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The Application of Equilibrium Beach Profile Theory to Coastal Hazard Identification in the Bay of Plenty

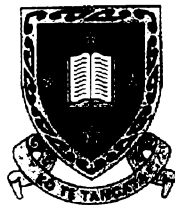
A thesis submitted in fulfilment of the requirements for the
Degree of

Doctor of Philosophy

In Earth Sciences
(Coastal Marine Group)

by

Vernon Ian Pickett



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Abstract

The Bay of Plenty (BoP) is situated on the north-eastern coast of New Zealand. It is low wave energy sand rich environment that is susceptible to the effects of intense mid latitude depressions and ex tropical cyclones. These can produce strong winds and onshore directed swells that are frequently associated with episodes of significant beach erosion. Such conditions are often exacerbated during the La Nina phase of the El Nino Southern Oscillation (ENSO).

The beaches in the BoP monitoring data set (48 sites) have been classified in this research using Dean's parameter to determine beach states according to the classification system of Wright and Short. Principally the beaches can be described from this analysis as Intermediate beaches with occasional Dissipative beach types, for example those located in the lee of headlands as at West End Ohope, and Reflective beach types, as for example those on the steeper opencoast beaches at Otamarakau.

Intermediate beaches consist modally of Longshore Bar and Trough morphologies (LBT) with strong representations from the other more dynamic and responsive intermediate beach types including the Low Tide Terrace (LTT), Transverse Bar and Rip (TBR) and Rhythmic Bar and Beach (RBB). The analysis confirmed that considerable beach state variability (involving up to $+56$ to $-60 \text{ m}^3\text{m}^{-1}$) can be expected from these beach types over relatively short time frames of days to months. The indications are that the Dean beach equilibrium model (1977) fitted the more dynamic intermediate beaches better than beaches located at the extremes of the Wright and Short (1983) spectrum.

The equilibrium beach profile (EBP) models and their derivations have been described prior to applying the Dean (1977) and Dean *et al.* (1993) two dimensional parametric models to the 48 profiles in the BoP dataset. The purpose of this assessment was to determine the equilibrium beach status of profiles for potential use in defining coastal hazard zones in the BoP. Both models require the definition of boundary conditions, the onshore limit being defined by mean sea level, while the offshore limit was defined by closure depth. This was determined from review of the geomorphic evidence, repeat profile analysis and calculation using wave data and the Hallermeier formulae (19878, 1981a).

The two EBP models were fitted by least squares regression (LSR) analysis to all beach profiles in the BoP dataset. In carrying this out both scale and shape factors were allowed freedom to vary so as to minimise the residual errors in the assessments. The results from this allowed statistical analyses to be carried out on both parameters to determine their most probable values. This confirmed the appropriateness of Dean's (1977) value of $\frac{2}{3}$ for the shape factor (or exponent) based on linear wave theory and uniform wave energy dissipation per unit volume.

The LSR analysis was repeated holding the shape factor at $\frac{2}{3}$ while allowing the scale factor (A) to change. The results from this analysis were then compared to the mean sediment data obtained from the profile monitoring database. This confirmed Dean's relationship between sediment fall velocity (grain diameter) and the regression derived scale factor values based on a log-log transformation.

Dean's 1977 and 1991 equilibrium profile models were then applied to the BoP profile dataset to determine each profile's equilibrium status representing the beach's potential to either erode or accrete. This potentially forms the first element of inputs to any coastal hazard zone determination because it affects spatially the location of mean sea level as a baseline from which to measure erosion limits. This analysis was carried out using three different closure depths and the two models with or without piecewise variation of the scale factor. The best overall fit using LSR analysis confirmed the appropriateness of the Dean (1977) model with profile averaged scale factor derived from the related sediment sampling.

As part of this work the Wang and Davis three sector profile model was also examined and applied to the BoP dataset. This model potentially better describes the nearshore 2-dimensional beach morphology because it incorporates the offshore bar so typical of Intermediate beaches in the BoP. However when scale and shape factors were held according to the data obtained from the earlier LSR analysis, the model fails to replicate the success achieved by its authors using Florida data.

Sea Level Rise (SLR) forms a second component of any coastal hazard analysis. The derivation of the Bruun Rule was examined from a variety of theoretical perspectives and was confirmed using equilibrium beach profile theory. As a consequence the Bruun Rule was applied within an equilibrium model using a MATLAB routine to predict likely profile shifts for the 'business as usual' climate change scenario of the IPPCC. Large Scale Coastal Behaviour (LSCB) theory (Cowell *et al.*, 2003; Stive, 2004) was then applied to four different locations to ascertain the potential counter effects of sedimentation utilising coastal sediment budgets and progradation rates.

Storm erosion presents a third coastal hazard component predictable using EBP theory. The model chosen for this was EDUNE (Kriebel, 1989), a two dimensional parametric model based around the concepts described in Kriebel and Dean (1985) and Kriebel (1989). A design storm was developed from regional climate and weather information and applied to all profiles in the dataset to determine erosion limits. This was then applied cumulatively with the other two erosion drivers (profile disequilibrium and SLR) as shown to predict a suitable coastal setback line (or coastal hazard zone) from mean sea level as a protection measure for development occurring along this sandy coastline.

Acknowledgements

The work for this thesis has taken place over a period long enough to see my children grow up into teenagers, and it is to them and to my long suffering wife Christine that I owe a great debt of gratitude for their forbearance, their patience, and their support. Words cannot adequately express my gratitude to them.

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Chapter 1

Introduction



Source: National Library, Erosion Paraparaumu Beach, 1948

1.1 The Need for Coastal Hazard Analysis

Human settlement immediately adjacent to the coast is often fraught with difficulties and problems. Cliffs are undercut and eroded, beach sediments constantly move around under the forcing action of wind, waves, and currents, and low lying areas can suffer inundation from storm surge and tsunami, all of which have the potential to cause severe property damage (see Figure 1.1) and in some cases loss of life.

Hazardous phenomena such as these may be random, seasonal, and sometimes episodic, but when they do occur at their extreme, the effects can be dramatic. Despite all these risks there seems to be an irrepressible desire, and indeed a need for many communities to be located on the coast, frequently for a host of historic, economic, political, aesthetic, and practical reasons. Consequently the hazards represented by these events have to be managed to minimise and hopefully avoid the risk in order for these communities to be sustainable.

A typical response to minimise hazard risk is for communities to build coastal protection works. This type of response often includes the construction of so called 'hard structures' such as sea walls, revetments,

groynes, and artificial reefs and headlands. In recent decades beach renourishment has been added to the arsenal of responses, in particular where the loss of sandy beaches threatens more affluent communities such as those located along the US East Coast (NRC, 1999). Whatever response is taken all can involve the investment of substantial amounts of capital over time to cover both establishment and ongoing maintenance costs.



Figure 1.1: Coastal Erosion at Ohiwa, 1976 (Healy, T.R.)

However it is questionable whether these responses are sustainable in the long term. Even so many communities see such answers as the only solution, often because of the high level of investment committed to development along the coast.

1.2 An Alternative Coastal Management Approach

An alternative response is to develop coastal management strategies that limit or restrict development namely through the establishment of coastal hazard zones (CHZ) or development setback lines. The effect of this approach is to either prevent development occurring at 'greenfield' sites in the first instance, or alternatively to act as a mechanism to restrict further development where existing urban development is under threat from the sea.

A particular example of this management strategy adopted in New Zealand for sandy beaches is characterised by Gibb (1981) and Healy (1980, 1993, 1999, 2002). The semi quantitative model to calculate a coastal hazard zone (CHZ) typically takes the form of:

$$CHZ = R + 2S_{\max} + X + D \quad (\text{Healy, 1993})$$

where,

- R is the long term shoreline erosion or accretion rate;

- $S_{\max}$ is the maximum decadal duneline fluctuation as a result of storm cut observed over the past 50 years as a result of sea level rise;
- D is the dune stability factor; and
- X is the duneline retreat anticipated as a consequence of sea level rise.

An alternative is to use numerical modelling to forecast beach responses to changing or extreme environmental conditions. This may be achieved either by employing a three-dimensional hydrodynamic model such as 3DD (Black, 1995), or alternatively by using two-dimensional empirically based parametric models that incorporate a sediment transport and morphologic change component. Models such as EDUNE (Kriebel, 1989) and SBEACH (Larson and Kraus, 1989) are examples of the latter representing particular model developments utilising equilibrium beach profile theory (Bruun 1954, Dean 1977, Kriebel and Dean 1985, and Bodge 1992). In this model beach morphologic change under varying storm conditions can be predicted to enable the potential for coastal hazard risk impact to be identified.

Chiu and Dean (1984) document a particular methodology developed for use in Florida to define the State's Coastal Construction Control Line (CCCL). The methodology employs a development of the Dean parametric equilibrium model to predict beach responses to storm conditions (Kriebel, 1982, 1989) utilising storm surge and wave input data provided via numerical finite difference models. This approach is used to define the "*...zone of impact of a one hundred year storm event along the sandy outer coastline ...of the State of Florida*" (Chiu and Dean, 1984). The program developed to achieve this objective applies seaward of the CCCL with a twofold purpose being to ensure:

- the protection of the adjacent shoreline; and
- the integrity of structures.

The basis of this approach incorporating concepts of Equilibrium Beach Profile (EBP) theory is the subject of the research documented in this thesis, the utility of which will be examined further as the basis for predicting coastal hazard impacts.

1.3 The Equilibrium Beach Profile Concept

The EBP concept suggests that a beach of specific mean grain size, if exposed to constant forcing conditions, normally assumed to be short-period breaking waves, will develop a profile shape which exhibits no net change over time (Larson, 1991). From the findings of five major studies Larson suggests that the validity of this concept has been verified through a large number of wave tank experiments on beach profile change.

The basic EBP profile is represented by Bruun (1954) and Dean's (1977) formula described in the following equation,

$$y = Ax^{2/3} \quad (1.1)$$

where x represents the offshore distance measured from Mean Sea Level, y is water depth and A is the scale factor which has been related to grain size (Dean 1977, Moore 1982, Dean 1987) and the exponent of $2/3$ defines the profile shape based on uniform energy dissipation per unit volume of water in the surf zone.

1.4 Thesis Aim

The overall aim of this research is to apply two-dimensional parametric modelling utilising EBP theory to coastal hazard assessment using profile and sediment data obtained from the Bay of Plenty coast (see Chapter 2), New Zealand, and to test its validity in providing alternative inputs to those used in the semi quantitative techniques (Healy 1980, Gibb, 1981, Healy and Dean 1999, Healy 2002) described earlier in this chapter, and widely applied in a New Zealand context. Underlying this are three broad scale objectives:

- 1) Investigation of a number of Bay of Plenty beaches to determine how well the EBP concept characterises these sandy beaches. This analysis will take into account the effects of sediment variation occurring within the beach profiles, and will use this information to predict the equilibrium status of these beaches and their potential to erode or accrete. In carrying out this work the following specific analyses will be undertaken:
 - determination of representative values of the scale parameter, A , and the shape parameter, m , for the measured beach profile using least square analysis;
 - evaluation of the relationship between the A parameter and sediment grain sizes and fall velocities in order to compare these with the established relationships for grain size (Moore, 1982) and fall velocity (Dean, 1987); and
 - ascertaining the influence of additional terms or alternative forms of the EBP equation to represent realistic shoreline slopes, cross-shore grain size variation and shoreline response characteristics.
- 2) Application of the EBP concept to an appropriate sea level rise scenario to predict long-term (50 to 100 year) beach responses to eustatic sea level change by applying a variation of the basic Dean/Bruun model to the profiles contained in the Bay of Plenty dataset.

- 3) Application of EBP to the prediction of short-term coastline responses to changes in relevant forcing conditions including tides, storm surge and wave climate. This has involved the development of various design storm scenarios for use as input into the Kriebel (1989) model EDUNE to forecast short term responses to various design storm events.

The combination of these sets of analyses will then provide input into the determination of appropriate CHZ models as an alternative to the Healy/Gibb approach discussed previously.

1.5 Structure of Study

In order to achieve the specific objectives, the study is structured as follows:

Chapter 2 describes relevant aspects of the Bay of Plenty coastal environment as background for the study. This includes a description of the geological-geotectonic setting, historic evidence of eustatic sea level changes, beach morphodynamics, sediment characteristics, and wave climate and in particular storm wave characteristics.

Chapter 3 discusses the theoretical concepts involved in the research and provides a review of relevant research and literature related to the concept of the Equilibrium Beach Profile and the varying forms applicable to beach modelling.

Chapter 4 describes the application of the EBP models to beaches in the Bay of Plenty, involving:

- determination of closure depth as a boundary condition for use in model analysis of the beach profiles;
- least square analysis to determine both fit and appropriate parametric values for modelling the equilibrium status of the beaches;
- determination of beach equilibrium status using various EBP forms; and
- implications of equilibrium beach state for forecasting coastal erosion potential in the Bay of Plenty.

Chapter 5 considers various relative sea level rise scenarios provided by the Intergovernmental Panel on Climate Change (IPCC) research and local relative sea level data for application in the Dean EBP model. The model is then applied to analyse the BOP dataset to establish likely beach responses and risk of coastal erosion and inundation over the next 100 years.

Chapter 6 considers the application of the Kriebel-Dean (1985) model (E-Dune) to the BOP beaches as a means of determining beach profile

response to significant storm events. This work is then utilised to determine the hazard risk implications for the study area.

Chapter 7 draws together the findings of the research and outlines the implications of the modeling results for determining CHZs and its potential application to the Bay of Plenty and other north eastern New Zealand beaches.

Chapter 2

The Bay of Plenty - Coastal Setting

2.1 Introduction

The Bay of Plenty (BOP) is situated on the northeastern coast of New Zealand (Figure 2.1). Its general aspect lies towards the north-northeast and as such it is generally protected from the sequences of anticyclones, low pressure systems and fronts that regularly cross the country from the south and west (Healy *et al.*, 1977). However the beaches of the BOP are susceptible to the effects of intense mid latitude depressions and extra-tropical cyclones that can produce strong winds and onshore directed swells that are often exacerbated during the La Nina phase of the El Nino Southern Oscillation (ENSO). These conditions are frequently associated with episodes of beach erosion along this coastal margin (Healy *et al.*, 1977; de Lange, 2000; de Lange and Gibb, 2000).



Figure 2.1: Bay of Plenty, North Island, N.Z (Source: Microsoft, 1997)

Healy *et al.* (1977) have described the Bay of Plenty coast as consisting of a long curving sandy barrier coastline occasionally broken by sandy inlets, lagoonal estuaries, and isolated rocky promontories (see Figure 2.2). More specifically the barrier morphology is formed mainly from Holocene sand deposits and includes tombolos, barrier spits and islands, and dune ridge sequences.

Much of the sands forming these features are derived from erosion of the acid volcanics of the adjacent Taupo Volcanic Zone (TVZ) that have been transported to and across the shelf at times of lower Pleistocene sea level. These have been subsequently reworked during the Holocene sea level rise and transgression and brought to shore under the action of waves and currents (Harray and Healy, 1978).

The term barrier has been defined by Thom *et al.* (1978) as “...bodies of detrital sediment, which rise above present sea level and block off or impound drainage from the hinterland. Typically they are described as elongate sand bodies parallel to the shore, and separated from the “mainland” in whole or in part by an estuary or lagoon, swamp or marsh, or sand or mud flat.”

Four main barrier types have been recognised (Thom *et al.*, 1978), these being prograded, stationary, receded or episodic transgressive. Prograded barriers are associated with abundant sediment supply, closely linked to large hinterland areas, but are also fostered by shallow shelf gradients and consequent wave energy reduction. Sand accumulation for the development of the dune system takes place at the beachface and is blown inland to form low relief foredune ridges typical of many Bay of Plenty beaches.

Stationary barriers on the other hand are held to be characterised by high dune ridge complexes often exceeding ten metres in height, but comprised of relatively few dune ridges. Often the dune ridges have a ‘hummocky’ appearance induced by dune blowouts and transgressive sand movement.

Receded or transgressive barriers are commonly associated with eroding shorelines and are normally characterised by estuarine, lagoonal and backbarrier sediments cropping out at the present shoreline (Thom *et al.*, 1981). Such barriers are often associated with rising sea levels or a shore-zone deficiency in sand relative to wave energy conditions.

Barrier deposits in the Bay of Plenty have characteristically developed either as prograded features as in the case of the Rangitaikei and Papamoa Plains or are currently stationary features such as at Opape where general foredune development is singular and well developed.

Three main factors have been considered responsible for the evolution of the current coastline. These are (Healy *et al.*, 1977):

- *tectonic warping* which influenced the formation of the basins presently occupied by Tauranga, Maketu, and Ohiwa harbours (Healy *et al.*, 1977; Shaw and Healy, 1962);
- *glacio-eustatic sea level fluctuations* that occurred throughout the Pleistocene and Holocene. This resulted in streams and rivers dissecting the coastal hinterland and terraces as incised valley systems, eroding up to a base level during the Pleistocene some 100 - 150m lower than present. Subsequently these valleys have infilled with sediment and new terraces formed following the most recent (Holocene) marine transgression (Davies-Colley, 1976). This process is ongoing to the present day.
- *rapid sedimentation* that occurred following sea level rise, which reached its current approximate level about 6,000 years ago. The present day coastal geomorphology is dominated by formations derived from Holocene sands of predominantly rhyolitic origin. It is believed that these sands were swept onshore in response to the sea level rise resulting in a rapid progradation of the shoreline (Harray and Healy, 1978). Progradation is extensive in some locations with over 9 km being recorded at Whakatane (Pullar and Selby, 1971)

2.2 Geological Description of the Coastal Bay of Plenty

The BOP is a microtidal embayment formed from a complex sequence of sedimentary and volcanic deposits. The region's geo-tectonic setting at the northeastern end of the Taupo Volcanic Zone has influenced the morphology of these deposits.

Current topographical forms of the coastal BOP have their origin in the middle to late Pleistocene. At this time a series of basins were formed by surface downwarping (Phizacklea, 1993) to create the Opotiki, Maketu, and Tauranga Basins (see Figure 2.3) and the inclined coastal terraces typical of the region. The basins have subsequently been infilled with terrestrial and estuarine volcanoclastic sediments (principally pumiceous) and non-welded and partially welded distal ignimbrites to influence the coastline that now characterises the Bay of Plenty and its harbours. Eustatic-tectonic changes in sea level during the Holocene transgression have subsequently modified the coastal form through erosion, sediment transport and deposition.

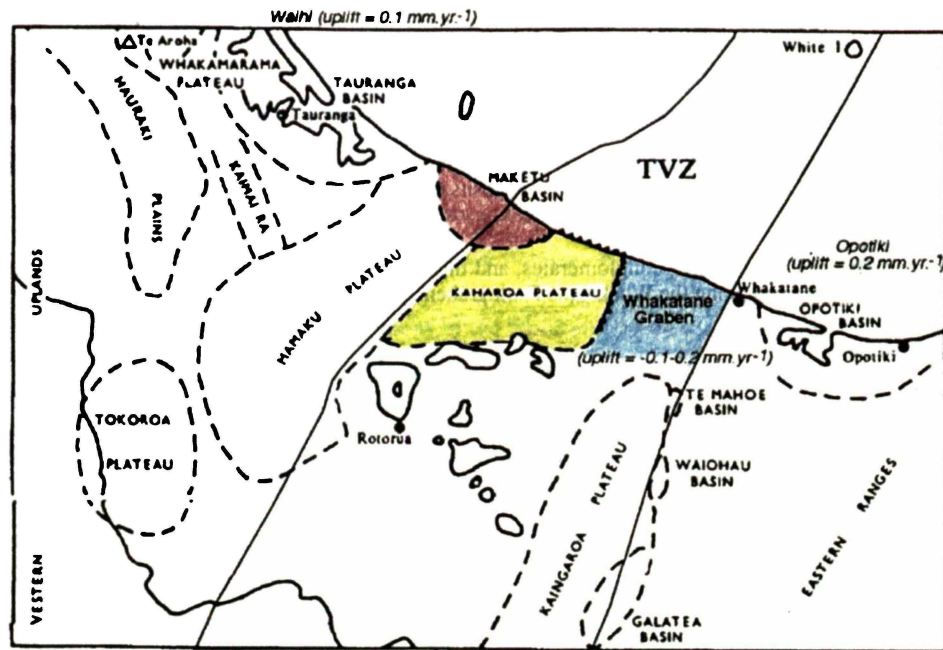


Figure 2.3: General Structural Characteristics of the Bay of Plenty (Source: Phizacklea, 1993)

Whakatane-Opoitiki

At Whakatane the Whakatane Graben and its associated faulting dominate the terrain. This structure formed following massive eruptions from the TVZ during the Pleistocene, with the last major eruption being that of the Matahina Ignimbrites (late quaternary) from the vicinity of Tarawera in the Okataina Volcanic Center (OVC) (Healy, 1967). This huge flow of hot pumice ash flooded eastward from the OVC across the Kaingaroa Plateau towards Galatea and down towards the sea. Ash flows continued from the centre but none were so large as the Matahina flow and have mostly remained unwelded.



Figure 2.4: Matata Coastal cliffs looking southeastward from Pikowai. Rotoiti Breccia deposits (Phizacklea, 1993) visible in the upper cliff face.

These later pumice flows cover a fan shaped sector from Te Puke to Kawerau that in some places is up to 150m thick. Collectively these deposits are known as the Rotoiti Breccias. Exposure of these breccias and the Matahina Ignimbrite occurs in the sea-cliffs between Matata and Otamarakau (see Figures 2.4 & 2.5).

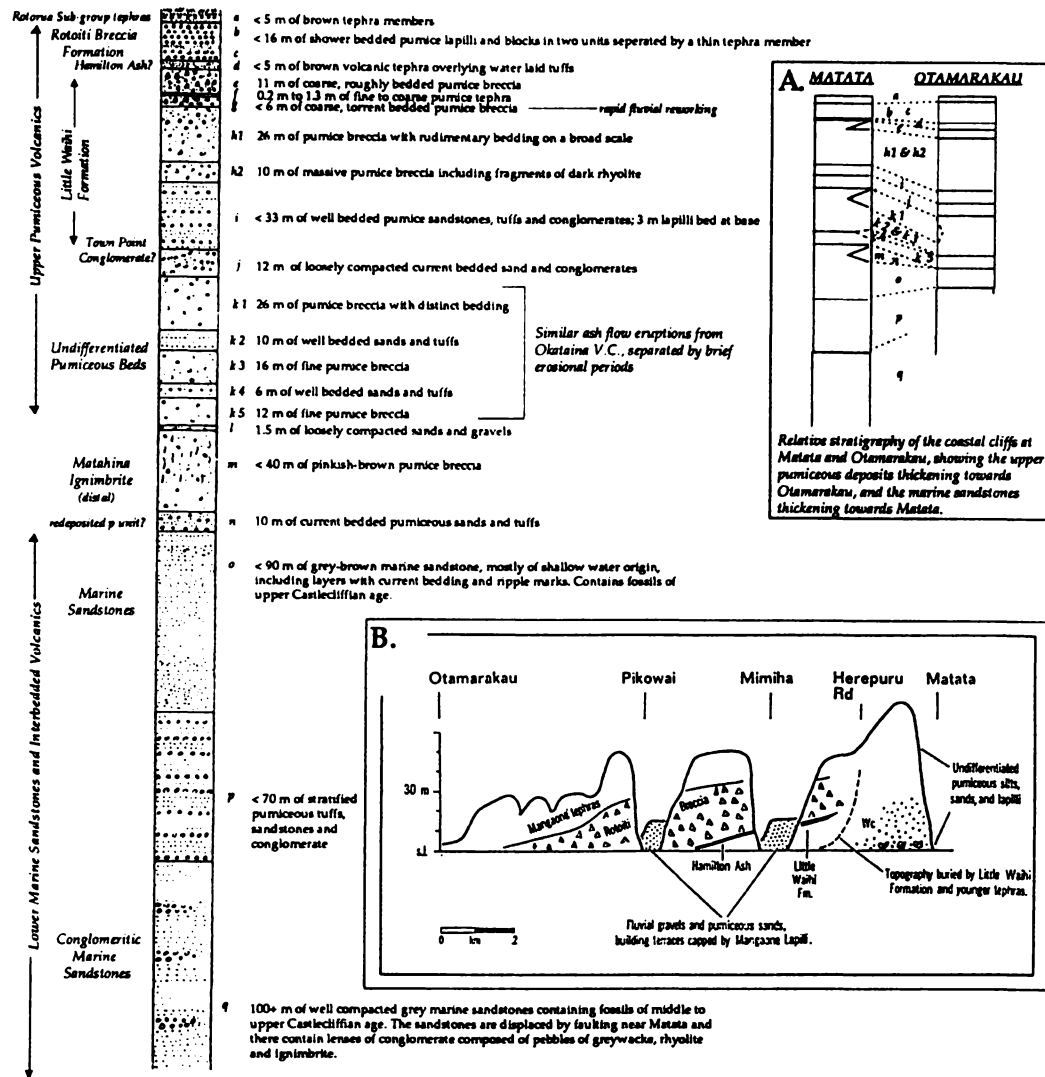


Figure 2.5: Generalised section of the Geology exposed along the Matata-Otamarakau coast. Inset A) schematic representation of the relative stratigraphy showing the differences in strata thickness between Matata and Otamarakau, and B) sketch of the coastal cliff exposures (Source: Phizacklea, 1993 modified from Healy and Ewart, 1965 and Chappel 1975).

East of the Whakatane Graben, basement Mesozoic greywacke is visible in the headland and sea cliffs between Whakatane River mouth and Ohope Beach. The geology of the Whakatane area is shown in Figure 2.8 (Healy, 1967). The greywacke is overlain by marine sandstones laid down in the mid-Quaternary (Castlecliffian - approximately 500,000 to 1,000,000 years b.p.). Eastward of Ohope and inland from the coast, the geology is dominated by the Jurassic-Lower Cretaceous flysch deposits of marine

sandstones, argillites, conglomerates and massive green volcanic sandstones of the Urewera greywacke (Healy *et al.*, 1964).

Closer to the coast the greywacke again is overlain by mid-Quaternary marine sandstones, conglomerates and fluviatile silts sands and gravels. This section of the Bay of Plenty is located within the North Island Shear Belt which is a zone of slip-strike faults that extends through the North Island to the Bay of Plenty to intersect the Whakatane Graben and the Taupo Volcanic Zone between Te Teko and Opotiki. The Whakatane, Waimana and Waioeka Rivers flow through this faulted zone following the north striking faultlines towards the coast. It can be expected that such geological influences will affect the nature and mineralogy of the sediment supply to the coast eastward of Ohope Beach.



Figure 2.6: Rangitaiki Plains (progradational) looking eastward over the Rangitaiki River Mouth towards the Whakatane headland. Cuspate foreland evident in the lee of Motuhora Island (to left of photograph).



Figure 2.7: Whakatane Headland with Piripai beach and Whakatane spit and River mouth in the foreground.

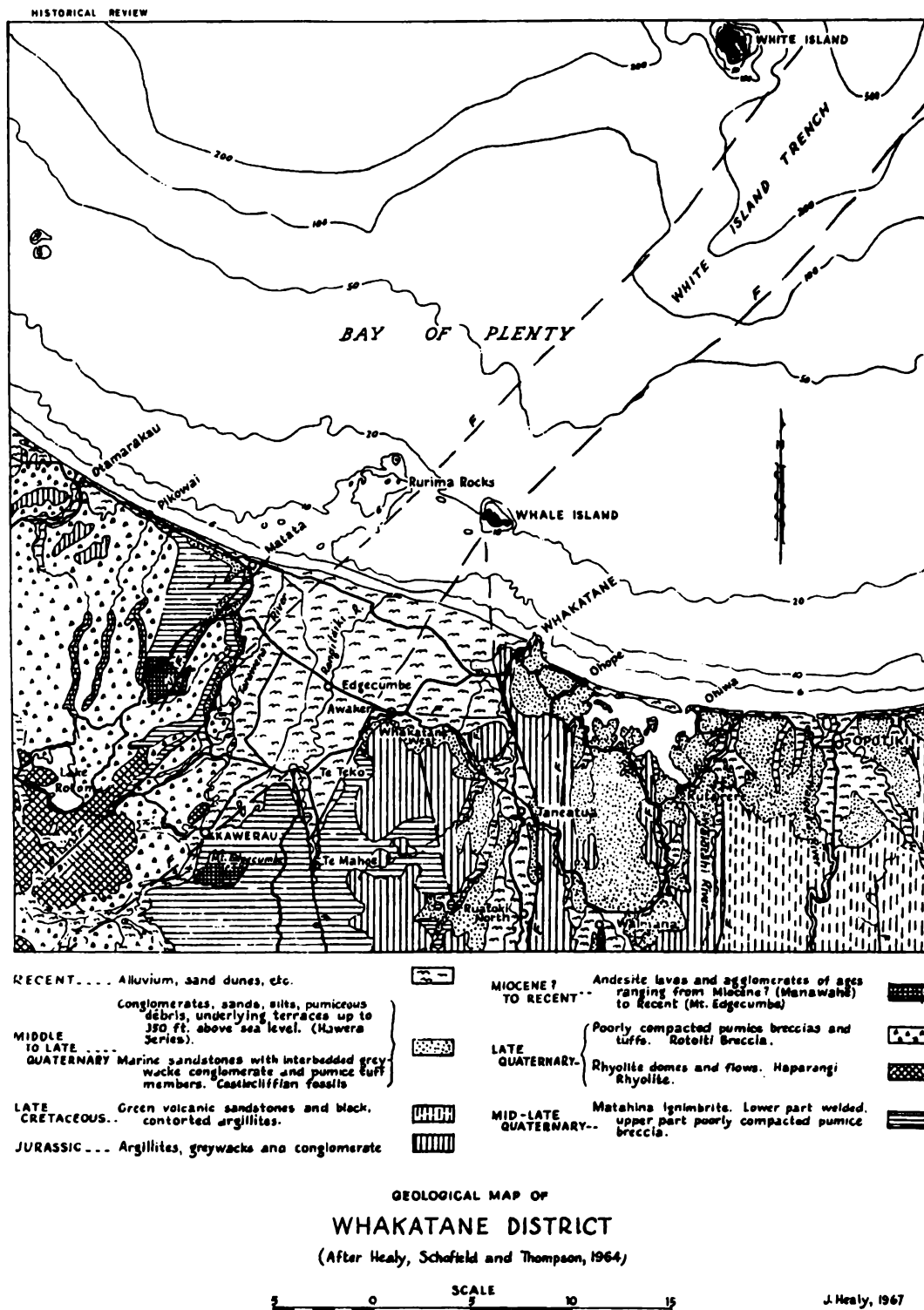


Figure 2.8: Geological Map of the Whakatane District (Source: Healy, 1967).

Major subsidence in the OVC either accompanied or followed the eruption of the Matahina Ignimbrites (Healy, 1967) forming a large caldera. The Rotorua basin appears to have drained into this caldera and from there into the Whakatane Graben to the sea. Since then the eruption of the large rhyolitic volcanoes of Haroharo and Tarawera have infilled much of this basin leaving various impounded lakes such as Tarawera, Rotoma and

Rotoiti. Lake Tarawera formed its outlet via the Tarawera River which drains into the Whakatane Graben and from there to the BOP coast, while Lakes Rotoiti and Rotorua drained to the north via the Kaituna River. Both these rivers and the ancestral Rangitaiki and Whakatane Rivers have been responsible for the transportation and deposition of significant volumes of both Okataina and Taupo sourced volcanic material into the coastal system between Papamoa and Whakatane thus contributing to significant long term coastal progradation in these areas.

According to Healy (1967) the last big downward movement in the Whakatane Graben was not merely the result of a collapse of the floor of the graben. There is evidence that the high block on the west has been tilted upwards right out to White Island, as indicated by the bathymetry, with White Island resting on a submarine ridge known as the Rurima Ridge (Shaw and Healy, 1962; Wright, 1989). Much of this ridge has been subsequently removed by sea erosion leaving the high cliffs west of Matata (a source of sediment for the beach systems in this locality) and a shallow sea extending out to the Rurima Rocks as its sole remnant. This ridge appears to demarcate the upthrown western margin of the Whakatane Graben (Nairn and Beanland, 1989) while the Motuhora Scarp and the eastern arm of the White Island Trench define its eastern boundary.

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Uplift at the margins of the graben is demonstrated by the presence of the Quaternary marine sediments (Castlecliffian) at considerable elevations (+300 m) above present day sea level on the western margin between Manawahe and Matata, and interglacial sediments on the eastern margin at Whakatane at elevations of 60 m. This indicates uplift rates of between 0.9 and 1.7 mm/year as a minimum (Nairn and Beanland, 1989) for the western margin compared to 0.5 mm/year for the eastern margin, while secular rates of subsidence within the graben based on shallow stratigraphic analysis are 2-3 mm/year (Pullar, 1983). When both subsidence and uplift are combined for the western margin of the graben then the total displacement over the last 0.3 Ma is 1.9 mm/year (Nairn and Beanland, 1989). This uplift helps to explain the sediment deposition occurring at the foot of the cliffs west of Maketu through to Otamarakau.

The Whakatane River is the largest river in the Whakatane-Ohope Beach region. Healy *et al.* (1977) describe the morphology of its mouth as a spit lagoon backed by a small dynamic estuary. The Whakatane Spit that bounds the estuary to the north is approximately 800m long. The basal end contains remnant ridges of Holocene parabolic dunes while the distal end is flat and shows signs of having been overtopped by waves during storm events (Healy, 1983; Saunders, 1999). Several authors have noted that the spit orientation towards the east with the Whakatane River mouth forced against Kohi Point, reflects the dominant littoral drift direction of the area (Healy, 1978, 1980, 1983; Gibb 1994; Hodges and Deely 1997).

The Matata-Kohi Point beach system of the Whakatane Graben (which includes Piripai Beach) is an accretionary feature that continues to advance seaward due to the surplus of material fed into the littoral system by the Rangitaiki and Tarawera Rivers despite the long term subsidence occurring within the graben. Saunders (1999) notes that Piripai beach exhibits a healthy berm and the presence of nearshore bars. The beach profiles tend to be steeper than the beaches located further to the east and the sand is coarser reflecting a more recent and direct volcanic source (Saunders, 1999).

To the east Ohope Beach forms a curvilinear feature with a general northeast aspect. The beach tends to be wide and flat at its western end with a distinct absence of dunes and berms fitting the morphodynamic characteristics of an eroded dissipative beach (Wright and Short, 1984). The beach tends to steepen further towards the east developing barred or multiple barred profile characteristics (Healy, 1978; Saunders, 1999).

Ohope Spit is a 6km long spit that forms the western extension of Ohope Beach. This spit partially encloses Ohiwa Harbour, a 24 km² barrier enclosed lagoon (Richmond, Nelson and Healy, 1984). The spit is formed from a series of well-vegetated transverse parabolic dunes that curve towards the harbour at their distal end (Saunders 1999). A much smaller spit (Ohiwa Spit) forms the harbours' eastern enclosure (Figure 2.9).



Figure 2.9: Photo looking East from the distal end of the Ohope Spit towards Ohiwa. Ohiwa Harbour and Spit to right and centre.

Ohiwa Spit has experienced periods of severe erosion over the last 100-150 years (Gibb, 1977, Saunders 1999). Hodges and Deeley (1997) determined that historical shifts in the position of Ohope Spit have generally been accompanied by migration of Ohiwa Spit, with recent erosion of Ohope Spit being reflected in progradation of the spit at Ohiwa.

Between Opape and Ohiwa the beaches consist of a mixture of barrier spits, coastal plains and narrow beaches abutting against steep cliffs (Healy *et al*, 1977). They noted that the beaches in this section of the coast were different from the rest of the Bay of Plenty study area in that they had a lower berm face angle and a broader profile width of 80 to 100m.

Further to the west Phizacklea (1993) identified three basic physiographic units along the 34km coastline between Maketu and the Tarawera River. The first of these units is Town Point, Maketu, a rock-strewn promontory bounded to the east and west by the Waihi and Maketu Estuaries. To the southeast of Town Point, Pukehina Beach encloses the Waihi Estuary. The beach is a narrow barrier spit (Phizacklea, 1993) consisting of late Holocene volcanic sands (Healy *et al*, 1977) the morphology of which has been significantly modified by residential subdivision. It is also susceptible to erosion and this poses a potential threat to some of the housing development that has encroached onto the foredune.

The coast east of Pukehina consists of a narrow sandy strip backed by cliffs cut into Pleistocene terraces composed predominantly of poorly compacted Rotoiti Breccia (Healy *et al*, 1964), Matahina Ignimbrite and marine sandstones in the Matata area (Phizacklea, 1993). Between Pukehina Redoubt and Otamarakau, there is limited frontal dune development, and the cliff is actively eroding in parts. Observations suggest that the beaches fronting the cliffs in this sector are merely a veneer and are cut down to a shore platform during major storm events (Healy *pers com.*). The removal of beach sands by diabathic exchange during storms will expose the cliffs to further erosion thus contributing additional sediment to the littoral system. In contrast the beach between Otamarakau and Matata features a broad dune ridge that separates the beach from the cliffs behind. Several small streams and rivers dissect this ridge and small lagoons and coastal swamps characterise the area.

The 18 km of coastline from the Tarawera River mouth to the Waitahanui Stream at Otamarakau is dissected by six major streams. In the south of this section where development is minimal the dune system is largely intact (Phizacklea, 1993). Phizacklea notes that sand mining around the Matata lagoon prior to 1986 caused moderate dune modification while closer to Otamarakau the dune system is healthy and well vegetated. The area has been subject to investigation by NIWA as part of baseline studies to determine coastal erosion/accretion (Phizacklea, 1993).

Maketu -Tauranga

In the Maketu-Tauranga area (i.e. within the Tauranga Basin) the geology is dominated by the presence of Pleistocene pyroclastic flow deposits, volcanoclastic and volcanogenic (reworked fluvial and lacustrine deposits) material and airfall ashes which underlie the gently sloping

terraces that surround the Tauranga Harbour. This volcanic material is predominantly rhyolitic including rhyolitic lavas, ignimbrites and tephra with occasional material of dacite, basalt and andesite origin (Briggs *et al*, 1996). A generalised stratigraphic column is shown in Figure 2.11 (Briggs *et al*, 1996). Airfall ashes or tephra from the TVZ also predominates in the surface features.

GENERALISED STRATIGRAPHY OF THE TAURANGA REGION

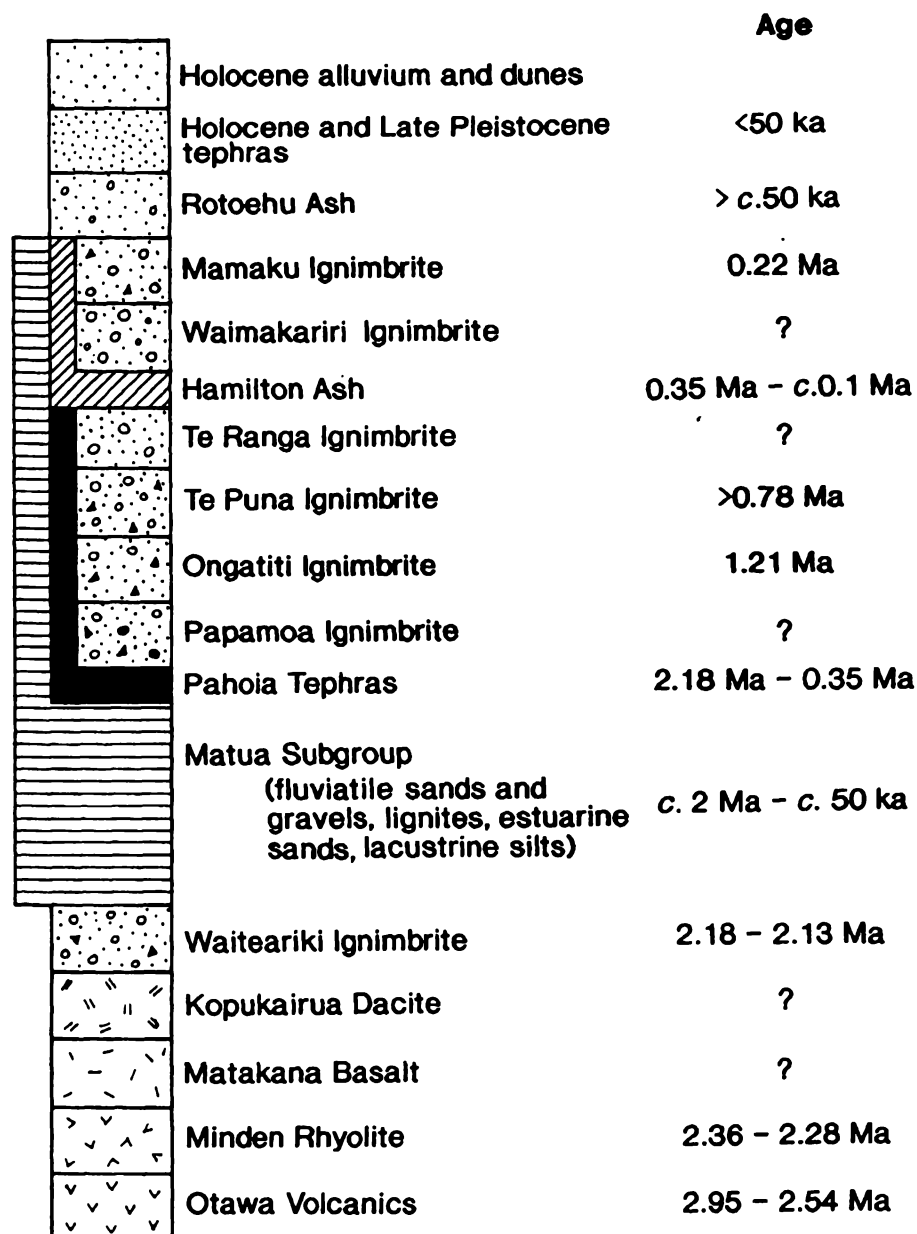


Figure 2.11: Generalised Stratigraphy of the Tauranga Area (Source: Briggs *et al*, 1996)

As described by Briggs *et al.* (1996) the Tauranga Basin is a Pleistocene fluvial-estuarine basin which was partially infilled during rapid subsidence caused after the eruption of the Waiteariki Ignimbrite (Brigg *et*

al., 1997). The material is comprised mainly of volcanoclastic sediments, airfall tephra and welded or partially welded ignimbrites. The basin is flanked to the west and south by the Kaimai Ranges, the Whakamarama Plateau, and the Mamaku Plateau, the latter two structures being formed from Pliocene and Pleistocene ignimbrite sheets, while the Kaimai Range is an upfaulted block of basaltic to rhyolite volcanoes of Miocene age (see Figure 2.12).

