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Evaluation of an Inner Shelf Site Off Tauranga Harbour, New Zealand, for Disposal of Muddy-Sandy Dredged Sediments

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ABSTRACT

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A planned extension of the Port of Tauranga requires capital dredging of material containing significant amounts of silt and clay. The existing disposal ground located about 4 km offshore in water depths of 15 to 25 m, is unsuitable as it was designed for slow migration of predominantly sandy materials onshore to nourish the adjacent beaches.

Investigation for a new disposal site involved consideration of alternatives, but the "best practical option" selected was offshore of the existing ground in water depths of 28–33 m. Site research included side scan sonar imagery of the sea floor, sediment sampling by SCUBA diving, and deployment of a current meter for several weeks during the spring season to obtain background hydrodynamic data.

Analysis of the data indicated that motion of medium to coarse sands occurs during periods of high swell conditions. Calculations of potential transport of discrete mud "clasts" suggest that small units ($\leq$2 cm) may move under large waves (T_s = 11 s, H_s = 1.6 m), but larger mud "clasts" would be stable. It is expected that the existing high disposal mound immediately shoreward of the proposed new disposal ground would hinder onshore migration of muddy clasts.

ADDITIONAL INDEX WORDS: *Disposal, cohesive dredge spoil, bed shear stress, threshold velocity.*

INTRODUCTION

The Port of Tauranga is New Zealand's largest export port located within a large tidal inlet estuarine system on the northeast coast of New Zealand. Tauranga Harbour has formed by a barrier island and tombolo system, influenced by the rhyolite dome of Mt. Maunganui (Figure 1). Essentially the harbour is located within a drowned valley complex with numerous marsh and tidal flat bounded reentrants along its inner margin (DAVIS and HEALY, 1993).

The development of the Port of Tauranga over recent decades has included numerous capital dredging campaigns. A single campaign in 1992 involved trailer-suction dredging of up to 5 Million m^3 of sediment within the harbour (HEALY *et al.*, 1991a, 1991b; MATHEW *et al.*, 1995; HEALY *et al.*, 1997) which was disposed in a large mound in Water Right Area 2192 (Figure 1). The sediment dredged to date has consisted mainly of marine shelly and gravelly sands with only minor amounts ($<$ 5 %) of silts and clays (HEALY *et al.*, 1991a). Most of the dredged material has been disposed of either in water depths of 15 to 25 m approximately 4 km off the coast, or nearshore in shallow water (4 to 7 m below chart datum defined as Mean Low Water Springs) to renourish adjacent Mt. Maunganui beaches (FOSTER *et al.*, 1994, 1996).

The planned wharf extension of the Port of Tauranga at Sulphur Point South (Figure 1), however, requires dredging of sediments with a significant amount of silt and clay associated with lithologies containing distal ignimbrites and estuarine muds (DAVIS and HEALY, 1993). These sediments are considered inappropriate to be disposed of within the Water Right Area No. 2192 because of the risk of muddy material migrating onshore and despoiling the beaches and rocky reefs.

Therefore the issue was to find a suitable site which:

(1) would not significantly impact the benthic ecology;
(2) did not affect *tangata whenua* sites (sacred sites of the Maori indigenous people);
(3) would not impact on adjacent amenity values, for example by despoiling sandy beaches due to re-transported mud;
(4) would not impact on commercial or recreational fishing sites;
(5) would not impact on areas used for recreational boating or public activities;
(6) is economically viable for port operations; and
(7) ideally allows disposal of "like-on-like" material to allow rapid ecological recolonisation after the disposal.

From initial assessment involving discussion with potentially affected parties, there appear two possible sites for disposal of muddy sediments. The first is located in water

