Beach Management Options at Lady Robinsons Beach, Botany Bay, Australia

S. Aijaz
Lawson & Treloar Pty Ltd
93 Normanby Road
Notting Hill, VIC 3168
Australia
sia@lat.com.au

D. Treloar
Lawson & Treloar Pty Ltd
PO Box 852
Pymble, NSW 2073
Australia
pdt@lat.com.au

Abstract- **The construction of the Sydney Airport parallel runway, along with port development works and natural processes in Botany Bay, has changed the pattern and intensity of waves that reach Lady Robinsons Beach. This has resulted in the beach being severely eroded in some areas, and expanded in others. The Sydney Ports Corporation has undertaken extensive studies to investigate the coastal processes of the area and to consider suitable methods for beach re-habilitation and management. This study investigated various beach management options for restoration of Lady Robinsons Beach. Wave and sediment transport modeling studies were conducted to assess the wave and sediment transport patterns. A beach management study program for fifty years planning period was prepared.**

I. INTRODUCTION

Lady Robinsons Beach forms the western shore of Botany Bay, Australia (Fig. 1). The land behind the beach is generally low and sandy, and is heavily urbanized, with a major road, The Grand Parade, running parallel to the beach over most of its length. There is an extensive parkland area between The Grand Parade and the beach. The beach is an important recreational amenity for the southern and western suburbs of Sydney, as well as being an area of historical and environmental significance and natural beauty.

The natural processes shaping the shoreline of Botany Bay have been disturbed by a number of major developments over the last fifty years. Dredging and reclamation works in the bay have been undertaken for construction of the major port facility of Port Botany; for construction of parallel runways at the Sydney Kingsford Smith International Airport; and for the Caltex oil refining facilities in the bay.

Since the commencement of major dredging activities and reclamation works for Sydney Airport and Port Botany, Lady Robinsons Beach has been subject to changed wave conditions. Many areas of the beach have been subject to severe erosion. In 1993, Sydney Ports Corporation (formerly MSB Sydney Ports Authority) investigated the beach system to identify the areas of erosion and to consider suitable options for restoring the beach amenity [1]. The 1993 study found that the beach south from Florence Street was severely eroded and needed immediate restoration measures.

The study concluded that of the total average beach erosion south from Florence Street, 47% was because of the construction of the parallel runways for the Sydney Airport and port related works, and 53% was erosion that would have occurred in the absence of any major works in the bay.

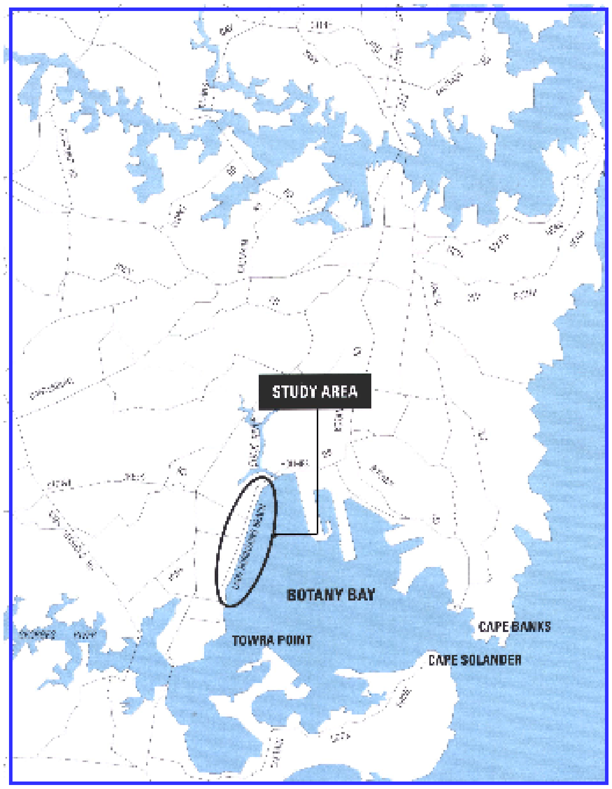

Fig.1. Lady Robinson Beach study area location.

The study recommended beach nourishment and groyne construction in the Dolls Point area. Following the recommendations, a stable solution was developed and implemented in 1997. This solution consisted of construction of six rock rubble and two concrete panel groynes.

