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Sediment Suspension and Morphological Response under Vessel-Generated Wave Groups: Torpedo Bay, Auckland, New Zealand

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ABSTRACT

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Waves, currents, suspended sediments and beach morphological response were measured using fast-response sensors over a 13 month period at Torpedo Bay, Auckland to evaluate the relative effects of vessel generated waves (VGW) and wind generated waves (WGW). WGW (H_s = 0.1–0.2 m, T_{pk} = 1–2 s) are severely limited by the maximum unrestricted fetch of only 2.5 km at this location. In contrast, VGW reach maximum heights in excess of 0.85 m, have an average H_s ~0.3 m and periods of 2–6 s on the foreshore.

The groupiness and nonlinear form of these large VGW makes them capable of entraining and suspending significant quantities of bottom sediment (concentrations reaching 10–100 g l $^{-1}$) resulting in sustained increases of turbidity in the nearshore region. VGW represent a significant proportion of the total energy available to transport sediment at Torpedo Bay, contributing as much as twice the sediment transport potential relative to wind-generated waves.

Sand resuspension events under non-linear (asymmetric and skewed) shoaling and breaking VGW exhibit a distinctive temporal structure. This structure is characterised by a marked instantaneous response to sharp accelerations, high velocities and intense turbulence under the crests of asymmetric breaking waves and also by a gradual accumulation and decay of suspended sediment in the water column. The former feature leads to net onshore transport while the latter feature leads to both a distinctive phase lag between the largest VGW and the event maximum suspended sediment concentration (SSC), and to the enhancement of turbidity in the nearshore.

Despite short term fluctuations in bed elevation of up to +/− 10 cm in response to large VGW and relatively high gross sediment transport, the net effect of both WGW and VGW on the sediment transport and foreshore response at Torpedo Bay appears to be insignificant.

ADDITIONAL INDEX WORDS: *Suspended sediments, beach, waves, sand, coastal erosion.*

INTRODUCTION

Wave-induced erosion of shorelines in narrow coastal waterways is often a serious problem particularly in areas experiencing significant amounts of boat traffic. Recently in New Zealand the issue of vessel generated waves (VGW) received widespread media attention with the introduction of high speed passenger ferries operating between Wellington on the North Island and Picton on the South Island. Concerns of environmental groups regarding the potentially destructive effects of ferry wash in the Marlborough Sounds brought the issue to a planning tribunal (see reviews by PARDY, 1995 and KÓS and BIELBY, 1995).

Similar concerns were voiced by the public in the Auckland Region regarding foreshore erosion at a number of locations around the Waitemata Harbour. In particular, the beach at Torpedo Bay, located only a few kilometers from central Auckland, is subject to a large number of waves produced by vessels as they travel past en route to destinations in the Hauraki Gulf and Waitemata Harbour on a daily basis throughout the year. For a number of years local residents have been concerned about the size and frequency of boat wakes arriving at the coastline and about the potential for erosion from the foreshore.

NANSON *et al.* (1994) and BOAK (1996) have reviewed previous work on VGW in rivers and coastal waterways and have reported investigations which examined the wave characteristics (*e.g.* JOHNSON, 1969; SCHOLER, 1974; NEWTON, 1977) and the magnitude of sedimentary response (*e.g.* PICKRILL, 1978; COWELL, 1992), but relatively few which have provided quantitative linkages between process and response variables. NANSON *et al.* (1994) established that a maximum wave height of 30–35 cm was a threshold for significant erosion of a steep (almost vertical) bank of unconsolidated sand on the Gordon River, Tasmania. Until recently, there has been relatively little work on the direct response of suspended sediments to VGW. ANDERSON (1974) obtained pumped samples of suspended sediment load before, during and after

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the onset of VGW on a tidal flat and determined that horizontal velocities as low as 15 cm s^{-1} were able to resuspend fine-grained estuarine sediments. GARRAD and HEY (1987) examined VGW in a Broadlands river and found that VGW were responsible for significant increases in suspended sediments and turbidity. SCHOELLHAMER (1996) examined hydrodynamic and SSC data under VGW in a dredged ship channel and found that large VGW resulted in prolonged (>8 hr) resuspension of fine sediments and estimated that VGW had the potential to produce one order of magnitude more sediment re-suspension than wind generated storm waves. Aside from these studies there have been no investigations utilising fast response sensors on sandy foreshores.

To address this situation a quantitative field study on the characteristics and effects of VGW was carried out at Torpedo Bay with an emphasis on sediment resuspension and foreshore response. The field investigation was carried out over a period of approximately 13 months to directly measure the processes acting on the sandy foreshore including the VGW and their associated effects on suspended sediment concentrations (SSC), suspended sediment transport and associated morphological response. The use of fast response wave, current and sediment transport sensors permitted a more detailed analysis of the temporal structure of the vessel generated wave groups and their influence on the near bed SSC than has been carried out previously.

The Study Site

Torpedo Bay, Devonport is situated on the northern side of the entrance to the Waitemata Harbour, Auckland (Figure 1). The beach at Torpedo Bay is typical of many harbour beaches in the Auckland Region with a relatively steep foreshore composed of a mixture of angular, moderately well-sorted, medium-coarse grain siliclastics (quartz) (36%), feldspars (8%) and carbonate shell hash (38%) which makes a rather abrupt transition with a more gently sloping low tide terrace composed of muddy siltstones of the Lower Miocene Waitemata Group.

The foreshore sediments exist in a semi-enclosed embayment being more or less confined to Torpedo Bay by the presence of North Head to the east and a small reef of volcanic outcrop to the west. Inputs of fresh sediment to the beach have been severely restricted by the construction of a seawall at the landward boundary of the beach since the turn of the century and by adjacent coastal protection works which prevent significant erosion of the sandstone and mudstone cliffs which border the bay.

Torpedo Bay is meso- to macro-tidal (maximum tidal range of 3.5 m) with the beach remaining sub-aerial for approximately half the tidal cycle. During the higher portion of the tidal cycle the beach is exposed to both wind generated waves (WGW) and several types of VGW; the former from a relatively narrow range of directions between the south-southwest and the south-southeast. The possible maximum size of WGW at Torpedo Bay (H_s = 0.1–0.3 m, T_{pk} = 2–3 s) is limited by the maximum unrestricted fetch of only 2.5 km (Figure 1). In contrast, VGW may reach heights of approximately 0.85 m with periods of 3–5 s on the foreshore.

Vessel surveys conducted by the Auckland Regional Council (Boak, 1996) reveal that under normal (non-holiday) conditions commercial ferries constitute a major portion of vessel traffic and overall contribute the greatest proportion of wave energy to the shoreline. The major commercial ferries are vessels with lengths of >30 m, which travel at speeds of ~30 knots and make more than 10 return trips per day. Table 1 summarises the dimensions, capacities and cruising speeds of the primary vessels which generated the wakes which were recorded during this study.