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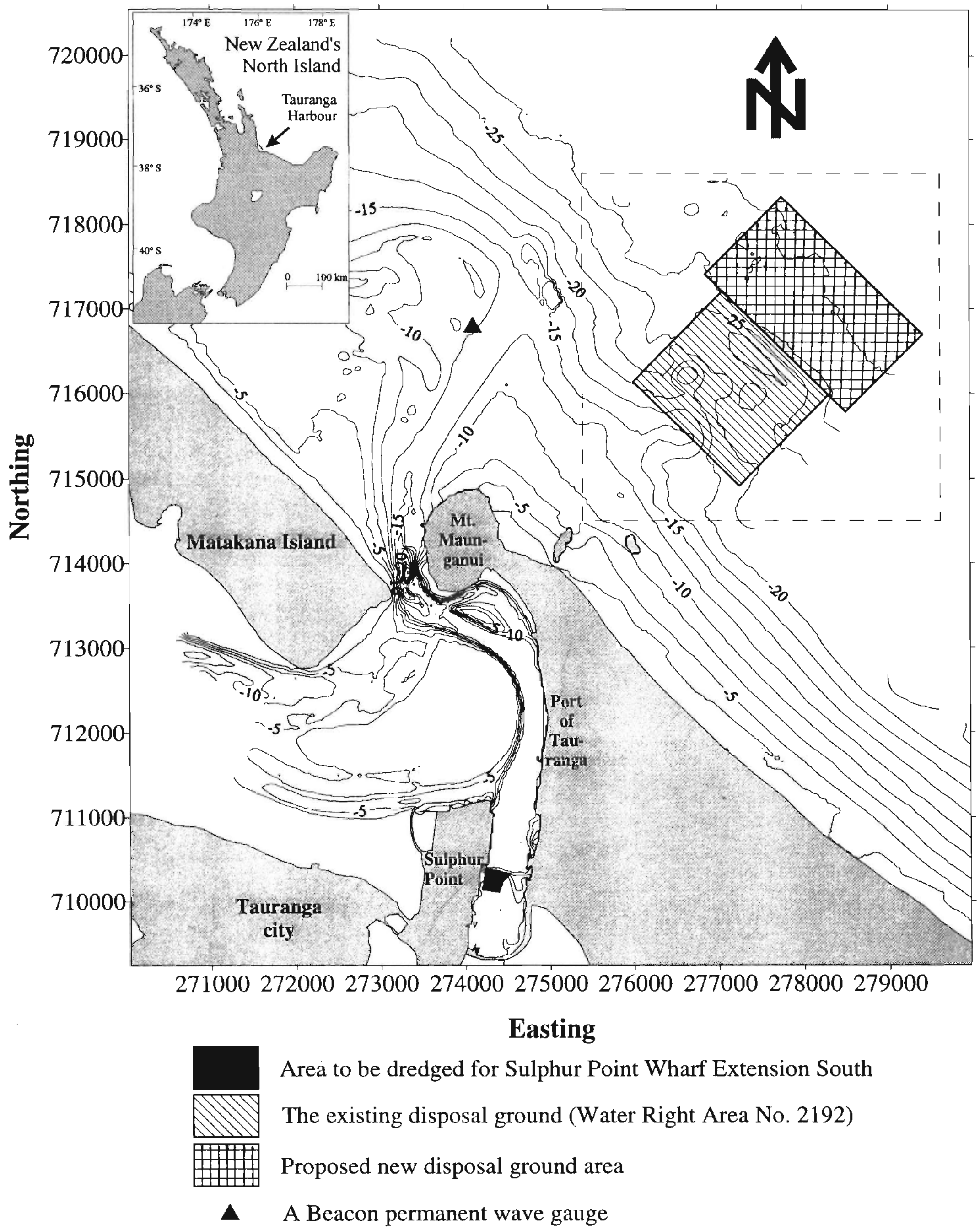

Figure 1. Overview of the southern part of Tauranga Harbour with the dredging area for the planned wharf extension at Sulphur Point and Water Right Area No. 2192 and the proposed new disposal ground on the inner shelf. The dashed line marks the area enlarged in Figure 2.

depths of ~ 50 m on the middle shelf about 17 km offshore from the port entrance. This site meets most of the requirements listed above except that the sediment out there is predominantly sandy and the distance is economically disadvantageous. The large costs involved in transporting the material out 17 km from the harbour entrance is a major disadvantage. Moreover this site has not, to date, been influenced by disposal and is more likely to show a greater diversity of marine life than sites with mobile coarser sediments further inshore.

The second alternative for a muddy sediments disposal ground is as a seaward extension of the existing major capital dredging disposal site, granted as Water Right Area No. 2192 (Figure 1) which is presently used by the Port of Tauranga for disposal of both capital and maintenance dredge spoil

(HEALY *et al.*, 1991a). This location is situated well clear of the popular sporting and recreational SCUBA diving areas, and has the advantage of being close to the disposal sites used so far. Water depths are about 28 to 33 m below chart datum. At such depths material on this site is less likely to be frequently stirred by waves of moderate to high magnitudes than on the presently used disposal ground. Although the texture of the sediments at this site does not exactly match that of the dredged sediments, the adjacent landwards topographic high mound of the existing disposed materials in Water Right Area No. 2192 will likely hinder any potential onshore transport of sediment from the proposed new site. After careful consideration of the alternatives for a new disposal site, the area comprising the seaward extension of the Water Right Area No. 2192 has been assessed as the "best practical option" after weighing up both environmental and economic issues.

A field investigation program was set up to further explore the suitability of this site for disposal of dredgings with a significant amount of silt and clay. This paper presents the results from the sedimentological, geophysical and oceanographic field investigations, and their analysis and interpretation.

