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Renourishment of a Flood-Tidal Delta Adjacent Beach, Tauranga Harbour, New Zealand

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ABSTRACT

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Pilot Bay Beach, a flood-tidal delta adjacent beach in Tauranga Harbour, has demonstrated a history of continual erosion. During a maintenance dredging programme in early 1984, the Bay of Plenty Harbour Board renourished the southeastern end of the beach with 2.1×10^4 m^3 of dredge spoil. The bay had been included in the Tauranga Harbour Study, which provided baseline data for a study of the behaviour of the renourished beach.

Tidal currents in Pilot Bay are affected by a flood-tidal eddy, which results in a dominant ebb-directed flow for most of each tidal cycle. However, this flow rarely exceeds the sediment entrainment velocity. Additional energy for the entrainment of sediment is provided by waves, particularly on the beach.

Sediment used for renourishment was very similar in composition and texture to the original beach sediment, except for a change in the dominant shell species, and the presence of pumice. The pumiceous clasts within the dredge spoil, being of very low density, were rapidly transported away from the renourished beach.

The sediment transport direction predicted by the dominant tidal flow direction, and by the spatial distribution of sediment texture, was confirmed by observed beach profile changes. Sediment moved from the renourished end of the beach, towards the northwestern end, where long term accretion may occur. During the period April 1984 to October 1987, the average rate of erosion of the renourished beach was 2.52 $m^3 \cdot day^{-1}$, giving an expected life of less than 13 years.

ADDITIONAL INDEX WORDS: *Sediment transport, sediment texture, beach renourishment, artificial beach, dredging, beach sediment.*

INTRODUCTION

Tauranga Harbour is a mesotidal estuary located on the northeastern coast of New Zealand, and formed behind two tombolos and a barrier island (DAVIES-COLLEY and HEALY, 1978; HEALY and KIRK, 1982). There are two major basins within the harbour: the Katikati Basin to the northwest; and the Tauranga Basin to the southeast. The Tauranga Basin is the focus of commercial development of the harbour and contains the Port of Tauranga (Figure 1). Pilot Bay Beach is a small (1.2 km) stretch of beach on the southern side of the Mount Maunganui tombolo, and is here described as a flood-tidal delta adjacent beach (Figures 2 & 3). In this location the beach is not exposed directly to ocean swell and sea, although it is affected by wave energy propagating through the harbour entrance, primarily by diffraction. Additional energy is available for entraining and transporting sediment from local wind-generated waves, vessel wakes, tidal currents, and storm water discharges (DE LANGE, 1988; DE LANGE and HEALY, 1989).

Pilot Bay Beach has been observed to be eroding, particularly at the southeastern end, since the mid-1950's, and eventually, in the mid-1970's, a rock-filled gabion basket sea wall was constructed to protect the adjacent road and coastal reserve (DE LANGE, 1988). This sea wall prevented further landward erosion, but continued loss of sand from the beach prompted the construction of a series of small wooden groynes at the Salisbury Wharf, or southeastern, end of the beach. These were ineffectual for preventing further erosion, and by June 1983 the beach consisted of a narrow strip of shell and pebble rich sand at the southeastern end of the beach, most of which lay entirely below mean high water (Figure 4), with a slightly

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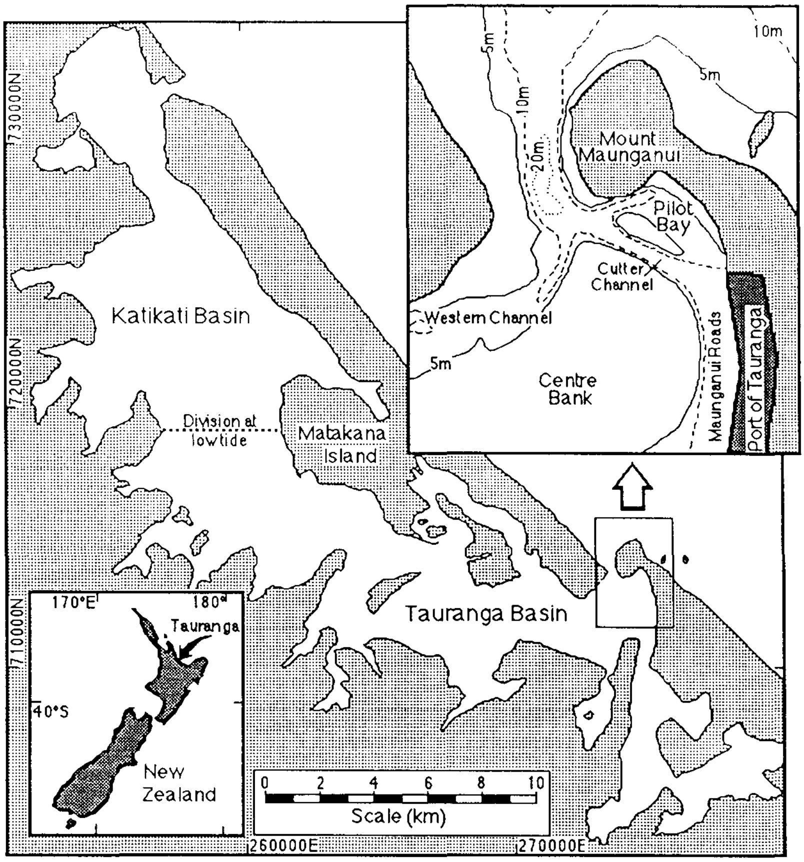

Figure 1. Map of Tauranga Harbour, showing the division of the harbour into two basins and the location of Pilot Bay.

greater extent of sandier sediment at the northwestern end.

