GENESIS Modelling of Sand Nourishment Options at Collaroy-Narrabeen Beach, Sydney

Acworth, C.A.

Coastal Unit, Queensland Climate Change Centre of Excellence,
Department of Environment and Resource Management, Brisbane, QLD

Abstract

Collaroy-Narrabeen is located on Sydney's Northern Beaches, 16km north of the CBD. A number of coastal processes operate within the embayment, and primarily due to the heavily developed shoreline, the processes of cross-shore variation and long term beach recession have constituted towards significant coastal hazard. GENESIS (GENEralised model for SImulating Shoreline change) is a coastal shoreline response model that can be used to assess the effects of sand nourishment and coastal structures that may be implemented as part of a coastal management strategy. Traditionally, an external wave model in GENESIS is used to calculate wave information along a nearshore reference line, which corresponds to a pre-breaking wave condition for the majority of the events in the offshore time series. In this application, the code of GENESIS was re-written by one of the authors, Mark Gravens, allowing for creation of a unique, site specific version that utilised nearshore wave time series at 10 equally spaced points along the curved embayment. The model was calibrated to the amount of sand that is known to terminate in Narrabeen Lagoon each year and the nourishment recommendations of NLA (1988b) and Patterson Britton (1993) were evaluated.

The most effective nourishment strategy for Collaroy-Narrabeen was found to be nourishment of Precincts 2 and 3 with construction of a groyne at Devitt Street. It was found that the objectives of providing protection for all beach development at threat and maintaining and enhancing recreational amenity could not be carried out in perpetuity with the use of a traditional rock groyne. However, it is suggested that these objectives may be achieved with the use of a more innovative geo-textile structure.

Introduction

The Warringah Council Local Government Area (LGA) is centrally located on Sydney's Northern Beaches, bounded by Manly LGA to the south, and Pittwater LGA to the north. Within Warringah, 14km of coastline stretches from Queenscliff Rock Pool in the south to the entrance of Narrabeen lagoon in the north. The Collaroy-Narrabeen embayment is the most northern in the Warringah LGA and is located approximately 16km north of Sydney's CBD. The embayment is separated into Collaroy Beach, bounded by Collaroy rock pool, which transitions to Narrabeen Beach, bounded by Narrabeen rock pool. The length of the embayment is approximately 3.6km, with Wetherill Street forming the map boundary between Collaroy and Narrabeen Beaches. Fisherman's Beach and Long Reef Point extend to the south, with Narrabeen headland and Turrimetta Beach to the north. Figure 1 shows the geographical location of Collaroy-Narrabeen.

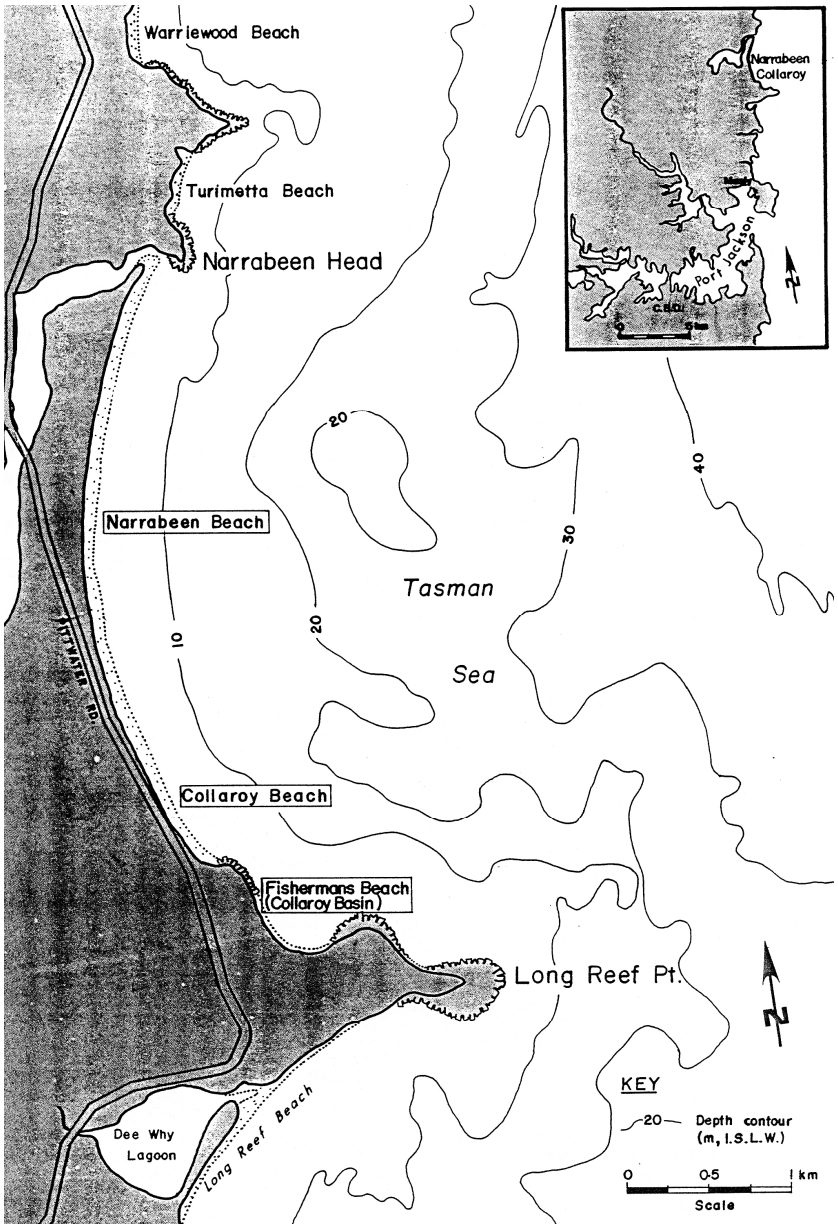

Figure 1: Geographical location of Collaroy-Narrabeen (PWD, 1987)

A number of coastal processes operate within the embayment, and primarily due to the heavily developed shoreline, the processes of cross shore variation and long term beach recession have led towards significant coastal hazard.

After a series of catastrophic storm events in the 1960s and 1970s, Warringah Council and the NSW State Government have actively taken steps to address these coastal hazards. In 1985, Warringah Council, in conjunction with the Public Works Department of NSW, prepared a Coastline Management Strategy for Warringah Shire (WSC 1985). The report determined Collaroy-Narrabeen as the area most at risk from coastal processes within the Shire, with the beach ranked nationally as the third most at risk from coastal hazard, behind Queensland's Gold Coast and Adelaide's City Beaches.

In view of this risk to development, Council undertook a number of coastal process hazard definition studies, and developed coastal management strategies (PWD, 1987; NLA, 1988a; 1988b; 1989) which ultimately led to preparation of the Collaroy-Narrabeen Coastline Management Plan (WC, 1997). This plan was formally adopted by Council in 1997, and, in accordance with the State Government's Coastline Hazards Policy, the plan has the major objectives of:

- preserving and protecting the beach as a national asset for public recreation and amenity; and
- ensuring that building and development along Collaroy-Narrabeen Beaches has regard to the current and future hazards of wave impact and coastal erosion.

Since adopting the plan, Council has carried out a number of investigations based on 4 broad management strategies with 13 associated actions. Some of these actions have not proven to be sustainable on longer time scales such as the purchase of properties, or popular with the local community such as the implementation of coastal structures. More recently the Sydney Coastal Councils Group has been successful in obtaining funding under the National Disaster Mitigation Program to undertake a scoping study on the extraction of offshore sand reserves for the purpose of large scale beach nourishment.

