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Sediment Budget and Equilibrium Beach Profiles Applied to Renourishment of an Ebb Tidal Delta Adjacent Beach, Mt. Maunganui, New Zealand

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ABSTRACT

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An ebb tidal delta adjacent beach was nourished by placement of dredged material in water depths of 4–7 m below Chart Datum. The beach and nearshore were subsequently monitored with accurate integrated beach-nearshore surveys along 7 transects. All the nourishment material could be accounted for by onshore movement resulting in 89 $m^3 m^{-1}$ of accretion within 15 months of placement.

Application of the Dean's Equilibrium Beach Profile model, before, during and after disposal, indicated that before nourishment the beach-nearshore profiles exhibited a deficit of sediment throughout their length. After nourishment, the profiles adjusted towards the equilibrium profile predicted by the model.

ADDITIONAL INDEX WORDS: *Beach nourishment, volume analysis, Dean's Equilibrium Beach Profiles.*

INTRODUCTION

When maintenance dredging was required for the main shipping channel through the ebb tidal delta at the entrance to Tauranga Harbour, it was proposed that some of the dredged sediment be used to renourish the ebb tidal delta adjacent to Mt. Maunganui Beach. Before this proposal was allowed to proceed, the consent granting authority required a detailed monitoring programme to determine the short-to-medium term movement of the renourishment material. Therefore, a research programme was devised which included prediction and monitoring of sediment near Mt. Maunganui Beach (FOSTER, 1991; FOSTER *et al.*, in press).

Included in the monitoring programme was a series of seven closely spaced, shore-normal profiles, surveyed from the top of the foredune out to a water depth of 14 m below Chart Datum, defined as Mean Low Water Spring. These data permitted a comprehensive beach sediment budget to be calculated over the period of monitoring. In addition, sediment textural data taken in conjunction with the beach-nearshore profiling enabled application of a refined model of Dean's Equilibrium Beach Profile (EBP) concept (DEAN, 1991; DEAN *et al.*, 1993).

Accordingly, the aims of this paper are to:

(1) present the results of the nearshore-beach sediment budget analysis for a renourished ebb tidal delta adjacent beach; and
(2) ascertain whether the nearshore-beach profiles were in equilibrium according to the Dean EBP model, both before and after dumping.

STUDY BACKGROUND AND RATIONALE FOR BEACH RENOURISHMENT

Mt. Maunganui is a 700 m long beach bordered to the west by Mt. Maunganui tombolo and to the east by Moturiki Island (Figure 1). The beach is characterised by a dune, berm and offshore bar (HEALY *et al.*, 1977). The wave climate for the Bay of Plenty next to the study area has been investigated by a variety of studies since the 1960's (Bay of Plenty Harbour Board 1969–1973, J. STEPHENSON, hydrographer, *personal communication*; DAVIES-COLLEY and HEALY, 1978; PICKRILL and MITCHELL, 1979; DAHM and HEALY, 1980; HARMS, 1989; DE LANGE, 1991) and ranges in height (H_s) from 0.5–1.5 m and period (T_s) from 5–9 sec for prevailing "everyday" conditions, with

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Figure 1. The 0.7 km long Mount Maunganui ocean beach and tombolo with Matakana Island in the background.

swells up to 2–5 m and periods of 7–9 sec during storms.

Morphodynamically, Mt. Maunganui Beach is the southeastern extension of the large ebb tidal delta of Tauranga Harbour (Figure 2). With the development of the Port of Tauranga as New Zealand's largest port, the necessity for deep water channels into Tauranga Harbour increased. This resulted in the deepening by dredging of the main Entrance Channel through the ebb tidal delta and a need for periodic maintenance dredging. It is possible that the dredging of the Entrance Channel may have inhibited the supply of littoral sediment to the beaches to the southeast. Thus, dumping material dredged from the ebb tidal delta close to the downdrift shore in a similar morphodynamic environment acts as a form of artificial bypassing (FOSTER, 1991).

Beach erosion at Mt. Maunganui occurred between 1943 and 1974 resulting in dune retreat of nearly 20 m, with the most extensive erosive period between 1943 and 1959 (HEALY *et al.*, 1977). Since the 1970's, the beach appears to have stabilised with erosion being minimal, probably due to shoreward migration of dredged material from the inner-shelf adjacent to Tauranga Harbour (HARMS, 1989; HEALY *et al.*, 1991b). Following the recommendation made by HARMS (1989) and the ongoing need of the Port of Tauranga to dispose of dredged material, a disposal site within the nearshore zone (4 to 7 m below Chart Datum) near Mt. Maunganui Beach was selected for beach renourishment using dredged material. Dredging and disposal were carried out using a split hopper dredge, the *Pelican*.