The 1993 study also identified areas of long term erosion along the beach north of Florence Street. For this section of the beach, 36% erosion was because of the construction of the runways and port related works, and 62% was erosion that would have occurred in the absence of these major works. On the northern section of the beach, continuing erosion has resulted in the loss of sub-aerial beach over almost 1 km in length.

The purpose of the present study was to investigate the beach management options north of Florence Street extending to the entrance of Cooks River. The restoration of Lady Robinsons Beach is necessary to protect a number of land based and marine assets and to meet the community's demand for the return of an important recreational and aesthetic resource. There is also a need to implement a system that will provide a stable beachfront and is a cost effective solution with minimum need for ongoing work.

II. COASTAL PROCESSES

Meteorological and oceanographic parameters, which determine coastal processes and are the salient features in the design and operation of beach management options, include wave and wind climates, currents and water levels, stormwater flows and beach sediment characteristics.

These parameters are described in detail in previous studies [1,2]. Tidal currents along Lady Robinsons Beach are small, especially in the area north of Florence Street, and have only a minor influence on coastal processes in the study area. Similarly, flow in and out of the Cooks River has negligible impact on the coastal processes in this area. However, nearshore wind driven currents will have a significant influence on longshore transport potential during periods of high wind events, especially when the wind direction is approximately parallel to the coast. Thus the definition of wind, waves and water levels, which are the key elements in determining design conditions of beach management options such as groynes, assessment of beach nourishment volumes, estimation of offshore sand losses during storms and for construction planning, was the principal task of this investigation.

Tidal planes derived from long term records at Fort Denison, Sydney Harbour are described in [3]. Tidal planes for Botany Bay and the study area are similar to those of Sydney Harbour.

Since wave driven sediment transport is depth dependent, elevated water levels, which are often associated with major storm events, result in increased erosion of the normally sub-aerial beach, while the seaward extent of cross-shore and longshore transport increases during storms accompanied by lower than normal water levels. Table 1 shows the extreme water levels for typical Average Recurrence Intervals (ARI), also derived from the Fort Denison water level records [1].

The nature of beach sediments influences the littoral transport processes, onshore/offshore transport and the stable beach slope for a particular location. Both magnitude and seaward extent of sediment transport increase with decreasing sediment size. Therefore, beach sediment sizes influence the seaward extent of structural options. Finer beach sediments result in flatter stable-beach slopes and, therefore, greater nourishment volumes than coarser nourishment material. Within the study area, the median grain size shows little variation from the average values along the beach of 0.30mm to 0.35mm [3]. Sediment analysis indicated the presence of clean sands with less than 10% silt/clay content and the beach sediments were found to be well to moderately sorted.

TABLE 1
EXTREME WATER LEVELS

ARI (years)	Water Level (m)
1	2.03
5	2.16
10	2.21
20	2.26
50	2.33
100	2.35

III. WIND WAVE MODELLING

Swell and wind wave climates along the shoreline of the study area are required for structural design, sediment transport and beach response modeling to determine groyne layout and beach nourishment requirements and to evaluate management option performance.

Energy averaged long term wave heights, periods, and directions determine the long term equilibrium beach alignments but, for the investigation of short term variations in alignment about the long term equilibrium alignment, time series of waves or a detailed wave climate defined by a large number of waves with different heights, periods, and directions, together with associated partial probabilities of occurrence are required.

For the present investigation, swell and wind climates at different locations within the study area have been computed using the final post-dredged bay with parallel runway bathymetry. Model output locations (Fig. 2) along the shoreline were selected to be generally in depths of -1.5m LAT.

Swell wave climates at each location were defined by wave refraction modeling using the nearshore wind wave propagation model, MIKE 21 NSW, developed by the Danish Hydraulic Institute [4]. Inshore wave direction, period and wave height coefficients were derived at each location for each of the 54 offshore wave direction – period combinations (9 directions and 6 periods) of a parametric offshore wave climate that was derived from over 20 years of recorded deep water wave conditions off Botany Bay [3]. The model was calibrated against directional wave parameters recorded by waverider buoys deployed in the bay [1].

