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Sand Transport and Shoreline Evolution, Northern Gold Coast, Australia

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ABSTRACT

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A net onshore supply of sand appears to exist along the northern Gold Coast beaches, resulting from an offshore profile shape at depths between 12-20 m that is flatter than that expected for dynamic equilibrium, a residual feature from past northward migration of the Nerang River mouth. Analysis of survey data over the period 1966 to 2002 shows progressive depletion of the lower profile (depths > 7.5 m out to 20 m) due to onshore supply and a substantial gain in the sand volume in the upper part of the nearshore and beach profile (depths < 7.5 m). Additionally, this section of shoreline has been nourished with about 3.7 million cubic metres of sand over the period 1974 to 2000, including an estimated 0.75 million placed from building sites.

However, despite the beach nourishment undertaken, the total volume of sand in the profile along the 10km section of beach analysed is only about 0.3 million cubic metres greater in 2002 than in 1966, indicating a corresponding local increase in the alongshore loss of sand. The reported historical changes and analysis of the longshore sand transport regime suggests that the evolution of the alignment of shoreline of the Spit has been commensurate with such a local increase of about 80,000 m^3/yr in the longshore transport rate north of Narrowneck, increasing to about 90,000 to 100,000 m^3/yr due to more recent beach nourishment works. This was matched initially by equivalent losses into the Broadwater and, following Seaway development, by a 'leakage' of sand past the bypass system and growth of the river entrance bar.

Beach management considerations need to account for these processes. The assessment undertaken supports the strategy of back-passing sand from the Seaway to the beaches to overcome future depletion of the onshore supply and associated recession of the shoreline alignment.

ADDITIONAL INDEX WORDS: *Onshore transport, longshore transport, Seaway, Spit, Nerang River entrance, beach nourishment, bypassing, management.*

INTRODUCTION

The northern Gold Coast shoreline between Surfers Paradise and the Gold Coast Seaway forms part of a progressively curving crenulate embayment that extends about 90 km between prominent headlands of Point Danger in the south and Point Lookout in the north. The beaches there are of high recreational value and require careful management (JACKSON ET AL, 1997).

A key feature of the coastline evolution in the area is the northward migration of the Nerang River entrance over the period 1920 to 1985 to form the Spit. Additionally, this section of shoreline has been nourished with about 3.7 million m^3 of sand over the period 1974 to 2000, comprising 2.95 million in direct nourishment and an estimated 0.75 million placed from local building site excavations (Greg Stuart, GCCC pers comm..). As well, the river entrance was stabilised with breakwaters in 1985 to develop the Gold Coast Seaway and sand bypassing commenced there in 1986 (ANDREWS and NIELSEN, 2001).

A comprehensive understanding of the sand transport processes along this coastal stretch is needed for appropriate management by Gold Coast City Council (GCCC) and State authorities to ensure sustainable beach and dune stability. Such understanding is required for suitable operation of the Gold Coast Seaway sand bypass system.

This paper sets out the results of analysis of the available survey data covering the beach, dune and nearshore profile over the period 1966 to 2002 for that purpose. Additionally, model analysis of the local longshore sand transport regime has been undertaken to assist in interpreting the measured past sand budget changes and the likely future pattern of coastal evolution. This provides a considerably more reliable basis for informing future management decisions than is presently available.

COASTLINE EVOLUTION

The study area covers the 10 km section of coastline between Surfers Paradise and the Gold Coast Seaway. This has developed over the past 6,000 years as a Holocene barrier dune system and barrier island/spit separating the Nerang River and Broadwater from the ocean (Figure 1). The entire Holocene unit is composed of mature marine sand. This was derived predominantly from a strong onshore supply during the last post-glacial transgression, together with a northward longshore supply along the beach system of northern New South Wales and the southern Gold Coast, extending north to Moreton Bay (STEPHENS, 1982).

Since the late 1800s, the location of the Nerang River entrance has varied considerably (Delft Hydraulics Laboratory, 1970), remaining just north of Main Beach from 1860 to 1920 (Figure 1) and then migrating northward by about 4 km from 1920 to 1985.

