Appendix F: Assessment of Bruun Factor

F.1 Preamble

The most commonly applied and well known model for beach response to SLR is that of Bruun (1962, 1988) which assumes that an elevation in sea level will result in a recession of the coastline. This model assumes that as the sea level is raised, the equilibrium profile is moved upward and landward, conserving mass and original shape, based on the concept that the existing beach profile is in equilibrium with the incident wave climate and existing average water level (shown in Figure F-1). A recession rate can be estimated using the Bruun Rule (Bruun, 1962, 1988) as the rate of sea level rise divided by the average slope of the active beach profile. Bruun's Rule is expressed as:

$$R = \frac{rX}{h+d_c} \qquad \text{(F.1)}$$

where R is horizontal recession (m)
r is sea level rise (m)
X is the horizontal distance between h and d_c
h is active dune/berm height (m)
d_c is profile closure depth (m, expressed as a positive number)

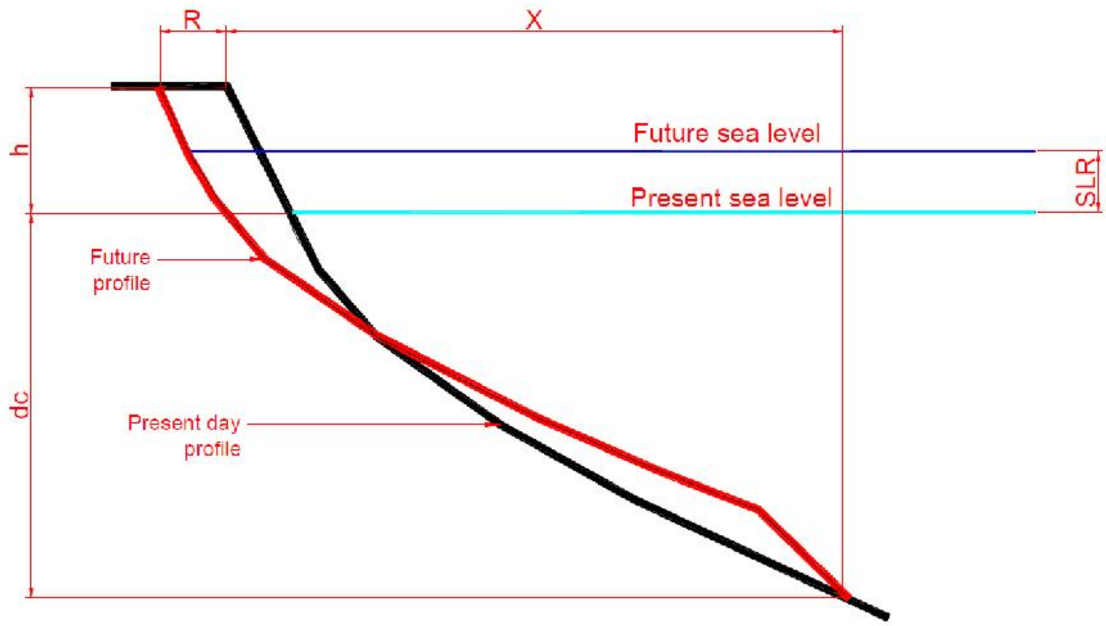

Figure F-1: Illustration of Bruun Rule

Typically, a Bruun factor, which incorporates profile slope at a particular site and thus gives horizontal recession distance as a function of sea level rise is used to calculate recession due to sea level rise at a given location. This appendix summarises the methodology to estimate the depth of closure, and therefore Bruun factor, for each of the beaches in the study area.

F.2 Depth of Closure

The depth of closure is defined as the depth corresponding to the offshore limit of active sediment transport. Its determination is subject to large uncertainty, and is commonly assessed using empirical methods or relying on site specific geology or sedimentology methods.

The primary method for establishing depth of closure in NSW coastal hazard assessments is generally the Hallermeier (1981) inner depth of closure. This method, four other alternative techniques and previously published estimates were collated for consideration by the expert panel. It should be emphasised that the purpose of estimating the depth of closure in this study was to provide an input to the Bruun Rule.

This section summarises the various methodologies used to assess the depth of closure at sites across ESC.

