MODELLING THE SHORELINE IMPACTS OF RICHMOND RIVER TRAINING WALLS

D Patterson[1]

[1]BMT WBM / University Of Qld, Brisbane, QLD

Introduction

The construction of river entrance training walls is generally aimed at improving navigability of the river mouth where waves and shifting sand shoals otherwise cause shallow and dangerous conditions. Where they are located on coastlines with significant net longshore sand transport, they potentially impact on the adjacent shorelines by interrupting the natural flow of sand along the coast, at least temporarily. The updrift shoreline and, over time, the bar area accrete by trapping the longshore transport. Correspondingly, the downdrift shoreline erodes because the supply there is reduced while the transport away continues, although there may be a localised area of accretion immediately downdrift adjacent to the structure. Where there is gross sand transport back and forth but little or no net transport, the training walls may cause accretion in the immediate vicinity with erosion further away on both sides.

The Richmond River training walls at Ballina (Figure 1) were constructed over a 20 year period from about 1890 to 1910 (WBM Oceanics, 2003; Helman, 2008). The north wall was extended during the 1960s. Huang et al (1999) studied the adjacent shoreline changes between 1947 and 1991 from photogrammetric analysis and concluded that:

- The walls caused accretion at both South Ballina and Lighthouse Beach;
- Storm erosion in 1974 caused extensive erosion of all beaches in the area and temporarily disrupted the prevailing trend of adjacent shoreline changes;
- After an initial high rate of shoreline change, by 1981-1991 an equilibrium shoreline position was being approached; and
- By that time, total sand bypassing of the walls had been restored.

Figure 1: Richmond River training walls

WBM Oceanics Australia (2003) analysed the photogrammetric data for the period between 1947 and 2000 and also reviewed other available information on changes following wall construction, finding that there was a significant northward net longshore sand transport, possibly as high as 350,000 m^3/year at the time of wall construction, with associated substantial accretion along about 8 to 10 km of the shoreline south of the walls. Patterson (2007b) analysed longshore transport rates along the whole region from Iluka to the Gold Coast and found a consistent progressively increasing pattern of net transport, with a contemporary rate at South Ballina of about 260,000 m^3/year that may have been higher prior to training wall construction.

This pattern of significant northward net longshore transport and extensive shoreline accretion south of the walls suggests that there would have been a corresponding large-scale net loss of sand further north. This may have affected beaches north to Lennox Head (Figure 2). This has been assessed by the modelling undertaken, as outlined below.

Figure 2: Beaches north of Ballina

Measured Historical Shoreline Changes

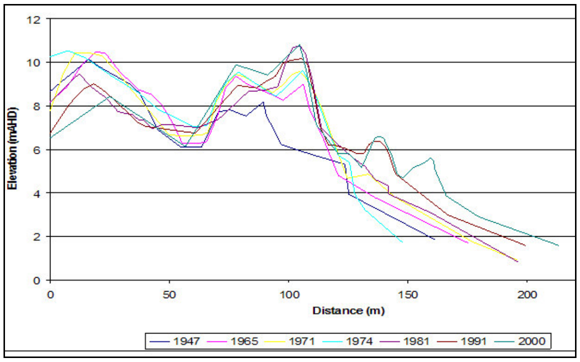
Photogrammetric Data

The photogrammetric data represents the only reliable source of quantitative information on shoreline changes in the region. The earliest date of suitable photography is 1947, some 55 years after commencement of the training wall construction. This data shows only the behaviour above the water level, potentially missing a large proportion of the total profile changes. Examples of the photogrammetry are shown in Figure 3 for South Ballina, Lighthouse Beach, Angels Beach and Seven Mile Beach (Lennox Head).

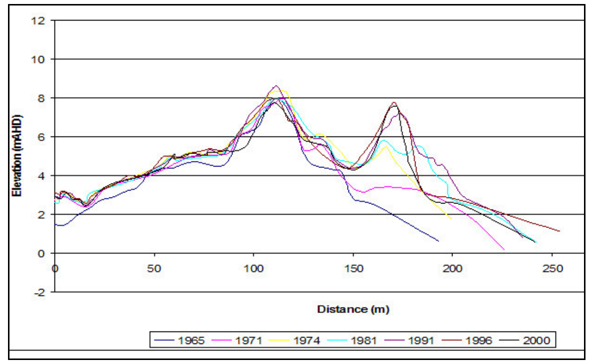
This data shows that:

- There had been considerable erosion of the main 10m high dune system north from Angels Beach to Seven Mile Beach prior to 1947;
- There is a lag in the major dune erosion with distance north, Seven Mile Beach still showing progressive retreat well after the beaches closer to Ballina had reached their most landward position;
- The erosion of the beaches north of Ballina continued through to 1967 – 1974 after which the dune system has accreted at a lower level of about 5m;

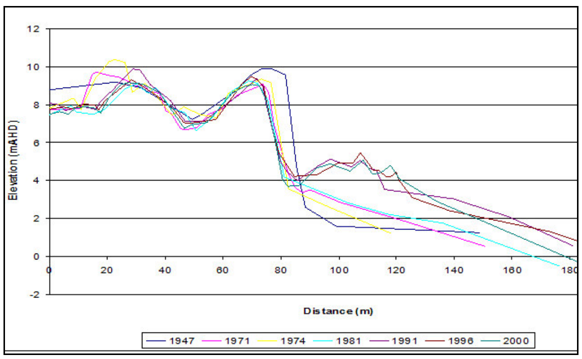
- There was apparent erosion with a steep scarp at South Ballina through to 1974, after which that beach and dune system has shown steady accretion; and
- Lighthouse Beach has experienced significant accretion of a substantial dune system since 1947.