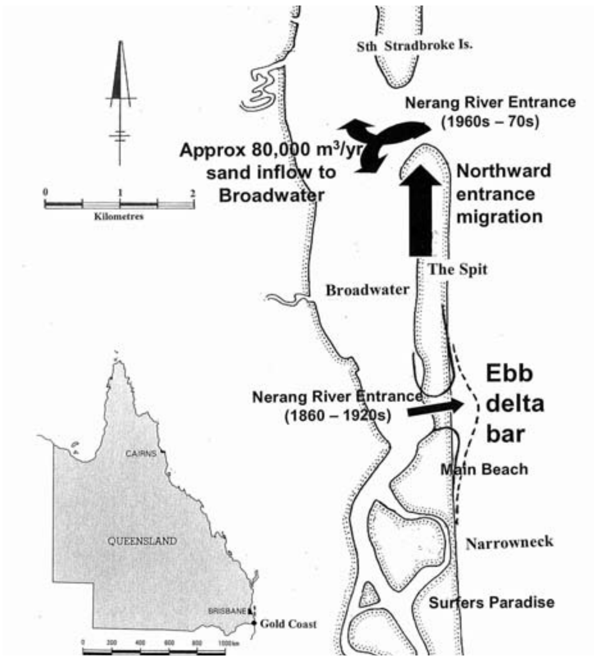

Figure 1. Locality plan showing northward migration of Nerang River entrance.

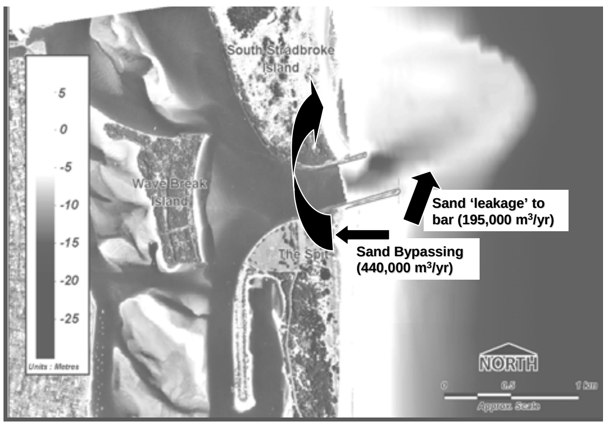

Figure 2. Gold Coast Seaway development of the former Nerang River entrance showing extensive bar formation, sand bypassing location and assessed sand transport.

This formed the Spit and eroded the southern tip of South Stradbroke Island. As is evident in Figure 1, the Spit grew with an alignment somewhat offset from that of the island, but with strongly recurved shape near its distal end. Analysis of survey data by Delft Hydraulics Laboratory (1970, 1976) determined that the spit growth was accompanied by movement of about 80,000 m^3/yr of sand into the Broadwater.

The entrance was stabilised by construction of the Gold Coast Seaway in 1985 and the sand bypass system in 1986 (Figure 2). Modelling and analysis of surveys at and near the Seaway (ANDREWS and NIELSEN, 2001) has found that the ebb delta bar grew at an average rate of over 200,000 m^3/yr from 1985 to 1999, with about 195,000 m^3/yr from 'leakage' past the bypass system and a decreasing amount derived from erosion of the Seaway channel. The average bypassing rate over that period was 440,000 m^3/yr, indicating a net longshore sand transport at the bypass system of 635,000 m^3/yr.

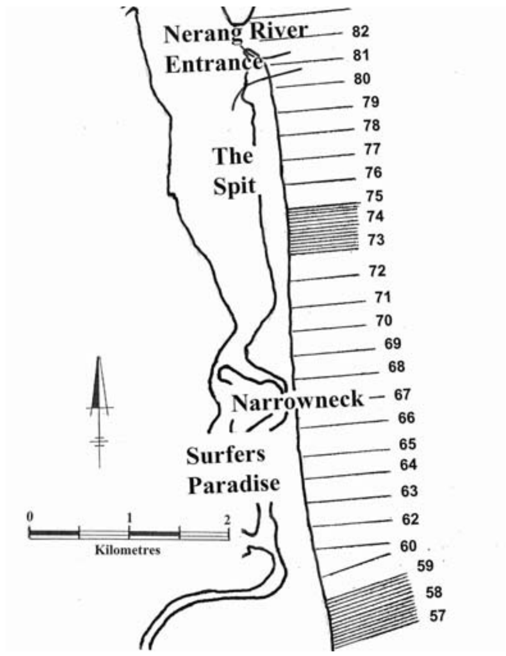

Figure 3. Location of ETA survey profiles.