During early 1984, the Bay of Plenty Harbour Board (BOPHB) undertook maintenance dredging close to Salisbury Wharf. A portion of the dredge spoil produced by this operation (2.1×10^4 m^3) was used to nourish the southeastern end of the beach (Figure 3). The nourishment of the beach occurred during the Tauranga Harbour Study (THS), shortly after the completion of the field data collection programme, which provided useful background data concerning the tidal currents and sedimentology in the Pilot Bay area (BLACK, 1984; BARNETT, 1985; HEALY, 1985). On completion of the renourishment, a monitoring programme was instituted to collect further data on the behaviour and medium-term impact of the renourished beach. The results of that programme form the basis of this paper.

HYDRODYNAMICS OF PILOT BAY

The tidal dominance of a particular channel within an estuary may be considered in terms of the relative duration of flood and ebb flows which exceed some threshold velocity, often the threshold of sediment entrainment (STERNBERG, 1979). However, the THS indicated that significant quantities of sediment (24000 m^3 y^{-1}), mainly pumice, were advecting through Pilot Bay at current velocities below the entrainment threshold velocity (BLACK, 1984; BARNETT, 1985). In addition, wave energy may entrain sediment within the littoral zone within estuaries, whereupon it may be trans-

Figure 2. Aerial view of Pilot Bay Beach following renourishment (August 1984).

ported by tidal currents (HARRIS, *et al.*, 1979; WARD, 1985). Hence the dominance of tidal flow within Pilot Bay was considered in terms of the relative duration of all flood- and ebb-directed flows.

Tidal currents were measured by the THS, during complete tidal cycles, at two locations in the vicinity of Pilot Bay (Figure 3), using Braystoke BFM0101 Multi-parameter Current Meters. These measurements indicated that Cutter Channel was slightly flood-dominated, whereas Pilot Bay was ebb-dominated (Figure 5). However, the two numerical hydrodynamic models employed by the THS produced conflicting results. The model 2DD developed by BLACK (1983) indicated an ebb-dominance in Pilot Bay, whereas System 21 developed by the Danish Hydraulics Institute indicated no flow dominance (DE LANGE, 1988).

During the monitoring programme, further tidal measurements within Pilot Bay were obtained with continuously recording Aanderaa current meters, deployed at 1 m above the sea bed (Figure 3). These data confirmed the ebb-dominance of Pilot Bay (Figure 6), although the flow rarely exceeded sediment threshold velocity (0.30 $m.s^{-1}$) within most of Pilot Bay (Sites 1, 2, and 6B1).

The ebb-dominance within Pilot Bay is due to the formation of a flood-tide eddy involving Cutter Channel. During the early stages of a flood tide, before the flood jet is established, water flows into the harbour in both Cutter Channel and Pilot Bay. Once the flood jet is established, the flood flow in Cutter Channel increases and a portion of the flow is diverted into the Salisbury Wharf end of Pilot Bay, starting the eddy. The strength and duration of the eddy varies, with an apparent periodicity of 4.5 days, which may reflect periodic perturbations in the direction of the flood jet (DE LANGE, 1988).

Waves within Pilot Bay are derived from two main sources (DE LANGE, 1988; DE LANGE

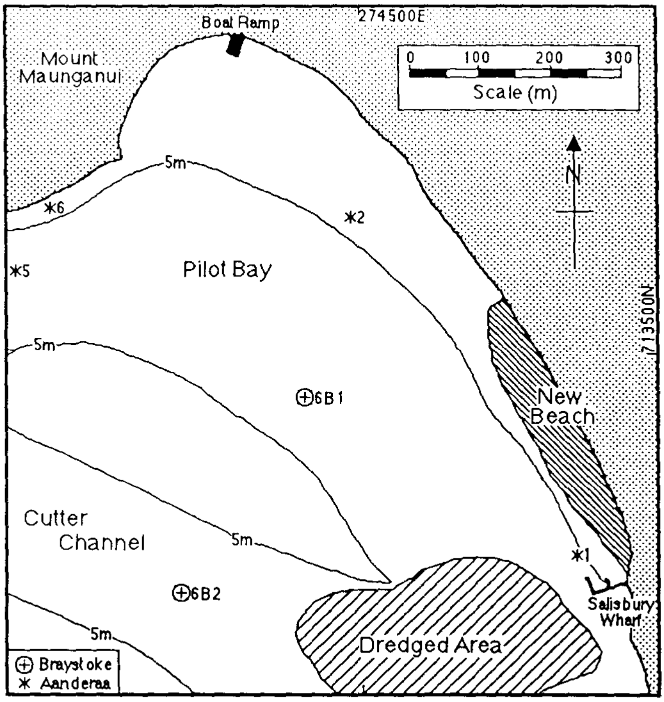

Figure 3. The sediment used to renourish Pilot Bay Beach was dredged from the junction of the Maunganui Roads, Cutter Channel, and Pilot Bay Channel, and piped to a discharge zone northwest of Salisbury Wharf. The locations of Aanderaa and Braystoke Current monitoring sites are also indicated.

and HEALY, 1989): diffraction of ocean swell waves through the entrance, and locally generated wind-waves. Wave data obtained from the southeastern end of Pilot Bay show that 70% of the wave energy is derived from the external wave field, but that this energy is associated with low amplitude, longer period waves ($H = 0.02-0.08$ m, $T = 4-8$ s). Locally generated wind-waves tend to be higher amplitude and shorter period ($H = 0.15-0.30$ m, $T = 2-3$ s). For Pilot Bay, the significant wave height (H_s) is 0.10 m and the mean period (T_z) 3.2 s. The maximum observed wave height and period were 0.69 m and 9.0 s respectively.

