Appendix E: SBEACH Model Methodology and Calibration

E.1 Preamble

The modelling program SBEACH (Storm-induced Beach Change) was developed by the U.S. Army Corps of Engineering (USACE) Coastal Engineering Research Center and is an empirically based two dimensional model used to examine the short-term response to beach, berm and dune profiles to storm events. Details of the model are given in Larson and Kraus (1989) and Larson, Kraus and Byrnes (1990). SBEACH considers sand grain size, the pre-storm beach profile and dune height, plus time series of wave height, wave period and water level in calculating a post-storm beach profile. In this study, SBEACH (version 4.03) has been used to quantify the estimated storm demand at each of the beaches in response to a synthetic design storm. This appendix outlines the methodology used in the SBEACH modelling and the calibration of the model to beaches within the ESC region.

E.2 Available Observed Profile Data at Bengello Beach

Through discussions with ESC and OEH, it was agreed that the SBEACH model would be calibrated at Bengello Beach, where reliable monitoring data exists. Bengello Beach has been monitored (approximately monthly) since 1972 with traditional survey techniques (Thom and Hall, 1991, McLean and Shen, 2006). The four profiles used for model calibration are shown in Figure E-1.

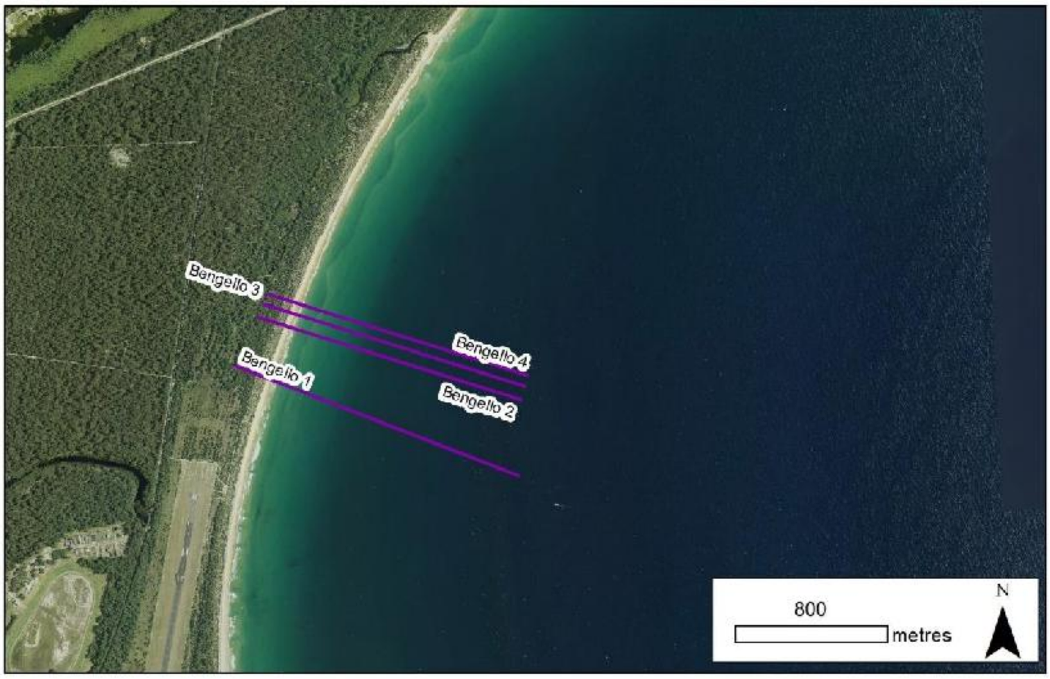

Figure E-1: SBEACH erosion profiles Bengello Beach (calibration only)

In the last 45 years, the most erosive period occurred over three weeks during May – June 1974 (shown in Figure E-2). Measured profile data was recorded at four profiles before and after this storm period, with recorded erosion summarised in Table E-1. The maximum storm erosion over this period was 200 m^3/m above -0.94 m AHD (estimated to be approximately 170 m^3/m above 0 m AHD) and the average storm erosion across the four profiles was estimated at 95 m^3/m

above 0 m AHD (McLean et al. 2010). Both the maximum and average storm erosion was used in model calibration to provide a range of estimated storm demands.

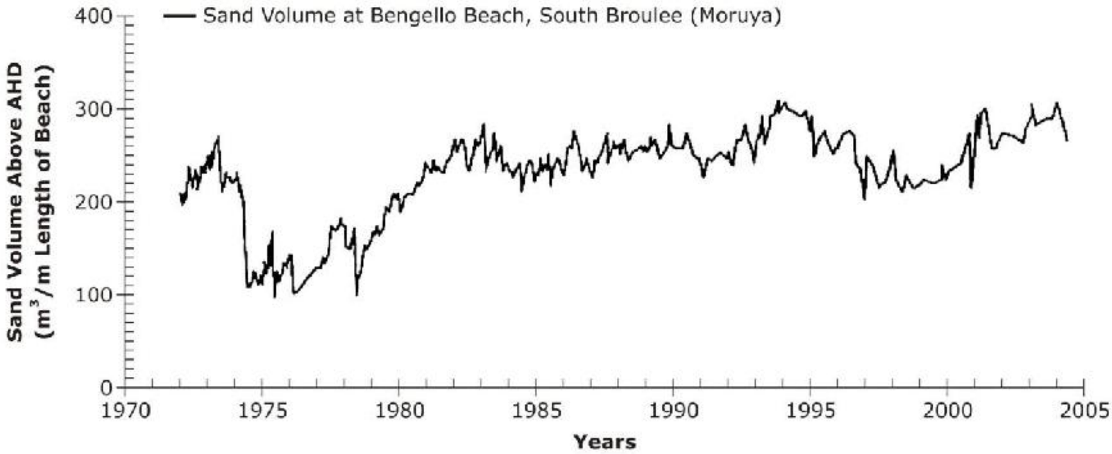

Figure E-2: Timeseries of sand volume change at Bengello Beach (Source: McLean et al., 2010)

Table E-1: Summary of Storm Demand at Bengello Beach for the 1974 Storm

Profile	**Volume of Storm Demand** (m^3/m above -0.94 m AHD)
1	150
2	200
3	130
4	160

Erosion data for the four (4) profiles at Bengello Beach from the 1974 storm period is available for calibration of the SBEACH model, however, the wave and water level data is not. The methodology used to create a synthetic design storm is described in the sections below.

A photograph of Profile 3 during the May-June 1974 storm sequence is shown in Figure E-3. The final scarp for this storm sequence is now degraded and vegetated but still visible in a photograph of Profile 4 taken on 30 June 2007 (Figure E-4).

Figure E-3: Bengello Beach (Profile 3 Looking North) 25 May 1974 - Further erosion occurred in early June 1974 after this photograph was taken (McLean et al., 2010)

Figure E-4: Bengello Beach (Profile 4 Looking North) 30 June 2007 after the "Pasha Bulker" Storm - left arrow indicates 1974-76 scarp, right indicates 1996-98 scarp (McLean et al., 2010)

E.3 Synthetic Design Storms

E.3.1 Design Offshore Wave Conditions

Shand et al. (2011) developed deepwater synthetic design storms, including a timeseries of significant wave height and peak spectral period, for a number of locations on the NSW coast, including Eden, south of Batemans Bay. In this study, the wave period and duration of the Eden offshore design storm has been adopted, however wave statistics from the Batemans Bay wave buoy have been used (generally 5% - 15% smaller than the wave climate at Eden). Note that the 100 year ARI offshore wave statistics vary with incident wave direction resulting in the development of three (3) offshore design storms for the 100 year ARI storm event (Figure E-5). The storm with the highest wave heights was applied for east-south-east, south-east and south-south-east directions. The storm with the lowest wave heights was utilised from the north-east and east-north-east directions. An intermediate storm was used for waves with incident directions of east and south.