Wind wave climates at each location were determined from the MIKE 21 NSW model using the wind climate defined from the directional mean hourly composite long term wind speed distribution [3].

The weighted mean wave energy flux direction (ϕ_m) at each wave climate location was computed as follows:

$$\phi_m = \frac{\sum P_i H_i^2 T_i \phi_i}{\sum P_i H_i^2 T_i}, \qquad (3.1)$$

where:

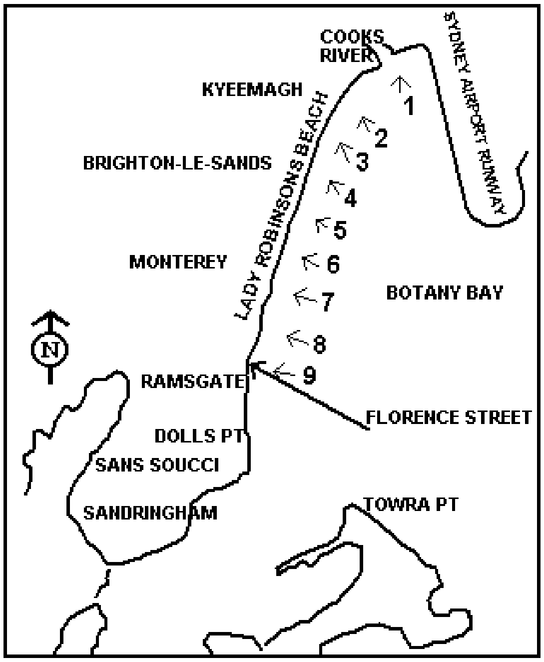

Fig.2. Wave climate locations for wind wave modeling.

ϕ_i = wave direction,
H_i = wave height,
T_i = wave period, and
P_i = probability of H-T-ϕ combination.

Sea and swell were computed separately and then combined to compute the mean wave energy flux direction as follows:

$$\varphi_m = \frac{(H_{se}^2 T_s \varphi_s + PH_{sw}^2 T_w \varphi_w)}{(H_{se}^2 T_s + PH_{sw}^2 T_w)}, \tag{3.2}$$

where :

H_{se} = swell median wave height,
H_{sw} = local sea median wave height,
T_s = typical swell period (adopted as 10s),
T_w = typical sea period (adopted as 2.5s),
P = probability of local sea,
φ_s = weighted mean energy flux directions for sea,
φ_w =weighted mean energy flux directions for swell.

The normal to the total net wave energy flux direction represents the approximate long-term potential equilibrium beach alignment. The total net swell and wind wave energy flux direction at each inshore wave location is presented in Table 2.

The estimated shore normal directions derived from beach surveys of 1998 are also shown in Table 2. At locations where the difference between shore-normal direction and weighted mean flux direction is large, the longshore transport potential will be significant. The magnitude of shore parallel wave energy flux is dominated by swell wave energy in the region south from Banks Street (location 6) with local sea wind wave energy flux dominating processes north from Bay Street (location 4).

TABLE 2
WEIGHTED MEAN DIRECTIONS

Wave location	Weighted Mean Wave Energy Flux Direction (°TN)			Shore normal direction (°TN)
	Swell	Sea	Combined	
1	-	173	173	147
2	-	144	144	135
3	-	154	154	125
4	114	148	144	111
5	109	139	132	107
6	113	140	119	112
7	103	119	104	104
8	100	103	100	99
9	101	95	100	105

Table 3 shows the combined significant wave heights exceeded at each wave site within the study area for an average persistence duration of 24 hours and average recurrence intervals up to 100 years. The wave heights have been computed along the –1.5m LAT contour from the log-normal distributions using linear wave theory and a wave period of 11s. Water depths have been defined by the corresponding water levels shown in Table 1.

Offshore swell wave data adopted for longshore transport modeling consisted of a) offshore directional wave data obtained from a waverider buoy deployed off Botany Bay; and b) offshore directional parametric wave climate developed from over 20 years of wave observations in deep water from the Botany Bay Waverider buoy system [1]. Wave coefficients were combined with these records to prepare wave climates at specified locations for input into longshore transport calculations.