The overall cost of dredging operations is a major factor in siting dredge dump grounds. Where possible, disposal sites are chosen for their proximity to the dredging operation and the compatibility of the dredged material with the native sediment to minimise adverse effects to marine ecosystems. The site chosen at Mt. Maunganui fits these criteria: it was close to source so transport costs were minimised when compared to the transportation distance required to the usual inner-shelf dump ground; and the materials chosen

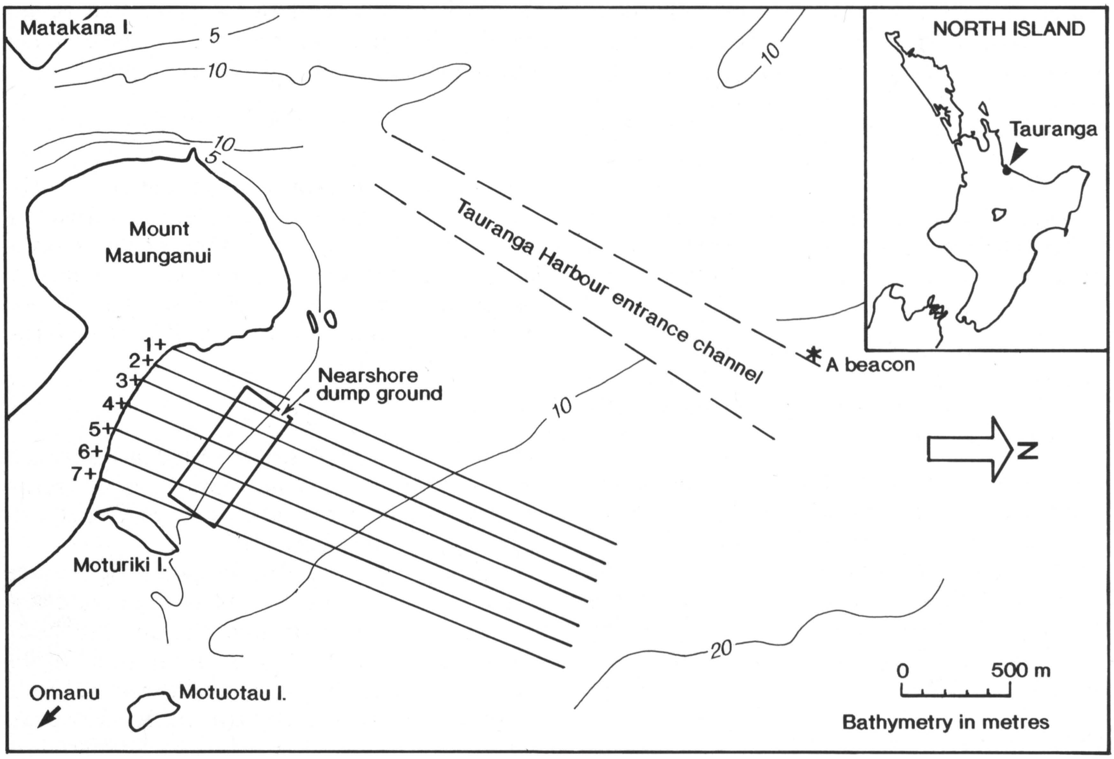

Figure 2. Location map of the study area, illustrating the locations of the 7 shore normal profiles and the inshore dump ground at Mount Maunganui Beach.

had few, if any, adverse effects on the environment (HEALY and MCCABE, 1990; HEALY *et al.*, 1991a; FOSTER, 1991; FOSTER, 1992).

The placement of dredged material in the nearshore zone at Mt. Maunganui would also have a positive mitigating effect against predicted accelerated sea level rise due to global warming (HEALY *et al.*, 1991a, 1991b). Promoting beach accretion by offshore berm emplacement will help maintain the beach amenity value and protect coastal developments in the future.

METHODS

To assess possible changes in the shape of offshore and beach profiles before the placement of dredged material, seven shore-normal survey lines were established at approximately 100 m intervals along Mt. Maunganui Beach (Figure 2). Actual spacing varied depending on where suitable survey bench marks, or monuments, could be established along the foredune and roadside reserve adjacent to the beach (FOSTER, 1991).

Surveys involved overlapping sub-aerial and bathymetric profiling. For the sub-aerial beach, standard staff and level surveys were conducted at times of maximum low tide and low swell. This enabled profiles to be overlapped with the nearshore bathymetric soundings conducted at high tide (mean spring tidal range = 1.5 m). Repeated beach surveys commenced in November 1989 and continued monthly throughout 1990 until completion of the study in May 1991 (FOSTER, 1991). The accuracy of this type of beach survey is of the order of ±0.05 m (GABLE and WANETICK, 1984).

Bathymetric surveys were carried out quarterly (November 1989 and February, June and October 1990 before disposal; December 1990 immediately after disposal; and February and May 1991 post-disposal) when calm wave and weather prevailed. Echo sounding surveys were conducted with the Port of Tauranga Ltd. survey vessel *Kairuri IV* using an Atlas Deso-20 33 kHz echo sounder. The echo sounder was connected to a TSS swell compensator that was used to digitally remove wave signals during sounding. Racal Microfix electronic position fixing was used to locate the vessel along the shore-normal profiles (with a known accuracy of position of ± 3 m). All depth measurements were made relative to the Port of Tauranga Chart Datum and plotted onto 1:5,000 scale charts by a CAD software system operation by the Port of Tauranga Ltd.