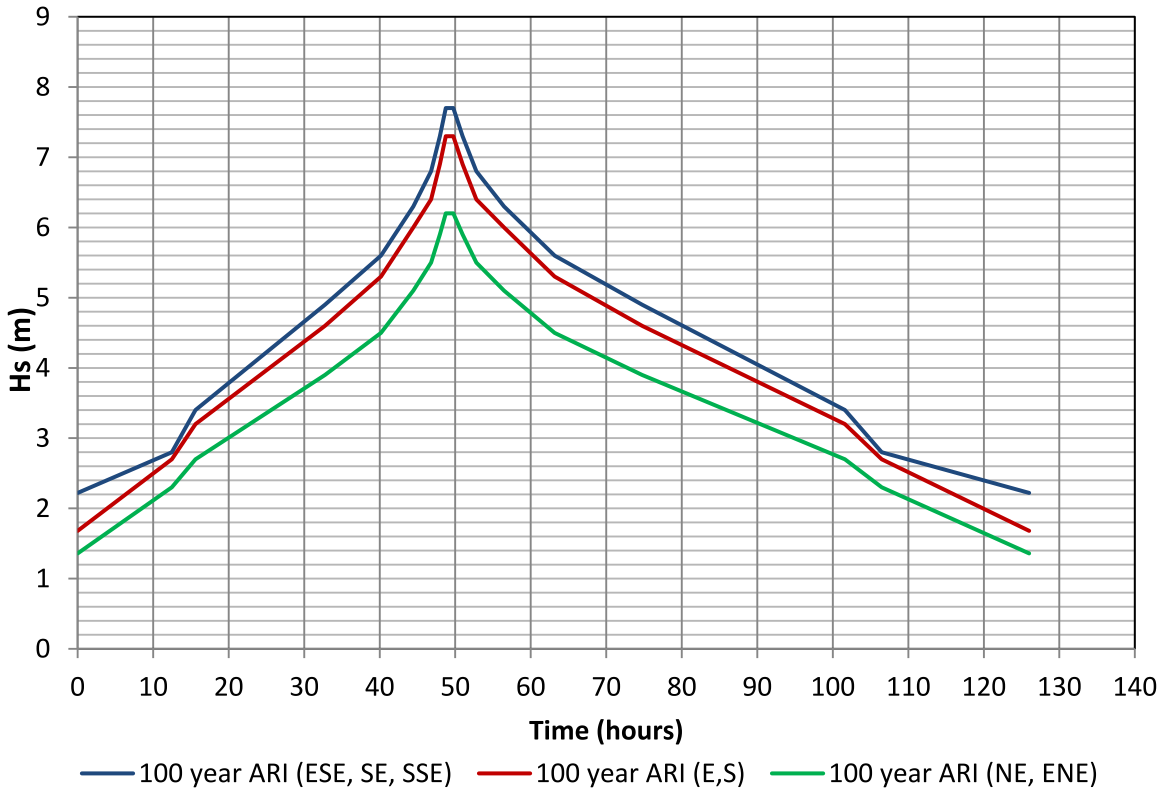

Figure E-5: Offshore design wave conditions for Batemans Bay

E.3.1.1 Storm Clustering

The worst case erosion events experienced by a beach are generally caused by the clustering of large storm events. Since beach recovery occurs over a much longer time frame than storm erosion, when the time between storms is sufficiently small, the beach is unable to recover to its accreted state. Major historical erosion events in NSW, such as the storms of 1974 and 1986, have been a result of multiple storms over a short (several months) period. To account for the effects of storm clustering, WRL has adopted a methodology of running two sequential 100 year ARI storms.

Thom and Hall (1991) showed that the timescales at which the beach recovery takes place is sufficiently slow, of the order of a week to several months, that the beach response to multiple erosion events would be relatively insensitive to the time gap between the storms. Therefore, for the purpose of SBEACH erosion modelling, the time gap between the storm is considered inconsequential.

E.3.2 Nearshore Design Waves

A SWAN model was developed to transform the offshore wave heights to local, nearshore waves (see Appendix D for more details on the SWAN modelling undertaken). Two (2) sequential (clustered) 100 year ARI storms were modelled with SWAN for seven (7) incident wave directions. The wave heights and directions at the model boundaries of the coarse grid were manually adjusted to ensure that the target wave conditions were reproduced at the Batemans Bay wave buoy location.

The local wave heights resulting from the seven (7) offshore design storm directions were extracted from the SWAN model at each transect where waves were beginning to break (1% of waves were broken). Using the output of the SWAN model, a single nearshore synthetic design storm was developed for the most critical (design) wave direction for each transect, using the same duration as the offshore synthetic storm. An example of the nearshore transformation of the waves at Bengello Profile 3 is shown in Figure E-6. The nearshore synthetic design storm extracted from the SWAN wave model at each transect became the input to the SBEACH erosion model.

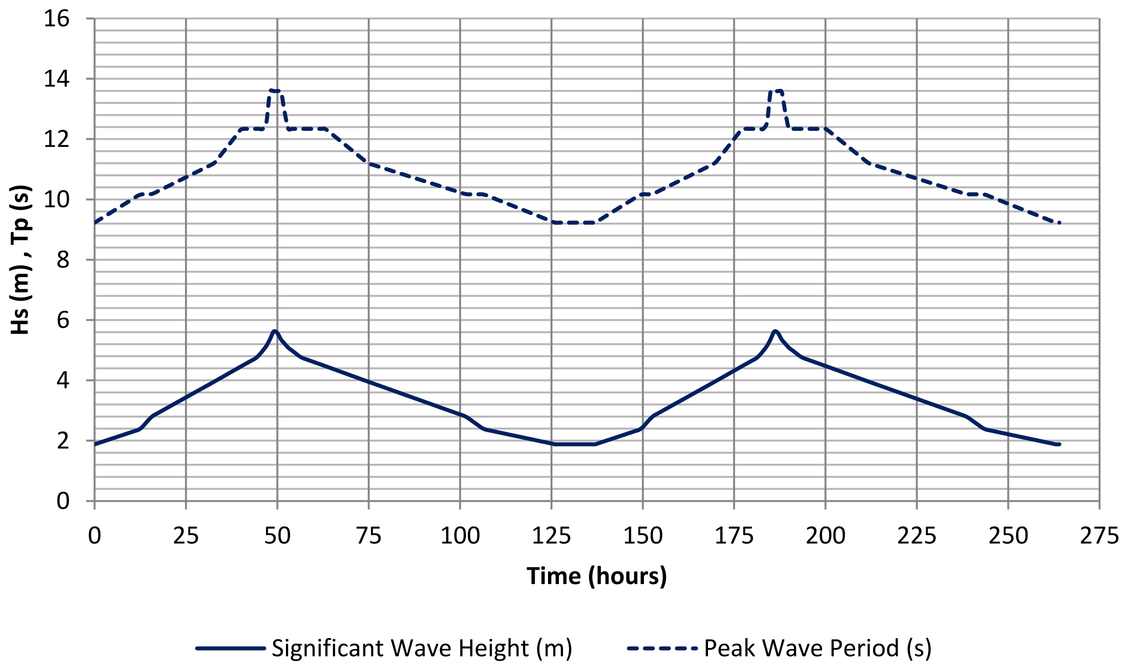

Figure E-6: Example of nearshore synthetic design storm used at Bengello Profile 3

E.3.3 Design Water Levels

Ocean water levels consist of (predictable) tides which are forced by the sun and moon (astronomical tides), and a tidal anomaly. The largest positive anomalies are associated with major storms and are driven by barometric setup (associated with low barometric pressure) and coastal wind setup, which are often combined as "storm surge". Water levels within the surf zone are also subject to wave setup, although this is modelled within the SBEACH package and is not required to be in the input water levels.

For storm erosion modelling purposes, a spring tide timeseries was generated (based on tidal constituents for Princess Jetty) using harmonic analysis with a peak water level of 0.82 m AHD (between 14/06/2011 – 20/06/2011). Extreme values analysis has been undertaken at Batemans Bay and defined the 1% AEP (100 year ARI) water level offshore to be 1.43 m AHD. This level includes both tide and storm surge, implying a maximum storm surge of 0.51 m must be applied at the peak of the storm to meet the required water level. It would be overly conservative to apply the maximum storm surge over the entire modelling period, so to better model the storm, the surge is allowed to increase linearly from nil to the maximum level and back to nil over the course of the storm. The resulting water levels for locations outside of Batemans Bay are shown in Figure E-7.