IV. SEDIMENT TRANSPORT

The shape and alignment of Lady Robinsons Beach is influenced by refracted ocean swell that enters Botany Bay, local wind and waves generated over the bay, flood flows from local storm water drains, many human influences, and flood and tidal flows from the Georges and Cooks rivers, although the influence of the latter is minor. At the southern end of the study area, at Florence Street, a large box stormwater culvert protrudes across the nearshore

TABLE 3
COMBINED DESIGN SIGNIFICANT WAVE HEIGHTS

Wave location	Design significant wave heights (m) exceeded for one day in:				
	1 year	10 years	20 years	50 years	100 years
1	-	-	-	-	-
2	0.5	0.9	1.1	1.4	1.7
3	0.5	1.1	1.3	1.7	2.0
4	0.6	1.1	1.4	1.8	2.1
5	0.5	1.0	1.2	1.5	1.7
6	0.5	0.9	1.3	1.3	1.5
7	0.7	1.3	1.5	1.8	2.0
8	0.8	1.3	1.6	1.8	2.1
9	0.6	1.0	1.2	1.4	1.6

zone. This typical groyne action is evidence of net southerly longshore transport at this location. At the northern end of the study area, the training walls of the Cooks River form an almost total barrier to longshore transport with only minor northward bypassing which is trapped by the total littoral barrier of the Sydney Airport runway.

The study area is therefore considered to form a single contiguous coastal process zone, with only a small interaction with processes south of Florence Street. Table 4 shows the location of streets and their distance or chainage from the southern training wall of the Cooks River. The street locations are also shown in Fig. 3.

Analysis of beach profile survey data (dating from 1973 at approximately six month intervals) has shown that longshore transport along Lady Robinsons beach is distinctly bi-directional [1]. Long term average littoral drift is to the north over the beach length north of a null point (zero transport rate) at approximately Pasadena Street, and to the south over the total beach length south of the null point. The maximum estimated northward average annual transport rate of approximately $5800m^3$/year occurs between Solander Street and President Avenue.

Coastal management options such as groynes and offshore segmented breakwaters control the natural movement of beach material by locally altering the orientation of the beach to be more parallel with the incident wave crests, and by intercepting longshore currents caused by wave breaking momentum and winds, thereby reducing longshore transport. Cross-shore transport, which is particularly important during storms when larger waves may be associated with elevated water levels, is responsible for transporting significant quantities of sub-aerial beach material seawards, and in some circumstances beyond the beach compartments created by groynes or offshore breakwaters. During a storm, longshore and cross-shore processes occur simultaneously causing a complex sediment movement environment.

Longshore sediment transport is caused by longshore currents in (and seaward of) the surf zone caused by waves that arrive obliquely to the shore, currents caused by shore parallel wind flux, and, to a very small extent at Lady Robinsons Beach, by longshore wave height variations and longshore tidal currents. The bulk of longshore transport occurs within the surf zone and the distribution of this transport across the surf zone depends on wave height, nearshore seabed profile and the cross shore distribution of sediments.

TABLE 4
LOCATION OF STREETS

Street Name	Chainage (m)
Cooks River	0
Bestic Street	510
Bay Street	1650
President Avenue	2340
Solander Street	2680
Robinson Street	2840
Barton Street	3190
Pasadena Street	3540
Florence Street	4170

Variations in magnitude and direction of longshore transport lead to areas of erosion and accretion along the beach as well as changes in the alignment of the shoreline. Where longshore transport rate decreases in the direction of longshore transport, an area of accretion will develop. Where the rate increases in the direction of the drift, a local area of erosion will develop. Structures such as groynes and offshore breakwaters vary, or completely block these longshore transport processes in sections of the coastline. Coastline orientation is then altered locally. Unless mitigation measures are included in the design, then downdrift of these types of structures there is likely to be an area of erosion, therefore, one area of the shoreline will have been improved, another will have been disadvantaged. Placement of a terminal structure near the location of maximum longshore drift, for example, Solander Street, minimizes the possible deleterious outcomes.

