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Assessing the Stability of Inner Shelf Dredge Spoil Mounds Using Spreadsheet Applications on Personal Computers

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ABSTRACT

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Three methods, *viz.* the HANDS and ALLISON (1991) method, predictions of sediment threshold, and predictions of sediment transport rate, are used to assess the long term stability of dredge spoil mounds on the inner shelf and compared with available observations of their behaviour. These methods are chosen for simplicity and ease of implementation with a spreadsheet application on a personal computer.

Three main approaches were followed: an evaluation of the annual, and daily limits, of onshore-offshore sediment movement near the spoil mound; a comparison between the theoretical thresholds of sediment motion and the annual wave height and period joint distribution; and an evaluation of sediment transport rates and directions using semi-empirical relationships.

The HANDS and ALLISON (1991) method had the smallest data requirements: mean and standard deviation of the annual significant wave height distribution; and the median grain-size at the mid-point of the shoal zone. Analysis of sediment threshold and comparison with wave climate required data concerning the annual joint wave height and period probability distribution, and sediment textural characteristics. Sediment transport rate calculations required the most detailed information about the site: annual joint wave height and period probability distribution; sediment textural characteristics; and mean unidirectional current velocity.

Using a spreadsheet, it is relatively easy to simulate a range of values (that span the likely conditions) with all three methods, if the necessary data are not available.

All the methods produced predictions consistent with available observations, and all were straightforward to implement within a spreadsheet application. The choice of method depends on the information required, with each method needing different data and providing contrasting but complementary outputs.

ADDITIONAL INDEX WORDS: *Sediment transport, threshold of sediment motion.*

INTRODUCTION

There is increasing global concern over the environmental impacts of dredge spoil disposal (PALMER and GROSS, 1979; KESTER *et al.*, 1983; MONTGOMERY and LEACH, 1984; NATIONAL RESEARCH COUNCIL, 1985; LEE and PEDDICORD, 1988; VAN GEMERT *et al.*, 1988; HEALY *et al.*, 1991; U.S. ENVIRONMENTAL PROTECTION AGENCY and U.S. ARMY CORPS OF ENGINEERS, 1991). Hence dump grounds are continuing to be extensively monitored (HEALY *et al.*, 1988; HARMS, 1989; FOSTER, 1991; HEALY *et al.*, 1991; FOSTER, 1992; HANDS, 1992; WARREN, 1992).

One of the major concerns commonly expressed over the dredge disposal is the fate of the dredge spoil following dumping. With the requirement of many ports to make environmental impact assessments and undertake dredge spoil monitoring, there is a need to predict the behaviour of the dredge spoil after dumping. Although this can be evaluated by numerical modelling (*viz.* SCHEFFNER, 1991), simpler methods on personal computers may permit rapid assessment of a range of disposal options.

Dredging programmes associated with port development have occurred at the Port of Tauranga, New Zealand's largest port, since the 1960's. Sediment dredged from the port area within the harbour and from the adjacent shipping channel through the flood and ebb tidal deltas has been dumped offshore. A series of sites from the nearshore zone to the inner shelf, spanning a range of water depths from 4–30 m, has been used (Figure 1).

The aim of this paper is to evaluate three meth-

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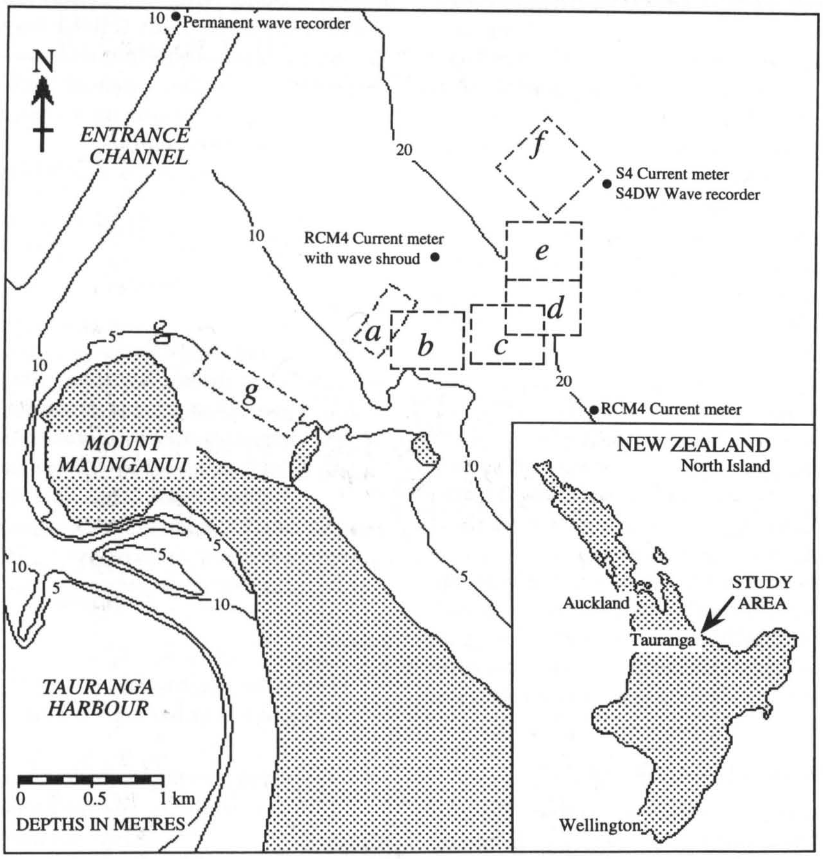

Figure 1. Location map of the dredge spoil dump grounds and instruments discussed in the text.

ods used to predict the likely behaviour of dredge spoil mounds with particular emphasis on their suitability for implementation on personal computers using spreadsheet application programs. Data from the Tauranga inner shelf is used to illustrate the method.