ANALYSIS OF PROFILE SURVEYS

Survey Data

As a result of the foresight of the Queensland Government in the 1960s and the continuing commitment by the (former) Beach Protection Authority and Gold Coast City Council, a unique data set of surveys exists for the area covering the beach, dune and nearshore profile area out to water depths of about 20-25 metres over the period 1966 to 2002. The data has been provided for this study by the Environmental Protection Agency (EPA) and GCCC.

Locations of the profile lines surveyed are shown in Figure 3 and are referenced as the ETA lines (Figure 3). The lines analysed extend from ETA 57 south of Surfers Paradise to ETA 80 at the Seaway. The surveys utilised thorough hydrographic and land-based survey procedures for location and depth, with due provision for tidal variation. The procedures used and quality checks undertaken in this study indicate suitable horizontal and vertical measurement accuracy for reliable analysis of volume changes, with stochastic level error of less than ±100 mm.

Nearshore Profile Shape

Review of the profiles at various locations along the study area shows a marked variation from the southern-most area to the northern section where the river entrance once discharged.

Specifically, there is a substantial 'bulge' in the profile below about RL-12 m relative to Australian Height Datum (AHD), AHD being approximately mean sea level. That bulge is interpreted as the residual ebb delta lobe of the river mouth and extends along that coastal section from Main Beach (ETA 70) to the Seaway (Figure 4).

The southern profiles (eg. ETA 58 and 65 in Figure 4) do not have such a lobe, indicating that the river mouth has not been that far south for at least some centuries. Those profiles appear to

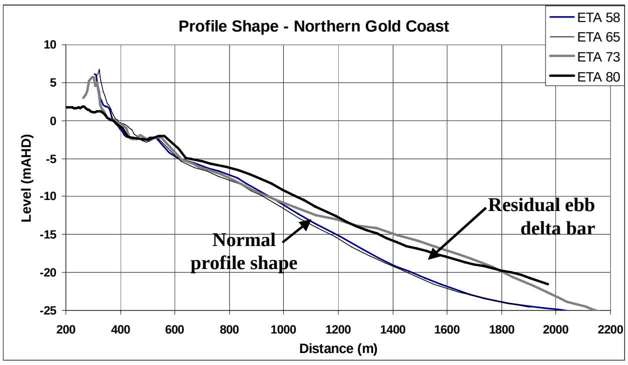

Figure 4. Shape of surveyed nearshore profiles showing the bulge representing the residual ebb delta bar in 1966.

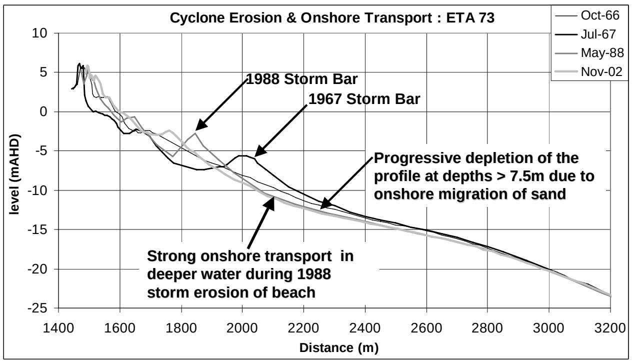

Figure 5. Evolution of profile ETA 73 showing cyclone erosion and progressive depletion of the deeper part below about RL-7.5 m (AHD).

represent the typical 'equilibrium' shape for the region, evolved with balance between offshore and onshore sand movement. The northern profiles are out of equilibrium due to the lobe and, subject to the capacity of the waves to move the sand, would be expected to adjust progressively towards the equilibrium shape. This is confirmed in Figure 5, in which selected surveys of ETA 73 are presented, showing progressive depletion over 1966 to 2002 by onshore transport of the profile below about RL-7.5 m, despite occasional occurrences of major storm bars.