Many formulations for the estimation of the magnitude of littoral transport rate have been developed. In this study, the Engelund and Fredsoe equations [5], as embodied in the LITPACK coastal processes modeling system developed by the Danish Hydraulics Institute [6], have been used. This formulation includes separate bed load and suspended load expressions. Bed load is evaluated as:

$$Q_b = \phi\sqrt{(s-1)gD_{50}^3}\,, \tag{4.1}$$

where:

Q_b = bed load transport rate (m^3/s),
D_{50} = the median sediment size,
s = specific gravity of the sediment,
ϕ is evaluated from

$$\phi = 5p\sqrt{\theta'} - 0.7\sqrt{\theta_c}\,, \tag{4.2}$$

where:

θ = Shield’s Parameter,
θ_c = critical Shields Parameter,

and

$$p = (1 + (\frac{\Pi\beta/6}{\theta'-\theta_c})^4)^{-1/4}, \tag{4.3}$$

where p is the probability that all the particles of a layer are moving.

The Engelund and Fredsoe formulation includes combined wave and current motion and β in “(4.3)” is a boundary layer parameter computed by the LITPACK model using combined current and wave conditions. It is given as:

$$\beta = 30K^2a/k, \tag{4.4}$$

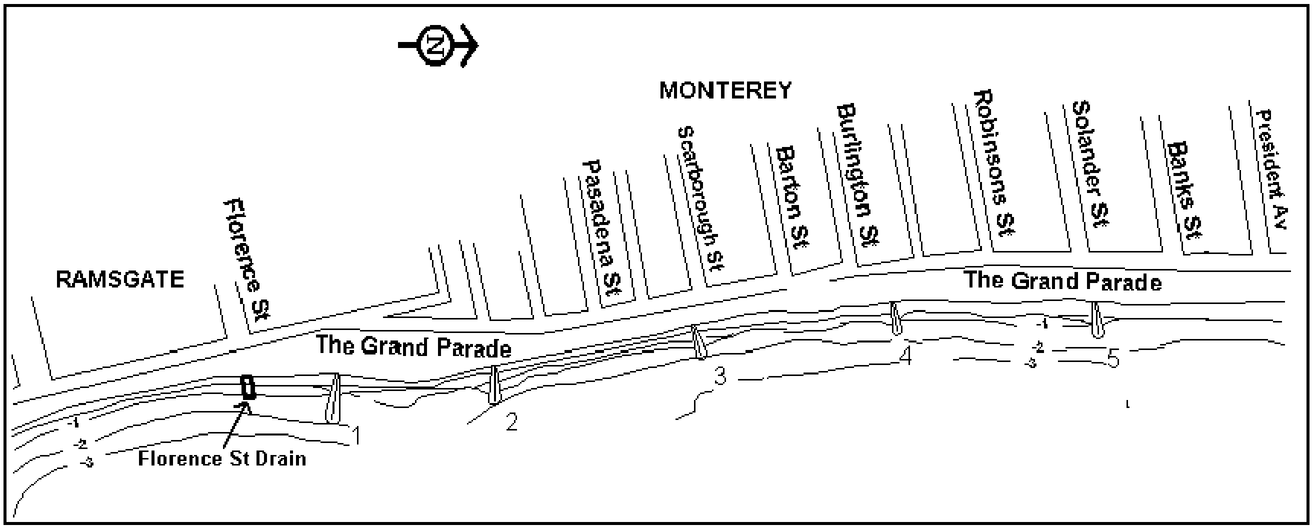

Fig. 3. Schematic layout of the study area and the groyne field.

where:

K = the von Karman constant,
k = bed roughness height,
a = near bed wave orbital amplitude.

Suspended sediment load is calculated using a profile of suspended sediment concentration and a net velocity profile, that is,

$$Q_s(t) = \int_{2d}^{D} U(y,t)C(y,t)dy\,, \qquad (4.5)$$

where:

y = height above the bed,
U = mean current,
D = water depth,
d = particle size,
C = concentration of suspended sediments.

Under-tow and wave drift may be included in the computation of mean current. The LITPACK modeling system includes a number of modules. One of these, LITDRIFT, computes longshore transport for selected time series of wave parameters, currents, and winds. Measured beach profiles, graded sediments, currents, wind, and bed roughness are included. The distribution of sediment transport across the profile and the combined wave and current hydrodynamics are computed. LITLINE is the module of the LITPACK model that computes changes to a shoreline over a period of time using spatially and temporally varying longshore transport. It includes coastal structures such as groynes and revetments.