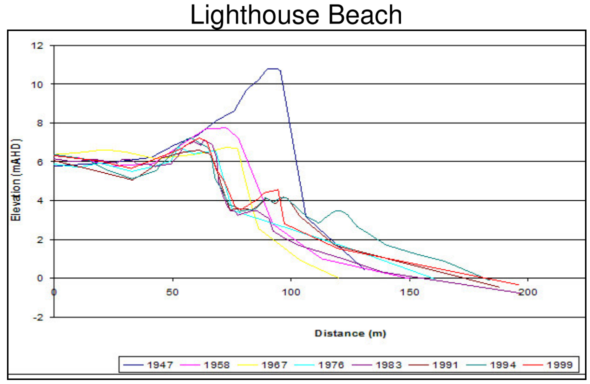
South Ballina



Lighthouse Beach



Angels Beach



Seven Mile Beach (Lennox Head)

Figure 3: Photogrammetric data (from WBM Oceanics 2003)

Observed Erosion Sequences

Anecdotal evidence is that the most severe erosion events in memory occurred in 1954, 1967 and 1974 (WBM Oceanics 2003). The 1954 cyclone tracked over Tweed Heads at 985 Hpa causing major erosion south from the Gold Coast. A series of cyclones affected the area in 1967 and the dune was temporarily breached through to Lake Ainsworth (Ardill & Assoc., 1988). Cyclones Pam and Zoe struck northern NSW in February and March 1974 with more severe beach erosion. The photogrammetric data clearly incorporates that erosion, as identified by Huang et al (1999).

WRL (1986) notes that the Richmond River training walls have had an effect on the movement of sand along the coast and the erosion at Lennox Head could be linked to this. Ardill & Assoc. (1988) records that the original 1884 subdivision there has a roadway reserve 100m wide from HWM and that newspaper articles observe considerable erosion between 1922 and 1946, with rock protection works commencing in the early 1940s. Recession from the top of bank on a 1922 plan to the top of the scarp in 1947 was about 20m. Helman (2008) records the retreat and breaching of the dune to a freshwater hind-dune lagoon at the southern end of the township sometime soon after 1913.

Existing coastal system processes

Geological evidence suggests a long term trend of shoreline recession at Lennox Head and Seven Mile Beach, with an exposed tree stump dated at 3,765 (±70) years BP exposed on the peat nearshore reef there (Geomarine 1990), indicating a former dune barrier seaward of that. Patterson (2007b) analysed longshore transport rates along the whole region from Iluka to the Gold Coast and found a consistent progressively increasing pattern of net transport, with a contemporary rate at South Ballina of about 260,000 m^3/year increasing to over 400,000 m^3/yr at Tallow Beach (Figure 4). This gradient in longshore transport could be construed as the cause of the erosion at Seven Mile Beach.

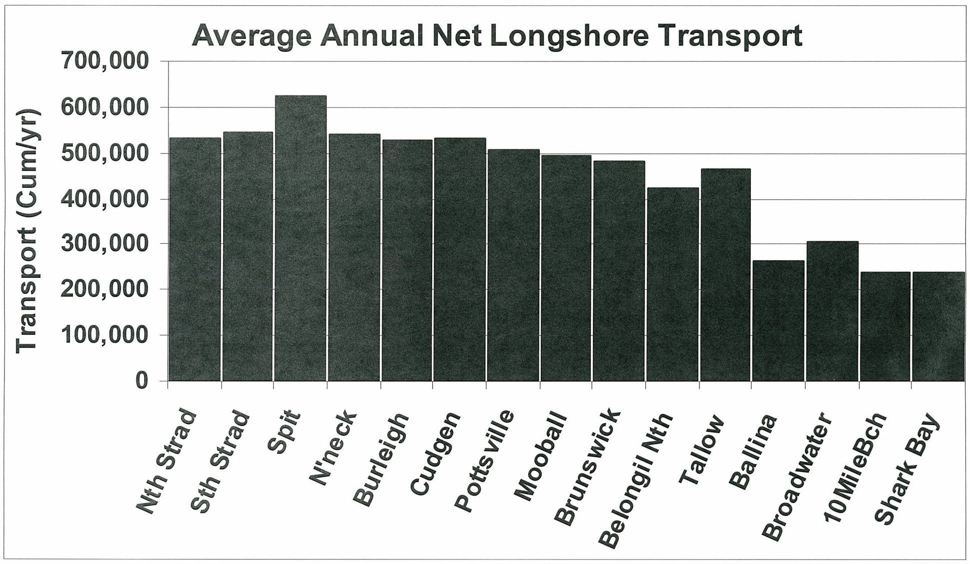


Figure 4 Calculated Annual Net Longshore Transport Rates (Patterson 2007b)