Dredge Spoil Disposal at Tauranga

Dredge spoil disposal at Tauranga has occurred at 7 offshore sites (Figure 1). One of the offshore sites (g) was selected to renourish the beach (Foster, 1991), while the remaining offshore sites were in deeper water (15–30 m) and located east to northeast of the harbour entrance (Foster, 1992). Over time, there has been an offshore progression of successive dump grounds providing a series of dump mounds along a roughly shore-normal transect between 4 m and 30 m water depth.

The dredge spoil consisted largely (> 90%) of fine to medium sand with 1–10% gravel-sized pumice and shell fragments and minimal (< 0.5%) mud. This is compatible with the natural sediments offshore, having a similar textural and bulk mineralogical composition (Dahm and Healy, 1980; Healy *et al.*, 1988; Healy and McCabe, 1990; Warren, 1992). Minor differences in composition are however apparent, which enable areas affected by dredge spoil to be identified by side-scan sonar (Harms, 1989; Foster, 1992). In particular the dredge spoil contains a higher proportion of pumice (Dahm and Healy, 1980; de Lange, 1988), and a shell assemblage that contains species not normally observed outside estuarine environments (Grace, 1990).

Surveys of the sea floor surrounding the mounds indicate that components of dredge spoil sediments extend beyond the limits of the dump grounds (HEALY *et al.*, 1988), particularly between the dump grounds and the harbour entrance, although it is not always clear whether this is due to sediment movement or off-target dumping. Studies of the oldest spoil mounds indicate an onshore movement of fine sand and low density gravel-sized sediment (DAHM and HEALY, 1980; HEALY *et al.*, 1988; HARMS, 1989; HEALY *et al.*, 1991). Further, a tracing experiment using fluorescent sand and repeated bathymetric profile monitoring indicated a clear onshore movement for sediment within the shallowest dump ground (FOSTER, 1991).

Repeated bathymetric surveys of the dump grounds before 1988 demonstrated that the spoil mounds underwent marked volumetric reductions during the first 2 years following disposal, after which they remained relatively static (HEALY *et al.*, 1991). The largest volumetric changes were found to occur on the shoreward side of the mounds. These changes were associated with an accumulation of fine sediment on the adjacent seabed consistent with a shoreward movement of fine sand. Similar behaviour has been observed for the younger mounds in deeper water (FOSTER, 1992).

METHODS OF ASSESSMENT

Two fundamental questions need to be addressed when assessing the placement of dredge spoil mounds:

(1) Will the dredge spoil mounds remain stable? (*i.e.*, can they be anticipated to retain most of their original volume and stay at the same location for more than a few years?); and
(2) What will be the likely fate of material which does not remain within the spoil mound?

Although application of numerical models may be used to answer these questions, simpler methods that could be readily applied to dredge spoil disposal sites generally—and could be implemented by spreadsheet applications on personal computers—are a possible alternative.

HANDS and ALLISON (1991) Method

HANDS and ALLISON (1991) present a method for assessing the long term stability of dredge spoil mounds from the cross-shore profile zonation limits of HALLERMEIER (1981). A spoil mound lying completely landward of the Hallermeier inner limit (HIL) lies within a zone of active sand transport and may be expected to disperse rapidly; whereas, a spoil mound lying completely offshore of the Hallermeier outer limit (HOL) may be expected to remain stationary. Mounds between these limits lie within a buffer or shoal zone where waves have some influence during a year, and their behaviour is less predictable.

The Hallermeier limits can be expressed as:

$$\text{(HIL) } 0.03\text{h} \geq \frac{(\xi\omega)^2}{\gamma \text{g}} \geq 8\text{D (HOL)} \qquad (1)$$

where

h = water depth (m),
ω = wave radian frequency (Hz),
D = median sediment diameter (m),
g = gravitational acceleration ($\text{m}\cdot\text{sec}^{-2}$),
ξ = horizontal wave orbital semi-excursion distance (m), given by transitional Linear wave theory as

$$\xi = \frac{\text{H}}{2\sinh(\text{kh})} \qquad (2)$$

where

H = wave height (m),
k = wave number (m^{-1}), and

$$\gamma = \text{s} - 1 = \frac{\rho_s - \rho}{\rho} \qquad (3)$$

where

s = relative sediment density,
ρ_s = sediment density ($\text{kg}\cdot\text{m}^{-3}$), and
ρ = fluid density ($\text{kg}\cdot\text{m}^{-3}$).

Normally evaluation of HOL requires a knowledge of the median sediment diameter characteristic of the shoal zone. This includes all regions where sand-sized sediment may be transported onshore or offshore by high wave energy conditions which occur for less than 12 hours a year or an annual probability of 0.137%.

A general guide-line for dredge spoil disposal, suggested by the *Shore Protection Manual* (SPM, 1984), would not place mounds within the shoal zone. Mounds would only be placed landward of HIL if they were required to be active, or seaward of the HOL if they needed to be stable.