V. LONGSHORE TRANSPORT MODELING

The longshore distribution, seaward extent and cross-shore distribution of longshore transport are the principal phenomena controlling the effectiveness and selection of beach management options. The LITDRIFT module of the LITPACK coastal modeling system [6] was used to examine the major parameters that define and quantify the sediment transport processes. The consequences of management options were investigated using the LITLINE module of the LITPACK model.

Longshore transport processes on an annual basis were investigated at the wave modeling locations (Fig. 2) using the LITDRIFT module. The input parameters were the parametric wave climate data, wind data, and the wave data from the wave modeling results. Graded sediments (10 fractions) with D_{50} parameters of 0.30mm and 0.35mm, a range of bed roughness heights and range of wind conditions were investigated.

The results show that the longshore transport at location 7 is generally smaller than at location 6. This is consistent with the more eroded state of the beach at location 7. Most of the transport occurs when there are strong winds having a significant coast parallel component. Additional longshore transport issues such as the offshore extent (depth) beyond which longshore transport does not occur and the distribution of transport across the beach face were investigated. It was determined that less than 5% of the longshore transport occurs in depths greater than 2m. Mean low water for spring tides is approximately 0.5m LAT, therefore, less than 5% of annual transport is likely to occur seaward of the –1.5m LAT contour.

The long term changes to the shoreline north of Pasadena Street were assessed using the LITLINE module of the LITPACK model. The present shoreline has eroded back to the sea wall southwards of Scarborough Street. The seawall will prevent any further retreat. Modeling results indicate that other than during major storms, seabed level at the sea wall is unlikely to erode lower than –0.2m LAT. A sea wall south from Robinson Street was included in the model and coastline changes up to 50 years were simulated using the long term wave climate and long shore transport potentials. The likely beach amenity recession without remedial works is described below (based on the location of zero beach width at MSL):

Barton Street	2005
Burlington Street	2015
Robinson Street	2045

Morphological response of the shoreline due to storm wave conditions occurs over relatively short time periods (hours to days). This response primarily involves the erosion of the normal sub-aerial beach face through the offshore transport and deposition near the storm wave break point to form offshore bars. The sub-aerial beach face slowly rebuilds over time periods of weeks to months as sand in the bar is transported shorewards under swell conditions.

Practical beach management options for Lady Robinsons Beach require an allowance in the design re-nourishment volumes to accommodate erosion of the beach face under storm waves, in order to preserve an adequate beach amenity following storm abatement. The seaward limits of cross-shore transport during storms are also required to determine suitable groyne lengths and offshore breakwater locations so that excessive quantities of beach material are not transported beyond the groyne compartments, and to define a reliable storm closure depth.

Storm erosion profile in the study area has been assessed using LITPROF, the beach profile module of the LITPACK model. LITPROF is a semi-empirical, dynamic equilibrium storm onshore/offshore erosion prediction model [6], where the bed level is determined by the continuity equation of the sediment mass coupled with onshore/offshore transport.

A range of test conditions were investigated. The wave period, T_z, was kept constant at 6s and a D_{50} of 0.30mm was adopted. Measured beach profiles at two locations (Brighton-le-Sands and Monterey) were used. Each simulation was undertaken for a period of 24 hours at a constant wave height (Table 3) combined with a semi-diurnal tide with high water peaking at the peak storm water levels (Table 1).

The results show that the storm bite at Monterey may be as large as 10m near top of run-up for a 20 year ARI storm, but only about 2m in the Brighton-le-Sands area. These results are consistent with the field data observations and model results described in [7].

VI. BEACH MANAGEMENT OPTIONS

The various beach management options considered to restore the Lady Robinsons Beach consisted of:

A. Initial and recurrent beach nourishment.
B. Five groynes with beach nourishment.
C. Three groynes with a dune system and nourishment.
D. Three groynes with beach nourishment.
E. Multiple groynes with initial nourishment.

Management options that included structural elements were designed using wave and water level parameters having 20 years ARI and 24 hours persistence. Longshore variation of wave height was not included in this analysis. A 50 years planning period was adopted. A design beach profile with a minimum beach width of 17.5m (including 10m for storm bite) from the seawall at a level of 3m LAT was developed with the following form:

3m to 1m	1V:10H
0m to –1m	1V:25H
-1m to –3m	1V:20H

Sources of sand for beach nourishment were identified within Botany Bay. These consisted of areas offshore of Kyeemagh and offshore of Dolls Point (Fig. 2).