METHODS

Site to be Dredged

The sediments in the area to be dredged for the port extension, have been investigated by the analysis of cores and subbottom profiles. At different stages of port development numerous cores have been taken in the port area during the last two decades. The re-perusal of high-resolution seismic subbottom profiles together with the core investigations permitted good interpretation of the sediment stratigraphy.

Proposed New Disposal Ground

The proposed new disposal ground has been investigated by undertaking:

- a bathymetric survey of the area proposed as the new disposal ground (Figure 2);
- a side scan sonar survey of the proposed new disposal ground area to map the distribution of different sediment types and structures, and morphological features in the area (for area covered by the profiles refer to Figure 2);
- a set of 5 sediment surface samples from the proposed new disposal ground area, retrieved by SCUBA diving (for positions refer to Figure 2). These samples were analyzed texturally with the Rapid Sediment Analyzer settling tube. These samples also represent a data set for ground truthing and calibrating the side scan sonar map; and
- an S4 electromagnetic recording current meter deployment in a water depth of 29 m to investigate current speeds and directions common in the area (position marked in Figure 2).

Combined with wave height and wave period data from a wave recorder operated by the port company at A Beacon about 3 km off the harbour entrance (position marked in Figure 1), and the wind direction from the weather station at Tauranga Airport, it is possible to predict the probability of sediment transport for various conditions.

RESULTS AND INTERPRETATION

Dredge Site

The sediments in the area to be dredged consist mainly of three different units: (1) a shelly and gravelly sand with minor amounts of silt and clay (< 3 %). This unit represents the youngest sedimentation in a marine environment. It is underlain by either (2) pumiceous sediments with silty-clayey sands and cohesive sandy-clayey silts, where the silt and clay content may attain 80 %, or by (3) cohesive estuarine clays, geotechnically described as "tight" (HEALY *et al.* 1991b) and containing about 90 % silt and clay. The silts and clays are partially of volcanic origin from tephras and distal ignimbrites, and contain pumice particles and smectite weathered from volcanic glass. The smectite clays produce a milky turbidity when the sediments are dredged. The seismic subbottom profiles suggest that the estuarine clays are deposited in a channel environment, and are thus interpreted as older than the pumiceous sediments (DAVIS and HEALY, 1993).

Based on the lithostratigraphic framework of the core investigation, the volumes of each unit can be estimated. The total volume in the area proposed for dredging is about 620,000 m^3. Table 1 gives the volumes and percentages of the different lithologies and grain sizes. The estimates for the amount of estuarine clay and the silt contents in the sediments are, however, fairly generous so that the real amount of silt and clay in the sediments is likely to be lower.

To minimize the disintegration of cohesive silt- and clay-rich sediments and thus minimize the volume of disturbed silt and clay dredgings and the generation of turbidity in the water column during the dredging operation, it is proposed that a digger type dredge which excavates the muddy sediment as discrete "bucket" loads be used. Since no "cutting" agitation of sediment and no pumping is involved in this dredging technique, the amount of turbid water leaving the dredge via the overflow, which contains high concentrations of very fine-grained suspended particles causing a long-lasting visual impact, is minimised.

Furthermore the disintegration of the dredged material during disposal is significantly reduced by this dredging process since the spoil falls as "clods" of material rather than behaving as discrete particles of disaggregated sediment descending as a dense fluid jet.

Proposed New Disposal Ground

Bathymetry

The bathymetry of the proposed new disposal ground comprises a near planar surface gently dipping seawards from ~ 28 m to 33 m below chart datum (Figure 2). Landwards the seafloor morphology is dominated by the disposal mound in the Water Right Area No. 2192 which rises from a water depth of ~ 27 m to 21 m. A number of other dredge disposal mounds can be identified also.