With regard to the nature of the Collaroy-Narrabeen coastal system, and the current status and objectives of the Coastal Management Plan (WSC, 1997), the aim of this paper was to determine if mass sand nourishment from offshore sources, as proposed by Patterson Britton (1993), is an effective coastal management strategy for Collaroy-Narrabeen.

Collaroy-Narrabeen beach nourishment investigations

Massive sand nourishment for each of the five precincts which are illustrated in Figure 2 at Collaroy-Narrabeen beach was first investigated by NLA (1988b). The report investigated development, recreational and amenity issues associated with various management strategies for each of the four precincts (where Precinct 1 is Fisherman's Beach and is beyond the scope of this study).

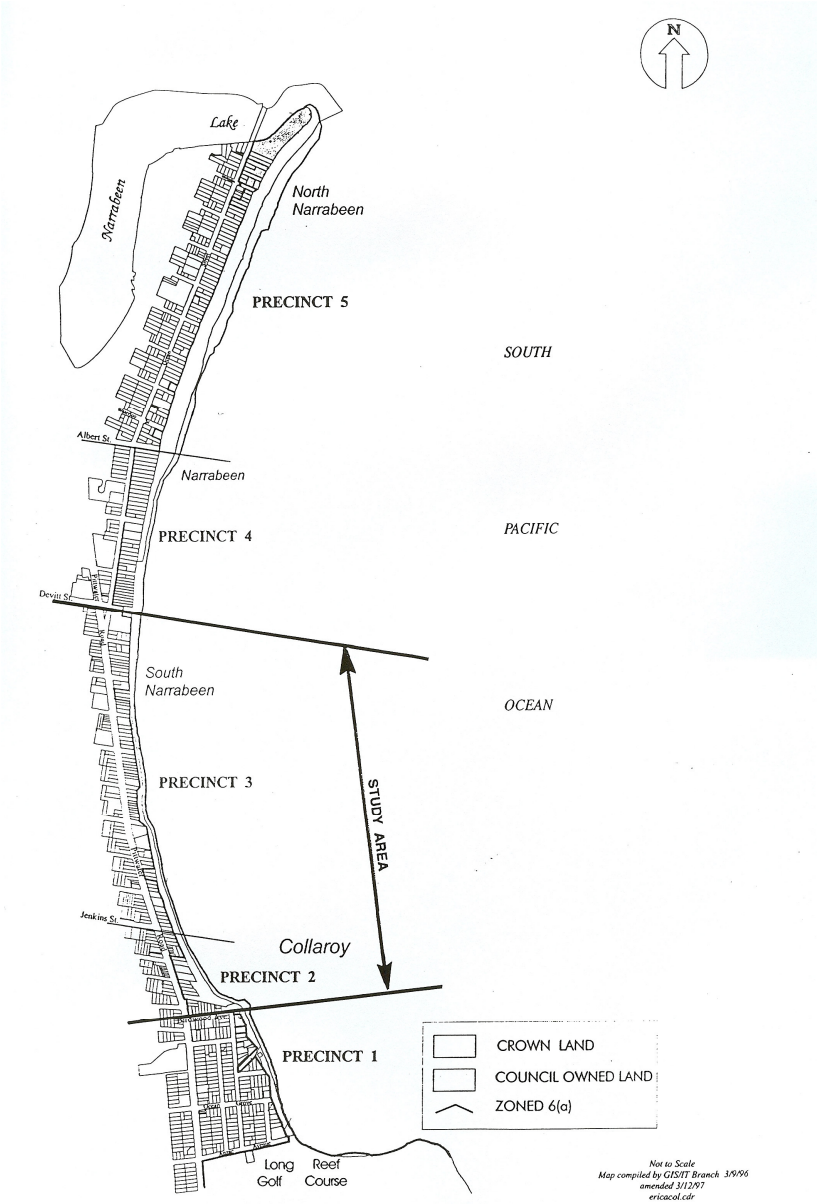

Figure 2: Location of Precincts 2-5 NLA (1988b)

Patterson Britton (1993) followed on from work undertaken by NLA (1988b), and re-estimated sand nourishment volumes for Precincts 2 through 5, source material and potential placement strategies. Two main objectives for the nourishment were established:

- to provide protection for all beachfront development at threat; and
- to maintain and enhance the recreational amenity of the beach,

Patterson Britton (1993) determined the volume of sand necessary to ensure protection for all development at threat to be substantially greater than the volumes required to provide a satisfactory beach width to maintain amenity. As a result, the

first objective was found to govern the amount of sand required. Assessment of beach nourishment requirements were carried out for two options

i) Nourishment of precincts 2 and 3 only, involving construction of a groyne near the boundary of Precincts 3 and 4 (Devitt Street) in order to contain the nourished sand.

ii) Massive beach nourishment for the entire Collaroy-Narrabeen Beach i.e. Precincts 2, 3, 4 and 5 to provide protection for all development at threat.

Based on the two options above, two estimates were prepared and are summarised below.

Nourishment to provide protection for development in precincts 2 and 3 against the storm erosion demand, and to meet the next ten years sediment loss

(a) volume required to provide protection against the storm erosion demand (precincts 2 and 3):

(i) sub-aerial volume (above AHD)

6m (dune height) x 30m (width) x 1,500 (length) 270,000m^3

(ii) sub-aqueous volume (below AHD)

- to -12m AHD
  12m x 30m x 1,500 540,000m^3

Sub-Total for (d) 810,000m^3

Nourishment of Precincts 2 - 5 to protect development against the storm erosion demand and to meet the next 10 years sediment loss

(b) volume required to provide protection against the storm erosion demand:

(iii) sub-aerial volume (above AHD)

6m (dune height) x 30m (width) x 3,600 (length) 648,000m^3

(iv) sub-aqueous volume (below AHD)

- to -12m AHD
  12m x 30m x 3,600 1,296,000m^3

Sub-Total for (a) 1,944,000m^3

Methodology

Introduction to GENESIS

GENESIS is a coastal shoreline and beach topography response model developed by Hanson and Kraus (1989) for the US Army Corp of Engineers. The acronym GENESIS stands for GENEralised model for SImulating Shoreline change, where shoreline evolution is produced by spatial and temporal differences in longshore sediment transport produced by breaking waves and boundary conditions.
Figure 3 shows a structural diagram of the input and output files used in GENESIS

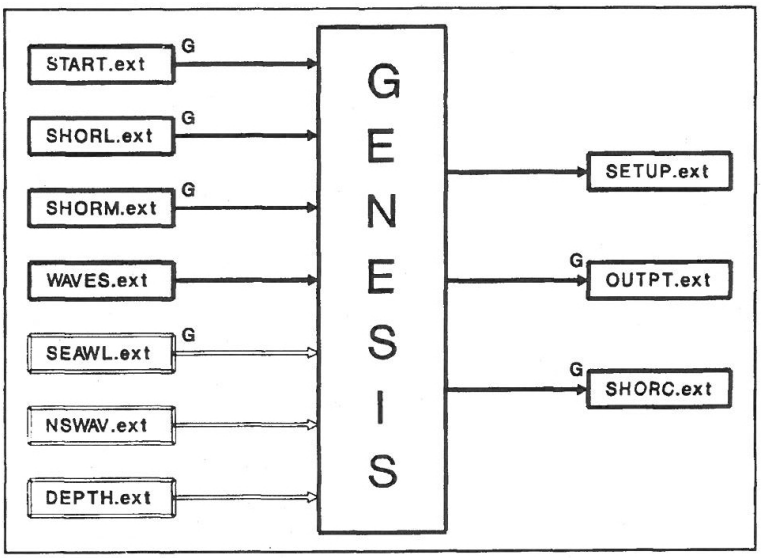

Figure 3: Input and output file structure of GENESIS (Gravens, 1992)

Development of GENESIS model

In order to develop a GENESIS model to simulate sand nourishment at Collaroy-Narrabeen, it was vital that the input files contained a good conceptualisation of the project site, as well as the factors that influence shoreline change.