METHODS

Field measurements were carried out at Torpedo Bay over a period of approximately 13 months between November, 1994 and December, 1995. The research involved three components: (1) foreshore process measurements of waves, currents and near bed SSC were made on thirteen occasions or approximately once per month; (2) morphological surveying of the beach was also carried out on a total of 22 days or approximately twice per month; and (3) a self-logging wave and current sensor (S4DW) was deployed in the offshore region for a continuous period of 62 days.

Beach surveying was conducted using a Sokkia Set 5 Total Station. Surveys were made along seven equally spaced shore normal profiles referenced to chart datum to provide estimates of profile shape and net beach volume change.

Point measurements of 3-dimensional velocities in close proximity (within 2–5 cm) of the fluid-sediment boundary were obtained with a Sontek Acoustic Doppler Velocimeter (ADV) (LOHRMANN *et al.*, 1994). Measurements of near bed SSC were made using two optical backscatter sensors (OBS-3) manufactured by D&A Instruments. Water surface elevations were measured with teflon coated capacitance wave gauges (WG-1) manufactured by Richard Brancker Research, Ltd. The instruments were mounted with adjustable brackets on galvanised steel frames. Velocity and SSC sensors were collocated and aligned in the longshore direction with a horizontal separation of 30 cm. The ADV was set to measure currents at a nominal elevation of 5 cm above the bed and was collocated with the lowermost OBS. A second OBS was situated 5 cm above the lower sensor. The vertical position of the sensors was often measured and adjusted between bursts of data collection to maintain a consistent nominal elevation for measurements. The horizontal position of the instrument frames was also adjusted periodically to maintain a consistent position with respect to wave breaking and the surf zone. The capacitance gauges were arranged in a cross-shore array along a beach survey line with one wave gauge collocated with the velocity/SSC sensors (Figure 2) in the surf zone.

The sensors were hardwired to a shore-based power supply and a high speed data acquisition system controlled by laptop computer. Bursts of 4100 data points were acquired at rates of 5 and 10 Hz. The ADV data were calibrated using manufacturer supplied software and vertical velocities were corrected for small errors in the alignment of the probe. The OBS sensors and wave gauges were calibrated according to standard laboratory procedures for these instruments.

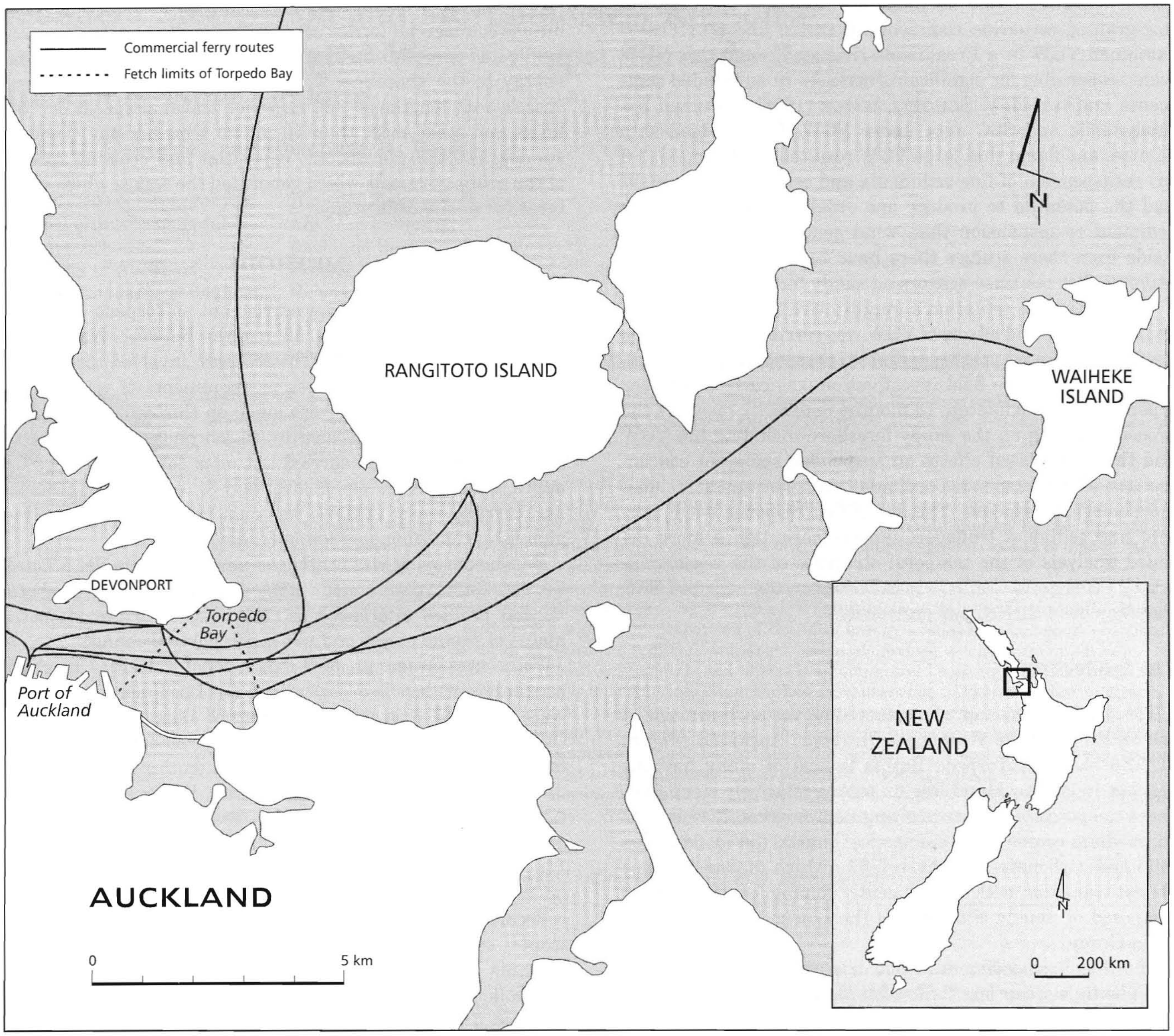

Figure 1. Location of Torpedo Bay, Auckland.

Table 1. *Specifications of vessels generating significant wakes at Torpedo Bay on a regular basis (adapted from Boak, 1996).*

Vessel	LOA (m)	B (m)	D (m)	LWL (m)	PC	S(ms^{-1}/knots)
Quickcat	33.4	12.9	2.0	30.2	650	13.3/26
Jet Raider	37.0	7.2	1.0	32.4	400	16.3/32
Quickcat II	23.0	8.5	1.5	20.3	270	13.3/26
Seaflyte	21.5	7.7	1.5	19.3	130	11.2/22

Notes: LOA = overall length; B = beam; D = draft; LWL = length at water line; PC = passenger capacity; S = cruising speed.