The waves within Pilot Bay are capable of entraining the sediment present down to a depth of 1.2 m (DE LANGE, 1988). Hence, sediment entrainment only occurs in the shallow regions within Pilot Bay, particularly the littoral zone, and transport of local sediment is confined to those regions. Any sediment which is transported to the deeper parts of the bay is unlikely to be transported further due to the low tidal velocities.

SEDIMENT CHARACTERISTICS

The original surficial beach sediment appeared quite coarse, mainly due to the concentration of shells and rhyolitic pebbles as a lag surface. In addition, cobbles derived from the gabion basket sea wall and wharf fill were present close to Salisbury Wharf. The sand fraction consisted mainly of organically coated quartz and feldspar, with a significant proportion (5–10%) of titanomagnetite. The sediment had a bimodal distribution and was negatively skewed (Figure 7), reflecting the presence of a shell and pebble lag. The dominant shell species present was *Chione stutchburyi* (cockle), derived from the sub-littoral zone adjacent to the beach.

The renourishment sediment was uplifted from an adjacent channel floor consisting of

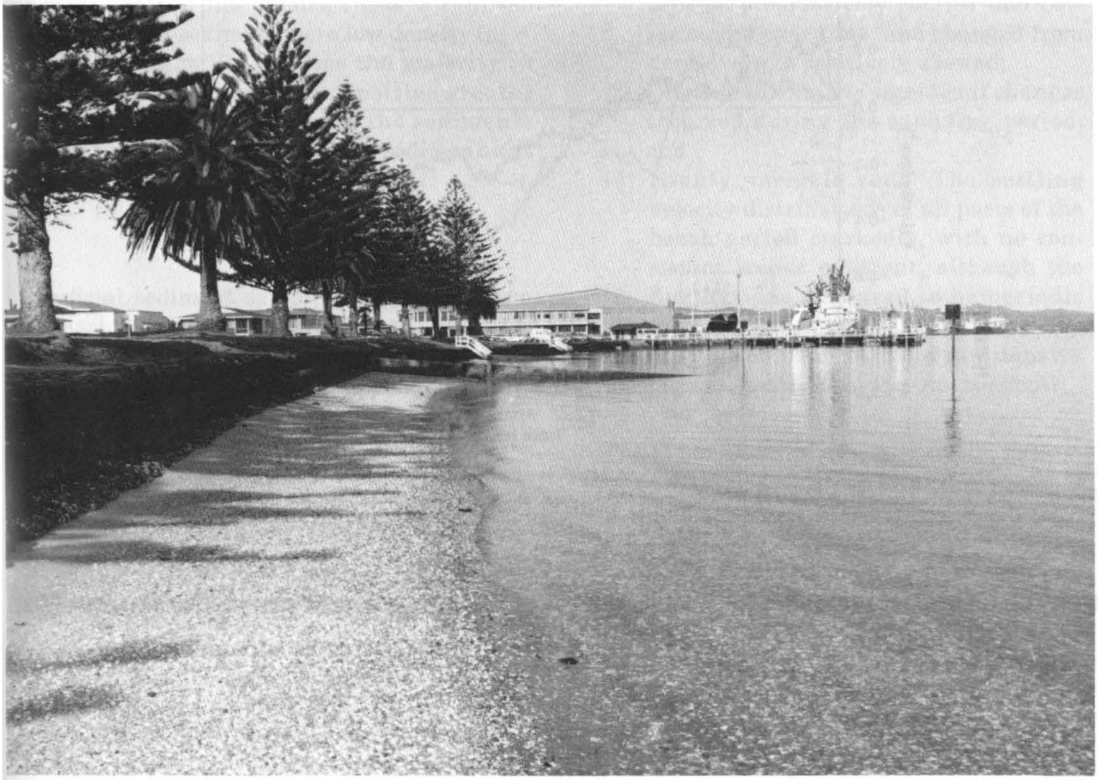

Figure 4. Pilot Bay Beach prior to renourishment (December 1983), in the vicinity of Salisbury Wharf.

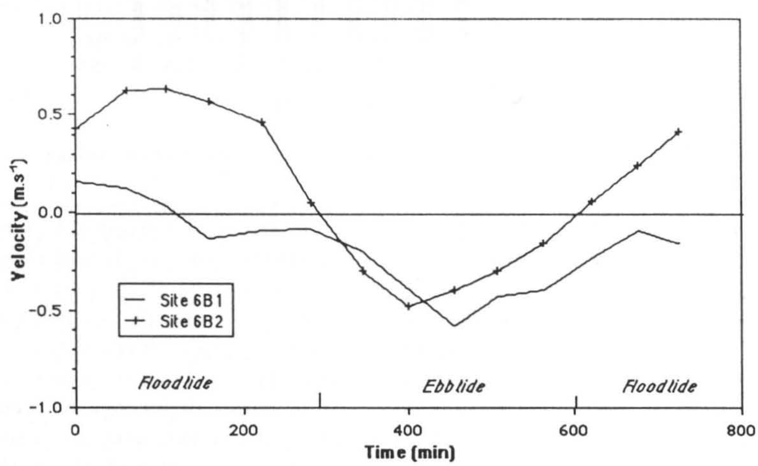

Figure 5. Time-velocity graph for Braystoke current measurements made in Cutter and Pilot Bay Channels during the THS (Figure 3). Ebb-directed flows are indicated by negative current velocities. The tidal flow within Cutter Channel is almost symmetrical, whereas the flow within Pilot Bay is strongly asymmetrical, indicating an ebb-dominance.