Sources of error in the bathymetric surveys in the Port of Tauranga survey equipment have been previously analysed by HEALY *et al.* (1991a) and are as follows:

(1) accuracy of echo sounder (0.05 m); and
(2) instrument and operational error and reduction of measured water depth to the tidal datum ($\pm$ 0.10 m).

The total error should not exceed $+0.2$ m, so that bathymetric changes which exceeded this value were considered significant (FOSTER, 1991).

Sediment samples for textual analysis were collected by SCUBA at intervals along the survey transects. The survey lines were also used to define the extent of sidescan sonar surveys of the area (FOSTER, 1991).

Beach Sediment Budget

If each measured profile is representative of a section of beach, the profile changes can be assessed for the volumetric change occurring along the beach, using the formula:

$$\Delta V = \overline{\Delta h} L W \qquad (1)$$

where ΔV = profile volumetric change (m^3), $\overline{\Delta h}$ = average vertical change (m) of the profile, L = length of the profile affected by change (m), and W = section width (m) as given in Table 1.

This analysis was carried out for 10 m segments along each profile, and the segments integrated over five sections of the profile. These sections were labelled by the main geomorphic feature located within them (Table 1 and Figure 3):

(1) beach face 0 to 100 m offshore
(2) swash zone—100 to 150 m offshore
(3) nearshore zone—150 to 400 m offshore
(4) dump ground—400 to 800 m offshore and
(5) inner shelf—800 to 1,200 m offshore

To further assess beach profile morphological change along the beach, an excursion distance analysis was performed. This involved consideration of the temporal changes in the distance along the profile to the first occurrence of a specified elevation. In this case, we specified a depth of 0 m, or Chart Datum, as this elevation was recognised as demonstrating the greatest change along Mt. Maunganui beach by FOSTER (1991).

Application of Dean's Equilibrium Beach Profile Concept

Dean's EBP concept suggests that given sufficient time the cross-shore profile, and indeed the three-dimensional beach system, would attain a shape in equilibrium with the forcing system, *e.g* waves and currents (DEAN, 1991; DEAN *et al.*, 1993). A simple geometric form of an EBP may be expressed as:

$$h(y) = Ay^{2/3} \qquad (2)$$

where h(y) = water depth at distance y from the shore (m), A = scale parameter which is dependent on sediment characteristics ($m^{1/3}$), and y = distance from the shore (m).

This equation was first proposed by BRUUN (1954) in an investigation of profiles from the Danish North Sea coast and Mission Bay, California. DEAN (1977) used the same equation in analysing 504 profiles from the Atlantic and Gulf Coasts of the United States and supported Bruun's value of $\frac{2}{3}$ for the exponent of y. An empirical relationship between A and sediment size, D, was developed by MOORE (1982) and subsequently refined by DEAN (1987).

Investigation of the EBP concept in New Zealand by DEAN *et al.* (1993) led to the development of a computer program for the Macintosh(TM), entitled *DeansProfile*, which predicts an equilibrium beach profile. The program employs an expanded form of Equation 2; which incorporates terms accounting for any cross-shore variation in grain size, determined by sampling, and the beach face slope of the measured profile. The full methodology is given in DEAN *et al.* (1993). This equation has the form:

$$\frac{dh}{dy} = \left(\frac{1}{\tan\beta} + \frac{3}{2}\frac{\sqrt{h}}{\sqrt{A}}\right)^{-1} \qquad (3)$$

where $\tan\beta$ = beach face slope.

The *DeansProfile* program enables an evaluation of the degree of "disequilibrium" exhibited by a profile. This is quantified by calculating the difference in volume between the actual and predicted profiles above the approximate depth of limiting motion for the period of consideration. The resulting predicted change in the position of

Table 1. *Summary of volumetric changes (m³) for each transect of Mt. Maunganui beach, and each defined geomorphic beach sector. The table summarises the changes between successive surveys, and the net change between the first and last survey during the study. The section width represents the average distance between lines lying halfway between the current transect and the adjacent transects. For Sites 1 and 7, the section width is the average distance between the current transect and the adjacent transect.*