A self-logging InterOcean S4DW current meter with pressure sensor was deployed for a period of 62 days approximately 250 m seaward of the shoreline in order to observe the deep water characteristics of the wave and current climate. The S4DW was situated at 1 m above the sea bed in water depths ranging between 1–5 m.

COMPARISON OF WIND-GW AND VESSEL-GW

Due to the limited fetch (maximum 2.5 km to southwest) at Torpedo Bay, naturally occurring waves at Torpedo Bay are dominated by short period, multidirectional waves which are continuously forced by the local wind field. Wave gener-

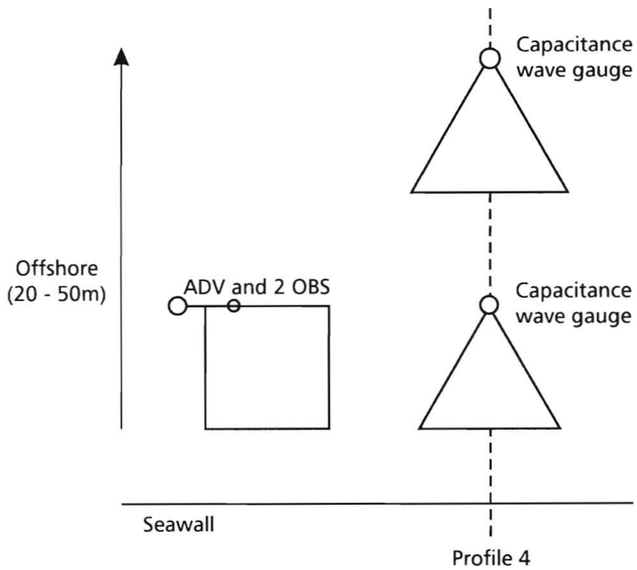

Figure 2. Schematic of instrument deployment on the foreshore at Torpedo Bay.

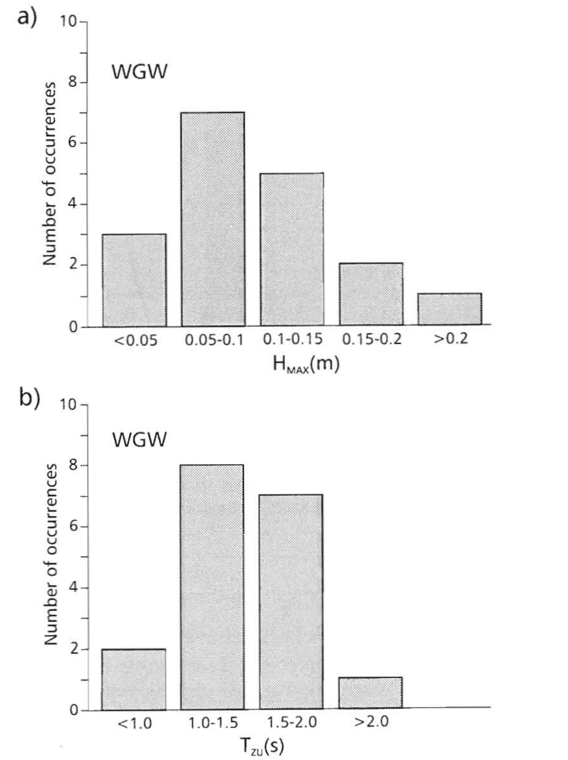

Figure 3. Frequency distributions of (a) maximum and significant wave height; (b) zero up-crossing period (T_{zu}) measured on the foreshore at Torpedo Bay for wind generated wave conditions.

ation at Torpedo Bay is controlled mainly by wind speed and fetch.

Characteristics of WGW recorded by the capacitance wave gauges on the foreshore are summarised in Figure 3. A 48 hour record from the S4DW situated 250 m offshore and a local wind gauge is shown in Figure 4. WGW reached a maximum of 0.23 m on the foreshore and show a direct dependence on wind speed and direction. Spectral analysis indicates that WGW energy occurs at modal periods of 1–2 s. Observed WGW characteristics are consistent with peak periods and wave heights obtained from wave hindcasting based on wind speeds between 5–15 m s^{-1} and the model suggested by DONELAN *et al.* (1985).

The largest WGW measured in the offshore region by the S4DW occurred when winds were from the south-southwest (maximum fetch) and show a strong dependence on wind speed (Figure 4). With wind speeds between 5–15 m s^{-1}, waves reached maximum heights of between 0.12–0.18 m in the offshore region.

Vessel generated waves (VGW) recorded during the study period were generally much larger than WGW. VGW also tended to arrive at an oblique angle to the shoreline due to their mode of generation as divergent wave trains from vessels travelling essentially parallel to shore.

Frequency distributions summarising significant wave height (H_s) and zero crossing period (T_{zu}) for measured VGW are shown in Figure 5. VGW ranged in significant height from 0.1–0.6 m with periods between 2–6 s. Figure 6 shows the distribution of VGW characteristics according to vessel type. The highest and longest waves were generated by the large commercial passenger ferries Quickcat and Jet Raider (see Table 1). Peak periods for VGW under the larger commercial ferries averaged between 4.5–5 s with average significant heights between 0.4–0.6 m. Considerable variability in the measured wave characteristics for individual vessels was observed at Torpedo Bay. This variability was attributed to variations in vessel speed, distance to sailing line, angle of sailing line and direction of travel as well as local bathymetry which influences the degree of wave shoaling, breaking and wave reflection from the beach.

By making some assumptions regarding the size and period of WGW and VGW and their gross sediment transport potential it is possible to make a relatively simple comparison which illustrates the relative importance of these two different types of waves over a 24 hour period (Figure 7). The cumulative wave energy flux attributable to WGW was estimated to first order assuming a constant wave height at breaking of 0.25 m and period of 1.5 s for a duration of 12 hours 25 minutes (2 half tidal cycles) in a 24 hour period. In the case of VGW, the cumulative flux was estimated by assuming 30 sets of VGW with 18 VGW per set, with a height at breaking of 0.4 m and period of 4.5 s. Cumulative energy flux available to transport sediment was based on a threshold breaking wave height of 0.2 m. This seems reasonable based on the time-averaged measurements of SSC shown in Figure 8 in which it is apparent that VGW > 0.20–0.25 m are capable of entraining and suspending significant quantities of material in the water column.