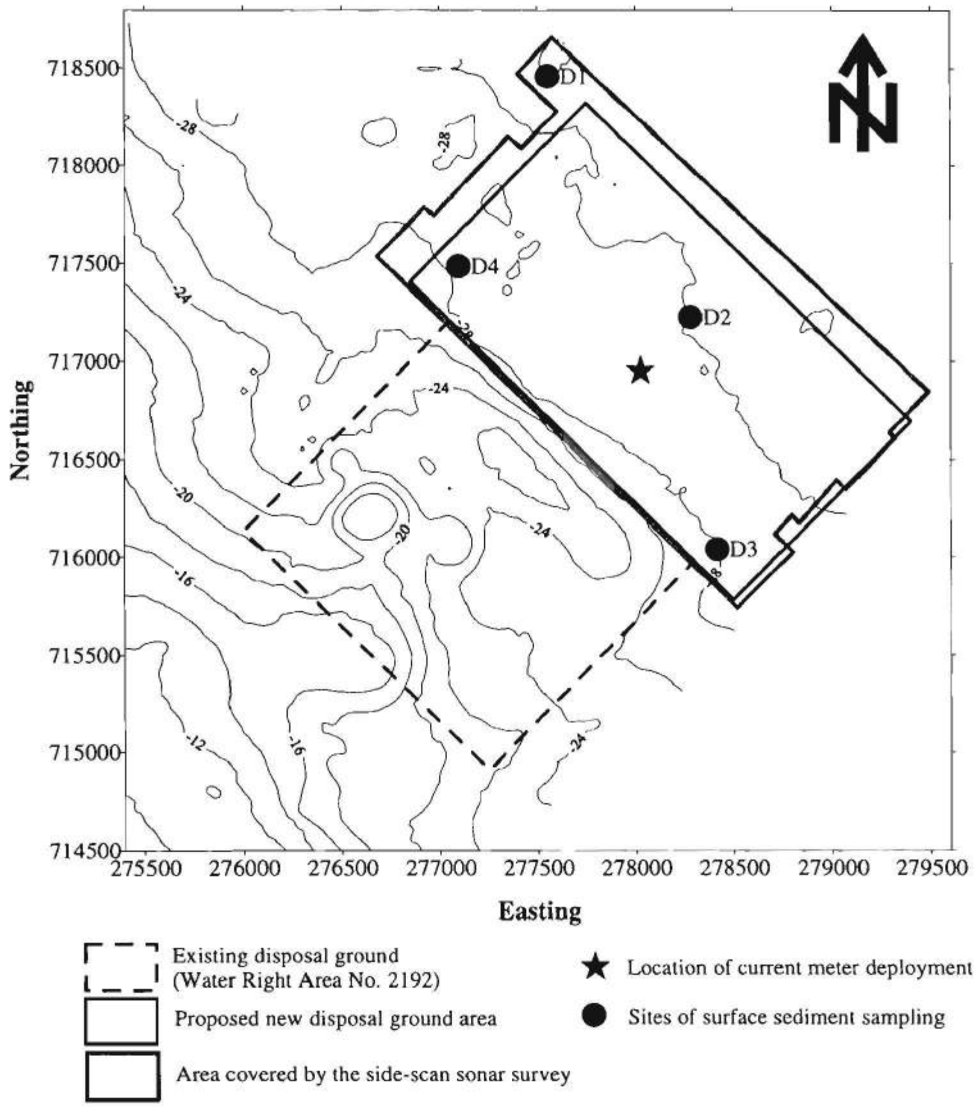

Figure 2. Enlargement of the inner shelf with Water Right Area No. 2192 and the proposed new disposal ground area. The gray-shaded line shows the outline of the area covered by the side scan sonar survey. The star marks the position of the current meter deployment and the dots indicate the positions of sediment sampling by SCUBA diving.

Side-Scan Sonar Survey

The side-scan sonar survey identified 4 major sonograph facies (Figure 3):

(1) *Coarse grained ripples* (following the terminology of BRADSHAW *et al.*, 1994; HEALY *et al.*, 1996) occur in medium to coarse sand with a bedform wave length of 0.6 to 6 m. The coarse grained ripples are aligned NW-SE parallel to the coast.

(2) *Featureless and finely rippled* facies in fine to medium sand. Since ripples smaller than about 0.05 m wavelength are below the resolution of the side scan sonar this facies may appear featureless on the sonographs in some areas. When ground-truthing the different lithologies by SCUBA diving however, small ripples were found in this sediment type as has been observed in many locations previously (BLACK and HEALY, 1983; 1988). Light gray shades indicate finer grain sizes associated with this facies.

(3) Irregular patterns of *dune bedforms* of different sizes, often covered with coarse grained ripples. A darker gray background reflection suggests predominantly coarser sand sizes. Based on change of bedform pattern this facies is interpreted to represent areas where sandy dredge spoil has been disposed or migrated seaward from disposal sites within Water Right Area No. 2192.

(4) *Sand wave* facies with wave length of 6 to 20 m, generally well developed in medium to coarse sand and often covered by coarse grained ripples. Since this facies occurs

Table 1. *Estimates of the volumes of marine shelly sand, pumiceous silty sand and estuarine mud and of the volumes of sand, silt, and clay based on the results from available core data.*

	Volume (m^3)	Volume (%)		Volume (m^3)	Volume (%)
Marine shelly sand	155,000	25	Sand	300,000	50
Pumiceous silty sand	235,000	38	Silt	225,000	35
Estuarine mud	230,000	37	Clay	95,000	15

only close to the crest of the disposal mound and within the area of the disposal ground facies, a connection between the sand wave formation, the decreasing water depth towards the disposal mound, generating more effective hydrodynamic wave driven transport of the disposed material, is likely.

(5) *Rocks and blocks* of disposed material have been mapped separately where they could clearly be recognized.

