CHAPTER ONE HUNDRED THIRTY EIGHT

A PRE-DREDGING SAND MOBILITY STUDY USING A RADIOISOTOPE TRACER

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ABSTRACT

The wave-driven movement of sand across the alignment of a proposed navigation channel was investigated using radioactive chromium-51 labelled tracer sand. The mean particle velocity and thickness of the mobile layer were determined over a two-month period, and an annual infill rate estimated.

Wave height and period were measured concurrently. Despite two storms, during which near-bed oscillating velocities of 1.5 m s^{-1} were calculated, the sand transport at 10 m (BMWL) appears to occur within the wave boundary layer. Onshore transport in the direction of wave propagation, due to mass transport velocity and wave asymmetry effects, was easily identified.

Tidal currents up to 1.2 m s^{-1} (at 3 m above bed) had less than the expected effect on the tracer dispersion pattern.

1. INTRODUCTION

The operating economics of modern bulk carriers demand that vessels be able to enter and leave ports at full capacity under most tidal conditions. Navigation channels must provide a minimum underkeel clearance of one metre. The potential of any port, in terms of size or draught of vessels which can enter, can be limited by the water depths in the approach channels, critical sections of which may be at some distance from the berths. [1] Maintenance dredging operations to keep these channels open must not be excessive.

At present, the main shipping channel for deep draught vessels entering and leaving the Port of Brisbane follows a long and complex path through Moreton Bay to avoid the extensive sand shoals which block the northern approaches. The Port of Brisbane Authority (PBA) has proposed that a new channel be dredged which could provide an alternative and more direct access (Figure 1(a)(b)). This channel would

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effectively "cut the corner", reduce the distance travelled by ships to and from the south by 40 km and require only 15 km of maintenance dredging as opposed to 30 km on the old route.

The new route would involve upgrading an existing tidal channel which is presently used by shallower draught vessels and constructing a shorter (3 km) section through a sand bar to link it with the open sea. In this critical section, water depth on the bar at low tide is 9 m, but a depth of 17 m is required for deep draught vessels.

1.1 Regional Sand Migration

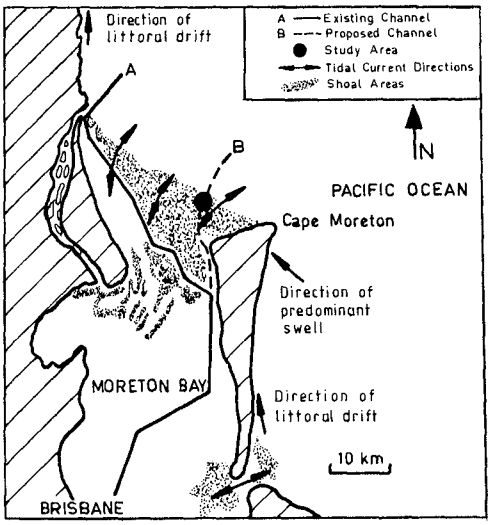
In this region of the east coast of Australia, it is generally recognised that there is a northward movement of sand. Extensive studies carried out by the Delft Hydraulics Laboratory [2] and the Queensland Department of Harbours and Marine (QHM) Coastal Protection Branch [3] revealed that 5×10^5t of sand moves past the nearby Gold Coast each year, pushed by currents in the surf zone generated by the predominantly south-easterly swell which, in southern Queensland, strikes the coast at an oblique angle. Evidence of this northward littoral drift can be seen where the training walls extending seaward of the entrance to the Tweed River have interrupted the sand flow. In the 16 years since their construction, approximately 8×10^6t of sand has been trapped behind the southern wall, starving the upstream Gold Coast beaches of their normal sand supply, and resulting in heavy beach erosion.