START file parameters

The 'START' file is the master file that contains the information required to run the simulation. GENESIS requires a range of beach morphology parameters that are specified in the beach section of the 'START' file. These include effective grain size, the depth of closure and berm height.

SHORL & SHORM (Shoreline position)

The first step in constructing the GENESIS grid is to establish a coordinate system. The initial shoreline position is located on this grid so that the oscillation of the shoreline in response to varying wave conditions can be measured. As a result of monthly topographical surveys carried out by a roving RTK-GPS unit, mounted to a quad bike, it was possible to obtain the 0m AHD (Australian Height Datum) shoreline contour for Collaroy-Narrabeen. Each quad bike survey is undertaken at spring low tides to maximise the amount of exposed beach and completed within one tidal cycle to an accuracy of 2cm (Harley and Turner, 2008). Shoreline coordinates from the September 2007 survey were plotted and modified to that of January 2000 using the coordinates at the 0m elevation along the 6 profile lines surveyed routinely by Andy Short.

A longshore axis (x), referred to as a baseline, was chosen and drawn with orientation to True North and a shore-normal axis (y) was then drawn pointing in the offshore direction to create a right hand system. This coordinate system used by GENESIS is shown in Figure 4. In order to reference shoreline positions to the baseline, the coordinates were redistributed at 20 m intervals. This resulted in 159 coordinates representing 3180 m on the ground. The Eastings of the shoreline were then subtracted from the Eastings of the baseline and formatted for entry into the SHORL and SHORM files.

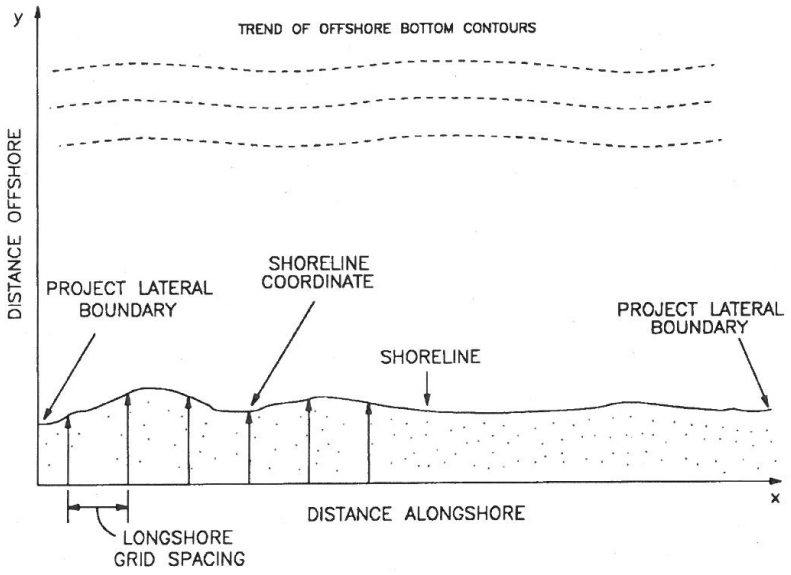

Figure 4: Model coordinate system (Hanson and Kraus, 1989)

SEAWAL (Seawall position)

A series of 526 coordinates at 2 m increments were obtained, representing the location of the ad-hoc seawall. The same method that was used to transform the

Shoreline coordinates described above was performed again resulting in construction of the 'SEAWAL' file.

WAVES (deepwater wave climate)

Wave data for Collaroy-Narrabeen was obtained from the Manly Hydraulics Laboratory (MHL) directional Waverider buoy located in 85m water depth at a latitude of 33˚ 46' 54'' S and a longitude of 141˚ 25'29'' E South. Fourteen years of daily Significant wave height, Peak spectral period and Peak wave direction (degrees True North) between 1993 and 2006 was assessed, and the most complete of the yearly data sets was found to be between the years of 2000 and 2006. This six year wave data set was used for the model simulations.

NSWAVES (nearshore wave climate)

It is well documented that a gradient in wave energy exists along the shoreline at Collaroy-Narrabeen with wave height increasing towards the north when modal wave conditions from the south-east prevail. In order to accurately replicate pre-breaking wave conditions along Narrabeen Beach the wave propagation model SWAN (developed by the US Army Corps of Engineers) was used by Mitch Harley to simulate the nearshore wave climate. The results of SWAN gave daily time series of wave height and direction for the six year data set at 10 equally spaced points along the embayment in 6m water depth.

As the standard application of GENESIS involves the association of many different offshore wave conditions to a single nearshore wave condition, it was found that the nearshore time series of wave information provided by SWAN could not be utilised as input to GENESIS. To see if it was possible to run GENESIS with these series' of wave information, the deepwater wave file (containing height, angle and direction) and corresponding nearshore time series (height and angle) were sent with an explanation and questions to Mark Gravens in the United States, one of the key developers of GENESIS. Mr Gravens assessed the data and altered the code in GENESIS, preparing a unique 'WAVES' file that contained both the offshore and nearshore wave information. The result was a site specific and highly unique version of GENESIS that was able to utilise nearshore the wave time series as calculated by SWAN.

Boundary conditions

Two diffracting groynes, 1,500m long, were used to replicate the effects of Long Reef and Turrimetta headlands. The entrance of Narrabeen lagoon was set as the left (northern) boundary and the southern part of Collaroy Beach as the southern. Groyne permeability, which determined the amount of sand that can be transmitted through the structure, was varied during the calibration process. The specifications of the Collaroy-Narrabeen GENESIS model are illustrated in Figures 5 and 6.