Although the VGW are nearly twice as high as the WGW, they are much less frequent than the continuous WGW in a 24 hour period, so that the overall cumulative power attrib-

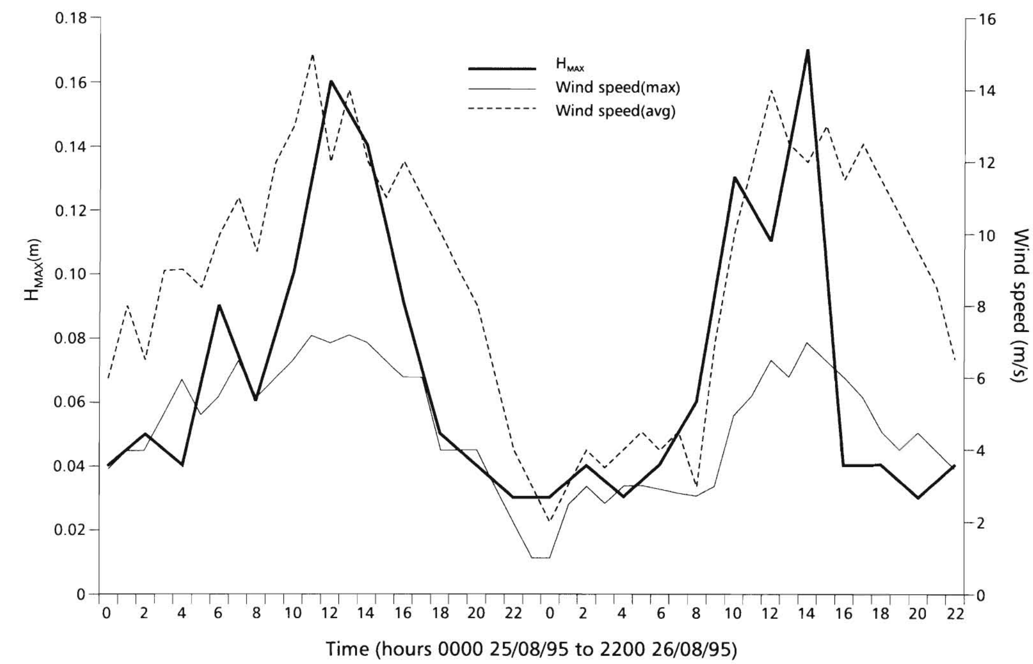

Figure 4. Average hourly wind speeds and maximum wind speeds recorded by anemometer and maximum wave heights recorded by S4DW current meter (25/08/95–26/08/95—adapted from Boak, 1996).

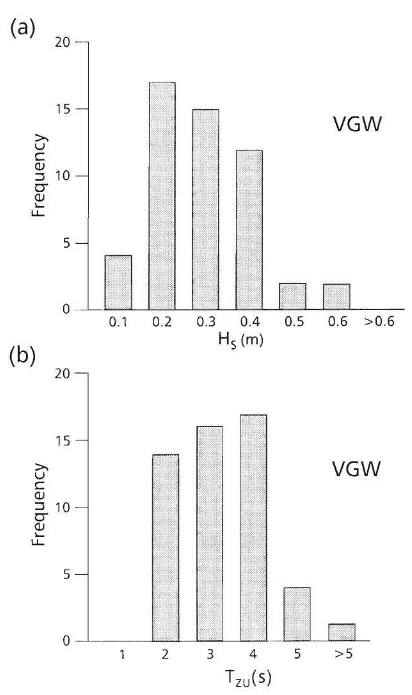

Figure 5. Frequency distributions of (a) significant wave height (H_s); (b) zero crossing wave period (T_{zu}) measured on the foreshore at Torpedo Bay for vessel generated wave conditions.

utable to VGW is approximately 6 times lower than that due to continuous WGW. However, because the VGW are larger they have a much greater potential for entraining sediment than the WGW (which are barely capable of moving sediment) and therefore the cumulative power of VGW waves with sediment transport potential is approximately twice as large as that of the WGW at Torpedo Bay. It is important to note that the assumed conditions correspond with average VGW conditions whereas maximum WGW conditions for the study period were utilised in calculations.

VGW GROUPS AND THEIR EFFECTS ON SAND RESUSPENSION AND TRANSPORT

Theory describing the geometry of VGW was first developed through experiments by FROUDE (1877) and further developed by KELVIN (1887). Moving vessels generate two wave trains consisting of a set of diverging waves that form at the bow and a series of transverse waves that also form at the bow and move forward in the direction of ship-travel with their crests normal to the sailing line (Figure 9, Froude, 1877; KELVIN, 1887; SORENSEN, 1973). This pattern remains steady for a vessel moving with constant velocity. Both waves decrease in amplitude with distance in the aft direction while crest-lengths increase. Wave heights increase to a maximum at the cusp loci, where the divergent and transverse wave trains intersect. Maximum wave height decreases as a hyperbolic function of distance such that wave height is reduced by half in the first four to six boat lengths from the sailing line, while decreases at greater distances are relatively small per unit increase in distance (JOHNSON, 1958).

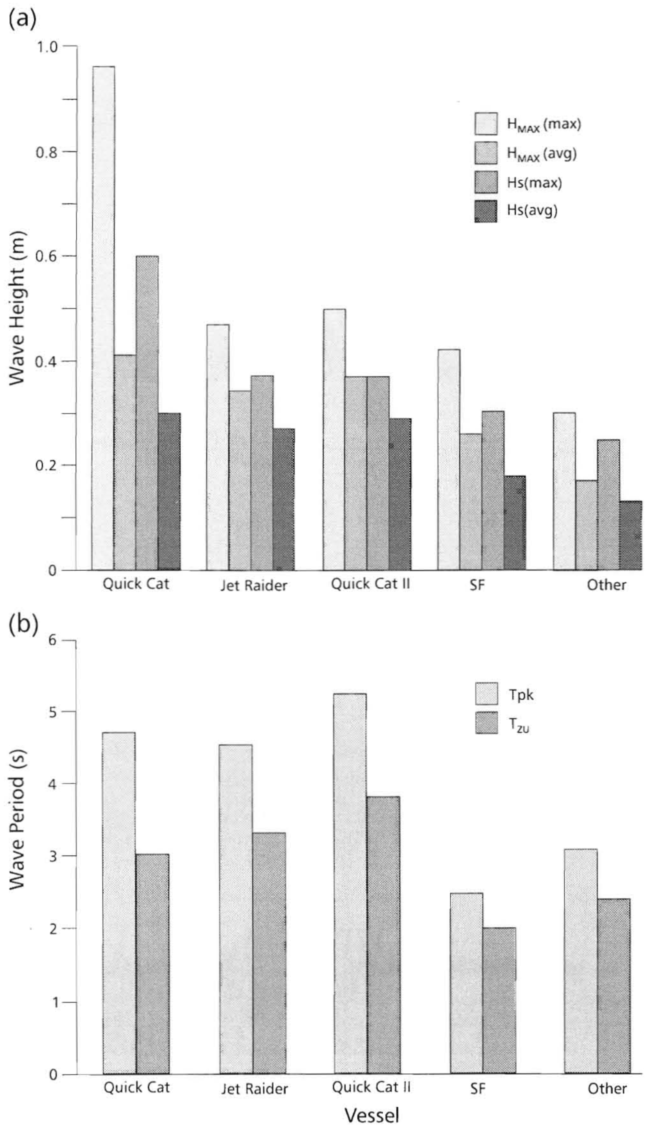

Figure 6. Distributions of vessel generated wave height (a) and wave period (b) according to vessel type measured on the foreshore at Torpedo Bay (Note: H_{max} (max) = maximum wave height; H_{max} (avg) = average maximum wave height; H_{sig} (max) = maximum significant wave height; H_{sig} (avg) = average significant wave height; T_{zu} = average zero crossing wave period; T_{pk} = average peak period).