HANDS and ALLISON (1991) considered this to be too restrictive and noted that many spoil mounds are located within the shoal zone. Following their approach the stability is determined by plotting two ratios relating the position of the spoil mound to the buffer zone lying between HIL and HOL, as given by:

$$\frac{HIL - B}{HIL} \text{ and } \frac{HOL - B}{HOL} \quad (4)$$

where

HIL = Hallermeier's inner limit,
HOL = Hallermeier's outer limit, and
B = water depth at the base of the mound.

Predictions of Sediment Threshold

It may be preferable to locate the spoil mound within the shoal zone where the annual probability of transport is higher, than beyond the restrictive HOL. If the joint wave height and period probability distribution are known, then it is possible to assess the probabilities of sediment movement occurring within the shoal zone.

Assuming Linear Wave Theory, the minimum wave height (H_{crit}) required to initiate sediment transport for any given wave period may be determined from:

$$H_{crit} = \frac{u_{crit} T \sinh(kh)}{\pi} \quad (5)$$

where

u_{crit} = critical orbital velocity at sediment threshold ($m \cdot sec^{-1}$), and
T = wave period (sec).

The critical orbital velocity at sediment threshold can be evaluated from the relationships of KOMAR and MILLER (1973). These may be expressed as:

$$u_{crit} = \begin{cases} \left(0.21\gamma g \sqrt{\frac{TD}{\pi}}\right)^{2.3} & D < 0.0005 \text{ m} \\ (0.46\gamma g T^{0.25}(\pi D)^{0.75})^{4/7} & D \geq 0.0005 \text{ m} \end{cases} \quad (6)$$

The combinations of wave height and period corresponding to the threshold of sediment motion may be compared with the joint wave height and period probability distribution for the site to determine the probability of sediment transport occurring.

Predictions of Transport Rates

Both methods above consider only wave conditions which exceed the threshold of sediment motion. More complicated analyses are required to assess the influence of additional superimposed currents or specify rates or directions of sediment transport.

Measurements of the wave and current conditions in the immediate vicinity of the dump grounds at Tauranga are sparse (Figure 1), comprising: a 3 month deployment of an Aanderaa RCM4 current meter (HEALY, 1985); a 3 month deployment of an Aanderaa RCM4 current meter fitted with a wave shroud (HARMS, 1989); and a 2 month deployment of a combined mooring of an InterOcean S4 current meter and InterOcean S4DW directional wave recorder (FOSTER, 1992; WARREN, 1992). All current meters recorded peak velocities <0.20 m sec^{-1}, and average currents <0.1 m sec^{-1}. The currents can be resolved into a tidal component of $\ll 0.1$ m sec^{-1} and a shore parallel residual that is strongly correlated with local winds (BARNETT, 1985; BRADSHAW *et al.*, 1991; FOSTER, 1992). These velocities are too low to entrain most sediment found on the deeper dump grounds, with the exception of low density pumice (DE LANGE *et al.*, 1991). Current velocities are normally less than wave-induced orbital velocities, which can exceed sediment threshold (HARMS, 1989; BRADSHAW *et al.*, 1991; WARREN, 1992).

The wave-induced bedload sediment transport rate (Q_b) over rippled beds, such as those observed on spoil mounds at Tauranga (HARMS, 1989; FOSTER, 1992; WARREN, 1992), may be given (NIELSEN, 1990) by:

$$Q_b = 0.15\xi\omega D(\theta_r - 0.02)^{1.5} \quad (7)$$

where θ_r = ripple crest Shields parameter, given by:

$$\theta_r = \frac{\theta'}{\left(1 - \frac{\pi\eta}{\lambda}\right)^2} \quad (8)$$

where

η = ripple height (m),
λ = ripple lenght (m), and
θ' = skin friction Shields parameter.

The ratio of the ripple height to the ripple length, or ripple steepness, may be determined from the empirical relationship of NIELSEN (1992), as:

$$\frac{\eta}{\lambda} = 0.342 - 0.34 \sqrt[4]{\theta'} \quad (9)$$

The skin friction Shields parameter is given by (assuming a planar bed):

$$\theta' = \frac{f_w(\xi\omega)^2}{2\gamma gD} \tag{10}$$

where f_w = wave friction factor.
The wave friction factor was established by (NIELSEN, 1992):

$$f_w = e^{(5.213(2,5D/\xi)^{09.194} - 5.977)} \tag{11}$$

The simplest method of determining the suspended load sediment transport rate is to assume that sediment is entrained in two aliquot's by the escaping lee vortices at the times of free stream reversal. Each aliquot of sediment is then transported a distance ξ in the direction opposite to the vortices that entrained it, and then deposited. Based on this 'grab and dump' model, wave-induced suspended sediment transport (Q_w) is given by NIELSEN (1992) as:

$$Q_w = C_0\xi w(A_b - A_f) \tag{12}$$

where

C_0 = reference suspended sediment concentration,
w = median settling velocity ($m \cdot sec^{-1}$), and
A_b, A_f = aliquot's of sediment entrained, given by

$$A_b = 0.5\left(\frac{u_t}{\xi\omega}\right)^6 \tag{13}$$

$$A_f = 0.5\left(\frac{u_c}{\xi\omega}\right)^6 \tag{14}$$

where

u_c = maximum crest velocity ($m \cdot sec^{-1}$),
u_t = maximum trough velocity ($m \cdot sec^{-1}$).