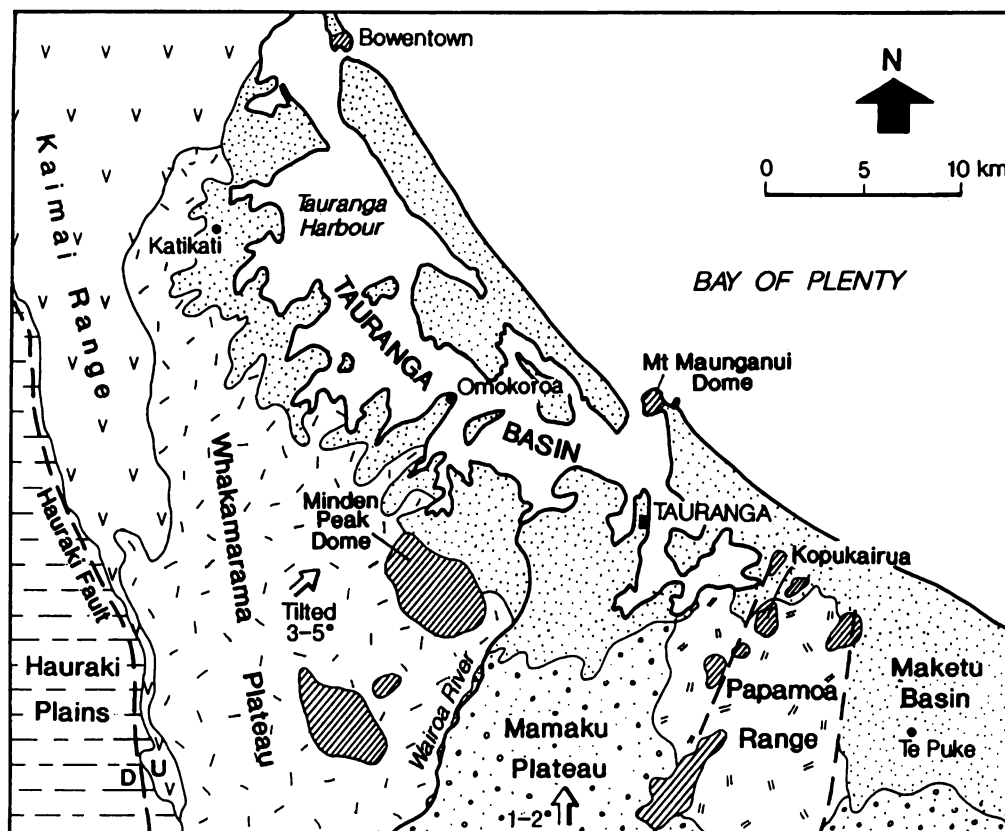


Figure 2.12: Map showing the main physiographic features of the Tauranga area (Source: Briggs *et al.*, 1996)

Several Pleistocene volcanic domes occur in the Tauranga region and these form prominent features within the landscape. The rhyolitic dome of Mt Maunganui (252 m) provides a steep conspicuous landmark at the eastern entrance to Tauranga Harbour and it is connected to Papamoa by a tombolo formed of dune ridges with thin peaty layers intercalated with thin airfall tephra (post Rotoehu ashes derived from the OVC <50ka). Other coastal rhyolitic features include Mt Drury, Bowentown (like Mt Maunganui a tombolo connected to Waihi Beach by a sequence of Holocene dune ridges) and the erosional remnants of lavas from Mt Maunganui that form the islands of Moturiki and Motuotau.

Briggs *et al.* (1996) note evidence of volcanic subsidence in the Aongatete district associated with possible caldera formation in the Pliocene as indicated by a negative gravity anomaly identified in the area. This may be part of a wider downwarping associated with the offshore Ngatoro

Basin as suggested by Cole (1978). Schofield (1968) has concluded from the levels of rock carvings at Ongare Point that coastal sea level was approximately 0.46-0.76 m below present levels 200 years ago, indicating a subsidence/relative sea level change rate of between 2 mm and 4 mm/yr. These rates are consistent with those determined by Abrahamson (1987) from investigation of the Rotoehu Ash covered Pleistocene dunes at Bowentown/Pios Point.



Figure 2.13: Aerial view of Papamoa Beach looking eastward over Te Puke lowlands.

The 40 km stretch of coast from Maketu to Mount Maunganui is a relatively wide zone of Holocene sandy progradation (Healy *et al.*, 1977; Wigley, 1990). The feature reflects the progressive development of a series of shorelines that evolved successively over the 6500 years (Wigley, 1990) since the time of the Holocene transgression. As a consequence the Te Puke lowlands represent the mature stage of a barrier estuary (Wigley, 1990) that infilled behind the prograding beach ridges (Figure 2.13). A convex seaward bulge in an otherwise concave coastal planform occurs around Papamoa. Healy *et al.* (1977) considers that this cusped foreland is developing as a result of long wave refraction around Motiti Island.

Beach profiles in this section of the Bay of Plenty are relatively steep and can be characterised generally as being narrow with poor back beach development (Figure 2.14). However this can vary quite significantly as noted by Healy *et al.* (1977). Analysis by Healy *et al.* (1977), Gibb (1994), Hodges and Dealy (1997) indicates that the beaches are subject to cyclical erosion events with the frontal dune complex periodically exhibiting a strongly faceted foredune that is subject to blowouts.



Figure 2.14: View of Beachfront development at Mt Maunganui East showing narrow beach and foredune development. Photo taken at High Tide.

Matakana Island is a 24 km long barrier island composed predominantly of Holocene sands (Healy, 1977). Healy (1977) describes the island as consisting of 20-30 dune ridges aligned parallel to the shoreline. These ridges show marked recurvature at both ends indicating that the island has grown longitudinally during the late Holocene towards the headlands of Bowentown in the north and Mt Maunganui in the south.

Panepane Point at the southern end of Matakana Island marks the entrance to Tauranga Harbour. This point has undergone both erosion and progradation during historic times. Analysis of survey records and hydrological charts has shown that Panepane Point has prograded by over 500m between 1852 and 1954 (Healy, 1977). However between 1954 and 1972 the point eroded back again by 100m (Healy, 1976).

The island in plan-form is gently curved with two cusped bulges at its northern and southern ends (Figure 2.15). Healy (1977) considers that both of these features are related to the adjacent ebb tidal deltas at Bowentown and Matakana Bank. In 1977 Healy described the Matakana beaches as varying from a relatively wide flat beach with a large back beach area in the north, to a narrow steep beach in the south. All beaches showed evidence of cyclical episodes of erosion and accretion typical of open coast barrier beaches (Bradshaw, 1991).

The coastline from Waihi Beach to Bowentown Head consists of a 9km curvilinear barrier beach attached as a tombolo to Bowentown Head. To the northwest of Waihi Beach the coastline is marked by a rocky stretch that reflects the proximity of the Coromandel Ranges (Michels and Healy, 1998). The Waihi headland represents what is considered to be the northern limit of the Bay of Plenty littoral system (Healy, 1980). Bradshaw (1991) considered both Waihi Beach and Matakana Island to be transgressive features that have migrated to their present positions from further offshore where they formed during lower stillstands.



Figure 2.15: Aerial view of Matakana Island looking Southeastward toward Panepane Point with a cuspate bulge in the shoreline showing opposite Matakana Bank at left.

Waihi Beach's position appears to have changed little in historic time although fluctuations of up 90m in shoreline position have been recorded from cadastral surveys and aerial photographs (Harray, 1976; Gibb, 1994, 1997; Hicks *et al.*, 1999). The duneline between Waihi and Bowentown Heads shows irregular traits characterised by large arcuate embayment features that vary in length between 800 and 2500 m and a "depth" of up to 140m (Stephens *et al.*, 1999). Wave refraction over irregular offshore bathymetry rather than infragravity wave effects is thought to be the major contributor to this periodicity (Stephens, 1996).

Waihi beach is comprised of fine to medium beach sands however sand adjacent to the Katikati delta is noticeably coarser than elsewhere (Hicks *et al.*, 1999) on the beach. Sub tidal profile morphology consists of an upper shoreface out to a depth of -5 to -8m below MSL, a lower shoreface from -8m out to a depth of approximately -20m and an inner continental shelf from -20m out about -50m (Gibb and Reinen-Hamill 1997; Hume and Hicks, 1993). The Katikati ebb tidal delta located offshore from

Bowentown Head overlies both the upper and lower shoreface (Gibb & Reinen-Hamill, 1997).



Figure 2.16: View of Waihi Beach showing relatively flat dissipative beach with minimal foredune development.

This delta is considered by Hicks *et al.* (1999) to substantially influence the morphology of Waihi Beach and Matakana Island by regulating the sediment supply to the beach littoral system through a mechanism that appears cyclical at both the multi, quasi and inter annual timescales. The 'near field' mechanism itself results from processes related to wave sheltering, localised wave focussing, scour by flood-tidal channels, bar migration and welding, and divergence in the longshore transport due to refraction. Hicks *et al.* (1999) consider that these processes combine over timescales of several years to produce a superposition of positionally fixed, migrating, and transient shore features.

In the 'far field' (i.e. away from the influence of the ebb tidal delta) beach change at Waihi is speculated to be associated with storm waves and cross-shore sand transport (Hicks *et al.*, 1999). However despite this the longshore transport regime also induced changes, albeit with different mechanisms dominating the effect on either side of the tidal inlet (Hicks *et al.*, 1997). On Waihi Beach the inter annual reversals in the net regional longshore transport potential (based on a short term dataset) are thought to be driven by climate cycling which appear to induce sand 'sloshing' between Waihi and Bowentown Heads. It is argued that this can cause subtle pivoting in the orientation of the shoreline over inter-annual timescales.

On Matakana Island Hicks *et al.* (1997) interpreted a weak trend of net sand loss superimposed on storm swell induced changes. Net sand losses

appeared to be associated with episodes of intense westward transport resulting in sand being pumped into the inlet and from there onto the Katikati ebb tidal delta where it is effectively locked up until sand bar migration can return sediment to the beach system. This means that erosion can accumulate on the beaches for several years before a sand slug is released and sand accumulation can begin again on the Matakana Island beaches.

2.3 Eustatic Changes

Large-scale sea level changes have had a dramatic influence on the development of Bay of Plenty coastal morphology over recent and geologic timeframes. This influence continues today with ongoing climate and tectonic deformation induced sea level change occurring within both a regional and worldwide context. An understanding of this context is required for two reasons:

- To recognise the forcing mechanisms behind contemporary coastal form developed over the Quaternary and in particular the Holocene, so that this can be recognised in scenario development for use in beach response modeling to predict the effects of sea level rise; and
- Secondly to use this information to assist in the interpretation of the beach response modeling results.

The Bay of Plenty coast is subject to worldwide and regional influences. At a worldwide scale such change is often referred to in the literature as eustatic change. Tooley (1993) has defined eustasy as a 'world wide change in sea level'. This followed from a definition of eustasy as 'the world-wide sea level regime and its fluctuations, caused by absolute changes in the quantity of sea water' (NB definition of uniform sea level rise has been challenged as a consequence of the empirical discovery of deformations in geoid relief - in Tooley 1993).

Donovan and Jones (1979) have described several possible causes of global sea level change, whereas Fairbridge (1961) identified four categories that will effect the eustatic sea level. These are:

- Tectono-eustasy, resulting in worldwide sea level change caused by the deformation of basins.
- Sedimento-eustasy resulting in a sea level change controlled by the addition of sediments of either pelagic or terrigenous origin.
- Glacial eustasy involving sea level change by addition or subtraction of water from the oceans through glacial storage.
- Steric change due to an expansion/contraction of seawater producing a consequential change in sea level caused by changes in temperature, density, or salinity.

Mörner (1987) summarised the eustatic variables into a table (Table 2.1). He also redefined eustasy as being absolute sea level change from whatever cause including both vertical and horizontal displacement from either geoid changes (caused for example by tectonic-gravity distortion), or dynamic change such as that caused by meteorological/climatic conditions.

EUSTASY	OCEAN LEVEL CHANGES	VERTICAL AND HORIZONTAL GEOID CHANGE	OCEAN BASIN VOLUME	TECTONO- EUSTASY	EARTH – VOLUME CHANGES	
					TECTONICS	OROGENY
						MID-OCEANIC RIDGE GROWTH
						PLATE TECTONICS
						SEA FLOOR SUBSIDENCE
						OTHER EARTH MOVEMENTS
					ISOSTASY	SEDIMENT IN-FILL
						LOCAL ISOSTASY
	HYDRO-ISOSTASY					
	INTERNAL LOADING ADJUSTMENT					
DYNAMIC CHANGES	OCEAN WATER VOLUME		GLACIAL EUSTASY			
			WATER IN SEDIMENT, LAKES AND CLOUDS, EVAPORATION, JUVENILE WATER			
	OCEAN MASS/LEVEL DISTRIBUTION	GEOIDAL EUSTASY	GRAVITATIONAL WAVES			
			TILTING OF THE EARTH			
			EARTH'S RATE OF ROTATION			
			DEFORMATION OF GEOID RELIEF (DIFFERENT HARMONICS)			
	DYNAMIC SEA LEVEL CHANGES	METEOROLOGICAL				
		HYDROLOGICAL				
		OCEANOGRAPHIC				

Table 2.1 – Summary of the Eustatic Variables According to the new definition of eustasy as ocean-level changes (Source: Tooley, 1993 after Mörner, 1987)

Mörner (1987) concluded that sea level changes could no longer be regarded as global phenomena that occur simultaneously or in parallel on a worldwide basis. Because of this he claims that it is necessary to define regional eustatic curves that can then be compared to others to resolve problems of crustal and mantle behaviour. Mörner (1976) drew particular attention to the geoid and its variation in shape over space and time and considered the implications of this on the registration of sea level in various parts of the world.

Gibb (1986) has developed a Regional Holocene Eustatic Sea Level Curve for determining vertical tectonic movement within New Zealand (Figure

2.17). Gibb's work defined regional eustasy as a time-dependent uniform change in sea level rise around the coast of New Zealand, regardless of causation. He assumed that changes in water density and circulation around the coast have remained constant for the Holocene. This would mean that eustatic sea levels recorded at various tectonically stable coastal sites would lie within decimeters of each other. Gibb based this assumption on steric levelling work carried out by Heath (1982) to compare dynamic height variance of the sea surface off of the West Coast. This work found that sea surface change varied by between 0.04 to 0.07 m toward Cook Strait from North Cape and Bluff over a distance of 1300 km. The result of Gibb's (1986) work using evidence sourced from a range of physical evidence including beach and chenier ridges, estuarine shell beds, and 'organic' shoreline deposits, suggests that culmination of the last marine transgression occurred at present sea level approximately 6.500 ± 0.1 ka (uncorrected ^{14}C dating).

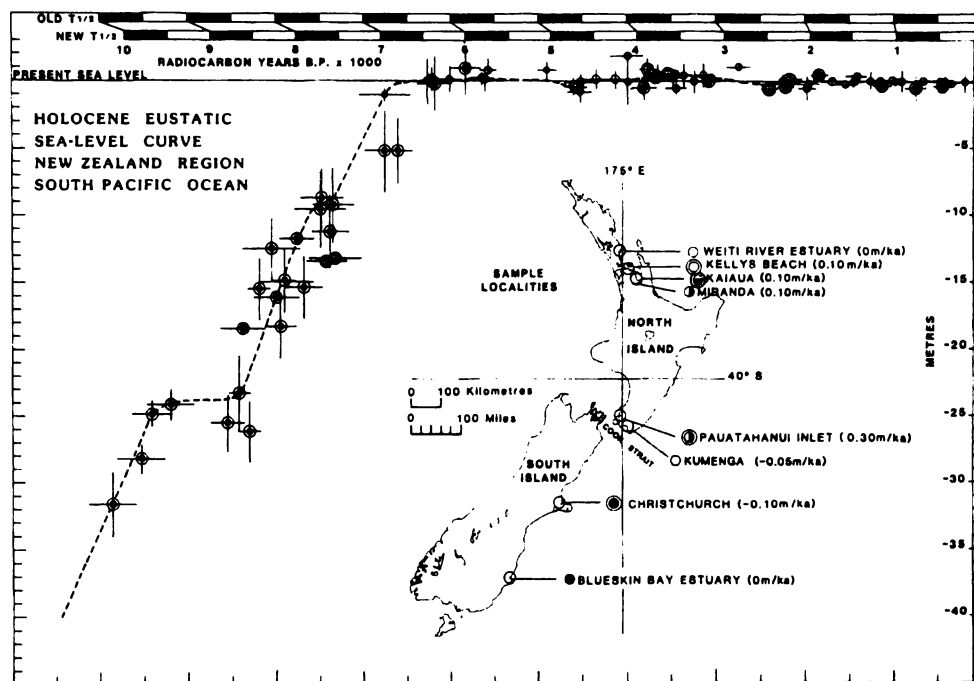


Figure 2.17: New Zealand regional sea-level curve relative to the present sea level compiled from eight sites. Symbols represent data from each site and bracketed values are tectonic uplift (positive values) and downdrop (negative values) rates in metres per 1000 years (m/ka). (Source: Gibb, J.G, 1986)

Since that time minor fluctuations of sea level in the order of decimeters have occurred around the New Zealand coast. Gibb's analysis suggests that a stillstand occurred between 6.5 to 5ka followed by an apparent regression (-0.4 m) between 5 to 4.5ka and a minor transgression (+0.6-0.9 m) from 4.5 ka to 3.5 ka. Since then sea level appears to have dropped to roughly present day levels. However Hannah's (1990) analysis of tide gauge records indicates sea level rise rates on the East Coast of 1.7mm/yr

over the last century and that this is consistent with eustatic changes observed elsewhere in the world.

One of the advantages of Gibb's work in defining a regional sea level curve is that it allows a graphical determination of tectonic uplift at other sites as compared to the reference sites described in his paper. Analysis of the data recorded for the nearest site to the Bay of Plenty coast (Miranda on the Firth of Thames) suggests tectonic uplifts in the order of 0.1 m/ka. This is approximately an order of magnitude less than that occurring at Whakatane where rates of approximately 2 m/ka have been identified both as subsidence and uplift within and marginal to the graben (Pullar, 1983; Nairn and Beanland, 1989).

However very little work appears to have been done to link geoid - spheroid determinations in New Zealand to vertical survey datum so that geologic evidence can be related to and verified by modern geodetic data. As a consequence it is difficult to assess in precise terms modern sea level changes that may be occurring around New Zealand's coast. It is also impossible to separate tectonic and eustatic components (e.g. from global warming) of sea level rise from information provided from tide gauge analysis (Hannah, 1988). It is understood that this situation is currently being addressed in a joint project between IGNS and the University of Otago using high accuracy GPS surveys.

Despite this lack of geodetic information on tectonic eustatic sea level change rates in New Zealand it is possible to describe a conceptual model for Bay of Plenty sea level changes and sedimentation over the Pleistocene-Holocene from geological evidence (Abrahamson, 1987) as a prelude to scenario development for coastal erosion prediction.

BoP Coastal Sedimentation in relation to late Holocene Average Sea Level (ASL)

The Pleistocene epoch represents the age of recent glaciation extending back over a period of approximately 1.6 Ma. During this epoch the world experienced a series of cold glacial periods which resulted in major fluctuations of sea level. At times the sea level has been considerably lower than today while at other times levels have been well above. Erosion of the hinterland during the intervening periods of high sea level has resulted in the formation of the marine sandstones deposited in the Castlecliffian Stage (approximately 500,000-1,000,000 yrs b.p.) and progradation of the Rangitaiki Plains at Whakatane and the coastal plains surrounding Te Puke between Ohinepanea and Papamoa.

In New Zealand the culmination of the postglacial marine transgression is well documented near 6.5 k.y. as described previously and shown in Figure 2.7 (Gibb, 1986; Abrahamson, 1987,). Evidence from the east coast of the South Island and the Great Barrier Reef in Australia (Carter *et al.*, 1986) is consistent with Gibb's (1986) work indicating that the postglacial

transgression in the southwest Pacific was episodic, comprising major stillstands punctuated by rapid rises in sea level. Locally Marks and Nelson (1979) and Pullar and Selby (1971) suggest that sea level was perhaps 2-3m higher than present sea level about 5ky b.p. with variations from this being attributed to local tectonic conditions, in contrast to the scenario argued by Gibb (1986) who would attribute such results as being affected by local tectonic movements.

Based on the work of Carter *et al.* (1986) and Gibb (1986) the shoreline started to migrate to its present position from its lowstand position at about 20-18 ky b.p. (-110 to 150 m below present sea level) in a series of steps identified at depths and likely ages of -113 m (18 ky b.p.); -86 m (17 ky b.p.); -75 m (15 ky b.p.); -56 m (12 ky b.p.); -46 m (11 ky b.p.); -28 m (9.5 ky b.p.); -24 m (9 ky b.p.); and 9 m (7.5 ky b.p.) before finally stabilising at about its present day level around 6.5 ky b.p.

As sea level rose over the late Pleistocene and early to middle Holocene, drowned valleys and gullies eroded into the underlying sediments and volcanics deposited during the last glacial period (70-18ky b.p.) were infilled by mobilised inner shelf sands. This produced what is thought to be a series of barrier formations at major stillstands (Carter *et al.* 1986; Gibb 1986) with some barrier features possibly buried beneath the modern sand wedge on the New Zealand inner shelf (Gibb, 1986). Additional material was added into the system around this time from the tephra deposits derived from volcanic eruptions in the TVC (see Section 2.2 above).

Holocene Progradation Rates in the BoP

Australian studies have indicated that at the cessation of the marine transgression, coastal embayments generally reacted rapidly (dependent on the energy regime, the shelf configuration, and sediment supply) to the disequilibrium produced in the transgressed surface. In the Bay of Plenty and Coromandel tephra-chronological evidence suggests that coastal progradation commenced between 4600 and 6000 years ago (Abrahamson 1987; Munro 1997). However progradation appears to have been initiated earlier in areas such as the Rangitaiki Plains (8000yrs b.p. - Pullar and Selby, 1971) where large volumes of volcanic material erupted from the TVC appears to have affected the equilibrium balance of the shoreface.

Pullar and Selby (1971) indicated that the rates of progradation on the Rangitaiki Plains have varied from an averaged 0.5 to 0.7 m/yr before the Tarawera eruption (1886A.D.) to about 1.3 m/yr in the period since. In addition Pullar and Selby (1971) noted that the foreshore planimetric form along the Rangitaiki Plains appears to have changed from a concave to a convex profile since the Taupo pumice eruption of 131A.D.

Investigations by Wigley (1990) and Abrahamson (1987) on Papamoa and Coromandel beaches indicate progradation rates varying from 0.06 m to

0.5 m /year over the last 6500 years for East Coromandel Beaches (Abrahamson, 1987,p183) with initial rates averaging 0.5 m/year during the early stages of the Holocene stillstand slowing to 0.2 m/yr since the Taupo eruption for Papamoa Beaches (Wigley, 1990). Over the last one hundred years Wigley (1990) estimates that progradation on the Papamoa beaches has been influenced by human settlement with additional sediment loading occurring in the Kaituna River due to land clearance resulting in the shoreline advancing approximately 50 m in the last 100 years.

2.4 Sediment Characteristics of the Bay of Plenty Nearshore Zone

Davies-Colley (1976), Healy *et al.* (1977), Healy (1978), Richmond (1977), Burton (1978), Dahm (1983), Phizacklea (1993), Munro (1994), Saunders (1999), Easton (2002) describe the various sediment characteristics of beach sand found in the Bay of Plenty. Healy *et al.* (1977) carried out a bulk analysis of sediment samples obtained during the Coastal Erosion Survey of the Bay of Plenty incorporating sampling from all beaches between Opape and Waihi Beach. In summary this work found that:

- the mineralogy was consistent with sediments sourced from rhyolite, ignimbrite and volcanic ash deposits originating from the Okataina and Taupo volcanic centres;
- there is a predominance of quartz and volcanic glass, although feldspars and heavy minerals are present;
- further work was required to analyse the mineralogy and textural distribution of the sediments found in the offshore zone and in adjoining rivers before the origin of sediments could be confirmed (Healy *et al.*,1977).

Healy (1978) carried out further analysis on sediment characteristics of the Rangitaiki Plains foreshore and river sands. The results of this work showed that:

- there is a large input of volcanic glass and alkaline feldspar from the Tarawera River. Further the presence of rhyolitic glass confirmed a localised origin for the sediment;
- the mineral ratios, especially of Feldspar:Glass and Quartz:Glass provide a good indication of the transport mechanism involved. That is the presence of glass indicates rapid transport to the coast where its concentration can be used to determine the catchment origin drift patterns (i.e. glass is soft and weathers very rapidly in the coastal environment under the action of waves;
- the presence of amphiboles such as hornblende and cummingtonite not only indicate an acid- intermediate volcanic origin consistent with the Bay of Plenty's location in the TVZ but cummingtonite in particular can be used as a natural tracer to determine sediment

movement patterns in the coastal zone. These sediment patterns are shown in Figure 2.18 (Healy, 1978).

- Sediment size analysis based on the sampling regime indicates that significant sediment supply is contributed from all three major rivers flowing through the Rangitaiki Plains and that there is a net littoral drift to the east. Analysis of the sediment sizes of samples from the Whakatane River indicates that the finer fraction moves around the Whakatane Heads and onto Ohope Beach to contribute to the Ohope Spit while the coarser material remains near to the river mouth. However there appears to be a localised movement of sediment to the west caused by refraction of waves that contributes to the formation of cusps in the lea of Motuhora (Whale) and Rurima Islands.

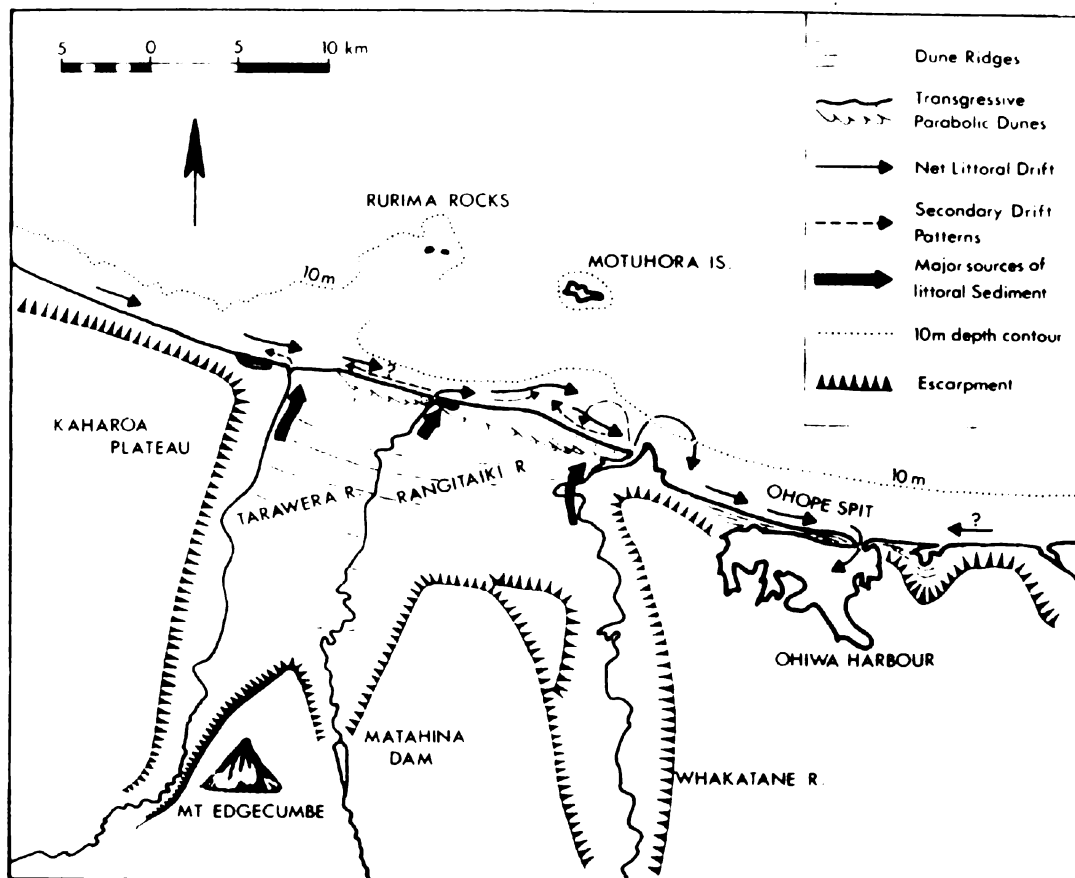


Figure 2.18: Sediment Drift Dynamics for the Rangitaiki foreshore (Source: Healy 1977)

Saunders (1999) analysed sediment distribution characteristics at West End, Ohope. No mineralogical analysis was attempted, but grain size distribution was assessed and various models applied to explain the mechanisms for sand distribution. The relevant findings are summarised as follows:

- Ohope Beach demonstrates a seaward fining of sediments similar to that found by Bradshaw (1992) for beaches in the Western Bay of

Plenty with the fining progression considered typical of barrier spit beaches ;

- All samples collected offshore Ohope Beach were fine sand, with a band of very fine sand occurring between 10 and 15 m, which reached its most landward position off Kohi Point;
- Sands collected offshore of Piripai beach were medium to coarse, although by 10 m depth this had progressed to fine sands. The cusp extension in a northerly direction suggests that coarser material from the Whakatane River is settling out in the lee of Moutohora Island;
- Local sorting characteristics of the sediment follows the grain size distribution with sorting becoming poorer with increasing depth, with very well sorted sediments found at the beach and very poorly sorted sediments at the 30m depth contour;
- A sharp transition occurs from moderately well sorted to poorly sorted sediments between 15 m and 20 m depth which Saunders (1999) considered to be indicative of the approximate seaward limit of active sediment transport under observed ambient wave conditions;
- Littoral drift is not likely to be the dominant sediment transport process along Ohope Beach although this will vary according to the frequency of large wave events. However an easterly littoral drift does contribute to a significant annual loss of sediment out of the Ohope cell (i.e. towards Ohiwa). Saunders (1999) noted a net annual loss from the beach of approximately 29,000 m³, a significant component of which is due to longshore transport in the surf zone;
- Diabathic exchange during storms where $H_s > 3.5$ m were capable of entraining up to 13.04 m³/m/day offshore whereas onshore movements of between 0.01 and 0.22 m³/m/day were measured during low energy or low onshore directed swell conditions;
- A conceptual model is proposed involving two counter rotational eddies offshore of the Whakatane Inlet and an easterly drift pattern along Ohope Beach towards Ohiwa. Westerly flows offshore of Kohi Point were correlated with an aerial photo of a large eddy offshore of Kohi Point. This has been implicated as a sand bypassing mechanism for Kohi Point while the westerly located counter clockwise eddy enhances distribution of sediment to Piripai Beach and the Whakatane Spit (see Figure 2.19).

Richmond (1977) analysed the sediment characteristics of samples taken within the Ohiwa harbour catchment and on Ohiwa Spit and found that volcanic glass dominated the mineral assemblage followed by feldspar and quartz. It is claimed that the high feldspar to quartz ratio and ferromagnesian mineral assemblage and high volcanic glass plus pumice indicates a volcanic heritage for the mineralogy. Richmond (1977) considers that the most obvious sources are the thick tephra cover that mantles most of the Ohiwa catchment and the littoral zone.

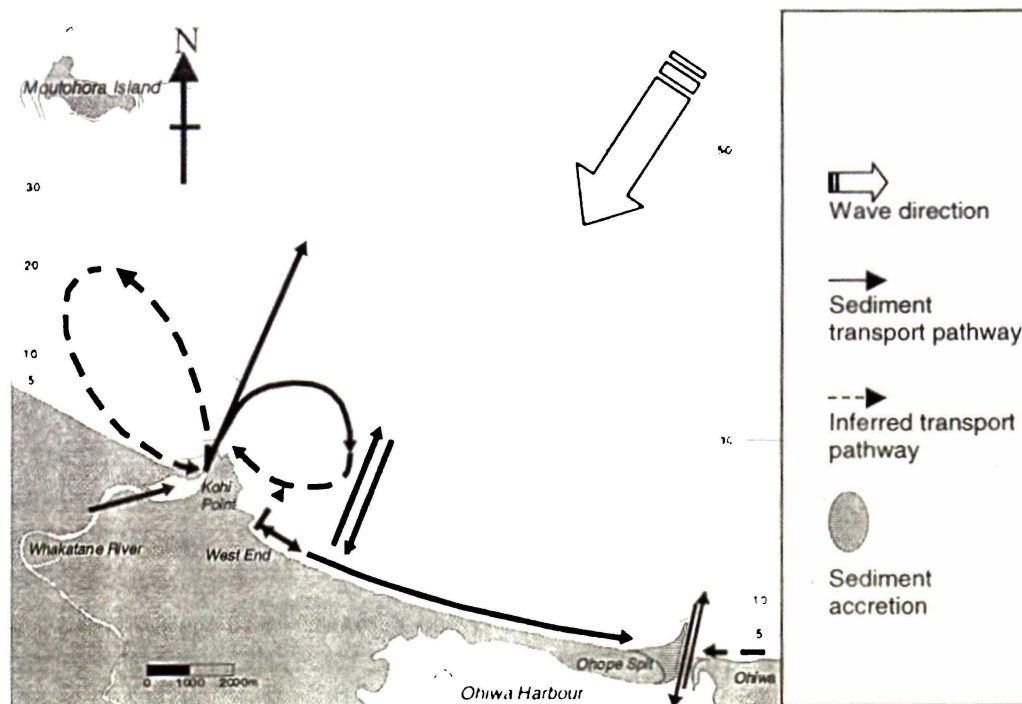


Figure 2.19: Conceptual model of sediment dynamics in the Whakatane-Ohope Beach Region. Bathymetry in metres (Saunders, 1999)

Phizacklea (1993) carried out an assessment of sediment composition for samples obtained from sites located between Pukehina and Matata. From this he concluded that light minerals constitute between 92 and 98% of beach sediments with heavy minerals constituting between 0.2 and 5.6% of the mineral assemblage and biogenic sourced carbonate material making up the balance. Phizacklea concludes that this mineralogy reflects the high input of quartzo-felspathic sediments derived from the Okataina volcanic centre.

Bradshaw (1991) carried out textural and mineralogical sediment analyses at Waihi Beach as part of a broader study of nearshore and inner shelf sedimentation of the Eastern Coromandel coast. Textural analysis indicated that fine-medium grained modern barrier spit beach sands appear to be supplied to some extent from their adjacent river catchments and that these have been reworked from adjacent lower and nearshore deposits.

Mineralogical examination of barrier and related fluvial deposits confirmed these conclusions. Two possible provenances are suggested based on abundance of volcanic glass, hypersthene, pyroxene and hornblende. This along with traces of biotite, zircon and apatite suggest a terrigenous source derived either from local catchments and harbours of the Coromandel Peninsula (cf. Kaimai and Minden Rhyolite Subgroups – Edbrooke, 2001) and/or from northward transport of sediments deposited by rivers draining the Taupo Volcanic Zone (Bradshaw, 1991).

From this work, longshore sediment transport in the Bay of Plenty appears to exist at two levels. Overlying everything is a general southeasterly drift of sediment along the coast. This is indicated by the orientation of the spits, harbour entrances, channels and ebb tidal deltas. However superimposed on this are patterns of localised sedimentary cells that distribute sediment within the littoral zone in a manner that is often in opposition to this regional trend. An example of this occurs at Pukehina where the spit and littoral drift orientation is to the northwest (Phizacklea, 1993).

2.5 Beach Morphodynamics: Theories and Concepts of Sediment Transport and Beach Classification and their application to Bay of Plenty beaches

The morphology of a beach is the result of the interaction of a number of complex processes that can be seen principally as a function of:

- sediment source;
- sediment budget;
- wave height, which controls wave run up and energy impact on the beach face;
- wave period, which controls the rate at which the beach receives energy; and
- sediment size, which influences sediment transport and beach slope. (Paton, 1993, Short, 1987, Wright and Short, 1984 & 1983,).

Changes to any one of these parameters can result in beach morphodynamic adjustment in response to changes in the forcing conditions acting at the time. A beach can therefore develop a modal form over time in response to these ambient conditions.

Several beach descriptive morphological models have been developed to classify beach types and to explain and predict changes in beach state between fully eroded and accreted end points. The Wright and Short (1983) model is discussed below as a prelude to completing the morphological description of the beaches included in this study.

2.5.1 Descriptive Beach State Models – Application to the Bay of Plenty

The Wright and Short (1983) model is a morphological system that classifies beaches into six beach states (see Figure 2.20) by combining factors associated with wave energy, period, and sediment size. Each of these beach states has a characteristic dominant beach-surf zone morphology and associated hydrodynamics (Paton, 1993). The beach states range from dissipative to reflective with four associated intermediate types included in the classification system.