F.2.1 Hallermeier Depth of Closure

Hallermeier (1981) stated that there were three simplified zones of sediment transport: the very active littoral zone closest to the shore, a buffer zone in which the bed is impacted by surface waves but to a lesser extent and an outer zone where surface waves have a negligible effect on the profile bed. Therefore two depths of closures can be established, the inner depth of closure indicates the end of the highly active littoral zone and the outer depth of closure, seaward of which surface waves have little effect on littoral transport. Hallermeier (1981) states that the inner depth of closure on a sandy beach as shown in Equation F.2 and Hallermeier (1983) expressed the outer depth of closure as per Equation F.3.

$$d_l = 2.28H_{s,t} - 68.5\left(\frac{H_{s,t}}{gT_s{}^2}\right) \qquad \text{(F.2)}$$

where d_l = inner depth of closure (m) below mean low water (MLW) level
$H_{s,t}$ = wave height exceeded 12 hours a year (m)
T_s = wave period corresponding with $H_{s,t}$ (s)

$$d_i = 0.018H_mT_m\sqrt{\frac{g}{D_{50}(s-1)}} \qquad \text{(F.3)}$$

where d_i = outer depth of closure (m) below mean low water (MLW) level
H_m = annual median significant wave height (m)
T_m = wave period corresponding with H_m (s)
s = specific gravity of sand grains, taken as 2.65
D_{50} = median grain size

For computation of the Hallermeier outer depth of closure, distance from the dune to the depth of closure was limited to 1500 m. Where the computed depth of closure exceeded this point, the depth 1500 m offshore from the dune was adopted.

F.2.2 Equilibrium Profile

Bruun (1954) (and later Dean, 1977) proposed the concept of beach profiles, such that the relationship between cross shore distance and depth could be related using equation F.4.

$$h = Ax^{\frac{2}{3}} \tag{F.4}$$

where h = depth (m)
x = cross shore distance (m)
A = sediment scale parameter (-)

Since the sediment scale parameter, A, is dependent on the median grainsize, this equilibrium profile can be rapidly generated for each site. At the inner sections of Batemans Bay, the bathymetry is relatively flat and shallow and sediment movement is driven not only by wave forces, but through water movement from the Clyde River and Cullendulla Creek. Therefore, the outer depth of closure method of Hallermeier (1983) may not be appropriate at these locations. For this study, an alternate calculation of the depth of closure was to estimate the location where the observed profile begins to significantly deviate from the Dean equilibrium profile, as shown in Figure F-2. This methodology assumes that where the profile significantly deviates in shape and slope to the equilibrium profile, the sediment transport is no longer dominated by waves, and can therefore be considered the depth of closure for the purpose of using Bruun's rule. This approach to estimate depth of closure has previously been used within Batemans Bay (SMEC, 2010) and at other international locations (e.g. NASA, 2010). In the absence of repeat bathymetry surveys offshore of the Batemans Bay beaches, this alternative depth of closure estimate is considered instructive. However, it is acknowledged that the equilibrium concept assumes constant wave conditions and does not include the presence of bars. Furthermore, the point at which the observed profile deviates from the equilibrium profile may be influenced by the timing of the profile measurement with respect to erosion and accretion modes.

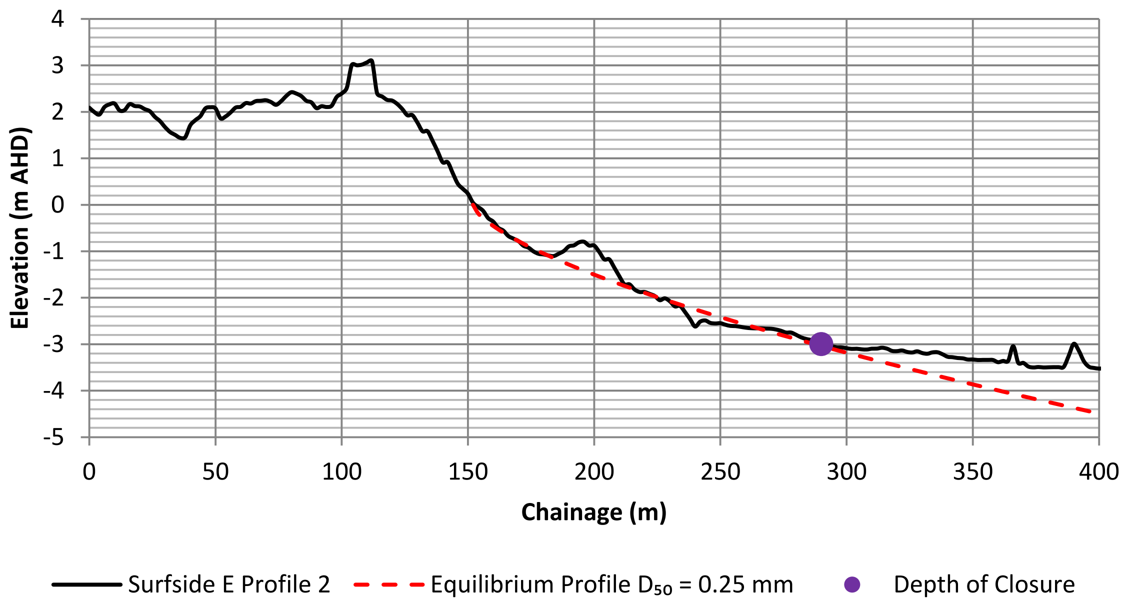

Figure F-2: An example of estimating the depth of closure using the equilibrium profile at Surfside Beach (East) profile 2

F.2.3 Site Specific Geology and Bathymetry

At a number of the beaches in this study, there are specific geological features and bathymetry that can be used to estimate the depth of closure. At these locations, there is an offshore reef which can be identified using aerial images, such as at Tomakin Cove in Figure F-3.