It is likely that similar quantities of sand are moving on the seaward side of Moreton Island and that the sand shoals in the northern reaches of Moreton Bay are the result of centuries of littoral drift. Sand has moved around Cape Moreton, along the northern beaches of Moreton Island, and has been deposited across the bay entrance. Tidal currents and wave action have moulded the 400 km^2 deposit into an ebb and flood delta cut by several deep tidal channels. Each tidal channel has its own smaller but identifiable ebb and flood fan. It is uncertain whether the deposit is now simply a "sink" for the sand or whether the shoals provide a bypass for all or some of the sand to beaches near Caloundra and further north. If bypassing is occurring, the critical section of the proposed navigation channel would cut across the sand migration route at right angles.

1.2 Sand Mobility at Channel Site

The hydrodynamics over the shoal system are complex. Local wind waves up to 2 m with 3 to 5 second periods can be generated in the bay; swell waves up to 5 m with 8 to 12 second periods resulting from storms at sea can cross the site; the diurnal tidal range is $\approx$2 m and generates reversing tidal currents with velocities up to 1.2m s^{-1}. The

(a)



(b)

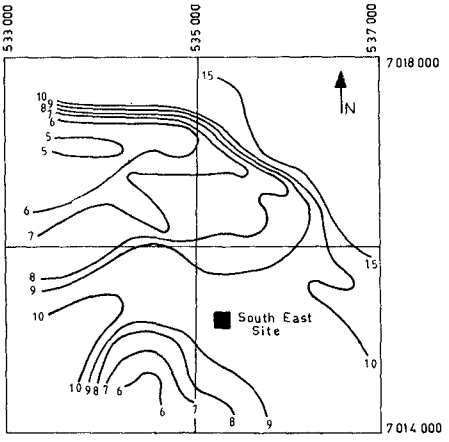


Figure 1. (a) Existing and proposed navigation channels through the Moreton Bay shoals.
(b) Depth contours over the ebb fan of the North East tidal channel.

conditions indicate a high bed mobility but the many variables involved make calculation or mathematical modelling of sand migration rates from hydrodynamic data difficult. Ebb oriented dune-forms exist in the deeper regions of the tidal channel. Some lower bed-forms occur on the fan itself but no clear indication of the major direction of sand migration can be defined.

Determination of siltation rates using a mobile bed hydraulic model equipped with tide and wave generators is expensive and some preliminary field data are required for precise tuning. Radioactive tracer techniques provide an alternative method to acquire qualitative and quantitative on-site data. The PBA contracted the AAEC Isotope Application Research Group to carry out on-site tracing tests. These were carried out between 26 April 1983 - 1 July 1983.

2. AIMS OF THE INVESTIGATION

Although there are many factors which could cause channel infill, and recognising that construction of the channel could radically alter the sediment movement pathways in the location, a possible cause of siltation would be the littoral-drift/bay-bypass mechanism. The radiotracer study was designed to investigate the presence of this mechanism.

The principal aims of the investigation were:

(i) To determine the direction of sand movement
(ii) To determine the rate of sand movement
(iii) To determine the rate of channel infill caused by any identified sand movement normal to the channel alignment.

3. SEDIMENT TRANSPORT RATES BY RADIOACTIVE TRACER TECHNIQUES

Quantitative sediment transport rates by the spatial integration method may be determined from

$$Q = 2VD \text{ td}^{-1}\text{m}^{-1}$$

where V = mean particle velocity (md^{-1})

D = mobile bed thickness (m)

and a bulk density factor of 2 is assumed.

Radioactive sand tracer is released onto the ocean floor. The spatial distribution of tracer is determined at suitable time intervals. The centroid of each complete scan is calculated. Shift in centroid location over the corresponding time interval gives the mean particle velocity (V).

The mathematical concept of bed-load movement is applied even though the actual particle movement may be a series of 'hops' in suspension followed by long periods in

which the particle remains buried in the sediment layer. This mobile layer has a thickness in ocean waters which depends on wave climate, particle size, ripple height and particle roughness. Its thickness (D) is determined from the vertical dispersion of tracer into the sea bed, measured by the count recovery method or by coring.