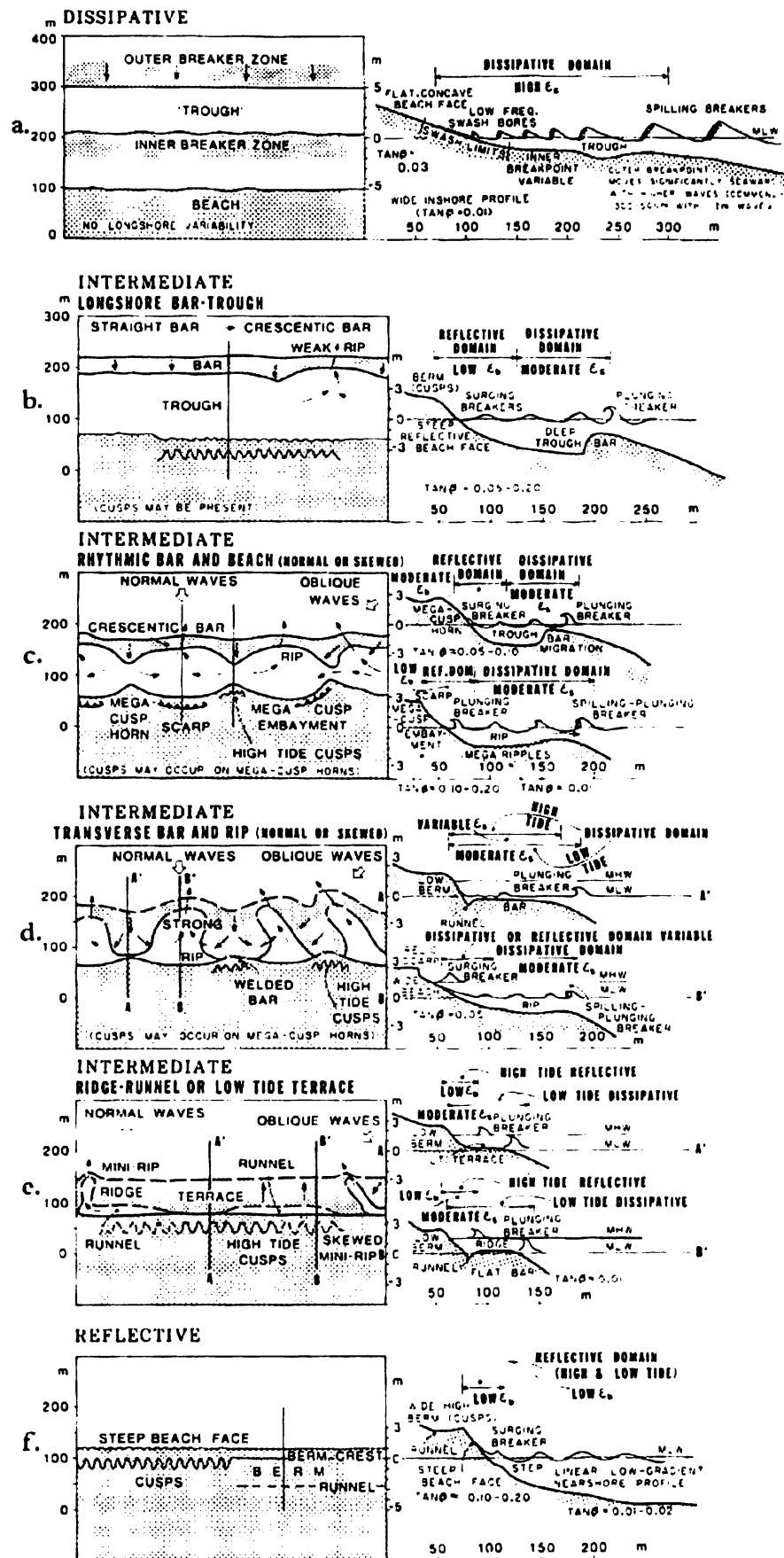


Figure 2.20: Plan and Profile configurations of the six basic beach states after Wright and Short (1983)

The model is derived from work carried out by these authors on eastern and southeastern beaches of the Australian coast. Two measurement parameters have been used to assist in the determination of the particular beach classification. These are the Dean's parameter, Ω , (Dean, 1973) and the surf scaling parameter, ε (Guza and Inman, 1975) where,

$$\Omega = \frac{H_b}{w_s T} \quad (2.1)$$

$$\varepsilon = a_b \omega^2 / (g \tan^2 \beta) \quad (2.2)$$

and H_b is the breaking wave height (m), w_s is the mean sediment fall velocity (m/s), T is the wave period (s), a_b is the breaker amplitude (i.e. $\approx H_b/2$), ω is the incident wave radiation frequency ($2\pi/T$), g is the acceleration due to gravity, and β is the beach/surf zone gradient which is undefined but appears to be dependent on beach type and the respective width of the active surf zone.

The Dean's parameter (Ω) has been used by various researchers (Dean, 1973; Wright and Short 1984, Short 1987) to help determine offshore and onshore sediment movement under varying wave and sediment conditions. Wright and Short (1984) used both Ω and ε to help delineate the six different beach states noted in their model (Fulton, 1991).

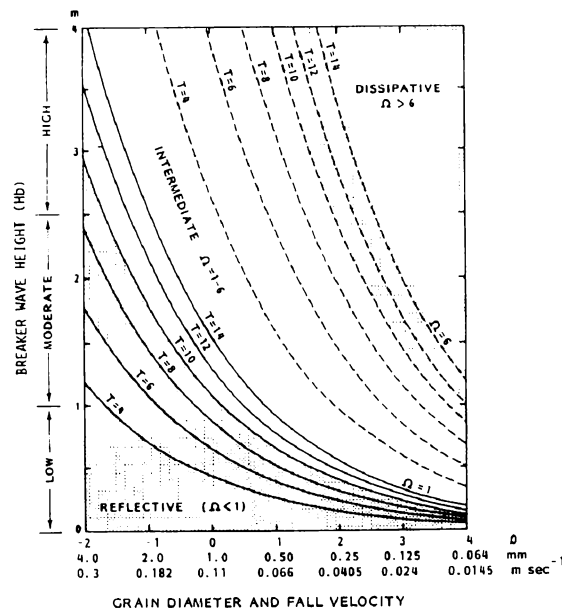


Figure 2.21: Plot of Threshold Values for $\Omega = 1$ (solid line) and $\Omega = 6$ (dashed line) for wave periods of 4, 6, 8, 10, 12 and 14 seconds. Dissipative conditions prevail when $\Omega = 6$; intermediate, $\Omega = 1.6$; and reflective, $\Omega < 1$. The corresponding zones for reflective and dissipative conditions when $T = 10$ are shaded (Source: Short, 1987)

Figures 2.21 and 2.22 illustrate the use of Ω as both a descriptive element and a predictor of beach-state. Figure 2.21 illustrates a plot of wave breaker height (H_b) versus Grain diameter and fall velocity while Figure 2.22 illustrates a plot of beach-state versus Ω .

Short (1987) identified that where the wave climate is variable beaches experience a greater temporal range in beach types in response to changing Ω than beach conditions where persistent swell conditions exist. Spatial variations in beach type were noted as being a product of regional variations in deep water wave climate, local variations in breaker wave climate and sediment size. Temporal variations in beach type on the other hand were identified as being solely due to changes in wave climate, except in unusual circumstance where sediment size changes (Short, 1987), perhaps as a result of longshore sand wave migration leading to the alteration of sediment composition of beaches.

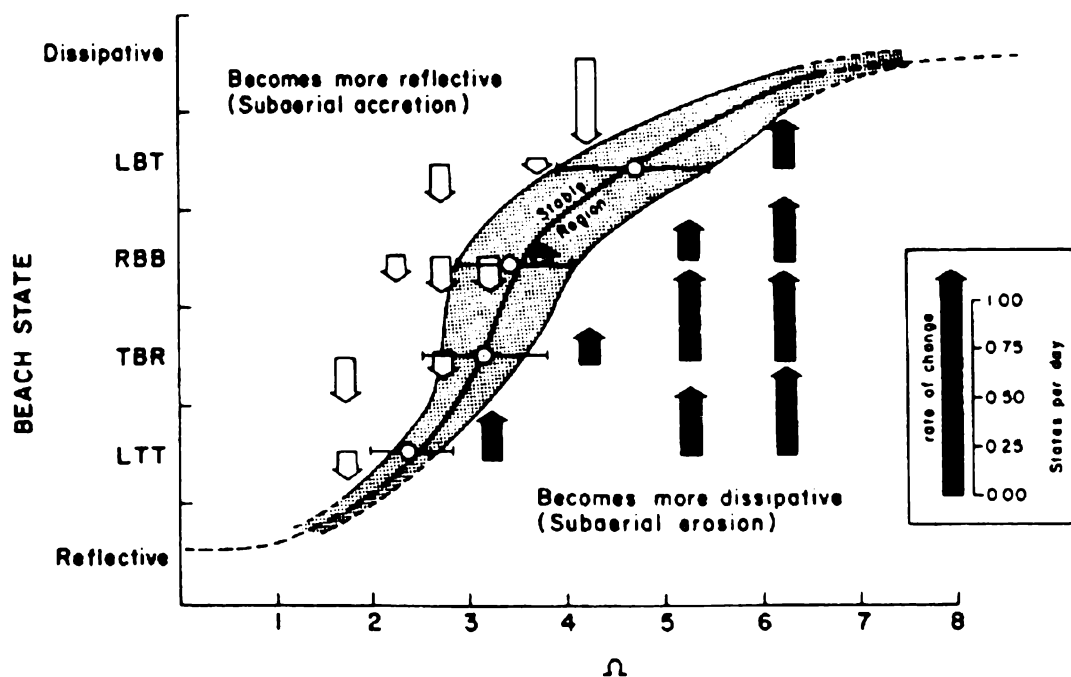


Figure 2.22: A plot of beach state vs. Ω . The solid line indicates the mean equilibrium association between state and Ω (see Table 2.2). The dashed area roughly delimits the stable zone within which beach change will be negligible. If the prevailing Ω lies above the stable zone, the subaerial beach will tend toward lower energy beach types through general onshore bar migration and beach accretion. If Ω lies below the zone, the beachface will experience erosion and move toward more dissipative conditions. The arrows indicate the rate of change in beach state per day (Source: Wright et al, 1984; Short, 1987)

Short (1987) contends that on the basis of the field data presented in the research that the parameter Ω permits the spatial and temporal variability

of beach type and consequently beach change to be predicted as a response to changes in waves and sediment characteristics.

In determining fall velocity for use in the model, Short (1987) advises taking sediment samples from the zone of maximum wave breaking, i.e. the most turbulent part of the profile. This is recognised as the swash zone for reflective beaches, the inner surf zone for intermediate beaches, and the outer surf zone for dissipative beaches.

Figure 2.21 displays the range of wave *vs.* sediment compositions (Short, 1987) required to produce reflective, intermediate, and dissipative beach types. Under ambient conditions the relationships described are descriptive. However where modal conditions change then the model relationships become predictive. This predictive element is further developed in Figure 2.22 by introducing a temporal element based on changes in beach states observed in the field.

Changes in beach state take time. Short (1987) noted that high values of Ω (e.g. $\Omega = 5$) lead to rapid rates of change of the order of 0.5 beach states per day (Figure 2.22) whereas low values lead to small rates of change in the order of 0.1 states per day or less. As the equilibrium state is reached the rate of change slows to zero as the beach state reaches or equals the predicted state under the model.

The amount of change determined using this approach is dependent on three factors (Short, 1987), namely the prevailing Ω , its duration and, the beach state prior to change. This means the larger the value of Ω the more rapid the change and the higher the likelihood there is of reaching the equilibrium state. Likewise the further the prior state is from equilibrium the larger the change and the greater the time required for this state to be achieved. For example, the amount of change required to shift from a reflective beach to a low tide terrace state is small relative to a reflective to dissipative change. Quoting Short, "The former requires relatively low Ω ($= 2.5$) for a few days whereas the latter requires high Ω (> 6) for several days to weeks."

The six beach states in this morphological model (see Figure 2.20) are described (Short and Wright, 1983; Wright and Short, 1984) in more detail and their general applicability is discussed in relation to Bay of Plenty beaches as follows:

Dissipative (D)

Dissipative beaches lie generally at the high wave energy end of the Wright and Short spectrum. Typically in Australia dissipative beaches are found where:

- modal wave periods are commonly between 10 and 12 seconds;
- waves exceed 2.5 to 3m and break 200-500m offshore; and
- sand sizes are in the fine to very fine range.

Wright and Short (1983) describe beaches in this state as being stable but located at the fully eroded end of the spectra. However Short (1979) and Wright and Short (1983) also note that when short wave periods prevail and/or the sand grain size is fine to very fine then a wide surf zone will exist under dissipative conditions even under moderate to low wave conditions where $H_b < 1.0$ m. This can be particularly so in fetch limited and short wave period environments.

Such states tend to dominate the northern ends of Waihi and Ohope Beaches where beach sand is fine grained (typically < 0.25 mm) and low wave energy and short fetch conditions often predominate. For example Macky *et al* (1995) identified El Nino wave climate from 3 years of wave buoy data obtained from a site located in 34 m of water 8 km offshore of the Katikati entrance. This wave data indicated a mean significant wave height (H_s) of 0.78 m ($H_b \approx 1.04$ m) and period of 6.1 s (T_s). This data indicates a Dean's parameter (Ω) of 6.1 which places north end Waihi beach at the dissipative end of the model's spectra under these ambient conditions.

Intermediate

Wright and Short (1983) identified four intermediate states between the Dissipative (eroded) and Reflective (accreted) end states as follows:

- Longshore Bar and Trough;
- Rhythmic Bar and Beach;
- Transverse Bar and Rip;
- Ridge and Runnel or Low Tide Terrace.

The *Longshore Bar and Trough* (LBT) consists of a bar and trough running parallel to the shore. The typical characteristics of this type of beach are:

- plunging breakers over bar 1.5-2.0 m in height
- weak to moderate rip currents (200-300 m apart)
- a deep trough (2-3 m);
- a moderate to steep beach face that is reflective at high tide;
- production of infragravity wave circulation and associated edge waves that impose a weak rip circulation;
- sediment is fine to medium sand. (Paton 1993; Short 1979)

The *Rhythmic Bar and Rip* (RBR) beach-state consists of:

- an undulating bar and trough which may be skewed dependent on the approach angle of the incident waves
- fine to medium sand;
- Waves plunge over the bar with moderate-strong rips every 150-300 m;
- 1.5m breakers - spilling to plunging breakers in rip feeders with plunging breakers over the bars;
- Distinct trough separated by detached bars. Trough conditions alternate from shallow depth with onshore directed currents behind the bar to deeper pulsating rip feeder and rip currents in the channels;
- Both reflective and dissipative zones within profile with surging breakers on beach face behind bars;
- Well formed mega cusp embayments

The *Transverse Bar and Rip* beach state consists of:

- a series of attached bars, rip troughs and undulating beach;
- fine to medium sand;
- Distinct rip troughs separated by bars every 150-300 m;
- 1-1.5 m breakers;
- bars are transversely welded to the shore with plunging waves alternating with deeper (1-2m) rip troughs and currents;
- Swash zone is shallow in the lee of the bars with a distinct berm. Waves in the rip channels are typified by plunging and spilling at low tide while surging occurs at the wide beach face at high tide to form high tide cusps. Beach conditions vary from dissipative to variable dissipative-reflective conditions depending on the tide and wave conditions.

The fourth intermediate beach state is the *Ridge-Runnel or Low tide Terrace*. This beach state consists of:

- a shallow bar or terrace which can be exposed at low tide;
- fine to medium sand;
- formed under waves typically 0.5-1.0 m in height;
- rip channels may become skewed to the beach face under oblique wave conditions;
- The swash zone is moderately steep with a low berm. At high tide the beach face may become reflective in the lee of the terrace. Otherwise breakers tend to be plunging over the terrace and bar as dissipative conditions prevail;
- the features tend to be regular
- mini or weak rip conditions may occur that form rip channels that dissect the low tide terrace.

Reflective (R)

Reflective beaches are found typically under low wave conditions on open coasts and in deeply protected embayments where wave shoaling and refraction significantly lower deep water wave energy (Fulton, 1991:27). They represent the accretionary extreme in beach types in that most of the mobile sand is stored in the sub aerial beach (Short, 1980). On more exposed coasts they may form after prolonged periods of low waves (Short and Wright, 1981), and on moderate to high energy coasts where sediments are composed of coarse gravel and or shingle beaches causing Ω to be less than 1 due to the high fall velocity of the sediment. However reflective conditions may also develop under high energy conditions where $H_b > 3\text{m}$ and where the fall velocity $\omega_s > 0.45 \text{ m/sec}$.

Under reflective conditions waves tend to reflect off the beachface and dissipate some of the wave energy back offshore. The beach face may exhibit beach cusps at the high tide mark, perhaps as a result of the development of edge waves by reflection and refraction of infragravity waves propagating in the longshore direction. The characteristics of *Reflective* beach types may be summarised as follows:

- $\Omega < 1$ and $\varepsilon < 2.5$ (Short and Wright, 1983; Short and Wright, 1984);
- Medium to coarse sand;
- 0-1 m breaker height;
- Uniform beach face conditions apart from high tide cusps spaced at approximately 20-30 m intervals;
- Tend to occur in very low energy environments.

The beach states therefore represent a transition from the high-energy erosive dissipative extreme through to low energy accretionary beach states. This process is accompanied by a decrease in the surf scaling parameter (see table 2.2).

Beach Type	Beach State	ε	H_b	Ω_s
Dissipative	Dissipative	> 20.0	> 2.5	> 5.5
Intermediate	Longshore Bar and Trough	20.0	2.0 - 2.5	4.70 - 0.93
	Rhythmic Bar and Beach			3.50 - 0.76
	Transverse Bar and Rip			3.15 - 0.64
	Ridge and Runnel	2.5	1.0 - 2.5	2.40 - 0.19
Reflective	Reflective	< 2.5	< 1.0	< 1.5

Table 2.2: Parameter ranges for various Beach States (Source: Wright and Short, 1983; Wright et al., 1984; Paton 1993 p88)

Paton (1993) summarizes the transition of beach energy states thus, "...As the energy decreases [from the maximum erosive state] a LBT state develops and the shoreward crest of the bar divides the profile into a reflective domain and a highly dissipative outer domain. As the bar welds onto the beach, the dissipative properties also move onshore and a RBB system

develops. This stage has longshore and shore-normal separation of dissipative and reflective sub systems. More dissipative regions grow at the expense of the reflective regions as transverse and anvil shaped bars of the TBR system develop. The shoals widen [*as wave energy decreases*] into the broad form of the LTT beach state and the beach becomes reflective at high tide and dissipative at low tide. The low tide shoals can [*then*] climb onto the sub aerial beach, the surf scaling parameter lowers and the beach becomes fully reflective."

Bay of Plenty Beach States

The BOP Coastal Erosion Survey (Healy *et al*, 1977) established 51 beach profile monitoring sites between Opape in the southeast and northern Waihi beach in the northwest. These sites now have benchmarks surveyed in to the regional geodetic survey grid and have been subsequently monitored (Hodges and Deely, 1997). In the early 1990s A. Dommerholt collected considerable data for these beach sites, and this information provides the basis of the following and subsequent analysis in this research.

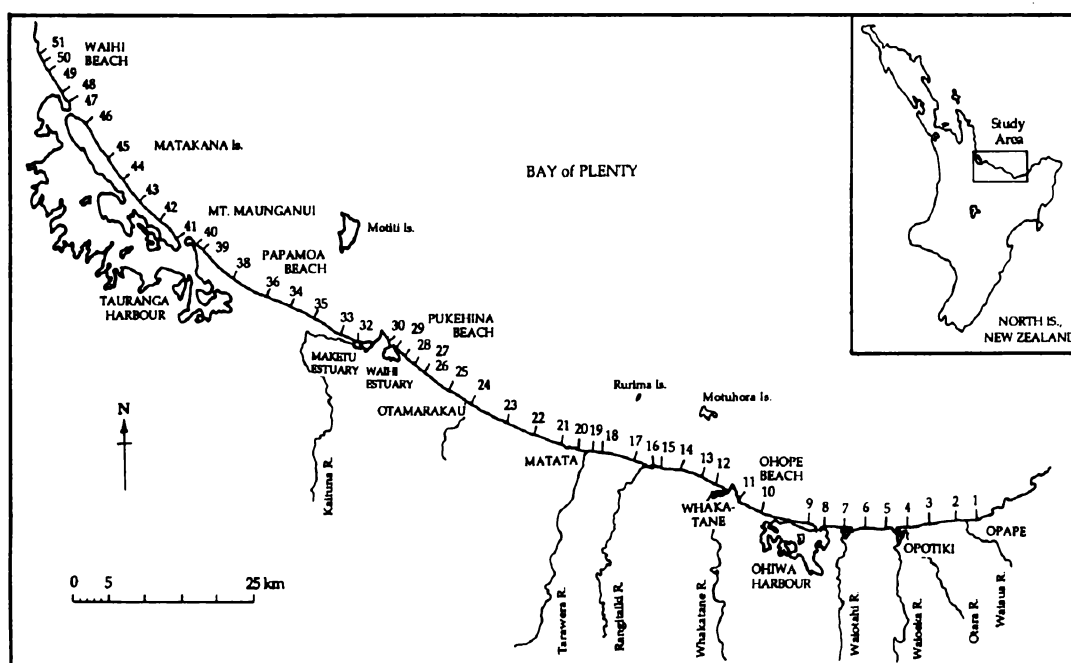


Figure 2.23: Map showing location of BOP Beach Profile Monitoring Sites
(Source: Healy, 1977)

Analysis of the sediment data gathered as part of Dommerholt's profile surveys in 1993 (Dommerholt, 1993) indicates a predominance of fine to medium grained sand (0.16 to 0.3 mm) located within the inner surf zone (0.5 to 8m water depths) for most beaches in the Bay of Plenty data set. Swell generated wave heights from observational wave data obtained by various researchers (see Table 2.6) generally lies within the range 0.8 to 1.5 m with average periods of 8 to 10s. Using this data as the basis of

assessment a theoretical modal wave state was defined based on a breaking wave height of $H_b = 1.2$ m and $T = 8$ s. The results of this analysis for the Bay of Plenty dataset is presented in Table 2.3 and shown in Figure 2.24a.

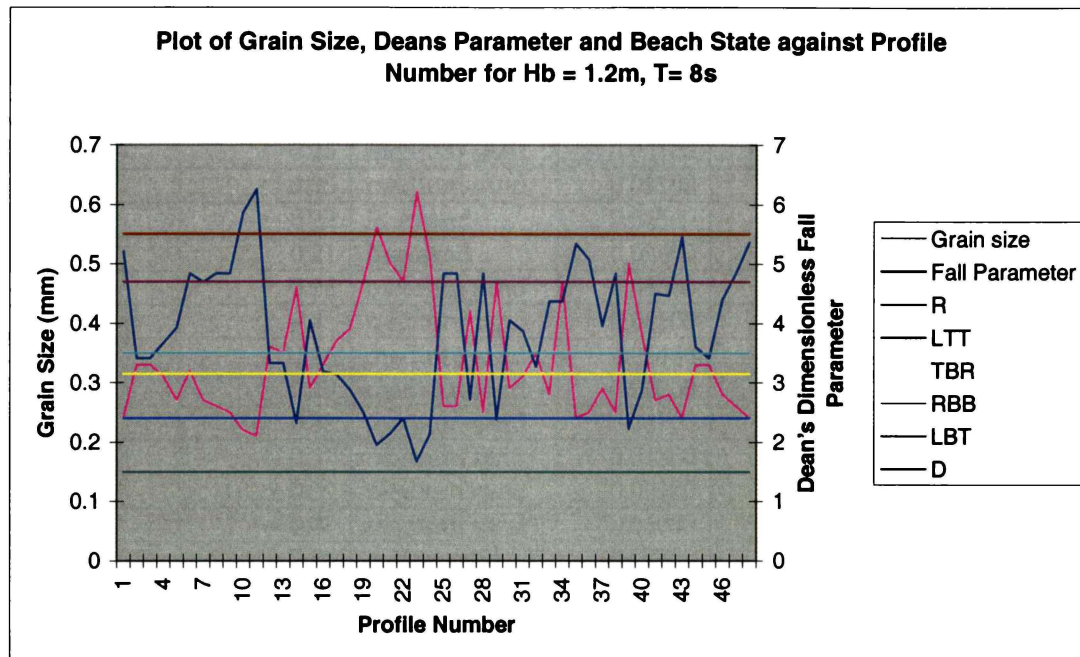


Figure 2.24a: Plot of Grain size (mm) and Dean's dimensionless Fall Velocity (Ω) versus profile number for Bay of Plenty beach monitoring sites for modal wave conditions, $H_b = 1.2$ m and $T = 8$ s. The threshold values of Ω for the six beach states identified by Wright and Short (1983) are also shown as horizontal lines on the graph. The dark blue line describes the variation of Ω as an inverse relationship with sediment size (pink line).

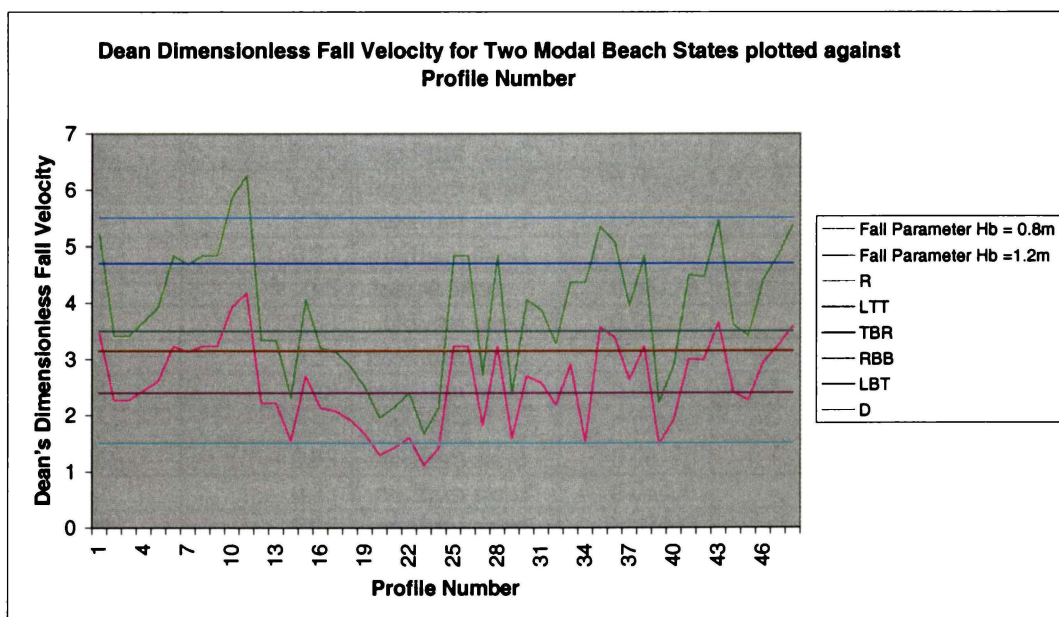


Figure 2.24b: Comparative Plot of two modal wave climates showing the influence of different breaking wave heights ($H_b = 0.8$ m and 1.2 m) on beach state for beaches in the Bay of Plenty dataset.

Beach profile No	m_z diameter	Size Class	W_s	Ω	Morphodynamic Type
1	0.24	medium sand	0.02880	5.21	LBT
2	0.33	medium sand	0.04400	3.41	RBB
3	0.33	medium sand	0.04400	3.41	RBB
4	0.31	medium sand	0.04100	3.66	RBB
5	0.27	medium sand	0.03830	3.92	LBT
6	0.32	medium sand	0.03100	4.84	LBT
7	0.27	medium sand	0.03200	4.69	LBT
8	0.26	medium sand	0.03100	4.84	LBT
9	0.25	medium sand	0.03100	4.84	LBT
10	0.22	fine sand	0.02560	5.86	D
11	0.21	fine sand	0.02400	6.25	D
12	0.36	medium sand	0.04500	3.33	TBR
13	0.35	medium sand	0.04500	3.33	TBR
14	0.46	medium sand	0.06486	2.31	LTT
15	0.29	medium sand	0.03700	4.05	LBT
16	0.33	medium sand	0.04700	3.19	TBR
17	0.37	medium sand	0.04800	3.13	TBR
18	0.39	medium sand	0.05200	2.88	TBR
19	0.47	medium sand	0.06000	2.5	LTT
20	0.56	coarse sand	0.07700	1.95	LTT
21	0.5	coarse sand	0.07000	2.14	LTT
22	0.47	medium sand	0.06250	2.4	LTT
23	0.62	coarse sand	0.08970	1.67	R
24	0.51	coarse sand	0.07050	2.13	LTT
25	0.26	medium sand	0.03100	4.84	LBT
26	0.26	medium sand	0.03100	4.84	LBT
27	0.42	medium sand	0.05540	2.71	TBR
28	0.25	medium sand	0.03100	4.84	LBT
29	0.47	medium sand	0.06300	2.38	LTT
30	0.29	medium sand	0.03700	4.05	LBT
32	0.31	medium sand	0.03880	3.87	RBB
33	0.35	medium sand	0.04588	3.27	TBR
34	0.28	medium sand	0.03432	4.37	LBT
35	0.47	medium sand	0.03432	4.37	LBT
36	0.24	medium sand	0.02810	5.34	LBT
38	0.25	medium sand	0.02960	5.07	LBT
39	0.29	medium sand	0.03800	3.95	RBB
40	0.25	medium sand	0.03100	4.84	LBT
41	0.5	coarse sand	0.06770	2.22	LTT
42	0.38	medium sand	0.05200	2.88	TBR
43	0.27	medium sand	0.03336	4.5	LBT
44	0.28	medium sand	0.03360	4.46	LBT
45	0.24	fine sand	0.02750	5.45	D
46	0.33	medium sand	0.04170	3.6	RBB
47	0.33	medium sand	0.04400	3.41	RBB
48	0.28	medium sand	0.03400	4.41	LBT
49	0.26	medium sand	0.03100	4.84	LBT
51	0.24	fine sand	0.02800	5.36	D

Table 2.3: Beach State Classification for Bay of Plenty Beaches based on modal wave conditions of $H_b=1.2$ and $T=8s$. Profile numbers refer to BOP Coastal Erosion Survey profiles established by Healy et al. (1977).

Figure 2.24a indicates that the majority of beaches within the Bay of Plenty are intermediate beach types ranging generally between RBB and LBT. Dissipative extremes are reached at Ohope, mid sections of Matakana Island and northern Waihi beaches where fine grain sizes exert significant influences over beach state. More reflective extremes are reached for profiles located at Matata where coarser sands exert their influence on beach state. Figure 2.24b shows the effects of reducing modal wave height from 1.2m to 0.8m on beach state resulting in a shift of up to 2 beach state conditions towards the accretionary or reflective end of the spectra.

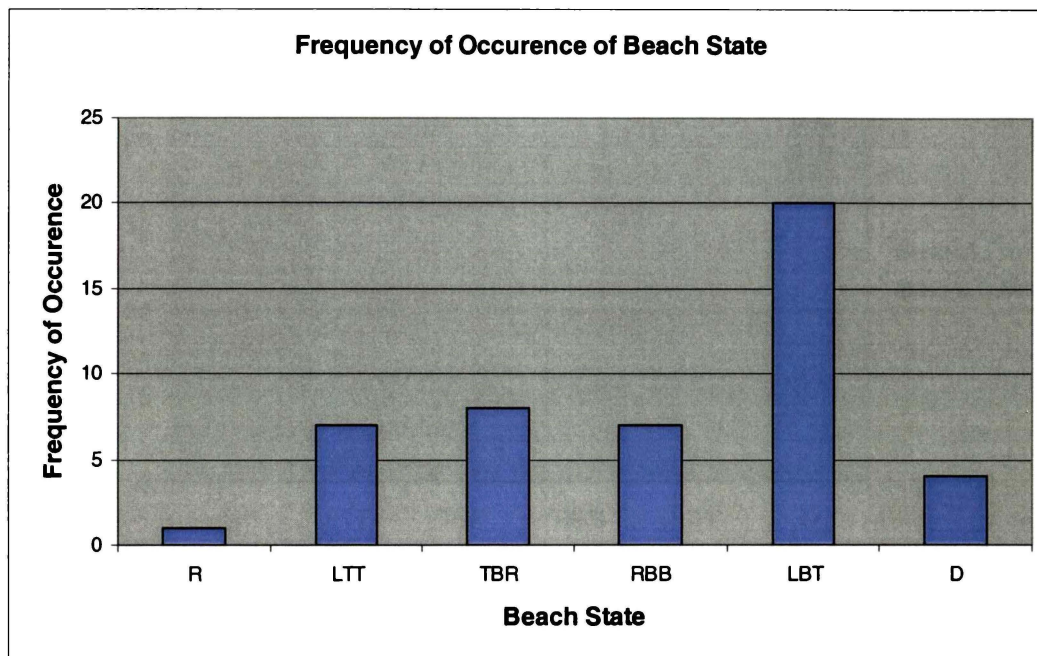


Figure 2.25, Plot of frequency histogram for beach states at 47 BOP beaches calculated for modal wave climate of $H_b = 1.2$ m and $T = 8$ s.

Figure 2.25 shows a simple frequency plot of beach state occurrence for all 47 beaches included in this study under a modal wave climate of $H_b = 1.2$ m and $T = 8$ s. The distribution indicates a Longshore Bar and Trough (LBT) modal beach state (20 beaches) for the Bay of Plenty with most beaches being classified as intermediate (42) under ambient conditions. Fifteen of these beaches also show strongly rhythmic characteristics (RBB or TBR) under this classification regime.

Figure 2.26 shows the effect on beach state prediction from a reducing H_b , which results in a shift of the predicted modal state from LBT to the Reflective – Low Tide Terrace morphology (R-LTT). Aggregation of the six beach states into three as described in Wright *et al* (1984) results in a clearer picture of the shifts involved. These are shown in Figure 2.27.

As indicated in Figures 2.24b, 2.26 and 2.27 a reduction in wave energy from $H_b = 1.2$ to 0.8m under this model will result in significant shifts in predicted beach state by up to two beach states. LBT beaches will therefore tend to move towards more rhythmic forms such as RBB and

TBR while rhythmic forms will tend to more reflective morphologies, which have a potential under this model to dominate as modal types under lower wave energy. However a LBT beach is one of the more stable beach types (see Figure 2.20) and as a consequence such a transformation could take up to 8 days to achieve under accretionary conditions (Wright *et al*, 1984).

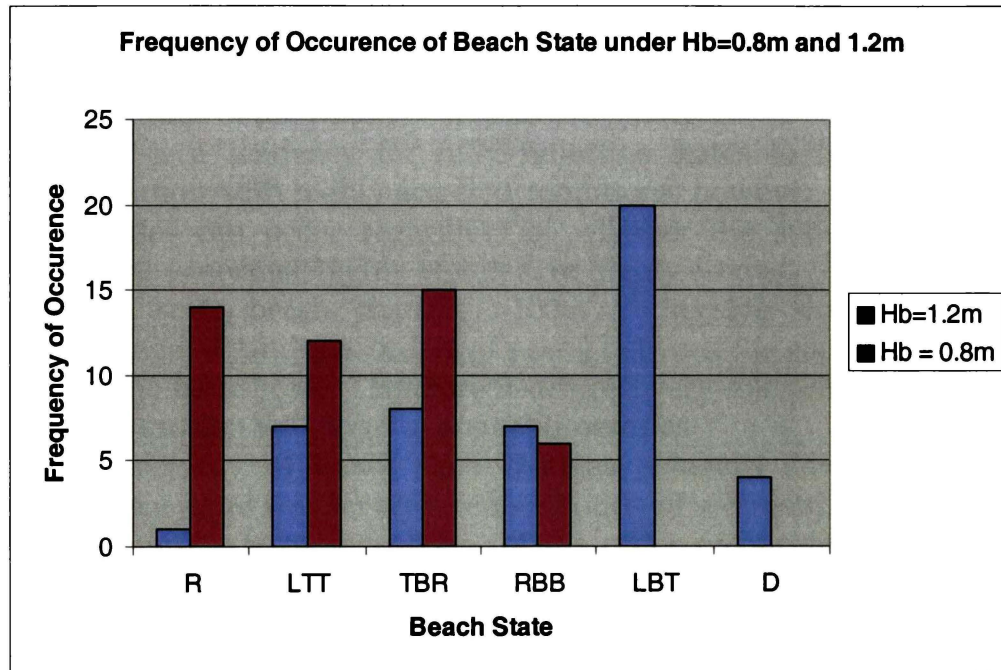


Figure 2.26: Frequency distributions of beach state for BOP beaches depending upon variation in modal wave heights.

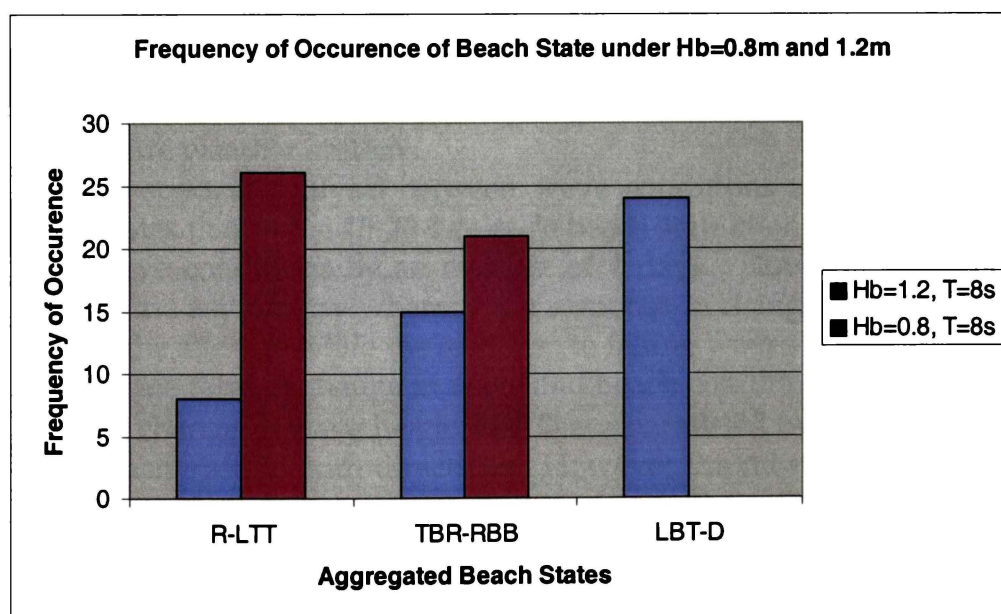


Figure 2.27: Frequency distribution of morphodynamic beach state under two modal wave heights using the aggregated classifications of Wright *et al*, 1984.

Under increasing wave energy, transformation of beach state is relatively rapid with erosion occurring 2 to 3 times as fast from the less stable rhythmic beaches to the more dissipative LBT-D form. Wright *et al* (1984) noted these transformations following observations of beach state conditions at Narabeen, New South Wales. Their work showed that:

- A moderate degree of seasonality was evident in the data with lower energy and more reflective conditions occurring in association with accreted beach conditions. However all states, including the more reflective states such as LTT beaches can occur at any time of the year.
- There is a tendency for fully reflective states to occur only in association with highly accreted conditions, however the full range of states can occur regardless of whether the sub aerial beach volume is normal, highly accreted, or highly eroded.
- Large scale beach changes $>100\text{m}^3\text{m}^{-1}$ involve slow on shore exchange of sand (i.e. orders of years) between the continental shelf and the backshore. Therefore beach recovery following significant storm erosion will occur at annual timescales.
- The majority of beach state changes generally involves higher frequency and smaller scale redistribution of sediment.
- The amplitude of short-term (of the order of one month or less) changes are similar in magnitude to seasonal responses; i.e. the full range of change in beach states can occur over periods of less than a month.
- Harmonic and spectral analyses of wave height and beach state change over time show that the largest amount of beach change takes place in association with 'cycles' of 70 –120 days. However a pronounced secondary peak in amplitude in beach state also occurs with a period of 15-20 days. Wright *et al.* (1984) attributed this short-term cycle as being related to the normal passage of low pressure weather systems.
- Cross-spectral analysis between wave conditions and beach state indicates that in the 15-20 day cycle beach state changes lag changes in wave conditions by an average of 4 days. However there is a response asymmetry whereby the response to rising waves is faster than the average while the response to falling waves is slower;
- The time rates of change in wave and beach conditions indicate that rapid change in wave height and Ω are paralleled by rapid changes in beach state in both directions. However the most rapid changes in beach state do not necessarily accompany the most rapid changes in wave height. For example, Wright *et al.* (1984) noted that rapid changes in beach state were observed even during periods when waves remain relatively constant in height and period implying a significant disequilibrium between beach state and incident wave energy.

- Long term averages of the time derivatives at Narabeen shows that beaches become more dissipative at an average rate of one state per 7.4 days and become more reflective at an average of one state per 8.1 days. These rates of change correspond to a full normal range of change within the time frames of one month or less (i.e. from LBT to LTT or vice versa). However the instantaneous or day to day rates vary considerably dependent on the antecedent state and immediate wave conditions.
- The results of the analysis of rates of change in beach state are presented graphically in Figure 2.22. The shaded area of the graph defines the stable regions around the equilibrium beach state (i.e. with incident wave energy). Disequilibrium exists everywhere outside of the shaded region. Therefore changes in beach state (i.e. erosion and accretion) can be expected to occur in the direction of increasing equilibrium at rates which are proportional to the instantaneous departure from equilibrium conditions and to the energy of the breakers and surf processes. In the case of Narabeen the rates were derived from observation although Wright *et al.* (1984) attempted to rationalise observations by regression analysis with limited success defining the rate of change as,

$$\frac{\Delta s}{\Delta t} = a + b[(\Omega - \Omega_e)\Omega^2], \quad (2.3)$$

where s represents beach state, t time, a and b being regression coefficients and $(\Omega - \Omega_e)\Omega^2$ representing the disequilibrium stress;

- Wright *et al.* (1984) propose that disequilibrium stress can also be used to determine the temporal behaviour patterns of beaches where there is a net input or export of sediment from a coastal sector as a consequence of littoral drift, local input from rivers, or net erosion owing to a relative rise of sea level. For example, a net input of sediment to the surf zone may maintain beach states that are more dissipative than they should be even though the beach is accreting. Conversely more reflective conditions can also be maintained where longshore export of sand or sea level rise positively skews the equilibrium stress distribution resulting in beach erosion without manifesting an erosional beach state.