However, it has been hypothesised (Roy, 2001; Cowell et al, 2001; Goodwin et al, 2005) that there may be an onshore supply of sand to the beaches from the inner shelf area where the profile slope is flatter than the commonly observed 'equilibrium' slope of about 1 degree (1:55). This supply compensates for the sand loss due to the longshore transport gradient. The so-called Byron sand lobe that extends south from Cape Byron to around Ballina is a feature that creates such flatter profile slopes (Figure 5). Analysis by the writer of profile changes over the period 1966 to 2002 at The Spit, Gold Coast where the profile has a disequilibrium bulge compared with adjacent areas (eg Broadbeach) (Figure 5) indicates the potential for an onshore supply of sand into the active upper profile of about 5-10 m^3/m/yr at depths of 12 to 15m, reducing to 1 m^3/m/yr at 18m (Patterson 2007a).

The writer has developed an empirical relationship for calculating the annual average onshore supply rate for the wave climate and sand properties along this region as functions of water depth and seabed slope (refer below). Applying this to the profiles at the Byron sand lobe suggest onshore supply rates of about 5 m^3/m/yr at 15m depth, reducing to zero further south at South Ballina. This supports the hypothesis that there is a residual supply of sand to these beaches that needs to be catered for in the modelling.

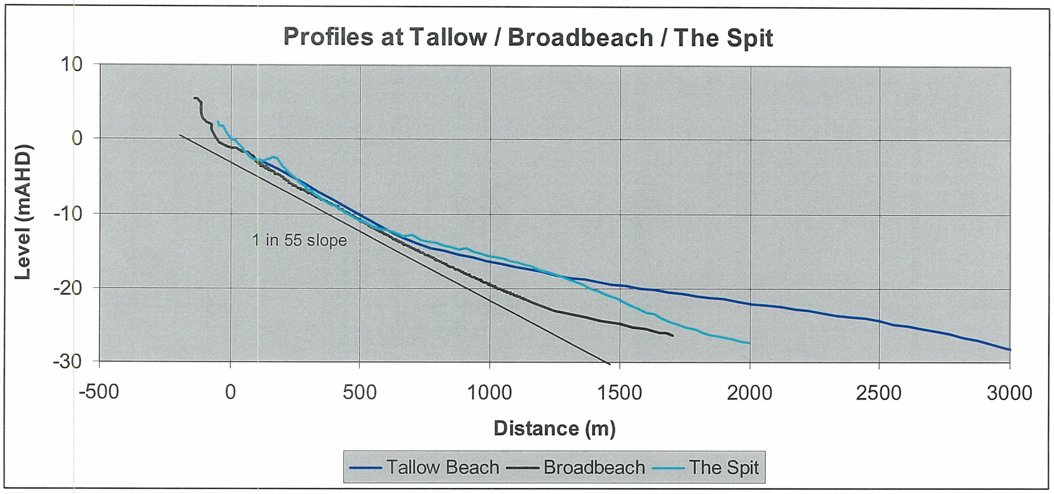


Figure 5 Byron sand lobe profile

Shoreline Modelling

Modelling Software

Shoreline evolution modelling has been undertaken with a new innovative shoreline evolution modelling software package developed by the writer as part of his doctoral research into long term Pleistocene-Holocene coastline changes in the region. The model provides for a range of features and processes not available in other packages, including large-scale sea level change, bedrock features that may be submerged reefs or headlands depending on the sea level at any time, two-dimensional coastline and continental shelf representation, long term cross-shore sand transport in water depths beyond the upper profile zone of frequent storm erosion exchange and versatile representation of breakwaters and rivers.

The model is based on the fundamental one-line theory to describe variations in the cross-shore shoreline position (x) as a function of alongshore distance (y), using equation 1:

$$\frac{\partial x}{\partial t}+\frac{1}{(D_d+D_{cl})}\left[\frac{\partial Q}{\partial y}-q_{on}\right]=0 \qquad (1)$$

where Q is the longshore transport, D_d is the dune height, D_{cl} is the depth of closure and q_{on} is the onshore transport per metre length of shoreline from outside the depth of closure, within the model framework as illustrated in Figure 6.