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total
Section width (m)	114.5	110.5	101.0	113.5	110.0	108.5	97.0	755.0
Beach face (0 - 100 m)								
Feb 90 - Jun 90	-6900	0	-500	3400	3300	2200	1900	3400
Jun 90 - Oct 90	-6900	0	0	-1100	-2000	-500	0	-10500
Oct 90 - Dec 90	1700	0	0	0	0	0	0	1700
Dec 90 - Feb 91	1700	0	0	1100	2200	400	500	5900
Feb 91 - May 91	2900	2800	2500		2200	900	4900	16200
Feb 90 - May 91	-7500	2800	2000	3400	5700	3000	7300	16700
Swash zone (100-150 m)								
Feb 90 - Jun 90	-6900	1600	0	1700	3300	2400	-8700	8700
Jun 90 - Oct 90	-6900	-5000	-15200	-3400	3300	500	-4400	-31100
Oct 90 - Dec 90	5200	6600	6100	6800	-1700	0	-1400	21600
Dec 90 - Feb 91	5200	-1700	-3000	5100	6600	700	1000	13900
Feb 91 - May 91	-8600	8300	4500	1100	5500	5600	14200	30600
Feb 90 - May 91	-12000	9800	-7600	11300	17000	9200	700	43700
Nearshore zone (150-400 m)								
Feb 90 - Jun 90	0	1700	1500	1700	5000	2400	0	12300
Jun 90 - Oct 90	-3400	-5000	-7600	0	-3300	0	-4400	-23700
Oct 90 - Dec 90	0	6600	0	0	0	0	0	6600
Dec 90 - Feb 91	1700	3300	-3000	-5100	3300	0	10200	10400
Feb 91 - May 91	1700	1700	-1500	-9100	-13200	0	2900	-17500
Feb 90 - May 91	0	8300	-10600	-12500	-8200	2400	8700	-11900
Dump ground (400-800 m)								
Feb 90 - Jun 90	0	4400	8100	0	13200	0	0	25700
Jun 90 - Oct 90	0	-13300	-20200	-9100	8800	0	-7800	-41600
Oct 90 - Dec 90	0	8800	18200	27200	26400	13000	0	93600
Dec 90 - Feb 91	0	-8800	-3000	-20400	-26400	-4300	0	-62900
Feb 91 - May 91	0	-8800	-3000	-6800	-5300	-3300	7800	-19400
Feb 90 - May 91	0	-17700	100	-9100	16700	5400	0	-4600
Inner Shelf (800-1200 m)								
Feb 90 - Jun 90	0	4400	12100	0	13200	6500	0	36200
Jun 90 - Oct 90	0	-13300	-16200	-9100	-8800	0	7800	-39600
Oct 90 - Dec 90	0	8800	0	0	0	0	0	8800
Dec 90 - Feb 91	0	0	1000	1100	0	0	0	2100
Feb 91 - May 91	0	0	0	0	0	0	15500	15500
Feb 90 - May 91	0	-100	-3100	-8000	4400	6500	23300	23000
Net change	-19500	3100	-19200	400	35600	26500	40000	66900

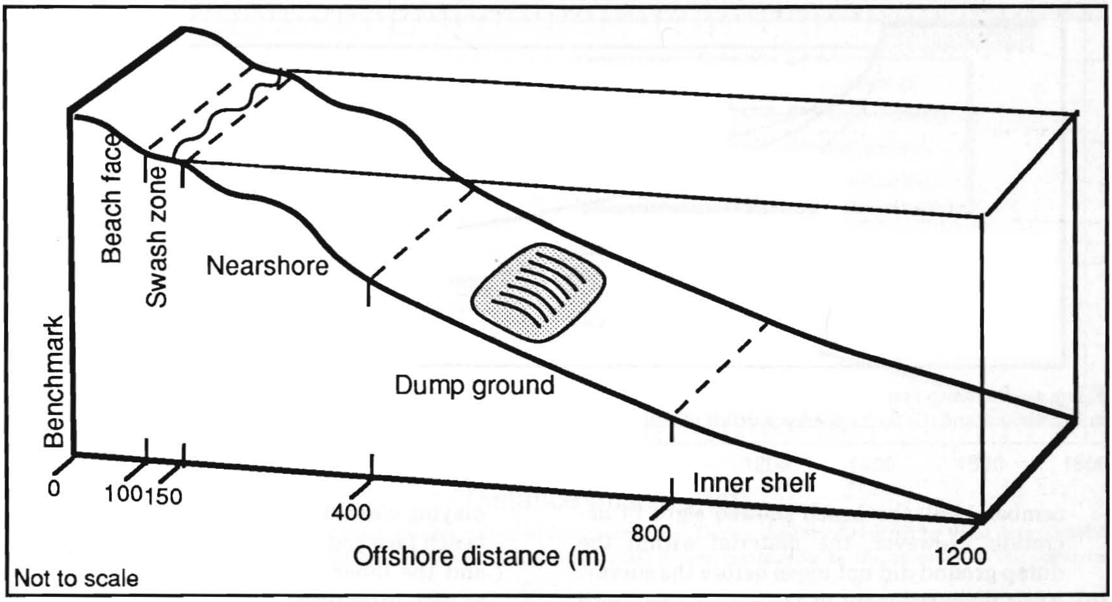

Figure 3. Definition sketch of the zones used for volumetric analyses to determine the sediment budget of Mt. Maunganui Beach. The boundaries are based on the offshore distance from the benchmark marking the start of the survey transect, and not on morphodynamic criteria.

the shoreline is determined by (DEAN *et al.*, 1993):

$$\Delta y = \frac{V' - V}{h_* + B} \quad (4)$$

where Δy = change in shoreline position (m), V = measured volume above selected datum ($m^3\ m^{-1}$), V′ = predicted volume above selected datum ($m^3\ m^{-1}$), h_* = depth of limiting sediment movement (m), and B = berm height (m).