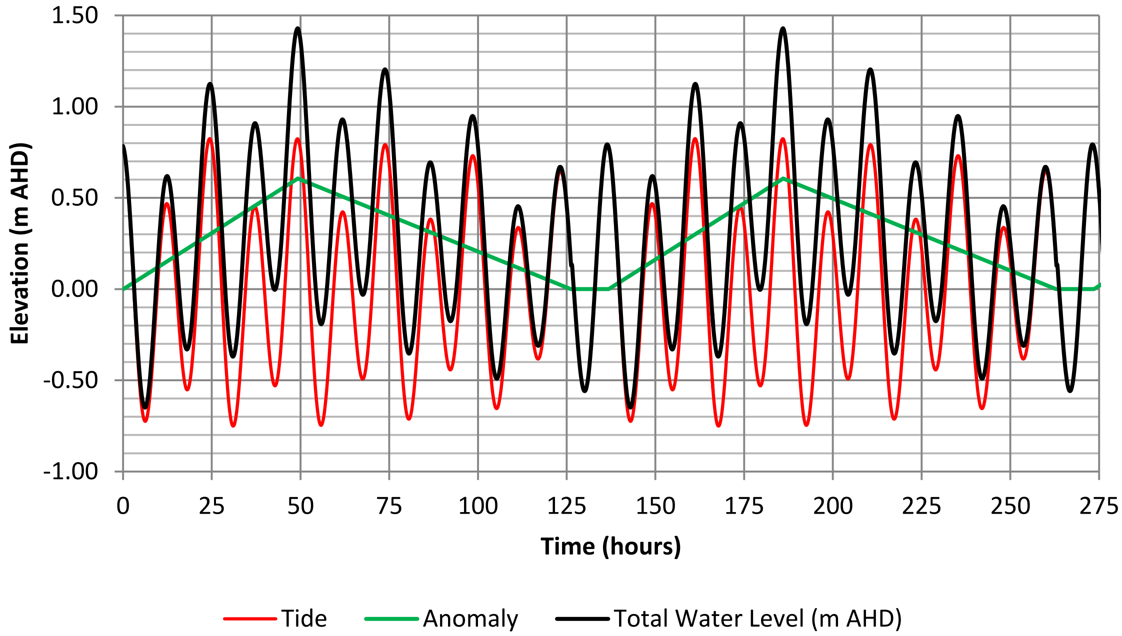

Figure E-7: Water levels used for SBEACH modelling at locations outside of Batemans Bay

For the beaches inside Batemans Bay (Surfside Beach, Long Beach and Maloneys Beach), the shallow bathymetry provides conditions that allow even higher water level conditions, due to the increase in water levels due to wind setup and inland flood events. The calculation of wind setup and flood levels is explained extensively in Section 3.3.3, however, the maximum water level at each location is presented in Table E-2. These water levels were achieved by adjusting the maximum storm surge level at these locations.

Table E-2: Summary of Maximum Water Levels for 100 year ARI Event used for SBEACH Erosion Modelling

Location	Maximum Water Level (m AHD)
Outside Batemans Bay	1.43
Maloneys Beach	1.54
Long Beach (Western End)	1.61
Long Beach (Central and Eastern End)	1.60
Surfside Beach (East) (Northern End)	1.75
Surfside Beach (East) (Southern End)	1.74

Figure E-8 to Figure E-22 show the local wave height, wave period and water level used for SBEACH modelling at each location.