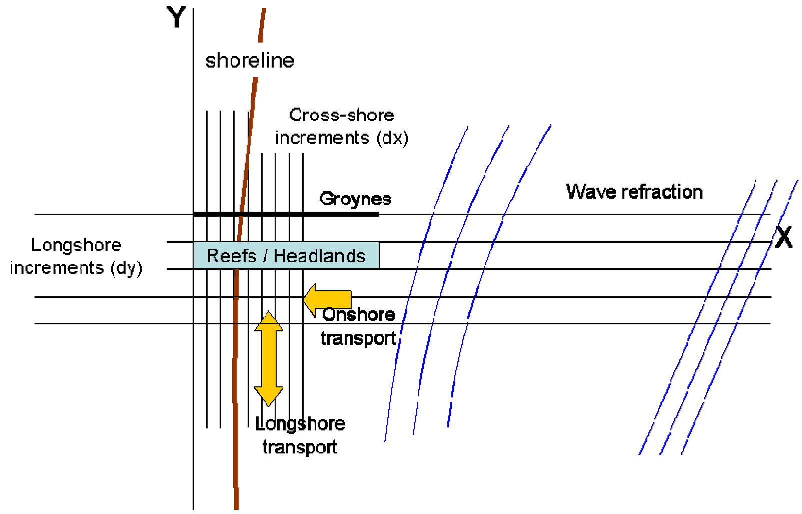


Figure 6: Modelling software schematisation

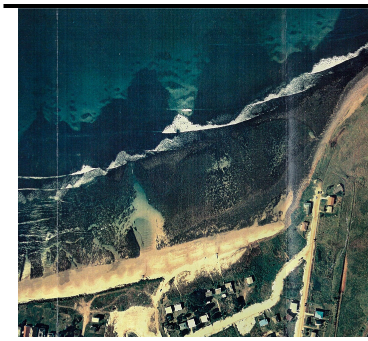
The model is run in time-stepping increments driven by time series of deep water waves and sea level. The waves are refracted using linear theory in four steps to the breakpoint with progressively varying depth contour alignments, thereby overcoming the constraint of straight and parallel depth contours and small shoreline angles to the alongshore Y axis. The longshore transport Q is calculated using the conventional CERC formula. For this modelling, q_{on} is based on annual average rates derived from analysis of profile changes at The Spit, Gold Coast (Patterson 2007a) as:

$$q_{on} = q_p \left(1 - \frac{S}{S_{eq}} \right)^n \quad (2)$$

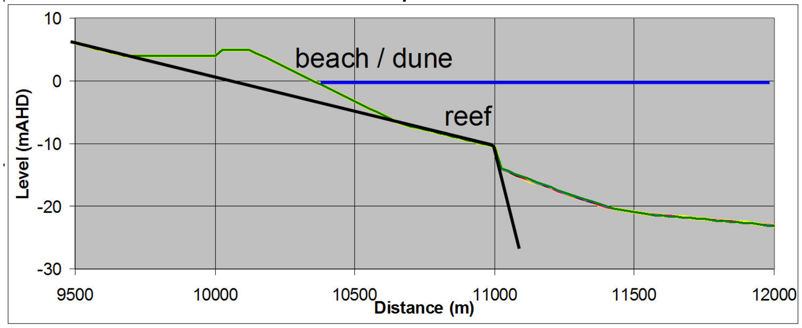
where q_p is the potential transport for a flat seabed derived for this modelling for $n = 0.4$ adopted as giving the best fit with the data, S is the bed slope and S_{eq} is the equilibrium bed slope derived from measured Gold Coast profiles as f^n(depth).

The model

The modelled coastline is complex with extended sections of headlands and small beaches perched on sloping bedrock. Lennox Head has a shallow reef structure extending over 200m out from the shoreline (Figure 7). A key feature of the model software is its highly flexible representation of bedrock features and structures such that this coastline may be simulated reasonably well. For example, headlands and reefs are represented as structures that occupy whole elements whereas groynes are located at the boundary between elements. Reefs may be set at any level and with any seaward extent and slope (Figure 7).



Lennox Head reef (1977)



Reef representation in model

Figure 7 Sloping reef representation

Further, the coastline south of the river faces southeast and the longshore transport regime is critically dependent on the southerly swell for the northward net transport there (Patterson 2007b). The use of suitable deep water wave data and the multi-step wave refraction process deals with this. The alignment of the 15m depth contour is progressively updated as the shoreline position and alignment change, giving realistic calculation of the nearshore refraction and breaking wave angles to the shoreline.

The model extent is illustrated in Figure 8. It has 240 alongshore elements of 250m length (60,000m) and 2,000 cross-shore elements of 25m length (50,000m) extending seawards from behind the dune to beyond the edge of the continental shelf. The coastline was represented directly as the prototype plan shape and the continental shelf slope approximated at each longshore element from chart depth data.

Figure 8: Model extent and grid element representation

Model simulations

The model uses a repeated 5 year cycle of recorded waves off Cape Byron. The model was calibrated to give an average annual net longshore transport of about 320,000 m^3/year at the Richmond River without the training walls. An onshore supply to the beaches was applied, increasing from zero near Ballina to 5 m^3/m/yr at Suffolk Park / Tallow Beach, as discussed above.

Following an initial 'warm-up' period of 100 years to establish an essentially stable balance of shoreline processes, the model was run over three 200 year simulation periods commencing at 1895, all with identical longshore and onshore transport relationship settings, representing:

- **Scenario 1:** The base case without training walls or sea level rise;
- **Scenario 2:** The historical case with training walls to date and projected to year 2095 without sea level rise; and
- **Scenario 3:** Scenario 2 with 0.5m sea level rise from year 1995 to 2095.

