CHAPTER 253

The Restoration of Bate Bay, Australia - Plugging the Sink

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Abstract

For more than 200 years aeolian processes have removed sand from the Bate Bay coastal compartment. This ongoing loss resulted in long term recession of the 5.5km beach. By the mid 1970's the recession threatened both public and private assets. A detailed coastal process study was undertaken to develop a management plan aimed at halting the recessional trend. The plan was progressively implemented over a period of 14 years. The result is that the foreshores of Bate Bay are now stable. The management strategy adopted has not only protected the public and private assets but has also enhanced the recreational amenity of the area. Throughout the project monitoring was undertaken of both the coastal process and the management options. These monitoring programs have provided useful information on the pragmatic application of traditional study techniques and on the effectiveness of the selected management options.

Introduction

Kurnell Peninsula is located some 25km south of Sydney Heads. The Peninsula is a coast parallel sandy isthmus linking the rock outcrop of Kurnell Headland to the mainland bedrock at Cronulla. It is the sandy barrier which forms the eastern boundary of Botany Bay. On its seaward side, to the east, lies the 5.5km, crescent shaped embayment of Bate Bay. The embayment includes the following beaches (from south to north) South Cronulla, North Cronulla, Elouera, Wanda, Green Hills/Cronulla and Boat Harbour (see Figure 1).

Residential development and formal parkland are the dominant foreshore features along the southern 2km of the Bay. North of Wanda, for a distance of some 1.7km unstable, unvegetated dunes dominated the landscape for at least 200

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years up until 1975. These dunes bisected the Peninsula, extending inland more than 1.5km, through to Botany Bay. The remaining 1.8km of foreshore consists of foredunes which were initially stabilised in the 1950's by the landholder; the Holt family.

During the period of European settlement, Kurnell Peninsula has undergone many changes of land use. Initially, the areas of natural coastal scrub land were used for grazing purposes. However by early this century South Cronulla had become a weekend recreational retreat. As its popularity grew residential and commercial development took place. Early development was concentrated in the more stable southern region of the Bay but by the 1930's the demand for land pushed the development northward into the unstable dune region at Wanda.

In the early 1950's, Sydney's need for construction and foundry sand focussed attention on commercially viable deposits such as the 30m high transgressive dune field of the Peninsula. In response to this, a major sand extraction industry developed. Over the past 40 years the activities of this industry have resulted in the removal of much of the hind dune region in the centre of the Peninsula.

Severe storms ravaged the Sydney coastline in May-June 1974. These storms resulted in significant erosion of the Bate Bay beaches. The foredune system throughout most of the embayment was destroyed. In response to this damage, coastal process studies were undertaken and a coastal management plan was developed and implemented over a period of 14 years.

The major elements of the plan were:

- nourishment of the embayment by feeding sand into the surf zone at South Cronulla;
- dune reconstruction at North Cronulla;
- seawall construction at Prince Street;
- foredune stabilisation at Elouera and Wanda;
- foredune reconstruction and stabilisation from Wanda to Boat Harbour;
- hinddune stabilisation in the centre of the embayment.

This paper summarises the project from the inception of the coastal process studies to the completion of the management plan and reviews the results.

Coastal Process Studies

Coastal process studies were commenced in 1975 using the methodology outlined by Gordon and Lord (1980). These initial studies provided the basis for the overall management strategy (Foster and Gordon, 1978, and Gordon, unpublished). The coastal processes were then monitored and analysed throughout the 14 years of the project. This enabled on-going "fine tuning" of the management plan and provided considerable insight as to the effectiveness of the various investigation techniques and the management options employed.

The studies began with extensive bathymetric, seismic and sediment surveys to obtain information on the seabed and subsurface morphology, seabed sediment and reef distribution and the depth of the active profile movement. These studies included side scan sonar, echo sounding and seismic surveys as well as an extensive sediment sampling program. Onshore, a geological survey was carried out to establish the age and mode of formation of the dune features of the Peninsula (Roy and Crawford, 1979).