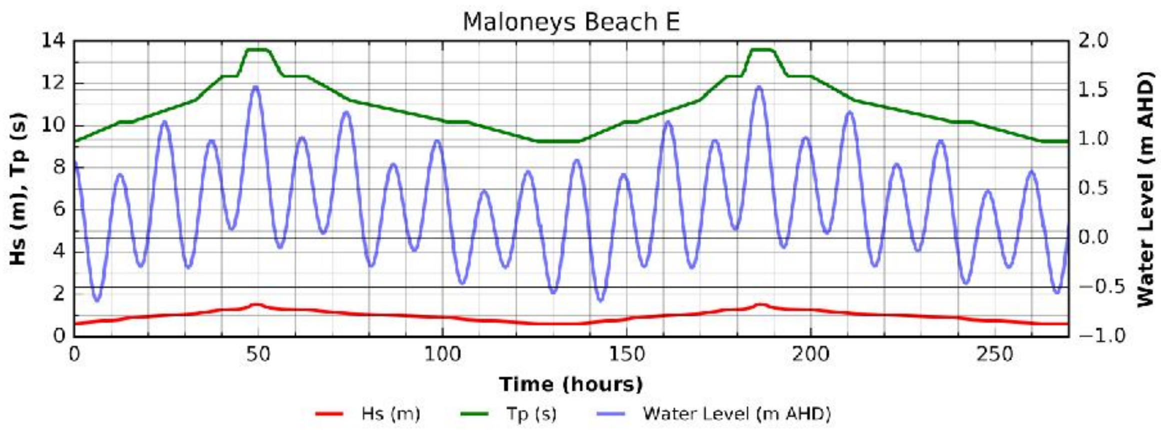

Figure E-8: Wave Height, Water Level and Peak Period for Maloneys Beach East

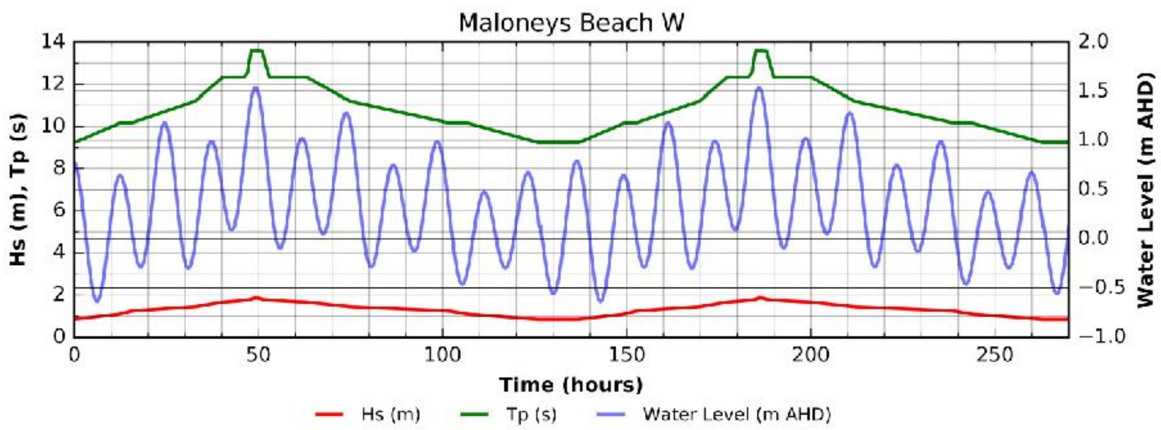

Figure E-9: Wave Height, Water Level and Peak Period for Maloneys Beach West

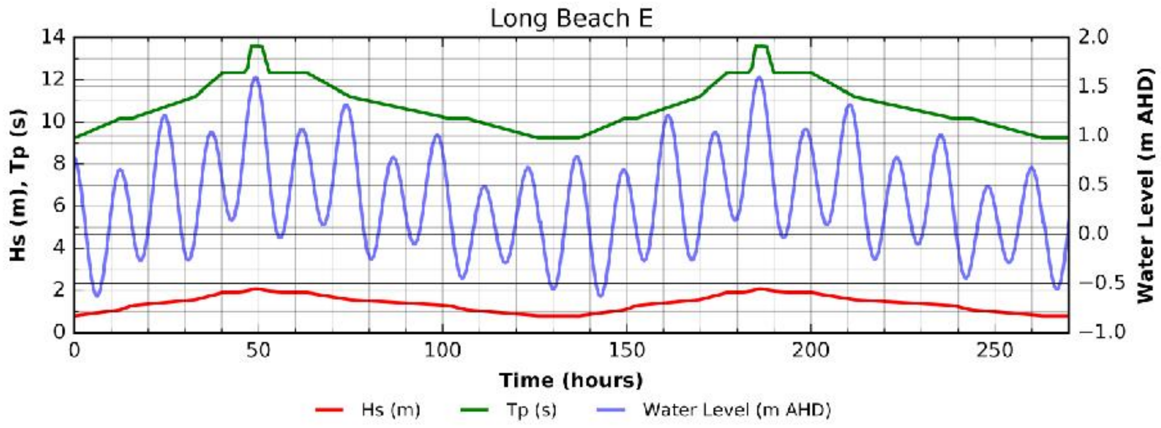

Figure E-10: Wave Height, Water Level and Peak Period for Long Beach East

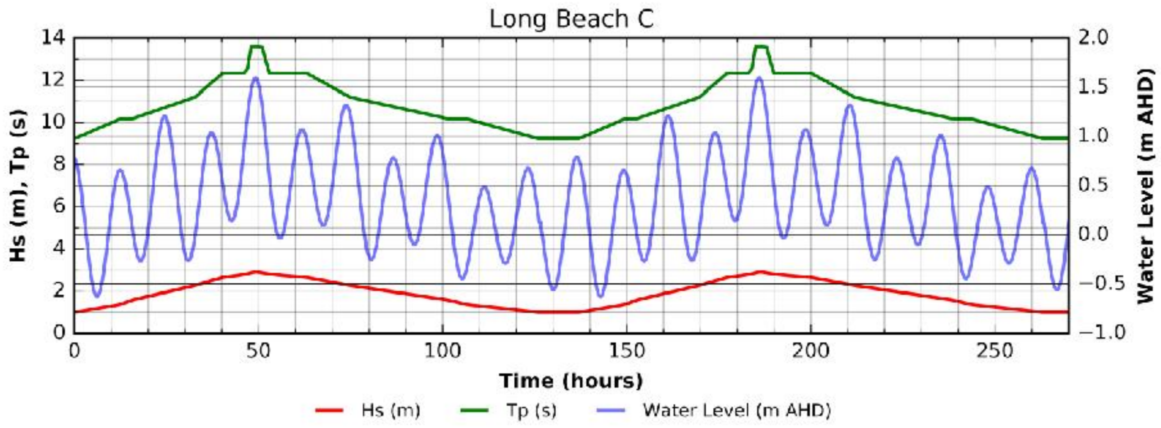

Figure E-11: Wave Height, Water Level and Peak Period for Long Beach Central

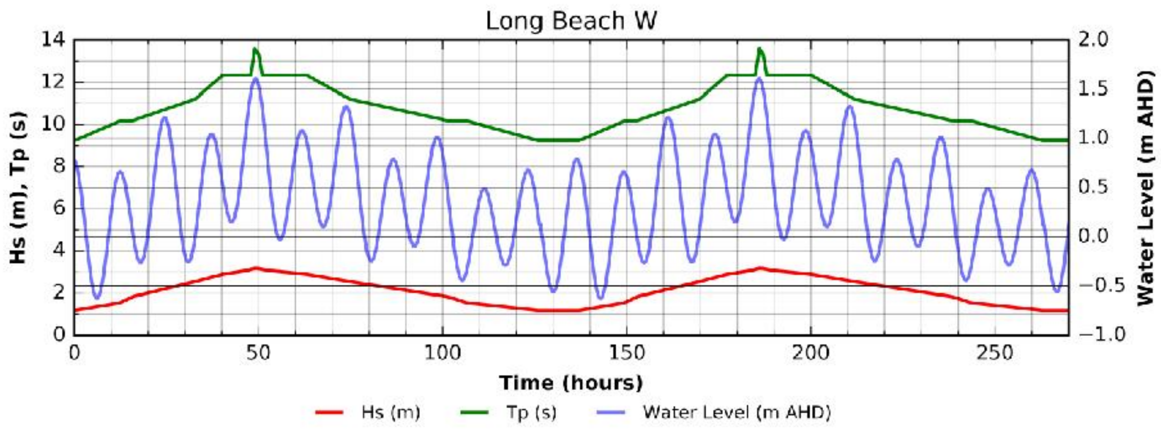

Figure E-12: Wave Height, Water Level and Peak Period for Long Beach West

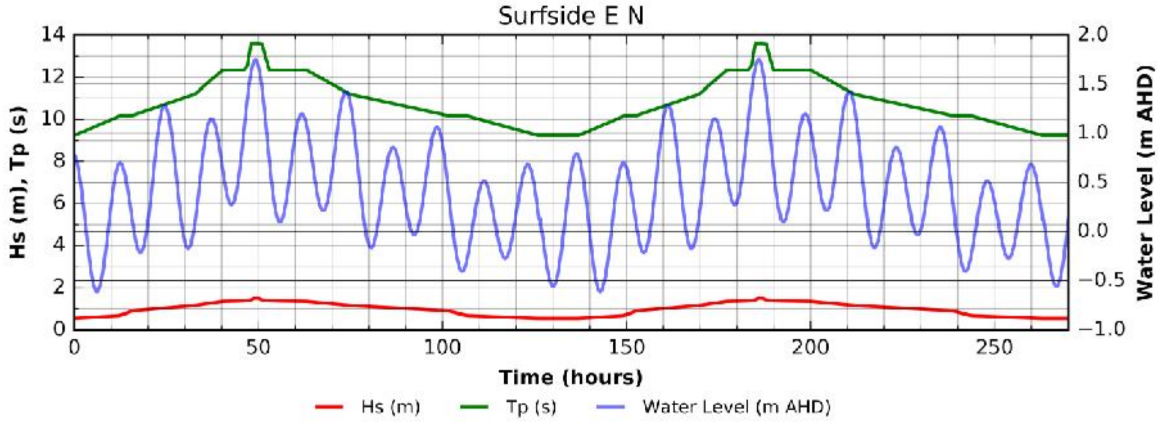

Figure E-13: Wave Height, Water Level and Peak Period for Surfside Beach East North

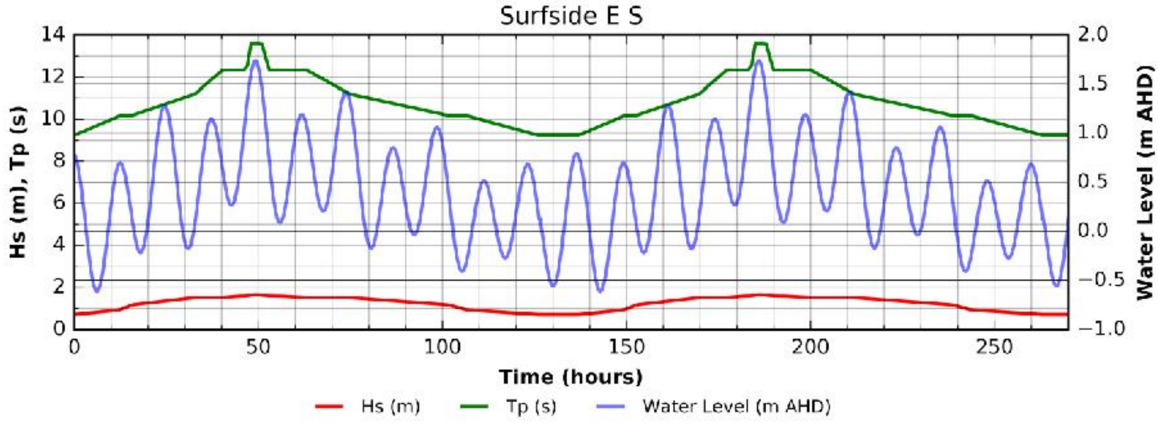

Figure E-14: Wave Height, Water Level and Peak Period for Surfside Beach East South