A. Initial and recurrent beach nourishment

Beach re-nourishment programs provide coastal protection and increase beach amenity by building a wider beach without the intrusions of structures on the foreshore. Examination of historical shore normal surveys indicates that the peak northward longshore transport occurs near Solander Street. There is a null point (zero net transport) near Monterey/Pasadena Streets. Shoreline recession occurs at the beach south of Solander Street. The beach near Monterey Street would require re-nourishment. A ten years plan of re-nourishment at Monterey requires an initial sand re-nourishment of 275,000m^3. Every ten years maintenance re-nourishment of approximately 105,000m^3 would be required to re-establish the beach profiles.

The LITLINE module of the LITPACK coastal model was used to examine the fate of the proposed sand nourishment at Monterey and to assess shoreline changes beyond the re-nourished area over a period of ten years. The results show that near Bay Street, the beach would prograde up to 6m over ten years but near Ch 3300, a recession of 34m over ten years would occur.

The main advantage of this option is that there are no hard structures and consequently, there is no loss of aesthetic appeal. Other benefits include continuous natural beach amenity north of Pasadena Street to the Cooks River; no disruption to pedestrian traffic; and no loss of foreshore park areas.

B. Five groynes with initial and recurrent nourishment

Groynes are shore normal structures which project seaward from the back-beach area sufficiently far into the sea to prevent or minimize longshore sediment transport. These structures may be built from rock (the most common material used in Australia), or wooden or concrete whalings. Groynes function by forming small beach compartments in each of which the normal to the shoreline becomes aligned with the local weighted mean wave energy flux direction. These directions are presented in Table 2. There will be little loss of sediments from the groyne compartments provided that the seaward ends of the groynes are placed in sufficiently deep water and they are of sufficient length to accommodate the shoreline realignment.

The five groyne option consisted of a series of five rock groynes placed at intervals between Florence Street and Solander Street (Fig. 3). The re-nourishment volume provides for an acceptable beach amenity following a storm bite of 10m in beach width. This groyne field layout was determined from a number of preliminary simulations and using the wave energy flux direction data (Table 2) together with present shoreline details.

The groynes would be constructed with a suitably designed rock core and two armour layers extending seaward to the –1.5m LAT contour on the design profile. The groyne crest levels would be placed at 2.3m LAT. The lengths of the groynes and groyne alignments were estimated to be:

	Length (m)	Alignment (^{o}TN)
Groyne 1	100	115
Groyne 2	94	105
Groyne 3	98	93
Groyne 4	98	98
Groyne 5	96	101

Groynes 3,4, and 5 have been tilted northward marginally in order to cause improved beach alignments and to provide a more similar beach width both sides of the groyne.

LITLINE modeling results for the long term shoreline changes for this option show that north of groyne 5, the shoreline would recede continuously from the time of construction with the potential to erode as far back as the car park in the next 50 years. An initial nourishment of 45,000m^3 would be required immediately north of groyne 5. This initial nourishment volume would provide an acceptable beach amenity for about ten years. Re-nourishment of 55,000m^3 would be required in this area, on average every ten years. The beach between groyne 1 and the drain at Florence Street would be improved by applying a re-nourishment volume of 54,000m^3. A total nourishment volume of 305,000m^3 throughout the groyne compartments was estimated for this option.

C. Dune system with three groynes and nourishment

This option involves construction of three groynes that protect the same length of the beach as the previous five groyne option. In addition, a dune area with a width of 20m at the rear of each groyne compartment would be established. The dune crest at Solander Street was designed at 8m LAT. Where the present sea wall has a low level of 3m to 4m LAT, the dune was designed to meet this low level. Where the back beach area exceeded 8m LAT, the dune crest was terminated at 8m LAT.