Longterm shoreline movement trends were examined using both historical ground survey data and photogrammetric analysis of large format vertical aerial photography. The ground survey data was available at a limited number of locations for a period of more than 100 years. The earliest survey (1863) was made available to the study by the Holt family. The photogrammetry focussed on reconstruction of cross sections through the beach and dune region, over time, rather than historical water line movement, as the latter was found to be too unreliable. Thirty five cross sections were established (see Figure 1). These were transferred through the nine sets of photography covering the 35 years prior to implementation of the management plan.

The erosion/accretion rates obtained from this analysis were calculated from both differential volume calculations undertaken for successive cross sections and foredune retreat/advancement measurements taken from comparison of the movement of position of the 3m and 5m contours over time. The average result, reduced as an implied shoreline movement, was then plotted (see Figure 1). Aerial photographs continued to be obtained throughout the implementation phase and the photogrammetry results checked against nine ground survey cross sections established in the embayment to monitor dune and beach movements and to verify the photogrammetric techniques.

Aeolian sand transport was examined by analysing historical survey and photogrammetric data and by developing numerical models of wind born sand transport. The historical information established the rate of landward movement of the transgressive "front" at the rear of the hinddunes, thereby providing the data necessary to calibrate the aeolian sand transport models. Because of the inherent inaccuracies of these models, particularly when applied to a non uniform surface such as a dune field and the need to take into account wetting and drying effects on transport rates, two alternative models were developed. One employed the Bagnold (1974) approach, the other was based on the method of Hsu (1974).

Examination of the longshore surf zone sediment transport processes commenced with a wave refraction/diffraction shoaling analysis for three points in the embayment (see Figure 1, Location A, B and C). The inshore wave height coefficients so obtained were then used in a sediment transport program to calculate