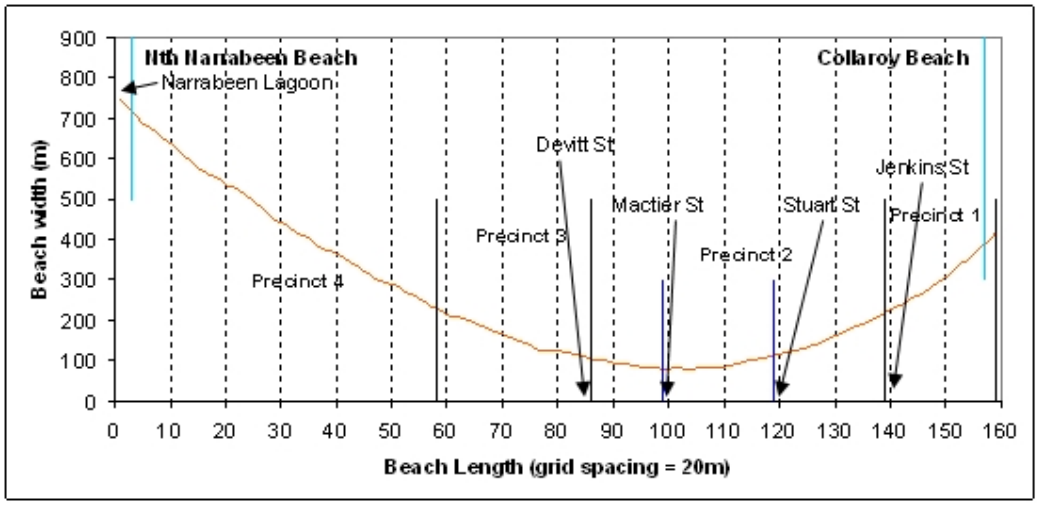

Figure 5: Conceptual GENESIS model of Collaroy-Narrabeen

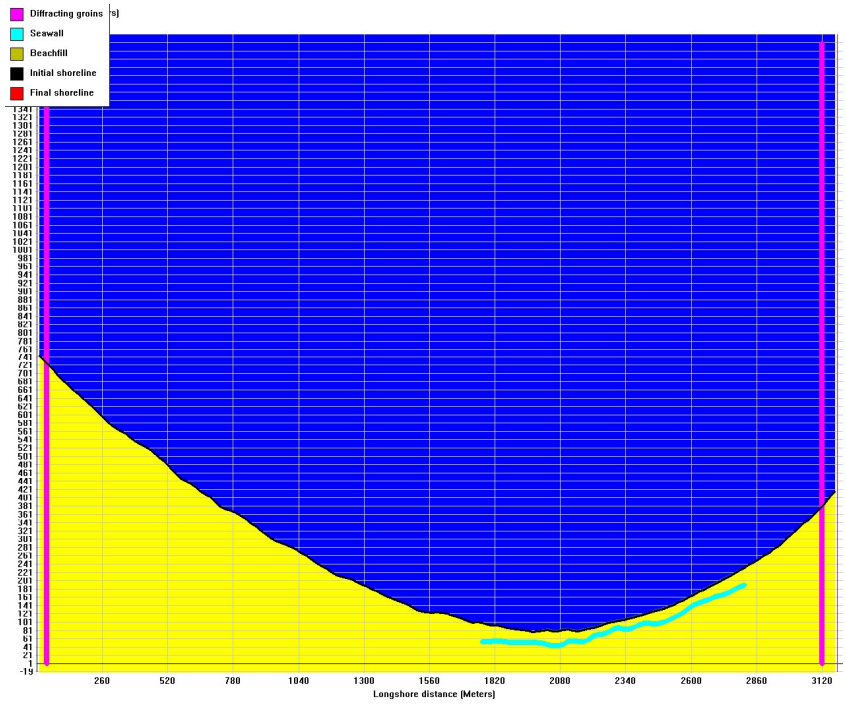

Figure 6: Initial shoreline position represented within the GENESIS graphical interface

Calibration

In order to utilise GENESIS for beach nourishment investigations at Collaroy-Narrabeen Beach, the model must first be calibrated. In order to achieve this, values controlling the magnitude and rate of sediment transport and shoreline change were varied and assessed. Through varying these values calibration was carried out by matching the longshore sediment transport rate over the 6 year period to the average amount of sand known to terminate in Narrabeen lagoon.

Narrabeen lagoon

Coastal processes move sediment northwards from Collaroy to North Narrabeen Beach, where the sand is trapped in North Narrabeen lagoon. Due to increasing urbanisation leading to water quality problems and foreshore flooding, a policy of opening the lagoon entrance through entrance dredging works has been carried out since 1975. Eight major entrance dredging works have been completed to date roughly every three to four years, with volumes of material removed up to 45,000m^3 (Wiecek and Floyd, 2007). The entrance dredging works have the dual benefit of minimising flooding to the surrounding properties and minor beach nourishment for Collaroy Beach. Table 1 shows past entrance clearing campaigns:

Year	Sediment Removed (m^3)	Approximate Duration
1975	150,000	5 months
1979	37,000	1 months
1982/83	60,000	-
1987	40,000	3 months
1990	30,000	4 months
1992/93	56,000	5 months
1995	27,500	4 months
1999	38,000	3 months
2002	40,000	4 months
2006	45,000	2 months

Table 1: Past entrance clearance operations (Wiecek and Floyd, 2007)

Based on the figures above, from 1982 to 2006, the average volume of sand that accumulates in Narrabeen lagoon is approximately 12,460m^3. This value was used to assess the volume of sand passing through the northern groyne (representing Narrabeen lagoon) per year, defining the calibration parameters. Calibration was carried out by varying the initial coefficient values and testing against the six year data set. Use of the final calibration values shown in Table 2 resulted in an average yearly transport rate of 12,695m^3 per year, being within 2% of that estimated as the infilling rate of Narrabeen lagoon (12,460m^3). Table 3 shows the yearly sediment transport values simulated by GENESIS in the final calibration.

Calibration coefficients	
K_1	0.085
K_2	0.0425
Northern groyne permeability	0.11
Southern groyne permeability	0
Groyne length	1500m
Grain size	0.3mm
Berm height	6m
Depth of closure	-12m

Table 2: Coefficients used for final calibration

	Nth Groyne (m^3)
2000	-5831
2001	5,000
2002	22,000
2003	22,000
2004	19,000
2005	14,000
Total	76,170
Average	12,695

Table 3: Yearly sediment transport results from the calibrated GENESIS model, where positive sediment transport volumes are northward moving and negative transport volumes are southward.

Nourishment Results

This section investigates beach nourishment scenarios that were recalculated by Patterson Britton (1993), and modeled by GENESIS. The four scenarios that were modeled include;

- 'Do Nothing'
- Nourishment of Precincts 2 and 3
- Nourishment of Precincts 2 and 3 with a groyne at Devitt Street
- Nourishment of Precincts 2 to 5

The nourishment volumes, shoreline advance, grid cell location and nourishment period for each scenario are outlined in Table 4. The results presented in this section show the initial and final shoreline positions after nourishment was carried out as well as the beach width change. The simulations commenced in January 2000, nourishment was placed between 1st June and 1st October 2002, and the simulation continued until December 2005. All beach lengths described in this analysis are taken as being southwards from North Narrabeen at 0m.

	Precincts 2-3		Precincts 2-5
Nourishment (m^3)	810,000		1,944,000
Shoreline advance (m)	30.82		33.96
Grid cells	85-159		1-159
Nourishment period (June 2002 to September 2002)	4 months	4 months	4 months

Table 4: Beach nourishment specifications for the Patterson Britton (1993) recommendations

'Do nothing'

Figure 7 and 8 show the results after the six year wave simulation when no beach nourishment has been carried out. The initial shoreline and 'Do nothing' shoreline cross several times, showing the alternation between eroding and accreting beach states along the compartment. From North Narrabeen 400m along the beach, the shoreline accretes by a maximum width of 30m before eroding to a maximum width of 25m between 400 and 800m beach length. The beach state then alternates again, with accretion peaking at a width of 30m, between the northern focal point (an area where the sediment transport changes direction) at 940m to 2,200m, before steady erosion of 30m southwards from this focal point along to Collaroy Beach.

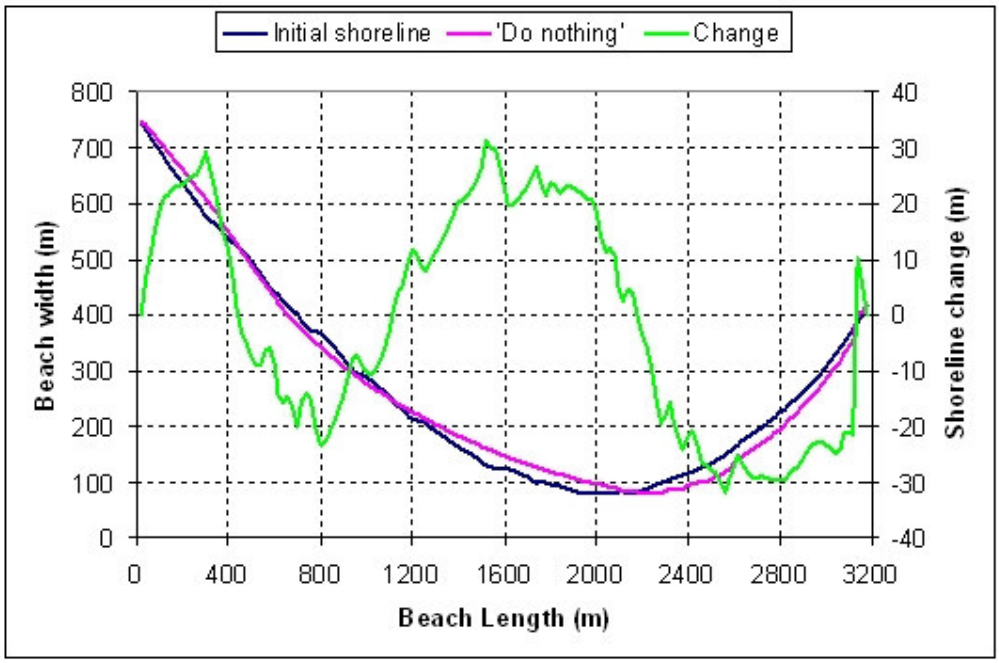

Figure 7: The 'do nothing' scenario showing the initial and final shoreline positions and the degree of change