For the purposes of this study, data required by *DeansProfile* include: sediment data collected along the shore-normal profile; detailed beach and bathymetric profiles for the same period; and measurements of the beach slope. These data corresponded to three time periods: June 1990, before renourishment; December 1990, immediately after placement of the nourishment material; and February 1991, two months after completion of renourishment.

The predicted beach profile was compared with the actual measured beach profile. For the purpose of this study, the Mt. Maunganui beach results were analysed to determine whether:

(1) measured beach profiles had an excess or deficit of sediment; and
(2) measured beach profiles were in equilibrium with the predicted profile.

A definition diagram of these concepts is given in Figure 4.

RESULTS

Summaries of the volumetric differences between beach-nearshore surveys, and net volume changes per geomorphic sector during the period February 1990 to May 1991, are presented in Table 1. The total volumetric change between successive surveys for each profile zone defined above is also plotted in Figure 5.

From perusal of Figure 5 and Table 1 the following can be deduced:

(1) Over the period of monitoring all of the 80,000 m^3 dumped in the nearshore can be accounted for as subsequent beach accretion.
(2) From February 1990 to June 1990, all geomorphic sectors showed signs of accretion.
(3) From June 1990 to October 1990, all sectors showed erosional trends.
(4) From October 1990 until, and including, the period of the nourishment dumping in De-

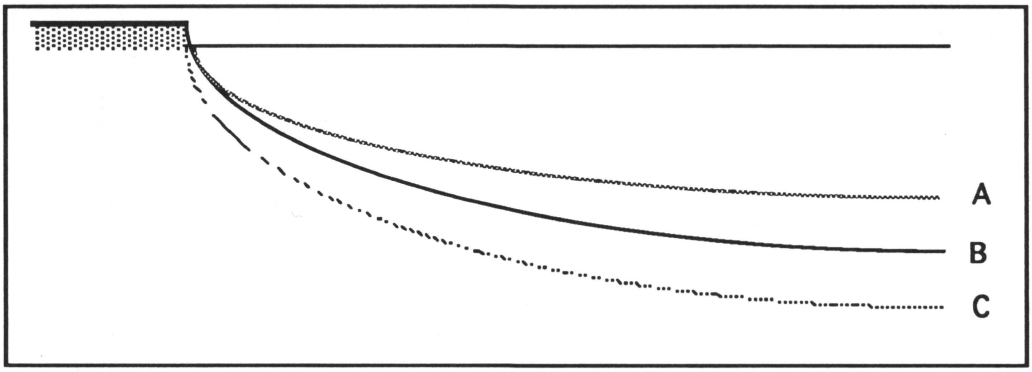

Figure 4. Definition sketch of the Equilibrium Beach Profile concept: (A) the profile has an excess of sediment; (B) the profile is in equilibrium; and (C) the profile has a deficit of sediment (after DEAN, 1991).

cember 1990, the beach showed signs of accretion. However, the material within the dump ground did not move before the survey.

(5) After renourishment in December 1990 until the February 1991 survey, the data reflect the onshore movement of dredged material from the dump ground with the dump ground displaying clear signs of reduction. Further, the beach face and swash zones showed accretion and the inner shelf underwent little change as very little seawards movement of material occurred. The sediment balance for October 1990 to December 1990 (Table 1) indicates that 93,600 m^3 was added to the system. This