After identifying the location of the reef feature that indicates the position of the depth of closure, local bathymetric surveys were used to estimate the depth at this point. This methodology was used at all beaches which have an obvious reef feature and included Sunshine Bay, Malua Bay, Guerilla Bay and Tomakin Cove.

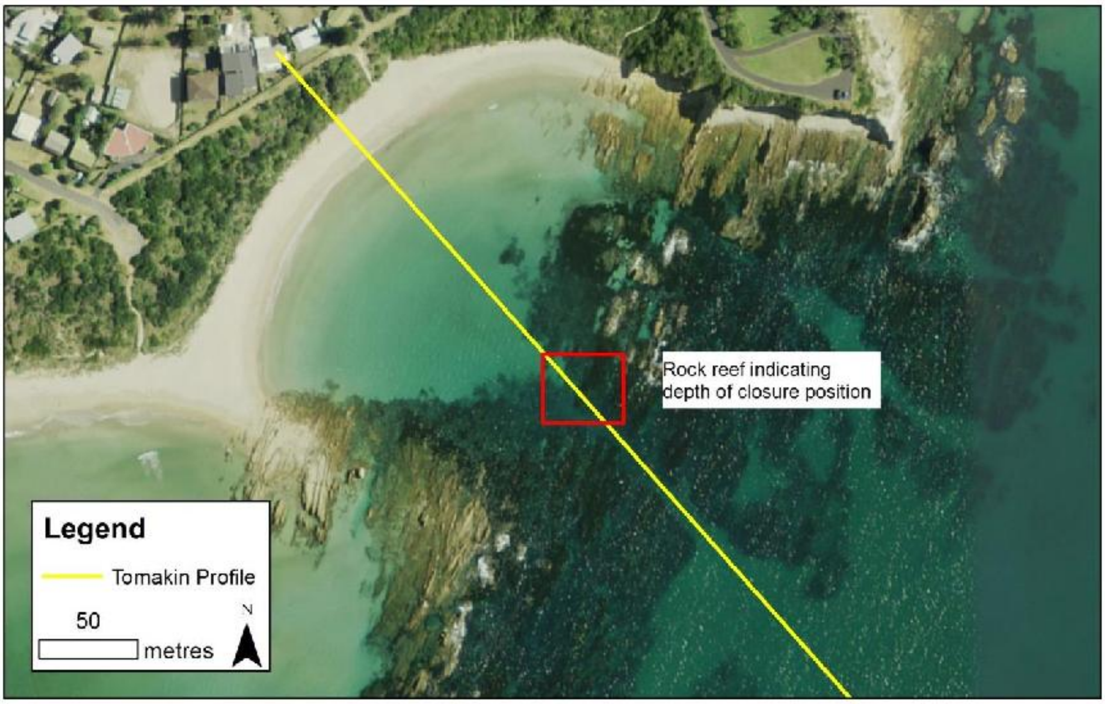

Figure F-3: Using the rock reef to identify the position of the depth of closure at Tomakin Cove

F.2.4 Wave breakpoint depth

Given that the depth of closure is the point at which sediment movement ceases to be driven by surface wave movement, it is conversely true that it is also approximately equal to the point where waves are no longer significantly influenced by the water depth. A simplistic approximation of this spatial position is the point at which waves first begin to break.

Using the SWAN model developed for the region (see Appendix D), the water depths at which 1% of the 100 year ARI waves were breaking were extracted at each location. This depth was then assumed as an alternate depth of closure at each location. WRL considers that closure depths estimated using this approach represent the lower limit (i.e. possibly unconservative) of sediment movement. That is, the adopted depth of closure should be at least the depth of 1% wave breaking.

F.3 Bruun Factor

The Bruun factor is calculated using Equation F.5 (refer also to Figure F-1) for a given dune location and depth of closure. This methodology was used considering the four (4) methodologies for depth of closure described above as they were appropriate and the resulting Bruun factors are collated in Table F-1. Note that sediment size was determined by mechanical sieving of samples collected at each location.

$$BF = \frac{h_D - h_c}{x_c - x_D} \qquad \text{(F.5)}$$

Where BF = Bruun factor
h_c = elevation of depth of closure (m AHD)
h_D = elevation of dune (m AHD)
x_c = relative cross shore chainage of depth of closure (m)
x_D = relative cross shore chainage of dune (m)

For reference, Table F-1 also states the previous estimates made in other studies, including NSW DLWC (1996), SMEC (2010), GBAC (2010) and BMT WBM (2009). Table F-2 summarises the distances used in the Bruun factor calculations.