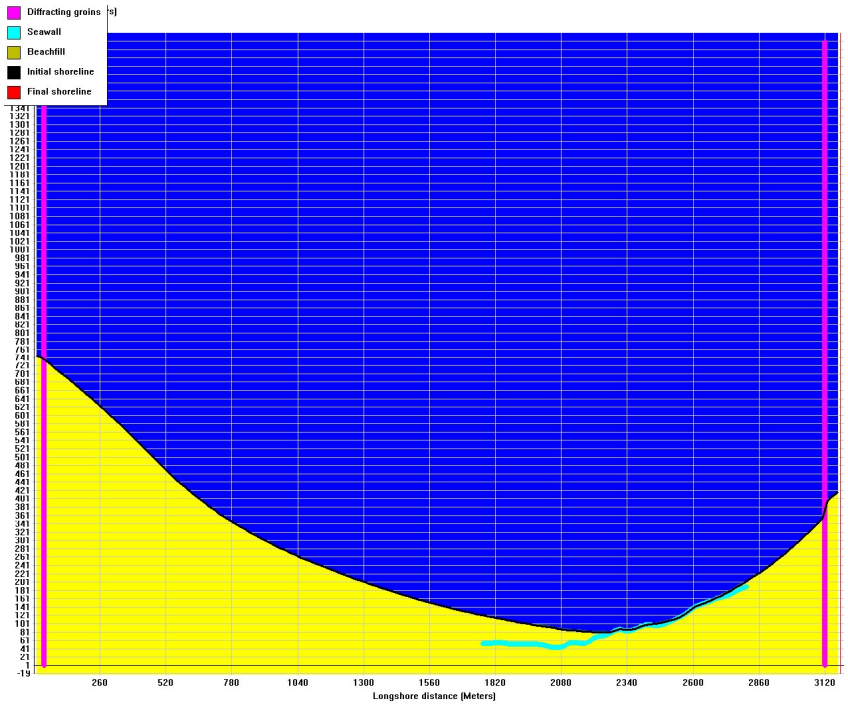

Figure 8: The 'do nothing' scenario represented in the GENESIS graphical environment.

Nourishment of Precincts 2 and 3

Figure 9 and 10 show the shoreline configuration when Precincts 2 and 3 are nourished. A similar pattern of shoreline change to that observed in the 'do nothing' scenario is seen, but on a slightly different magnitude. There is accretion from the northern focal point at 1,080m out to a maximum of 50m in the middle compartment of the beach, with a smaller magnitude of erosion southwards of the focal point which has shifted southwards to 2,500m.

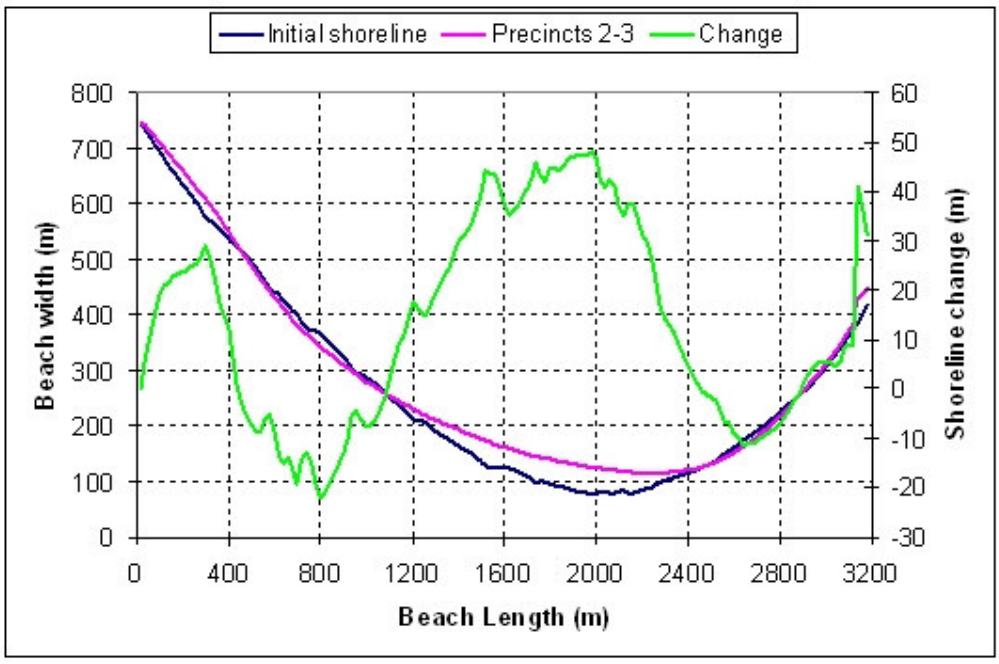

Figure 9: Nourishment of Precincts 2-3 showing the initial and final shoreline positions and the degree of change

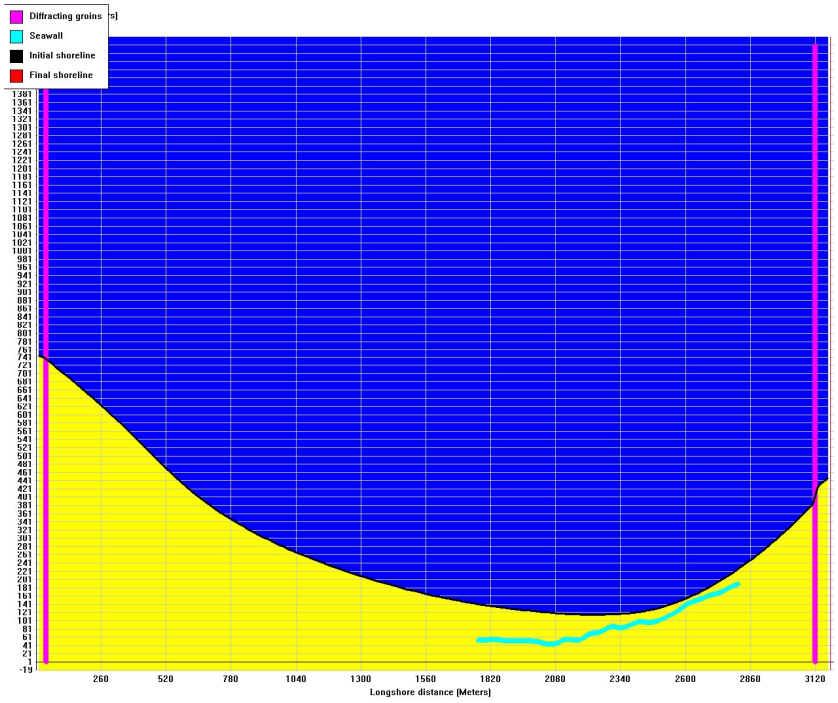

Figure 10: Nourishment of Precincts 2-3 represented in the GENESIS graphical environment.