From these investigations it is apparent that considerable beach state variability can be experienced over relatively short time intervals of days, weeks and months. Such conditions are apparent on beaches in the Bay of Plenty. Smith and Benson (2000) have documented this using information derived from repetitive beach profiling at monthly intervals extending over a period of 15 years. Their work showed a normal distribution of cut and fill events occurring at profile site 21 (Matata -see Figures 2.23 and 2.29) as a representative site for ten beach monitoring sites located between Ohope and Mount Maunganui. Note that under modal wave conditions this beach is classified as LTT-Reflective or fully accreted (see Table 2.3 and Figure 2.24b).

Smith and Benson (2000) showed that Site 21 at Matata was slightly accreted by 0 to 5 m³m⁻¹ over the 15 year study period, which included events ranging from erosion of -60 m³m⁻¹ to accretion of 56 m³m⁻¹. However there was also considerable activity at volumes significantly less than the above extreme values, occurring at periods of up to 1 to 2 months.



Figure 2.29: Aerial photo taken looking east along Matata coast to Matata in far distance (left). Profile 22, is adjacent to the campground in the middle distance, with Profile 21 in far distance adjacent to Matata Township. Note rhythmic features of beach and steep beach face typical of LTT to Reflective beach state.

Like Wright *et al.* (1984), Smith and Benson noted that the reasons for the volume changes were related to climate, which in New Zealand's case is characterised by the regular passage of low and high pressure systems across the country every five to eleven days. They further concluded from their data:

- that short term changes on east coast (Bay of Plenty) beaches indicate the wave climate is characterised by periods of quiescence separated by short periods of large waves associated with passing depressions;
- seasonal patterns in beach behaviour with the largest average sub aerial beach volumes occurring in March and May, and the smallest beach volumes between the months of August and October. This seasonal behaviour accounted for $\pm 10\%$ of beach change from mean beach volumes; and
- that ENSO cycles affect beach volumes with the greatest volumes of material occurring on beaches during El Nino phases with its dominant westerly (offshore) wind patterns. La Nina events on the

other hand encourage onshore winds associated with passing depressions resulting in beach erosion (Smith and Benson, 2000).

Dean's Equilibrium Profile and the Wright and Short Beach State Model

Kotvojs and Fried (1991) have examined the application of the Dean's equilibrium beach model (equation 1.1) in relation to the beach types identified by Short and Wright (1983) and Wright and Short (1983 and 1984). Specifically two statistical measures were applied to examine the success of Dean's equation in representing beach profiles under varying energy environments. These were the Kruskal-Wallis H test, and a non-hierarchical cluster analysis.

The Kruskal-Wallis test was used to determine whether there were significant differences between the measures of 'goodness of fit' and Dean's shape factor (i.e. the exponent) for different beach states. The results of the analysis indicated that at the 0.05 confidence level there was a significant difference between the measures of goodness of fit (Percentage error (PE) and root means square error (RMS)) for the different beach states. The following table reproduced from Kotvojs and Fried's paper summarises the results:

	Reflective	Intermediate	Dissipative	Significant Difference
RMS	1.51	0.42	0.15	Yes
PE	53%	45%	28%	Yes
m	0.49	0.65	0.83	Yes
Significant Difference ¹	Yes	No	Yes	

¹ between m and Deans value of 2/3

Table 2.4: Mean Value of measures for beach profiles in their modal beach state (Kotvojs and Fried, 1991) for a dataset consisting of 25 modally reflective profiles from the New South Wales coast, 957 intermediate profiles measured over 9 year period for 9 transects at Narabeen, NSW, and 12 modally dissipative profiles for beaches at Goolwa, Middleton and South Goolwa, South Australia.

Given that most of the beaches included in this study are intermediate with some having reflective and dissipative morphologies these results have obvious implications for exponent values used in the application of Dean's Equilibrium Beach Profile (1.1) to define BOP beach profiles (Chapter 4).

2.5.2 Bay of Plenty Beach Characteristics

In brief the Bay of Plenty barrier beaches (Waihi Beach, Matakana Island, Mount Maunganui-Papamoa, Maketu, Pukehina, Whakatane, Ohope and Ohope-Opape) can generally be described as progradational features formed following the Holocene marine transgression and since the last

Beach	Section	Name	Trend from 1990 to late 1996 (advance + /retreat -) (m)	Present Beach State	Historical trend over last 60 to 100 years(advance + /retreat -) (m)	Historical State of Beach
Hikurangi	1	Opape East	+20	Advance	-25	Advance
	2	Waiau River West	+8	"	0	"
	3	Tirohanga Stream West	+3	"	-20	"
	4	Hikurangi West	-8	"	-25	"
	5	Waiohanga Beach East	+12	"	+30	"
	6	Waiwhakatoitoi	+4	"	+20	"
	7	Waiohanga Spit	+2	"	0	"
	8	Ohiwa Spit	+32	"	-55	Retreat
Ohope	9	Ohiwa Harbour	-70	Retreat	+200	Advance
	10	Ohope	-7	"	+65	"
	11	West End (Revingtons)	-11	"	+15	"
Thornton	12	Whakatane Spit	+26	Advance	+25	Advance
	13	Piripai (Keepa Road)	+3	"		"
	14	Golf Links Road	+11	"	+55	"
	15	Airport	+1	"	0	"
	16	Rangitaiki East	+3	"	+45 to 120	"
Pukehina - Matata	17	Rangitaiki West	+16	Advance	+50	Advance
	18	Lawrence's Farm	+1	"		"
	19	Tarawera East	+9	"	+55	"
	20	Matata Domain	+3	Dynamic Equilibrium	0	Dynamic Equilibrium
	21	Matata (old Extraction Pit)	+1	"		"
	22	East of Murphy's Motor Camp	+6	"		"
	23	East of Pukowai Free Camp	-0.7	"	-20	"
	24	Otamarakau Patterson's Sand Extraction	-8	"	-25	"
	25	Rodgers Road	-8	Retreat	-15	Retreat
	26	Pukehina Trig	-8	"		"
	27	Pukehina East	-5	"		"
	28	Pukehina Middle	0	"	-13	"
	29	Pukehina West	-4	"	-8	"
	30	Maketu Headland Beach			0 to -3	"
Papamoa	32	Kaituna River East	+6	Dynamic Equilibrium	-14	Retreat
	33	Kaituna West	+3	"		"
	34	Taylor Street Papamoa	+1	"		"
	35	Papamoa Beach (Hickson's)	0	"	0	"
	36	Papamoa	-0.4	"		Advance/Retreat
	38	Te Maunga	-0.4	"		"
	39	Mount Maunganui East	-1.5	"	+2 to +60	"
	40	Mount Maunganui	+9	"		"
Matakana	41	Matakana Bank	-5	Retreat		Advance
	42	Bird Sanctuary Matakana Island	-2	"	+100 to +515	"
	43	Matakana Island Centre (South)	-7	"		"
	44	Matakana Island Centre	-2	"	+30	"
	45	Matakana Island Centre (North)	-9	"		"
	46	Matakana Island North End	-36	"	+55 to 60	"
Waihi	47	Waihi Beach South	-9	Retreat		Retreat
	48	Waihi Beach Pio's Point	-2	"	-35	"
	49	Waihi Beach - Island View	-1	"	-8	"
	50	Waihi Beach Loop	-4	"		"
	51	Waihi Beach North	-5	"	0	"

Table 2.5: Trends in advance and retreat of Bay of Plenty Beaches over the last century and from trends identified by Gibb (Hodges and Deely, 1994)

stillstand approximately 5-6000yrs b.p. Using the morphodynamic classification of Short and Wright (1983) they can also be described typically as intermediate beaches (modal state - Long Shore Bar and Trough) fluctuating in morphology between dominant reflective and dissipative extremes dependent on ambient wave energy and wind conditions. The beaches however tend to be steeper and comprised of coarser sand between Whakatane and Pukehina where morphology conforms more towards the accretionary reflective form described in the Short and Wright (1983) model. The relevance of this model and its relationship with equilibrium beach theory is investigated further in Chapter 4.



Figure 2.30: Aerial view of the southern end of Matakana Island with the Tauranga Harbour Entrance at left. Matakana Bank (geomorphically the ebb tidal delta) and Profile monitoring site 41 are in the middle foreground (see Figure 2.32 below for site map).

Some evidence exists to indicate that the rates of progradation in the Bay of Plenty may have slowed as a result of the littoral system reaching equilibrium after the last major sediment input which occurred following the Taupo eruption of 131A.D. If this is the case then many of the beaches will have reached a subtle stage of dynamic balance as evidenced by the results of the Bay of Plenty coastal monitoring program (Gibb, 1994; Hodges and Deely, 1997). The results of the monitoring analysis carried out by Gibb (1994) as reported by Hodges and Deely (1997) are shown in Table 2.5.

The magnitude of the beach changes noted in table 2.5 imply that most of the beach profiles observed are in dynamic equilibrium with the wave climate and the sediment supply with only a few exceptional cases. The exceptional cases being those profile measurements made adjacent to

notoriously unstable locations such as the distal end of spits and in proximity to ebb tidal deltas where complex current and wave interactions affect shoreline behavior. Examples of these unstable sites include Ohiwa Spit, Matakana Bank (Profile 41 – Figure 2.30) and the north end of Matakana Island (Profile 46 – Figure 2.31).



Figure 2.31: Aerial view of beach erosion on Matakana Island in the vicinity of Beach Profile Monitoring site 46.

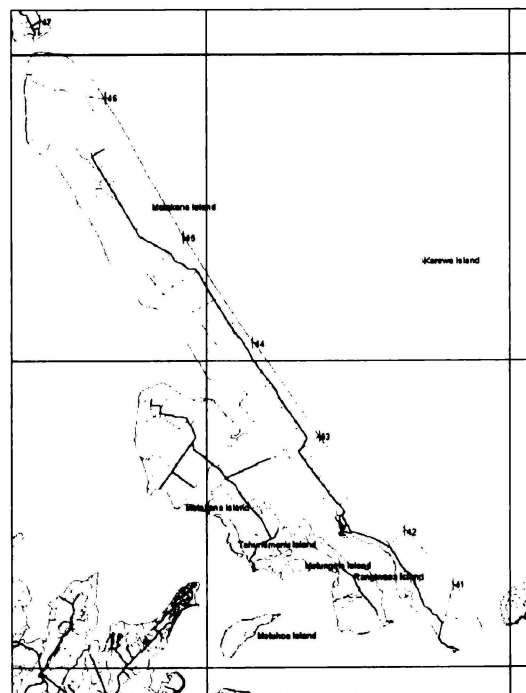


Figure 2.32: Map showing Matakana Island and beach profile monitoring sites. Tauranga Harbour Entrance and Mount Maunganui located at bottom right. Katikati Entrance at top left

2.6 Wave Climate Characteristics of the Bay of Plenty

The Bay of Plenty can be described as a low energy lee-shore with deep water wave conditions derived from ship observations of $H_s=0.15-1.5\text{m}$ and $T_s=5-7\text{s}$ (Pickrill and Mitchell, 1979). Healy *et al.* (1977) describes the BOP wave climate as a mild-meso energy swell wave environment with an offshore significant wave height of approximately 1.5m and a nearshore significant wave height of 0.6m.

However limited data exists from which to characterise the varied wave climate found at Bay of Plenty beaches. Gibb (1997, after Komar 1996) has stated that a continuous wave record of 33 years is required in order to estimate the wave parameters for waves with a 1% probability of occurrence. However all records available for the Bay of Plenty are of relatively short term duration, (measured in different places using a variety of techniques), and with the longest data set available being that recorded by Ports of Tauranga Ltd from the 'A' Buoy wave recorder at the terminal lobe of the ebb tidal delta. This recorder has been operating continuously supplying data for this site from September 1989 (de Lange, 1991).

Other wave height information relevant to the Bay of Plenty includes that sourced from the following:

- shore based observations of breaker height, wave direction, and longshore current made for approximately 1 year at Waihi Beach by Harray (1977) and Whiritoa Beach by Christopherson (1977);
- recorded estimates of wave conditions (wave height and direction) by Harbour Pilots for roughly 3 days a week over a 2 year period at the Tauranga Harbour entrance (Davies-Colley, 1976);
- wave height summaries derived from shipping reports and shore based observations by Pickrill and Mitchell (1979);
- estimates based on visual observations of 9a.m. surf heights at Mount Maunganui Beach between February 1977 and March 1978 (Dahm and Healy, 1980);
- 3.5 months of S4DW wave and current meter measurements at Pukehina Beach by Phizacklea (1993);
- 3 years of wave measurements from an ENDECO Buoy moored in 34 m of water off of the Katikati entrance to Tauranga Harbour, by Macky *et al* (1995);
- analysis of wave data obtained from 'A' buoy wave data by Mathew (1997);
- 4 months of S4DW wave meter measurements by Saunders (1999) in 34 m and 10 m depths off of West End, Ohope Beach covering both winter and summer conditions in 1997-98; and

- wave data collected by Easton (2001) in 16 m of water offshore from Pukehina Redoubt and Newdicks beach in winter 2000 and summer 2001.

The following table is based on de Lange (1991), and summarises the results of this information:

Source	Site	Period	No of Obs.	H (m)	T (s)	Comment
Hydraulics Research Station (1963)	Tauranga Harbour		None	1.5	6	Estimated from average wind conditions using an empirical relationship
Bay of Plenty Harbour Board (unpub.)	North Rock Tauranga Harbour	Feb 1969-Jan 19973	-	0.6	-	Estimated daily mean (or maximum during storms) of pressure transducer records
Davies-Colley (1976)	No.1 Reach Tauranga Harbour	1974-1975	150	1.5	-	Mean of visual observations made by Harbour Pilots at irregular intervals
Davies-Colley (1976)	Salisbury Wharf Tauranga Harbour	Jul-Sep 1975	59	0.3	1.35	Mean of visual observations & estimates from wind data. It is unclear how period was determined
Harray (1977)	Waihi Beach	Apr 1974-May 1975	57	0.6	11	Weekly means of daily visual observations obtained by standard procedures
Harray (1977)	Waihi Beach	Apr 1974	13	0.33	9.6	Daily Means from a pressure transducer in 5m depth, 340m offshore
Davies-Colley & Healy (1978)	No1 Reach Tauranga Harbour	1974-1975	-	1.5	6	Data from Davies-Colley (1976) & Hydraulics Research Station (1963)
Harray & Healy (1978)	Waihi Beach	Apr 1974-May 1975		0.6	11	Data from Harray (1977)
Dahm & Healy (1980)	Mt Maunganui Beach	Feb 1977-Mar 1978	140	1.1	-	Mean of irregular daily visual observations of 9am surf height
Phizacklea (1993)	Pukehina - Matata	July - August 1993	time series data	0.6	5.7	S4/10 wave recorder
Stephens (1996)	Waihi	28/6/95 -1/7/95	64	0.48	7.3	S4DW
Saunders (1999)	Ohope (West End)	6/12/97 - 20/2/98 & 20/7/98 - 20/8/98	time series data -	H _s = 0.81 - 1.09	T _s = 8.07 - 7.98	S4ADW & S4DW
Easton (2002)	Pukehina - Matata	8/3/01 - 7/4/01	time series data	H _s = 0.44	T _s = 10.9	S4ADW

Table 2.6: Summary of wave observations carried out in the Bay of Plenty (modified from de Lange, 1991)

Electronic time series wave data has been collected since 1989 and reported by a number of researchers. De Lange (1991) describes an analysis of data recorded at the Port of Tauranga wave recorder positioned at 'A' Beacon, Tauranga Harbour Entrance. Wave data for the period 27 June 1989 to 20 August 1991 were analysed and mean wave conditions were found to be $H_{mo} = 0.501$ m and $T_p = 10.63$ s where H_{mo} is the significant wave height and T_p is the peak wave period.

De Lange (1991) describes the wave climate at 'A' Beacon as consisting of persistent long period swell with a local sea component superimposed. The dominant approach direction for waves in this dataset was from the northeast quadrant with a minimum significant wave height of 0.13 m. Following calibration checks using an InterOcean S4DW directional wave recorder de Lange (1991) determined that waves heights measured by the A beacon recorder were under-recorded by between 60-80%. A linear regression relationship established between the two recorders indicated that the mean annual significant wave height should be adjusted to 0.81 m.

De Lange (1993) carried out an extremal wave analysis to determine the likely significant and maximum wave heights using the same Tauranga dataset. The wave predictions determined using differing distributions are contained in table 2.7 below.

	FT-1	Weibull Distribution			
		k=0.75	k=1.00	k=1.40	k=2.00
Correlation	0.9876	0.9943	0.9733	0.9894	0.9950
Sum square of residuals	0.0340	0.7276	0.1673	0.347	0.0126
Return Period (y)	H_s (m)	H_s (m)	H_s (m)	H_s (m)	H_s (m)
2	4.64	4.59	4.64	4.63	4.60
5	5.25	5.40	5.32	5.19	5.06
10	5.71	6.06	5.83	5.59	5.38
25	6.31	6.98	6.52	6.09	5.76
50	6.77	7.71	7.03	6.45	6.03
100	7.23	8.47	7.55	6.80	6.29

Table 2.7: Expected significant wave height with the specified return based on Fisher-Tippett Type I and Weibull distributions (Source: de Lange, 1993).

The most reliable predictions are given by the distribution with the highest correlation and lowest sum of squared residuals (de Lange, 1993). De Lange's analysis showed that the Weibull Peak distribution with a shape factor of $k=2.00$ provided the most reliable predictions. This distribution has been plotted in Figure 2.33 with the 90% confidence limits indicated by the dotted lines.

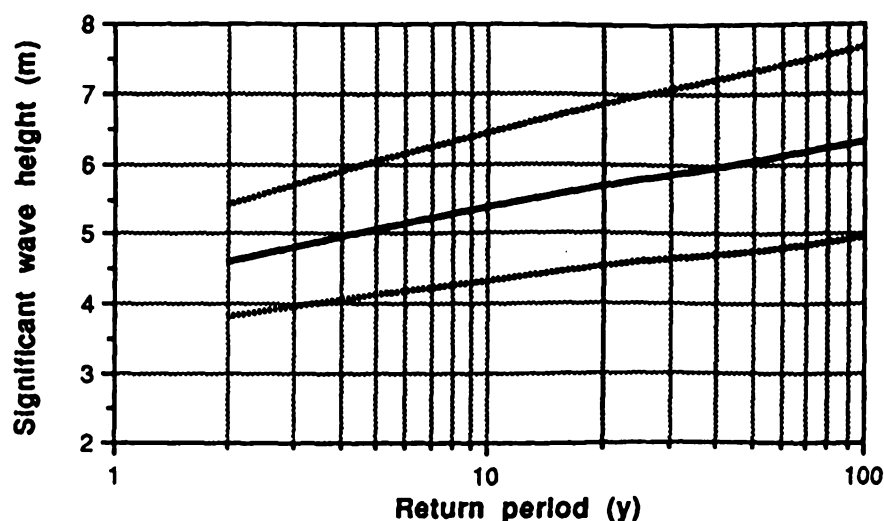


Figure 2.33: Extreme significant wave height predicted by the Weibull distribution with $k=2.00$. Dotted lines indicate 90% Confidence Intervals (Source: De Lange 1993)

On the basis of this analysis de Lange determined that a 20 year significant wave height for the Port of Tauranga entrance was 5.76 m, which corresponds to a maximum wave height of between 7.94 and 8.05 m based on the observed relationship in the data between significant and maximum wave heights. Likewise for a 100-year return period storm $H_{\max}$ was likely to be 9.23 m with the 90% confidence interval ranging between 11.1 and 7.3 m.

Macky *et al.* (1995) reported the results of 3 years (1991-1993) of wave buoy measurements from a site located in 34 m-water depth off of the Katikati entrance. Reported significant wave heights from this study were less than 1 m for 70% of the time with a mean of 0.8m and a maximum of 4.3 m. Wave steepness analysis indicated that many of the waves originated close to the buoy and that most of the wave energy arrived from the northeast to eastern sector. Spectral analysis also showed considerable variability in short-term wave energy with some weak seasonality evident in the record. Significant wave heights exceeded 1.2m more often in all three winters, and in spring 1992 and autumn 1991 than in summer (Macky *et al.*, 1995).

The data for the Macky *et al.* study however was gathered during a period now recognised as being dominated by El Nino weather conditions. This phase of the Southern Oscillation results in wind patterns that are often characterised by offshore directed westerlies which drive offshore directed surface currents and produce weather patterns that lower the frequency of wave generating storms traversing the area (*pers com.*, de Lange 1998). Therefore the results of Macky *et al.* (1995) are skewed to lower energy conditions than would otherwise be evident if La Nina wave conditions

were analysed. These factors have implications for the interpretation of equilibrium conditions of beaches in the Bay and for the application of storm scenarios for erosion prediction.

Earlier the Central Laboratories of the Ministry of Works gathered wave information for the period between the 6th July 1977 and 17th March 1978 from a wave buoy moored off of Hicks Bay in deep water (Macky *et al.*, 1995). This data has been analysed and commented on by various authors (Pickrill and Mitchell, 1979; Frisby and Goldberg, 1981; Macky *et al.*, 1995). Based on this information Pickrill and Mitchell (1979) described the northern wave climate as being, *"...sheltered from the prevailing westerly and southerly winds and waves that dominate the wave climate on the west and south coasts and influence the remainder of the East Coast. Deep water records from East Cape show the predominant approach direction to be from the north through to east...The northeasterly waves originate from tropical cyclones passing north of New Zealand, from blocking anticyclones, and from depressions moving down from the northwest..."*. Wave heights vary between 0.5 m and 1.5 m and periods of 5 to 7 s with heights at the beach typically varying between 0.4 to 0.8 m with periods of 9 to 12 s (Gibb & Reinen-Hamill, 1997 after Pickrill and Mitchell 1979).

Harris *et al.* (1983) agree that wave energy in this region comes mainly from the north to north-east sector with some refraction of southerly swells occurring around East Cape, with concomitant reduction in wave height. Significant deepwater wave heights vary depending upon ambient weather with conditions ranging from lows of 0.37 m under anticyclonic conditions to 5.2 m under the combined influence of a merged Tasman and weak ex tropical cyclone with a fetch to the east. Harris *et al.* noted that wave conditions were rarely less than 0.5 m with the overall average being about 1.25 m. The highest wave recorded in the dataset was 7.8 m under the influence of a blocked Tasman cyclone. The average significant wave height that was calculated from the average spectrum was 1.55 m.

Gibb and Reinen-Hamill (1997) reported data from the Port of Tauranga wave recorder located at A-Beacon gathered during three cyclone events, (Fergus, Drena and Gavin) that impacted on the Bay of Plenty between December 1996 and March 1997 to demonstrate the effects of 'extreme' events on wave climate. The data are shown in Table 2.7 (reproduced from Gibb and Reinen-Hamill) below.

These data reveal that at their peak Cyclones Fergus, Drena and Gavin generated significant waves of up to 7.0-9.0 m, 3.5-4.4 m, and 4.2-4.7 m and maximum wave heights of between 9.1 and 10.5 m, 5.4 and 6.3 m, and 5.5 and 7.2 m respectively. This information will be referenced further in Chapter 5 as input into design storm scenarios for use in the required storm erosion modeling.

CYCLONE FERGUS									
Day	Tide			Wave Heights (m)		Wave Period (s)	Storm Tide(m)		
	State	Height	NZST	H-sig.	H-max	T _z	Sulphur Pt	Tug Berth	A-Beacon
29 Dec 96	Low	0.2	03:59	1.5-1.8	2.5-3.2	7.51-8.27	0.00	0.00	0.00
	High	1.7	10:24	1.6-2.1	2.1-3.5	8.36-9.10	0.05	0.00	0.00
	Low	0.3	16:33	2.2-2.7	3.2-4.6	8.44-9.10	0.04	0.03	-0.10
	High	1.6	22:39	2.3-3.0	3.8-4.7	8.71-9.10	0.15	0.08	0.04
30 Dec 96	Low	0.3	04:39	2.9-3.8	4.3-6.0	8.53-9.75	0.12	0.11	0.04
	High	1.7	11:06	4.0-5.1	5.0-7.6	9.00-12.41	0.21	0.18	0.12
	Low	0.3	17:15	5.1-6.8	6.4-8.5	9.75-12.22	0.35	0.32	0.12
	High	1.6	23:19	7.0-9.0	9.1-10.5	11.53-13.65	0.57	0.51	0.17
31 Dec 96	Low	0.3	05:19	4.8-7.1	6.2-9.7	11.87-13.65	0.34	0.28	0.23
	High	1.7	11:48	3.7-4.8	4.9-7.1	10.63-11.53	0.23	0.15	0.18
	Low	0.3	17:57	3.0-4.0	4.1-5.2	9.87-10.77	0.10	0.07	0.03
1 Jan 97	High	1.6	00:01	2.4-2.9	2.9-4.3	7.95-9.00	0.15	0.09	0.13
CYCLONE DRENA									
Day	Tide			Wave Heights (m)		Wave Period (s)	Storm Tide(m)		
	State	Height	NZST	H-sig.	H-max	T _z	Sulphur Pt	Tug Berth	A-Beacon
10 Jan 97	High	2.0	08:02	0.5-0.6	0.7-1.0	7.25-8.90	0.07	0.00	0.21
	Low	0.2	14:03	1.0-1.4	1.8-2.6	6.16-6.60	0.01	0.03	0.14
	High	1.9	20:15	2.7-3.8	3.7-6.1	7.65-8.44	0.15	0.12	0.24
11 Jan 97	Low	0.1	02:22	3.5-4.4	5.4-6.3	8.44-9.20	0.25	0.22	0.18
	High	2.0	08:52	2.6-3.4	3.7-5.0	7.80-8.80	0.21	0.19	0.24
	Low	0.2	14:56	2.3-2.9	3.2-4.8	7.95-9.00	0.23	0.22	0.12
	High	1.9	21:07	1.4-1.6	2.1-2.7	8.19-9.00	0.11	0.06	0.18
CYCLONE GAVIN									
Day	Tide			Wave Heights (m)		Wave Period (s)	Storm Tide(m)		
	State	Height	NZST	H-sig.	H-max	T _z	Sulphur Pt	Tug Berth	A-Beacon
10 Mar 97	Low	0.0	01:41	1.1-1.3	1.6-2.2	9.52-12.04	-	0.16	0.20
	High	2.0	08:07	1.5-1.8	2.0-2.8	10.23-11.70	-	0.12	0.28
	Low	0.0	14:16	2.3-2.6	2.8-3.9	11.37-12.79	-	0.11	0.00
	High	1.9	20:31	2.9-3.3	3.8-5.0	12.04-14.12	-	0.05	0.15
11 Mar 97	Low	0.0	02:36	3.9-4.8	5.5-6.5	12.22-14.36	-	0.10	0.14
	High	2.0	09:00	3.1-3.8	4.2-5.5	11.37-12.79	-	0.10	0.25
	Low	0.0	15:07	3.4-4.2	4.1-6.4	11.22-12.22	-	0.18	0.21
	High	1.9	21:24	3.4-4.4	4.5-6.5	11.06-12.79	-	0.18	0.40
12 Mar 97	Low	0.0	03:30	4.2-4.7	5.5-7.2	11.06-11.67	-	0.30	0.32
	High	1.9	09:52	3.4-3.7	4.2-6.4	11.06-12.04	-	0.21	0.40
	Low	0.0	15:58	2.5-3.1	3.2-4.5	10.23-12.04	-	0.23	0.23
	High	1.9	22:15	2.2-3.0	2.6-4.2	10.63-11.70	-	0.18	0.37
13 Mar 97	Low	0.0	04:21	1.8-2.2	2.5-3.5	10.50-11.06	-	0.22	0.30
	High	1.9	10:44	1.8-2.4	2.8-3.8	11.22-12.41	-	0.15	0.30
	Low	0.0	16:47	2.0-2.4	2.5-3.8	10.11-11.53	-	0.18	0.10
	High	1.8	04:07	1.5-1.8	2.3-3.3	10.36-11.53	-	0.15	0.31

Table 2.7: Wave and Storm Tide Data for Cyclones Fergus, Drena, and Gavin recorded by the Port of Tauranga at A Beacon and within Tauranga Harbour at the Tug Berth and Sulphur Point wharves (Source: Gibb J.G. and Reinen-Hamill R.A., 1997).

2.7 Conclusion

Bay of Plenty beaches have developed mainly on Holocene barrier deposits over the last 6000 years. The current physical characteristics of this environment are microtidal with typically low energy swell and wave

conditions driving beach morphology. However wave heights can increase and vary dramatically, particularly during the passage of cyclonic storms and associated fronts that can bring northerly winds and swells to the Bay of Plenty Coast. It is the periodic passage of these storms, especially those of tropical origin (ex-tropical cyclones), that can result in extremely low pressures and strong winds causing storm surge and high waves ($H_s > 8$ m) conditions along the coastline. These events can cause significant erosion and coastal inundation and have the potential to cause significant property damage in vulnerable locations (e.g. Waihi Beach, Papamoa, Pukehina, Ohope and Ohiwa Spit).

The barrier deposits are predominantly prograded, formed from substantial volcanic sediment input transported to the coast from rivers rising in the North Island volcanic centers of Okataina, Taupo and Haroharo. Sediment sampling and analysis indicates that the beaches are mainly fine to medium grained sand beaches consisting of quartzofeldspathic mineralogy with some localised coarse sand beaches located in the vicinity of Matata (see Profiles 20 to 24, Figure 2.13a) northwest of Whakatane (Healy *et al*, 1977; Phizacklea, 1993).

From the evidence reviewed sea level appears to be rising long term with rates of approximately 1.7 mm/year (Hannah, 1988 & 1990). This result is consistent with global rates cited in the literature. The response to this rising sea level would normally presume coastal retreat. However this trend does not appear to be evident in the monitoring results obtained over the last 25 years and in response to specific tectonic events such as the Edgecumbe Earthquake in 1987. Evidently sediment inputs into the Bay of Plenty littoral system have been sufficient to maintain beaches over the interdecadal period. However it is also interesting to note that secular uplift rates in the vicinity of the Whakatane Graben (Nairn and Beanland, 1989) are also equivalent to sea level rise rates thus complicating any potential explanation for this coastal sector.

Analysis of sediment sampling results associated with beach profiling (using mean fall velocities) classified in accordance with Wright and Short's (1983) Beach State model indicates that the beaches sampled were predominantly intermediate beaches with the modal state being longshore bar and trough under dominant wave conditions of $H_b = 1.2$ m and $T = 8$ s. However other more rhythmic beach topographies were also well represented, in particular those beaches described in the literature as Rhythmic Bar and Beach (RBB) and Transverse Bar and Rip (TBR).

Beach state, however, is highly responsive to weather, climate and incident wave energy with changes in beach state occurring over periods less than a month with minor changes occurring at daily and weekly intervals. Rates of change are dependent on the amount of disequilibrium that exists between wave energy and current beach state. Wright *et al* (1984) have shown that average rates of change based on long-term

observations vary between one state per 7.4 days for beaches becoming more dissipative and one state per 8.4 days for beaches becoming more reflective. With greater disequilibrium, change rates can be substantially increased to 0.5 states per day (Wright *et al*, 1984) where significant wave energy drives beach state change towards the dissipative end of the spectra (see Figure 2.22).

Hodges and Deely (1997) identify the historical trends of advance and retreat for the beaches included in this study. The size of beach change measured at or above Mean Sea Level in this analysis (see Table 2.5) is entirely consistent with the beaches existing in a state of dynamic equilibrium, and existing as intermediate beach states. Wright *et al* (1984) indicated that short-term beach change at Narabeen involves volume changes less than $50 \text{ m}^3\text{m}^{-1}$ with maximums generally less than $100 \text{ m}^3\text{m}^{-1}$. Volumetric changes of this order resulted in changes of between one and three-beach states over periods of 15-20 days at rates between 0.1 and 0.5 states per day.

Smith and Benson (2000) identified that most of the changes experienced in their study of Bay of Plenty beaches were typically of the same order when analysed at monthly intervals. For a single beach profile at Matata Maximum beach volume changes measured ranged between $-60 \text{ m}^3\text{m}^{-1}$ and $+56 \text{ m}^3\text{m}^{-1}$ with 4% being less than $\pm 25 \text{ m}^3\text{m}^{-1}$. The modal class for this beach showed slight accretion over time. Analysis of the sediment characteristics for this beach indicate that the beach was at the reflective end of the intermediate beach state spectra (LTT) and consequently may be prone to short term changes of 1 to 2 beach states as a response to wave energy changes. The Narabeen results indicate that such beach state changes involve volumetric changes of approximately $40\text{-}50 \text{ m}^3\text{m}^{-1}$, a result that appears to be consistent with the changes noted for the Bay of Plenty Beaches by Smith and Benson (2000).

Finally there is evidence that ENSO cycles (Smith and Benson, 2000) tend to influence beach state conditions in the Bay of Plenty on a seasonal through to decadal basis. Consequently it is likely that at any point in time beach state will also be dependent on the phase of the Interdecadal Pacific Oscillation (IPO) (de Lange and Gibb, 2000; de Lange 2000) because the IPO tends to modulate or act as a carrier wave for the ENSO cycle. These cycles tend to act as overall drivers of climate and thus will affect beach state.

The factors that tend to influence beach state include incident wave energy, dominant wind direction, sea level and atmospheric pressure, and water temperature. During El Nino extremes, sea level on the east coast of New Zealand falls, due mainly to lower water temperatures and offshore wind stress, while during the opposite ENSO phase (La Nina) water levels

are elevated as a result of increased water temperatures and onshore wind stress.

ENSO also changes the frequency of extratropical cyclones affecting New Zealand (de Lange, 2000). These form with increased frequency during La Nina conditions as tropical cyclones north of New Zealand and these track along paths that are more likely to affect New Zealand and in particular its northeast coast (de Lange, 2000). La Nina also appears to affect the frequency of storms from other origins and as a consequence influences air pressure patterns across New Zealand, affecting the frequency and magnitude of storm surges along the coast (de Lange and Gibb, 2000).

Furthermore ENSO also affects the distribution of winds over New Zealand. During La Nina the subtropical anticyclonic belt moves south increasing the incidence of northerly winds and on shore (or erosive) conditions, while during the El Nino phase the westerly wind belt moves north producing westerly or offshore winds (and accretional conditions) over the Bay of Plenty.

Smith and Benson (2000) compared beach volumes in terms of both ENSO and seasonal conditions. They found that ENSO cycles were reflected in beach state with the greatest beach volumes occurring during El Nino while onshore winds and increased storm and wave energy during La Nina resulted in increased beach erosion. Further, their work indicated that the Southern Oscillation might affect beach volumes by $\pm 10\%$ from modal beach state with some losses being much greater during erosive events.

Smith and Benson (2000) also identified seasonal variations in beach condition that take place with the largest average beach volumes occurring in March to May and the smallest volumes between the months of August and October. Seasonal variations were shown to account for $\pm 10\%$ of beach change. The combination of both conditions may act to reinforce either erosive or accretional conditions and thus affect the observed beach state class.

The information reviewed in this chapter, together with the physical and morphodynamic characteristics described provides background data for use as input into the modeling work carried out in chapters 4, 5 and 6 relating to a conceptual erosion-hazard model for the Bay of Plenty, and provides potential explanations for the modeling results obtained.

Chapter 3

Equilibrium Beach Profile Models

3.1 Introduction

The overall aim of this research as outlined in Chapter 1, is to apply two-dimensional parametric modelling utilising EBP theory to coastal hazard assessment. This chapter discusses the theoretical concepts involved with this approach with a particular focus on the application of profile evolution models to coastal hazard assessment.

3.2 Profile Evolution Models - Background

Application of beach profile modelling allows the prediction of beach behaviour under variation of forcing mechanisms. However because of the complexity of the forcing mechanisms, predicting beach change to any degree of accuracy is often difficult.

De Lange (1998) identified that prediction approaches can be divided into two basic types:

- profile evolution models which concentrate on diabathic sediment transport and the consequential changes that can occur to beach profile morphology; and
- planform evolution models that alternatively concentrate on parabathic transport and related plan morphology.

Roelvink and Brøker (1993) identified four main types of profile evolution models, namely:

- descriptive models that classify beach state in terms of simple parameters An example of this type is the Wright and Short (1984)
- morphological model incorporating the Dean parameter as discussed in Chapter 2;

- equilibrium Profile models evolving a characteristic shape as a function of wave and sediment characteristics, e.g. Bruun (1954) and Dean (1977);
- empirical profile evolution models as an extension to the equilibrium concept. Examples include the Kriebel and Dean (1985) model that has evolved into EDUNE by Kriebel (1989) and SBEACH (Larson and Kraus, 1989). In these models the rate of cross-shore transport, and thus the motion of the depth contours, is proportional to the deviation of the profile slope from equilibrium conditions. Because these models utilise empirical coefficients they require calibration for use at any given sites; and
- 'process' based or 'deterministic' profile models employ numerical descriptions of processes that contribute to profile development. In this way they can be used or developed to model beach profiles in a quasi three-dimensional form (Roelvink & Broker, 1993). These models tend to be complex and are therefore difficult to apply.

This research focuses on profile evolution models, and this chapter reviews the theory and the application of equilibrium beach models and their development into empirical profile evolution models such as SBEACH (Larson and Kraus, 1989) and EDUNE (Kriebel, 1989).

3.3 Definition of the Equilibrium Beach Profile

Fenneman wrote in 1902, *"There is a profile of equilibrium which the water would ultimately impart if allowed to carry its work to completion. The continual change of shoreline and the supply of new drift are ever changing conditions with which no fixed form can be in equilibrium. There are, however, certain adjustments of current, slope, and load which, when once attained, are maintained with some constancy. The form involved in their adjustments is commonly known as the profile of equilibrium. When this profile has once been assumed the entire form may slowly shift its position toward or from the land, but its slope will change little or not at all."* (Bruun, 1954).

Many other definitions and descriptions also occur in the literature. In the *Encyclopaedia of Beaches and Coastal Environments* (Pilkey et al., 1993; Schwartz, 1982) a profile of equilibrium is defined as a *"long-term profile of ocean bed produced by a particular wave climate and type of coastal sediment"*. In 1983 Dean described the equilibrium beach profile as *"...an idealisation of conditions which occur in nature for particular sediment characteristics and steady wave conditions"*. A further example is provided by Larson (1991) who described the equilibrium beach profile as: *"A beach of specific grain size, if exposed to constant forcing conditions, normally assumed to be short period breaking wave, will develop a profile shape that displays no net change in time."*

Dean (1991) listed four characteristics of equilibrium beach profiles (EBPs). These are:

- they are usually concave upward;
- the smaller the sand diameter, the more gradual the slope;
- the beach face is usually planar; and
- steeper waves result in more gradual slopes.

However the literature dealing with EBP concepts recognises that this represents an ideal and that this profile is difficult to identify in nature. Rather there is "... *a dynamic equilibrium that exists as the beach profile changes continuously in response to surf zone conditions*" (Moore, 1982). Kriebel *et al.* (1991) state that "*A beach profile in true equilibrium never exists in nature because nearshore water levels, waves, and currents are constantly changing*".

A common characterisation of the equilibrium beach profile is that developed by Bruun (1954) and Dean (1977). This is based on the well-known equation,

$$y = Ax^m \quad (3.1)$$

in which y (or sometimes h) represents the depth from the water surface (often taken as mean sea level), x represents the distance offshore, and A and m are empirical coefficients based on statistical analysis and best fit to measured profiles (Komar and McDougal, 1994). The coefficient A is essentially a scale parameter that has been subsequently related to sediment characteristics (viz. Moore, 1982; Dean, 1987), and m is a coefficient that determines the shape or more precisely the degree of curvature for the predicted profile from equation 3.1.

Dean (1977) and Bruun (1954) concluded from statistical analysis of a large number of beaches in Denmark and along the southern and eastern shores of the United States, that a constant value of m could be fixed at $\frac{2}{3}$. They also concluded that an EBP could be predicted from equation 3.1 which produced a profile extending seawards from the shoreline that is smooth, monotonic, and concave upwards.

3.4 Derivation of the Dean Model - Theory and its Problems

3.4.1 Origin of the Model

The Dean model had its derivations from the work of Bruun (1954). Bruun carried out periodic surveys initially of the Danish coast to determine shoreline position and depth contours in an attempt to determine annual bottom scour, dh , as a function of the shoreline recession, dx , and the distance x from the shoreline to the specified point at depth h , where the

scour is known. Evidence of a potential relationship came from consideration of profile data to a depth of -9m taken from the Northern and Southern barriers enclosing Lime Bay on the Danish North Sea coast.

Profiles were evaluated from historical data for the period 1874 to 1948 of which the 1934 profiles were regarded as being representative of the equilibrium profile. These then provided the reference profiles for the development of the model. They were chosen because they characterised a period that was marked by minimal recession of the overall profile.