3.1 Choice of Tracer

Chromium-51 ($t_{\frac{1}{2}}$ = 27 days; γ = 0.32 MeV) was chosen as the most suitable radioisotope for preliminary investigations in Moreton Bay. Direct underwater detection is possible but the energy is low enough to reduce the need for bulky shielding during transport and tracer release procedures.

3.2 Tracer Sand Preparation

Two kilograms of sand were taken from the shoals, washed, graded (0.2 mm median diameter), nitric acid-washed, to remove shell grit (5%), etched in hydrofluoric acid to remove iron and manganese oxides, and dried. Ammonium dichromate solution was added until the sand was just moistened. The ammonium dichromate was decomposed by heating to 600°C; this produced an even coating of green chromium sesquioxide on the sand. Wet and dry self-abrasion followed by repeated washing removed all loose oxide and oxide deposited on the high spots on the grains. Microscopy showed that the residual oxide was extremely well attached on fissures and etched pits. Laboratory tests showed negligible levels of chromium in supernatant water after extended periods of violent agitation. It is therefore unlikely that any label would detach under marine conditions. No significant density change is involved since residual chromium content is 0.35%.

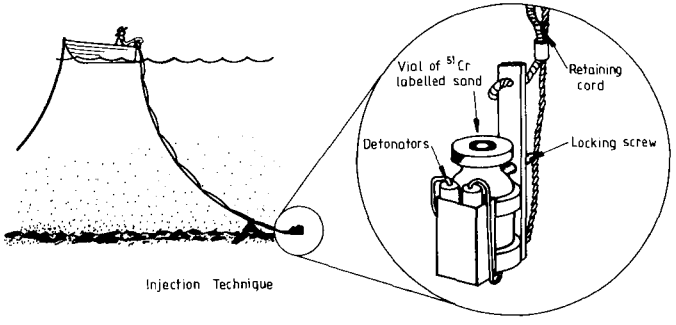


Figure 2. Tracer release technique. Vials of chromium-51 labelled sand are transferred from lead delivery pots into brass holders preloaded with two electric detonators. Detonation on the sea bed breaks the vials and releases the tracer sand.

Neutron activation of the label to chromium-51 was carried out in the X-202 bulk irradiation facility in the AAEC's materials testing reactor HIFAR.

3.3 Tracer Release

For preliminary tests a site, located 1 km south-east of the proposed channel line (Figure 1b) was chosen as representative of the area.

Mean water depth at this site was 10 m BMWL. The detonation technique was used to inject tracer sand into the sea bed (Figure 2) over a slack water period on 28 April 1984. Twelve vials, with a total activity of 1.45 Ci 50 (GBq) were used. Total mass of tracer was 0.6 kg. This technique is quick and simple. Release was complete in 30 minutes. The incorporation of tracer into the bed material.

3.4 Tracer Monitoring and Determination of Mean Particle Velocity V

The subsequent lateral movement of the tracer was followed over a period of two months. A waterproof scintillation detector was mounted on a sledge and dragged over the sea bed on fixed lines. The sledge position was fixed using HIFAR navigation equipment, and shore stations at Caloundra and Woorum as reference points. Usually, the tracks ran along fixed arcs of ∿27 km radium with Caloundra as the central point. The navigation equipment is accurate to ±3m. Count rates were corrected for radioactive decay and superimposed over the tracks provided by the PBA surveyors. Isoactivity contours were drawn and centroid and lateral movements of the tracer determined. In tracer studies, in an ocean environment, tracer advection in one direction can be masked by tracer diffusion in all directions. Successive scans show considerable overlap and centroid shifts are often tens of metres. Recently the very accurate navigation systems available have made it possible to track on a 10 m grid spacing at up to 30 km from shore stations, and to reveal these small shifts. By endeavouring to limit the initial area of the labelled zone, tracing on such a tight grid does not become arduous and most complete scans can be accomplished in one day of fair weather.