Nourishment of Precincts 2-3 with a groyne at Devitt Street

Figure 11 and 12 show the nourishment of Precincts 2 and 3 with a groyne located at Devitt Street (1,720m along the beach). The shoreline configuration shows a remarkable build up of sand on the southern side of the groyne with accretion out to 80m from the initial shoreline position. There is 40-50m of erosion immediately northwards of the groyne and good beach width in the vicinity of the ad-hoc seawall.

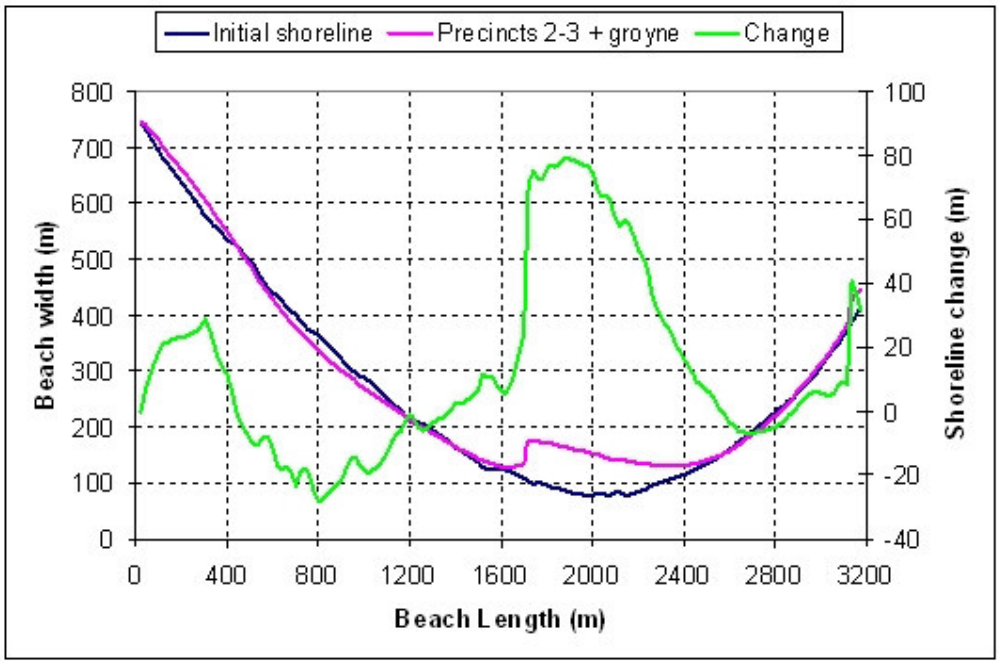

Figure 11: Nourishment of Precincts 2-3 with a groyne at Devitt Street showing the initial and final shoreline positions and the degree of change

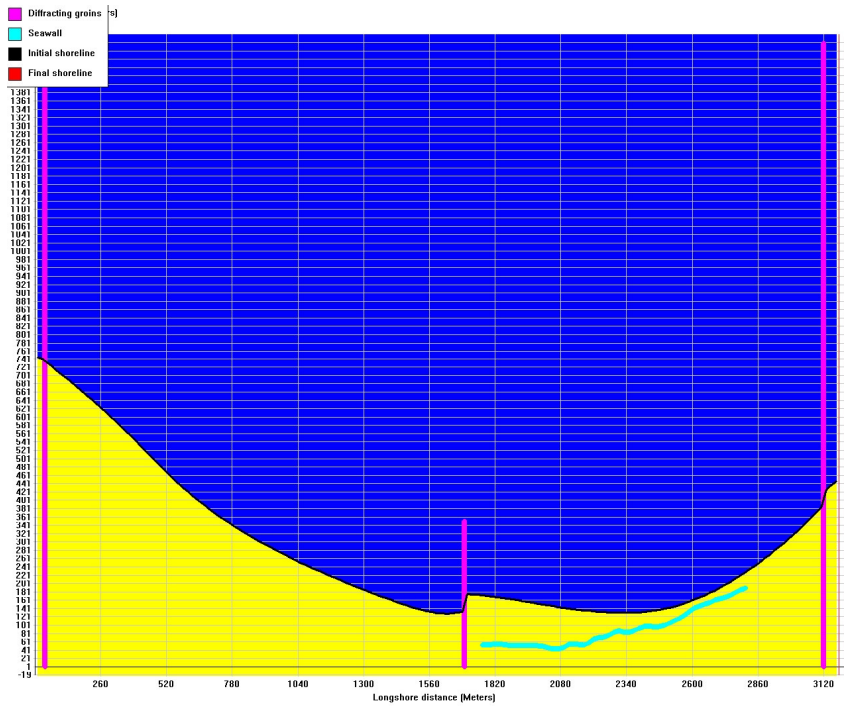

Figure 12: Nourishment of Precincts 2-3 with a groyne at Devitt Street represented by the GENESIS graphical environment.

Nourishment of Precincts 2-5

Figures 13 and 14 show the shoreline position when 1.2 million m^3 of sand is equally distributed along the shoreline. It is important to note that NLA (1988b) recommend that a groyne would be needed at the entrance of Narrabeen lagoon to prevent sediment from infilling the lagoon. Modelling of the groyne was attempted, however as shoreline results and sediment transport results did not change, no further presentation of these results are provided. When the entire beach is equally nourished the equilibrium profile after six years is similar to the 'do nothing' scenario, only further seaward.

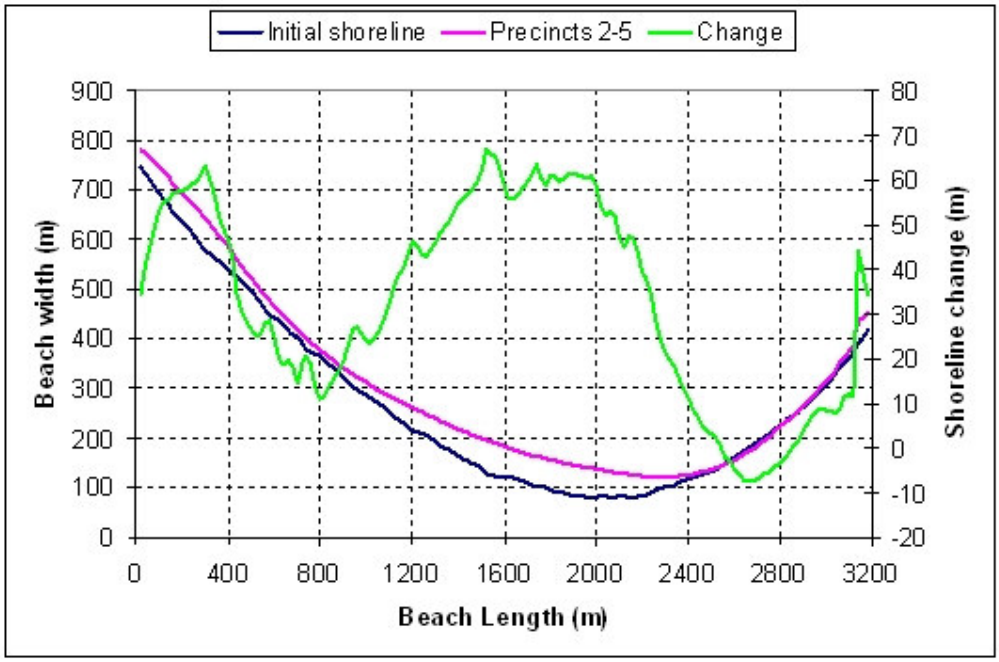

Figure 13: Nourishment of Precincts 2-5 showing the initial and final shoreline positions and the degree of change