The reference suspended sediment concentration is found by (NIELSEN, 1992):

$$C_0 = 0.005\theta_r^{\ 3} \tag{15}$$

The S4DW directional wave recorder observations indicate that the wave-induced velocity distributions at Tauranga are not symmetrical with the crest velocities exceeding the trough velocities. Therefore, to replicate the observed inequalities, second order Stokesian wave theory was used to evaluate the near bed peak crest and trough orbital velocities. These are given by

$$u_c = \frac{3}{4}\left(\frac{\pi H}{L}\right)^2 \frac{C}{\sinh^4(kh)} + \frac{HgT}{2L\cosh(kh)} \tag{16}$$

$$u_t = \frac{3}{4}\left(\frac{\pi H}{L}\right)^2 \frac{C}{\sinh^4(kh)} - \frac{HgT}{2L\cosh(kh)} \tag{17}$$

where

L = wavelength (m), and
C = wave phase velocity ($m \cdot sec^{-1}$).

Non-wave current velocities at the inner shelf dump grounds near Tauranga are too low to initiate sediment transport. However, they are capable of transporting sediment suspended by wave orbital motions. A simple extension of the "grab and dump" model, used for the wave-induced suspended sediment transport model above, is to assume that sediment entrained each half wave period is transported by the unidirectional near bed current during that half wave period. At Tauranga the unidirectional current is roughly shore parallel; whereas, the wave-induced currents are roughly shore normal. Therefore, the combined current and wave suspended transport rate (Q_c) may be given by (NIELSEN, 1992):

$$Q_c = C_0 wT \frac{u_* \eta}{\kappa 2l} \tag{18}$$

where

u_* = time averaged friction velocity ($m \cdot sec^{-1}$),
κ = von Karman's constant (≈ 0.4), and
l = thickness of the wave dominated boundary layer (m).

The time averaged friction velocity is given by NIELSEN (1992) as:

$$u_* = \frac{\kappa u(z_r)}{\ln\left(\frac{z_r}{z_0}\right) - \ln\left(\frac{z_a}{z_0}\right)} \tag{19}$$

where

$u(z_r)$ = measured unidirectional current at height z_r above the bed ($m \cdot sec^{-1}$),
z_0 = zero-intercept level of log velocity profile (m),

$$\frac{z_a}{z_0} = 0.44\frac{\xi\omega}{u_*} \tag{20}$$

and where

z_a = zero-intercept level of log velocity profile in the presence of waves (m).

```
Function FindDL (Hs,Sdev,Ratio,Lo)
{ Function to calculate dimensionless root 2πdl/L for HIL by secant method }
Define x0,x1,x2,Constant,diff,fx0,fx1
Constant = (Pi()^2*(Hs+5.6*Sdev)^2)/(0.03*Ratio*Lo^2)
x0 = 0
x1 = 0.6
diff = 1.0
While (Abs(diff) > 0.001)
     fx0 = x0*Sinh(x0)^2*Tanh(x0) - Constant
     fx1 = x1*Sinh(x1)^2*Tanh(x1) - Constant
     If (fx1-fx0) = 0.0
          x2 = 0.0
          diff = 0.0001
     Else
          x2 = x1 - fx1*(x1-x0)/(fx1-fx0)
          diff = x2 - x1
          x0 = x1
          x1 = x2
     End If
End While
Return x2
End Function {FindDL}

Function HIL (Hs,Sdev,Ts,Sdensity,Fdensity)
{ Function to calculate Hallermeier inner limit }
Define Ratio,Lo,TwoPiDL,limit
Ratio = (Sdensity-Fdensity) / Fdensity
Lo = (Gravity()*Ts^2) / (2.0*Pi())
TwoPiDL = FindDL(Hs,Sdev,Ratio,Lo)
limit = TwoPiDL * Tanh(TwoPiDL) * (Lo/(2.0*Pi()))
Return limit
End Function {HIL}
```

Figure 2. Example of the Script programming language used by Claris Resolve. The Script function HIL determines the Hallermeier Inner Limit using Equation 1, given the mean and standard deviation of the annual significant wave height (Hs and Sdev respectively), the mean annual significant wave period (Ts), and the sediment and fluid density (Sdensity and Fdensity respectively).

The thickness of the wave dominated layer is given by:

$$l = ez_a \tag{21}$$

where e = 2.718281828 . . .

Implementation Using Spreadsheet Applications

All the above relationships were implemented as functions in the commercially available Claris Resolve, a spreadsheet application, using the built-in Script. Claris Resolve contains all the necessary mathematical functions required to evaluate the above expressions, which would allow all the equations to be defined as cell formulae within the spreadsheet. However, this approach requires the use of a large number of cells to store intermediate steps or very long cell formulae that are difficult to check.

The use of a programming language, such as Script in Claris Resolve or Macro in Microsoft Excel, allows the creation of functions that may be shared between spreadsheets. These functions are easier to check for errors, and may be compiled to provide an increased computation speed. The Script programming language is similar to Pascal but without rigid variable typing. Instead, variables are treated as cells in a spreadsheet. All the spreadsheet functions can be accessed from with-