It was adopted for modelling purposes that the training walls were established over the period 1895 to 1910. Predictive modelling to year 2095 without and with sea level rise has been undertaken to assess the likely trend of shoreline change to date and over the next 100 years as well as the relative impact of 0.5m sea level rise over the next 100 years. The seawalls at Lennox Head are not represented. Modelled shoreline changes there are thus equivalent to those occurring without the control of those structures.

While the model may not have been perfectly in balance in terms of longshore / onshore transport and shoreline stability at the start of each scenario run, it is to be noted that the true nature of such balance is not actually known and, by using the model as a tool to facilitate analysis relative to the baseline case, the incremental impacts of the training walls and sea level rise should be reasonably well identified.

The model results have been correlated against the measured beach/dune quantity changes from the photogrammetry for the period after 1947 for Angels Beach and Lennox Head (Figures 9 and 11 respectively with locations of Lennox Head survey blocks shown in Figure 10). The model indicates that substantial impacts of the training walls had already passed along the coastline prior to 1947 and some subjective benchmarking of the sand quantity change at that date was needed. Furthermore, in correlating the model and measured quantities, provision must be made for the beach/dune erosion due to the storm erosion, which affected the area during the 1950s to 1970s, particularly 1974 (Huang, 1999), and the subsequent recovery of the dune system associated with short term cross-shore exchanges of sand that are not included in the model simulations.

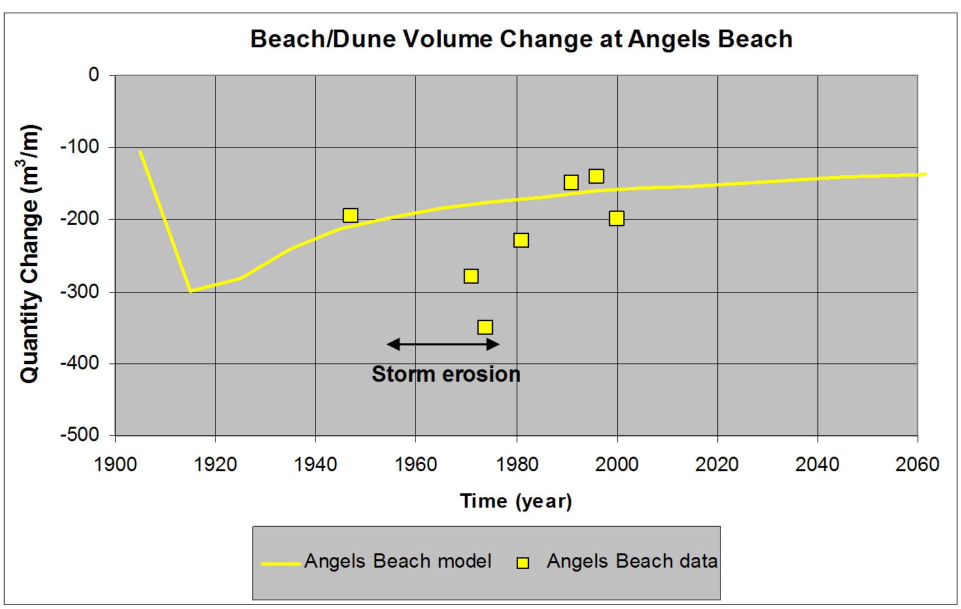


Figure 9: Model versus measured beach/dune quantity changes at Angels Beach

It is of note in Figure 10 that Blocks 1 and 2 cover the area of nearshore reef whereas Blocks 3 and 4 are north of any apparent reef, allowing more recession. The model results in Figure 11 also show the predicted trend of change at Lennox Head in the absence of future sea level rise, indicating some further recovery of the shoreline at the southern end of Lennox Head and relative future stability along Seven Mile Beach.