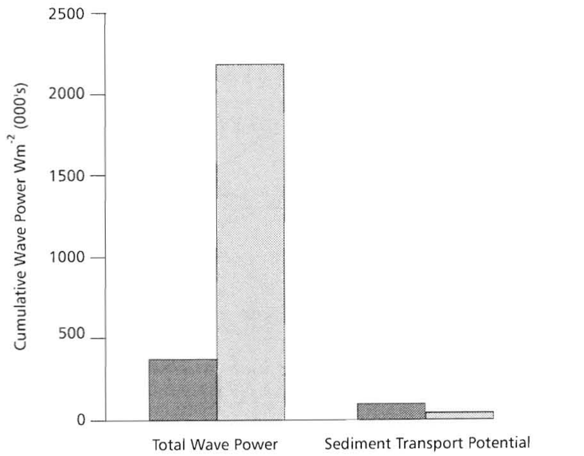

Figure 7. Comparison of cumulative wave power and gross sediment transport potential for WGW and VGW over a hypothetical 24 hour period.

The same factors inducing variability in time-averaged characteristics of VGW resulted in significant variation in the time series associated with individual vessels passing Torpedo Bay: these include variations in vessel speed, distance to sailing line, angle of sailing line with respect to the beach, direction of travel, local water depth and refraction patterns. Another factor inducing time-variation in VGW groups at Torpedo Bay is related to vessel-type. Specifically, waves generated by multi-hull vessels such as catamarans produce a set of diverging wave trains from each hull. These wave trains interact between the hulls so that the resulting wake has two parts: the outside diverging waves and a mixed wave train from the inner sides of the hull. KIRK (1989) observed that catamaran generated wave groups generally contain more waves than those generated by monohulls and therefore have greater potential for modification to the foreshore.

Figure 10 shows time series of VGW together with near bed SSC measured on the foreshore at Torpedo Bay which illustrates the nature of the variability both within and between different types of vessels. The series shown in Figure 10a was generated by a small commercial monohull ferry

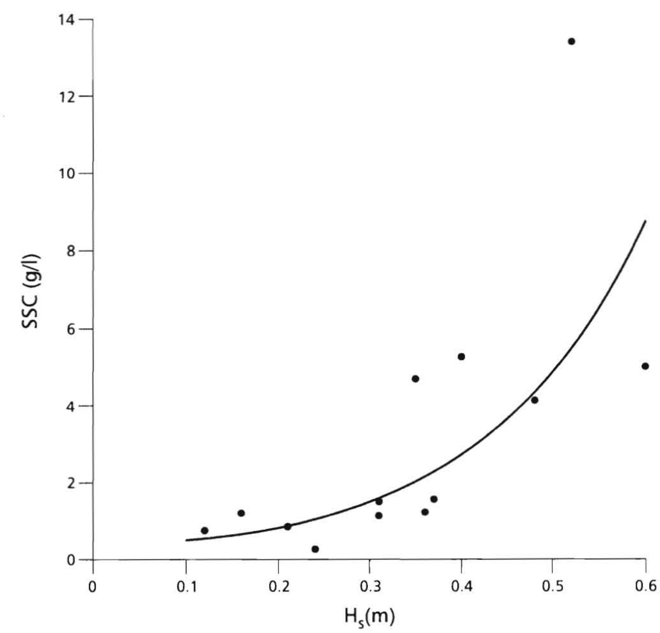

Figure 8. Time-averaged near bed (z~5 cm) SSC as a function of Hs. The trendline is a least-squares fit corresponding to the equation: $SSC = 0.27e^{5.8Hs}$.

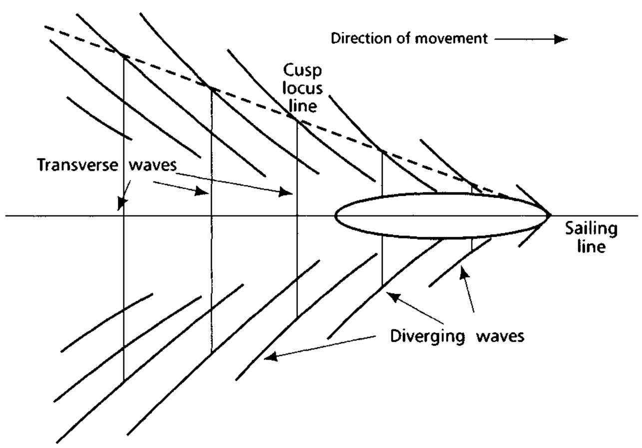

Figure 9. Schematic illustrating wave-crest patterns generated by a vessel in deep water (adapted from Sorenson, 1973).

Manu while the remainder (Figure 10 b–e) were generated by the commercial catamaran *Quickcat*. The *Quickcat* ferry produced the largest VGW measured at Torpedo Bay. Figure 10 and Figure 11 also illustrate that commercial ferries tend to generate larger waves when travelling from Auckland rather than to Auckland due to the relative proximity of the sailing line to Torpedo Bay on the outbound trips. The vessel *Quickcat* also tended to produce multiple wave groups and longer wave trains than other large high speed monohull vessels such as Jet Raider, though the distinction between the two vessels was not always so readily apparent in the measured time series at the beach (*e.g.* compare series a to d in Figure 11).

Secondary groups also appear in the groups generated by monohull vessels such as Jet Raider (Figure 11) reflecting the wave-wave interactions which produce similar time variation in groups of natural propagating wave trains. In shallow water, the VGW exhibit other non-linear features including both skewness and asymmetry, with sharply peaked crests, broadened troughs as well as a tendency for a saw-toothed profile to develop on the approach to the break-point.

The time series of SSC portrayed in Figure 10 (a–e) also exhibit considerable variability which reflects not only the variation in the size of the VGW but also slight variations in sensor elevation and the cross-shore position of the sensors, particularly proximity to the breakpoint. Very large instantaneous SSC occur at the breakpoint and in the swash zone under large VGW (Figure 10 c–e). These VGW generate SSC of similar magnitude to large breaking waves and swash in natural surf zones owing to the large amounts of turbulence and high bed stresses generated by such waves (*e.g.* BEACH and STERNBERG, 1991; JAFFE and SALLENGER, 1992; OSBORNE and GREENWOOD, 1993). On a wave by wave basis, the peak SSC is clearly correlated with the crests of VGW rather than with the troughs, but peak SSC tends to lag the peak velocities under the wave crests by 0.5–1.0 s.