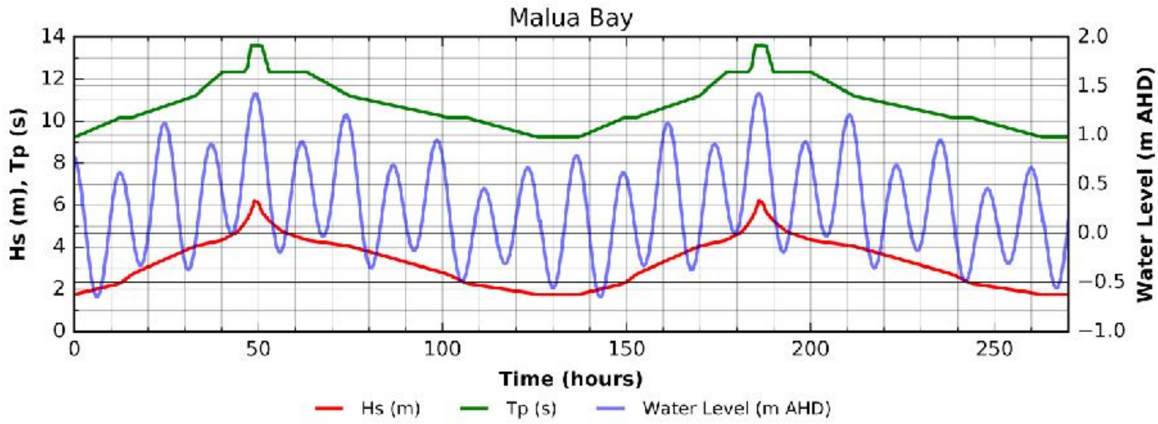

Figure E-15: Wave Height, Water Level and Peak Period for Malua Bay

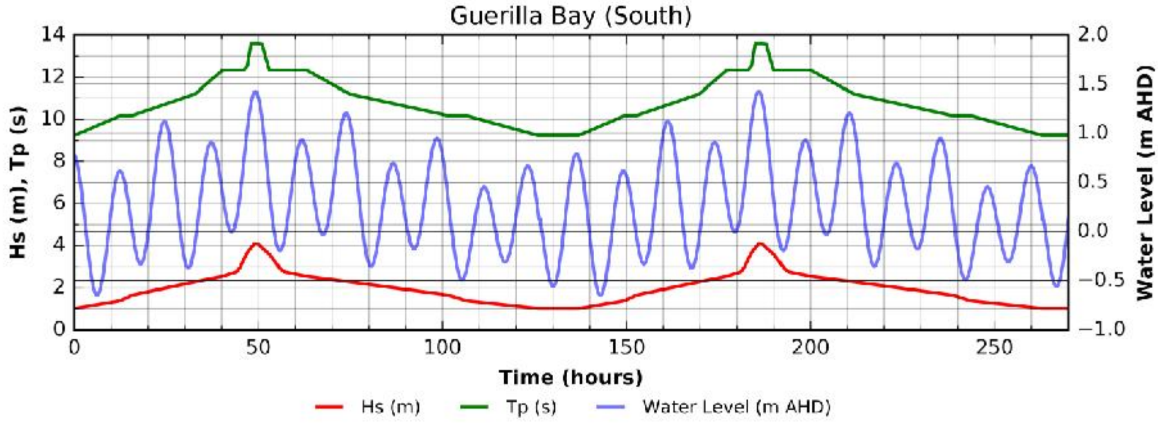

Figure E-16: Wave Height, Water Level and Peak Period for Guerilla Bay (South)

