ per m of shoreline (e.g., sum of 1000 $m^3$ loss associated with mean trend recession + 400 $m^3$ temporary loss associated with the 1:100 year storm). The diagram was generated using the Shoreface Translation Model (Cowell *et al.*, 1995).

### *4.2.2. Profile behaviour*

The prevalence of a mixed gravel-sand profile in the study area complicates the usual approach. The basic Bruun method assumes that material eroded from the inner part of the profile (including the upper beach and dune) will be displaced offshore to maintain an equilibrium submarine profile after a sea-level rise (i.e., the offshore sea bed must translate upwards by the same amount as sea-level rise, but this vertical shift is limited to some maximum distance offshore, given by *l* in equation 2).

It is safe to assume however that the gravel and coarse-sand constituents of the uplifted barrier will not be displaced offshore to the bury the present-day sand bed. The dynamics of mixed sand-gravel profiles are not very well understood (Mason and Coates, 2001) but, based on what currently is known, the gravels on the beach probably remain trapped there on a time average basis: i.e., in relation to mean trend changes. Storm response in this regard however seems to depend on the proportion of sand: more sand causes more gravel to be displaced offshore (Mason and Coates, 2001).

Dean (1991) has dealt with the problem of equilibrium profiles on mixed sediment beaches: he suggests that a piece-wise approach is used for separate parts of the profile. That helps in estimating what sort of profile to use in a Bruun approach on such beaches, but it provides no



guidance in terms of profile kinematics if we assume that gravels will not be displaced offshore as a Bruun response.

It is safest to assume that, if mean-trend change is occurring (due to sea-level rise or alongshore losses), then the sand component in the barrier ridge, beach and upper shoreface will be depleted. So this component will go toward offshore aggradation in a Bruun response. Two possibilities thereby exist regarding Bruun response in the study area:

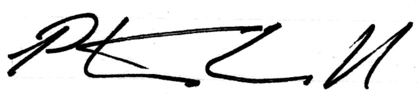
1. If the sand fraction is, for example, 50 percent of the beach and backshore volume, then the coast would need to recede twice the distance predicted by equation 2 to liberate enough sand to aggrade the offshore profile by the amount required to maintain an equilibrium profile. (That is, the recession would be twice as far as in cases where the beach and backshore is composed entirely of sand.) In reality, the process inevitably would lead to an armouring of the upper beach by sand-depleted gravels, preventing sufficient recession to win the requisite volume of sand. This in turn would lead to the second type of response.
2. If the volume of the sand fraction is insufficient to permit maintenance of an equilibrium profile offshore (i.e., the water gets deeper seaward of the beach through time), then the Bruun approximation gives an over-estimation of recession. With such a response, the increased water depth seaward of the beach face would necessarily mean increased expose to wave energy at the beach. For a gravel beach, this does not necessarily mean increased erosion; although it might, depending on the proportion of sand within the barrier (Mason and Coates, 2001). The complication exists that the beach may become more reflective, causing the active beach face to build up higher (Hanslow, 2000) and an increase in the height of the beach step (Hughes and Cowell, 1986).

These two types of responses can be expected to result in under- and over-estimation of $X$ respectively. On balance therefore, although the basis for application of the Bruun Rule to the type of environment prevailing in the study area is not well established, the armouring effect probably favours the second type of response. On this basis, application of equation 2 is a conservative approach. Type 2 profile behaviour also supports the limited definition of closure depth used in the CMCL method.

### *4.2.3. Closure depth*

Closure depth is a critical issue because it determines $d$ and $l$ in equation 2: the deeper the closure the larger both these variables become, although $l$ grows faster if the profile is concave up, which is usually the case (Cowell *et al.*, 1999). Thus deeper closure depths give greater shoreline recession due to a given sea-level rise.

Estimation of closure depth in a Bruun-type of analysis is always the most vexed issue (Thieler <u>*et al*</u>., 2000). Common practice in beach nourishment and offshore mining projects is to apply the Hallermeier (1981) annual closure depth. The problem here is that annual-closure-depth concept applies to annual time scales whereas in reality closure is time-scale dependent (Nicholls *et al*., 1998, Hinton and Nicholls, 1998; Hinton *et al*., 1999). In New South Wales, The Department of Land and Water Conservation has oversight of coastal management and rejects the annual closure-depth approach to predictions required for multi-year or multi-decadal time scales. Moreover, Hallermeier (1981) originally recommended use of his so-called offshore limit (annual limit to significant sediment disturbance) in application of the Bruun Rule (which is a multi-decadal problem).



The CMCL method however uses closure depths ranging from only -4.7 m in the relatively sheltered southern part of the area to -5.3 m in the exposed northern part. At the exposed site, Hallermeier closure depths of $d > 10$ m, and offshore limits of $d > 40$ m would be expected based on similar wave climates elsewhere (Cowell *et al*., 1999). CMCL base selection of closure depth on the results of repeat offshore surveys, across-shore variation in sediment size and profile shape, and with regard to the mixed sand-gravel beach and shoreface characterising the study area.

Ordinarily, the closure-depth values used by CMCL would be far too small for application to sandy beaches: they would lead to significant under estimation of coastal retreat due to rising sea level. For sand beaches, the limits of measurement resolution typical of offshore surveys are significant in terms of potential volume exchanges between the beach and the lower shoreface when integrated over Bruun Rule time scales. For the mixed sand-gravel environment prevailing in the study area however, considerations outlined in Section 4.2.2 (i.e., Type 2 response) suggest that only the inner part of the profile will undergo a Bruun response. Therefore, use of small values for $d$ and $l$ are probably justified on this basis. The veracity of this proposition however depends upon the proportion of sand in the gravel-sand matrix of the barrier.

Currently the proportion of sand is unknown. It is recommended therefore that sediment samples be obtained from the barrier sub surface through coring to evaluate the sand content. Based on this evaluation, the potential for a Type 1 response to sea-level rise can be better assessed, and hence the likelihood of a greater Bruun response by the beach (i.e., due to significantly larger $d$ and $l$ in equation 2).

## 4.3. FLUCTUATING COMPONENT OF SHORELINE CHANGE: FACTOR *S*

The fluctuating component of shoreline change is measured as the maximum horizontal excursion in the MHWS shoreline landward of a standardised location (1995 MHWS shoreline), as evident in the available data. This approach sidesteps the need to know the full excursion distance of the shoreline between conditions of maximum accretion and maximum erosion. More specifically, it is unnecessary to know the location of the shoreline at times of maximum accretion. The advantage here is that the point of maximum erosion is not always effaced during phases of beach accretion: the top of the erosion scarp often remains visible (Sec. 4.1.2). The CMCL method exploits this behaviour to determine $S$.

The project brief specifies a 100 year planning horizon. The implicit assumption in the method is that the maximum observed value of $S$ captures a design storm erosion event relevant to the 100 year time scale. This may or may not be the case, but allowance is made by CMCL through the uncertainty factor $F_s$. The CMCL method applies an $F_s$ that is roughly 100% of $S$. Such a conservative value is probably adequate to also allow for effects of possible changes in the wave regime due to climate change.

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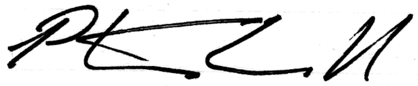

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