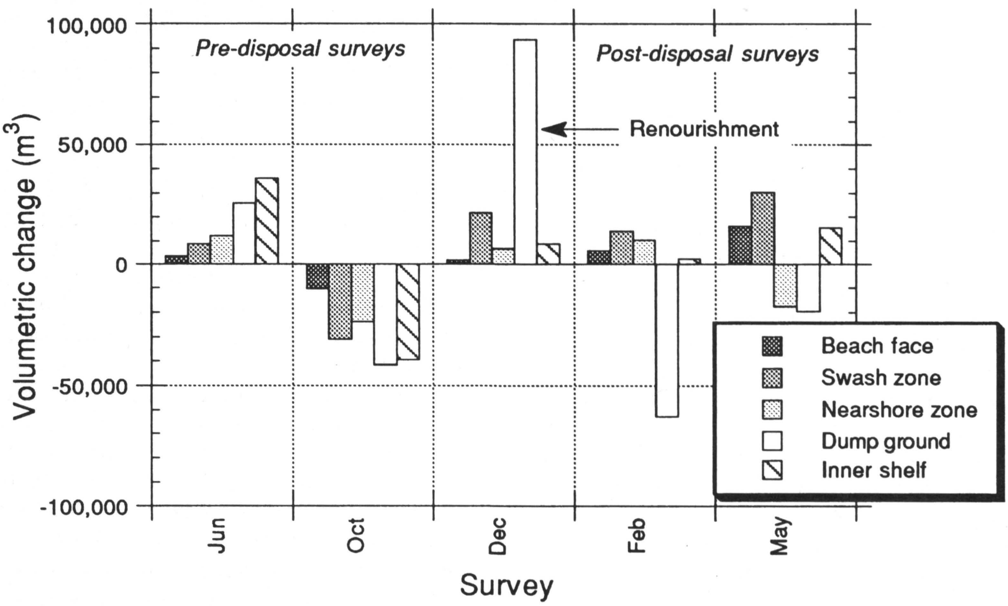

Figure 5. Plot of volumetric change of the defined geomorphic sectors integrated along Mt. Maunganui beach relative to February 1990. The plot shows variable change in volume prior to dumping—from accretion in February 1990 to erosion in October 1990, then accretion after emplacement of the nourishment dump in December 1990. Trends following dumping reflect the movement of material onshore from the dump site.

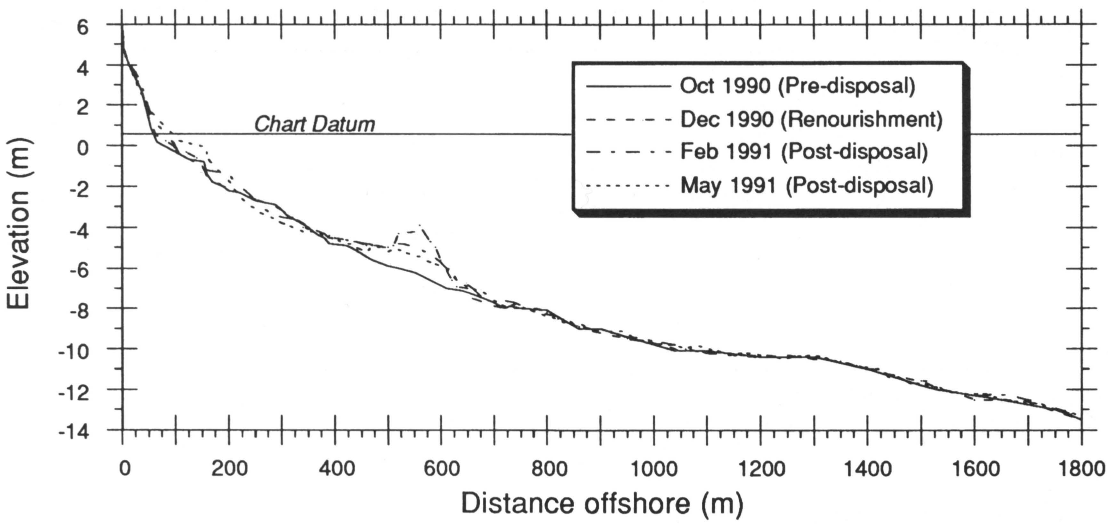

Figure 6. A representative example of beach profiles measured for survey Site 5. During the period covered by these data (October 1990 to May 1991), the variation at offshore distances greater than 1,200 m was comparable to the accuracy of the surveying techniques.

sediment comprises 80,000 m^3 of dredged material plus an additional 13,000 m^3 from outside the surveyed region.

(6) By May 1991, the beach face and swash zone had been substantially renourished. Profile data (*viz.* Figure 6) indicated that the dump mound had been reduced by approximately 85% of its height and volume.

(7) The overall sediment budget for the period February 1990 until May 1991 was +66,900 m^3. This value equates to accretion of 89 m^3 m^{-1} of beach. However, the dump ground and nearshore zone of the profiles demonstrated a sediment loss over this period.

Changes in the "excursion distance" from the foredune benchmarks for each profile to Chart Datum, a measure of beach width, are plotted on Figure 7. The beach width narrowed from February 1990 until December 1990, when renourishment took place. The surveys for February 1991 and May 1991 show that beach width increased as material from the dump ground moved ashore and accreted in the swash zone. However, we do not have historical long-term data on the range of natural fluctuations of this parameter for comparison.

Beach surveying results also indicated a trend of accretion occurring along the eastern margin of Mt. Maunganui Beach (Site 7). This has been interpreted as being the result of Moturiki Island (Figure 2) acting as a large natural groyne, thus restricting longshore movement of sediment to the east towards Omanu Beach. No measurements of longshore transport rates were made for this study, but the profile results tend to reinforce the hypothesis of HEALY *et al.* (1991b) that the deepening of the entrance channel to Tauranga Harbour has negatively influenced littoral processes to the east of Matakana Island and has limited natural nourishment of the downdrift beaches.

Analysis of EBP's for each of the seven shore-normal beach and bathymetric profiles showed that overall pre-disposal beach profiles exhibited an apparent deficit of material in the surf zone out to a depth of 10 m, beyond which an excess of sediment became apparent. The excess of sediment in this area is believed to be the result of the relative closeness of the beach to the ebb-tidal delta system of Tauranga Harbour (FOSTER, 1991). Post-disposal profiles showed similar trends, but were closer to equilibrium than previously.