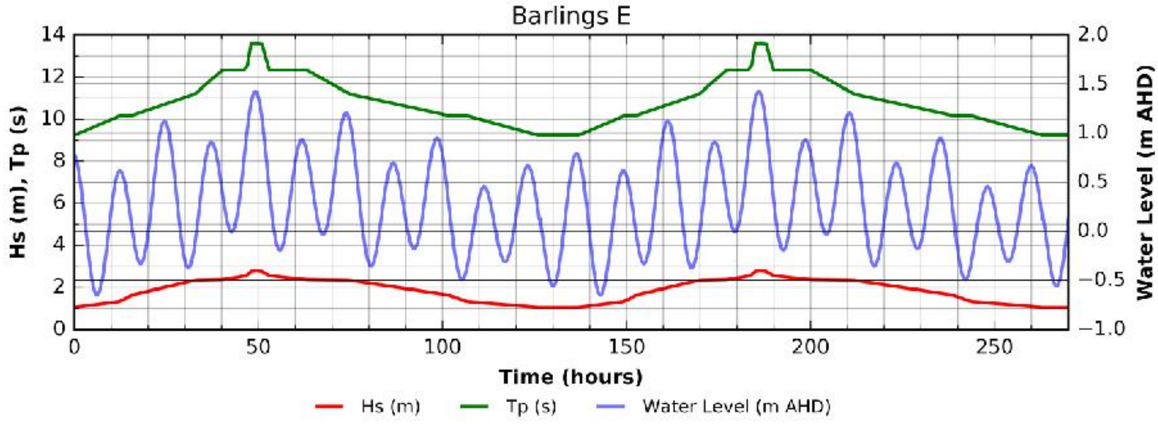

Figure E-17: Wave Height, Water Level and Peak Period for Barlings Beach East

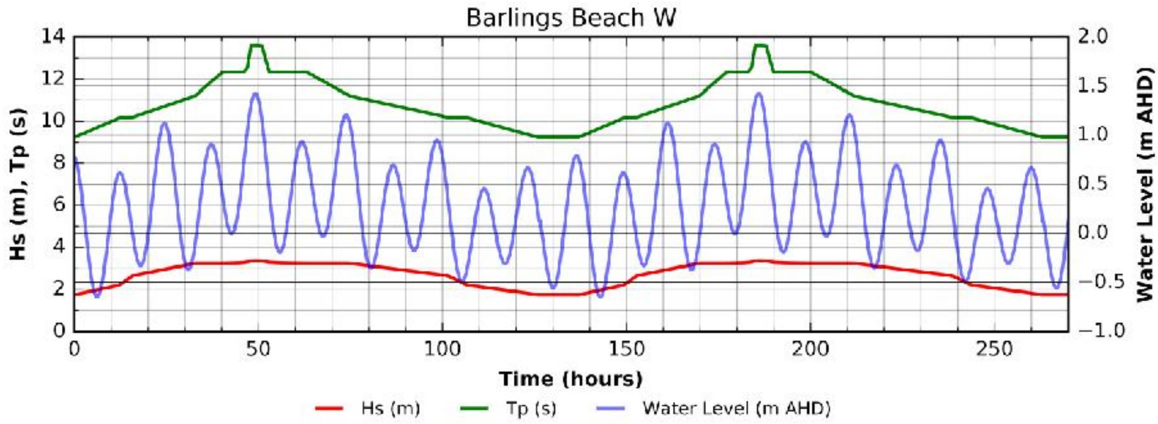

Figure E-18: Wave Height, Water Level and Peak Period for Barlings Beach West

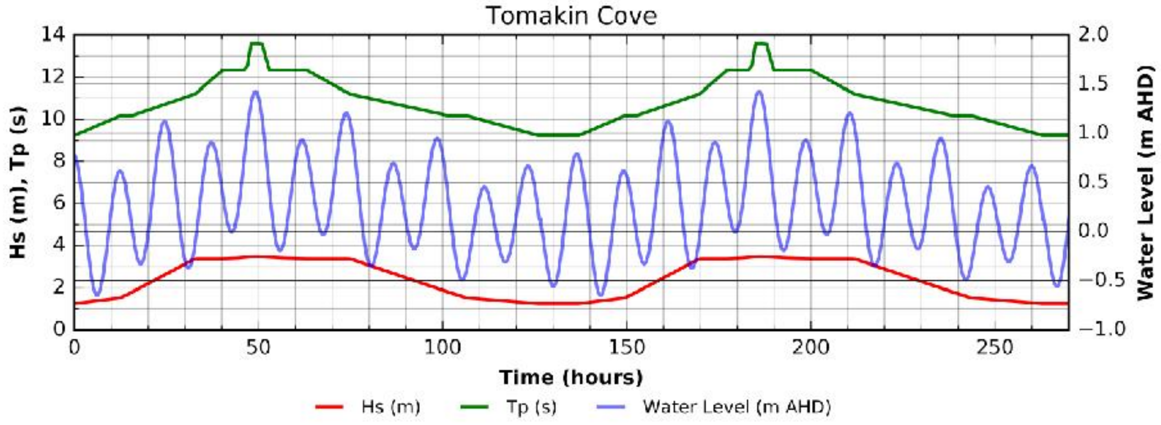

Figure E-19: Wave Height, Water Level and Peak Period for Tomakin Cove

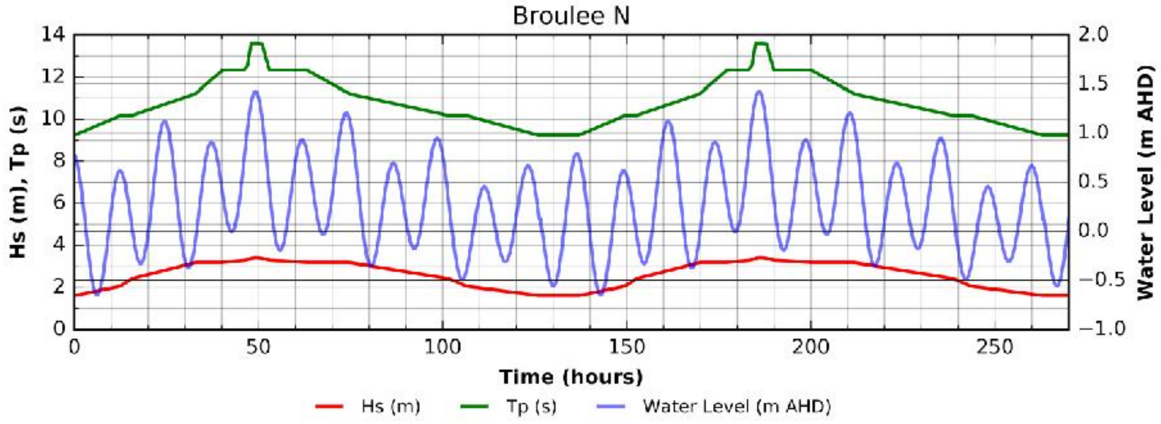

Figure E-20: Wave Height, Water Level and Peak Period for Broulee Beach North

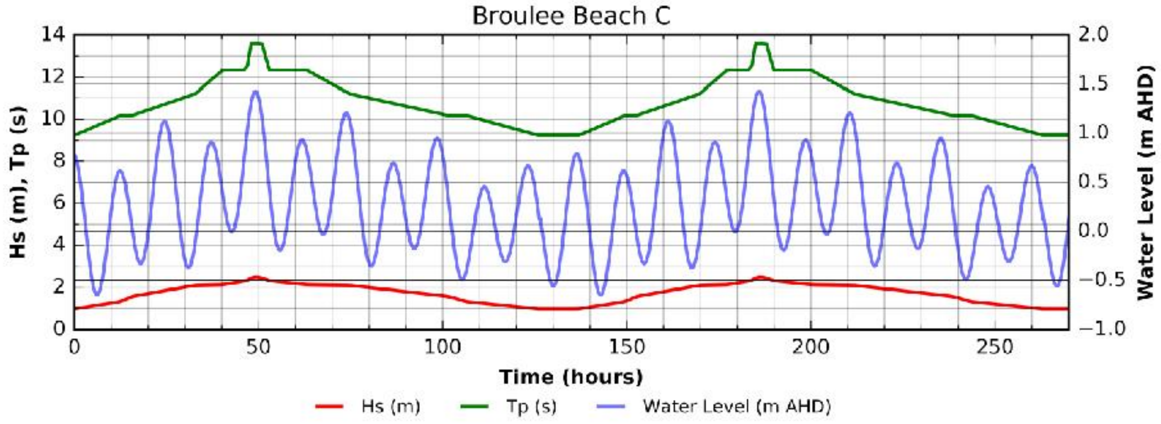

Figure E-21: Wave Height, Water Level and Peak Period for Broulee Beach Central

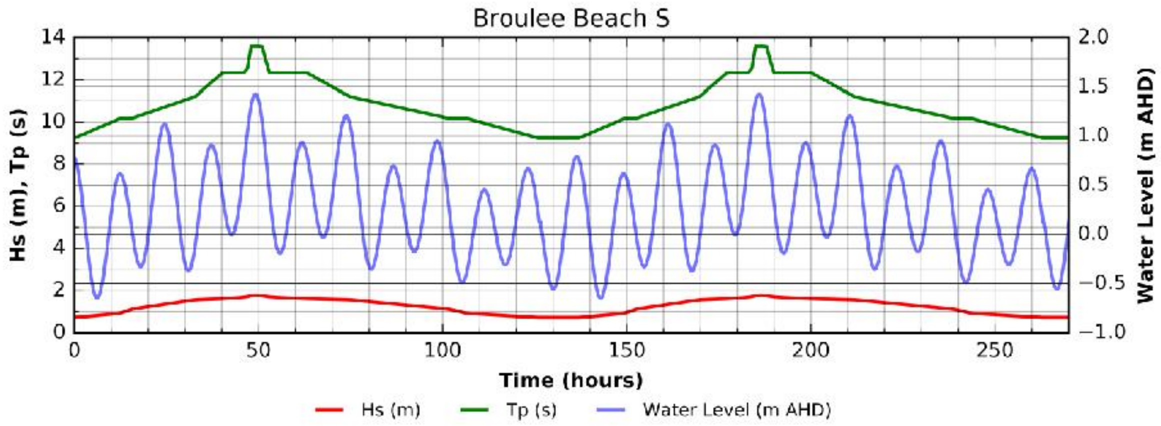

Figure E-22: Wave Height, Water Level and Peak Period for Broulee Beach South

E.3.4 Phasing of Extreme Ocean Water Levels and Design Wave Conditions

WRL, in conjunction with NSW OEH (formerly NSW DECCW) completed a detailed joint probability analysis of significant wave height and tidal residual for Sydney. The analysis showed that for design where both tidal residual and wave height are of interest, their occurrence cannot be assumed to be independent and the joint occurrence of extreme events should be considered. At locations where there is a lack of sufficient data, marginal extremes should be combined assuming complete dependence of the variables (Shand et al., 2012). Since no joint probability assessment has been undertaken for Eurobodalla local government area, complete dependence of extreme water levels and wave heights has been assumed for the 1% AEP (100 ARI) storms for the purpose of SBEACH erosion modelling.

E.4 Calibration at Bengello Beach

In calibrating the SBEACH model, the aim is to reproduce a surveyed change in beach profile in response to known climatic conditions. In the absence of wave and water level conditions at Bengello Beach, a 100 year ARI synthetic storm was developed for each of the four (4) profiles for use in calibration. While the exact recurrence interval of the 1974 storm period is not known, Figure E-2 shows the erosion event caused by that storm was significantly greater than observed erosion at any other period during 45 years of monitoring. Without further monitoring, it is considered appropriate to assume this erosion event was approximately equivalent to a 100 year ARI erosion event at Bengello Beach.

Since the methodology was developed so that it could be used at every other beach location, the elevations along the initial profile was extracted at a 2 m spacing from the available survey data. At Bengello Beach, there were profile surveys for the beach face (survey taken 17/11/2014) and a hydrosurvey of the nearshore bathymetry (survey taken on 18/11/2014). This data was supplemented with the 2011 LIDAR and AHS bathymetry as required to make a measured profile that was sufficiently long to be appropriate for SBEACH modelling.

The SBEACH model was calibrated under two separate conditions – aiming to achieve the maximum storm erosion observed at a single profile at Bengello Beach in 1974 (170 m^3/m above 0 m AHD) and, over the four (4) modelled profiles, to achieve the average erosion observed across the whole beach over the same period (95 m^3/m above 0 m AHD). These two target values were established because it is not known whether the maximum volume at Profile 2 coincided with a rip-head embayment (rip-heads are not included in SBEACH). This resulted in two sets of model sediment transport rate (k) coefficients that were used to give a range of values to represent the 100 year ARI storm demand elsewhere in the study area.