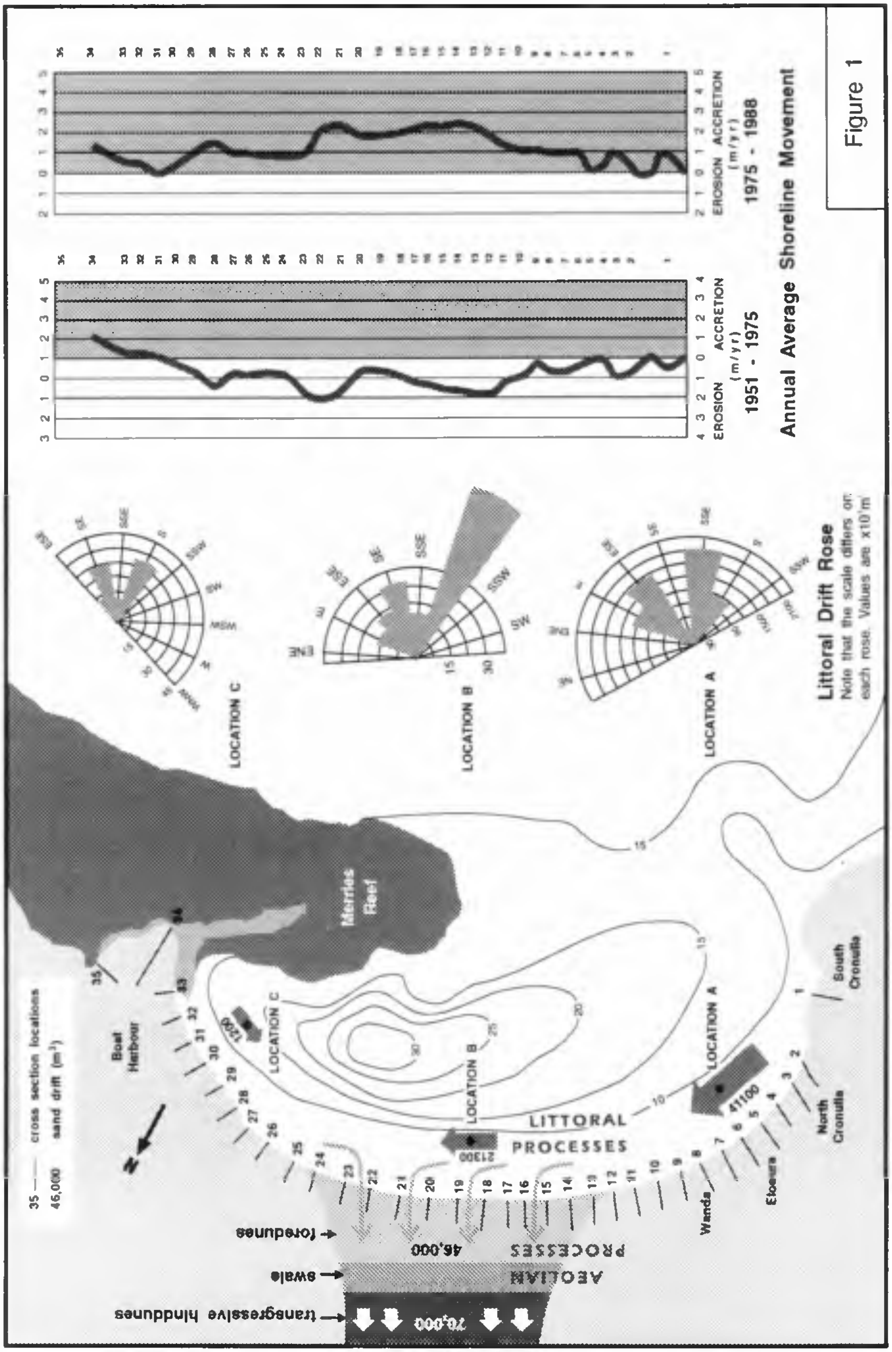

35 — cross section locations
46,000 sand drift (m³)
Boat Harbour
Merries Reef
LOCATION A
LOCATION B
LOCATION C
LITTORAL PROCESSES
AEOLIAN PROCESSES
46,000
70,000
41100
21300
1200
foredunes
swale
transgressive hinddunes
North Cronulla
South Cronulla
Wanda
Elouera
Littoral Drift Rose
Note that the scale differs on each rose. Values are x10³m³
EROSION ACCRETION
(m/yr)
1951 - 1975
1975 - 1988
Annual Average Shoreline Movement

Figure 1

transport roses at each of these points.

The wave refraction analysis was based on a computer program developed from Wilson's method (Wilson, 1966). The results were manually adjusted as outlined in SPM (1973/84) to include diffraction effects. A 46 by 34 numerical grid using a 200 metre grid spacing was adopted and a 10 second deepwater wave period was used for most program runs. The characteristic wave period of 10 seconds was selected after examination of the then available 5 years of data from a Waverider buoy located 3km northeast of Bate Bay in 80m of water. Selected runs were made with 8 and 12 second waves to check sensitivity.

Five offshore wave approach directions were selected to generate a matrix of inshore wave height coefficients. The coherence of the results was checked by plotting the coefficients of refraction/diffraction/shoaling and the wave angle to the contours, along the wave ray, for each deepwater wave approach direction. Discontinuity's and/or anomalies were thereby readily identified, examined and numerically smoothed, if appropriate. The inshore wave coefficients given by the refraction/diffraction/shoaling analysis were verified by comparing them to Waverider data from an inshore buoy deployed for two years at Location A, within the bay.

The sediment transport calculations were based on the "SANDGUS" program (published in Gordon and Acikgoz 1984) developed around the CERC equation (SPM 1973/84). This program, which was first developed for this project, uses the annual deepwater wave spectra, shoals, refracts and diffracts that spectra along the rays through the wave coefficient matrices obtained from the refraction/diffraction analysis and then calculates sand transport. The wave coefficient matrices only extended to 10m water depth. Inshore of this depth the model applies the straight parallel contour assumption using Snells Law to calculate refraction. The deepwater wave spectra used was that available from the offshore Waverider site. As the project progressed the data set available from this site increased from 5 years to 20 years and hence some review of earlier calculations was necessary.

For the purposes of this study it was assumed that all longshore transport took place at the break point. This point was calculated for each one metre wave height class. Although an oversimplification, the approach proved quite adequate as no shore normal structures existed or were being considered as management options.