Out of this work Bruun formalised the relationship describing the equilibrium profiles for both the northern and southern barrier data which resulted in the formula

$$dh = \frac{P_1 dx}{x^{1/3}} \quad (3.2)$$

in which P_1 is a constant for each profile, but may vary along the coast. Bruun integrated this equation is integrated to take the form of,

$$h^{3/2} = Px \quad (3.3)$$

or alternatively,

$$h = Ax^{2/3} \quad (3.4)$$

where $A=P^{2/3}$. Values for P ($\text{ft}^{1/2}$) were found to be 0.09 for the average northern barrier profile and 0.082 (Bruun, 1954) for the southern barrier profile giving equivalent A values of 0.201 and 0.189 ($\text{ft}^{1/3}$) or equivalent A values in metres^{1/3} of 0.135 and 0.127 for a sand grain size of 0.2 to 0.3 mm (Bruun, 1954).

Bruun then expanded his analysis to profiles of Mission Bay, California, USA. Using the data from six surveys carried out during 1950 he noted that the "fairly stable" beach and seaward decrease in median grain size indicated that the profiles had reached maturity and a quasi-equilibrium state. The main changes found in the profiles between surveys were consistent with the seasonal migration of sediment seaward over the winter period and shoreward during summer caused by seasonal changes in wave climate. The profiles were therefore grouped according to winter (3 surveys) and summer (2 surveys) profiles from which representative P values of 0.096 and 0.1 were obtained providing equivalent A value of 0.141 and 0.145 $\text{m}^{1/3}$ (0.2095 and 0.2155 $\text{ft}^{1/3}$) respectively while holding the m coefficient fixed at $2/3$.

Dean (1977) subsequently analysed 502 profiles from the dataset compiled by Hayden *et al.* (1975), extending from the eastern end of Long Island to the Texas-Mexico border on the U.S. East and Gulf of Mexico coast. The locations of these profiles are shown in Figure 3.1. Dean's initial investigations were centred on a least squares analysis in which equation 3.1 was fitted to individual profiles in the data set in an analysis that allowed both parameters in the power curve freedom to vary.

The resulting distribution of values for m derived from that analysis clearly indicated that the exponent value was centred on 0.6 to 0.7, with an overall average value (Dean, 1977) of 0.66 (see Figure 3.2). The corresponding A parameter averaged from the dataset $\approx 0.244 \text{ m}^{1/3}$ (ranging from 0.053 to $0.268 \text{ m}^{1/3}$ based on geomorphic provinces) compared with Bruun's (1954) averaged values of between 0.127 and $0.145 \text{ m}^{1/3}$. In contrast to the ' m ' parameter the values obtained for the A values were strongly skewed with more than 70% of results less than that of the mean.

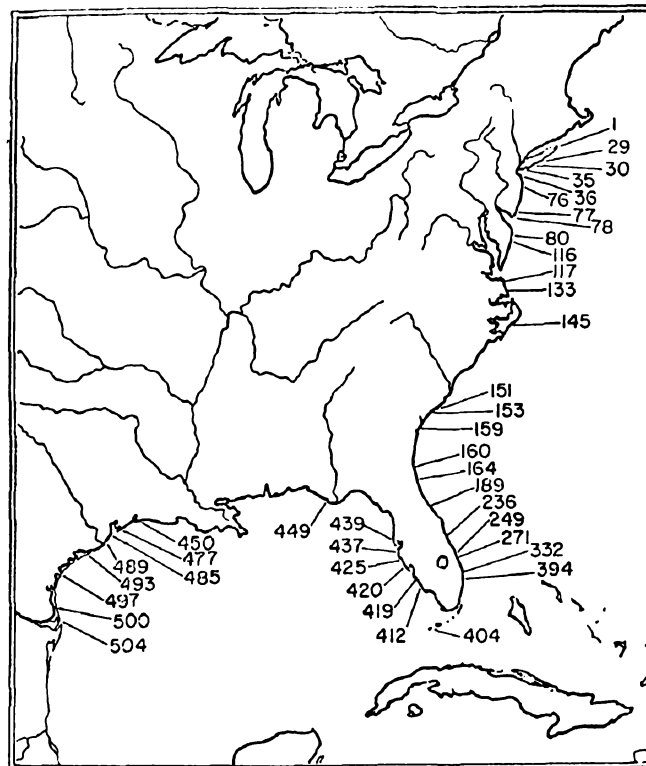


Figure 3.1: Location Map showing the 502 Profiles used in the analysis of Dean (Source: Dean, 1977).

However, encouraged by the central value and distribution of the m value Dean carried out subsequent analysis to characterise A holding the m value constant at $\frac{2}{3}$. The resulting range of A values were markedly reduced with over 99% of values below $0.202 \text{ m}^{1/3}$ and no values exceeding $0.337 \text{ m}^{1/3}$.

Additionally, nearly 70% of values were located in the range between 0.067 and 0.135 $\text{m}^{1/3}$ with the average value for A being 0.101 $\text{m}^{1/3}$. Significantly, the overall root mean square error between the measured and predicted profiles increased only slightly, from 0.62m with a variable m to 0.65m with $m=2/3$.

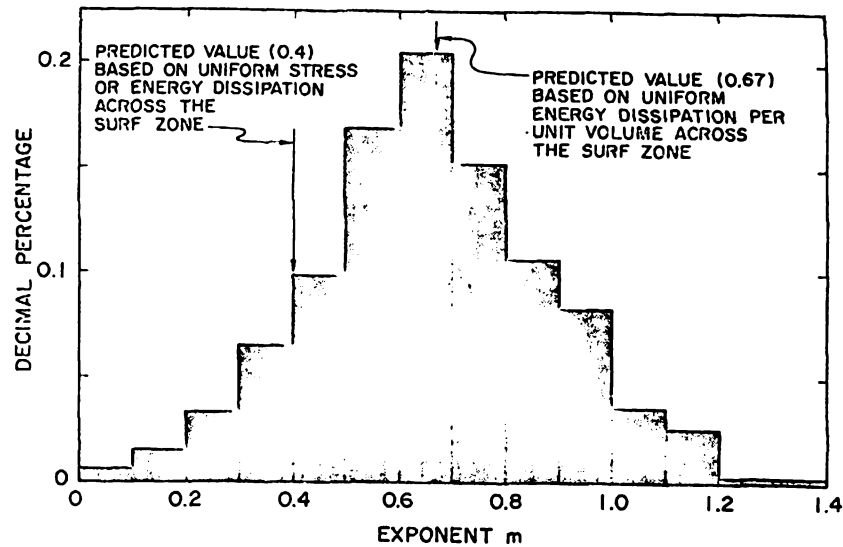


Figure 3.2: Histogram of Exponent m in Equation $h=Ax^m$ for 502 United States East Coast and Gulf of Mexico Profiles – see Figure 3.1 (Source: Dean, 1977).

3.4.2 Theoretical Derivations

Empirical relationships of a power form which represent the EBP however require explanation in terms of theory in order to provide the empirical results with some meaning. Both Dean and Bruun have both attempted to provide this explanation in terms of a causal mechanism.

Bruun (1954) suggested that the profile form seaward of the bar may be controlled by cross-shore shear stress on the bed resulting from wave action. Under equilibrium conditions the shear stress per unit area and the gradient of transported wave energy were both considered to be constant. The equation that resulted may be readily reduced to equation 3.4. A second approach assumed the loss of wave energy was solely a result of bottom friction and that this loss per unit area was constant. This resulted in a profile of the form:

$$h = A \frac{x}{T^{4/9}} \quad (3.5)$$

in which T is the wave period. A small range of wave periods would effectively reduce this equation to equation 3.4.

Dean (1977) presented three potential forcing mechanisms involved in the development of EBPs. These mechanisms were based on the hypothesis that sediment of a given grain size will be stable in accordance with the incident energy acting upon it. Principally this energy results from wave action through a complex system of constructive and destructive forces Dean (1991). Dean (1977) analysed the mechanism based on linear wave theory utilising the assumption that the ratio of breaking wave height to water depth is constant. Therefore strictly the mechanisms can only be applied to the surf zone and for spilling waves although the model has generally been applied to the broader zone of wave influence.

Dean (1977) considered the equilibrium profile form to be potentially controlled by one of three mechanisms:

- uniform longshore shear stress;
- turbulence resulting from uniform wave energy dissipation per unit plan area; or
- turbulence resulting from uniform wave energy dissipation per unit water volume.

All three mechanisms produced an equilibrium profile of the form $h = Ax^m$.

The following table illustrates the related m values obtained.

Energy Dissipation Mechanism	'm' coefficient values for $h = Ax^m$
Uniform Longshore Shear Stress	2/5
Turbulence: uniform wave energy dissipation per unit plan area	2/5
Turbulence: uniform wave energy dissipation per unit water volume	2/3

Table 3.1: Energy Dissipation Mechanism and derived 'm' Coefficient (modified from Dean, 1977)

These results correlate well with the central tendency for m found by Bruun (1954). Bowen (1980) also found equivalent values for 'm' using a different approach to Dean to derive equilibrium profiles with exponent values of 2/5 and 2/3.

While these derivations of the equilibrium beach profile (particularly the uniform energy dissipation per unit water volume) have proven useful in

directing subsequent development of the Dean EBP, they are generally given little consideration in the practical application of the model owing to the number of inherent assumptions.

3.4.3 Definition of Model Parameters

In the Dean EBP model the two parameters controlling the nature of the profile are the A (shape factor) and m (scale factor) parameters. A significant amount of research has therefore focused on trying to refine these two parameters in terms of both theory and in relation to the values assigned to them.

The ' m ' parameter controls the amount of curvature in the profile. Depending on the value assigned the profile may vary from convex upward ($m > 1$) to a linear profile ($m = 1$) to concave upward ($m < 1$), with a continuing reduction in m values below 1 corresponding to an increasing degree of curvature (see Figure 3.3). Dean (1977) determined the m value as $\frac{2}{3}$ based on empirical analysis of a large data set of 502 profiles. This confirmed Bruun's (1954) earlier figures and enabled him to further develop the model based on $y = Ax^m$ without having to consider any variability of both m and A . However while this may have been acceptable for the profiles investigated, it is important to consider the general applicability of this figure to reflect beaches in general.

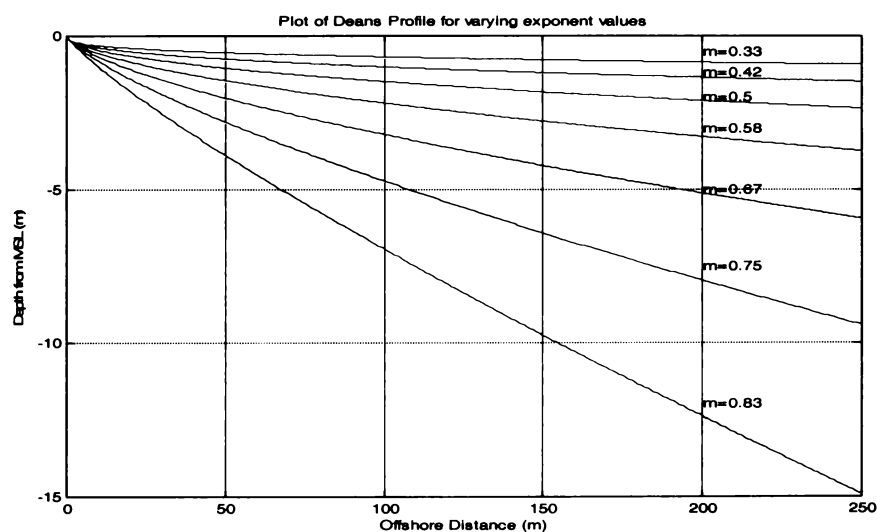


Figure 3.3: Plot of Dean's Equilibrium Profile $y = Ax^m$ for varying exponent value for m . Note increasing degree of curvature with reduction of m .

The m parameter results collated in Table 3.2 include values derived from various geographical origins, with each investigation comprising a number of profiles and beaches. Variations of beach sediment size and mineralogy, wave climate and tidal range are also evident in the reports. The results presented are therefore by necessity average values. Of the 10 studies listed, six report best fit m values very close to 0.67. Kotvojs and

Fried (1991) grouped profiles dependent upon whether their modal beach states were representative of intermediate, reflective, or dissipative forms as defined by the Wright-Short model of morphodynamic beach state (Wright and Short, 1984; Wight *et al*, 1985).

As discussed in Chapter 2 the Wright and Short (1984) model classifies beaches according to their characteristic morphologies and dominant surf zone dynamics or processes. The reflective and dissipative states in this model represent the extremes bounding the intermediate beach states.

The intermediate beach forms analysed by Kotvojs and Fried (1991) had an average best fit of 0.65 in close agreement with the other six studies noted here. The value obtained for the reflective beaches is in close agreement with that reported by Green and Boon (1988) for beaches included in their study which "exemplify the reflective state"; while the results obtained for dissipative beaches are in close agreement with Vellinga's results (from Kotvojs and Fried, 1991).

The empirical results are summarised in Table 3.2 and appear to provide some evidence of a relationship between the parameter m and the beach type, with beach type being dependent on the nature of the forcing mechanisms controlling profile development and shape. That is, it may be concluded for beaches of a modal intermediate state (i.e. neither reflective nor dissipative) that the appropriate ' m ' value to apply is 0.67 while m values of approximately 0.5 (2/5) and 0.8 (4/5) may be more applicable for dissipative and reflective beaches respectively.

Author	' m ' Parameter
Boon & Green (1988)	0.55
Bruun (1954)	0.67(2/3)
Dean (1977)	0.66
Hughes (1978) cited in Stockberger & Wood (1990)	0.671
Kotvojs & Fried (1991)- reflective	0.49
- intermediate	0.65
- dissipative	0.83
Moutzouris (1991)	0.68
Seymour & Castel (1988)	~ 0.67
Stockberger & Wood (1990)	0.632
Vellinga (1982) cited in Kotvojs & Fried (1991)	0.78
Wright et al. (1982) cited in Wright et al (1991)	0.45 (2/5)

Table 3.2, Best Fit values for the ' m ' parameter as determined by various studies

It is noted that many of the studies used profiles that extend seaward well beyond the normal extent of the surf zone. This may call into question the theoretical derivation of the equilibrium beach profile in terms of both the mechanisms proposed by Dean (1977) described previously and the consequent values derived for m . This has implications for the subsequent development and application of the Dean model based on either the use of a constant m value of $\frac{2}{3}$ or to corroborate the values provided in Table 3.2 for the various modal beach states.

Work by Larson and Kraus (1996a, b) and Larson *et al.* (1999) revisited the theoretical basis for the Dean EBP and their work presents a model that re-examines the theoretical derivation of the Dean profile. The approach proposes a two-zoned definition of the EBP similar to that of Inman *et al.* (1993). In this approach the inner or surf zone represents a beach profile developed under surf or breaking wave conditions while the outer or offshore zone depicts the portion of the EBP formed under shoaling or unbroken waves.

The surf zone coincides with that of Dean's (1977) profile for which Dean (1977) and Bruun's (1954) exponent value of $\frac{2}{3}$ was confirmed. However the proposed model differs from Dean (1977) in that the model allows for water and sediment circulation and sedimentation within the surf zone. Whereas Dean's approach is 'localised' (Larson *et al.*, 1999) by the assumption of sand redistribution through uniform energy dissipation per unit volume with no allowance made for sediment transport across the profile (i.e. there is an implicit assumption of zero sediment transport).

Larson and Kraus (1996a) and Larson *et al.*'s (1999) model assumes that sediment suspended by wave energy dissipation is circulated through the surf zone by undertow action adjacent to the seabed. The return shoreward directed flow is responsible for ensuring that no sediment is lost beyond the breakpoint as a result of resuspension of sand under the action of breaking waves. The model relies on a sediment balance approach to formulating the profile response. This is done assuming that the change in profile form towards equilibrium occurs as a result of the suspension of sediment under the turbulence caused by wave breaking, redistribution by current action and deposition or sedimentation under the effects of gravity. Changes in profile shape therefore occur as a result of spatial variations in the volume of sand suspended due to the direct influence of turbulence caused by wave breaking.

The authors acknowledge that the sediment balance equation incorporating these effects could be expanded to include an allowance to incorporate the effects of beach slope and asymmetry of the velocity field. However such a modification would not permit a simple parameterisation of terms and therefore does not permit an analytical solution to be

developed to determine an EBP shape. To overcome this problem Larson *et al.* (1996a) make the explicit assumption in the model that undertow transportation of sediment dominates within the surf zone over forces resulting from beach slope and wave asymmetry.

The sediment balance equation for this formulation takes the form of:

$$(q_u c_0)_{x+\Delta x} - (q_u c_0)_x = \mu w c_0 \Delta x \quad (3.6)$$

for an element Δx , where the sediment transport in the undertow m_u is taken as the product between the flow q_u and a characteristic concentration c_0 (mass of sediment/unit water volume) in the sediment layer that is transported offshore. The transport m_u increases with x and this is balanced by a vertical transport m_w due to net sedimentation where m_w is parameterised in terms of c_0 and the sediment fall velocity w . The return flow is expressed in terms of the shoreward directed mass transport due to wave breaking as,

$$q_u = \lambda_u (gh)^{1/2} \gamma h \quad (3.7)$$

where λ_u is an unspecified coefficient, g the acceleration due to gravity, h the profile depth, and γ the breaker depth ratio. Equation 3.7 therefore illustrates that the breaking wave height (γh) and wave speed ($(gh)^{1/2}$) determines local mass transport. Combining equations 3.6 and 3.7 and letting Δx approach zero yields the following equation which describes the relationship between wave height and speed, and sediment fall velocity and concentration:

$$\frac{d}{dx} (\lambda_u \sqrt{gh} \gamma h c_0) = \mu w c_0 \quad (3.8)$$

where h and c_0 are unknowns.

However in order to derive an EBP from equation 3.8 the sediment concentration (c_0) must be solved and the expression integrated to solve h with respect to x . Using linear wave theory Larson *et al.* (1999) derived an expression for wave energy dissipation per unit volume and time (W_b) in the bottom boundary layer as:

$$W_b = \frac{1}{\Delta s} \frac{2}{3\pi} f_d \rho u_0^3 \quad (3.9)$$

where Δs is the typical thickness of the boundary layer, f_d the wave energy dissipation coefficient, and u_0 the bottom wave orbital velocity. Equating

this expression with the work needed per unit volume and time to keep the sand in suspension,

$$W_b = c_0 \frac{\rho_s - \rho}{\rho} gw \quad (3.10)$$

yields

$$c_0 = \varepsilon_f \frac{1}{\Delta s} \frac{2}{3\pi} f_d \frac{\rho u_0^3}{gw(s-1)} \quad (3.11)$$

where s is the specific weight of the sediment (ρ_s/ρ). Using Grant and Madsen (1979) bottom boundary layer thickness defined as $\Delta s = k_b u_m T$, (where k_b is a non dimensional coefficient, u_m is the shear velocity based on the maximum shear stress $\tau_{b,max}$, and T is the wave period) to substitute back into equation 3.11 using $u_m = (f_w/2)^{1/2} u_0$ yields:

$$c_0 = \frac{\varepsilon_f}{k_b} \frac{2\sqrt{2}}{3\pi} \frac{f_d}{\sqrt{f_w}} \frac{\rho}{gw(s-1)} \frac{u_0^2}{T} \quad (3.12)$$

where,

$$u_0 = \frac{1}{2} H \sqrt{\frac{g}{h}} = \frac{1}{2} \gamma \sqrt{gh} \quad (3.13)$$

with H being the wave height and $H = \gamma h$ (γ is the breaker index ≈ 0.78) being assumed for breaking waves. Substituting (3.13) into (3.11) yields,

$$c_0 = \frac{\varepsilon_f}{k_b} \frac{\gamma^2}{3\sqrt{2}\pi} \frac{\sqrt{f_w}}{w} \frac{\rho}{(s-1)} \frac{h}{T} \quad (3.14)$$

where f_w is the wave friction factor and $f_w = f_d$. This shows that the characteristic concentration in the bottom layer (c_0) varies proportionally with the water depth and increases with offshore distance to the breakpoint. Solving equation 3.8 using equation 3.14 results in a EB profile. Since c_0 appears on both sides of equation 3.8, all quantities that are independent of x may be eliminated resulting in the following equation:

$$\frac{d}{dx} (\lambda_u \sqrt{gh} \eta^2) = \mu w h \quad (3.15)$$

This equation may be differentiated with respect to x and h and then integrated with the boundary condition of $h=x=0$ as follows:

$$\begin{aligned}
\text{Let } Q &= qh = \lambda_u \sqrt{gh} \gamma h^2 \\
\frac{\partial Q}{\partial x} &= \frac{\partial Q}{\partial h} \frac{\partial h}{\partial x} \\
\frac{\partial Q}{\partial x} &= \frac{5}{2} h^{3/2} \lambda_u \sqrt{g\gamma} \frac{\partial h}{\partial x} \\
\frac{5}{2} h^{3/2} \lambda_u \sqrt{g\gamma} \frac{\partial h}{\partial x} &= \mu w h \\
\frac{5}{2} h^{1/2} \lambda_u g^{1/2} \gamma \partial h &= \mu \partial x \\
\lambda g^{1/2} \gamma \int \frac{5}{2} h^{1/2} \partial h &= \mu w \int \partial x \\
\lambda g^{1/2} \gamma \frac{10}{6} h^{3/2} &= \mu w x \\
h^{3/2} &= \frac{3}{5} \frac{\mu w}{\lambda_u \sqrt{g\gamma}} x
\end{aligned}$$

and this reduces to the familiar power equation,

$$h = \left[\frac{3}{5} \frac{\mu w}{\lambda \sqrt{g\gamma}} \right]^{2/3} x^{2/3} \text{ and,} \quad (3.16)$$

$$h = Ax^{2/3} \quad \text{where } A = \left[\frac{3}{5} \frac{\mu w}{\lambda_u \sqrt{g\gamma}} \right]^{2/3}. \quad (3.17)$$

This independently confirms the theoretical exponent value (shape factor) for the EBP. The scale factor A is shown to have a functional relationship with w (sediment fall velocity) and g (gravity) equivalent to the derivation of A by Kriebel *et al.* (1991) (also compare with Bowen, 1980). That is

$$A = 2.25 \left(\frac{w^2}{g} \right)^{1/3} \quad \text{and} \quad \left(\frac{24}{5} \frac{\beta(s-1)}{\epsilon \kappa^2} \right)^{2/3} \approx 2.25 \quad (3.18)$$

where β is an unknown concentration factor, ϵ is a fraction of the wave energy dissipation per unit volume due to wave breaking in which ϵ must equal the energy dissipation associated with suspended sand grains falling under their own submerged weight, and κ is the breaker depth ratio, where $\epsilon D_e = \beta(s-1)\rho g w$, with s being the specific gravity of the sediment. This is then substituted into Dean's formulation (Kriebel *et al.*, 1991: see equation 3.21 below) for A to obtain the above relationship in terms of grain fall velocity. This is discussed further in the following sections.

The offshore zone in Larson *et al.* (1999) is more problematic in its application. The authors have analysed the derivation of an EBP using three different approaches.

- The first approach utilises a heuristic assumption that the profile shape seaward of the breakpoint at equilibrium is such that the waves minimise the dissipation of energy as they progress across the profile.
- The second approach involves the integration of a detailed sediment transport formula proposed by Madsen (1991, 1993) to determine an EBP slope that produces zero net transport of sediment.
- The third approach involves the formulation of a conceptual model that assumes a balance at equilibrium between onshore transport due to wave asymmetry and offshore transport due to gravity.

The development of these formulations results in the derivation of EBPs that are of the power form for the offshore zone with exponents that vary slightly but all three approaches produce power functions with exponent values around 0.2 (Larson *et al.*, 1999). These formulations confirm the common observations that the offshore profile is milder than that produced within the surf zone.

However to apply the offshore models in the sense demanded in this study (i.e. to determine profile response to disequilibrium) requires either:

- The determination of the boundary conditions h_b and h_c and the direction of sediment transport for the first formulation, or
- Determination (for formulations 2 and 3) of the local sediment transport rate (based on an assessment of the balance between offshore and onshore transport rates) in relation to EBP shapes obtained from laboratory and field data.

This is required so that some of the unknown coefficients in the transport formulae can be either determined or eliminated completely from the formulae. Larson and Kraus (1996b) have developed such sediment transport formulae that allow calculation of the sediment transport rate for the offshore zone based on how far the profile is from equilibrium. Further evaluation of this approach is required to determine whether it offers advantages over a single parametric curve as developed by Dean (1977).

Defining the 'A' Parameter. The dimensions of A within the original Dean (1977) model are length raised to the power of an exponent which equals 1-m. If m was allowed to vary the dimensions of A could change from profile to profile. This would greatly complicate the correlation of A with other factors which may control profile shape. Setting m constant at

$2/3$ therefore defines the dimensions of the A parameter, the units of A being $(\text{metres})^{1/3}$. The theoretical derivation of $h=Ax^{2/3}$ has been derived from the basis of uniform wave energy dissipation per unit water volume.

Equations 3.19 to 3.21 describe the relationship.

$$\frac{\partial(EC_g)}{\partial x} = \frac{\gamma}{8} \sqrt{g\kappa^2} \frac{\partial}{\partial x} (h^{3/2}) = hD_3(D) \quad (3.19)$$

$$h = A_3 x^{2/3} \quad (3.20)$$

In which,

$$A_3 = \left[\frac{24}{5} \frac{D_3(D)}{\gamma \sqrt{g\kappa^2}} \right]^{2/3} \quad (3.21)$$

The derivation of the Dean formulations from linear wave theory is shown below:

$$F = \frac{\gamma}{8} \kappa^2 \sqrt{g} h^{3/2}, \text{ where } \gamma = \rho g \quad (3.22)$$

$$\frac{\partial F}{\partial x} = \frac{\partial F}{\partial h} \frac{\partial h}{\partial x}, \text{ and}$$

$$D_3 = \frac{1}{h} \frac{\partial F}{\partial x},$$

$$D_3 = \left[\frac{5}{16} \sqrt{g\kappa^2} \gamma h^{1/2} \frac{\partial h}{\partial x} \right] \frac{1}{h}. \quad (3.23)$$

Integrating both sides yields,

$$\int D_3 dx = \int \frac{5}{16} \sqrt{g\kappa^2} \gamma h^{1/2} dh,$$

$$D_3 x = \frac{5}{16} \frac{2}{3} \sqrt{g\kappa^2} \gamma h^{3/2},$$

and equating for h produces the Dean EBP model as defined above where,

$$h = \left[\frac{24}{5} \frac{D_3}{\gamma \kappa^2 \sqrt{g}} \right]^{2/3} x^{2/3} \quad (3.24)$$

$$\text{and} \quad A = \left[\frac{24}{5} \frac{D_3}{\gamma \kappa^2 \sqrt{g}} \right]^{2/3} \quad \text{with} \quad h = Ax^{2/3}. \quad (3.25)$$

Dean (1977) used linear wave theory to develop this relationship, the primary feature being that "the A parameter may singularly be related to the stability characteristic of the sediment under a certain level of turbulent water particle fluctuations". Based on this consideration Dean (1977) presented a relationship between the wave energy dissipation rate per unit volume and the sediment size or fall velocity, w , of a sediment particle. Where $w^2 \propto D^{2.5}$ (based on spherical quartz spheres of 0.2- 0.3mm dia.) and $w^2 \propto D$ for Reynolds Number ranges in which the drag is quadratic.

Dean (1977) has stated that there are several possible relationships that could be proposed to represent the variation of the dissipation factor D_3 with sediment characteristics. He notes that it may be possible to solve this from the following idealised equation,

$$\frac{\partial e_t}{\partial t} + \frac{\partial}{\partial x}(Ve_t) = D_3 - \beta(t) \quad (3.26)$$

in which e_t represents the turbulent energy density per unit volume, V is the convective velocity of turbulent energy transfer and β the transfer rate from turbulent energy to heat. The term D_3 represents the production of turbulent energy via the dissipation of organised wave energy. Dean considers that while it is possible to obtain solutions to equation 3.26 based on assumed values for the input parameters, meaningful solutions required further experimental and theoretical investigation. A more useful approach considered by Dean was to obtain a functional relationship between D_3 and sediment characteristics

The functional relationship between D_3 (uniform energy dissipation per unit volume) and sediment size using quartz spheres is shown in Figure 3.4. Using the average A value determined from the 502 profiles from the study, Dean (1977) then plotted the energy dissipation function $D_3(D)$ against particle diameter based on,

$$D_3(D) \propto w^2(D) \quad (3.27)$$

or for sediment diameters D_A and D_B ,

$$D_3(D_B) = D_3(D_A) \frac{w^2(D_B)}{w^2(D_A)} \quad (3.28)$$

Empirical Relationship Between A and Sediment Characteristics. The principal empirical relationship between A and sediment size, D , used to date is that presented by Moore (1982). Forty field and laboratory profiles were analysed to determine the best fit A values for the EBP equation

$h = Ax^{2/3}$. The subsequent A value for each profile was subsequently plotted against either the profile median grain size or range of grain sizes where this was known. Data from two other studies (Hughes & Swart) were added to the plot (Moore, 1982).

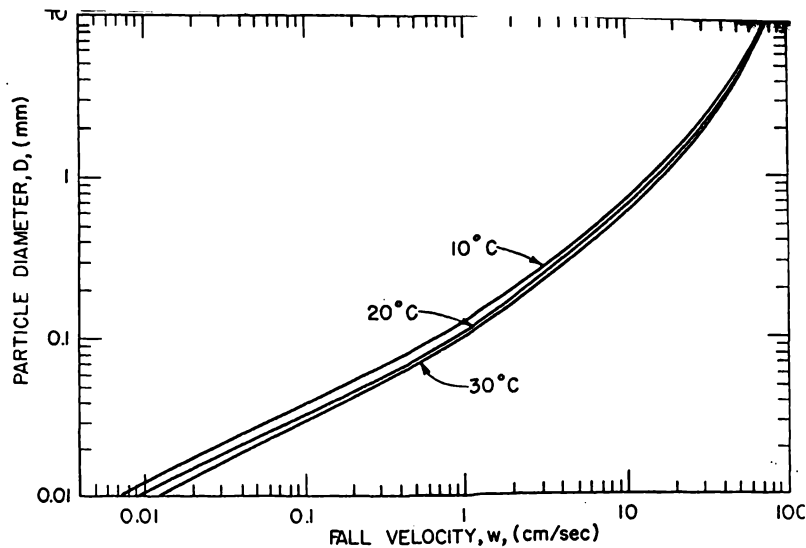


Figure 3.4: Fall Velocity versus Diameter for Quartz Grains, (Source: Dean, 1977)

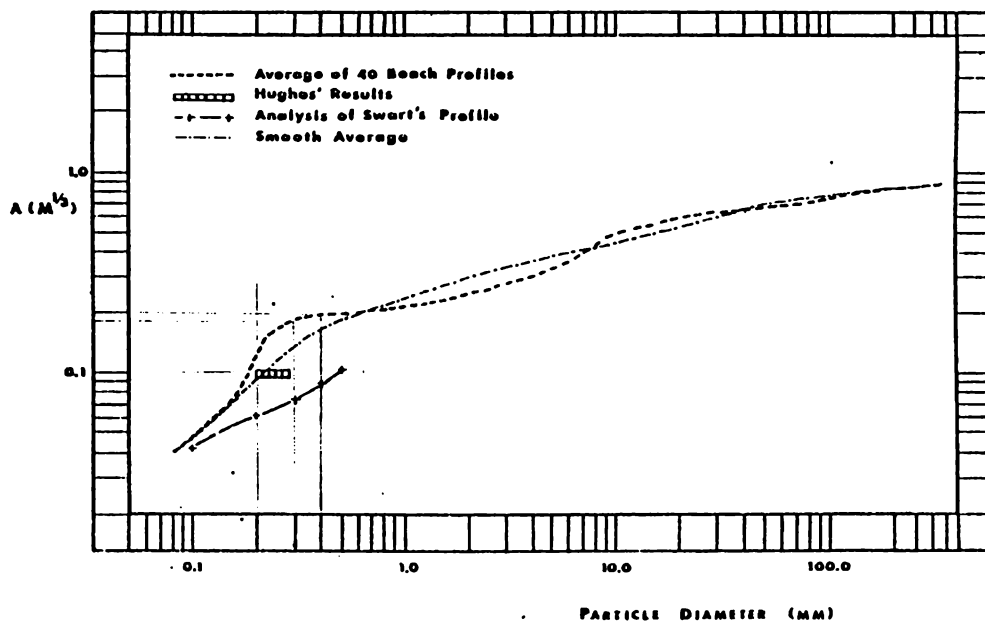


Figure 3.5: Particle Diameter versus shape factor A (Source: Moore, 1982)

A "smooth average" line through the plotted data was suggested as representing the A vs D relationship. By transforming the sediment size to fall velocity, w , using a standard empirical relationship, Dean (1987) redefined A with respect to w (see Figure 3.6). This resulted in a near linear plot on the log plot. The equation for this relationship is:

$$A = 0.067w^{0.44} \quad (3.29)$$

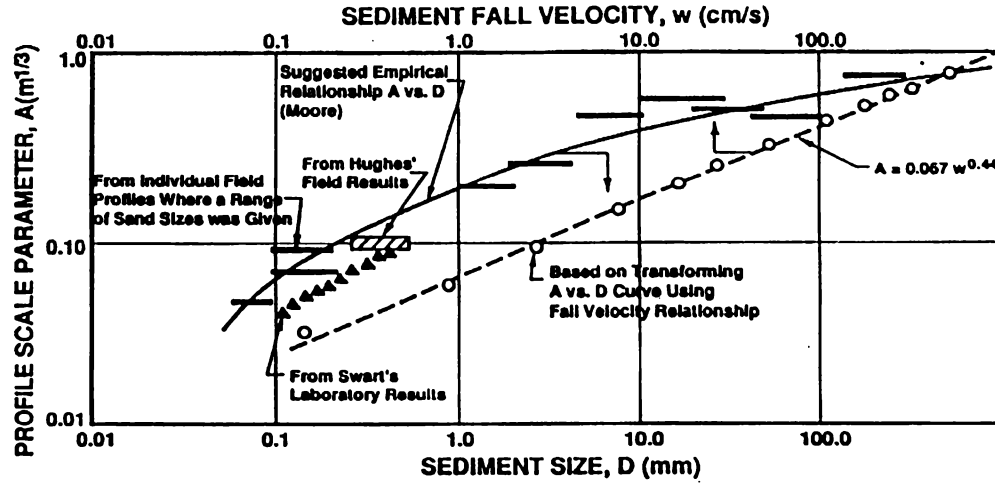


Figure 3.6: Beach Scale Factor, A , vs. Sediment Diameter, D , in relationship $h = Ax^{2/3}$ (Modified from Moore, 1982), and transformed A vs. D Empirical Relationship to approximate linear A vs. w relationship as a log-log relationship (Source: Dean, 1987)

An approach to relate A to fall velocity on a theoretical basis was outlined by Kriebel *et al.* (1991), the resulting expression for sediment sizes typical of sand beaches being given by:

$$A = 2.25\{w^2/g\}^{1/3} \quad (3.30)$$

where g is the acceleration due to gravity. This expression may reduce to:

$$A = 1.051w^{2/3} \quad (3.31)$$

Kriebel *et al.* (1991) consider that equation 3.30 above agrees reasonably well with that obtained by Dean (1987) following correlation of the units of w used between equations (i.e. the dimensions used in equation 3.29 are cm/sec while equations 3.30 and 3.31 would require dimensions of m/sec for units of A to be in m^{1/3}). As an example, medium sized sand with a fall velocity of 5cm/s ($D \gg 0.35$ mm) would result in A values of 0.136 and 0.143 using the Dean (1987) and Kriebel *et al.* (1991) expressions respectively. The Kriebel *et al.* relationship between w , d_{50} and A are represented graphically in Figure 3.7.

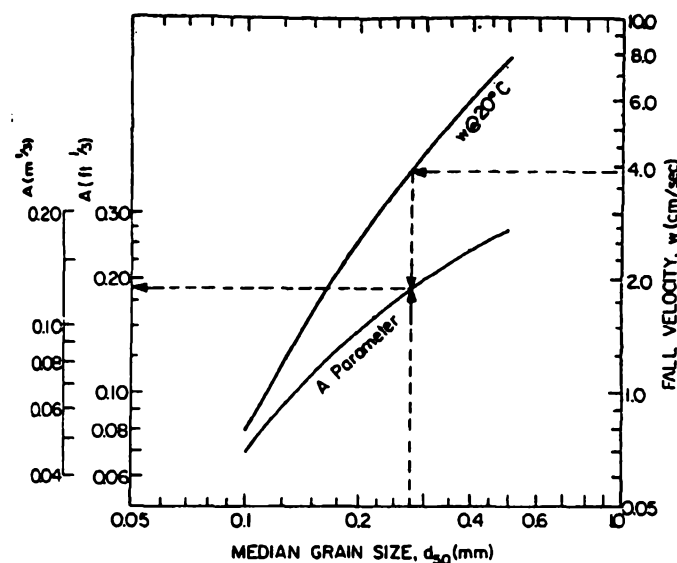


Figure 3.7: Dependence of A on sediment fall velocity, (Source: Kriebel *et al.*, 1991).

3.4.4 Problems

Pilkey *et al.* (1993) provide a detailed critique of the EBP model. In summary the authors' viewpoint sees the morphology of the beach as a complex interaction of forcing mechanisms that are ever evolving and changing over time. It is a point of view that regards beach processes as essentially chaotic in nature in which random patterns of forcing interact to produce the morphology apparent at the time. It is also a point of view that requires models to replicate these 'chaotic' states in order to predict accurately morphological responses to changes in the physical environment. They criticise the EBP approach of Dean and others based on the following criteria:

- That energy dissipation is uniform across the surf zone. This ignores the contribution shear stress caused by bottom flows provides as the primary force acting to shape the beach;
- The requirement for a sand rich beach environment. Pilkey *et al.* state that few beaches around the world meet this requirement;
- That sand size is the sole factor determining beach slope and shape. Pilkey *et al.* includes comparative evidence from beaches in Queensland and California that disputes this;
- That grain size decreases offshore. Again this is shown not to be the case from field evidence; and
- The definition of a closure depth beyond which no sediment moves is questioned based on work by Wright *et al.* (1991) and Short (1979).

The Pilkey *et al.* (1993) critique is reasoned and provides a valid examination of the assumptions and inherent problems associated with implementing EBP models in a coastal management context. The authors require that supporting evidence be presented to support the use of the EBP model. They conclude that in their view beach morphology can best be described in stochastic terms because of the complexity of the forces acting within this environment, rather than by simplistic empirical based models.

Dubois (1993) in response to Pilkey *et al.* accepts much of the criticisms of the model but also states in its defence that the model also provides an ideal of the most basic form and that it is in this simplicity where its strength lies as a valuable research tool. By representing the ideal in its simplest form (i.e. as a function of wave energy dissipation) the profile serves as the ultimate reference tool to which all observed profiles can be compared. Differences to the model require explanation and explanations advance our understanding of the coastal setting. One reason identified is the lack of uniformity in sediment size found across profile sampled in the field. This suggests that the shape of the profile should vary in the cross-shore direction and between profile locations. As a consequence Dubois suggests that the exponent should vary from Dean and Bruun's 0.67. Alternatively the scale factor which has been shown by Dean (1977), Moore (1982) and other researchers to be directly related to sediment size and fall velocity, may be varied from point to point on the profile in order to adjust the profile form.

Irrespective of this there are some beaches where the assumption requiring sand rich environments cannot be met and geological conditions such as local stratigraphy tend to dominate as a control of profile form. It is under these situations that the model cannot be used.

Another reason noted by Pilkey *et al.* and Dubois for a poor fit between the theoretical equilibrium profile and those measured in the field is related to the location of offshore bars within the profile. Dubois (1993) suggests that the presence of such bars raises a primary research question as to why these bars exist. In particular they question what assumptions (relating to the 'Dean' equation) are not met so as to cause the interaction between waves and sediment to produce such bars?

Dubois (1993) suggests that the presence of offshore bars should not deter us from using the power equation so long as it is employed for the shoreface seaward of the bar, noting that such deviation from the ideal profile is often localised and as such represents concentrated dissipation of wave energy as a result of wave breaking. Additionally he argues that it doesn't negate the assumption of uniform energy dissipation when averaged over time as the dominant profile forming mechanism across the sub aerial profile.

Loss of sediment from the shoreface is also claimed by Pilkey *et al.* (1993) to violate one of the assumptions required as part of the EBP approach. It is pointed out that during storms downwelling currents can transport sediment to depths beyond which it can be readily returned to the shore by fairweather waves and upwelling currents (Wright *et al.*, 1991). Often overwash can also remove sediment from the shoreface and this is particularly evident in the behaviour of barrier islands along the east coast of the USA as a result of hurricane activity and onshore wave conditions (Pilkey *et al.*, 1993; Komar, 1998; Morang *et al.*, 1999). A net loss of sediment from this source causes the profiles to retreat. Dubois (1993) suggests that this poses another research question, "why are sediments being lost from both ends of a shoreface?" Dubois considers the reason to involve sea level rise, which increases the frequencies of overwash and causes potential sediment sinks over the inner continental shelf. With shoreline retreat accompanied by strong down welling currents it is claimed that sediment can be trapped at depth and therefore lost on the inner shelf.