The boundaries of the different sonograph facies have been classified as either "sharp" or "transitional". Large areas of coarse grained ripple bedforms are the dominating facies, and are typically overridden by patches and sheets of transgressive fine sand, as has been noted previously on lee coast inner shelves (BLACK and HEALY, 1983; DELL *et al.* 1985, HEALY, 1985; BLACK and HEALY, 1988; HARMS 1989, BRADSHAW *et al.* 1994; HEALY *et al.*, 1996). These fine sand sheets undergo active sediment transport under lower orbital velocities than for the coarser sand (COOK and GORSLINE, 1972; HARMS, 1989; MATHEWS *et al.*, 1995). The patches and drapes of finer sand often reveal elongated or finger-shaped features which typically orientate normal to the coastline (BLACK and HEALY, 1983; HEALY, 1985; HARMS, 1989). Along the landward boundary of the proposed new disposal ground the different bedform pattern identified suggests seaward spreading of the spoil from the topographic highs of the disposal mounds.

Grain Size Measurements

The samples retrieved from the area of the proposed new disposal ground represent two different grain size populations, mapped as facies 1 and 2 on the side-scan sonar survey. The settling velocity-size distributions revealed a grain-size range of about 0.125 mm to 0.750 mm for the fine-grained sediments, peaking at about 0.320 mm and a grain size range of 0.350 mm to 1.0 mm for the coarser grained sediments with its maximum at about 0.600 mm. The samples were moderately well to very well sorted and had a silt and clay content of just about 1 %.

Deployment of Current Meter, Wave and Wind Data

An S4 current meter was deployed during the period of 1 October 1997 until 23 October 1997 (Julian day 273 until 295 in 1997) in the area proposed as the new disposal ground (Figure 2). The current speeds were recorded at 1 m above sea floor in "burst" mode (mean current speed and direction

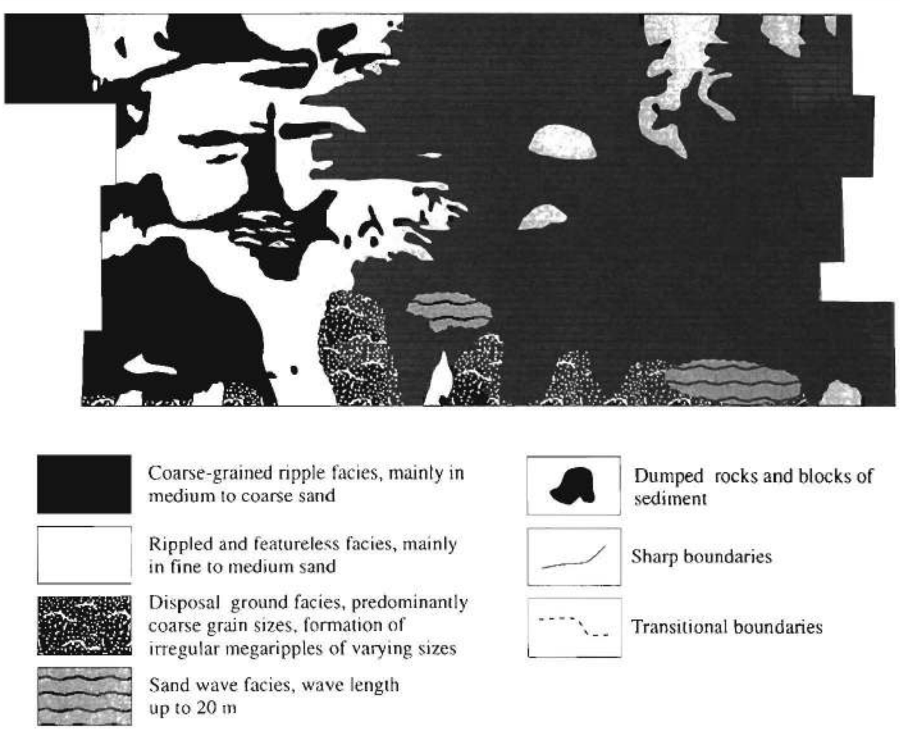

Figure 3. Map showing the area covered by the side-scan sonar survey and our interpretation of the features on the sonographs. Refer to Figure 2 for position of this area on the inner shelf.