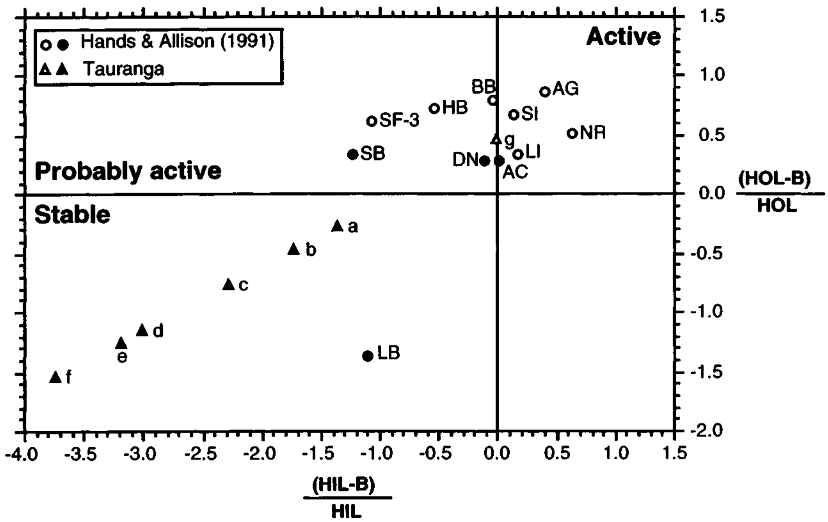

Figure 3. Locational stability diagram from HANDS and ALLISON (1991) with the Tauranga dump grounds added (a–g). The open symbols indicate sites with active spoil mounds, and the solid symbols represent stable spoil mounds. Sites SB, DN and AC plot within the stable region when the correct wave data are used (HANDS, *personal communication*, 1991).

in a Script function. Figure 2 is an example of the Script functions used to evaluate the HIL as defined by Equation 1.

The Script functions are used within a Claris Resolve spreadsheet in the same manner as the standard spreadsheet functions. Therefore, it is relatively easy to generate a matrix of results for ranges of input conditions. The graphical capabilities for the spreadsheet application may then be used to display the results in a more readily assimilated form.

The analyses discussed below were all performed on a Macintosh PowerBook 100 notepad computer. None of computations took more than 3 minutes for ~600 combinations of input parameters.

RESULTS AND DISCUSSION

HANDS and ALLISON (1991) Method

An analysis of 2 years' data from the permanent wave recorder at the entrance to Tauranga Harbour resulted in a mean annual significant wave height of 0.50 m with a standard deviation of 0.38 m, and a significant wave period of 9.1 sec (DE LANGE, 1991). The median grain size at the approximate mid-depth of the shoal zone is 0.2 mm (FOSTER, 1992). Assuming quartz density sediment, these correspond to HIL and HOL of 5.5 and 10.2 m respectively.

The stability ratios defined by Equation (4) for the various historical dump grounds at Tauranga (a–g in Figure 1) as well as the original data from HANDS and ALLISON (1991) are plotted in Figure 3. The Tauranga dump grounds lie predominantly outside the shoal zone with only the shallowest dump ground (g) encroaching seaward of the inner limit. This is consistent with the finding that the shallowest dump ground was active (FOSTER, 1991), whereas the remainder were essentially stable (HARMS, 1989; FOSTER, 1992).

Both the Hallermeier limits are functions of sediment density. For the typical range of densities occurring within the dredge spoil at Tauranga (DE LANGE, 1988), there is considerable variation of the limits of the shoal zone (Figure 4a). In particular for pumiceous sediments (1,120–2,370 kg m^{-3}), all the dump grounds lie landward of the HOL; whereas, for iron-sands (mainly titanomagnetite, ρ_s = 4,680 kg m^{-3}), all spoil mounds lie seaward of HOL. Only the HOL is affected by grain diameter. Although the variation is less for changes in grain size than for sediment density, clearly the HOL moves further offshore with decreasing grain size (Figure 4b). This implies that mounds composed of fine sediment will be active further offshore than mounds composed of coarse sediment.

Therefore, at Tauranga where the dredge spoil displays a range of sediment densities and grain sizes, repeated application of the HANDS and ALLISON (1991) method for individual dredge spoil components predicts that low density pumiceous sediments and fine quartzo-felspathic sediments would be active at all dump ground sites; and shell fragments would be active at most sites. This is consistent with the observed rapid onshore movement of pumice, and broken and whole bivalve shell material, and slower onshore movement of fine sediment (DAHM and HEALY, 1980; HEALY *et al.*, 1991; FOSTER, 1992).

Predictions of Sediment Threshold

Figure 5 summarizes the combinations of wave height and period corresponding to the threshold of sediment movement for a range of water depths and grain sizes. The grain diameters chosen correspond to the boundaries of sand size classes in the Udden-Wentworth classification (MCMANUS, 1988). Clearly, at any given depth and wave period, progressively higher waves are required to initiate sediment transport as the grain size increases. The period associated with the smallest wave height capable of initiating sediment transport also increases with depth indicating that swell waves become increasingly important offshore.

Combining the annual joint wave height and period distribution from the permanent wave recorder site and the sediment median diameters for the dump grounds indicates probabilities of transport that progressively increase from 15% at site f (WARREN, 1992), to 40% at site e (HARMS, 1989), to >95% at site g (FOSTER, 1991). Further, sediment within the dump grounds (a–f) indicated as stable by the HANDS and ALLISON (1991) method is capable of moving with annual probabilities of transport greater than the 0.137% used to define HOL. However, this approach does not determine whether the mobilized sediment leaves the dump grounds or merely oscillates about a fixed position.