The areal disposition of the tracer relative to two reference points connected by a line parallel to the proposed channel alignment for the period 4 May to 1 July 1983 is shown in Figure (3). Tidal action stretched the concentration contours in the ebb and flood directions. There is also an identifiable movement in a north-westerly direction along the wave orthogonal and across the line of the proposed channel. This movement, attributed to wave generated mass transport velocity and wave asymmetry

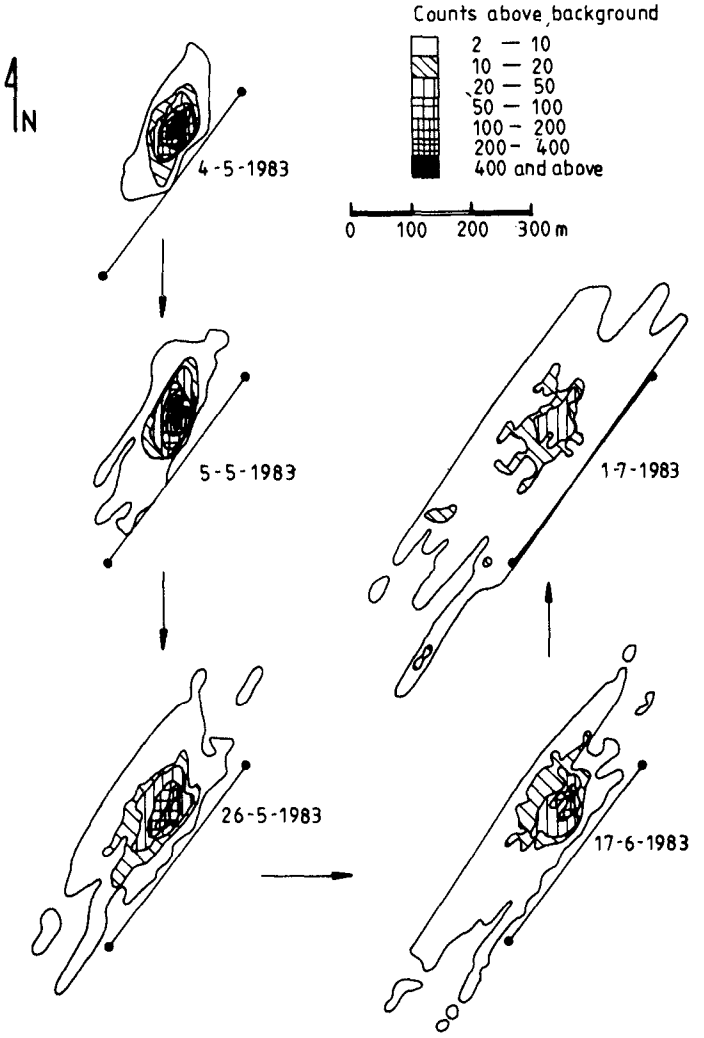


Figure 3. Lateral dispersion of labelled zone over the two month test period. Movement is shown relative to two reference points joined by a line parallel to the channel alignment.

effects, can be regarded as "onshore" transport.

The movement normal to the direction of the tidal currents and across the channel alignment is plotted as a function of time in Figure 4 (a). The integrated count along the lines at 10 m intervals from the reference line are plotted on the vertical axis for each complete scan. The Lateral shift of the centroid position is plotted as a function of time in Figure 4 (b) and indicates a steady movement towards the north-west.