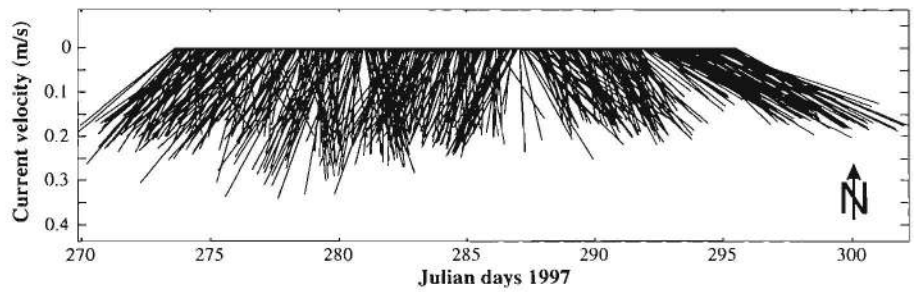

Figure 4. Stickplot of current speeds and directions during 1 October 1997 (Julian day 273) to 23 October 1997 (Julian day 296) on the proposed new disposal ground, measured with an S4 current meter deployed 1 m above the seafloor.

of 120 measurements for 1 minute every 10 minutes) and are shown in Figure 4. Separation of the tidal component shows that tidally induced current velocities are low, generally in the range of 0.015 to 0.03 ms^{-1} (Figure 5).

For the duration of the measurement period the record is characterized by southerly flowing currents. Initially a southwesterly direction prevailed, but after 2 weeks the current turned to a southeasterly direction which dominated the record for the last 3 days. The maximum current speed, more than 0.30 m s^{-1} (Figure 5), was attained on 5 October 1997 and is associated with a northeasterly onshore wind (Figure 6). The southerly and southeasterly current components indicate the main direction of the longshore current, whereas the southwesterly component probably is associated with an upwelling event at the coast during strong offshore winds from the southwest. These observations are consistent with the wind-shelf current model derived by BRADSHAW (1991).

The significant wave heights during this period, recorded at A Beacon at the nearby ebb tidal delta, vary in the range of 0.2 to 1.7 m; maxima of the wave height were associated mainly with northerly winds (Figure 7). Zero up-crossing wave periods ranged from about 7 to 12 s.

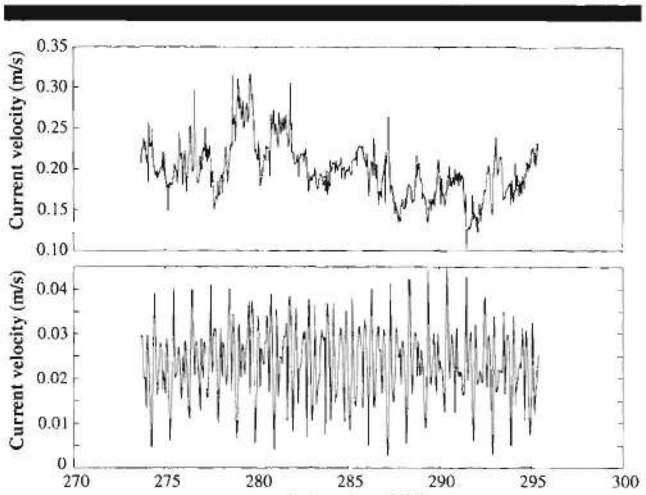

Figure 5. Residual (upper figure) and tidal (lower figure) current speeds measured at 1 m off the bottom on the proposed new disposal ground.

Incipient Sediment Motion

To test for the potential stability of the dredged material to be dumped in the proposed new disposal site, an investigation of incipient sediment motion under the given conditions was undertaken. The "Shields type criterion"

$$\frac{\bar{\tau} + \hat{\tau}}{\rho(s - 1)gD} = 0.04 \qquad (1)$$

has been applied following AMOS *et al.* (1988). In equation 1, $\bar{\tau}$ is the time-averaged bed shear stress, $\hat{\tau}$the peak wave-induced bed shear stress, ρ the density of water, s the relative density of sediment ($=\rho_s/\rho$ with ρ_s being the particle density), g the acceleration due to gravity and D the diameter of representative sediment particles. The time-averaged bed shear stress $\bar{\tau}$ can be estimated by

$$\bar{\tau} = \frac{1}{2}\rho 0.003\bar{u}_{100}^{2} \qquad (2)$$

where $\bar{u}_{100}$ is the mean current velocity 1 m above the bed. The peak wave-induced bed shear stress $\hat{\tau}$ can be estimated using

$$\hat{\tau} = \frac{1}{2}\rho f_w(A\omega)^2 \qquad (3)$$

where f_w is the wave friction factor for the fully developed, rough turbulent regime (NIELSEN, 1992), and which can be calculated (JONSSON, 1966; SWART, 1974; NIELSEN, 1992) using

$$f_w = \exp\left[5.5\left(\frac{r}{A}\right)^{0.2} - 6.3\right] \qquad (4)$$

In this equation r is the hydraulic roughness, determined by $r=2.5D_{50}$; A is the orbital wave amplitude of fluid just above the boundary layer and ω is the radian frequency ($=2\pi/T$, where T is the wave period).