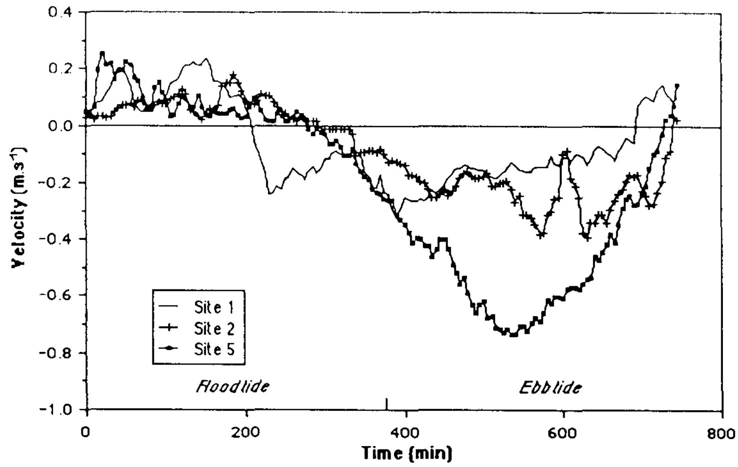

Figure 6. Time-velocity graph for the Aanderaa current meter measurements within Pilot Bay (locations given in Figure 3). Ebb-directed flows, which are indicated by negative current velocities, clearly predominate over the tidal cycle.

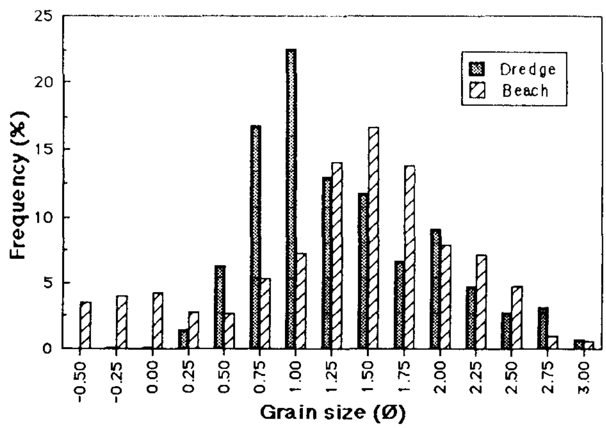

Figure 7. Particle size distributions for the prenourishment surficial sediments (average of 11 sites) and the dredge spoil (average of 3 sites).

unconsolidated sand with active megaripples, which represented a sediment transport null point (BLACK, 1984; HEALY, 1985). This area was known to have a history of accretion, and the THS indicated that accretion is likely to continue, requiring maintenance dredging every 7–10 years (BLACK, 1984). The sediment was a moderately well sorted (σ = 0.64 Ø), medium sand ($Ø_{50}$ = 1.18 Ø or 0.48 mm), consisting mainly of quartz, feldspar, and pumice. The size distribution was unimodal, with the modal sediment being slightly coarser than the modal size of the original beach (Figure 5). All the clasts were fresh and clean, lacking the organic coating of the original sediment. The dominant shell species present was *Paphies australis* (pipi), derived from extensive beds within the harbour tidal channels.

The major difference between the original sediment and renourishment sediment was the presence of pumice clasts in the dredge sediment. These clasts display an increase in density with decreasing size, due to the loss of voids (DE LANGE, 1988), so that they can display a wide range of densities (ρ_s = 1120–2370 kg.m^{-3}). Most of the pumice clasts within the renourishment sediment were low density (ρ_s = 1120–1850 kg.m^{-3}), whereas the majority in the original sediment had densities greater than 2000 kg.m^{-3}. Otherwise the sediments were very similar, so the dredged sediment was suitable for use in the renourishment.

TEXTURAL CHANGES

Surficial sediment samples were taken from the beach at monthly intervals for the first year after renourishment, and at irregular intervals subsequently. Each sample was taken from the top 10–20 mm of the beach, and 50–100 g subsamples were analyzed in the University of Waikato Rapid Sediment Analyzer to determine the size and settling velocity distribution (DE LANGE, 1988). Due to the variety of sediment densities (1120–4680 kg m^{-3}) and particle shapes (bladed to spherical) within the beach sediment, the settling velocity distributions were considered more appropriate than hydrodynamically derived size distributions. Hence the results will be presented in terms of χ units as defined by MAY (1981), with an increase in settling velocity (increasing χ values) being interpreted as a fining of the sediment.

One year after beach renourishment, several zones could be distinguished along Pilot Bay beach based on observed temporal variations in the settling velocity distributions (Figure 8):

(1) Renourished zone. Initially this zone consisted entirely of dredge spoil which was progressively eroded and reworked. The supra-littoral region of the beach remained relatively constant over time, whereas the littoral and sub-littoral regions became coarser due to the formation of a shell and pebble lag;
(2) Mixing zone. This zone initially consisted entirely of the original beach sediment, which became progressively mixed with sediment from the renourished beach. The sub-littoral and supra-littoral regions of the beach remained fairly constant, except for a slight fining of the sediment in the highest regions of the beach where aeolian dunes formed. The littoral zone became progressively coarser and better sorted over time, and changed from negatively to positively skewed;
(3) Unaffected zone. No significant changes occurred during the sampling period; and
(4) Highly variable zone. The settling velocity distributions of all parts of the beach varied markedly, with no consistent trends apparent, although the fluctuations appeared to be periodic (Figure 9). These fluctuations are attributed to influxes of low density pumice clasts following storm events.