SSC events under VGW groups also exhibit a similar temporal structure to SSC events under natural wave groups

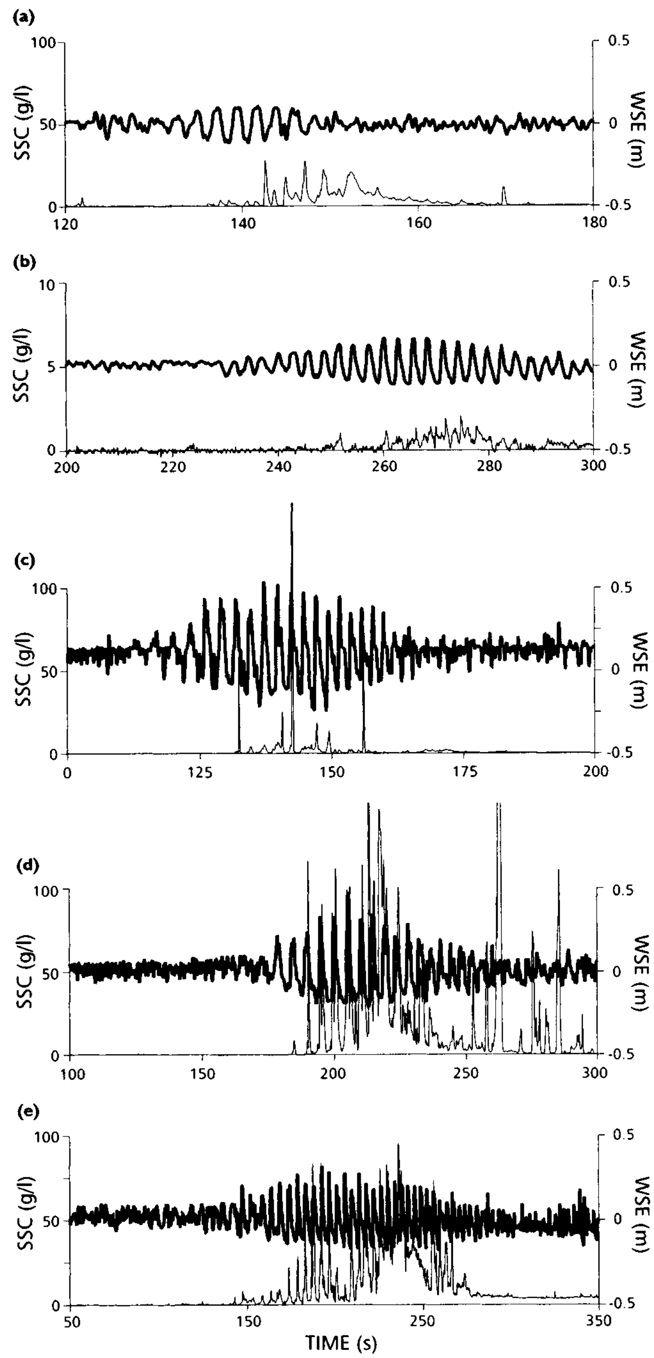

Figure 10. Selected time series of water surface elevations and near bed SSC under VGW: (a) vessel: Manu travelling to Auckland, 13:00, 18/07/95; (b) Quickcat to Auckland, 13:30, 02/08/95; (c) Quickcat from Auckland, 18:10, 23/10/95; (d) Quickcat from Auckland, 19:50, 23/10/95; (e) Quickcat from Auckland, 14:10, 29/10/95.

with an instantaneous response to individual large waves coupled with a gradual "ramping up" and "decay" of SSC as the event progresses. Overall, the suspension events exhibit a phase lag with respect to the onset of the VGW group. Max-

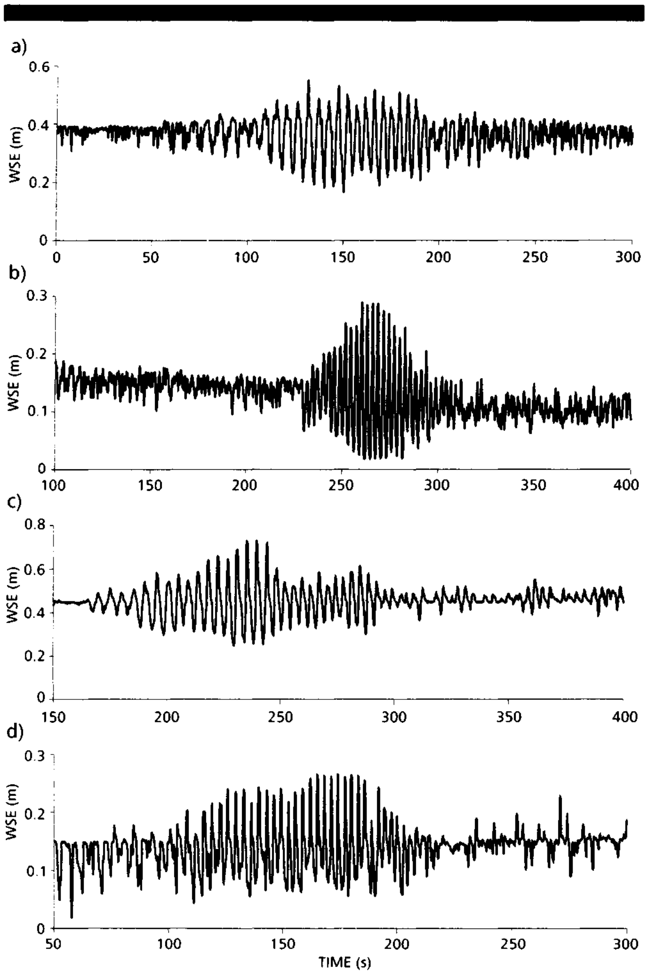

Figure 11. Selected time series of VGW by Quickcat illustrating the effect of distance of sailing line from the beach: (a) Quickcat from Auckland, 12:10, 02/08/95; (b) Quickcat to Auckland, 13:30, 02/08/95; (c) Jet Raider from Auckland, 12:10, 10/30/95; (d) Jet Raider to Auckland, 11:30, 10/30/95.

imum event concentrations lag the occurrence of the largest waves in the VGW group by 1–2 waves or more.

Figure 12 a–f shows two examples of the cross-shore velocities (U), SSC, instantaneous cross products of U with SSC, and the instantaneous turbulent kinetic energy (TKE). In a time-averaged sense, TKE is equivalent to half the sum of the variances of the turbulent fluctuations in the three coordinate directions (u′, v′, w′), times the fluid density, ρ:

$$\frac{1}{2}\rho\overline{k^2} = \frac{1}{2}\rho\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

(DYER, 1986), whereas in this paper an instantaneous measure of TKE is based on the instantaneous sums of squared deviations of the 3D velocity field which represents the total kinetic energy of the fluid.