A comparison of the time-averaged bed shear stress exerted by the current $\bar{\tau}$ and the peak wave-induced bed shear stress $\hat{\tau}$ during the period of the current meter deployment in October 1997 shows that both vary in the same range (Figure 8) but the peak wave induced bed shear stress dominated during periods of high significant wave heights whereas the bed shear stress exerted by the current prevailed during periods of low wave height and high current velocity.

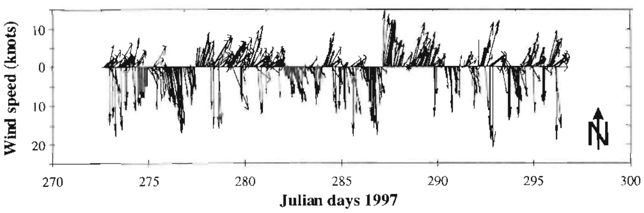

Figure 6. Stick plot of wind speeds and directions to at Tauranga airport from 1 October 1997 (Julian day 273) to 23 October 1997 (Julian day 296).

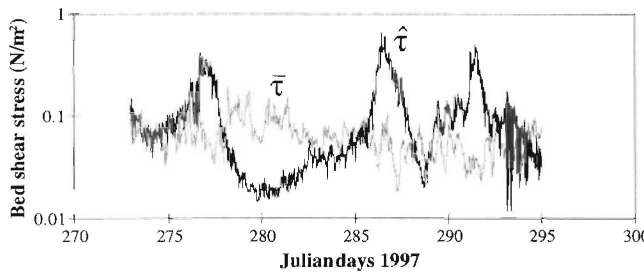

Figure 8. Comparison of the time-averaged bed shear stress $\bar{\tau}$ exerted by the current and the peak wave-induced bed shear stress $\bar{\tau}$ during the period of the current meter deployment in October 1997.

The calculations of threshold current velocities for the incipient motion of different grain sizes under the given wave conditions during October 1997 show, compared to the recorded current velocities, that with increasing wave height the threshold current velocity for the initiation of particle motion drastically drops (Figure 9). The threshold velocities for different grain sizes which represent the coarse and fine limits of the two different grain size populations naturally present in the area, show that fine sands of 0.125 mm would likely have been mobile during most of the deployment period, whereas medium sand of 0.35 mm would have been mobile only during periods of high waves (Figure 9).

As noted above the cohesive material is to be dredged by a "digger type" dredge. Based upon observation and experience in Port Gisborne and elsewhere in New Zealand, this type of dredging results in a high proportion of the disposed cohesive material falling in "clumps" or clods. The question arises as to the stability of the cohesive clumps of muddy sediment after disposal on the proposed spoil ground. Assuming a mud clast density of $\rho_s = 1300$ kg m^{-3} calculations were undertaken for the set of wave conditions recorded which show that theoretically only muddy clasts of < 1–2 cm would be mobile under the peak wave conditions of H_s = 1.6 m and T_s = 11 s.

Assuming the measured wave periods represent a JONSWAP spectrum (HASSELMANN *et al.*, 1973) instead of a monochromatic wave (as the calculations for Figures 8 and 9 are based on) enhances the effect of lower threshold velocities with increasing wave height (and even coarse-grained particles would likely have been mobile during periods of high waves) whereas during current-dominated times the impact is weak.

DISCUSSION

The sea floor sediments in the area of the proposed new disposal ground in water depths of 28 to 33 m were rather immobile during the period of the current meter deployment, except during periods of high waves. Finer grained sands would have been mobile more frequently except for cohesive sediment in "clumps" which require significantly higher threshold velocities.

Since the dredge spoil from the Sulphur Point Wharf Extension South that is proposed to be disposed of on the inner shelf is markedly cohesive, and the material disposed will likely fall largely as discrete clumps, calculations show that muddy clasts > 1–2 cm would theoretically be stable on the disposal site and should not undergo extensive bottom transport except in rare events of large wave heights of long periods. Naturally some of the dredged muddy sediment would become disaggregated to a silt-clay slurry, and this material would become transported from the disposal site under normal wave action and local currents. Note, however, that past experience with muddy sediments disposed on spoil grounds

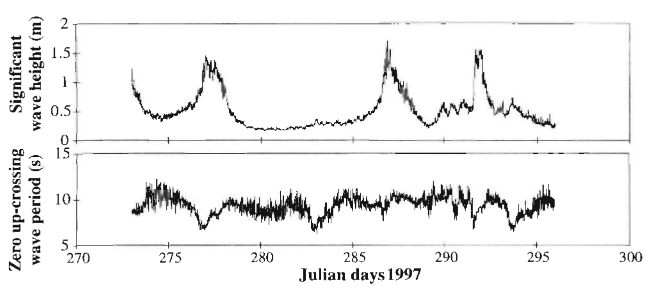

Figure 7. Significant wave height (upper figure) and zero up-crossing wave period (lower figure) recorded at A Beacon outside Tauranga Harbour entrance from 1 October 1997 (Julian day 273) to 23 October 1997 (Julian day 296).