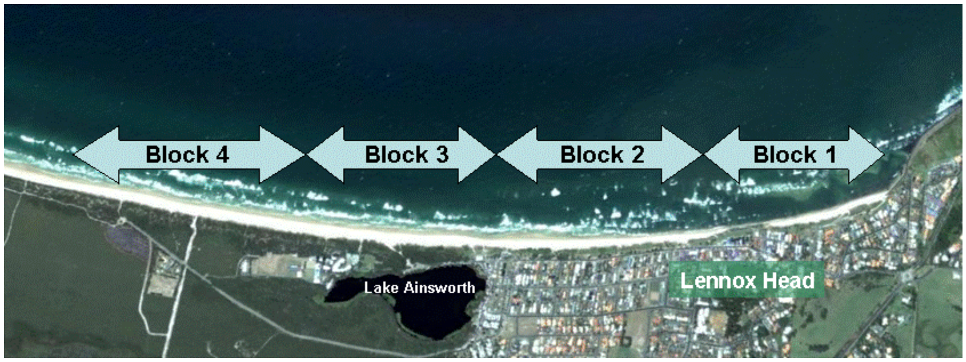


Figure 10: Location of photogrammetry blocks at Lennox Head

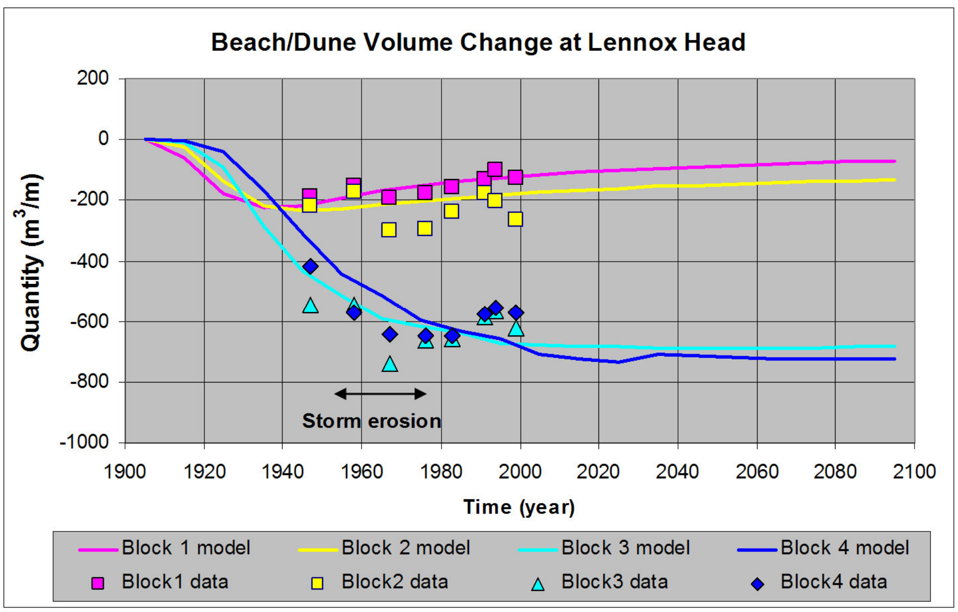


Figure 11: Model versus measured beach/dune quantity changes at Lennox Head

The model indicates that there has been a long term reduction in the annual average rate of transport past the Richmond River and the downdrift beaches (Figure 12). Plan view plots of the sequential shoreline positions at 10 year intervals derived from the model are shown in Figures 13 and 14. These show importantly that the rocky and pocket beach nature of the coastline between Ballina and Lennox Head are such that:

- only limited erosion occurs due to the bedrock controls of the headlands and underlying reefs; and
- a substantial proportion of the sand losses caused by the training walls are transferred north relatively quickly to Lennox Head and Seven Mile Beach.

The model suggests that the downdrift erosion from the training walls has not yet affected the beaches at Suffolk Park or Tallow Beach. However there is potential for the erosion to be felt there over the next 100 years.

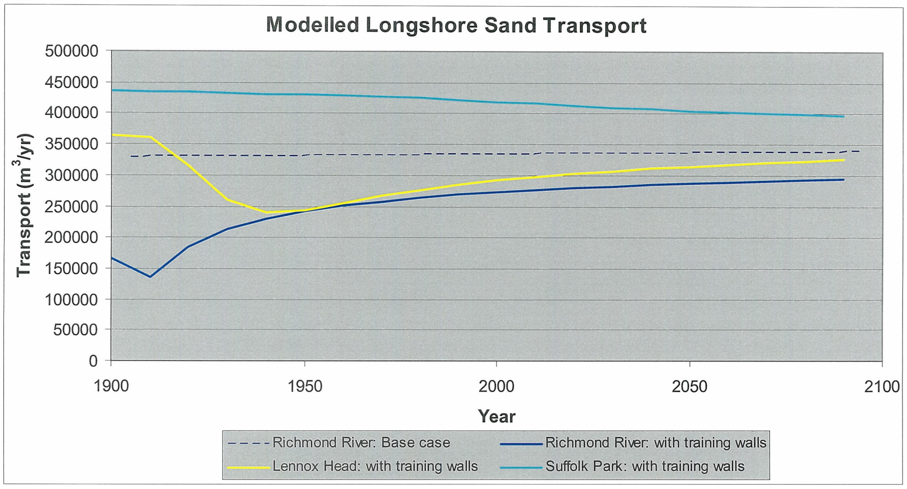


Figure 12: Modelled transport past Richmond River and downdrift beaches

The erosion will be exacerbated by sea level rise, particularly immediately north of each controlling headland. The impacts of sea level rise have been identified in the modelling by subtracting the result for Scenario 2 from that for Scenario 3 in terms of shoreline position changes in the model. This is shown in Figure 14. This indicates the normal 'Bruun Rule' extent of shoreline recession along the extended beaches at the south and north ends of the model but a more complex interaction of cross-shore and longshore effects where the coastline would continue to respond to headland and reef controls.