The onshore transport mechanism for profile depletion has been confirmed on the basis of:

- Calculations by the author of shoreward mass transport potential under the prevailing waves using a procedure based on wave asymmetry (BAILLARD, 1981);
- The limited potential for longshore transport distribution of the sand at the depths involved, as essentially all longshore transport occurs at depths less than RL-10 to RL-12 m (PATTERSON, 1999; DELFT HYDRAULICS LABORATORY, 1970, 1976); and
- Lack of evidence in the profiles of corresponding deposition of sand in the longshore direction.

Sand Volume Changes

Analysis of the changes in the profiles within various depth bands along the 10 km study area has been undertaken, as presented in Figure 6 in terms of cross-section area changes (m^3/m) in each of the profile locations for various depth bands (above RL-7.5 m, RL-7.5 m to –15 m and below RL-15 m). Figure 7 summarises these results in terms of the gross transfers of sand between the depth bands analysed.

The results indicate:

- A net gain of 4.41 million m^3 along the upper beach and dune area above RL-7.5 m;
- A net loss of 3.81 million m^3 in the band between RL-7.5 m and RL-15 m; and
- A net loss of 0.31 million m^3 below RL-15 m, being a loss of 0.47 million along the ebb delta bar lobe area, a gain of 0.09 million at the southern area and 0.07 million immediately adjacent to the Seaway.

Overall, there has been a substantial gain in the sand volume in the upper profile and beach/dune area but a net gain of only about 0.3 million m^3, despite the extensive beach nourishment undertaken. This can have occurred only if the supply from offshore has been offset by loss of sand in the longshore direction as part of the upper profile longshore transport regime.

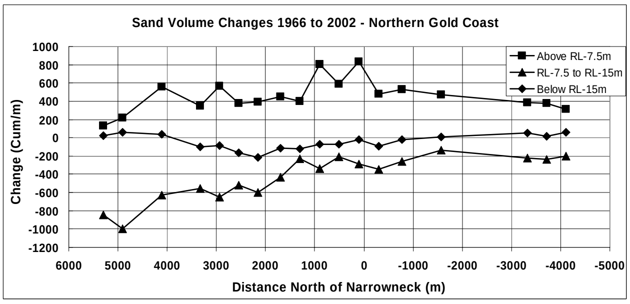

Figure 6. Calculated changes in sand volume in various depth bands versus distance along the coastline - 1966 to 2002.

Additionally, profile analysis has been undertaken of the onshore migration of the cyclone bar formed in 1967 (Figure 5) to determine short term rates of onshore sand transport. The results are shown in Figure 8 – July to Oct 1967 and Oct 1967 to Sep 1968). This assessment shows that even major beach erosion and offshore bar development is essentially restored to pre-erosion conditions within about 4-5 years, thus representing only a temporary perturbation of the long term trends.

Interpretation of Onshore Supply Rates

The profile changes at various selected profiles have been analysed at one metre depth intervals to interpret rates of net onshore sand transport over the period 1966 to 2002 as a function of water depth. The results are presented in Figure 8, indicating:

- Strongest onshore transport in the vicinity of the ebb delta bar lobe (ETA 73 and 75) where the profiles are most out of equilibrium, with an onshore supply of about 1-2 m^3/m/yr even at a depth of 18-20 m;
- Significantly less onshore supply towards the southern part of the study area (ETA 57 and 63) where the profiles are close to equilibrium, with no onshore movement from the deeper parts below 10-12 m and some slight offshore transfer below RL-15 m probably due to the benefit gained from the beach nourishment.
- A lower rate of onshore transport over the long term than occurs during recovery of cyclone erosion when the profiles are significantly out of equilibrium at relatively shallower depths.