The predicted probabilities of sediment movement assume a quartz density. However, the densities of the sediments at Tauranga vary between 1,120 and 4,680 kg m^{-3}. As Figure 6 demonstrates for this range of densities, there is a considerable variation in the minimum wave height required to initiate sediment movement for any given wave period. In particular, the probabilities of movement of low density grains, such as pumice, are considerably higher than for quartz sediment. Figure 5 also indicates that the fine quartz sand

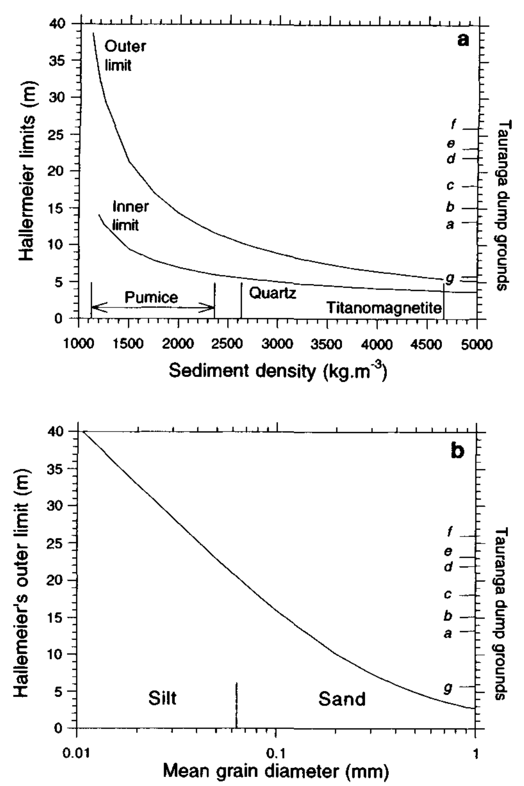

Figure 4. Changes in the depth of the Hallermeier limits, HIL and HOL, with variations in: (a) sediment density; and (b) mean grain diameter.

in the dredge spoil is more likely to be transported than the medium sand. These predictions are consistent with the observed behaviour of spoil mounds at Tauranga.

This method requires the annual joint wave height and probability distribution to be well defined, as well as data for the sediment texture within the dumping ground. This is a larger data requirement than needed for the HANDS and ALLISON (1991) method. Evaluation of sediment threshold also does not provide much useful information about the long term stability of spoil mounds within a dump ground. However, it does indicate that the frequency of sediment motion is an important parameter if turbidity in the immediate vicinity of the dump ground is of concern.

Predictions of Sediment Transport Rate

The models for sediment transport rate are consistent with the previous methods. They indicate

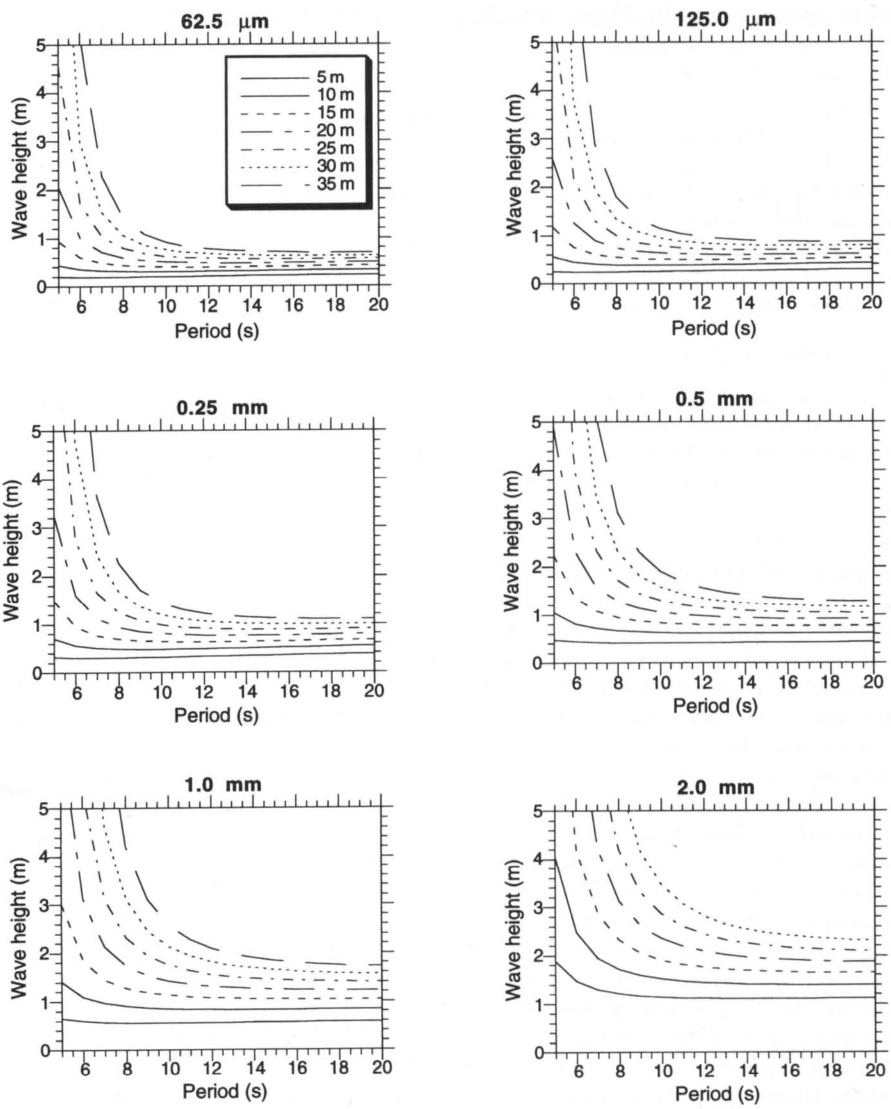

Figure 5. Minimum wave height required to initiate sediment motion for a range of wave periods and water depths corresponding to the range of depths at the Tauranga dump grounds. The grain diameters chosen correspond to the sand-size class boundaries in the Udden-Wentworth particle size classification scheme. A constant quartz density (2,650 kg m^{-3}) is assumed.

high rates of transport per unit width ($> 10^{-5}$ m^2 sec^{-1}) close to shore in depths $<$6 m for the average annual wave height and period with rates decreasing to almost zero at depths $>$10 m (Figure 7). Although measurements of transport rate have not yet been made at Tauranga, the suspended load rate trends match turbidity measurements made along shore normal transects (FOSTER, 1992), and the bedload transport rates are consistent with the progression of bedforms observed along shore normal transects (WARREN, 1992).