The results of the sediment transport analysis were compared with sand tracer studies. Some 10 tonnes of dyed sand were released into the surf zone at South Cronulla. This material was tracked intensively over a period of 1 month and, to a lesser extent, over a period of 3 months. Initially samples were taken on a 50 metre grid extending 0.5km longshore from the injection point and offshore to 10 metres of water depth. The samples were obtained by divers driving one metre core tubes into the seabed. During the first week the entire grid was covered twice a day. The samples were then sectioned and examined under a microscope. As the grid was progressively extended the number of grid points rationalised and the sampling rate reduced once the movement pattern of the dyed sand became apparent.

The results of the sand tracer experiment were compared with a data set generated by the "SANDGUS" computer model for the prevailing conditions during the experiment. It was found that for Bate Bay the CERC equation, as presented in SPM 1984, produced results of the same order of magnitude as those obtained from the experiment. This calibration of the CERC constant was seen as critical, as experience elsewhere in NSW had indicated that the constant can vary considerably depending on site conditions.

The Sediment Budget of Bate Bay

Integration of the various studies provided an understanding of the overall coastal process system of the embayment.

The sediment and geological studies showed that Bate Bay is substantially a closed compartment with no significant losses or gains across its longshore boundaries.

Prior to implementation of the management plan, the potential sediment transport rates in the surf zone were calculated to be 41,000m^3/yr net northward in the southern third of the embayment (Location A), where the gross transport was 700,000m^3/yr; 21,000m^3/yr net north transport in the centre of the embayment (Location B) on a gross movement of 165,000m^3; and 1,200m^3/yr net southern transport (Location C) on a gross of 86,000m^3 in the northern third of the embayment behind Merries Reef (see Figure 1).

The high values for both gross net drift in the southern end of the embayment were associated with the exposure of this area to a broader range of deepwater wave approach angles and the misalignment of this section of the bay prior to the management plans implementation. The low gross drift in the centre of the embayment was consistent with the relatively high onshore/offshore movements which take place in this area. That is onshore/offshore in the centre of the embayment dominates over the longshore processes. In the northern section of the embayment the low gross and net drift reflect the sheltering of Merries Reef. The net transport rate of 21,000m3/yr, northwards, calculated at Location "B" in the centre of the embayment (Figure 1), was consistent with observations that some of the material moving north from the southern end (Location A) had already been lost into the dunes.

The aeolian transport studies were undertaken for both the foredunes and the hinddunes. For the foredunes, the Bagnold approach yielded a net landward potential rate of transport of 24m^3/m/yr while the Hsu method gave a result of 32m^3/m/yr (see Figure 2). Based on these results an average rate of 28m^3/m was adopted as the potential for sand transport in the foredune. This translated into a net average landward potential for transport of sand in the foredune region of some 46,000m^3/m, provided material was available for entrainment.

Applying the same theoretical approach to the hinddunes the calculated annual net landward potential for transport of sand was found to be 60,000m^3. The analysis of historical survey and photogrammetric data indicated that the average annual movement of the transgressive dune front into the vegetation on the western side of the peninsula was between 8m/yr and 10m/yr giving a total annual net transport rate westward of 90,000m^3. Given the assumptions and accuracies of the methods used a figure of 70,000m^3/yr was adopted as representing the net westward drift rate in the hinddune.

The difference in availability of sand for entrainment explains the apparent anomaly between the foredune and hinddune transport rates. The beach was an average of 20m wide whereas the area available to feed the hinddunes was some 100-200m wide. This differential in transport was evidenced by the evolving topography of the dunefield. The rate of landward movement of the centroid of mass of the hinddunes had historically been greater than that of the foredunes. This had created an ever widening interdunal swale, the area between the foredunes and hinddunes. The swale was some 100 to 150m wide by 1975.