Discussion and Conclusions

Modelling the coastline at and north from Ballina is highly complex because of the variable shoreline alignment and, particularly, the extensive presence of bedrock headlands and reefs that control the sand transport processes. There is little doubt that the modelling undertaken does not represent those features and processes with a high level of accuracy. However, it is considered that the essential processes and controls are reasonably well simulated such that the impacts of the training walls have been identified realistically.

The key conclusions are:

- The training walls appear to be the dominant influence on the sustained shoreline erosion that has been experienced at Lennox Head and Seven Mile Beach.
- In the absence of sea level rise, the shoreline appears to be recovering slightly at south Lennox Head and has stabilized along Seven Mile Beach. Ongoing monitoring is needed to confirm this.
- Despite the above, there appears to have been a long term reduction in the longshore transport past the training walls and along Seven Mile Beach and some impact of the training walls may start to be felt at Suffolk Park over the next 100 years.
- Sea level rise will exacerbate the erosion at all beaches in a manner that is more complex than that indicated by application of the 'Bruun Rule', with headland controls minimizing recession updrift and exacerbating recession (up to 2-3 times) downdrift of those controls. This is a significant issue for future management considerations. Note that the modeled behaviour at Lennox Head does not include the control on recession provided by the seawalls constructed there.

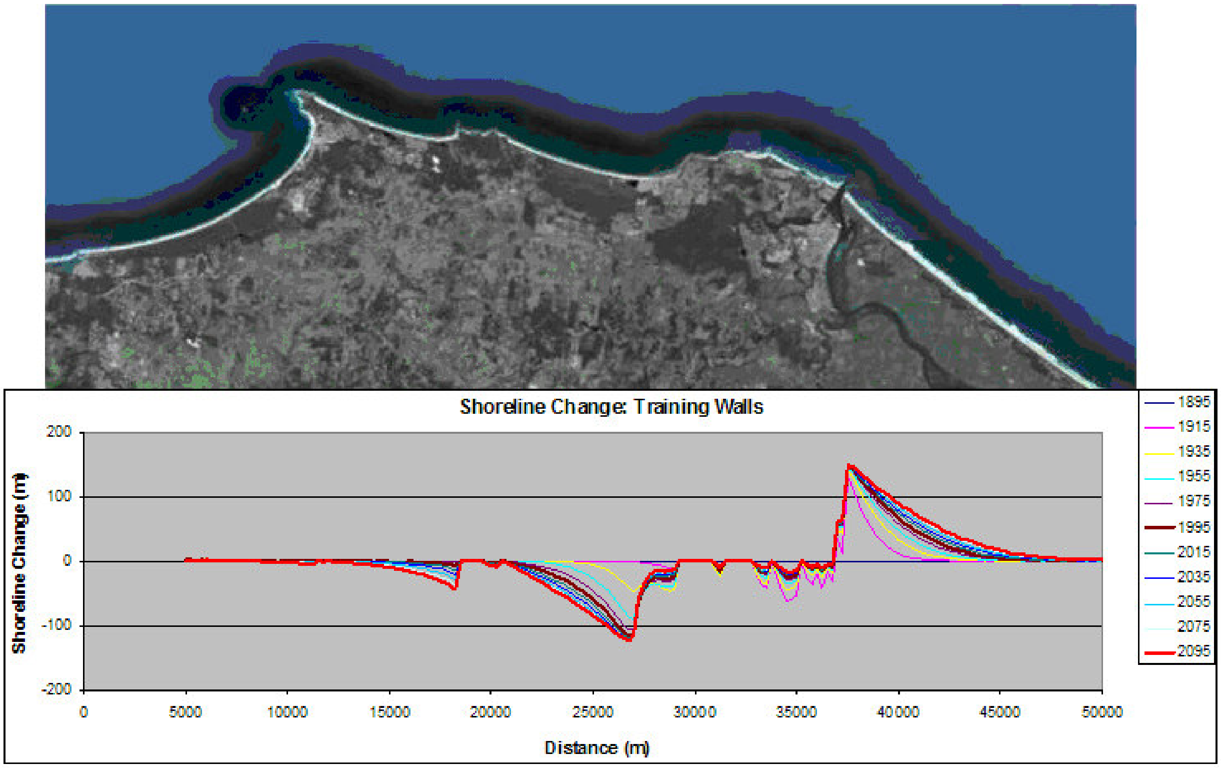


Figure 12: Modelled impacts of training walls on shoreline position

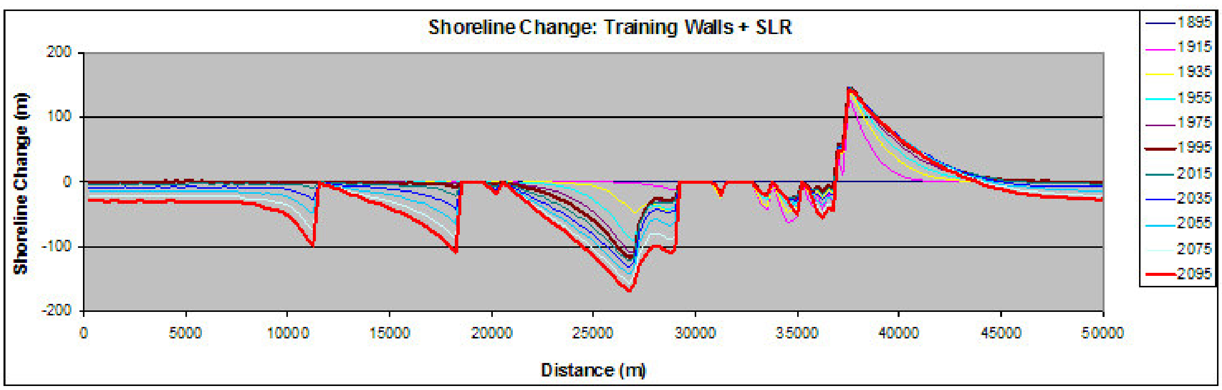


Figure 13: Modelled impacts of training walls and sea level rise on shoreline position

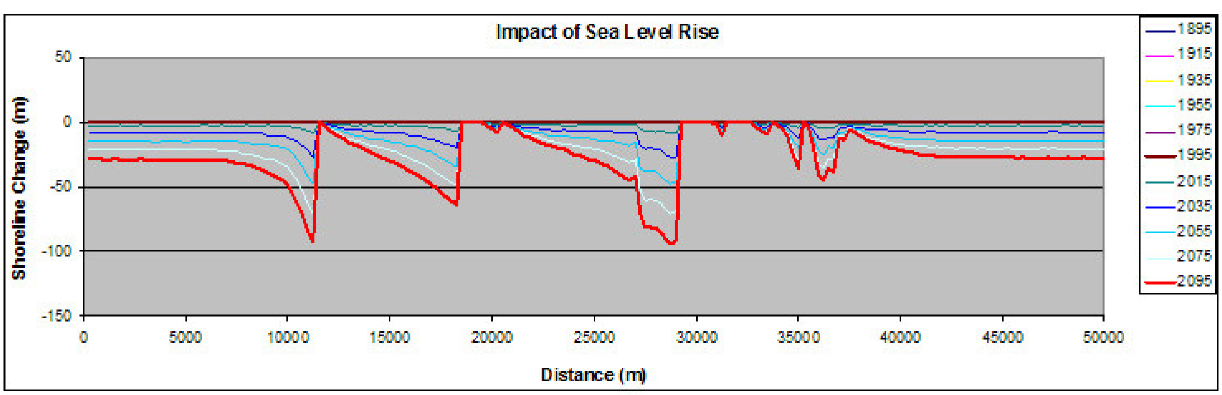


Figure 14: Modelled impacts of sea level rise on shoreline position

- The modeling software used for this analysis is versatile and effective for this application involving complex headland and reef structures and sea level rise.