The analysis also indicates that bedload transport is directed onshore towards Mt. Maunganui Beach, and suspended sediment transport is shore parallel at most sites. The onshore movement of bedload is consistent with observations of the dis-

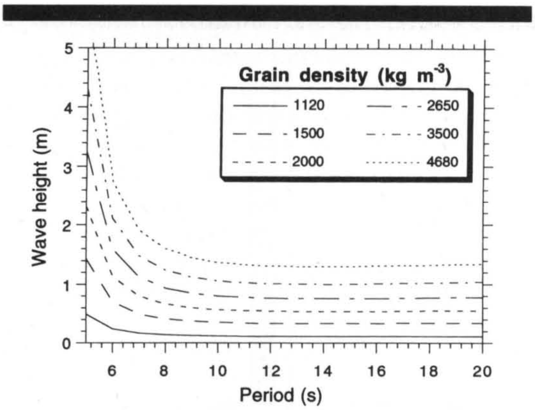

Figure 6. Minimum wave height required to initiate sediment motion for a range of wave periods and sediment grain densities spanning the observed range at Tauranga. A constant grain diameter of 0.25 mm and water depth of 20 m were used.

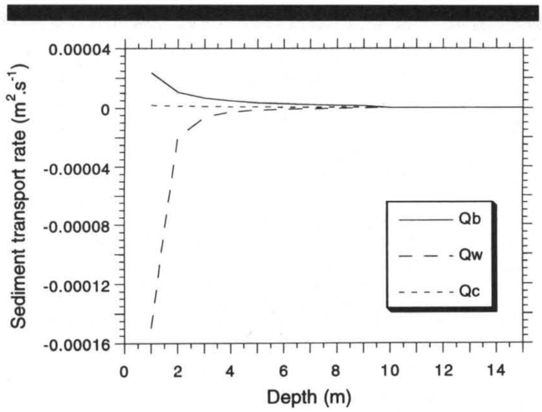

Figure 7. Bedload (Q_b), wave-induced suspended load (Q_w) and wave-current interaction suspended load (Q_c) sediment transport rates per unit width (m^2 sec^{-1}) for a range of depths. A wave height of 0.50 m, wave period of 9.1 sec, sediment density of 2,650 kg m^{-3}, grain diameter of 0.31 mm, settling velocity of 46.5 mm sec^{-1}, and 0.1 m sec^{-1} current measured at 1 m above the sea bed were used.

persal of dredge spoil and tracers at the various dump grounds. No useful data yet exist to confirm the direction of suspended sediment transport.

Measurements made at the deepest dump ground (f) show that the mean grain diameter and settling velocity following dumping had increased to 0.44 mm and 67.8 mm sec^{-1} from 0.31 mm and 46.5 mm sec^{-1} respectively. Figure 8 indicates the increase in bedload transport rates for wave conditions exceeding threshold for both the pre-dump