However as Dubois (1993) points out the loss of sediment from the profile doesn't necessarily preclude the usefulness or the validity of the EBP concept because if the 'active' profile is short of sand compared to the ideal then the beach will readjust until equilibrium is reached. If the beach is continuously experiencing sand loss then the beach will continue to retreat irrespective of whether there is a static 'depth of closure' and the EBP model should predict this. Dubois (1993) developed the power equation $y=px^m$ into the following form to predict beach erosion rates.

$$\Delta x = (y_i/p)^{1/m} - [(y_i - S)/p]^{1/m} \quad (3.32)$$

where y_i is the limited depth of sediment transport, S is the rate of rising sea level to predict beach erosion rates (Δx), p is a scale parameter dependent on the texture of bottom sediments, and m is the shape factor ($m = 2/3$ in Dean, 1977).

Some of the research responses to these criticisms identified in the research literature are discussed further in the next section.

3.5 Alternative forms of the Dean Model

3.5.1 Modifications to the Profile

A shortcoming of the Dean EBP equation is that it predicts an infinite or vertical slope at the shoreline where 'x' is equal to zero. This is illustrated by examination of the slope of the profile, which is given by the derivative of equation 3.4:

$$\frac{dh}{dx} = \frac{2}{3} \frac{A}{x^{1/3}} \quad (3.33)$$

It is evident that as x tends to zero, the profile slope, dh/dx will tend to infinity. This is true for any models having the form of equation 3.4 as long as the exponent is less than one (Komar and McDougal, 1994).

Inman *et al.* (1993) and Inman and Masters (1994) considered profile formation a bimodal process and divided the profile into “shoreline” and “bar berm” segments, matched at the breakpoint bar, rather than fit a single parabolic curve. Iteration of the origin points to obtain the curve with the highest correlation coefficient gave origins for both the shore-rise and bar-berm segments above the actual profile. The resultant predicted profile has non-vertical slopes in all positions corresponding to the measured profile.

Kriebel *et al.* (1991) and Bodge (1992) presented identical methods wherein a linear beach face slope is introduced to describe the profile near the still-water level with the Dean EBP form adopted seaward of the tangent between the linear beach profile and the EBP. As a consequence the usual origin of the Dean EBP form is displaced seaward of the x -axis profile origin.

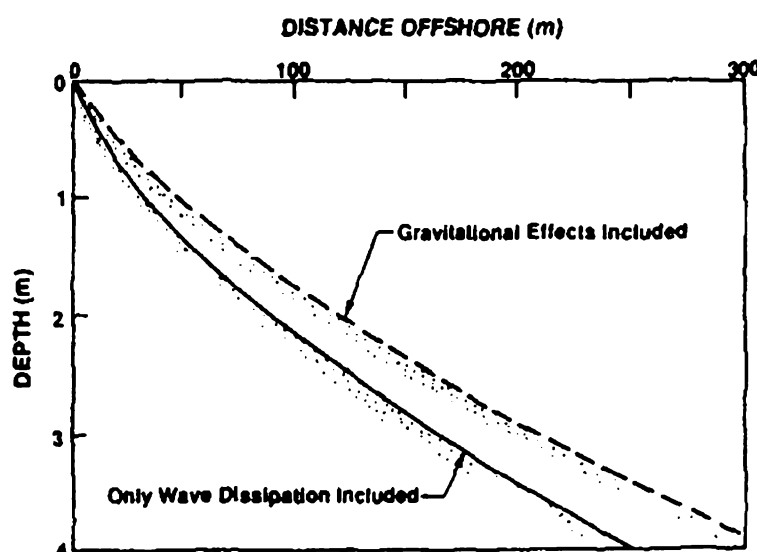


Figure 3.8: Comparison of equilibrium beach profile with and without gravitational effects included. $A=0.1\text{m}^{1/3}$ corresponding to sand size of 0.2m (Source Dean, 1991).

The third approach incorporates an additional term that gives a near linear non-vertical slope close to the shoreline. This diminishes in influence seaward as the profile becomes similar to the original Dean EBP

form. The modified equilibrium profile has the form (Dean, 1991; Kriebel *et al.* 1991; Dean *et al.* 1993):

$$x = \frac{h}{BSL} + \left(\frac{h}{A} \right)^{3/2} \quad (3.34)$$

In defining the *BSL* as the gradient of the beach face slope, Dean (1991) and Dean *et al.* (1993) have presented an option which is more readily applied than that described by Kriebel *et al.* (1991) based on the work of Larson and Kraus (1989). The addition of this *BSL* term will yield predicted EBPs with gentler slopes due to the elimination of the steeper component of the exponential curve from the calculation (Figure 3.8).

3.5.2 Variable Sand Diameter

On many natural beaches the mean sediment size decreases with distance offshore. However this decrease is not constant typically decreasing more rapidly closer to the shoreline. These beaches also characteristically display a steeper inshore profile and a more gentle offshore profile (Larson, 1991). Theoretically the Dean model should therefore be enhanced by allowing the *A* parameter to vary to reflect the change in sediment size along the profile.

Work and Dean (1991) and Larson (1991) have investigated best fit approaches to varying the '*A*' parameter in the Dean EBP profiles to provide for this variation in sediment size across the profile. This has been accomplished by Work and Dean by varying *A* linearly between known sediment sample points while Larson varied *A* exponentially in order to better reflect the relationship between sand size and profile form. In developing his modification to the Dean (1977) model Larson started from Dean's equilibrium condition implying constant wave energy dissipation per unit volume along the beach expressed as,

$$\frac{1}{h} \frac{dF}{dx} = D_{eq} \quad (3.35)$$

where *F* is the wave energy flux, *x* is the cross shore distance originating at the shoreline, and *D_{eq}* is the equilibrium energy dissipation assumed to be dependent on grain size. This equation was then rewritten using small-amplitude wave theory for shallow water as,

$$K\sqrt{h} \frac{dh}{dx} = D_{eq} \quad (3.36)$$

where,

$$K = \frac{5}{16} \rho g \sqrt{g} \gamma^2 \quad (3.37)$$

and ρ is the density of water, g is the acceleration due to gravity, and γ is an empirical constant relating wave height to water depth in the surf zone. In solving equation 3.36, D_{eq} is assumed to be a known function of x where grain size varies across shore. The solution to equation 3.35 involves integrating with respect to h while imposing a boundary condition of zero at the shoreline to produce the expression,

$$h = \left(\frac{3}{2K} \int_0^x D_{eq} dx' \right)^{\frac{2}{3}} \quad (3.38)$$

Larson (1991) states that evaluation of the integral in equation 3.38 requires two pieces of information namely, (1) knowledge of the variation in median grain size d_{50} across the profile, and (2) the relationship between D_{eq} and the median grain size. Where $D_{eq} = D_{\infty}$ the solution of equation 3.38 reduces to the familiar form of the Dean equation (see equation 3.4) where,

$$A = \left(\frac{3D_{\infty}}{2K} \right)^{\frac{2}{3}} \quad (3.39)$$

However median grain size will vary over the depth of the profile with an expectation that grain size will decrease with distance offshore. Assuming this, the variation of D_{eq} with distance can be described as,

$$D_{eq} = D_{\infty} + (D_0 - D_{\infty}) e^{(-\lambda x)} \quad (3.40)$$

where D_0 and D_{∞} are the equilibrium energy dissipation for the material at the shoreline and in the offshore respectively ($D_0 \geq D_{\infty}$), and λ is an empirical coefficient describing the rate at which D_{eq} approaches D_{∞} . Using equation 3.22 the equilibrium profile shape given by equation 3.38 is,

$$h = A \left(x + \frac{1}{\lambda} \left(\frac{D_0}{D_{\infty}} - 1 \right) (1 - e^{(-\lambda x)}) \right)^{\frac{2}{3}} \quad (3.41)$$

in which A is presently defined based on D_{∞} .

Work and Dean (1991) also investigated profile prediction by varying A through a series of blindfolded tests in which the EBPs were determined

directly from the sediment characteristics illustrated in Figure 3.6. The methodology involved applying several schemes for the determination of A from sediment data sampled along measured profiles. The tests applied involved applying the following tests in order to investigate whether these improved the fit of the Dean profile (Dean, 1977) to measured data. The tests were:

- 1) the 'blindfold test' involving the application of

$$h^{3/2}(y) = \int_0^y A^{3/2}(D) dy \quad (3.42)$$

which reverts to 3.1 if the scaling factor is held constant across the profile. If the cross shore distribution of sediment is piecewise continuous and hence A is piecewise continuous, 3.42 may be integrated to find:

$$h^{3/2} = h^{3/2}(y_n) + A^{3/2}(D_n)(y - y_n) \quad y_n < y \leq y_{n+1} \quad (3.43)$$

where D_n is the sediment size for the region $y_n < y \leq y_{n+1}$. Thus the solution can be marched step by step from the still water line.

- 2) 'Best Fit' tests which assume a functional form for the cross shore distribution of the A parameter and then uses an iterative scheme to determine the parameters that best predicts the measured profile. Three tests were derived involving different schemes for the determination of A for use in Dean's (1977) equation (3.4). The three tests applied involved: (i) use of a constant A ; (ii) linear variation between sediment samples along the profile; and (iii) exponential variation to determine the cross-shore variation of A . The fit to the measured profiles were then determined using least square techniques in which the representative error is minimised.

The piecewise approach using the blindfolded test has subsequently been applied by Dean *et al.* (1993) to beach profiles located on the east coast of the north Island of New Zealand.

Larson (1991) concludes from his work that a modified expression of the Dean EBP equation (see equation 3.17) did enable a more realistic description of the measured profile. But he noted that the expression was complicated by the increases in the number of parameters to be estimated and in the complexity of fitting by least squares the equation to the field data. In contrast Work and Dean (1991) concluded that the use of additional parameters did not improve the fit obtained by best fit methods, while inclusion of the cross shore variation in sediment size was of mixed success. These results were also similar to those obtained by Dean *et al.* (1993).

3.6 Alternative Forms of Equilibrium Beach Profile Models

The following discussion outlines some alternative models that either depart fundamentally from the Dean (1977) approach, as in the case of Bodge (1992), or alternatively have refined the Dean model beyond the fundamentals of uniform energy dissipation across the surf zone in an attempt to introduce more realism (i.e. a breakpoint bar) into the approach (Wang and Davis, 1998).

3.6.1 Profiles as Exponential Expressions

Bodge (1992) and Komar (1998) consider that an exponential relationship provides a better approximation of the profile form. The theoretical development of this approach has been derived from the development of Stoke's edge wave theory (Komar and McDougal, 1994). Bodge (1992) demonstrated that this form of the EBP fitted the data of Hayden *et al.* (1975) as used by Dean (1977) better than the power form of Bruun (1954). The exponential equation took the form of,

$$h = B(1 - e^{-kx}) \quad (3.44)$$

where B and k are empirical coefficients. The coefficient k determines the concavity of the profile and according to Bodge (1992) takes values ranging between 3×10^{-5} and $1.16 \times 10^{-3} \text{m}^{-1}$ for the Hayden *et al.* (1975) data set. The proportionality coefficient B is the offshore depth to which the profile approaches asymptotically. In practice the sediment closure depth may be used as a measure of this depth.

The slope of the relationship described in equation 3.44 is given by

$$S = \frac{dh}{dx} = kBe^{-kx} \quad (3.45)$$

At the shoreline where $x=0$ the beach face slope can be defined by $S_0=kB$. Equating for B and substituting S_0 into equation 3.45 provides an alternative form of the model as developed by Komar and McDougal (1994),

$$h = \frac{S_0}{k}(1 - e^{-kx}) \quad (3.46)$$

or,

$$h = \frac{\tan \beta_0}{k}(1 - e^{-kx}) \quad (3.47)$$

where $\tan\beta_0$ represents the beach slope at the shoreline. Komar and McDougal (1994) have rearranged this further to provide a dimensionless relationship that enables the determination of the concavity coefficient k in terms of the 'closure depth' co-ordinates as follows

$$\frac{h_c}{x_c \tan \beta_0} = \frac{1 - e^{-kx}}{kx_c} \quad (3.48)$$

where h_c and x_c are the closure depth and offshore distance to closure depth. Equation 3.48 allows the profile shape to be determined by the sediment texture through the surrogate measure of beach slope and the annual wave climate by incorporating the closure depth parameter (Hallermeier, 1981; Birkmeier, 1985).

Komar and McDougal (1994) determined a solution to k by expanding the exponent e^{-kx} using Taylor's series expression for h . Using this approach equation 3.46 becomes

$$h = \frac{S_0}{k} \left[(kx) - \frac{(kx)^2}{2!} + \frac{(kx)^3}{3!} - \dots \right] \quad (3.49)$$

Using this expression for h and substituting this back into equation 3.48 yields the solution for k to the third order approximation as follows,

$$k = \frac{1}{x_c} \left[\frac{3}{2} - \left(\frac{6h_c}{S_0 x_c} - \frac{15}{4} \right)^{\frac{1}{2}} \right] \quad (3.50)$$

From this equation it is apparent that the higher the value of k the greater the decrease in overall slope compared with S_0 and vice versa. This relationship is therefore consistent with beach variations observed between reflective and dissipative beaches with small values of k being associated with steep beaches at the shoreline, and shallow dissipative beaches being associated with larger values of k , (Komar and McDougal, 1994; Komar, 1998; de Lange, 1998).

3.6.2 Barred Beach Profiles

Both the Dean/Bruun and the Bodge profile models described previously provide smooth monotonic curves as an approximation of the natural beach form. Inman *et al.* (1993) used a compound curve involving two segments of Dean type power curves to simulate a bar type feature in their profile model. In fitting the curves to the profiles they allowed the exponent to vary in the equation $y = Ax^m$ and found that m was nearly the

same for both segments. The value that they obtained for m (0.4) concurs with exponent values that Bowen (1980) derived by incorporating Stokes type wave-orbital motions within the theoretical solution justifying the Dean/Bruun model. The profile form of Inman and co-workers is shown in Figure 3.9.

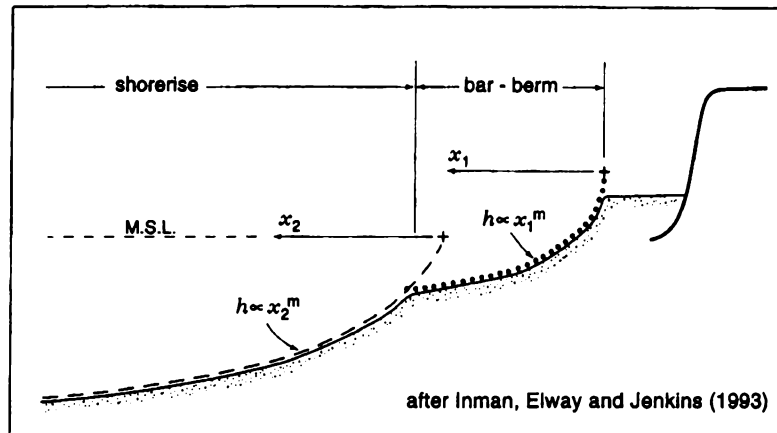


Figure 3.9: The compound curve of Inman *et al.* (1993) where the generalised Bruun/Dean profile $h = Ax^m$ is fitted separately to the inshore bar-berm and offshore shorerise segments, in part giving rise to an offshore bar where the segments join. The origins for the fitted curves, indicated by crosses, are elevated above the beach so as to avoid infinite slopes at the shore and on the bar (Source: Komar 1998, p.281).

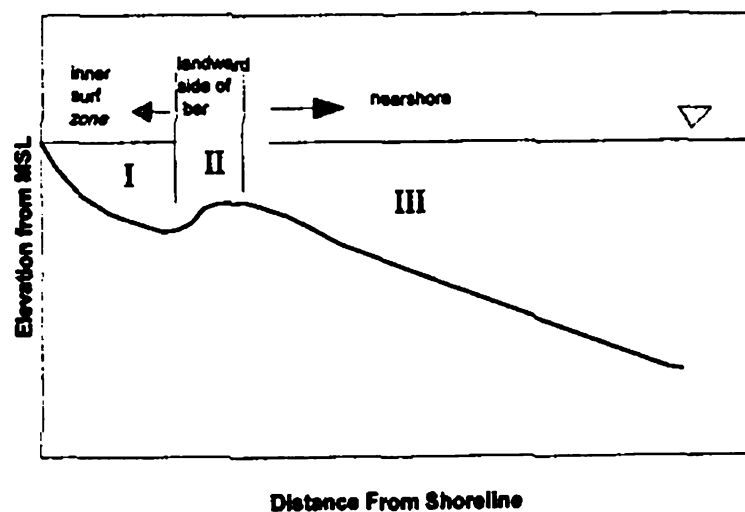


Figure 3.10: The three segments used to describe a beach profile in Wang and Davis (1998)

Wang and Davis (1998) adapted the approach of Inman *et al.* (1993) to incorporate an additional section within the beach profile in between the bar-berm and shorerise sections of Inman *et al.* They reason that the existence of the bar/trough feature indicates that the uniform energy dissipation fundamental to the Dean (1977) model may not be continuous

throughout the whole barred profile. Their proposition is that seaward of the breakpoint bar energy dissipation may be occurring to a pattern that is different to when the wave enters the inner surf zone where the pattern may be something entirely different.

Therefore they reason that the barred profile may be described as a series of Ax^m forms as described by Inman *et al.* The three segments (Figure 3.10) formulated by Wang and Davis (1998) are described as follows:

- 1) the nearshore zone, from the top of the bar to the closure depth, where the dominant processes after profile morphology are wave shoaling and breaking on top of the bar;
- 2) the landward side of the bar characterised by a landward dip and a landward increase of depth; and
- 3) the inner surf zone, from the bottom of the trough to the shoreline, dominated by secondary wave shoaling and breaking.

The three segments are expressed as follows:

$$\text{The inner surf zone} \quad h(x) = A_1 x^{m_1} \quad \text{for } 0 < x \leq x_{tr} \quad (3.51)$$

$$\text{The landward bar-slope} \quad h(x) = h_{tr} + \frac{h_{bt} - h_{tr}}{x_{bt} - x_{tr}} (x - x_{tr}) \quad \text{for } x_{bt} < x < x_{tr} \quad (3.52)$$

$$\text{The nearshore zone} \quad h(x) = A_2 (x - x_2)^{m_2} \quad \text{for } x_{bt} \leq x < x_{cd} \quad (3.53)$$

where A_1 and A_2 are dimensional scale factors for the inner surf and near shore zones respectively and m_1 and m_2 are empirical shape factors as defined by Dean (1977), (x_{tr}, h_{tr}) are the co-ordinates of the trough bottom, x_2 is the intercept of the nearshore portion of the profile with 0 water level, (x_{bt}, h_{bt}) are the co-ordinates of the bar top, and x_{cd} is the offshore distance to closure depth. It is claimed that this schematised representation of the barred profile enables improved prediction and representation of beaches when compared to that produced by Dean's (1977) monotonic profile.

The two scale factors A_1 and A_2 were used to define the scaling of all three segments. The best-fit values obtained have been plotted for the beach dataset analysed and the results shown in Figure 3.11 (Wang and Davis, 1998). The inner surf value A_1 decreases slightly from north to south as a consequence of the sediment sources for the various beaches while the nearshore region values are relatively constant. The values obtained for the scale factors are consistent with those anticipated from the Moore (1982) and Dean (1977, 1987) relationships for A v. sediment diameter/sediment fall velocity.

The best-fit shape factor m_1 value obtained for the inner surf zone agreed with the $2/3$ determined by Dean (1977). The average shape factor resolved for m_2 in the nearshore zone was 0.82 with a standard deviation of 0.02 (Figure 3.12), which is slightly larger than the 0.67 value considered consistent with uniform wave energy dissipation (Dean, 1977). The difference was assumed by Wang and Davis (1998) to be due to the incorporation of the intercept distance x_2 into the profile model for this segment.

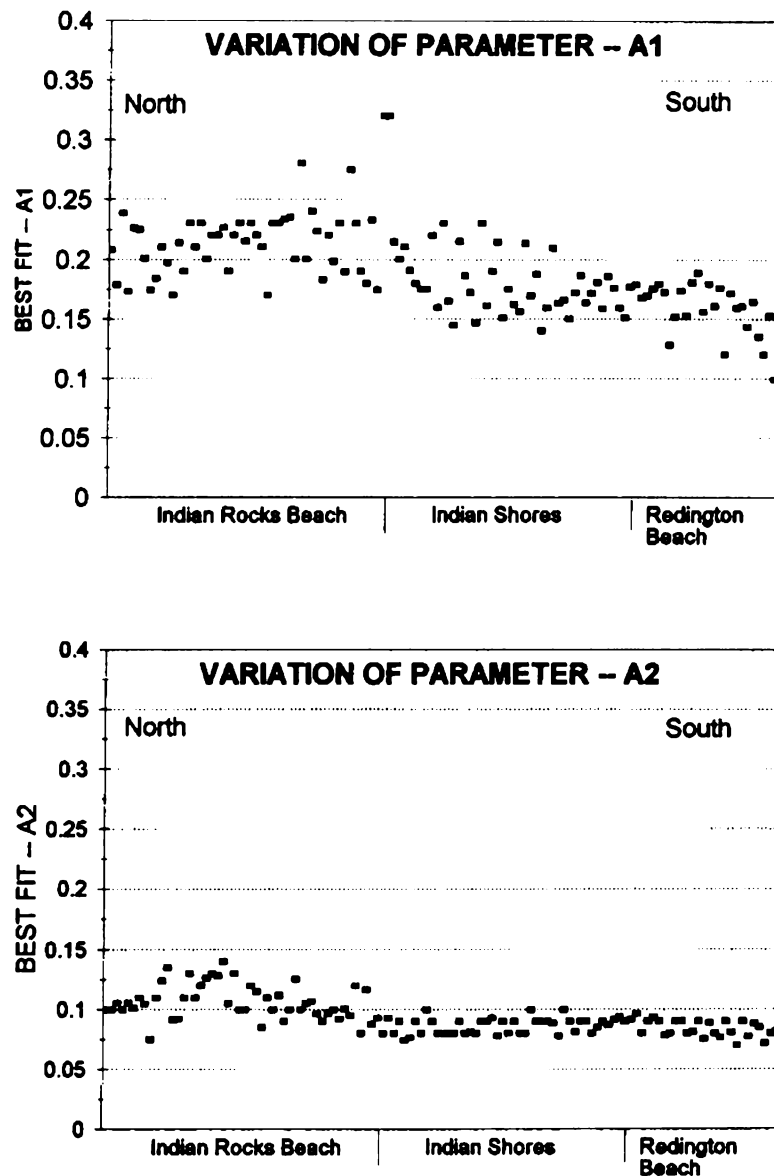


Figure 3.11: Variation of Parameters A_1 and A_2 determined by Wang and Davis (1998) from profile analysis of beaches at Sand Key, Florida (Source: Wang and Davis 1998).

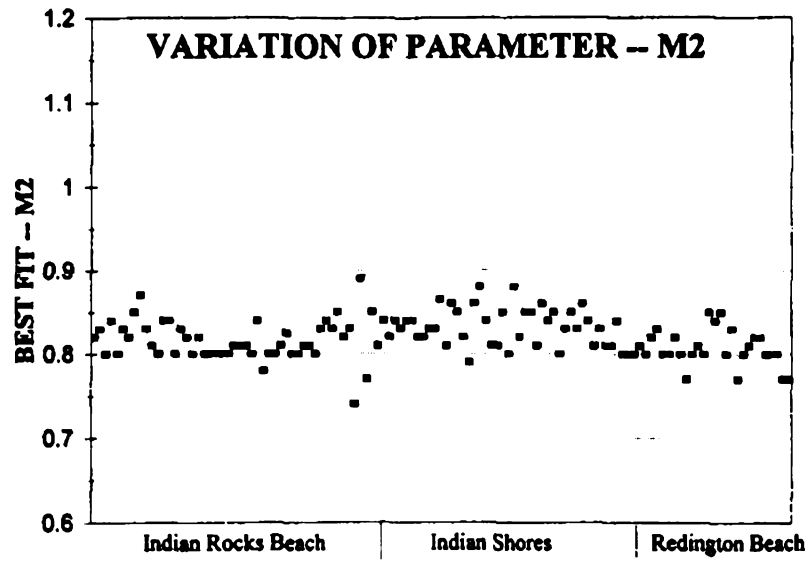


Figure 3.12: Variation of the Shape Factor m_2 from Wang and Davis, 1998. Average Shape Factor (m_2) = 0.82, s.d. = 0.02

Wang and Davis (1998) found that the intercept distance x_2 exerts a significant influence over the shape of the nearshore zone profile. The dimension does not have any morphological significance apart from providing modelling convenience. However Wang and Davis did examine its relationship with other variables within the model and found a fairly consistent ratio between the between best-fit values for x_2 and the offshore distance to the top of the bar as measured from the shoreline. This then enables estimation of the intercept distance from the position of the breakpoint bar as,

$$x_2 = 0.652x_{bt} \quad (3.54)$$

The following equations represent empirical formulae developed for west central Florida barrier coast based on equations 3.51 to 54,

$$h(x) = 0.19x^{2/3} \quad (3.55)$$

$$h(x) = h_{tr} + \frac{h_{bt} - h_{tr}}{x_{bt} - x_{tr}}(x - x_{tr}) \quad (3.56)$$

$$h(x) = 0.09(x - 0.652x_{bt})^{0.82} \quad (3.57)$$

3.7 Determining Equilibrium Beach Status – The Application of Equilibrium Beach Profile Theory to Beach Stability Analysis

A fundamental principle incorporated in the definition of beach equilibrium is that a beach out of equilibrium with the forces acting upon

it will adjust to a shape that will bring it back into equilibrium. Dean (1991) and Dean *et al.* (1993) developed this concept as a design tool to allow the determination of beach shift resulting from beach disequilibrium. The procedure involves comparison between both measured and computed beach profiles to determine whether the measured profile lies above or below the profile of equilibrium.

In the Dean (1977) model, as discussed, the predicted profile shape is determined solely from a beach's grain size characteristics as a function of wave energy dissipation. In general if the profile lies above the calculated profile the beach profile is said to be sand rich and the profile will adjust to equilibrium through the redistribution of sand along the profile causing accretion at the shoreline. If the profile of equilibrium lies below the measured profile then profile adjustment will cause shoreline erosion as sand is redistributed to lower parts of the profile out to closure depths.

The application of this concept will allow the determination of the equilibrium status of a beach at any given time, and whether the beach is susceptible to erosion or accretion. Chapter 4 discusses the application of this approach to beach profiles contained within the Bay of Plenty Regional Council's coastal monitoring dataset using a selection of the various models discussed.

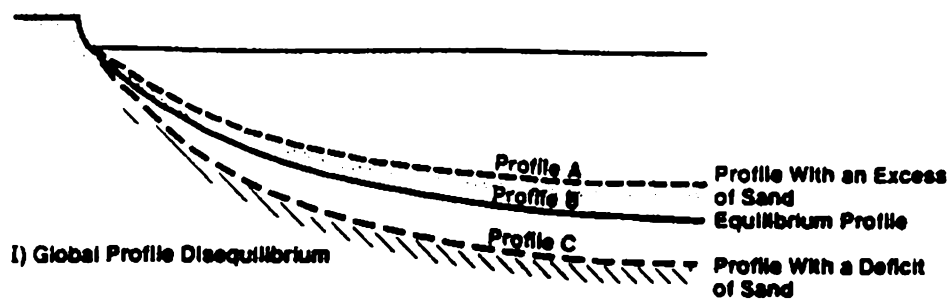


Figure 3.13: Characteristic profile shapes showing disequilibrium resulting from either surplus or deficit sediment in the beach profile. (Source: Dean *et al.*, 1993)

3.7.1 Diabathic Transport and Equilibrium Transport

Moore (1982), Kriebel and Dean (1985), and Kriebel (1986) have considered profiles that are out of equilibrium and have hypothesised that the rate of offshore transport of sediment is proportional to the difference between the actual and equilibrium wave energy. The resultant volumetric flux (Q_s) of sand particles can be described as,

$$Q = K(D - D_{eq}) \quad (3.58)$$

where Q is the volumetric flux, D is the incident energy dissipation rate and D_{eq} is the equilibrium energy dissipation rate. K represents a rate constant for the volumetric flux of sand (Moore, 1982). The solution of this equation provides for a solution of equilibrium profile adjustment over time occurring from a change in ambient wave climate.

To achieve this solution energy dissipation is calculated using the following formula provided from linear wave theory.

$$D = \frac{5}{6} \sqrt{g} \kappa^2 \gamma h^{1/2} \frac{dh}{dx} \quad (3.59)$$

In addition sediment size is related to energy dissipation through the shape factor A in the curve $h = Ax^{2/3}$, where,

$$A = \left[\frac{24}{5} \left(\frac{D}{\gamma \kappa^2 \sqrt{g}} \right) \right]^{2/3} \quad (3.60)$$

In order to quantify the relationship between sediment size and energy dissipation, numerous actual and laboratory beach profiles were analysed by Moore in order to quantify the relationship between sediment size and energy dissipation. This involved digitising the various profiles and subjecting them to a least squares analysis in order to determine the best value for A for each profile conforming to the curve $h = Ax^{2/3}$. Forty profiles (Moore, 1982) in all were analysed to determine the 'A' value for equilibrium conditions, which then enabled the estimation of the equilibrium energy dissipation (D_{eq}) of the respective sediment particles.

Moore's (1982) determination of the transport rate coefficient was based on replicating Saville's (1957) laboratory investigation. The numerical model started with a 1:15 planar beach and waves were generated at a 15 foot depth. These waves travelled along a horizontal bottom until shoaling and breaking on the planar beach. The cumulative erosion over a 30-minute period was calculated using Moore's finite difference erosion model and the transport rate coefficient was varied to determine a comparison of calculated cumulative erosion to Saville's laboratory results.

The results of Moore's simulation are shown in Figure 3.14. This work determined a transport rate coefficient of $K = 2.2 \times 10^6 \text{ m}^4/\text{N}$ based on a grain size of 0.2 mm. Kriebel and Dean (1985) noted that based on dimensional arguments, K should vary with the length scale of the system, however because Saville's work was carried out at a fairly large scale then K should be applicable to full-scale conditions.

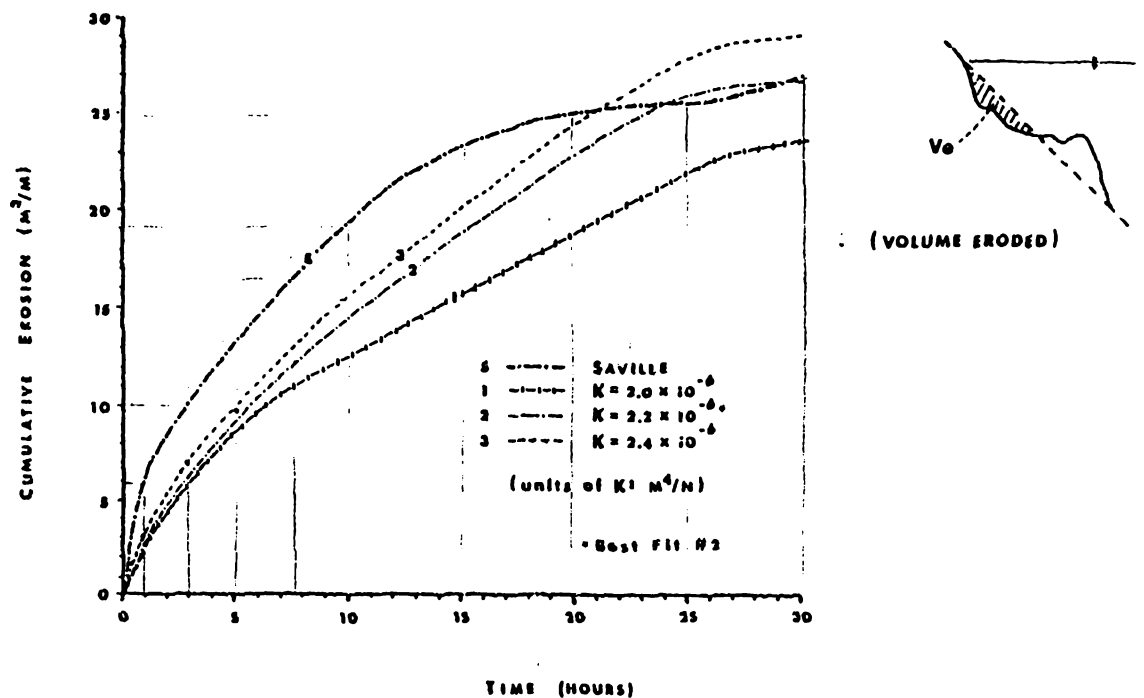


Figure 3.14: Effect of varying the sediment transport rate coefficient on cumulative erosion during the simulation of Saville's (1957) laboratory investigation of beach profile evolution for 0.2 mm sand size (Source: Moore, 1982).

Kriebel (1986) also carried out calibration work for his beach erosion model EDUNE using equation 3.58, data from Saville's (1957) work, and field data from the Florida reference profile R-41 Hurricane Eloise dataset. The results of this analysis were focussed on determining the transportation rate coefficient utilising the EDUNE model. This calibration indicated K values of between 0.004 and 0.005 ft^4/lb or 7.76 and 9.70 m^6/N . The difference between Kriebel's values and those obtained by Moore were put down principally to a difference in the numerical scheme used in the EDUNE model (Kriebel, 1989). The result of Kriebel's calibration work is shown in Figure 3.15. This will be discussed in more detail in section 3.8.1.

The importance of Moore and Kriebel's analyses is that it allows the solution of profile change over time, under conditions of varying wave energy.

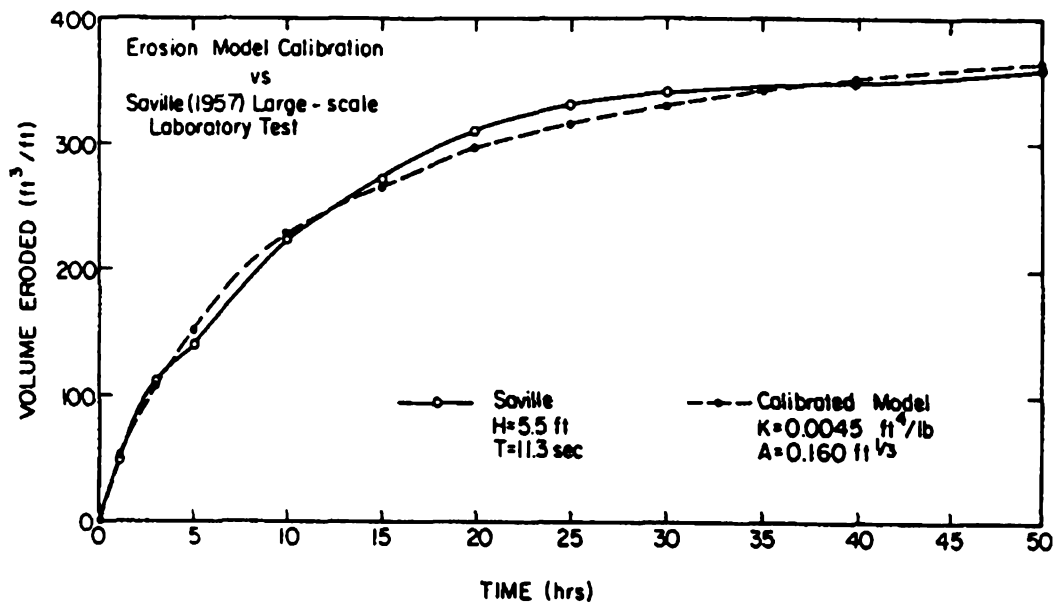


Figure 3.15: Comparison of Cumulative Erosion for Calibrated Model and Saville's Laboratory Experiment (Source: Kriebel 1986).

3.8 Storm Induced Beach and Dune Erosion - Application of equilibrium based Empirical Profile Evolution Models to Erosion Prediction

The previous discussion concentrated on the derivation and application of relatively simple 2 dimensional and static equilibrium beach models for profiles located generally below still water level (MSL). However some of the most noticeable beach morphological responses to weather conditions involves both beach face and frontal dune responses to storm and wave events. Bijker *et al.* (1989) have identified that the degree to which dune erosion (and consequently beach face morphology) occurs is a function of random storm surge conditions and may be determined as follows:

- the shape of the erosion profile is determined by the significant wave height and the grain diameter;
- the position of the erosion profile in the vertical sense is determined by the storm surge levels (as measured just outside the breaker zone); and
- the position in the horizontal sense is determined by placing the erosion profile over the coastal profile in such a way that an erosion-sedimentation balance is obtained in the direction perpendicular to the coast.

Bijker *et al.* (1989) illustrate this by a number of examples (see Figure 3.16). The left hand side of the diagram shows the profile development

occurring prior to the storm whilst the right hand illustrates the profile response to storm surge induced erosion.

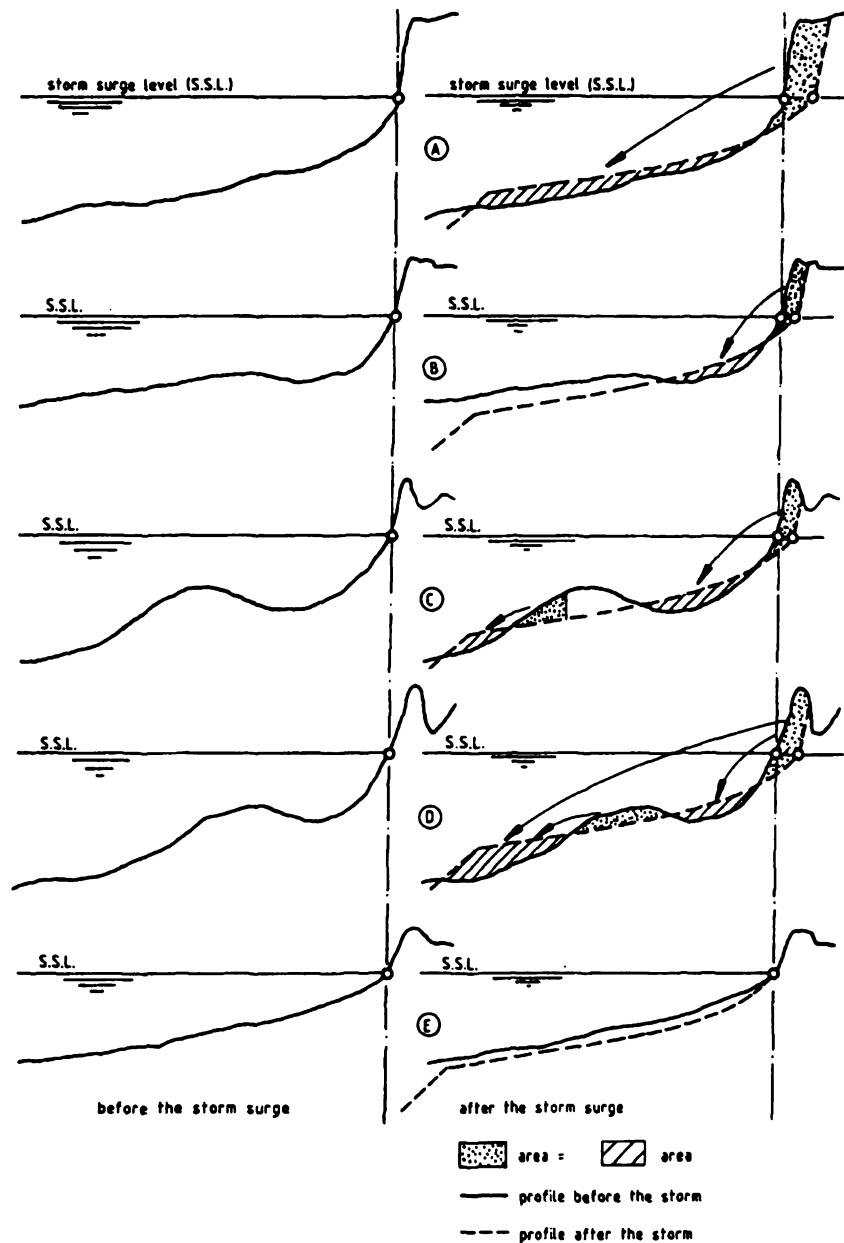


Figure 3.16: Analysis of Dune erosion: examples of sand movement (Source Bijker et al. 1989).

Van de Graaff (1986) identified two different mechanisms for the loss of dune material, these being, a) gradual erosion, and b) erosion during storm surge. Gradual erosion is seen as being caused principally by longshore sediment transport whereas storm surge events have the potential to cause large-scale sediment movement (principally through diabathic exchange) over relatively short periods of time.