Time series in Figure 12 c–f indicate that the magnitude of instantaneous TKE under the wave crests is usually much larger than under the wave troughs. This is attributed to the intense accelerations associated with the strongly asymmet-

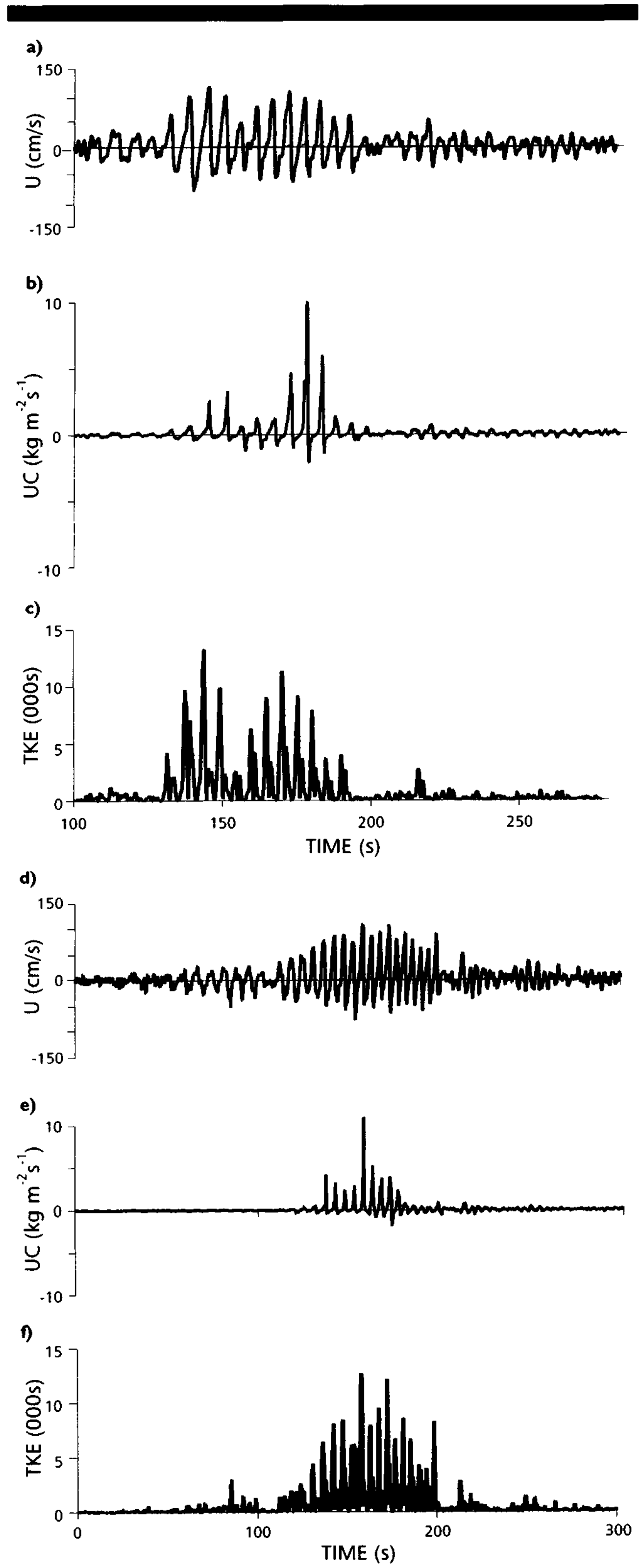

Figure 12. Time-series of (a) cross-shore velocities and SSC; (b) instantaneous cross product of U and SSC; (c) instantaneous TKE and SSC for Quickcat from Auckland 09:15, 02/08/95; and (d) cross-shore velocities (U) and SSC; (e) instantaneous cross product of U and SSC; (f) instantaneous TKE and SSC for Quickcat from Auckland 12:10, 02/08/95.