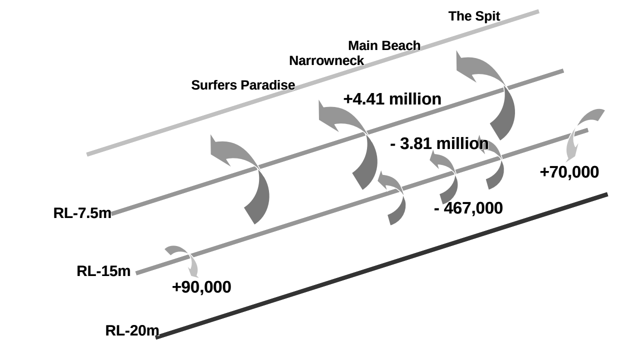

Figure 7. Summary of measured long term sand volume changes in the nearshore profile 1966 to 2002.

The net onshore supply to the Spit from deeper water (below RL-7.5 m) is measured at 4.1 million m^3 over 36 years, an average rate of 114,000 m^3/yr. However, this represents an upper limit to the long-term average since no major cyclone erosion has occurred in recent years, abnormally depleting even the southern ‘equilibrium’ profiles below RL-7.5 m by about 175 m^3/m. Allowance for some erosive re-distribution more consistent dynamic equilibrium in the upper part of the profiles indicates a long-term average rate of about 80,000 m^3/yr.

There is an indication that the onshore supply rate depends on both water depth and the profile slope, its conformance or otherwise to the ‘equilibrium’ slope at any particular depth.

ANALYSIS OF LONGSHORE TRANSPORT

Previous Investigations

Considerable investigation of rates of longshore sand transport along the Gold Coast has been undertaken over the past 35 years (DELFT HYDRAULICS LABORATORY, 1970; PATTEARSON and PATTERSON, 1983; ROELVINK and MURRAY, 1992). These were based on progressively improved wave information, but to date without reliably recorded directional data.

The conclusions drawn from these investigations are:

- The average annual net longshore transport rate at the southern Gold Coast beaches is about 500,000 m^3/yr. That is the target rate for the sand bypassing at the Tweed River;
- There is only a small increase in the net longshore transport rate along the Gold Coast, by most probably no more than 50,000 m^3/yr, suggesting a likely rate at the Seaway of up to 550,000 m^3/yr.

Refined Analysis from Recorded Wave Data

There is now a substantial record of continuous data from the ‘Brisbane’ wave recorder off Point Lookout over the period 1997 to present. This has been sourced from the Queensland EPA for use in refining the longshore transport calculations, for the first time based on reliably accurate recorded directional wave data.

A conventional methodology has been followed for these calculations, involving:

- Analysis of wave propagation from deep water to provide refraction transformation relationships to various nearshore locations along the coast;
- For each wave record in the data time series:
    - Estimation of the bed friction provision based on wave height and direction,
    - Further propagation to the break point to estimate breaker height and angle,
    - Calculation of the longshore transport rate.

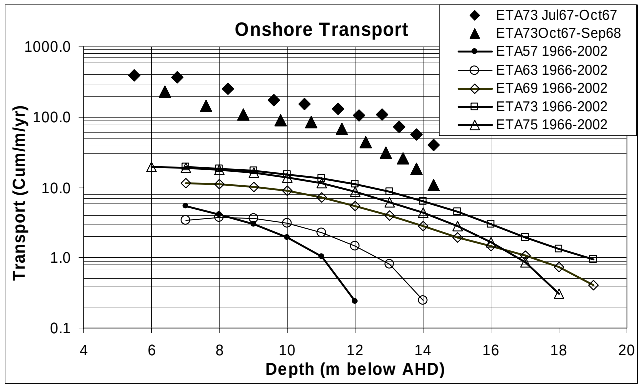

Figure 8. Summary of measured onshore sand transport rates for both post-cyclone (ETA73, 1967) and long term (various, 1966 to 2002).

Table 1: Calculated annual net longshore sand transport for Northern Gold Coast and Stradbroke Islands.

Location	Annual Net Sand Transport (m^3/yr)
North Stradbroke Is.	536,000
South Stradbroke Is.	560,000
The Spit	635,500
Narrowneck	540,000
Burleigh	522,000

The ‘Queens’ method (KAMPHUIS 1991) was used for the calculations, being preferred over the CERC method because it accounts for the wave period as well as grain size and beach slope.