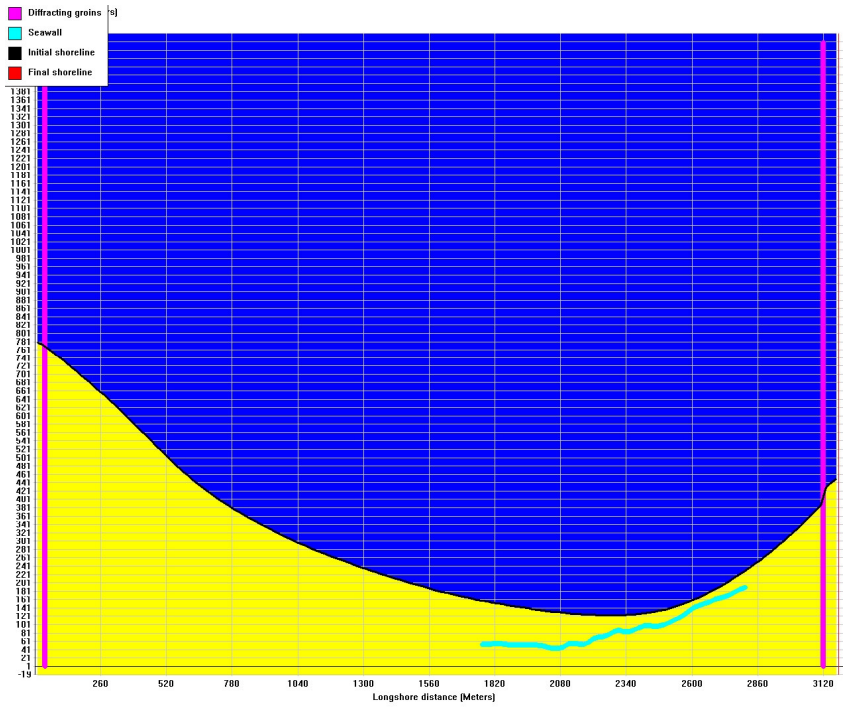

Figure 14: Nourishment of Precincts 2-5 represented in the GENESIS graphical environment.

Nourishment Progression

The shorelines at the end of the 2nd, 4th and 6th years during the six year simulation and the shoreline progression change was plotted for each of the three nourishment scenarios set out by Patterson Britton (1993). The aim of this was to see how the shoreline evolved from its initial position, to the final nourished profile and where the nourishment moved within the beach compartment. Figure 15 and 16 show these results for nourishment of Precincts 2 and 3.

The initial 2001 shoreline and the remaining 2002-2005 shorelines show that there was no difference between the first year of simulation and the remaining five years from North Narrabeen along to the lagoon. For the remaining section of the beach there is a notable difference between the 2002 and 2003-2006 shorelines as the beach steadily accretes along to 2,400m and then steadily erodes from the southern focal point to Collaroy. These results show that the six year data set used in the simulations was not long enough for the nourished material to gradually move northwards to the lagoon.

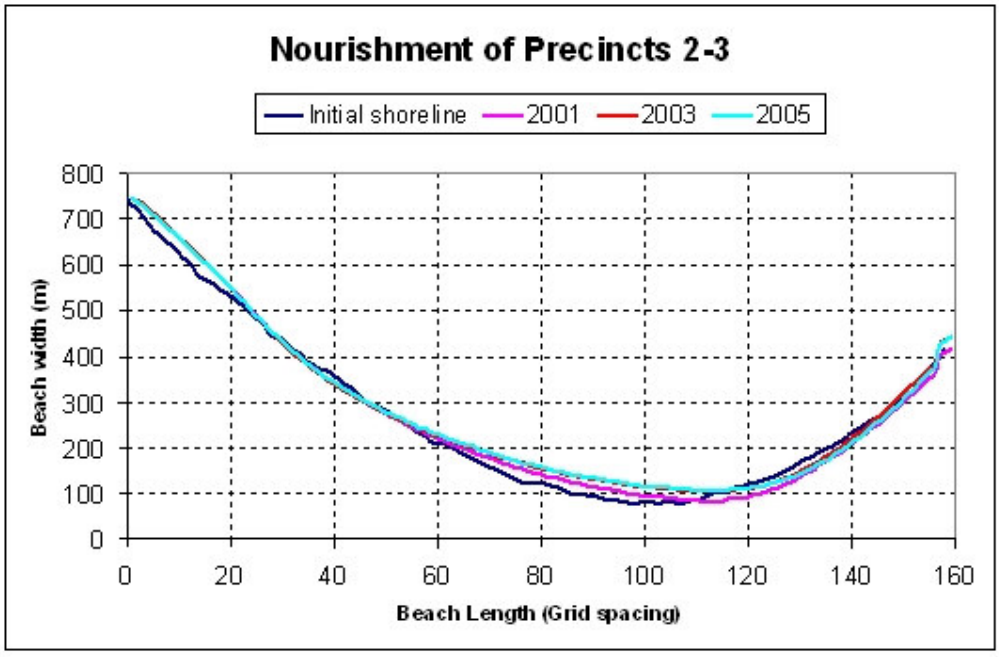

Figure 15: Bi-yearly shoreline progression when Precincts 2-3 are nourished

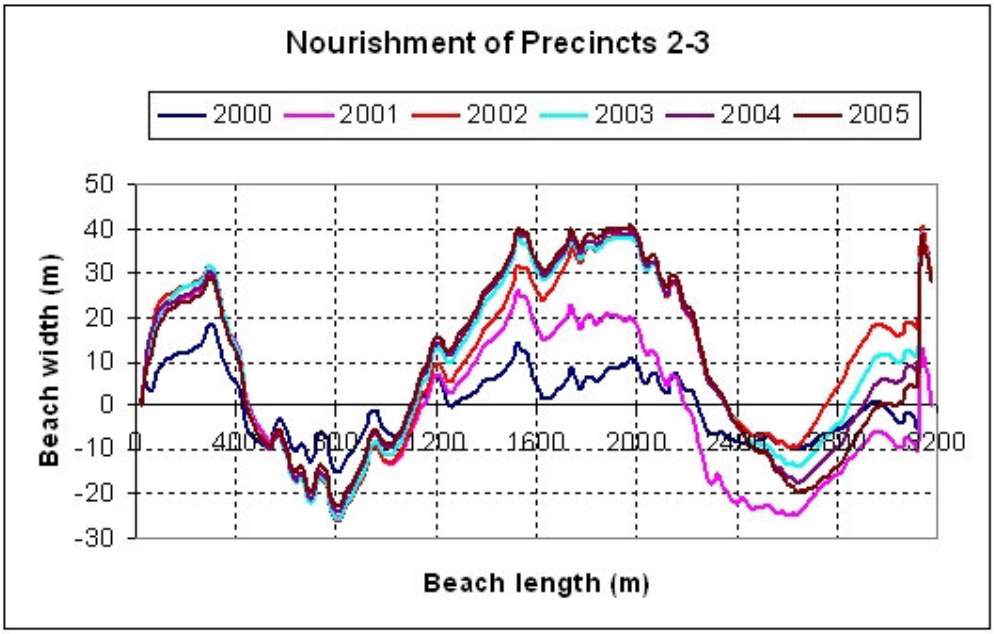

Figure 16: Yearly shoreline change when Precincts 2-3 are nourished

Discussion

A successful beach nourishment campaign will require comprehensive knowledge of the coastal processes dominating the Collaroy-Narrabeen embayment. This includes a quantitative assessment of nourishment evolution and an understanding of the main processes that will affect the fill performance. The purpose of running the 'do nothing' simulation was to identify how GENESIS modelled medium term coastal processes and the implications that these processes would have on the fate of the nourished material. This baseline 'do nothing' scenario shows that GENESIS has identified compartments alongshore that are particularly prone to erosion and these areas are characterised by a series of three focal points located along the embayment.