The major changes observed in the nature of the beach sediments along Pilot Bay beach during the monitoring programme were: (i) the rapid loss of pumice clasts from the renourished beach; and (ii) the spread of pipi (*Paphies australis*) shell material towards the northwest associated with the reappearance of fresh cockle (*Chione stutchburyi*) shells on the renourished beach. Episodic appearances of pumice clasts were observed at the extreme northwestern end of the beach, usually following local storms.

SUNAMURA and HORIKAWA (1972) developed a model relating the spatial variations of size distributions to sediment transport direction. This model has previously been applied in New Zealand with reasonable success (BRIDGEWATER, 1986). Accordingly the model was applied to Pilot Bay, but using settling velocity parameters instead of the size parameters of the original model (DE LANGE, 1988). The model compares the spatial trends of median settling velocity and sorting. Of the possible combinations of trends which may be obtained, four are considered to define transport directions (Figure 10).

The model consistently predicted an overall transport direction for Pilot Bay beach from the Salisbury Wharf end, towards Mt. Maunganui. In detail, this model suggested that transport directions in the mixing zone referred to above, were variable, particularly after storm events when, either no trend was apparent, or the direction opposed the overall transport direction for the beach.

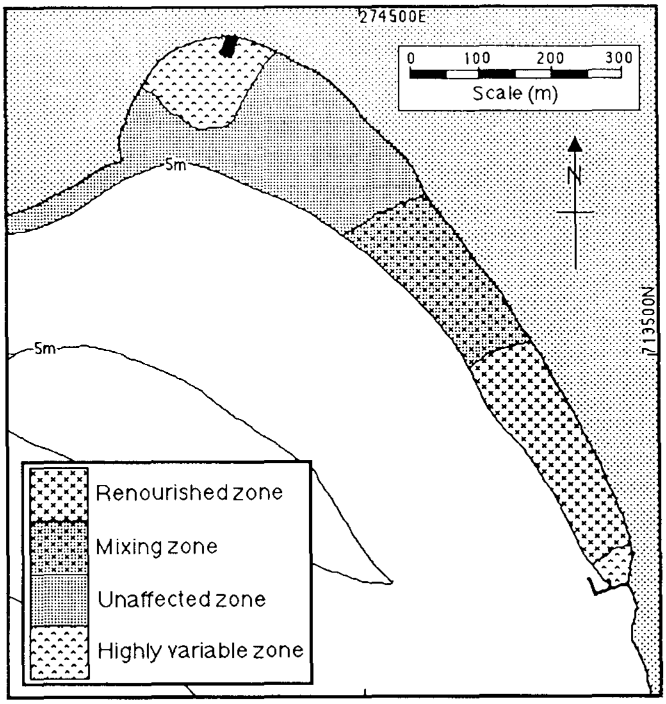

Figure 8. Textural zones identified along Pilot Bay Beach on the basis of temporal textural variations 1 year following renourishment (March 1986).

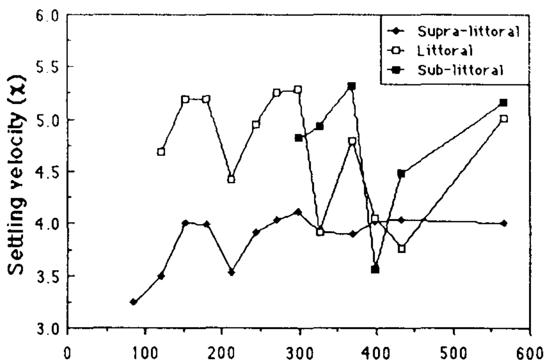

Figure 9. Temporal variations in the mean settling velocity (χ) observed within the highly variable zone of Pilot Bay Beach. Increases in mean settling velocity (indicating a decrease in apparent grain size) occurred after storms and were associated with an influx of low density pumiceous clasts.

BEACH PROFILE CHANGES

Prior to renourishment, the BOPHB established several survey transects across Pilot Bay Beach, and these were resurveyed periodically during the monitoring programme. The resulting data were digitized and analyzed in terms of: (a) the distance to specified elevations;

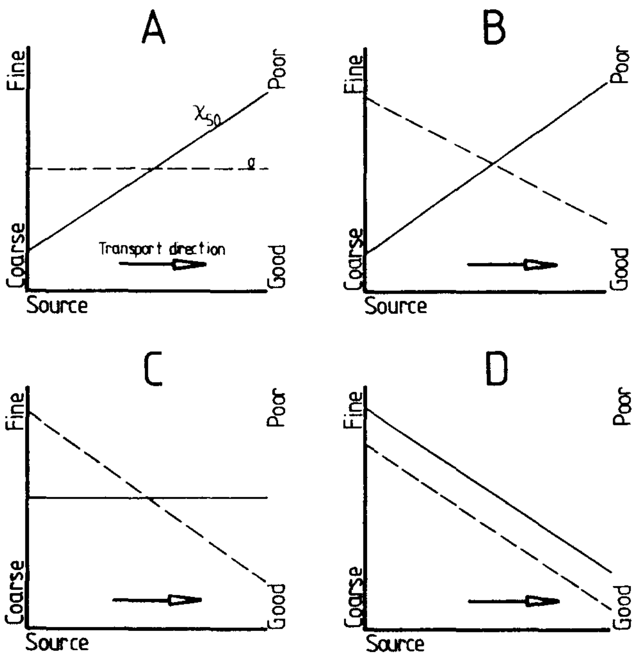

Figure 10. Spatial trends of median settling velocity and sorting which are considered significant in terms of defining sediment transport directions (After Sunamura and Horikawa (1972)). **A** indicates a progressive fining of the sediment with no change in sorting; **B** indicates a fining in sediment with improved sorting; **C** indicates no change in mean grain size with an improvement in the sorting; and **D** indicates a coarsening of the sediment with an improvement in sorting.