The Dutch experience is that gradual erosion makes up a relatively minor component of overall beach erosion, this being valued by Van de Graaff at $50 \text{ m}^3\text{m}^{-1}$ per year or approximately 2 m horizontal erosion per year (Van de Graaff, 1986). On the other hand under Dutch design conditions, a storm surge rise of approximately 4 m above normal can be expected. In these circumstances of high water levels and high waves resulting in storm surge conditions, large quantities of dune material can be eroded in an offshore direction. Approximately $400 \text{ m}^3/\text{m}$ in 5-10hrs is a realistic order of magnitude of erosion resulting in a dune retreat of approximately 70 metres (Van de Graaff, 1986). In such conditions a safety zone is required to protect at risk communities from significant erosion. Two numerical models designed to meet this need are described below.

3.8.1 EDUNE Model

Kriebel (1989) developed a two dimensional numerical model (EDUNE) to simulate storm surge and beach and dune erosion based on the concepts and theory developed earlier by Dean (1977, 1984), Kriebel and Dean (1985) and Kriebel (1986). As a consequence the underlying theory and assumptions behind the generalised equilibrium model of Dean as described earlier in this chapter also apply to this model.

The original program EBEACH, was adopted by the State of Florida for assessing hurricane impacts, and the US Army Corps of Engineers for erosion control and design of beach renourishment projects (De Lange *et al.*, 1997). EDUNE has been developed from this program to enhance model applicability and realism (Kriebel, 1989). The improvements over the original EBEACH include

- 1) a new treatment of the sediment transport rate on the beach face, which allows slope variations as the beach face erodes;
- 2) a new treatment of the wave uprush limit, which allows formation of a near vertical erosion scarp; and
- 3) a revised numerical solution of the governing equations, which eliminates numerical instabilities experienced in EBEACH.

Kriebel (1989) claims that the revisions allow for a wider range of pre and post storm profiles and input/output options. These include:

- 1) input of either schematic pre-storm profiles or input of digitised survey data for nearly exact representation of existing pre-storm profiles;
- 2) simulation of beach fill cross sections;
- 3) simulation of low dunes that may be overtopped;
- 4) simulation of narrow dunes that may erode completely; and
- 5) simulation of dunes backed by vertical or sloping seawalls.

As discussed previously the model has also undergone a calibration and verification process as reported in Kriebel (1986).

The program utilises the original Dean Profile as defined in equation 3.4. ($h=Ax^{2/3}$) and shallow water linear wave theory to approximate the offshore sediment transport rate, Q , where

$$Q = K(D - D_{eq}) \quad (3.58)$$

and ΔD represents the surplus energy dissipation per unit volume at each depth contour across the profile. K represents the sediment transport rate parameter that has been determined empirically by model calibration using Saville's (1957) large scale laboratory experiments as shown in Figures 3.17 and 3.18. Based on a least squares fit of the predicted profiles to those measured by Saville, the sediment transport rate parameter K was found to be $0.0045 \text{ ft}^4/\text{lb}$ ($8.873 \times 10^{-6} \text{ m}^4/\text{N}$). Kriebel (1989) reports that the EDUNE model was then further tested against a reference profile (R-41) surveyed by the Florida Department of Natural Resources where the K value was further confirmed.

Using 20 severely eroded profiles from the Hurricane Eloise data set Kriebel (1989) evaluated the model's sensitivity and bias (see also Kriebel 1986). This illustrated that the model was capable of predicting the observed eroded volumes to within approximately 25 to 40 per cent, but with little bias towards over or under predicting (see Figure 3.17). Kriebel also found that the model predicted the location of the post storm dune scarp to within about 30 to 40 per cent but the distribution tended to be biased towards under prediction.

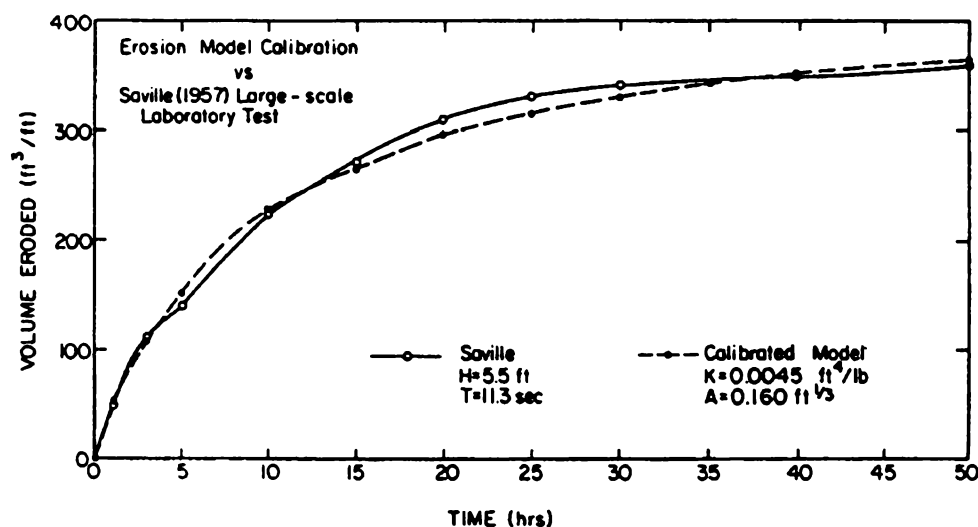


Figure 3.17: Calibration of EDUNE model based on a comparison of predicted eroded volumes to those of Saville (1957) (Source - Kriebel 1989).

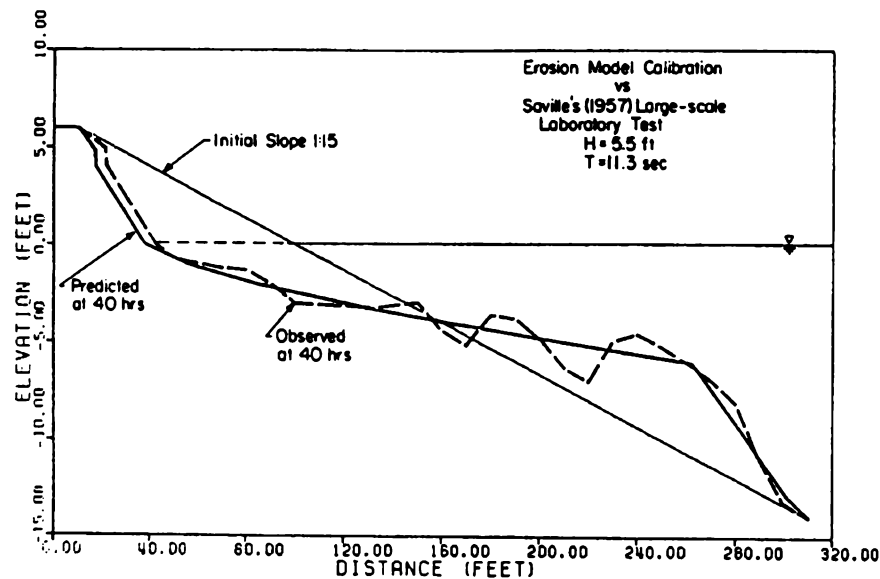


Figure 3.18: Comparison of final predicted profile compared to that of Saville (1957) based on model calibration. (Source- Kriebel, 1989)

In this case it was found that better dune scarp predictions were obtained using a slightly larger value of K between 0.005 and $0.0055 \text{ ft}^4/\text{lb}$ ($9.702 \times 10^{-6} \text{ m}^4/\text{N}$ and $1.067 \times 10^{-5} \text{ m}^4/\text{N}$). Figure 3.19 from Kriebel (1986) illustrates the sensitivity of predicted volumes to variations in the sediment transport coefficient. Kriebel (1986) also noted that K could vary dependent on whether variable wave heights were used versus a uniform wave height in the modelling scenarios

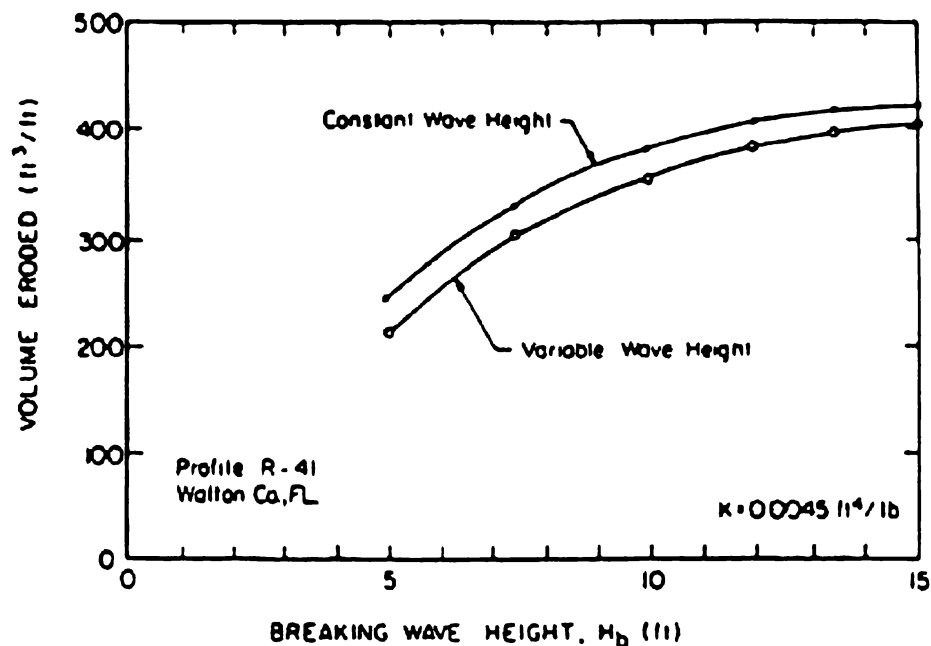


Figure 3.19: Sensitivity of Predicted Volume Eroded to Wave Height Description (Source Kriebel, 1986)

Kriebel (1989) recommends that $K=0.0045 \text{ ft}^4/\text{lb}$ ($8.732 \times 10^{-6} \text{ m}^4/\text{N}$) should be used as the default value in the model where no other data is available.

However he also recommends that where sufficient data does exist, then this should be used to re-calibrate the EDUNE model to determine an appropriate transport rate parameter for use under local conditions. Presumably this data would take the form of measured pre and post storm profiles, wave height data, and/or sediment characteristics.

3.8.2 SBEACH Model

Like EDUNE this model predicts macroscale changes to beaches as a result of the action of storm waves and surge effects over time. However SBEACH provides a level of sophistication not found in EDUNE in that the model incorporates provision for the growth and development of breakpoint bars and routines to model the effects of wave energy flux variations due to random wave breaking within the surf zone (Larson and Kraus, 1996).

The overall direction of sediment transport is evaluated in the model based on empirical relationships determined between wave steepness and the Dean number, $H/w_s T$ (Komar, 1998a; Larson and Kraus, 1989). In a study carried out as part of the models development, Larson and Kraus found that a relationship between the deepwater wave steepness (H_0/L_0) and the dimensionless fall speed parameter or Dean number, (Dean, 1973) provided the most reliable parameters to determine the direction of sediment transport. The following figure (Figure 3.20) is a plot taken from Larson and Kraus's work based on Large Wave Tank (LWT) data showing profile response as bar or berm (erosion or accretion) profiles in terms of the two parameters.

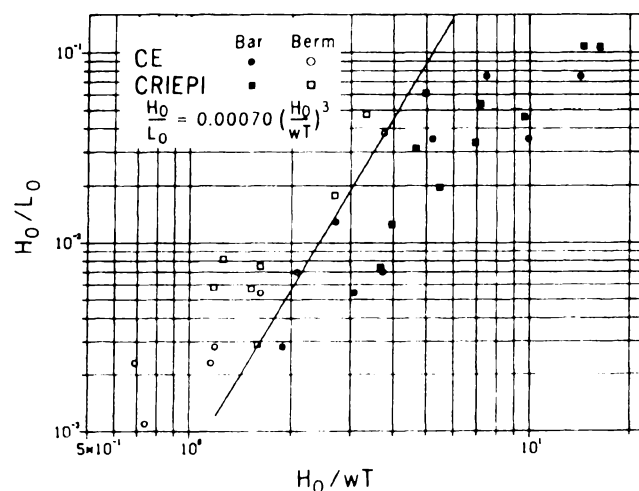


Figure 3.20: Criterion for distinguishing profile type by use of wave steepness and dimensionless fall speed parameter (Source: Larson and Kraus, 1989).

The line drawn between the two response cases separates the erosional profile from that of the accretionary and is defined by the following relationship,

$$\frac{H_0}{L_0} = M \left[\frac{H_0}{wT} \right]^3 \quad (3.59)$$

where $M = 0.00070$ and H_0 , L_0 and T are deepwater wave height, length and period respectively.

SBEACH was developed originally to provide a model that could be used for coastal engineering applications that reproduced macro-scaled morphological features along the profile. To do this Larson and Kraus (1989) subdivided the profile into four zones,

- Zone 1 – the pre-breaking zone that extends from the seaward limit of significant profile change to the breakpoint;
- Zone II – is the breaker transition zone and this extends from the wave break point to the plunge point;
- Zone III – is the broken wave zone that extends from the plunge point shoreward to the point of wave reformation or to the swash zone; and
- Zone IV – is the swash zone that extends from the shoreward boundary of the surf zone to the shoreward limit of wave runup.

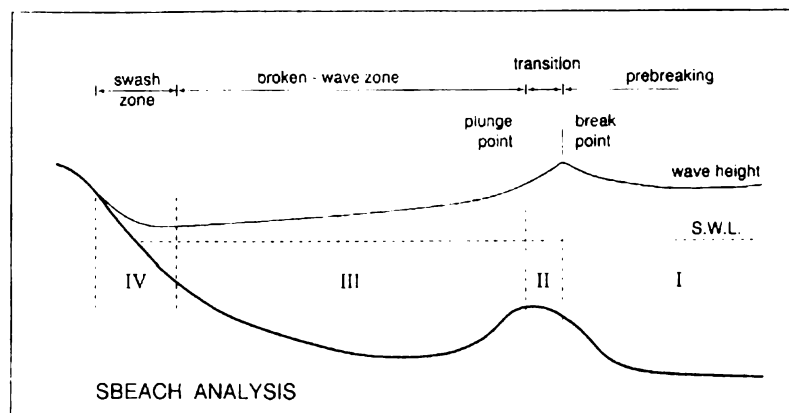


Figure 3.21: The four principal zones of cross shore transport (Source: Larson and Kraus, 1989).

Empirical and theoretical relationships are then used to characterise the formation and development of the various morphological features characteristic of these zones. The model uses empirical definitions to describe the form of features and derivations of q , the transport rate

variable, to determine the profile change over time resulting from incipient wave energy.

A full discussion of the approach taken to approximate the dominant morphological processes and to determining the transport rate variable q in the four zones is contained in Larson and Kraus (1989, pp.137-153), while the following points provide a general summary of the approach taken in the model:

- In **Zone I**, where transforming unbroken waves predominate, Larson and Kraus (1989) recognised that a micro scale approach to sediment transport such as that governed by ripple dynamics and sophisticated transport rate models were felt to be inconsistent with the macroscale approach adopted for the development of the model.

However from empirical analysis of sediment transportation in the offshore vicinity of the breakpoint they showed that the net transportation rate was well approximated by an exponential decay rate with distance from a point somewhat seaward of the location of the maximum transport rate. From their research this point was shown to be located in the vicinity of the breakpoint with the transport rate q in zone I being described by the following relationship,

$$q = q_b e^{-\lambda(x-x_b)} \quad (3.60)$$

where q_b is the transport rate at the breakpoint, λ is the spatial decay coefficient, and x_b is the offshore location of the breakpoint.

- In the breaker zone (**Zone II**) determination of the quantitative characteristics of the net transport rate proved too difficult in the region described between the break and plunge points. Consequently Larson and Kraus (1989) used empirical LWT data to measure the spatial variation in rates over time.

The form and location of the bar is determined by a number of empirical parameters including: temporal rate coefficients (α), bar volume and equilibrium bar volume (V , V_{eq}), bar crest depth (h_c), trough depth to crest depth ratio (h_t/h_c), maximum bar height (Z_b), bar location and speed of movement as represented by the bars centre of mass (x_{CM}), breakpoint to maximum trough depth distance (l), and seaward and shoreward bar slope characteristics (β_1 , β_2 , β_3). Many of these parameters were determined by least squares regression fit of observed values derived from the LWT work with quantitative and qualitative checks carried out against field data to confirm the appropriateness of the assessed parameter values and derived empirical functions.

The following are some of the representative values and relationships derived for these parameters:

$$V = V_{eq} (1 - e^{-\alpha T}) \quad (3.63)$$

$$\frac{V_{eq}}{L_o^2} = 0.028 \left[\frac{H_o}{wT} \right]^{1.32} \left[\frac{H_o}{L_o} \right]^{1.05} \quad (3.64)$$

$$h_c = 0.66 H_b \quad (3.65)$$

$$\frac{h_t}{h_c} = 2.50 \left[\frac{H_o}{L_o} \right]^{0.092} \quad (3.66)$$

$$\frac{Z_B}{L_o} = 0.122 \left[\frac{H_o}{wT} \right]^{0.59} \left[\frac{H_o}{L_o} \right]^{0.73} \quad (3.67)$$

$$\alpha T = 117 \left[\frac{H_o}{wT} \right]^{-2.30} \quad (3.68)$$

- In **Zone III** (the broken wave zone) a profile form and transport relationship similar to that determined by Dean (1977), and Kriebel and Dean (1985) has been utilised to determine shape and rate of profile change. This is not unexpected, as this is the zone where energy dissipation can be expected to be in accord with the theoretical 'form' derived by Dean (1977). The analysis carried out involved establishing the correlation between wave energy dissipation per unit volume and transport rate using the energy flux relationship for linear wave theory,

$$F = \frac{1}{8} \rho g H^2 \sqrt{gh} \quad (3.69)$$

where ρ is the density of water and the energy dissipation D is given by $\partial F / \partial x$ (see equation 3.34). A modified form of the transport relationship used by Moore (1982) and Kriebel (1982) as reported by Larson and Kraus (1989) was applied in Zone III with a term added to account of the effect of local slope on localised sediment transport. The transport rate q is written as follows,

$$q = \begin{cases} K \left(D - D_{eq} + \frac{\varepsilon}{K} \frac{\partial h}{\partial x} \right) & D > D_{eq} - \frac{\varepsilon}{K} \frac{\partial h}{\partial x} \\ 0 & D < D_{eq} - \frac{\varepsilon}{K} \frac{\partial h}{\partial x} \end{cases} \quad (3.70)$$

where,

K = empirical transport rate coefficient

D = wave energy dissipation per unit volume

D_{eq} = equilibrium energy dissipation per unit volume

ε = transport rate coefficient for the slope dependent term.

The equilibrium energy dissipation (D_{eq}) is calculated using the familiar relationship described previously. That is

$$D_{eq} = \frac{5}{24} \rho g^{2/3} \gamma^2 A^{3/2} \quad (3.71)$$

where γ is the breaker index (H_b/h_b). The addition of the slope term in equation 3.69 will produce a gentler equilibrium profile taking the form,

$$h\sqrt{h} + \frac{\varepsilon}{K} \frac{24}{5\rho g^{3/2} \gamma^2} = A^{3/2} x \quad (3.72)$$

- The form of the beach in **Zone IV** is determined based on the presumption that a beach that is eroding will produce a barred profile while a beach that is accreting will produce a berm profile. The form of the bar has already been discussed in relation to the morphological features of Zone II. Theory tells us that a berm is a sub aerial feature that forms as a result of the onshore transport of sand which occurs as a function of reducing wave steepness and sediment characteristics.

A berm typically forms above the still-water level but its influence can extend below the water surface resulting in accretion of the shoreline position with time. The point on the profile where berm formation is initiated mainly depends on the run up limit. Limited wave tank data indicated that the centre of mass for the berm was located at approximately half of the run up distance as measured from still-water level. The parameters used in the model to characterise the berm included centre of mass, the equilibrium bar volume, its maximum height and the landward and seaward berm slopes.

In the model the transport rate distribution is approximated by a linear decay with distance from the shoreward end of the surf zone. That is the transport rate is linearly extended from the end of the surf zone using arbitrarily set at between 0.3 and 0.5m depth to the run up limit of the wave bore. The slope avalanche angles observed in the data (average value of 28°) were then used to limit the berm slopes produced. If avalanching occurred then the volume produced is redistributed to adjoining calculation cells. In the numerical model the residual angle of repose following shearing was set to 18° based on the observed empirical evidence.

- The numerical model requires the conservation of sediment mass over time. It does this by breaking the profile zones into a series of finite intervals with the conservation of mass being satisfied by,

$$\frac{\partial q}{\partial x} = \frac{\partial h}{\partial t} \quad (3.73)$$

- Boundary conditions for the model are no sand transport shoreward of the run limit; and seaward of the depth where significant sand movement occurs. The run limit is defined by the empirically derived equation 3.74 relating the surf similarity parameter of Battjes (1975) to the LWT data (Larson and Kraus, 1989) as follows,

$$\frac{Z_R}{H_0} = 1.47 \left[\frac{\tan \beta}{\sqrt{H_0/L_0}} \right]^{0.79} \quad (3.74)$$

where Z_R is the maximum subaerial height of the active profile above still water level for either berm or bar profiles, β is the beach slope and H_0 and L_0 are the deep water wave height and wavelength respectively.

- The depth of significant sand movement is determined through the exponential decay of the transport rate with distance from the breakpoint. Calculation ceases where the transport rate in individual cells equates to a small-predetermined value with the transport rate in the following cell being set to zero.

3.8.3 Vellinga Model

An alternative computational model to those previously described has been developed by Vellinga (1983) to predict beach and dune erosion during storm surges. This model is based on wave flume studies at the Delft Hydraulics Laboratory. In this model it is assumed that during surge events, the initial beach profile is reshaped to a so called erosion profile which according to Vellinga (1983) can be described by the equation,

$$(7.6 / H_{os})_y = 0.47 \left[(7.6 / H_{os})^{1.28} (w / 0.0268)^{0.56} x + 18 \right]^{0.5} - 2.0 \quad (3.75)$$

where:

H_{os} = actual significant "deep" water wave height;

w = fall velocity of particles (0.0268 = fall velocity in m/s; $D_{50} = 250\mu\text{m}$);
 x = distance from the new dune foot (m);
 y = depth below maximum storm surge level (m).

The extent of the erosion profile extends from the eroded dune foot to a distance defined in the seaward direction by:

$$x = 250(H_{os} / 7.6)^{1.28} (0.0268)^{0.56} \quad \text{and} \quad y = 5.72(H_{os} / 7.6) \quad (3.76)$$

Vellinga assumes a slope of 1:1 for the dune erosion scarp with the erosion profile being connected with the initial profile at its seaward limit by a slope of 1:12.5. In summary the storm profile is fitted iteratively until the volume eroded balances the volume deposited offshore (De Lange *et al.*, 1997). The model output in terms of the reference profile plot is shown in Figure 3.22.

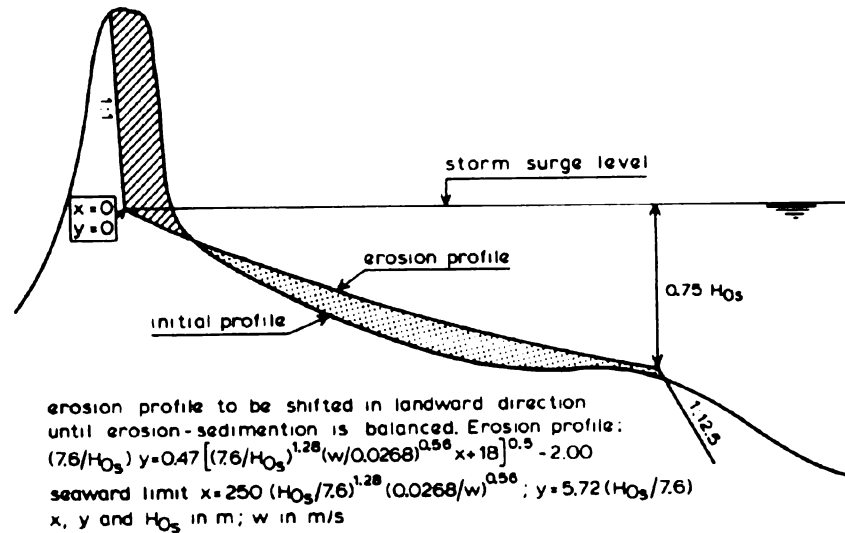


Figure 3.22: Principle of Computational Model to determine storm erosion where H_{os} is the significant deep water wave height, w is sand fall velocity. Source: Vellinga, 1983.

The computer model has been developed with reference to model conditions (Vellinga 1982, 1983) using a reference profile derived from large-scale wave tank experiments. The scale model conditions involved the following values:

- $H_{os} = 7.6\text{m}$
- $T = 12\text{s}$
- $D_{50} = 225\mu\text{m}$, and
- t = duration of trial being 5hrs after start of the prototype.

The derived computer model was then tested under field conditions using two known storm surge events (1953 and 1976). Vellinga (1983) described the agreement derived as being satisfactory with Figure 3.23 providing a summary of the verification results.

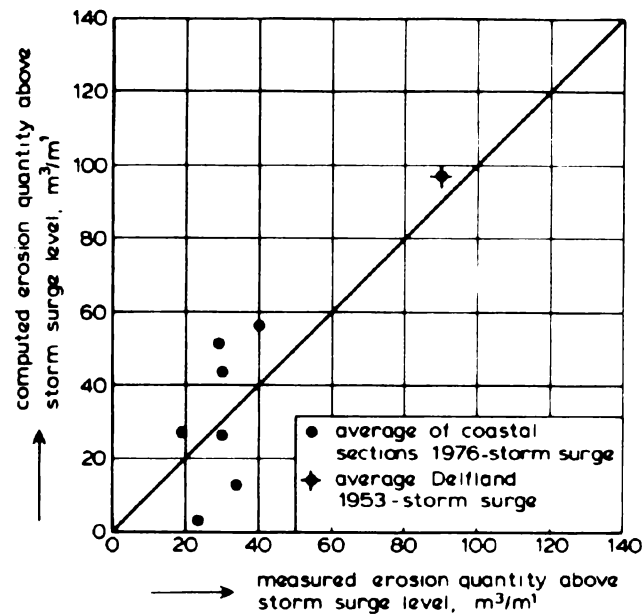


Figure 3.23: Verification of computational model, erosion quantities 1953 and 1976 storm surges. Source: Vellinga 1983.

Vellinga (1983) reports two sources of inherent inaccuracies with the computational model, these being:

- Inaccuracies of the measurements in the model (initial profile, water level, wave height, grain size, and the resulting erosion quantity);
- Inaccuracies in the scale relations for the conversion of model data to prototype.

However these inaccuracies were not accounted for in the design of the model as the process derived was considered too much of a 'black box' to develop a realistic fault tree. Therefore all model data was considered to be 100% true with the accuracy of the model derived by comparison of measured against predicted quantities (see Figure 3.24)

Vellinga (1983) concluded that the accuracy of the model derived from these quantities could be described by a normal distribution with a standard deviation of,

$$\sigma_A = 0.10A + 20m^3/m^1 \quad (3.77)$$

where A is the computed erosion above storm surge level in m^3/m , and σ_A is the standard deviation of the differences between the predicted and the measured quantities. Therefore for a predicted $100\text{m}^3/\text{m}$ event the accuracy based on standard error calculation is likely to be 30%, a figure that is comparable to that reported for the EDUNE model described above.

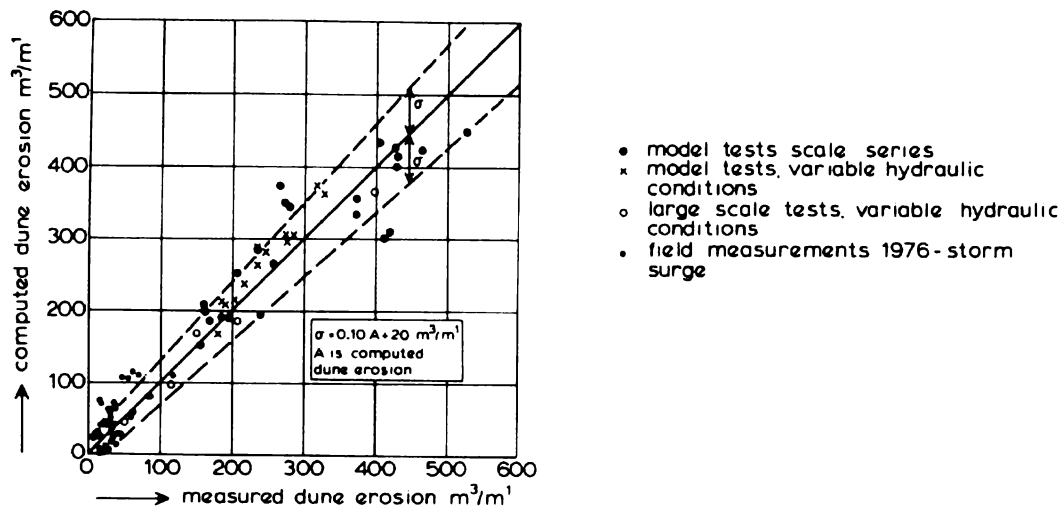


Figure 3.24: Accuracy of Computational Model showing computed versus measured dune erosion in m^3m^{-1} of beach (Source: Vellinga 1983).

3.9 Conclusion

This chapter has reviewed the theory by Bruun (1954) and Dean (1977) for determining the two dimensional equilibrium status of sandy beaches. It describes research carried out to verify the basic model together with various modifications proposed to improve its realism and descriptive abilities such as those documented in Kriebel and Dean (1985), Dean (1991), Bodge (1992), Inman *et al.* (1993) Dean *et al.* (1993) and Komar and McDougal (1994)). Subsequently three models were examined that employed the EBP concept to predict beach responses to specific storms events, viz. Kriebel (1989), Larson and Kraus (1989), and Vellinga (1983).

The application of these concepts to the Bay of Plenty beach profiles is examined more fully in the following chapters. In particular the concepts described by Dean (1997) and Kriebel and Dean (1985) are applied to predict coastal responses, not only to overall equilibrium conditions, but also to individual forcing mechanisms such as erosion resulting from storm surge.

Chapter 4

Application of the Dean Equilibrium Beach Profile to Bay of Plenty Beaches

4.1 Introduction

This chapter describes the application of the Dean Equilibrium Beach profile and its variants to forty-eight Bay of Plenty beach profiles to achieve the following:

- Document application of the Dean EBP model's application to measured Bay of Plenty profiles to determine appropriate scale and shape factors for use in the Bay of Plenty;
- compare the derived scale and shape factors with typical values found by Bruun (1954), Dean (1977), and Dean (1991) for eastern United States beaches;
- compare the model's ability (including the Dean (1991) variant) to characterise the sandy beaches of the Bay of Plenty, and finally;
- to assess the predictive potential of the model to determine the equilibrium status of Bay of Plenty Beaches (i.e. whether the beach is potentially erosive or accretional) for use and further development in coastal hazard modeling.

The methodology employed involves the following procedures:

- The application of a least squares regression analysis to determine the ability of the power curve of Dean 1977 (equation 4.1) to represent the forty-eight profiles of the Bay of Plenty data set. The coefficient of variation R^2 was used as the measure to determine 'goodness of fit'. The two parameters of Dean's equation were allowed to vary independently as part of a blindfolded regression analysis in order to determine values for each profile for both the scale factor (A) and the shape factor (m).

$$y = Ax^m \quad (4.1)$$

- The values derived for the scale and shape factors were then averaged and compared to the values derived stochastically by Dean (1977) and Bruun (1954) for the 504 beaches used by Dean from the eastern United States of America and the dataset of 32 profiles from Lime Bay, northern Denmark. The purpose of this work was to verify the theoretical derivations of Dean 1977 and Larson and Kraus (1997) for the power value of the shape factor m used in the application of EBP theory to coastal erosion modeling.
- The Dean (1977) EBP model represented by equation 1.1 was derived for use within the surf-zone. This closure depth can vary depending upon wave forcing conditions applied to a beach at any given time. The blindfold regression analysis results achieved above were therefore tested as to their sensitivity to depth of closure based on a range of depths determined using Hallermeier estimates for both inner and outer limits. In addition the resulting values of A derived from the regression analysis were then compared to A values calculated from sediment values to conclude whether there were any correlation between the independently obtained values for each profile.
- Following confirmation of the appropriateness of the Dean model (1977), both the Dean 1977 and 1991 models were then applied to the dataset using the confirmed shape factor obtained for the Bay of Plenty Beach dataset. The power curves were fitted to the measured profiles to closure depth estimates of both the inner and outer Hallermeier limits. The goodness of fit to measured profiles was resolved using the calculated values of the root mean square residual error determined for each profile.
- As part of this analysis the equilibrium status of each beach profile was also determined based on the methodology of Dean *et al.* (1993). The status of each beach was recorded based on its Erosion/Accretion potential and profile shift values. This was evaluated using routines developed in MATLAB for each of the four approaches taken (i.e. the Dean 1977 and 1991 models with profile averaged and piecewise determination of the scale factor A). As a result of this analysis the preferred modeling approach could be evaluated for use in the Bay of Plenty

4.2 Description of Profile location

The physical characteristics of the Bay of Plenty beaches comprising the study area were fully described in Chapter 2. This section develops that description into a specific characterization of the measurement sites used in the application of Dean EBP theory to coastal hazard identification as part of a generic methodology that is the product of the research documented in this thesis.

The measured profiles consist of data surveyed by Dommerholt (unpublished research data, University of Waikato) in 1993 for the Bay of Plenty Regional Council beach monitoring sites (see Figure 4.1). Data used consisted of both measured profiles and sand grain diameter measurements from bottom sediment sampling taken along the profile at the time of survey. These profiles were subsequently re-measured in 1997 by the BOPRC and this data has been used for profile comparison purposes.

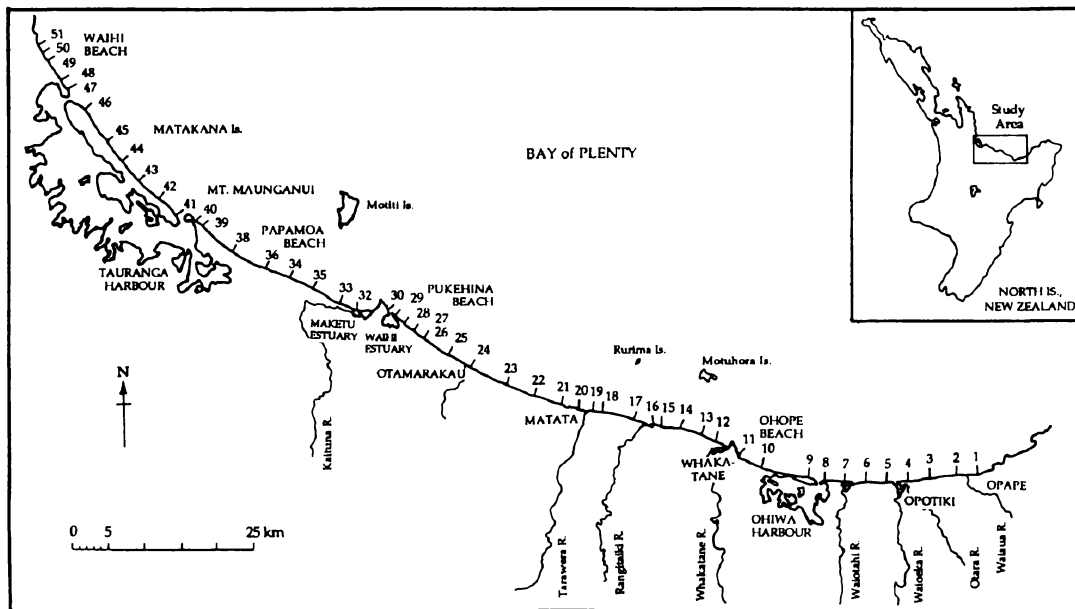


Figure 4.1: Bay of Plenty Beach Profile Monitoring Sites

The beach monitoring sites were established by Healy *et al.* (1977) and documented in a report prepared for the Bay of Plenty Catchment Commission and three subsequent reports by Healy (1978). The objective of this original work was to establish an information database on coastal changes occurring in the Bay of Plenty to ensure that:

- reasonable safeguards were in place to protect coastal developments from inundation and erosion; and
- appropriate policy responses could be implemented by planning agencies to control inappropriate development.

The original survey had as its aims the following (Healy *et al.* 1977):

- to conduct a field survey to investigate the state of health of the beaches and dunes in relation to beach erosion as of January-February 1977;
- to initiate long term monitoring of selected beaches and dune profiles at selected beach and dune profiles at critical sites;

- to investigate the sedimentology and bulk mineralogy of the beach, dune and nearshore zone sediments as an aid to the problems of identifying the source of sediment in the littoral zone; and
- to record the nearshore submarine topography in relation to the typical beach and dune profiles.

This work is important in that it established the benchmark reference profiles and geomorphic characteristics of the study area necessary to implement the modeling approach taken in this thesis work for coastal hazard identification.

4.3 Application of Equilibrium Beach Profiles to Existing Profile Data using the Dean Model

The theoretical derivation of Dean's EBP models has been described in Chapter 3. Dean's approach has been applied to this research work through a series of four numerical models developed in MATLAB to ascertain the equilibrium status of the BoP beaches. These models determine both the goodness of fit of the EBP and the shift required (i.e. erosion or accretion) for the profile to achieve equilibrium.

Initially the values of the shape and scale parameters used in the Dean model require determination. Dean (1977) used stochastic techniques to derive the appropriate values for the parameters to confirm the theoretical model using the 504 profiles contained in his dataset. A similar approach was used here to establish the parameters for use in the application of the model to Bay of Plenty conditions.

This involved fitting Dean's parametric model (1977) to the Bay of Plenty dataset by way of a 'blindfold' regression analysis in which both parameters were left free to vary. The objective of this exercise was to determine the most appropriate value of the shape factor, m , for use in the Bay of Plenty and to cross-reference the sediment derived scale factor values obtained from measured field data with the scale factor values determined from the regression analysis.

4.4 Determination of Parameters for use in the Dean EBP

Recollect (Chapter 3) that it had been suggested by Bruun (1954) and Dean (1977) that a power curve of the general form described in equation 4.1 represents a beach that is in two dimensional (profile) dynamic equilibrium with the available wave energy and sediment grain size.

The methodology employed involved the following:

- Applying a blindfold regression analysis to determine appropriate scale and shape factors for use in the BoP;
- Comparison of the results of this analysis with those obtained by other researchers such as Dean (1977) and Moore (1984); and
- Use of these parameters to determine the equilibrium status of the beach profiles and as a consequence allow determination of the beaches potential for erosion or accretion.

However determination of appropriate boundary conditions is required before this work can be carried out. The shoreward limit adopted by most researchers is Mean Sea Level (MSL) while the offshore limit has been defined variously as '*the seaward limit to significant wave effects*' (Hallermeier, 1981a), '*the limiting depth of motion*' (Charles, 1994) or '*closure depth*' (Kraus, 1992). This matter is discussed further in section 4.5.

4.5 Limit of Significant Sediment Exchange or Closure Depth

Application of the EBP profile models requires knowledge about the limits within which "significant" (i.e. detectable) sediment exchange occurs along the profile resulting from the action of breaking waves. The term "significant" in this context means identifiable exchange along the surveyed profile, or volumes of sediment transfer sufficient to cause noticeable morphologic change on the profile. For modeling purposes the inner boundary is often defined as mean sea level (although clearly the active beach profile extends to the dunes) whereas the outer or seaward limit, often termed the depth of closure, can be ascertained in one of three ways (Hallermeier, 1981b):

- estimation of the limit of significant sediment exchange along the profile from geomorphic/geologic evidence, for example, the depth where a distinct change in profile shape occurs;
- determination of 'closure depth' from time series profile survey data as the point where net zero or negligible change occurs in the profile over time (Kraus, 1992);
- estimation of the theoretical closure depth from wave climate models such as those derived by Hallermeier (1981a,b,c)

It is important to note that while the limit of significant sediment exchange inherently suggests that the sediment is confined within a two dimensional closed system, evidence from a variety of sources (Pilkey *et al.*, 1993, Wright *et al.*, 1991) suggests that in reality this may not be so. Wright *et al.* (1991) identifies a complex unpredictable set of drivers that act to force sediment movement in the upper shoreface. These include the following:

- interactions between 'groupy' incident waves and forced long waves;
- wind induced upwelling and downwelling currents;

- wave current interactions; and
- gravity induced downslope transport

These mechanisms tend to act against the assumptions inherent in the Dean model (Pilkey *et al.*, 1993). However many of these forcing mechanisms will either act at the micro scale to provide the mechanism to form localised variations in beach and shoreface morphologies such as longshore bars, or they may act to explain at the macroscale why deviations occur from an averaging models such as Dean's EBP.