Acknowledgements

I wish to thank the NSW Department of Environment and Climate Change for making available the Byron wave data used in the analysis. BMT WBM Pty Ltd and the Coastal Division, Civil Engineering, University of Queensland have supported the research undertaken in developing and applying the modelling software.

References

Ardill & Associates (1988). Statement of Environmental Effects for Proposed Seawall at Lennox Head.

Cowell P., Stive M., Roy P., Kaminsky C., Buijsman M., Thom B. and Wright L. (2001). Shoreface sand supply to beaches. Proc 27th Int Conf. Coastal Engineering (2001).

Geomarine (1990). Environmental Impact Statement for Beach Management at lennox Head.

Goodwin I., Stables M. and Olley J. (2005). Wave Climate, Sand Budget and Shoreline Alinement Evolution of the Iluka-Woody Bay Sand Barrier, Northern NSW, Australia, Since 3000 Yr BP. Marine Geology, Elsevier

Helman P.B. (2008). Two hundred years of coastline change and projected future change, Fraser Island to Coffs Harbour, East Coast, Australia. PhD thesis, Southern Cross University.

Huang H., Short A.D., Zeng T. and Hanslow D. (1999). Impact of river training walls on adjacent beaches, Ballina, New South Wales, Australia. Chinese Journal Oceanology and Limnology, Vol.17 No 1, 1999.

Patterson D C (2007a). Sand Transport and Shoreline Evolution, Northern Gold Coast, Australia. Journal of Coastal Research SI50, ICS2007, Gold Coast, 2007.

Patterson D C (2007b). Comparison of Recorded Brisbane and Byron Wave Climates and Implications for Calculation of Longshore Sand Transport in the Region. 18th Australasian Conference on Coastal and Ocean Engineering, Coasts and Ports 2007, Melbourne, July 2007.

Roy P. (2001). Sand deposits on the NSW inner continental shelf. Geoscience Surveys report.

WBM Oceanics Australia (2003). Ballina Shire, Coastline Hazard Definition Study. Report prepared for the Ballina Shire Council, October 2003.

Water Research Laboratory (1986). Coastal protection at Lennox Head. Tech report No 86/14, December 1986. University of NSW WRL, Manly Vale, NSW.