As discussed in Section 4, Table F-1 (except for the last three columns) and Table F-2 were presented to each member of the expert panel. They were then asked for their preferred values for Bruun factor (minimum, maximum and mode) at each beach section on the basis of the presented information and their own experience on the Eurobodalla coast. The experts' independently preferred values were then blended into a consensus range shown in the last three columns of Table F-1.

Table F-1: Depth of Closure and Bruun Factor Estimates for the Study Area

Beach	Section	WRL D_{50} (mm)	Elevations (m AHD)						Bruun Factors (-)								
			Dune	Inner Depth of Closure	Outer Depth of Closure	Divergence from Equilibrium	Break-point Depth	Rock/ Reef Depth	Inner Depth of Closure	Outer Depth of Closure	Divergence from Equilibrium	Break-point Depth	Rock/ Reef Depth	Previous Estimates	Adopted Consensus Values		
															min	mode	max
Maloneys Beach	East	0.21	5.9	-2.7		-11.0	-2.9		10		59	10		50[1], 20-22[2]		**10**	
	West	0.21	6.3	-3.6		-11.0	-2.8		9		60	9					
Long Beach	East	0.24	3.4	-3.9		-8.2	-3.2		25		60	22		40[1], 20-22[2]	**15**	**20**	**50**
	Central	0.24	3.8	-4.2		-7.5	-4.4		16		56	17		-	**15**	**20**	**50**
	West	0.24	5.3	-5.7		-8.2	-6.0		18		52	19		40[1], 23-25[2]	**15**	**20**	**50**
Surfside Beach (East)	North	0.25	2.9	-3.0		-2.6	-2.3		31		25	23		25[1], 19-20[2]	**20**	**25**	**30**
	South	0.25	3.1	-3.3		-3.0	-2.3		36		29	23			**20**	**25**	**30**
Surfside Beach (West)	Central	0.21	1.9											20[4]	**15**	**20**	**30**
Sunshine Bay	Central	0.21/1.01	3.8	-6.7	-11.0		-7.0	-4.4	37	71		38	24	45-62[2]		**40**	
Malua Bay	Central	0.34	5.2	-8.0	-21.1		-12.0	-14.7	28	44		31	33	40-49[2]	**25**	**30**	**50**
Guerilla Bay (South)	Central	0.29	4.2	-5.0	-14.8		-7.5	-11.4	20	34		22	21	25-35[2]		**25**	
Barlings Beach	East	0.28	7.2	-3.7	-11.1		-3.1		17	52		16		70-85[2]		**50**	
	West	0.32	6.2	-6.7	-11.5*		-6.0		26	79*		22		85-95[2], 56[3]			
Tomakin Cove	Central	0.19	6.6	-6.9	-11.5*		-6.3	-2.8	24	74*		24	21	85-95[2], 40[3]	**20**	**25**	**60**
Broulee Beach	North	0.21	7.5	-6.4	-15.0*		-5.7		31	63*		28		65-75[2]	**25**	**30**	**65**
	Central	0.21	6.6	-4.3	-15.6		-3.9		30	62		29			**25**	**30**	**65**
	South	0.21	4.6	-3.5	-11.3		-2.4		32	53		19			**25**	**30**	**65**

* Where the distance from the dune to the Hallermeier outer depth of closure was more than 1.5 km, depth of closure was assumed to at 1.5 km offshore

[1]DLWC (1996) [2]SMEC (2010) [3]GBAC (2010) [4]BMT WBM (2009)

Table F-2: Distances for Bruun Factor Estimates for the Study Area

Beach	Section	Distances from Dune to … (m)				
		Inner Depth of Closure	Outer Depth of Closure	Divergence from Equilibrium	Break-point Depth	Rock/Reef
Maloneys Beach	East	85		997	89	
	West	91		1037	79	
Long Beach	East	181		693	144	
	Central	130		638	139	
	West	195		700	211	
Surfside Beach (East)	North	179		136	118	
	South	231		176	123	
Surfside Beach (West)	Central					
Sunshine Bay	Central	387	1043		405	194
Malua Bay	Central	363	1167		542	647
Guerilla Bay (South)	Central	185	653		256	326
Barlings Beach	East	190	957		169	
	West	338	1500*		266	
Tomakin Cove	Central	322	1500*		317	197
Broulee Beach	North	432	1500*		366	
	Central	325	1375		302	
	South	260	837		133	

* Where the distance from the dune to the Hallermeier outer depth of closure was more than 1.5 km, depth of closure was assumed to at 1.5 km offshore