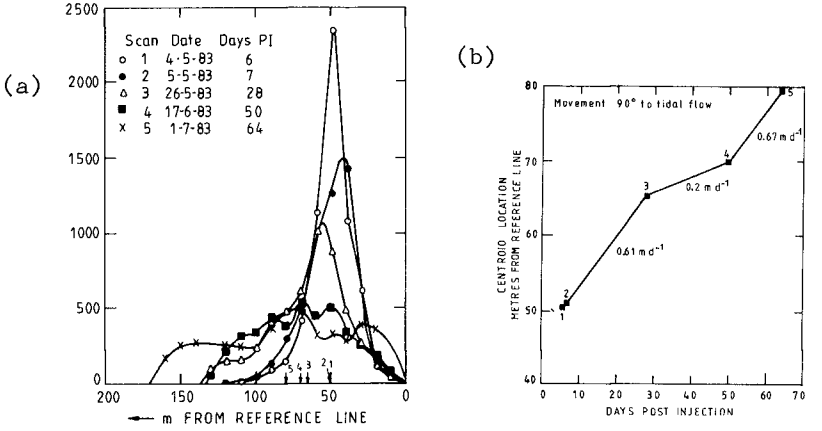


Figure 4. (a) Lateral distribution of tracer
(b) Centroid location as a function of time after tracer release. Mean particle Velocities are indicated.

During the 56 days, following an initial 7-day period of tracer incorporation, there was a lateral shift of 28.8m, resulting in a mean particle velocity (V), normal to the channel alignment, of 0.52 m day^{-1}:

3.5 Thickenss of the Mobile Layer (D)

As tracer sand becomes incorporated into the bed material the total activity which is apparent to a sledge mounted detector falls absorption by bed material of the γ-ray emission from tracer particles.

The ratio of apparent activity : injected activity (% recovery) is a function of the γ energy of the isotope employed and the incorporation thickness.

The detector response to buried tracer is described by the equation

$$\frac{\alpha N D}{\beta f_o A} = 1-e^{-\alpha D}$$

where α is the absorption coefficient at the relevant γ-energy for a sandwater mix; N is the number of counts recovered; f_o is the detector response where tracer is a surface layer only; A is the total activity injected; D is the depth of tracer incorporation; and β is a non-homogeneous distribution factor [4]. The factors α and f_o were determined in a laboratory tank from the count rate reduction observed when a plane source of chromium-51 was buried under increasing thicknesses of sand. Under these circumstances

$$f = f_o \, e^{-\alpha d}$$

where f is the observed count rate and d is the covering thickness; d can also be regarded as the mean depth of tracer incorporation. The total thickness depends upon the vertical distribution factor β. A value of $\beta = 1.25$ was used in this study. The value of α and f_o for chromium-51 and the detector used was found to be $17.9 m^{-1}$ and 2.8 counts $s^{-1} \mu Ci^{-1} m^{-2}$ respectively.

Figure 5 shows the measured mean tracer particle depth (d) and the derived total thickness of the mobile layer (D) as the ratio of apparent activity : released activity expressed as percentage.

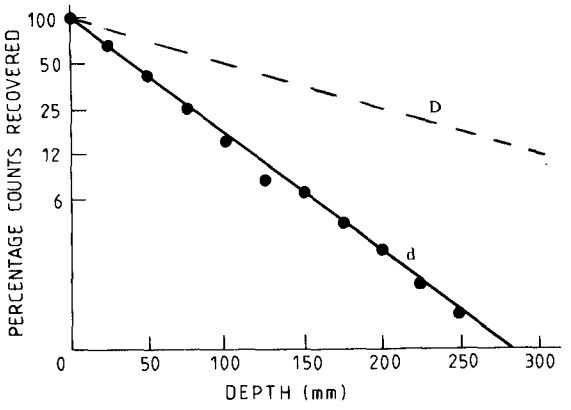


Figure 5. Calibration curves used in the determination of the mean particle burial depth (d) and overall thickness of the mobile layer (D).

The percentages of total possible counts recovered per complete scan, together with the mobile bed thickness calculated from these values, are plotted as a function of time

in Figure 6. After an initial period of seven days, incorporation was apparently complete and remained constant at a depth (D) averaged over the whole labelled zone of 0.25 m. A similar period for full tracer penetration was found during tests in Swansea Bay, Wales [5].