The photogrammetric analysis supplemented by the historical survey record showed that, prior to implementation of the management plan, longterm coastal retreat was occurring throughout most of the embayment. Figure 1 summarises the recessional trend. Recession rates varied from an average of 0.5m/y in the southern end to 2.0m/yr in the centre of the embayment. The accretion trend shown in Figure 1, from section 30 to 34 in the north of the embayment, was produced by the dune works undertaken in the mid 1950's by the landholder of this portion of the embayment. The high recession rates in the centre of the embayment were associated with the area of unstable foredunes where aeolian processes continuously removed sand from the beach into the transgressive dunefield. The differential recession rates were reflected in the shoreline alignment. The central 2km of beach became noticeably indented as compared to the overall alignment of the embayment foreshore.

Integration of the recession rates throughout the embayment, for an active profile depth which varied from 8m at South Cronulla to 10m in the centre of the embayment and reduced to 6m in the northern portion behind Marries Reef, indicated that the net loss of was 51,000m^3/yr.

Within the accepted accuracies of the methods used to define the coastal processes, this foreshore recession rate of 51,000m^3/yr agreed well with the aeolian transport induced loss into the transgressive dune sink of 46,000m^3/yr and the net littoral drift feed mechanism of 42,000m^3/yr.

In summary, Bate Bay was found to be a closed coastal compartment. The destabilisation of the dunes in the centre of the embayment over 200 years ago allowed an aeolian sink mechanism to develop. The resulting loss of sand from the surf zone, beach and foredunes in the region adjacent to the sink caused the shoreline to retreat. This in turn produced a misalignment of the beach system which propagated to both ends of the bay. The misalignment in turn induced an evolving littoral drift system which increasingly fed sand from both ends of the bay towards the middle. Immediately prior to implementation of the management plan the average annual net quantity involved in this loss was approximately 45,000m^3.

Management Plan - Overview

The main aim of the management plan was to "plug the sink". Restoration of the beach amenity at the southern end of the embayment and protection of assets threatened in this region were also given high priority. In general, the emphasis was placed on a "soft" management strategy aimed at establishing a well vegetated foredune throughout as much of the embayment as possible. Further, rather than mechanically forcing a new shoreline alignment on the embayment, the technique used involved: the establishment of some initial dunes on the existing alignment; feeding of the surf zone with nourishment sand; allow the natural process to distribute the material throughout the embayment and also allow these processes to adjust the foreshore/dune alignment and the offshore seabed. The final phase of stabilisation included the hinddunes in the centre of the embayment. This work was aimed at retaining sand reserves which may be required in the future for on-going beach nourishment and overcoming the wind blown sand problems associated with these dunes.

The new foredune region was sized to provide a sufficiently large area of stabilised dune to stop the landward loss of beach material by aeolian processes and to provide adequate material to accommodate short term erosion associated with storm events. In the areas where there was insufficient width to establish the necessary foredune because of space constraints, such as at South Cronulla and Prince Street, alternative methods had to be considered. These included the nourishment of South Cronulla Beach and the construction of a seawall at Prince Street where residential buildings were under direct threat from erosion.

The Prince Street seawall option was only selected after an exhaustive series of studies, spanning some 10 years. These studies failed to identify an alternative, acceptable to the community, which would also be more in keeping with the "soft" engineering management philosophy adopted for the remainder of the embayment.

Management Plan - Implementation

The Bate Bay foreshore restoration program commenced in 1975 with the fencing of foredune "paddock" areas along Wanda and Elouera. This was followed by the infilling of blowouts and washthroughs in the foredunes in the centre of the embayment. Sand catching fences were then erected and well defined beach access tracks constructed.

As the coastal process studies showed that the major sand feed to the aeolian sink in the centre of the embayment was from the south, the decision was taken that, following the initial stabilisation of the foredunes throughout the embayment, sand would be fed into the surf zone process from the south and allowed to distribute by natural means to establish new beach alignments. The nourishment of the embayment was therefore carried out at South Cronulla Beach. The project began during 1977-78. Some 80,000m^3 of sand were trucked from the hinddune region of the centre of the embayment, to South Cronulla. There the sand was spread by bulldozer. Work was halted during the 1977/78 swimming seasons and recommenced in mid 1978 when a further 47,000m^3 were placed. The underwater profile of the surf zone was also allowed to reform by natural processes. A public education program was undertaken in conjunction with the nourishment to overcome community misapprehensions associated with the apparently high initial loss of nourished beach at South Cronulla as sand re-distributed along the beaches to the north and as profile development took place.