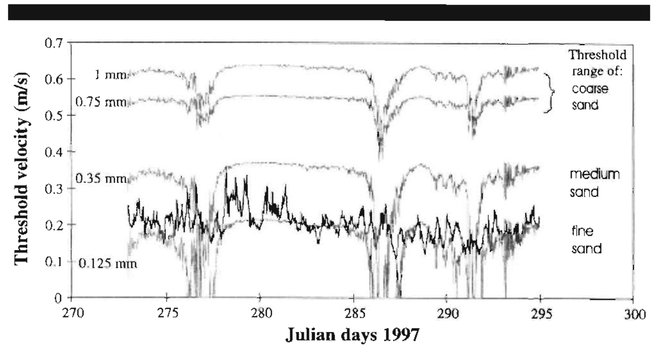

Figure 9. Measured current velocities 1 m off the bed (black line) on the proposed new disposal ground and calculated threshold velocities for different grain sizes (gray lines). Note that the finer grained sands that naturally occur in this area would at least partly move whereas the threshold velocities for the coarser grained sand particles have not been reached during the deployment period.

in shallower sites has not resulted in any muddy sediments being deposited on the adjacent beaches.

During the period of current meter deployment, the currents were predominantly directed to the south, as would be the sediment transport at that time. The high topography of the adjacent onshore disposal ground, however, would be expected to inhibit transport of fine-grained material towards the coast, while during storms the downwelling induced by strong onshore winds (HARMS, 1989) suggest that sediment movement would be offshore. Evidence of offshore transport from earlier shallower dump grounds is reported in HEALY *et al.* (1988).

CONCLUSION

The proposed new disposal ground is considered suitable for dredge spoil with significant silt and clay content. Based upon the data available and experience with historical dredge spoil disposal at shallower sites, sediment transport by wave and current action generally does not occur for medium and coarse sand during normal fair weather conditions. However the threshold velocities for medium and coarse sand are exceeded during large swell waves (MATHEW, 1997). The natural cohesion of the pumiceous sandy-clayey silts and estuarine muds when excavated by a digger dredge (as compared to cutter and trailer suction dredge) allows the dredged material to retain a clump structure when dropped from dredge barges, and the clump size requires a much larger threshold velocity for transport than the noncohesive sands. When disposed on the proposed new site in 28–33 m water depth some 4–5 km offshore, the muddy material is not expected to create a problem on the adjacent beaches.

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ZUSAMMENFASSUNG

Für eine geplante Erweiterung des Hafens von Tauranga/Neuseeland ist es erstmals erforderlich, kohäsive Sedimente mit einem erheblichen Anteil an Silt und Ton auszubaggern. Dieses Material kann nicht mehr, wie bisher, auf einer Deponie ca. 4 km von der Küste entfernt in einer Wassertiefe von 15 bis 25 m abgelagert werden, da diese so konzipiert wurde, daß das auf ihr abgelagerte Sediment langsam küstenwärts wandert, um das Sandvolumen der angrenzenden Strände zu ergänzen.

Daher wurde die Eignung eines Ablagerungsgebiets in der seewärtigen Verlängerung der bisher benutzten Deponie für das Baggergut aus dem Hafen untersucht. Im Frühjahr 1997 wurde in diesem Gebiet eine Seitensichtsonar-Vermessung durchgeführt und die Sedimentoberfläche in mehreren Tauchgängen beprobt. Ergänzt wurden diese Untersuchungen durch die Verankerung eines Strömungsmessers für mehrere Wochen, um eine Vorstellung der hydrodynamischen Verhältnisse dieses Gebiets zu bekommen.

Die Ergebnisse aus diesen Untersuchungen zeigen, daß die natürlich vorkommenden mittel- und grobkörnigen Sande im wesentlichen nur während Phasen starken Wellengangs mobil zu werden beginnen. Theoretische Berechnungen über den möglichen Transport von Silt- und Tonklasten (Dichte $\rho_s = 1300$ kg m^{-3}) ergeben, daß nur große Wellen ($H_s = 1.6$ m, $T_s = 11$ s) in der Lage sind, Partikel mit einem Durchmesser von < 2 cm zu bewegen, während größere Klasten unter diesen Bedingungen transportresistent sind.

Ein küstenwärtiger Transport wird jedoch durch den Anstieg zu den Erhebungen des bereits abgelagerten Sediments auf der bisher genutzten Deponie erheblich erschwert, so daß das untersuchte Gebiet für die Ablagerung von silt- und tonreichen kohäsiven Sedimenten für geeignet erachtet wird.