(b) the beach slope at specified elevations;
(c) the elevation at specified distances;
(d) the unit volume (m^3 m^{-1}) above and below chart datum; and
(e) the unit volume (m^3 m^{-1}) above specified elevations.

The elevations considered were mean high water (MHW), mean sea level (MSL), and mean low water (MLW). However, in order to assess the minimum beach area available for public use, the study concentrated on changes above MHW.

At the southeastern end of the beach, renourishment increased the area above MHW by 500%, and the MHW mark lay 10–30 m further seaward (Figure 11). Although the distance to the MHW elevation has not decreased consistently, the beach has continued to erode since renourishment. By October 1987, the beach area above MHW was reduced to less than half that present immediately after renourishment. The artificial beach was considerably steeper (4°30′ or 1:13) than the original beach (1°40′ or 1:34), and some of the initial erosion was associated with an adjustment of the beach slope to 2°15′ (1:25).

Comparing the beach unit volumes above MHW, for the same periods as displayed in Figure 11, indicates a systematic pattern of erosion (Figure 12). The sites closest to Salisbury Wharf (B,C, and D), and to the boat ramp (I), undergo fairly steady erosion following renourishment. The middle sites (E,F,G, and H) tend to accrete, or remain essentially static, for the first 2–3 years after renourishment before undergoing erosion. All sites eroded significantly by the final survey (October, 1987).

The pattern of erosion observed is consistent with sediment transport from the southeastern end of the beach towards the northwest, with erosion in the middle region of the beach being compensated for by sediment supplied from updrift regions. Eventually, 2–3 years after renourishment, the availability of sediment from updrift regions diminished, and the rate erosion of the middle region increased.

The volume of sediment present in the beach

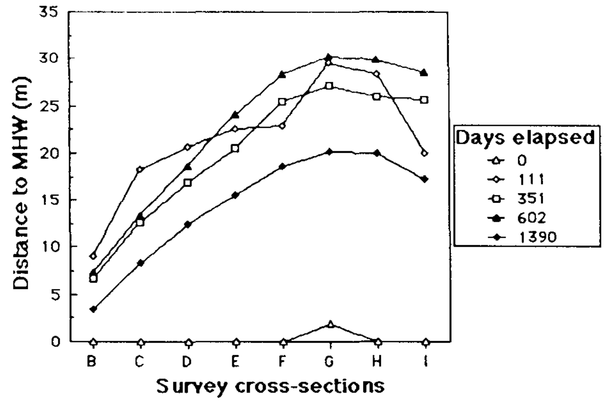

Figure 11. Distance to the mean high water elevation from the location of the gabion basket seawall for Pilot Bay Beach. The initial survey (day 0) was performed on December 16, 1983, and the first survey after renourishment (day 111) was performed on April 4, 1984.

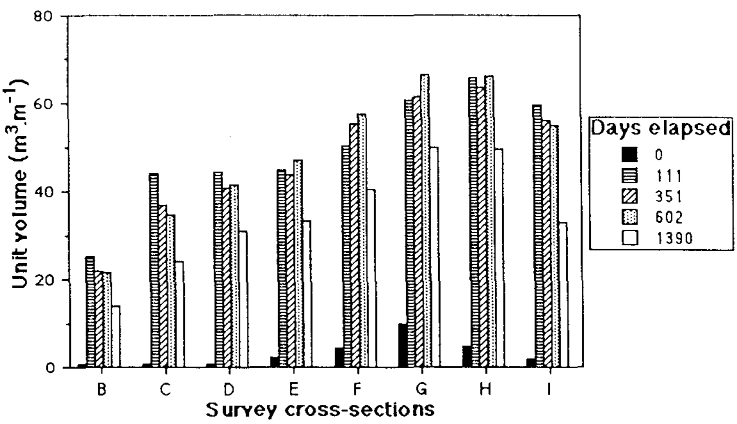

Figure 12. Unit volumes ($m^3.m^{-1}$) above mean high water for Pilot Bay Beach corresponding to the surveys in Figure 11.

was determined by dividing the beach into sections corresponding with each survey profile. The unit volumes above MLW obtained for each profile were converted to volumes per unit area (m^3 m^{-2}) and multiplied by the appropriate section area to derive the section volume. The beach volume represents the sum of the section volumes, multiplied by a correction factor, derived by comparing the survey beach volume, immediately after the completion of dredging, with the measured dredge volume (it was assumed that all the dredge material was deposited above MLW).