Figure 8 shows a representative series of equilibrium profiles for survey Site 5 located midway along Mt. Maunganui Beach (Figure 2), and extending offshore through the middle of the dump ground. They illustrate that before renourish-

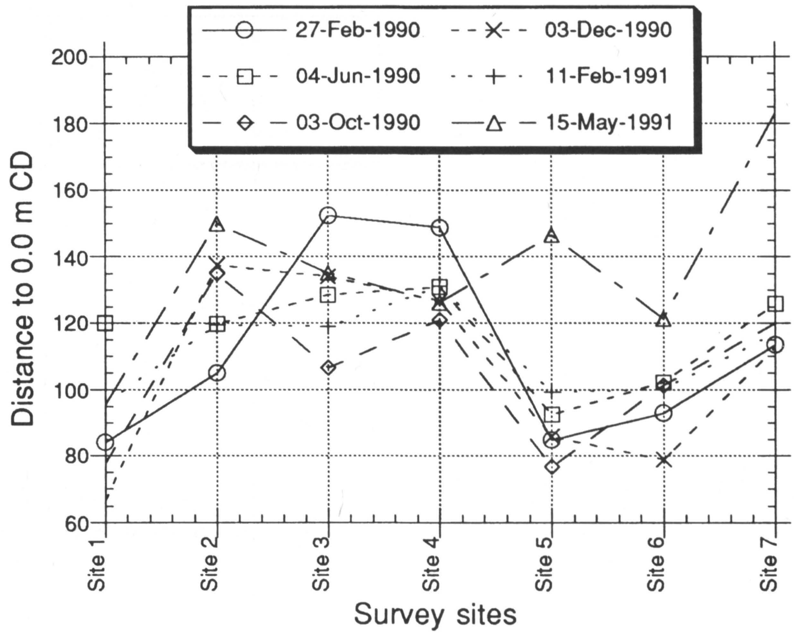

Figure 7. Excursion distance from profile bench mark to Chart Datum (approximately MLWS) for surveys conducted over the period of February 1990 to May 1991.

ment the profile exhibited an apparent deficit of sediment near the beach, trending towards an excess of sediment seaward of the dump ground (> 800 m). Immediately after renourishment in December 1990, the profile was influenced by the spoil mound and displayed an apparent adjustment of the profile towards equilibrium.

DISCUSSION

Numerous international examples abound in the literature of the analysis of beach sediment budgets and volumes, including the results of major research programs, such as: DUCK85 (MASON *et al.*, 1991); NSTS (SEYMOUR, 1991; HOWD and BIRKEMEIER, 1991); and C^2S^2 (FORBES, 1991). These include the comprehensive calculation of both the onshore-offshore and longshore components of sediment budgets as part of overall studies into coastal processes. Further examples include VAN VESSEM and STOLK (1990) who calculated a sand budget for the entire Dutch coastline; REYNOLDS (1987) who calculated sediment budgets for Marco Island, Florida, as an aid to coastal planning and development; SIMPSON *et al.* (1989) from Oceanside, California, who used sediment budget results as part of the calibration of a numerical shoreline change model; and LU *et al.* (1991) whose results from southern California, U.S.A., are used as part of an overall coastal management and planning effort.

These examples illustrate a wide variety of uses to which sediment budgets can be put; however, most are restricted to the mean sea-level or just below low water mark. This is particularly true of previous studies in New Zealand (HUME *et al.*, 1992). The study at Mount Maunganui provides a modern set of detailed information about beach profiles and volumes that encompass the beach-nearshore zone to closure depth.

The sand budget calculated for Mount Maunganui beach was to determine the volume change of the study area before and after the nourishment of the nearshore profile by split hopper dredge. The sediment budget calculated here also supports the use of equilibrium beach profile models for determining equilibrium or sediment deficit/excesses occurring at Mount Maunganui.

The data collected also gave an indication of seasonal beach changes. The wave climate in the Bay of Plenty exhibits a weak seasonality (HUME