Table E-3 summarises the calibrated SBEACH parameters under the two calibration cases. The final eroded profiles for each Bengello Beach profile are provided in Figure E-23, Figure E-24, Figure E-25 and Figure E-26. By decreasing the sediment transport rate coefficient from 2.5 x 10-6 to 1.5 x 10-6 m4/N, the erosion of the dune face significantly decreases, allowing the much lower average storm demand figure to be achieved. Table E-4 shows the SBEACH modelled storm demands at each of the four (4) profiles at Bengello Beach. Using the parameters described above, the SBEACH model is considered to represent the observed erosion figures well, although it is noted that maximum single profile erosion occurred at Profile 3 (based on 2014 survey data) rather than at Profile 2. The two sets of model parameters were then used at each subsequent beach to obtain an upper and lower limit of erosion expected at each location.

Table E-3: Summary of Calibrated SBEACH Parameters

Coefficient/ Variable (notation used in model)	Value (calibrated to average erosion)	Value (calibrated to maximum erosion)	Brief Description
DXC	Variable (1 and 2 m)	Variable (1 and 2 m)	Model grid size
DT	20 minutes	20 minutes	Time step
K	1.5 x 10^{-6} m^4/N	2.5 x 10^{-6} m^4/N	Sediment transport rate coefficient
KB	0.005	0.005	Overwash transport parameter
EPS	0.002 m^2/s	0.002 m^2/s	Slope dependent transport rate coefficient
LAMM	0.5	0.5	Transport rate decay coefficient multiplier
TEMPC	20°C	20°C	Temperature
ISEED	4567	4567	Seed for random number generation
RPERC	20%	20%	Random variation in wave heights
DFS	0.3	0.3	Landward surfzone depth
D50*	0.33	0.33	Effective median grainsize in the surfzone
BMAX	30°	30°	Avalanching angle