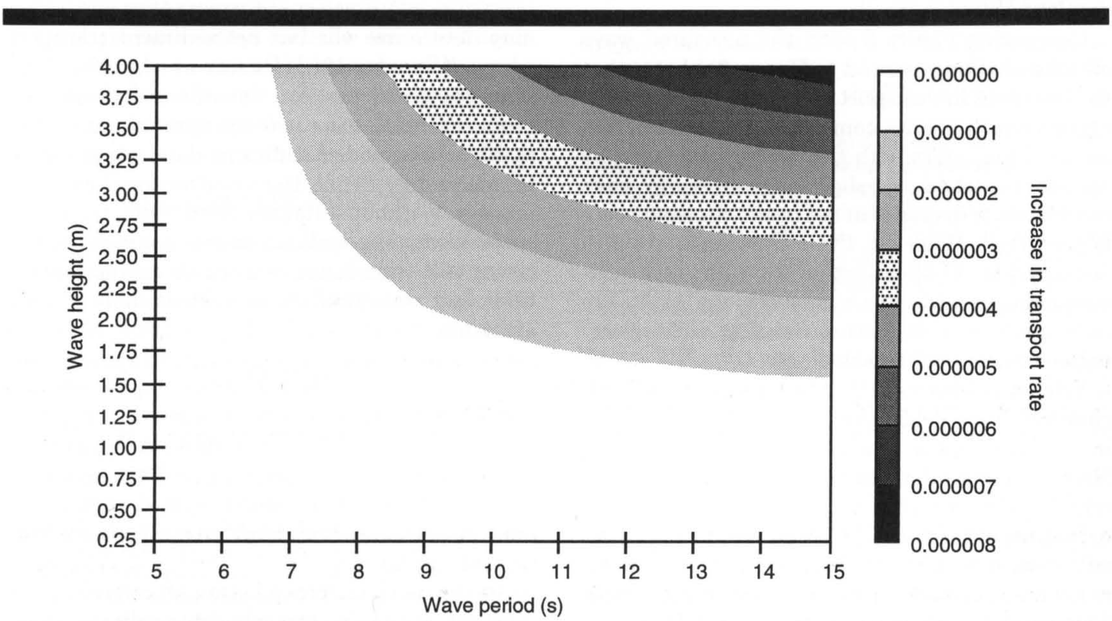

Figure 8. Increased bedload sediment transport rates per unit width (m^2 sec^{-1}) following dredge spoil disposal for a range of wave height and periods. A sediment density of 2,650 kg m^{-3}, a water depth of 25 m, and 0.1 m sec^{-1} current measured at 1 m above the sea bed were used for both pre- and post-dump conditions. A grain diameter of 0.31 mm and settling velocity of 46.5 mm sec^{-1} were used for pre-dump conditions. After dumping the respective values were 0.44 mm and 67.8 mm sec^{-1}.

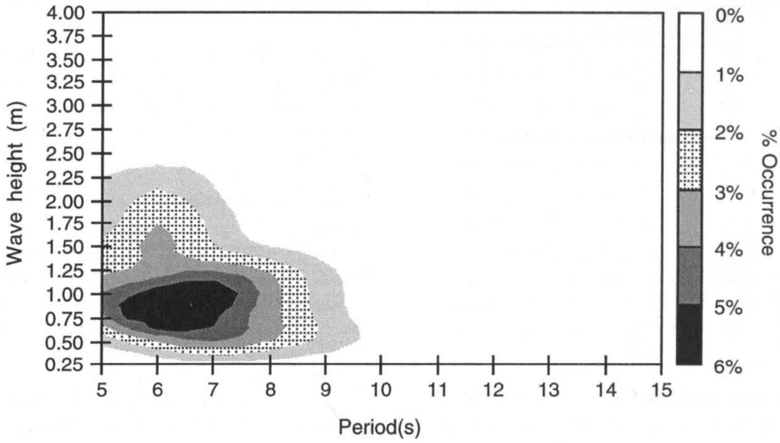

Figure 9. Joint wave height and period distribution for Tauranga dump ground f. Data were recorded as 3 minute bursts every 3 hours over a 2 month interval by an InterOcean S4DW wave recorder.

and post-dump sediment. At slightly lower energy conditions, there is a decrease in rates because the sediment threshold for the coarser post-dump sediment was not exceeded whereas the pre-dump sediment could move. The suspended load due to wave action (Q_w) and current-wave interaction (Q_c) displayed similar trends.

Comparing Figure 8 with the measured wave climate at dump ground f (Figure 9) shows that the increases in transport rate occur for wave conditions which are not common (large, long period swell). This agrees with the predictions made by the other methods. At slightly lower energy wave conditions, a decrease in sediment transport rate is predicted. However, these conditions are also not common. Without actual transport rate measurements to calibrate the analysis, the results are only qualitative but are consistent with observations made at Tauranga.

The equations used in the transport rate calculations were developed for quartz density sediment spanning a limited range of grain sizes. NIELSEN (1992) demonstrates that several of the relationships may not be applicable to sediment with different densities or shapes that vary markedly from spherical. Therefore, transport rates for non-quartz sediments were not calculated. This causes some difficulties due to the presence of pumice and titano-magnetite at Tauranga, but these constituents account for <15% of the dredge material so the method is appropriate to the bulk of the sediment.

The HANDS and ALLISON and sediment threshold methods both assume that sediment grain size and wave-induced orbital motions are the factors that control locational stability of dredge spoil mounds. However, although wave-induced motions may be responsible for initiating sediment transport, unidirectional currents of various types may determine whether net sediment transport occurs (WRIGHT, 1987; PILKEY *et al.*, 1993). The NIELSEN equations can incorporate these currents; thereby, more closely approximating the real world provided sufficient data are available to adequately define the unidirectional currents present. Without suitable current data, the use of spreadsheet applications allows the rapid simulation of a wide range of possible current conditions and re-evaluation as current data become available.

SUMMARY

All the methods used to assess the long term stability of dredge spoil mounds on the inner shelf and within the nearshore zone at Tauranga gave consistent predictions which agreed with available observations. Therefore all methods are considered applicable.

All the methods proved straightforward to implement within a spreadsheet application; although, the processing time required varied considerably between the HANDS and ALLISON (1991) method and the transport rate calculations.

The HANDS and ALLISON (1991) method was

the easiest to apply and gave a good indication of the long term stability of the spoil mounds. This method had the smallest data requirements, needing only the mean and standard deviation of the annual significant wave height distribution and the median grain-size at the mid-point of the shoal zone. However, due to the variation in sediment density and grain size within the dredge spoil, it was necessary to repeat the analysis several times for each of the major components.

Analysis of the sediment threshold and comparison with the wave climate did not provide significantly more useful data than the HANDS and ALLISON (1991) method for predicting the long term stability of the spoil mounds. However, if the movement of sediment within the dump ground is of concern, sediment threshold data does provide an indication of the frequency of movement. This method required data concerning the annual joint wave height and period probability distribution and the sediment textural characteristics of the dredged material and dump ground.

The sediment transport rate calculations show promise but require calibration with field observations to provide quantitative results. The method also required more detailed information about the site including: the annual joint wave height and period probability distribution; the sediment textural characteristics; and the mean unidirectional current velocity within the dump ground.

Using a spreadsheet, it is relatively easy to simulate a range of values that span the likely conditions if the necessary data are not available.

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