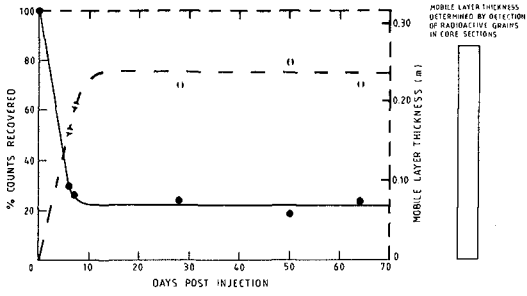


Figure 6. % Counts recovered and derived thickness of mobile layer (D) plotted against time after tracer release. The mobile layer thickness determined from cores is shown to the right.

Cores were taken from the labelled zone after 50 days using a vibration corer powered by compressed air. These cores were sliced into 0.02 m sections and the chromium-51 content measured in the laboratory (NaI crystal with multi-channel analysis). Active particles were found evenly distributed over the range shown in Figure 6. The deepest particle was 0.27 m below bed level, corroborating the value of 0.25 m found by the count recovery method.

Unlike tracer tests involving mud, relatively few active particles are employed during sand tracer tests. A prohibitive number of cores would be necessary to obtain a complete vertical distribution profile.

3.6 Sand Transport Rate

The wave driven transport rate normal to the tidal current and channel alignment can be calculated from the values of V and D.

$$Q = 2VD$$
$$= 2(tm^{-3}) \times 0.52\ (md^{-1}) \times 0.25\ (m)$$
$$= 0.26 \text{ tonnes } d^{-1}\ m^{-1}$$

Based on this transport rate a 3000 m channel cut through the fan will intercept 2.85×10^5 tonnes of sand per year. This preliminary value, calculated from data acquired over only a two-month period and a single central downstream location, appears reasonable and equivalent to ≈60% of the

known littoral drift rate.

An extended study is in progress using iridium-192 labelled tracer sand ($t_{\frac{1}{2}}$ = 74 days) which has been released as a 2000 m line source.

3.7 Current and Wave Data

Sections of the record of velocity and direction of the diurnal tidal current measured 3 m above the bed are shown in Figure 7. The region is ebb dominated. Both ebb velocity and duration exceed that of the flood tide. The ebb-flood and flood-ebb current direction change occurs through the south-eastern seaward sector.

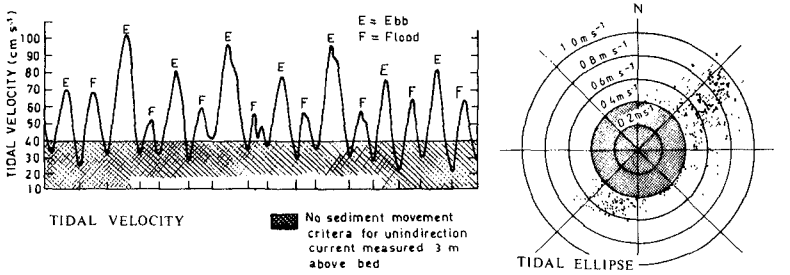


Figure 7. Section of tidal current velocity and direction record.

Wave height (H_s) wave period (T_s) and the near bed maximum oscillating current velocity (U_b), calculated from linear wave theory, are shown in Figure 8. A period of "heavy" weather (S_i) and two storms (S_2, S_3) are indicated. A value for U_b of 1.55 m s^{-1} was calculated for the peak of both storms S_2 and S_3.