The beach volumes above MLW were regressed against the time elapsed (days) after the completion of the beach renourishment (days 111 to 1390). This predicted an average erosion rate of 2.52 m^3 day^{-1} from the entire renourished zone during the survey period (April 1984 to October 1987), and suggests total removal of the renourished beach within 13 years. Although the regression line calculated is a reasonable fit (Figure 13), with a regression coefficient (r^2) of 0.81, the total life of the renourished beach is probably less than predicted, because the average erosion rate is increasing with time in response to a reduced sediment supply from the updrift regions of the beach.

Although, the analyses considered above may

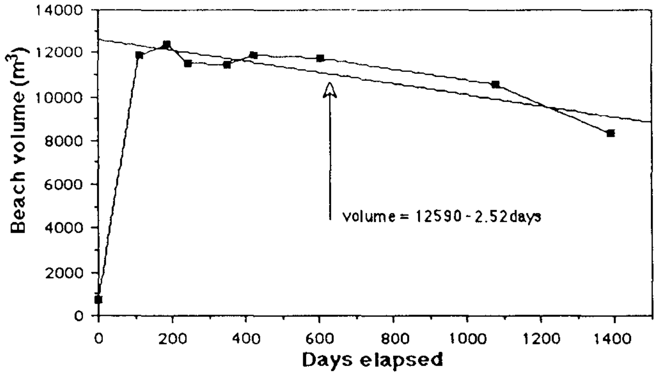

Figure 13. Beach volume above MLW (m3) for Pilot Bay Beach. The regression line shown predicts that all the sediment added during renourishment will be lost in 13 years.

convey the impression that the observed changes in the renourished beach occurred in a steady, uniform manner, the changes actually occurred episodically. Three main factors contributed to the observed changes:

(1) Storm wave activity. Local wind-generated waves provided the energy needed to entrain sediment on the beach, especially the waves generated by westerly to northwesterly storms with wind speeds of 10–15 $m.s^{-1}$ and durations of 6–12 h (DE LANGE, 1988). These storms generated a steep chop ($H_s = 0.3$ m, $T_z = 2$ s), which cut back the higher reaches of the beach, particularly in the vicinity of MHW;
(2) Stormwater discharge from outfalls. Stormwater outfalls discharge stormwater from Mount Maunganui Borough into Pilot Bay at ~500 m intervals. The outfalls terminate at the seawall, so that the discharge is across the beach. During rain storms the discharge would excavate deep channels across the beach and form deltas into Pilot Bay. The channels would subsequently be infilled by sediment from the adjacent beach, but the deltas remained, being beneath the effective wave base (DE LANGE, 1988); and
(3) Maintenance work. During the study period maintenance work activities, including clearance of storm outfalls, boat ramps, and slips, produced a net loss of sediment from the beach. This mainly affected the Salisbury Wharf end of the beach where the renourished beach impinged on a boat slip, which required occasional clearance. The sediment removed from the slip was deposited below MLW where most sediment slumped below wave base.

FUTURE TRENDS

During the study period the sediment eroded from the renourished beach accumulated in 2 main areas (Figure 14):

(1) Immediately downdrift from the renourished beach. The sediment formed a shore-parallel sub-littoral spit attached to the western end of the renourished beach. This feature grew rapidly during the first 6 months following renourishment, but has remained essentially static since then; and
(2) Adjacent to the boat ramp at the northwestern end of the beach. Approximately half the sediment lost from the renourished beach by October 1987 had accumulated immediately adjacent to the boat ramp. The accumulation in this area has necessitated regular excavation of the boat ramp to enable its continued use.

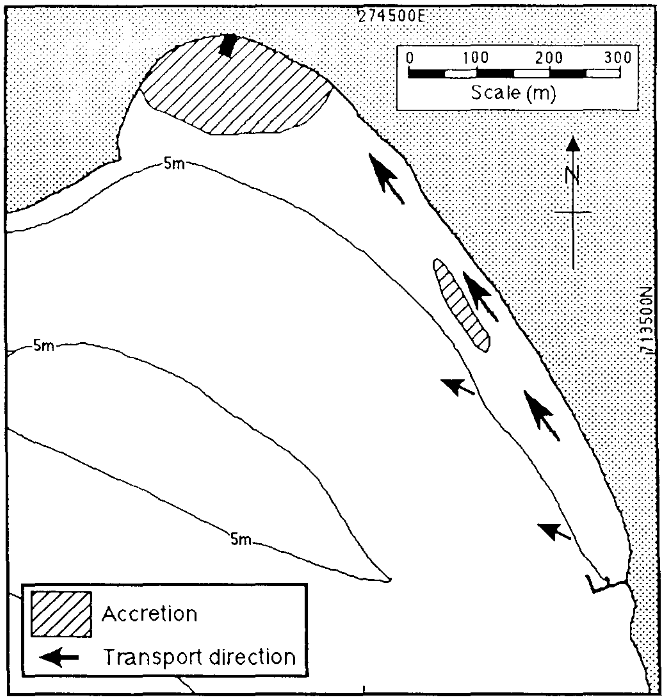

Figure 14. Summary of the sediment transport pathways for the renourishment sediment, and the major zones of sediment accumulation during the period April 1984 to October 1987.

Therefore, the main sink for sediment is the region in the vicinity of the boat ramp, and, in the long term, most of the sediment from the renourished beach can be expected to accumulate there. Once the sediment is in the vicinity of the boat ramp it is unlikely to move further, since the tidal currents in this region (<0.15 m s^{-1}) are well below sediment threshold, and the region is sheltered from wave activity (DE LANGE, 1988).