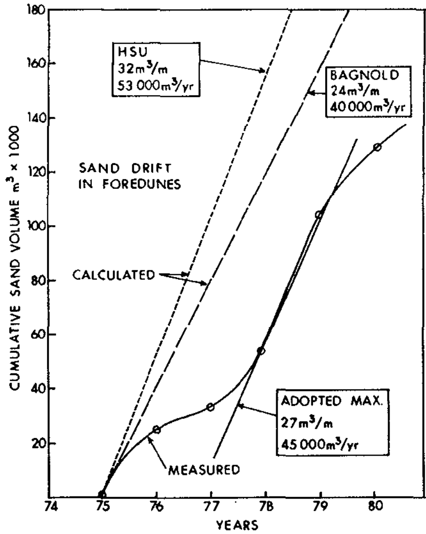
While the South Cronulla nourishment project was underway effort was also concentrated in establishing the primary dune stabilising plants in the Elouera-Wanda foredunes and along the Cronulla/Greenhills foreshore. Thus, as the nourishment sand moved north, the dune fields were ready to trap material. Strengthening and fencing of the vegetated dunes in the northern part of the embayment was also undertaken to produce a similar standard of management throughout the embayment. The overall result was a re-alignment of the embayment foreshore and the natural evolution of a viable foredune system.

Revegetation of the hinddunes in the centre of the embayment (Wanda Reserve) commenced in 1983. The revegetation was completed by 1989.

In 1985 work started on the final link in the plan. A 340m long seawall featuring pre-cast concrete armour units (Seabees) was constructed during 1985/86 along the toe of the Prince Street embankment (Hirst and Foster, 1987). This link joined the dune stabilisation work at North Cronulla to that at Elouera and provided protection to the threatened residential buildings in Prince Street. The ends of the wall were returned into the dunes to allow for the expected storm erosion at these points. Rock filled wire mattresses were placed under the beach in front of the structure to prevent toe erosion. A walkway was incorporated into the seawall crest design thus providing a continuous public foreshore pathway from South Cronulla headland to Elouera.

Results/Discussion

The Bate Bay foreshore is now fully stabilised, some 5km of vegetated foredunes have been successfully established. In the hinddune dune region the



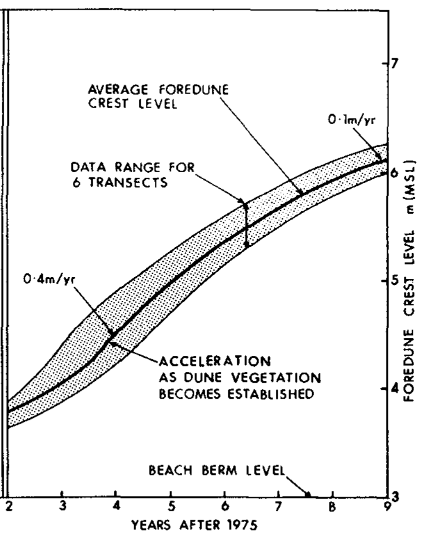


Figure 2 Accretion of Sand in the Foredunes

Figure 3 Buildup of Foredune Crest Level

transgressive dunes stretching some 1.7km along the foreshores have also been stabilised. The sink has therefore been "plugged", the pre-existing longterm shoreline erosion halted and overall foreshore re-alignment achieved. Recreational beaches now extend from South Cronulla to Boat Harbour. The net shoreline and foredune movement over the 17 years following implementation of the management plan has shown an accretional trend, despite the occurrence of several major storms (Figure 1). The accretion has been greater in the centre of the embayment, as was predicted by the coastal process studies.

The point source feed of nourishment at South Cronulla proved to be the most economic method of achieving a "natural" restructuring of the embayment's beach/dune system.