The groyne lengths were estimated to be 120m, 130m, and 160m for groyne 1 (north of Florence Street), groyne 2 (near Scarborough Street) and groyne 3 (near Solander Street) respectively. LITLINE modeling shows that the beach width in the area, which is north of groyne 3 would be reduced from the 17.5m design width to only 7.5m in a period of approximately five years. An initial nourishment of 45,000m^3 would be required in this area immediately following construction. The initial nourishment volume would provide beach amenity for a period of about ten years. Re-nourishment of 50,000m^3 would be required in this area on a ten year basis. A total nourishment volume of 603,000m^3 was estimated to nourish the beach and dune areas between Florence Street and Solander Street.

D. Three groynes with beach nourishment

This option is the same as the previous option except that it does not involve any initial nourishment for a dune system. The initial and recurrent nourishment north of groyne 3 are same as provided above. A total nourishment volume for the beach area between Florence Street and Solander Street was estimated to be 253,000m^3. In addition, nourishment volume of 45,000m^3 would be required north of groyne 3 and re-nourishment of 50,000m^3 on a ten year basis would be required in this area.

E. *Multiple groynes with initial nourishment*

The multiple groyne option consists of a series of groynes located between President Avenue and the entrance to the Cooks River, in addition to the five groynes proposed in the five groyne option. There are a total of twelve groynes. Nourishment volumes were based on design profiles that incorporated a minimum design beach width of 7.5m in addition to a storm bite determined by LITPROF at specific locations.

Groyne lengths were determined such that each groyne would extend to –1m LAT from the new beach. The three northern most groynes would extend to –0.5m LAT. The details of groyne configuration and sand nourishment volumes for each groyne compartment are provided in [8]. This option required a total of 751,000m^3 of sand nourishment between President Avenue and the Cooks River entrance. Both the number and size of groynes required to contain this volume of sand is substantial with most of the groyne lengths exceeding 150m. Such a large number of groynes is unlikely to be either economically feasible or aesthetically pleasing.

F. Preferred Option

The selection of the five restoration options was based on consideration of the following factors:

1) Visual impression and community acceptance
2) Initial and recurrent costs
3) Engineering feasibility and restoration value
4) Environmental impacts

The preferred option for the restoration of Lady Robinsons Beach was selected to be the five groyne option with initial and recurrent nourishment (Option B). This option was chosen because of the following reasons:

1) Creation of a long term stable beach from Florence Street to Cooks River with least adverse impacts.

2) No loss of foreshore park areas.

3) Provision of recreational fishing facilities.

4) The proposed rubble mound groyne construction will provide a beach amenity that is consistent with works already undertaken in the southern section of Lady Robinsons Beach.

5) Borrow areas have been identified within Botany Bay and avoid the need to import sand during the 50-year planning period.

Whilst the initial and recurrent nourishment option is the most aesthetically pleasing and has the least initial capital cost, it requires the largest volume of sand for re-current nourishment. Hence, it has high recurrent costs. The five groyne and three groyne options have similar groyne material quantities, beach nourishment volumes and therefore have similar costs. However, the five groyne system would provide lowest visual impact because it has shorter groyne lengths than the three and twelve groyne options. Since aesthetic appeal is an important consideration in the community's acceptance of a preferred option, the shorter and less obtrusive five groyne option would be widely acceptable while providing the necessary level of stability. The multiple groyne option would provide a stable beach with no recurrent nourishment, but it has high costs in addition to causing adverse noise, air, and water quality impacts.

G. Environmental Impacts

Environmental issues, including both the natural environment and the human environment, during both construction and operational phases were considered. These are described in detail in the Environmental Impact Statement (EIS) prepared for this project [8]. Specific impacts considered in the EIS include ecological, construction noise, air and water quality, construction traffic, visual aesthetics, fishing practices, community disruption, and public acceptance.

VII. CONCLUSIONS

Wave and sediment transport modeling were undertaken to define the parameters and examine the processes controlling longshore transport on Lady Robinsons Beach. Longshore transport modeling was used to assess the impacts of the beach management options on the long term shoreline alignments and erosion and accretion trends. Severe erosion of the northern section of Lady Robinsons Beach will continue if no action is undertaken. The five groyne and re-nourishment option was selected to be an effective solution for the restoration of Lady Robinsons Beach. There is substantial Australian experience with the beach re-nourishment and groyne options. This option would provide a stabilized beach between Florence Street and Cooks River entrance with least impacts on the human and surrounding marine environment as compared with the other options.

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