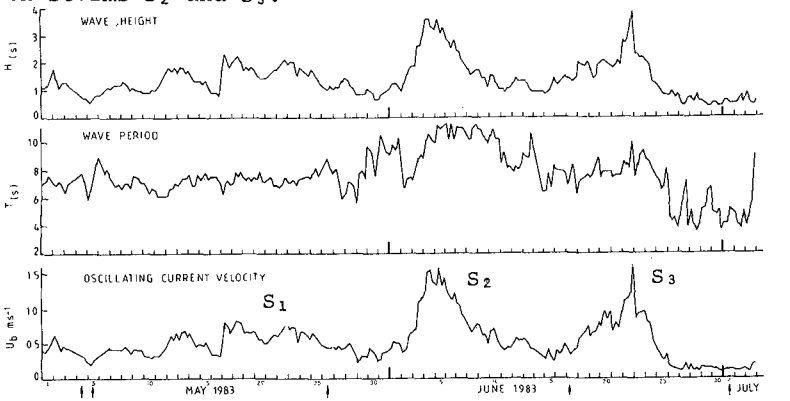


Figure 8. Wave height, wave period and calculated oscillating near bed current during test period.

The deepwater wave climate for the area, from data accumulated over several years [3], is compared with the slightly more energetic climate recorded during the study in Figure 9.

The records indicate that criteria for the initiation of movement for 0.2 mm sand under steady (tidal) or oscillating (wave generated) currents were exceeded at all times.

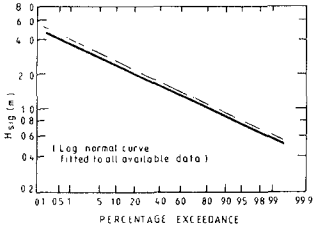


Figure 9. Annual wave climate ———, and wave climate recorded during test period ----------.

4. CONCLUSIONS

Movement of sand towards the north-west and across the proposed channel alignment has been identified.

The values found for the mean particle velocity (V = 0.52 m d^{-1}) and thickness of the mobile layer (D = 0.25 m) result in a sand transport rate of 0.26 t $m^{-1}d^{-1}$. This value is strictly only applicable to the central 600 m of channel and for the two months during which sand movement was monitored. Variation in water depth over the fan is small and the wave climate during the test period was representative of the annual average. It is therefore not unreasonable to extrapolate the measured value in both time and space. On this basis a 3000 m channel will intercept 2.85×10^5 tonnes of sand per year, equivalent to 60% of the known littoral drift rate.

On first examination a remarkable feature of the study is the relatively low advection rate of the 0.2 mm bed material, and deserves further comment. The labelled zone remained compact throughout and exhibited little stretching in the direction of the tidal currents. No offshore transport could be detected but onshore transport in the direction of wave propagation and across the line of tidal flow was apparent.

Behaviour of this kind is characteristic of transport processes occurring very close to the bed where steady current velocities are weakest and where wave mass transport velocities supplemented by wave asymmetry effects are strongest, and in the direction of wave advance.

During the storm events S_2 and S_3 maximum near-bed orbital velocities calculated from linear wave theory were 1.5 m s^{-1} which would have eliminated bed ripples and caused a sheet flow condition similar to that observed by Jonsson (6) utilising equivalent velocities in wave tunnel studies.

Considerable quantities of sand would have been mobilized in oscillating motion both as bedload and suspension in agreement with the measured mobile layer thickness of 0.25 m. However the superimposed steady (tidal) current has little advective effect on this dense slurry apparently trapped in the wave boundary layer. Weakening of the steady current velocities within the wave boundary layer has been predicted by Fredsøe (7) and measured by Bakker and Doorn (8) in a flume. Under these circumstances steady current velocity profiles with roughness lengths of the order of the wave boundary layer thickness are obtained. Similar effects have been observed in field studies (9).

Upward transfer of sediment to heights above the bed, where the steady current could cause advention, is suppressed by the steep density gradient between the near bed slurry or rheological layer (10) and the water immediately above.

It is of interest to note that, while the depth of water at the study site was 10 m (BMWL), the beach profile closure depth is 9.5 m (BMWL) on this part of the east coast of Australia (11). This value should be compared with the water depth at the boundary between near shore and shoal zones as defined by Hallermeier. This boundary is at the deepest water depth where "suspension" processes can occur under extreme wave conditions, and is calculated to be 9.0 m (BMWL) (12).

5. REFERENCES

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