Dune re-building was monitored throughout the project. Figure 2 shows the cumulative accretion rate and Figure 3 summarises the foredune crest level development at 6 of the survey transects located in the centre of the embayment. These figures show that, following the initial mechanical re-construction, accretion was relatively slow over the first 2 years. This outcome was unexpected at the time as shown by the Bagnold and Hsu based prediction of Figure 2. The delay was due to the difficulties experienced in establishing the pioneer plants in such a harsh environment and on such a large scale. An increase in the rate of accretion began in the 3rd year with maximum rates of accretion achieved in the 4th year when the full potential of the aeolian process were focussed towards dune building. By the

5th year accretion started to taper. Although not shown, by the 12th year it was not possible to discern further buildup. In summary, at Bate Bay the time period required to establish a viable foredune system with a diversity of plant life capable of self sustenance, was found to be some 10 years. Intensive management was necessary for the first 5 years although a lower level of support was required for a further 5 years. This timescale was in part a function of the scale of the project.

The net accretion in the dunes and on the beach of some 180,000m^3 was greater than the 127,000m^3 of the nourishment supplied. It is believed that the additional material was supplied through a subtle steepening of the offshore profile, although survey accuracy makes this difficult to quantify. There remains the possibility however that some material which has moved onshore from deeper water during the beach building conditions and is now trapped in the dunes, will be released during a future extreme storm event.

A key element to the success of the Bate Bay project was the detailed coastal processes studies carried out at inception and the ongoing monitoring of those processes, and the systems response, during implementation of the management plan. Central to this approach was the care taken to calibrate and verify the surf zone and aeolian sand transport models.

The total costs of the initial studies and the ongoing monitoring (adjusted to 1991 values) was A$700,000. While this is a substantial sum it was only 8% of the overall project costs of A$8.5M and less than 0.2% of the A$350M value of the assets protected. Further, the stabilisation of the 5.5km of foreshore has allowed expansion of the public recreation areas and for development to take place in the backdune region. Future development of the embayment is centred on retention and maintenance of the newly established foredunes as a buffer zone.

6. Acknowledgments

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Appendix 1. References

Bagnold, R.A. (1954). The Physics of Blown Sand and Desert Dunes, Methuen and Co. Ltd., London, 1954.

Foster, D.N. and Gordon, A.D. (1978). Beach Protection, Cronulla. Proceedings 4th Australian Conference on Coastal and Ocean Engineering, Institution of Engineers, Australia, Adelaide, November 1978.

Gordon, A.D. (unpublished report). Coastal Process of Kurnell Peninsula. Public Works Department Report No. 88 047.

Gordon, A.D. and Lord (1980). An Approach for Understanding Coastal Processes. Proceedings 17th International Conference on Coastal Engineering, American Society of Civil Engineering, Sydney March 1980.

Gordon. A.D. and Acikgoz, D.H. (1984). SANDGUS-Surf Zone Sediment Transport Calculation User's Manual. Public Works Department, N.S.W., Coastal Branch, June 1984.

Hirst, E.H.W. and Foster, D.N. (1987). The Design and Construction of Prince Street Seawall, Cronulla. 8th Australian Conference on Coastal and Ocean Engineering, Institution of Engineers, Australia, Launceston, December 1987.

Hsu, S.A. (1974). Computing Aeolian Sand Transport from Routine Weather Data. Proceedings 14th International Conference on Coastal Engineering, American Society of Civil Engineers, Copenhagen, 1974.

Roy, P.S. and Crawford, E.A. (1979). Holocene Geological Evolution of the Botany Bay - Kurnell Region, Central New South Wales Coast. Department of Mineral Resources, New South Wales Geological Survey - Record Volume 20, Part 2, pp 159-250.

SPM (1973/84). Shore Protection Manual. U.S. Army Corps of Engineers, Coastal Engineering Research Center 1973 (Republished most recently 1984).

Wilson, W.S. (1966). A Method for Calculating and Plotting Surface Wave Rays. U.S. Army Corps of Engineers TM-17, Coastal Engineering Research Center, Washington, D.C., Feb. 1966