*D50 varied across other beaches depending on the observed grainsize

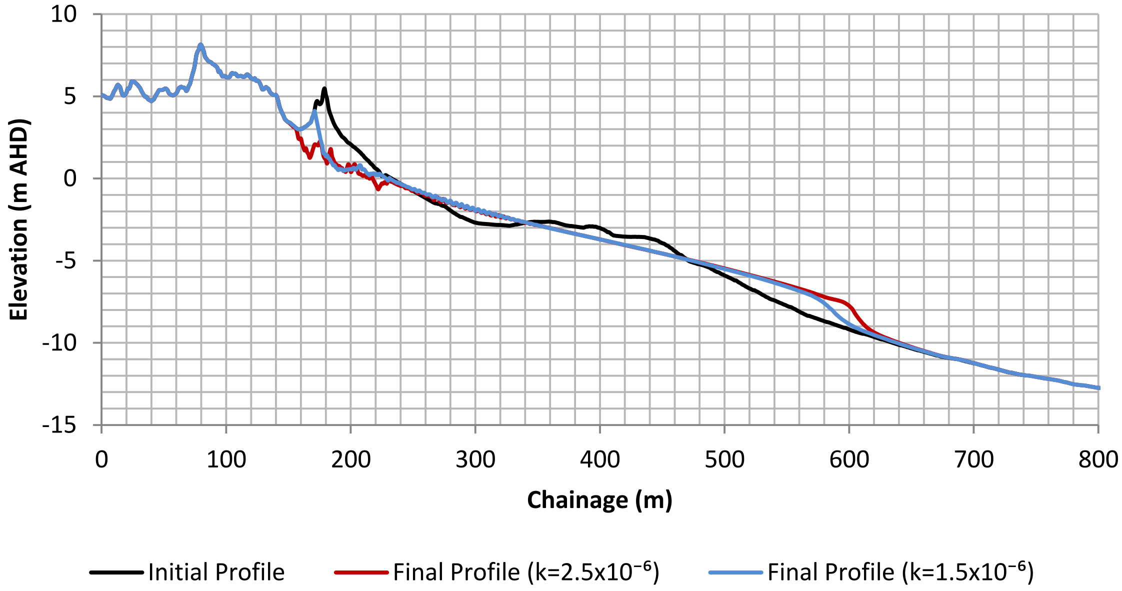

Figure E-23: SBEACH results at Bengello Beach Profile 1

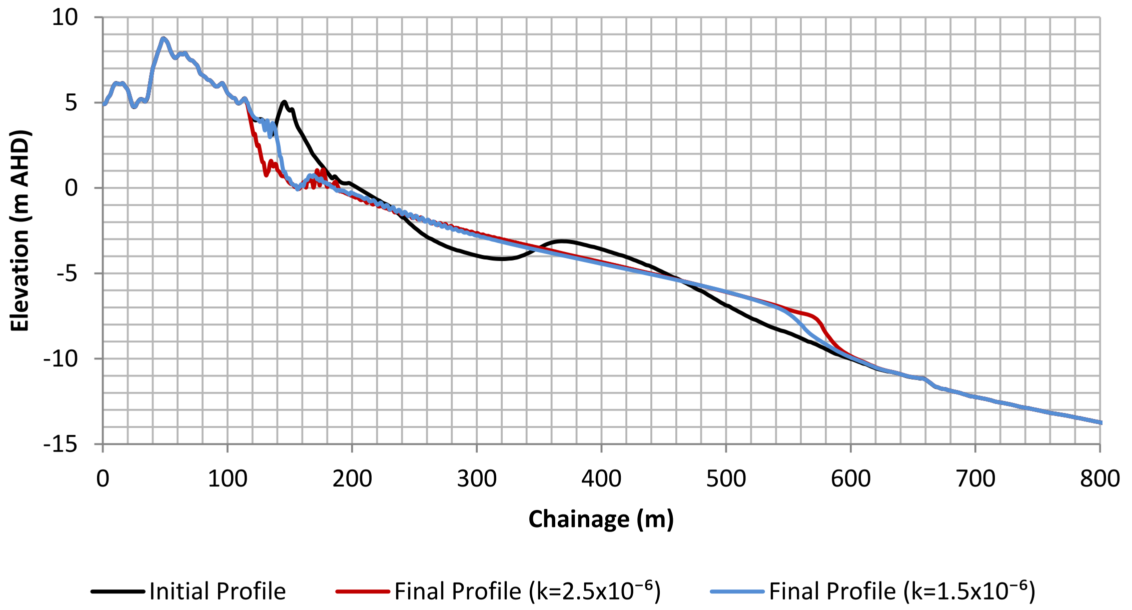

Figure E-24: SBEACH results at Bengello Beach Profile 2

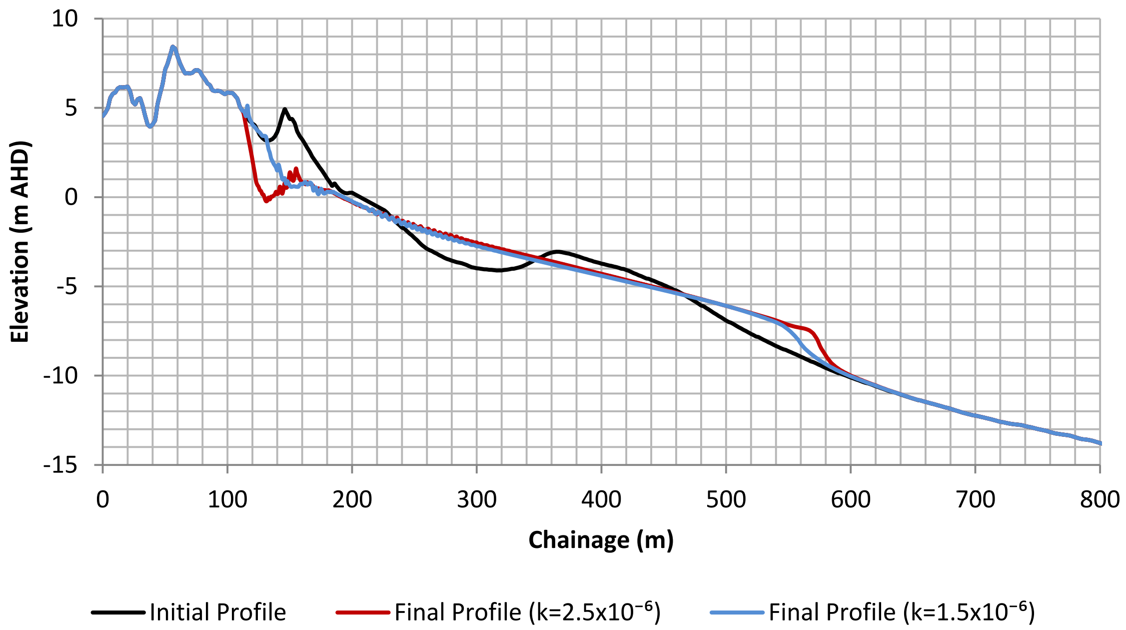

Figure E-25: SBEACH results at Bengello Beach Profile 3

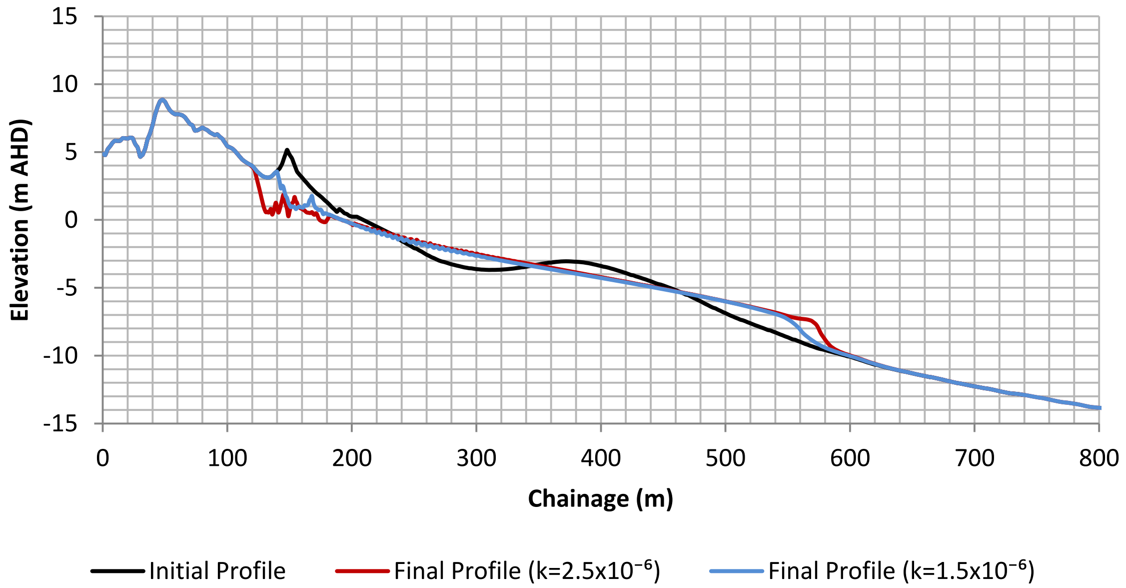

Figure E-26: SBEACH results at Bengello Beach Profile 4

Table E-4: Summary of Calibrated Storm Demands at Bengello Beach

Profile	Storm Demand **k=1.5x10^{-6} m^4/N** (m^3/m above 0 m AHD)	Storm Demand **k=2.5x10^{-6} m^4/N** (m^3/m above 0 m AHD)
Bengello Beach 1	86	125
Bengello Beach 2	109	155
Bengello Beach 3	113	174
Bengello Beach 4	88	146
Maximum	113	174
Average	99	150

E.5 SBEACH Modelling Locations

SBEACH erosion modelling was undertaken at nine (9) beaches in the study area, as shown in Figure E-27 and Figure E-28. Where the beaches were long enough that the wave climate would vary significantly along the beach, multiple representative transects were used (15 total transects). WRL has previously collected and analysed sediment samples collected at each location to determine sediment size, and this is summarised in Table E-5. At Sunshine Bay, a distinct bimodal distribution of sediment size was observed and both grainsizes are provided. This type of sediment distribution is also observed at Caseys Beach (adjacent beach to the north) as discussed in NSW PWD (1987).

Figure E-27: SBEACH erosion profile inner Batemans Bay

Figure E-28: SBEACH erosion profiles southern area

Table E-5: Summary of Grain Size at Each Location

Beach	Section	D_{50} (mm)
Maloneys Beach	East	0.21
	West	0.21
Long Beach	East	0.24
	Central	0.24
	West	0.24
Surfside Beach (east)	North	0.25
	South	0.25
Surfside Beach (west)	Central	0.21
Sunshine Bay	Central	0.21/1.01*
Malua Bay	Central	0.34
Guerilla Bay (south)	Central	0.29
Barlings Beach	East	0.28
	West	0.32
Tomakin Cove	Central	0.19
Broulee Beach	North	0.21
	Central	0.21
	South	0.21

* Sediment at Sunshine Bay has a bimodal distribution as discussed in Sections 2.2 and 5.3.2.

At each of the profile locations indicated in Figure E-27 and Figure E-28, profile data was extracted from the best available topographic and bathymetric surveys as shown in Table E-6.

Table E-6: Date of Available Surveys for Study Area

Beach	Topographic Survey Date	Bathymetric Survey Date
Maloneys Beach	23/7/2014	24/7/2014
Long Beach	29/7/2014	29/7/2014
Surfside Beach (east)	30/7/2014	30/7/2014
Sunshine Bay	24/11/2016	-
Malua Bay	30/7/2014	30/7/2014
Guerilla Bay	-	29/7/2014
Barlings Beach	31/3/2015	1/4/2015
Tomakin Cove	31/3/2015	1/4/2015
Broulee Beach	31/3/2015	1/4/2015
Batemans Bay	-	8/7/2015

Where no site specific surveys were available, or data was required beyond the extents of the surveyed areas, the most recent LIDAR (2011 outside of Batemans Bay and 2005 inside the bay) and the AHS bathymetry dataset was used to supplement the surveys.

E.6 Results of SBEACH Modelling

Table E-7 summarises the modelled storm demand for the 100 year ARI event at each of the beaches. No results are presented for Sunshine Bay, as the bimodal nature of the sediment distribution makes it inappropriate for SBEACH modelling. Additionally, Surfside Beach (west) has also not been modelled as the strongly refractive wave conditions mean that erosion processes are not cross shore.

Table E-7: Results of SBEACH Modelling for the 100 Year ARI Storm

Beach	Profile	**Storm Demand Average Erosion** (m^3/m above 0 m AHD)	**Storm Demand Maximum Erosion** (m^3/m above 0 m AHD)
Maloneys Beach	East	73	96
	West	113	156
Long Beach	East	68	87
	Central	92	132
	West	105	137
Surfside Beach (east)	North	43	54
	South	46	55
Surfside Beach (west)	-	n/a	n/a
Sunshine Bay	-	n/a	n/a
Malua Bay	-	115	153
Guerilla Bay	-	103	153
Barlings Beach	East	50	64
	West	60	106
Tomakin Cove	-	84	132
Broulee Beach	North	47	89
	Central	34	56
	South	39	52

The SBEACH erosion modelling has included measurements of the local bathymetry and sand grain size and modelled nearshore wave conditions specific to each transect. As discussed in Section E.4, the model was calibrated at an open coast location (Bengello Beach) and the same model parameters were applied at lower energy sites. Although based on a limited dataset, Leadon (2015) has suggested that the model sediment transport rate (k) coefficient is inversely proportional to beach slope. Since constant k values were used in this study based on a high energy calibration location with a low beach slope, modelled erosion volumes at beaches with steep slopes may be over-predicted. WRL considers that this is likely to be the case at Maloneys Beach and Guerilla Bay (south). However, the consensus values for 100 year ARI storm demand adopted by the expert panel considered multiple factors and at these two beaches are significantly lower than the SBEACH predictions.