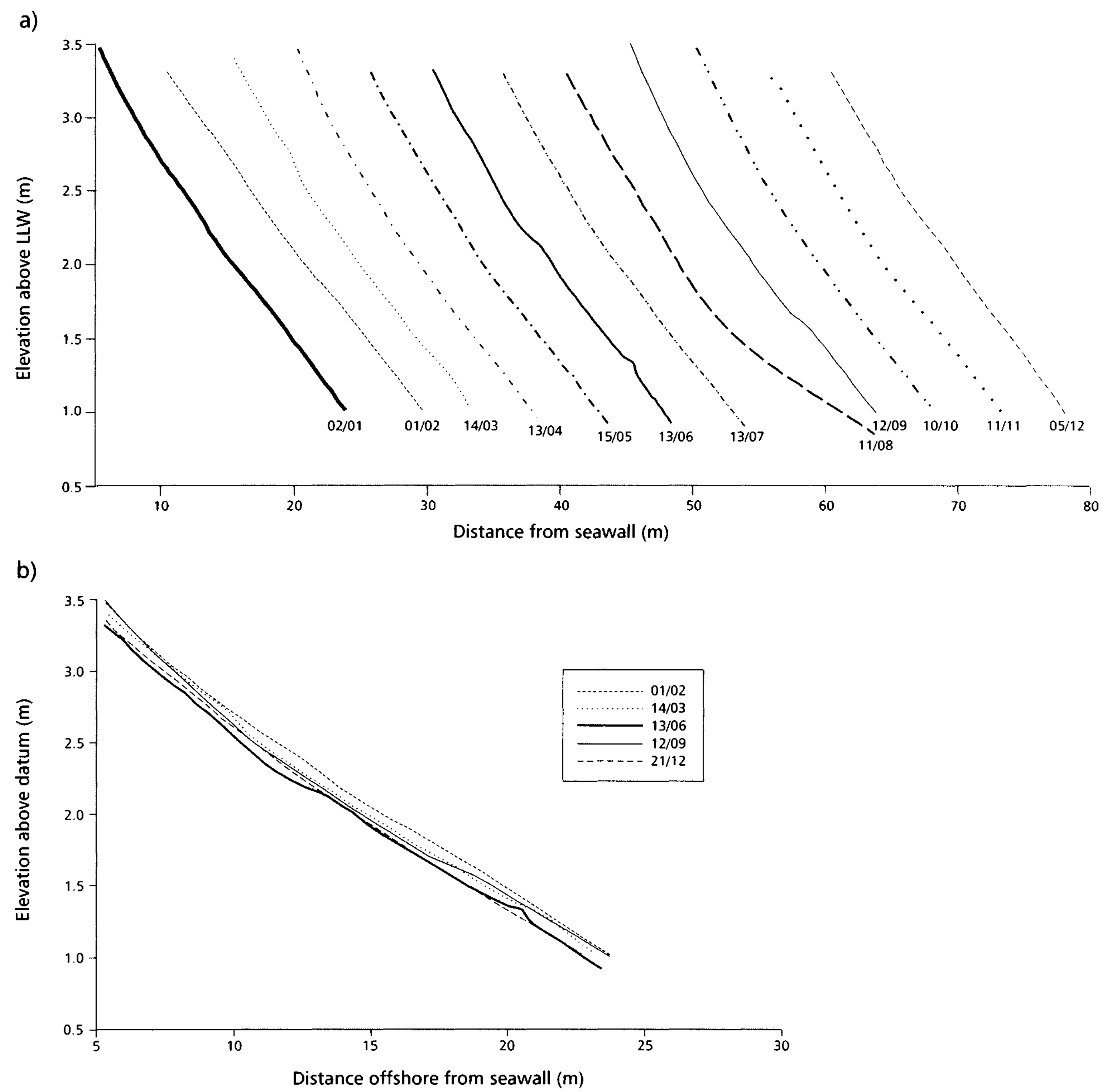

Figure 13. Profiles of the foreshore at Torpedo Bay along the instrument deployment line: (a) time-series of monthly profiles through the experimental period (note that each profile has been offset horizontally by 5 m); (b) quarterly profiles illustrating net profile changes over the experimental period.

ric wave crests as they approach the break point. Instantaneous SSC responds rapidly to the much larger instantaneous TKE under the crests of the large waves. It seems likely that the lag of 0.5–1.0 s between the maximum horizontal velocity and SSC represents both the time required for vertical transport from the bed to 10 cm and possibly the influence of horizontal advection of sediment from the breakpoint. In the case of large breaking waves, the sensors were often situated just landward of the breakpoint in the swash zone and inner surf zone.

Figure 12B and E show that the instantaneous suspended sediment transport is skewed in the onshore direction owing to the strong correlation of SSC peaks with the crests of VGW. Since the SSC associated with individual waves near the beginning of the group tends to settle completely in each half cycle, there is little or no offshore transport during the early part of the VGW event. However, as the VGW group progresses the waves increase in size and re-suspend more sediment than can settle in one half wave cycle. A settling tube analysis of the bed sediment at Torpedo Bay indicates a mean settling velocity of 0.05–0.07 m s^{-1}. This suggests that the average time for most sediment to settle from a height of 0.1 m (OBS sensor elevation) is between 1.4–2 s or just less than ½ a wave period. However, based on the quantities of sediment reaching 0.1 m and visual observations which indicated sediment being suspended throughout the water column (mean depth = 0.4 m) under breaking waves, it seems likely that significant quantities of material reached elevations between 0.1–0.4 m and would therefore require settling times of up to 1 full wave cycle. The result is a cumulative increase in the amount of sediment, particularly finer fractions, in the water column as the group progresses and a slight increase in the amount of offshore transport due to the coupling of SSC with the troughs of the waves. The accumulation of sediment in the water column through time might also account for the gradual ramping up of the instantaneous SSC and more importantly for the phase lag between the peak event concentration and the largest waves in the group. The latter might also be caused by a gradual increase in fine material in the water column as the suspension event increases owing to the sheltering effect of larger grains present in the poorly sorted bed sediment.

It is also clear from a number of time-series that SSC remains above pre-event levels for some time after the passage of the VGW. This indicates that the VGW are adding a significant quantity of fine sediments which require longer settling times and therefore contribute to enhancement of turbidity in the nearshore.

MORPHOLOGICAL RESPONSE OF THE FORESHORE

Under almost all conditions, the beach morphology at Torpedo Bay corresponds closely with the low energy macro-tidal equivalent of the low-tide terrace modal beach state (WRIGHT and SHORT, 1982). According to SHORT (1991): "with decreasing wave energy, macro-tidal beaches (tide range >3 m) will eventually grade into tide-dominated mud flats. However, before that point is reached, a transition occurs where the beach face grades vertically into a low gradient tidal flat. Beach-tidal flat systems are characterized by relatively steep, coarse grained reflective beach face (usually no cusps) which grades at some point below MSL into a fine grained very low gradient tidal flat".

Beach morphodynamic states were evaluated for various wave and beach profile measurements using the model of MASSELINK and SHORT (1993). The results of this analysis indicate that under most conditions, the beach corresponds to the above description (BOAK, 1996). The time-series of foreshore profiles in Figure 13 a and b indicate a relatively steep foreshore with consistent slope throughout the experimental period. The morphodynamic modelling suggests that under some of the larger VGW groups and the largest wind-wave events coupled with neap tidal range the beach may have a tendency to mobilise so that the foreshore may tend towards a lower slope for a short period of time (*e.g.* profile 11/08 in Figure 13A).

Short term fluctuations in local bed elevation change of up to ±/−10 cm occurred on the foreshore under the influence of VGW groups, but it is clear from the repetitive profiling and sediment transport measurements that these short term changes were relatively insignificant with respect to the overall stability of the sediment volume. Repetitive profiling through the experimental period (Figure 13B) indicates overall stability of the foreshore with a slight tendency for net accretion under the influence of VGW.

CONCLUSIONS

A number of commercially operated vessels entering and leaving the Waitemata Harbour in Auckland regularly produce wave groups which have significant heights and periods which are approximately double that of the maximum wind generated waves experienced at Torpedo Bay. Overall these waves have a gross sediment transport potential which is greater than the sustained influence of wind-generated waves on the beach.

The groupiness and nonlinear form of these large vessel generated waves makes them capable of entraining and suspending significant quantities of bottom sediment with instantaneous SSC reaching between 10–100 g l^{-1}. SSC events under nonlinear (asymmetric and skewed) shoaling and breaking VGW exhibit a distinctive temporal structure similar to natural wave groups in the surf zone. Time series indicate a marked instantaneous response to sharp accelerations and the occurrence of high TKE under asymmetric wave crests early in the suspension events and a distinctive phase lag of 0.5–1.0 s with respect to wave crest. These phase lags are important in determining the direction and magnitude of net sediment transport which in the examples shown here was predominantly onshore. This short term phase lag is possibly indicative of horizontal advection of sediment from the initial break-point landward into the inner surf zone and swash zone.

As the VGW group progresses, more SSC is injected into the water column than can settle completely in a half wave cycle. This has a cumulative effect on the instantaneous SSC and is also responsible for inducing a phase lag between the event maximum SSC and the occurrence of the largest waves in the group. The gradual accumulation of fine sediments in particular contributes to enhanced turbidity in the nearshore for upto several minutes following the passage of the VGW group.

Both wind generated waves and vessel generated waves appear to have a relatively minor effect on the sediment transport and foreshore response at Torpedo Bay. Short term fluctuations in bed elevation of up to ±10 cm occurred in response to large VGW groups. Time series suggest that the VGW have a tendency to produce onshore transport due to a strong correlation between instantaneous SSC and the crests of the VGW and therefore would appear to play a role in maintaining the existing beach profile rather than causing net sediment loss.

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