Beach Oscillation

Acworth (2004) undertook REF DIF modelling to determine wave heights along the shoreline at Collaroy-Narrabeen. The results of the modelling clearly showed shadow areas or zones of reduced wave height along the embayment when the modal wave from the north east, east and south east was simulated. It was concluded that these shadow zones were due to the effects of refraction, and convergence and divergence of the waves as they refract and diffract due to the underlying bathymetry and boundary conditions. It seems reasonable that GENESIS is identifying these shadow zones (focal/pivot points) alongshore in response to the nearshore wave climate and the longshore sediment transport in these areas is responding through setting up compartments of increased and reduced sediment transport.

Shoreline evolution of all the nourished scenarios was found to follow the same pattern of shoreline oscillation as described by the 'do nothing' scenario. Through analysing the results it is interesting to note the shifting of the northern and southern major focal points and the corresponding shifting and extension of the location of the accreting and eroding compartments. Movement of these focal points with different placement scenarios and with larger volumes of sediment, in particular the southward shifting of the southern point, has great effects on the location of the shadow zone of erosion that extends to Collaroy. The exact location of the focal point and the location of the corresponding shadow zone will cause significant localised erosion along Precincts 2 and 3, which are the most vulnerable locations.

These results indicate that the nourishment material is finding equilibrium with the medium term coastal processes, and, although deposition of large volumes of sand will not change the sediment transport effects of the heavily refracted embayment, the material will bring the beach further seaward, providing more protection for foreshore properties.

Limitations to GENESIS

It is well recognised that GENESIS has a number of limitations that restrict the accuracy of the results. The keys limitations of GENESIS are that it is a one line model that represents the nearshore profile as a single line, essentially making the assumption that the profile erodes or accretes uniformly over the vertical height from the upper berm down to the depth of closure. Also, GENESIS does not cater for any cross-shore transport. Coastal hazards at Narrabeen have been described as being cross shore variation and long term beach recession. From the results presented and the limitations and assumptions of GENESIS it would seem that there is a significant longshore sediment transport component operating at medium to long-term timescales at Collaroy-Narrabeen, with short term cross shore processes likely to be interrelated and superimposed, amplifying and exacerbating erosional trends.

Although the cross shore variation cannot be separated and determined with the use of GENESIS, the longshore component contributing to long term beach recession has been successfully modelled. In taking these results it would seem a likely conclusion that the amount of beach nourishment must be able to cater for the long term beach recession, due to longshore sediment transport, losses from the depth of closure and sea level rise as well as short term storm demand.
.

Recommendations and conclusion

In assessing the most effective nourishment option, it is important to keep in mind the objectives of Patterson Britton (1993). These were:

- to provide protection for all beachfront development at threat; and
- to maintain and enhance the recreational amenity of the beach.

Although the first of the two objectives is relatively straightforward, the second is highly ambiguous, with different people having various definitions of 'recreational amenity'. In order to provide protection to all beachfront development at threat, the Patterson Britton (1993) nourishment option of Precincts 2 and 3 with a groyne at

Devitt Street would be the most effective. This option extends the zone of accretion by 460m from the 'do nothing' scenario, with the beach accreting out to a maximum of 80m with a relatively small degree of erosion along Collaroy. Although there is a localised zone of approximately 40m of erosion immediately northwards of the groyne, this could be counteracted by placement of 200,000 m^3 of sand in Precinct 4, immediately north of the proposed groyne structure (Patterson Britton, 1993). This sand would act to accommodate the existing ongoing sediment losses along Precincts 4 and 5 as well as account for the interruption to littoral supply to this section of the beach due to construction of the groyne (and may however, move into the lagoon). The foreshore area immediately northwards of the proposed groyne is used as a recreational area and there is no development along this stretch of beach.

In making this recommendation it is important to point out that nourishment of the entire embayment would also act as an effective option to provide protection for all beachfront development at threat. However, as the time series utilised in this modelling exercise was not long enough to observe sand nourishment moving along the beach and into the northern compartment, it is likely that, as predicted by both NLA (1988b) and Patterson Britton (1993), a groyne or training wall would be needed along North Narrabeen to prevent the lagoon from gradually infilling.

Structural options are needed to contain the nourishment and fulfil the first objective; however, a traditional rock structure would revoke the second objective of maintaining and enhancing the recreational amenity of the beach. A groyne at North Narrabeen is likely to destroy a world class surfing break, while a groyne at Devitt Street is likely to have less of an impact on the beach amenity but is also not highly favoured by the community. It is suggested that a geotextile structure could be implemented at Devitt Street, allowing for the nourishment to be contained while not compromising beach amenity to the same degree as a traditional rock boulder groyne. Such structures have been used at various locations along the Australian coastline and generally provide a more aesthetic, user-friendly environment.

References

Acworth, C.A. (2004). Methodology for predicting berm elevation along the NSW coastline. Unpublished Honours thesis: School of Geosciences, University of Sydney.

Benedet, L., Finkl, C.W., & Hartog, W.M. (2007). Processes Controlling Development of Erosional hotspots on a beach nourishment project. Journal of Coastal Research 23 (1) 33-48.

Gravens, M.B. (1992) Shore protection and restoration program instruction report, CERC-92-1 User's guide to the shoreline modelling system (SW). Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hanson, H., and Kraus, N. C. (1989). GENESIS: Generalized Model for Simulating Shoreline Change, Report 1, Technical Reference, Technical Report CERC-89-19, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Harley, M.D., and Turner, I. L. (2008). A simple data transformation technique for pre-processing survey data at embayed beaches. Coastal Engineering 55: 63-68.

NLA (1988a) Narrabeen-Collaroy Fisherman's Beach coastal management strategy, phase one: hazard definition, April 1998: report of the coastal management steering committee, prepared by Nielsen Lord Associates, Report No. 87020.01.003, Sydney Prepared for Warringah Shire Council.

NLA (1988b) Narrabeen-Collaroy Fisherman's Beach coastal management strategy, management options, December 1988, report of the coastal management steering committee, prepared by Nielsen Lord Associates, Report No. 88013.01.001, Sydney Prepared for Warringah Shire Council.

NLA (1988b) Narrabeen-Collaroy Fisherman's Beach coastal management strategy: management options Appendices, February 1989, Nielsen Lord Associates and Travers Morgan Pty Ltd, Sydney. Prepared for Warringah Shire Council

Patterson Britton (1993). Collaroy-Narrabeen Beach nourishment investigations, July 1993, Patterson Britton & Partners Pty Ltd, Sydney. Prepared for Warringah Council

Patterson Britton (2003). Narrabeen lagoon entrance clearing operation post completion report. Prepared for Warringah Council by Patterson Britton & Partners Pty Ltd.

Public Works Department (1987). Collaroy-Narrabeen Beaches – Coastal Process Hazard Definition Study, December 1987, Public Works Department Report No. 87040, 1987 Prepared for Warringah Shire Council.

Warringah Shire Council (1985). Coastal management Strategy, Warringah Shire Council, 1985, Sydney.

Warringah Council, (1997). Collaroy-Narrabeen Coastline Management Plan. A Coastline Hazards Policy Plan of Management. Warringah Council, 1997, Sydney.

Wiecek, D. and Floyd, J. (2007). Does dredging in ICOLL entrances improve tidal flushing? Published on the website:
http://www.coastalconference.com/2007/papers2007/Danny%20Wiecek.pdf