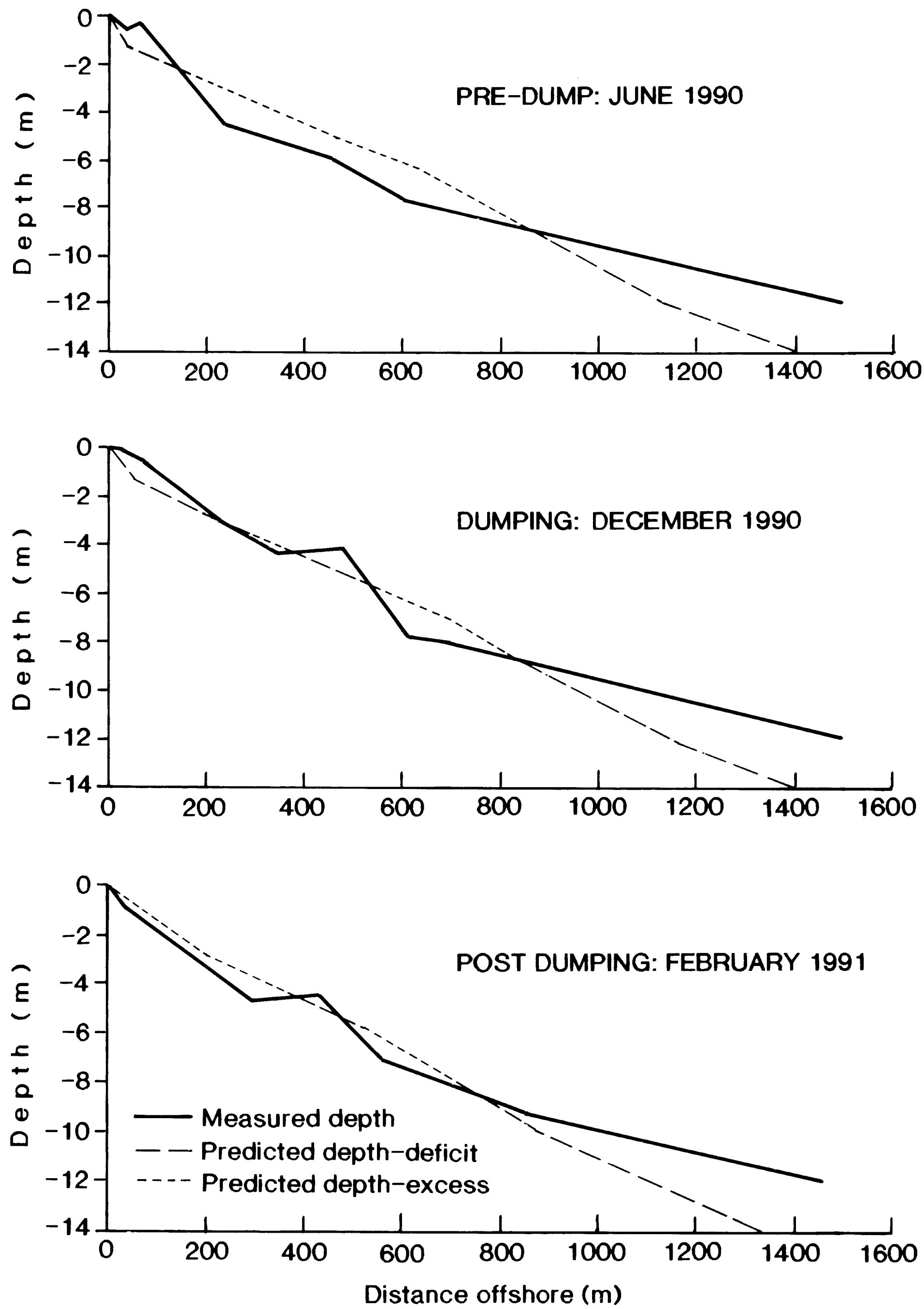

Figure 8. Illustration of the results of the Dean EBP analysis from the study of FOSTER (1991) for representative survey Site 5. The figures depict a change in equilibrium of the profiles from: (a) June 1990, six months prior to dumping; (b) immediate post-dumping profile measurements made in December 1990; and (c) in February 1991, two months after dumping.

et al., 1992). At Mount Maunganui, autumn profiles (February to June 1990 and February to May 1991) generally exhibited minor erosion of the profile; winter profiles (June to October 1990) displayed major erosion of the beach face and swash zones; while spring and summer profiles (October to December 1990, December 1990 to February 1991) exhibited accretion from both renourishment and development of a classic summer profile. No major storms occurred during the period of the study and this may influence the scale of the results.

CONCLUSIONS

A number of conclusions may be draw from this study:

(1) The nearshore dredge spoil dumping program conducted by the Port of Tauranga during November 1990 to January 1991 contributed substantially to the volume of material contained within the beach and nearshore profiles of Mt. Maunganui Beach. All nourishment material could be accounted for within the nearshore and beach system. It is likely that the adjacent Moturiki Island acts as a natural groyne to prevent the active transport of material alongshore to the southeast, in the direction of natural littoral drift along this coast.

(2) Monitoring of the nearshore dredge spoil dump demonstrated that most of the 80,000 m^3 of material added to the nearshore profile moved ashore to renourish the beach face and swash zone along the 700 m long beach.

(3) Between February 1990 and May 1991, a total volume of 93,600 m^3 of sediment was added to the total beach system, including 80,000 m^3 by nourishment. This equates to 89 $m^3\ m^{-1}$ of material added to the beach.

(4) Application of the Dean's Equilibrium Beach Profile model before, during and after renourishment indicated that before disposal the beach tended to have a sediment deficit, and that after nourishment the profiles adjusted towards the equilibrium profile predicted by the model.

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