Thus, a time series of longshore transport has been determined for locations at Burleigh, Narrowneck, the Spit, South Stradbroke Island and North Stradbroke Island, from which the annual net rates have been derived. These are listed as annual averages in Table 1 and indicate:

- A general prevailing net rate along the northern Gold Coast and Stradbroke Island of about 540,000 to 560,000 m^3/yr;
- A higher rate at the northern end of the Spit of about 635,000 m^3/yr, significantly higher than the rate prevailing in the region.

Minor differences and variations in these rates are not significant, being within error margins of the data and methodology applied. They are generally consistent with the previous investigations. However, of particular note is the markedly higher annual rate at the Spit, about 95,000 m^3/yr higher than the rate at Narrowneck. This results from the shoreline alignment of the Spit that is somewhat further seaward at its southern end (i.e. more accreted there) than would have been the case in the absence of the onshore supply from the residual lobe.

DISCUSSION

The natural evolution of the northern Gold Coast shoreline has involved cycles of movement of the Nerang River entrance with associated growth of the Spit. The locally higher net longshore transport rate at the Spit suggests that the shoreline alignment that evolved there is consistent with a beach being supplied with additional sand from offshore, estimated at 80,000 m^3/yr.

Prior to Seaway development and beach nourishment, about 80,000 m^3/yr was transported into the Broadwater as the river entrance migrated north. There was also a net supply from offshore in the local area (the residual ebb delta bar lobe) sufficient to make up that volume of sand such that there was no net loss of sand from the beach system.

Following beach nourishment and Seaway development, the longshore transport rate at the bypass system of 635,000 m^3/yr (ANDREWS and NIELSEN, 2001) is about 95,000 m^3/yr more than the rate at Narrowneck. This suggests that the nourishment, possibly together with the bypassing, has caused a further increase in the longshore transport by about 15,000 m^3/yr over the natural rate, the mechanism being a slight further seaward shift in the beach alignment along Main Beach and southern Spit area.

Based on an average negative differential of 90,000 m^3/yr along the study area over the 36 years assessed, a net longshore loss of 3.24 million m^3 would be expected. Allowing for a total beach nourishment quantity of 3.7 million m^3, the net gain would be 0.46 million m^3, corresponding reasonably, within survey accuracy, to the measured net gain of 0.3 million m^3.

The onshore supply from the residual lobe would be expected to reduce over time. In the absence of further beach nourishment, this would lead to shoreline recession along the Narrowneck to southern Spit area and reduced longshore transport along the Spit. In the natural system, this probably led to a breakthrough at either Narrowneck or Main Beach and repetition of the evolutionary cycle. To prevent this under present managed circumstances, back-passing of sand from the Seaway to Narrowneck-Main Beach would appear justified. Further investigation is needed to understand the present trends and response processes taking place in developing and quantifying such a strategy.

CONCLUSION

Analysis of profile surveys along a 10 km section of the northern Gold Coast beaches over 36 years from 1966 to 2002 has identified the existence of a residual ebb delta lobe deposited as the Nerang River entrance migrated between around Main Beach and the present Seaway position. There is a significant continuing natural onshore supply of sand from that lobe of up to 4-5 m^3/m/yr at RL-15m and 1-2m^3/m/yr at RL-18m as the profile tends towards the equilibrium shape. This, together with beach nourishment, has led to an alignment of the Spit shoreline that is somewhat more seaward at its southern end than otherwise expected, causing a local increase in the longshore sand transport of about 90,000 m^3/yr from Narrowneck to the Seaway.

Over time, this onshore supply will reduce as the lobe is depleted and, without further nourishment, the shoreline will tend to recede accordingly. This will require careful management for maintenance of the beaches and an adequate dunal buffer in front of the development. Back-passing of sand from the Seaway appears justified. Further analysis of the present trends of sand movement, consideration of the sand bypassing needs for South Stradbroke Island and the likely response behaviour of the Spit alignment is needed to quantify such a strategy.

The profile shape south of Narrowneck shows no evidence of a lobe and appears to exhibit the ‘equilibrium’ shape for the region. There is no onshore transport from deeper water in that area, although there appears to be some offshore-directed minor gain of sand at depths below RL-15 m resulting from the benefit of the beach nourishment and maintenance of the equilibrium shape.

ACKNOWLEDGEMENTS

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