SUMMARY

Pilot Bay provides an example of the beach nourishment history of a flood tidal delta adjacent beach in a large meso-tidal inlet and estuarine lagoon system. The beach has had a history of erosion, and during 1984 the south-eastern end of the beach was renourished. The subsequent behaviour of the renourished beach and the adjacent beach were monitored between April 1984 and October 1987.

The tidal flow patterns within Pilot Bay are controlled by a flood-tide eddy, resulting in a dominant flow in the ebb-direction, although the flow velocity (averaging <0.15 m s^{-1}) rarely exceeds the sediment entrainment velocity (0.30 m s^{-1}). Sediment transport within Pilot Bay is due to entrainment of sediment by wave activity combined with tidal currents. The ebb-dominance of the tidal currents predicts a net sediment flux from the Salisbury Wharf end of the bay towards the boat ramp.

The sediment used for renourishment was very similar to the original beach sediment, both in terms of composition and texture. The major difference was the presence of large quantities of low density pumice clasts in the renourishment sediment. These clasts were easily transported by the conditions extant in Pilot Bay, resulting in a rapid loss of pumiceous sediment from the renourished beach. There is no evidence to suggest that the remaining constituents of the renourishment sediment behaved differently to the original sediment.

The SUNAMURA and HORIKAWA (1972) method was used to derive sediment transport directions from the spatial variations in mean settling velocity and sorting of surficial beach sediments. The predicted transport directions were consistent with the directions predicted by the dominant tidal flow direction and the observed changes in beach profiles.

The expected life of the renourished beach is similar to that reported by GIARDINO *et al.* (1987), and LUDWICK *et al.* (1987), at between 8–13 years. The duration before redredging of the basin which supplied the renourishment sediment, is predicted likewise as every 7–10 years (BLACK, 1984). Further renourishments from this source are feasible, depending on economic and social constraints. Subsequent renourishments are expected to behave in the same manner as the initial event studied, in which case the gradual infilling of the shallow region in the vicinity of the boat ramp is probable.

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□ RÉSUMÉ □

Le delta de marée de flot de Pilot Bay Beach, qui est adjacent à la plage de Tauranga Harbour est en continuelle érosion. On a constaté, au cours d'un programme de maintenance de dragage début 1984, que la baie de Plenty Harbour Board réalimentait l'extrêmité SE de la plage avec une perte de 2,1 × 10^4 m^3 de dragage. La baie a donc été incluse dans l'étude de Taraunga Harbour qui donnait les données de base pour l'étude du comportement d'une plage réalimentée. Dans la Pilot Bay, les courants de marée sont affectés par des turbulences de flot se traduisant par un courant dirigé dans le sens du jusant pour la plupart des cycles de marée. Ce phénomène ne dépasse que rarement le seuil de mise en mouvement du sédiment. L'énergie supplémentaire nécessaire à la mise en mouvement est fournie par les vagues, particulièrement sur la plage. Les sédiments utilisés pour la réalimentation avaient un composition et une texture semblables à celles de la plage d'origine. Il n'y avait que l'espèce dominante des coquilles qui changeait et présence de ponce. Les fragments de ponce de faible densité, étaient rapidement transportée loin de la plage réalimentée, et perdus pour le dragage. La direction du transport sédimentaire prédite par le courant de marée dominant et par la distribution spatiale de la texture sédimentaire a été confirmée par les changements du profil de plage. Les sédiments migrent depuis l'extrêmité réalimentée de la plage vers le NW, où peut se produire une accrétion à long terme. Durant la période d'avril 1984 à octobre 1987, le taux moyen d'érosion de la plage réalimentée était de 2,53 m^3 par jour, ce qui donne une durée de vie de moins de 13 jours.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*

□ ZUSAMMENFASSUNG □

Pilot Bay Beach, ein Strand neben einem Flutdelta im Tauranga Harbour, zeigt eine lange und kontinuierliche Erosion. Während einer Ausbaggerung im Frühjahr 1984 wurde das SE-Ende des Strandes vom Bay of Plenty Harbour Board mit 2,1 × 10^4 m^3 Material aufgespült. Die Bucht wurde in die Studie über den Tauranga Harbour aufgenommen, um das Verhalten dieses aufges-

pülten Strandes zu untersuchen. Die Gezeitenströmungen in der Pilot Bay werden von einem Flutwirbel beeinflußt, der aus einer dominanten Ebbströmung während der meisten Zeit des Tidezyklus resultiert. Diese Strömung erreicht jedoch nur selten eine Geschwindigkeit, die zum Sedimenttransport notwendig ist. Die zusätzliche Energie dafür wird durch Wellenbewegung am Strand beigesteuert. Die für die Strandaufspülung benutzten Sedimente sind in der Zusammensetzung und Textur dem ursprünglichen Strandsediment sehr ähnlich, abgesehen von einer Abweichung bei den hauptsächlich vertretenen Muscheln und dem Vorhandensein von Bimsstein. Die sehr leichten Bimssteine werden rasch vom aufgespülten Strand entfernt. Der durch den dominanten Gezeitenstrom und die Sedimenttextur bestimmte Sedimenttransport wurde durch wiederholte Vermessungen der Strandprofile festgehalten. Die Sedimente bewegen sich vom aufgespülten Strandende nach NW, wo wahrscheinlich längerfristig ein Zuwachs stattfindet. Zwischen April 1984 und Oktober 1987 betrug der mittlere Abtrag am aufgespülten Strand 2,52 m^3/Tag, so daß eine Lebensdauer von weniger als 13 Jahren gegeben ist.—*Dieter Kelletat, Essen/FRG.*