Cowell *et al.* (1999) note that the concepts of closure are totally inadequate at time scales of decades or longer, otherwise known as *large scale coastal behaviour* (LSCB) because depth of closure is held to increase with time scale (Nicholls *et al.*, 1998). They point out that annual closure depths are almost certainly less than those for profile closure over the long term extending from decades to millennia (see Figure 4.2).

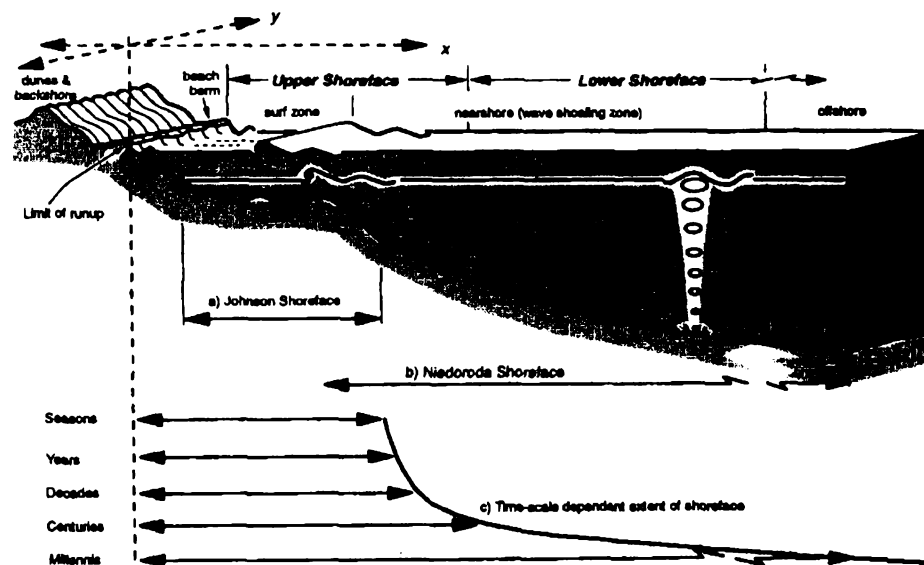


Figure 4.2: The various definitions of the shoreface depicting the time scale for morphological change at various depths along the beach profile. (Source: Cowell *et al.*, 1999)

The following provides a review of the available literature on the subject of 'closure depth', and, where appropriate, identifies the physical evidence required to form conclusions about the concept's application in determining the equilibrium status of beaches in the Bay of Plenty as discussed later in this chapter.

Geomorphic - Geologic Evidence

The active zone of surf dependent sediment transport occurs in the upper shoreface. The limit of this zone in the Bay of Plenty is defined as occurring at depths between 4 and 7 m, where this depth represents the limit of the of the modern sand prism (Hume and Hicks, 1993). Gibb and

Reinen-Hamill (1997) suggests that this extreme limit of surf related processes might be defined by subtle changes in both gradient and sediment characteristics.

Hallermeier (1981b) interpreted Dietz's (1963) work to imply that the seaward limit of wave activity is revealed at some locations by the depth where bathymetric contours are parallel to a relatively straight shoreline caused by shoreline infilling due to onshore movement of sand, and smoothing of irregularities due to wave activity on the nearshore sand wedge as shown in Figure 4.3.

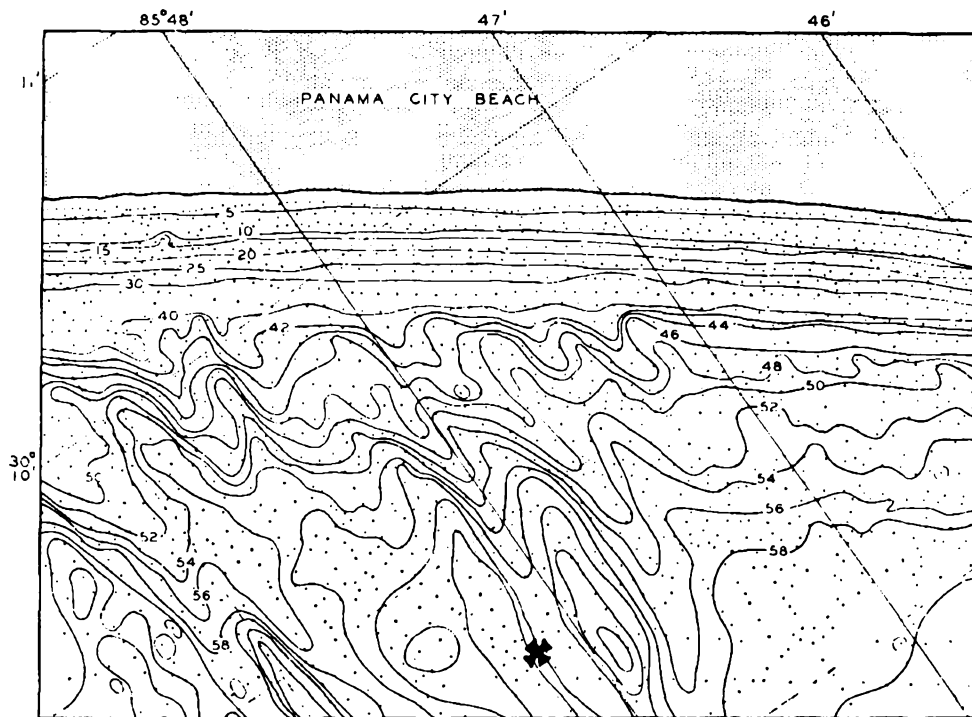


Figure 4.3: Detailed topographic form of the inner shelf off of Panama City, Florida. A smooth gradient extends to a depth of 40 feet (12 m) which Dietz suggests represents the limit of the marine equilibrium profile (Source: Dietz, 1963).

Everts (1978) suggested a geomorphic definition equivalent to closure depth. He defines this as the junction between two characteristic profile sections referred to in his work as the curved shoreface and the plane ramp (Figure 4.4). The overall profile shape is defined by a mathematical function that represents the plane ramp as a straight line and the curved shoreface as an exponential term with a maximum steepness near the shoreline and maximum concavity near the ramp (i.e. indicating that wave energy decreases exponentially with distance). The profile shape function (see equation 4.2) was fitted to 49 sites along the US Atlantic and Florida coasts and the shoreface ramp boundary determined from the junction depth. This was then compared to depths determined by the shore parallel contour method.

$$z = (1 - G)(ax + b) + G(g(1 - \exp^{-\frac{x}{c}})^f) \quad (4.2)$$

where, z is the bottom depth below MLW datum, G is a term to combine the shoreface ramp, x is the distance seaward of the shoreline, g is the depth at the shoreface-ramp boundary, and f is an exponent defining the concavity of the shoreface (Everts, 1978).

Everts found no relationship between the geometric characteristics of the shoreface and the ramp suggesting different origins for these sectors. He suggests that the shoreface may be in or approaching some form of equilibrium with the existing wave climate, shelf currents available sediment supply, sea level changes and other factors with the seaward limit to the curved shoreface indicating the maximum water depth where significant wave action could affect formation of the profile. On the other hand he postulated that the large scale ramp bathymetry is probably a function of past events.

Everts reported that the geometric analysis gave more self-consistent results along the US Atlantic and Gulf of Mexico when compared to the results obtained by applying Dietz's (1963) methodology noting that there was no correlation between the shore-ramp boundary (or the geometric limit depth) and the depth at which shore parallel contours ceased. Everts work indicated that the shoreface-ramp boundary varied in depth between 5 and 20 m according to location, with the depth of the boundary being dependent on factors previously described such as available sediment supply, ambient wave climate, shelf currents, sea level changes, and past geologic history as a determinant of bottom morphology.

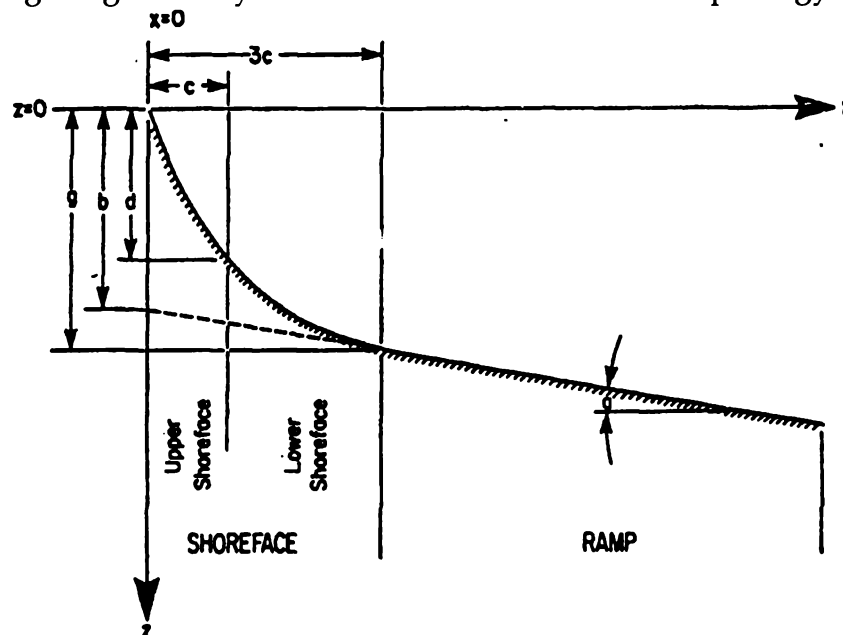


Figure 4.4: Definition sketch of an idealized Inner Continental Shelf profile showing planar, seaward dipping, ramp sector and the concave up shoreface sector (Source: Everts 1978)

Another type of indirect seaward limit indicator reported by Hallermeier, (1981b) involves apparent changes in sediment characteristics along the subaqueous profile. Inman (1949) observed that the relationship between sediment sorting and skewness to median sediment diameter permits inferences to be made about the conditions under which the sediment was transported and deposited. The theory is based around empirically derived relationships between grain size and threshold velocities sufficient to initiate sediment movement which can lead to preferential sorting of grain size according to depth and ambient wave height and associated bottom currents. This can lead to characteristic signatures of sediment grain size distribution along the sub aqueous beach profile.

Hallermeier (1981b) noted that Charlesworth provided an example of the detailed application of this concept for the New Jersey nearshore, while Bradley suggested that the limit to surf effects for a California site was defined by the distribution of angular and rounded pyroxene sand grains along the nearshore profile. For other sites, Hallermeier notes that Pilkey and Frankenberg, Swift, and Gordon and Roy have also reported distinct breaks in sediment diameter (and occasionally colour) along the shoreface profile which have been interpreted as indicating the seaward limit of usual wave dominated sedimentation, agitation, and surficial transport processes.

Hallermeier (1981b) also identified that the absence of specific fauna may provide yet another indirect marker of the limit of significant wave agitation within the profile, although he indicates that this is inexact due to the lack of an established quantitative relationship between species presence, sediment movement and wave processes. To date, to the writer's knowledge, no established link has been identified between faunal species indicators and the effects of wave agitation for BoP beach profiles.

A review of the profile and sediment information obtained by Dommerholt (1993), suggests that Gibb and Reinen-Hamill's (1997) proposition for the Bay of Plenty that the location of profile slope changes and sediment characteristics act as an indicator of 'closure depth' may have some justification. Plots of the profiles (offshore distance v. depth) and sediment grain size (d_{50}) based on sediment fall velocities from the Rapid Sediment Analyser are contained in Appendices 1 and 2. A summary of this work showing superimposed plots of all BoP profile and sediment data is shown in Figure 4.5.

The two plots contained in Figure 4.5 indicate a rapid fining of sediments in the offshore direction with a distinct change in sediment grain size occurring between 400 and 500m offshore. This offshore distance corresponds to a depth of approximately 6 - 7m below MSL indicating a probable location of closure depth and significant wave activity. It is interesting to note that the outliers from this general trend are located on profiles that are situated in close proximity to ebb tidal deltas. These

occur at major harbour or river entrances including Whakatane, Pukehina, Maketu, Mt Maunganui and Bowentown.

Hume and Hicks (1993) have documented work in the Bay of Plenty to characterise the morphological features of the parabathic and diabathic zones. These morphological features include ripples, mega-ripples, sand waves, well-sorted sand deposits and lag deposits, all features that are products of oscillatory flow due to wave action and currents resulting from a number of forcing mechanisms.

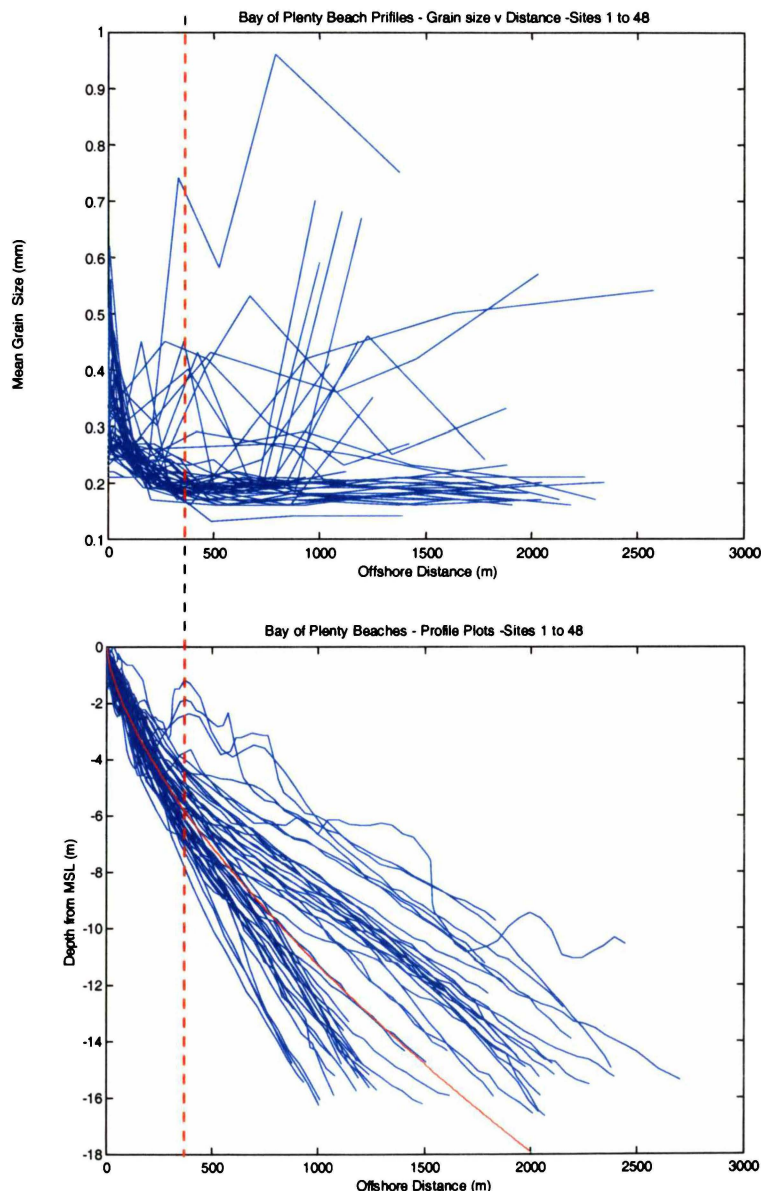


Figure 4.5: Plots showing mean grain size and depth plotted against offshore distance for Bay of Plenty Beaches. The red line in the lower figure represents the average Dean Equilibrium Profile derived from data for 48 BoP beach monitoring sites.

Bradshaw *et al.* (1991) identified that sediment movement on the inner shelf on the East Coast of the Coromandel immediately adjacent to the

BoP was susceptible to wave driven currents that reversed dependent upon dominant wind direction, with offshore driven northerly bottom currents being associated with strong onshore winds. It is thought that this current represents a more complex 3 dimensional downwelling circulation driven principally by a shore set up of water due to a combination of storm surge and inverse barometric effects. The resultant downwelling current sufficient to initiate sediment transport is deflected to become shore parallel along the Coromandel coasts in order to maintain a geostrophic balance with pressure gradients and Coriolis forces as evident by the tendency for the current duration to exceed the inertial wind periods.

During intervening light winds or offshore directed winds little sediment transport occurs on the inner shelf because the weakly directed southerly current is and low swell conditions is insufficient to initiate sediment transport. Nearshore scuba observations during these so called calm periods, indicated that whilst weak 'to and fro' movement of sand was observed due to wave oscillatory currents at depths ranging from 12 to 24 m, sediment transport was only initiated at shallower depths where a net onshore transport occurred (Bradshaw *et al.*, 1991).

Harms (1989), Foster (1991), Foster (1992), Warren (1992), and Mathew (1997) describe the shoreface features offshore of Mt Maunganui Beach. Harms (1989) notes a fine well sorted sand facies in the study area parallel to the shore extending up to 1000 m offshore from the beach to approximately 10 m water depth with an irregular coarse sand facies surrounded by fine to medium sand belt butting up against this to at least 4 km offshore. The fine sand facies is either flat or lightly rippled indicating the limit of storm wave activity.

Harms (1989) was the first to report the sediment data and bottom morphology that net sediment transport in the onshore direction resulting from 'general' wave activity is more likely to be important in the nearshore zone at depths less than 7 m principally due to the effect of asymmetric wave orbital stress. Foster (1991) showed that within a 6 month period that sediment moved onshore onto Mt Maunganui Beach from a sand dump ground located in 6 m of water.

Hume and Hicks (1993) report as a result of work done at the Katikati entrance and Waihi Beach that the steep seabed profile flattens out at about 4-7m depth below the lowest astronomical tide. Below this depth the shoreface is noted as having a convex upward bulge out to about 22-24m depth where there is a flat bench. They also note that the profiles north of the Katikati entrance tend to be steeper with a pronounced convexity compared to the upper shoreface profiles for Matakana Island.

Hume and Hicks (1993) note that the sands of the upper and middle shoreface are well sorted fine quartzo-felspathic sands. These fine sands

are typically rippled (shore parallel) as a result of orbital wave current action and that they form the modern sand prism out to a depth of 4 to 7m. Below this depth the fine sands are still found as a blanket covering but they become increasingly patchy with depth until at depths of 15 to 20m the seabed comprises mainly mega-rippled medium to coarse grained poorly sorted sands.

Mathew (1997) identified closure limits based on observations of nearshore bottom features, current and wave data and surficial sediment characteristics as lying between 6 and 15 m dependent on wave conditions with the shallower depth being identified as the zone affected by surf related processes while the deeper limit represents the depth limit for processes related to shoaling based on average annual wave data.

To conclude this discussion these observations indicate that the limits of significant sediment exchange or the active profile limits resulting from surf activity for BoP beaches are likely to range between 4 and 10 m offshore with perhaps the most likely value being around 6-7 m below MSL.

Evidence from Repetitive Beach Profile Measurement (Morphological)

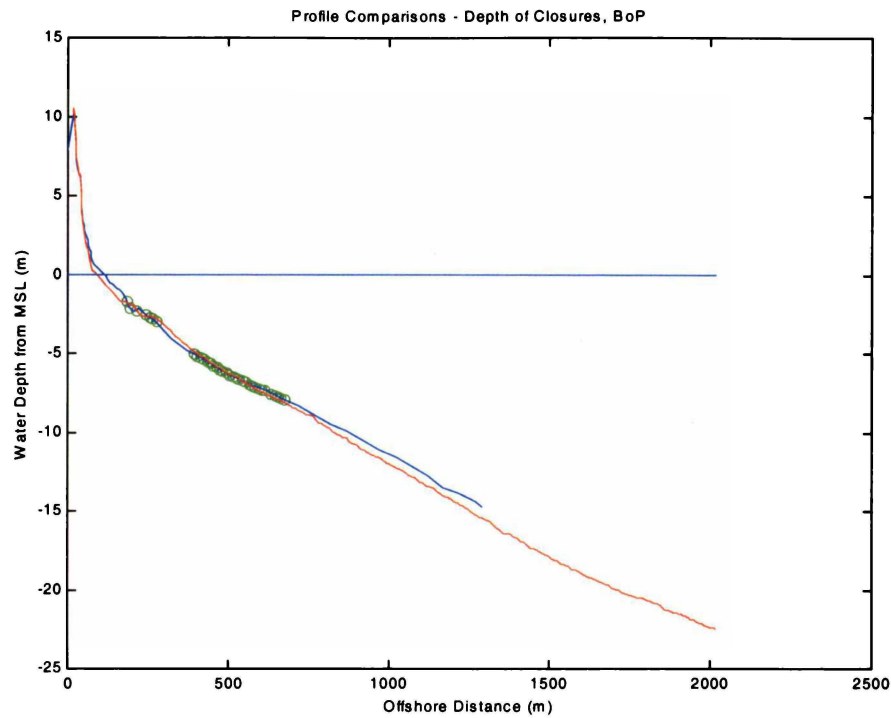
Kraus (1992) has defined the depth of closure (D_c) as that depth where waves can no longer produce measurable changes in the depth of a profile. However Kraus points out that this is not the depth where sediment ceases to move, but is that point on the profile where before and after surveys over time identify negligible changes in profile depth. This determination is obviously time dependent as larger waves will cause more significant profile change to a greater depth than smaller waves with lesser transporting power. To this extent the approach is complimentary to the more analytical approach of Hallermeier (1981a).

A graphical analysis has been carried out to compare profile variation over time using a profile dataset held by Environment Bay of Plenty. The data was analysed according to location to determine whether variation of closure depth occurred within the broad morphological classifications (Wright and Short, 1984) described in Chapter 2.

The dataset in the main consists of profile measurements taken 5 years apart. The initial dataset was measured using Electronic Distance Measuring (EDM) survey equipment providing accuracy limits of $\pm 0.2\text{m}$ vertical and $\pm 0.5\text{m}$ horizontal. The 1998 data was measured using the same approach providing similar accuracy limits as the earlier survey.

A MATLAB routine was developed to analyse the profile information so that the exchange limit (or closure depth) may be rationalised for each profile contained in the data set. The data input to the routine is in the form of matrices containing distance, depth and profile identifier

a) Profile 38, Omanu showing minor divergence of profiles at depth. Closure depth approximately 5m below Mean Sea Level (MSL)



b) Profile 40, Mt Maunganui showing profile convergence occurring at approximately 5-6m below MSL.

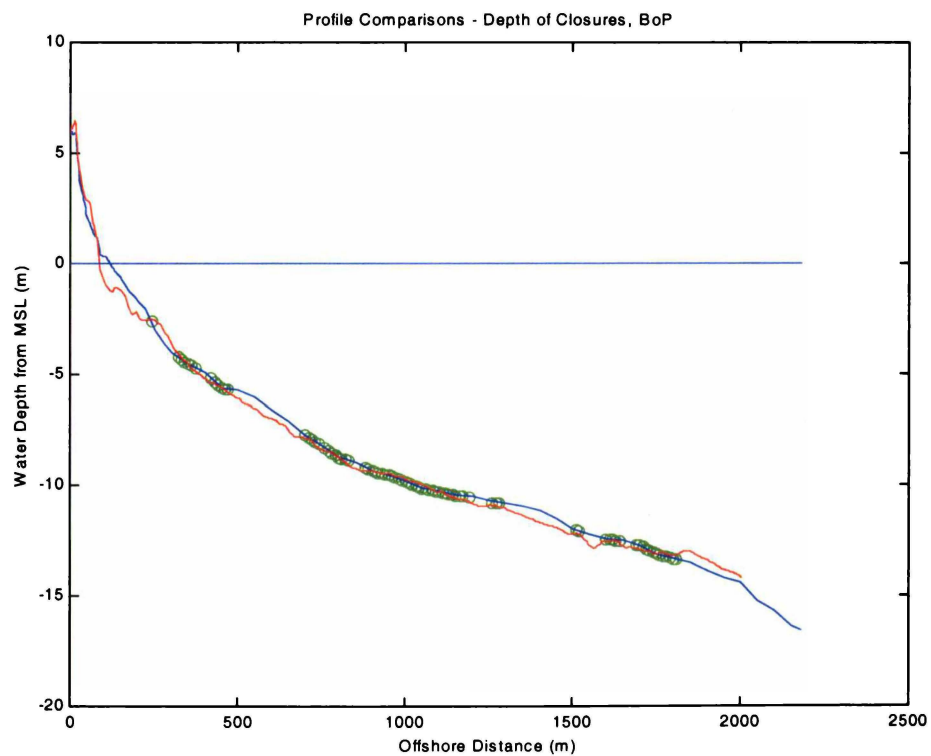


Figure 4.6: Examples of two profile plots showing comparisons between surveys dated 4/92 (blue) and 6/97 (red). Green circles indicate no change in depth as a potential marker for closure depth

information. The routine standardizes both profiles to equivalent length and depth by interpolating between measurement points to produce two profiles capable of comparison.

Profile No.	Dates of comparison surveys m/yr	Estimated Depth of Closure (m)	Depth of Change in Slope (m)	Profile Convergence	Comment
1	4/92; 6/97	4-6	7	Y	Convergent profiles
2	4/92; 6/97	4	7	N	
3	4/92; 6/97	4-6	7	N	
4	4/92; 6/97	Indeterminate		N	Parallel profiles
5	4/92; 6/97	6	6-7	Y	Convergent profiles
6	4/92; 6/97	Indeterminate		N	Parallel profiles
7	4/92; 6/97	8 & 12	7-8	Y	Convergent profiles
8	4/92; 6/97	Indeterminate		N	Ebb tidal delta
9	4/92; 6/97	Indeterminate		N	Ebb tidal delta
10	4/92; 6/97	5	7	N	
10	4/92; 6/97	Indeterminate	8	N	No change in profile
11	4/92; 6/97	4 & 14	6	Y	Convergent profiles
11	4/92; 5/97	4 & 14	6	Y	
12	4/92; 5/97	6	7	N	Profiles divergent
13	4/92; 5/97	10	10	Y	Convergent profiles
14	4/92; 5/97	8.5	9	N	Divergent at depth
15	4/92; 5/97	6	8	N	Parallel at depth
16	4/92; 5/97	8	9	Y	
17	4/92; 5/97	5	9	N	Minor divergence
20	4/92; 5/97	4	4	N	Minor divergence
22	4/92; 5/97	5	7	N	
23	4/92; 6/97	Indeterminate	9	N	Divergent profiles
24	4/92; 6/97	5.5	8	Y	Convergent profiles
25	4/92; 6/97	6	8?	Y	Convergent profiles
26	4/92; 6/97	5 & 14	6	Y	Convergent profiles
27	4/92; 6/97	7 & 12	7	Y	Convergent profiles
28	5/92; 6/97	6 & 11.5	8	Y	Convergent profiles
29	4/92; 6/97	6	6	Y	Convergent profiles
30	4/92; 6/97	6	6	Y	Convergent profiles
32	4/92; 6/97	6	6	N	Minor divergence >10
34	4/92; 6/97	5-7	5	N	Divergent at depth
35	4/92; 6/97	Indeterminate	6	N	Strongly divergent
36	4/92; 6/97	6	6-8	N	Minor divergence
38	4/92; 6/97	5	6	N	Divergent at depth
39	4/92; 6/97	5	5	N	Divergent at depth
40	4/92; 6/97	5-6	10	N	
43	4/92; 6/97	6 & 11	7	N	Divergent at depth
44	4/92; 6/97	4	5-6	N	Divergent at depth
45	4/92; 6/97	6	8-9	N	Divergent at depth
46	4/92; 6/97	6	Indeterminate	N	Ebb tidal delta
47	4/92; 6/97	6	Indeterminate	N	Ebb tidal delta
48	4/92; 6/97	Indeterminate	7-8	N	No coincidence
49	4/92; 6/97	5?	7	N	No coincidence
50	4/92; 6/97	6?	7	N	Divergence at depth
51	4/92; 6/97	7	8	Y	Convergence

Table 4.1: Estimates of Closure Depth from Repeat Profiling for BoP Beaches for 1992 and 1997. Mean values for various coastal sectors are given subsequently in Table 4.2.

Interpolated and measured depths along the profiles are then compared and where depth differences are less than the nominated vertical error limits (0.2 m) of the survey then these points are identified both graphically and numerically as points of profile coincidence. Clusters and patterns of these points are then used to identify likely limits of sediment exchange. Examples of the profile plots obtained from this analysis are shown in Figure 4.6 while the results of the analysis are contained in Table 4.1 and Appendix 3.

One significant problem identified during the analysis was the apparent lack of coincidence of the surveyed profile lines between repeat surveys. This shows up in divergent or non-convergent profile lines in particular at depths where profiles are expected to converge as shown in Figure 4.7. This results from several possibilities namely that:

- either significant littoral sediment accumulation has occurred in the offshore profile; or
- significant erosion has occurred at the beach face; or
- the repetitive survey profile lines are not coincident and diverge in relationship to each other; or
- relative errors in the measurement process between surveys arise due to limitations and specifications of the equipment used.

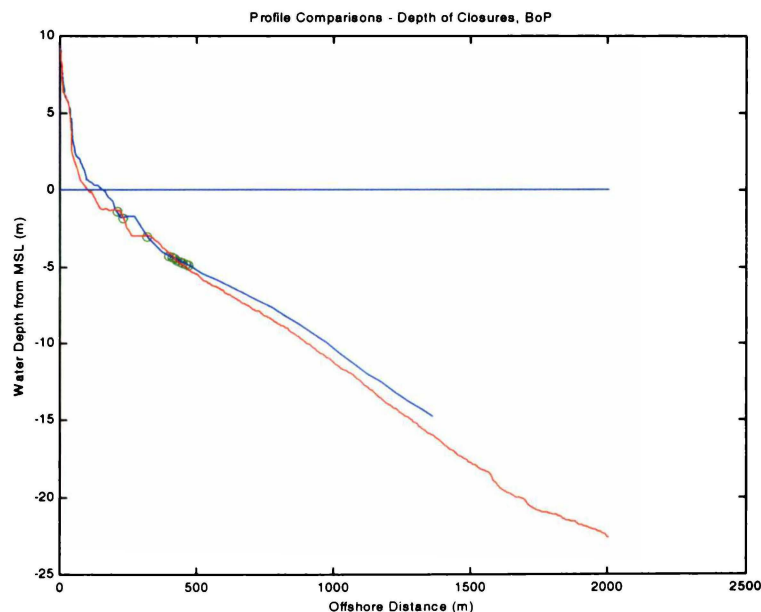


Figure 4.7: Profile 39, Mt Maunganui showing increasing divergence of profile at depths greater than 5m relative to MSL.

In many of the cases identified in Table 4.1 profile divergence during survey is the more probable explanation as the alternatives would either result in significant accretion over time from onshore sediment movement during low swell and offshore weather conditions, or alternatively significant shoreline retreat would be evident. Neither of these conditions is apparent in the profile dataset. The monitoring information reported by

Healy (1977, 1978), Gibb (1994), Hodges and Deely (1997), and Gibb and Reinen-Hamill (1997) and the evidence derived from the application of the Dean model as discussed later, tends to confirm this proposition.

While the limited survey data does not permit rigorous statistical analysis of the results, the data can be used to identify or imply the likely limits of significant sediment exchange or closure depths for the majority of the profiles contained in the data set. This information together with the supporting evidence referenced in this section is considered sufficient to indicate appropriate 'closure depths' for use in the hazard model employed later in this research.

The average 'closure depths' for the various 'geomorphic' sections (see section 4.6) of the Bay of Plenty coast are summarised in Table 4.2 below. On the basis of these results an indicative 'closure depth' appears to lie generally between 5 and 9 m with an average of 5.5 m relative to MSL datum. Estimates of closure depth derived from the profile shape comparison lies generally between 6.5 m and 8 m with an average of 7 m. Therefore both pieces of evidence tend to indicate that an appropriate approximation for closure depth is 6 m below MSL. Further evidence on this matter is discussed in the following sections.

Profile Section	No. of Profiles	Average Depth of Closure	Average Depth of Change in Slope
Opape – Ohope	13	5	7
Whakatane - Pukehina	16	6	8
Maketu – Mount Maunganui	7	5.5	6.5
Matakana Island	4	5.5	7
Bowentown – Waihi Beach	5	6	7
Overall Average		5.5	7

Table 4.2: Indicative Depth of Significant Exchange or Closure Depth for Geomorphic Sections in the BoP.

Evidence from Wave and Sediment Modeling

Hallermeier (1981b) describes an alternative approach to the methods described above, based upon a methodology derived directly from wave and sedimentation theory. The theoretical development of this approach using documented results of wave interactions with sand beds relies on the concept of zonation of the seasonal beach profile. There are three zones: the littoral zone, the shoal zone and the offshore zone.

The littoral zone (Figure 4.8) extends to the seaward limit of intense bed activity caused by extreme near breaking wave conditions and breaker related currents (Hallermeier, 1979, 1981a, 1981b, 1983). The shoal zone on the other hand extends from the seaward edge of the littoral zone to a water depth where expected surface waves are likely to cause little sand transport. In this zone waves have neither a strong or negligible effects on the sand bed. Seaward of the shoal zone lies the offshore zone of

relatively deep water where surface wave effects (excepting long waves) are negligible.

The middle or shoal zone is seen as a buffer area (Hallermeier, 1981b) where sand transport processes result from sand deposition from the two flanking zones. That is, extreme waves can carry sediment from the littoral zone offshore into the landward section of the shoal zone while smaller more common waves can transport sediment onshore into the seaward section of the shoal zone. The Hallermeier model defines the depths of these limits as a two dimensional system where wave and sedimentation geometry are the only two factors considered. This is either because information on shore parallel flows is considered to be rarely available, and/or because the importance of three-dimensional effects is not clearly understood at these intermediate depths (Hallermeier, 1981b).

Hallermeier uses linear wave theory to develop the model because of its convenience and accuracy in providing peak near-bed velocities resulting from non breaking waves at intermediate water depths (Hallermeier 1981a & b).

The two depths chosen, d_i and d_e (see Figure 4.8) were established as geometric limits for wave interactions with a sand bed. The shoal zone is defined in terms of these limits throughout a typical year so that significant longshore transport and intense diabathic transport due to waves are restricted to depths smaller than d_e , and significant on/offshore transport by waves is restricted to depths less than d_i .

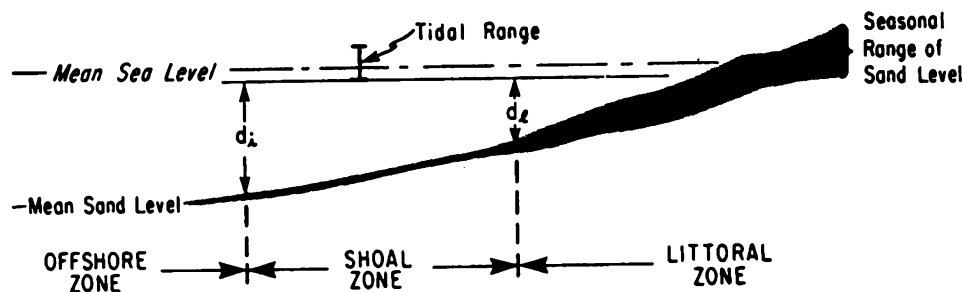


Figure 4.8: Annual zonation of seasonal sand beach profile; d_i is maximum water depth for motion initiated by median wave conditions, and d_e is maximum water depth for nearshore erosion by extreme (12 hours per year) wave conditions. (Source Hallermeier, 1981b)

Hallermeier (1978, 1981a) showed that the inner limit depth corresponding to the erosive action of wave was dependent on the Froude number describing sediment suspension energetics, this being:

$$\Phi_c = (U_b^2 / \gamma'gd) = 0.03 \quad (4.2)$$

where U_b is the maximum horizontal fluid velocity at water depth d according to linear wave theory, g is acceleration due to gravity, and γ' is

the ratio of the density difference between sediment and fluid to the fluid density. Empirical analysis of this relationship reported by Hallermeier (1981b) showed that the peak near-bottom fluid kinetic energy per unit volume (a key concept for Dean, 1977) was sufficient to raise an immersed grain a distance (0.015d).

Equation 4.1 can be rewritten using linear wave theory (Hallermeier, 1981a) for any given erosive wave condition to determine the inner surf limit to the littoral zone as

$$d_l = 2.28H_s - 68.5(H_s^2/gT_s^2) \quad (4.3)$$

or as shown in Kraus (1992),

$$\frac{d_l}{H_s} = 2.28 - 10.9 \frac{H_s}{L_s} \quad (4.4)$$

where H_s is the local significant deep water wave height and T_s the corresponding significant wave period. Hallermeier (1981a) claims that this equation represents a yearly 'close-out' depth when evaluated using extreme wave heights H_{sx} , exceeded more than 12 hours per year with an associated wave period T_{sx} . Hallermeier (1981b, p.260) claims that the evidence to support such claims is referenced in the work of Balsillie, Delft Hydraulics Laboratory, and Nordstrom and Inman.

To define the outer Hallermeier limit (d_o) knowledge is required about swell wave induced sand motion from waves moving across relatively flat sand beds. Hallermeier (1980) reviewed this topic and concluded that the Froude number (assuming a thoroughly mixed near boundary layer) at which critical sand motion is initiated is described by the following relationship,

$$\phi_c = (U_b^2/\gamma'gD) = 8 \quad (4.5)$$

where the variables and constants remain the same as for equation 4.2 with D representing the grain size diameter. From empirical evidence this Froude number specifies the critical peak near bottom fluid kinetic energy per unit sediment grain volume sufficient to move an immersed sand grain a distance four times its diameter (Hallermeier, 1981a).

Applying linear wave theory to the variables in equation 4.5 for any given wave height and period allows definition of the maximum depth limit for sand motion through the depth dependence of U_b (Hallermeier, 1981a & b). The calculation is consequently related to practical applications through the use of median wave height data, and typical sand characteristics for sediment situated in the shoal zone. In terms of the

limit d_i , it is argued from empirical evidence that the median annual significant wave height is the appropriate wave characteristic for defining such a limit because it is under these conditions that consistent onshore sand movement is initiated within the shoal zone, although proof of this is not strong.

Hallermeier (1981b) reported that a modified exponential distribution fits cumulative measured nearshore wave heights well. Based on a full year of daily wave height measurements the modified exponential distribution gives the extreme wave height exceeded 12 hours per year as:

$$H_{sx} = \bar{H}_s + 5.6\sigma \quad (4.6)$$

and the yearly median wave height as :

$$H_{sm} = \bar{H}_s - 0.3\sigma \quad (4.7)$$

Substitution of equation 4.6 into equation 4.2 and utilizing linear wave theory leads to the derivation of:

$$\xi \tanh \xi \sinh^2 \xi = \frac{4\pi^4 (\bar{H}_s + 5.6\sigma)^2}{0.03\gamma' (gT_s^2)^2} \quad (4.8)$$

where

$$\xi = \frac{2\pi d_i}{L} \quad (4.9)$$

and the maximum horizontal orbital velocity

$$U_{\max} = \frac{\pi H}{T [\sinh(2\pi d/L)]} \quad (4.10)$$

This can be solved iteratively to provide a value for the inner limit d_i .

The outer limit can be solved by substituting equation 4.7 into equation 4.5 to obtain

$$\sinh\left(\frac{2\pi d_i}{L_s}\right) = \left(\frac{\pi^2 (\bar{H}_s - 0.3\sigma)^2}{8\gamma' gDT^2}\right)^{0.5} \quad (4.11)$$

Approximations of equations 4.3 and 4.11 have been determined by Hallermeier (1981b) as

$$d_i = 2H_s + 11\sigma \quad (4.12)$$

$$d_i = (H_s - 0.3\sigma)T_s (g/5000D)^{0.5} \quad (4.13)$$

These formulae have been applied by a number of researchers to closure depth calculations for different beaches in the Bay of Plenty. Table 4.3 below summarises the various results

Location	Source	Wave Height (H_s) - m	Period (T) (sec.)	Grain Size (D) (mm)	Inner Limit - d_i (m)	Outer Limit - d_o (m)
Tauranga	Dommerholt (1993)	0.81	10.63	0.38	7.55	15.10
Waihi	Hay (1991)				6-8	10-13
Waihi	Harray & Healy (1978)	0.6	11	0.4	5.76	9.41
East Cape	Pickrill & Mitchell (1979)	0.5	7	0.29	4.49	7.21
Tauranga	Marine Geosciences A	0.658	8.9	0.25	6.05	13.41
Tauranga	Marine Geosciences B	1.26	9.3	0.62	10.74	17.54
Waihi Beach	Healy (1993) after Foster (1991)	1.596			6	13
Waihi	Hume & Hicks (1993)	0.767	11	0.15	6.6	25.1
Tauranga	Matthew (1997)	0.75	8.66	0.4	5.91	11.92
	Matthew (1997)			0.3	5.91	14.34
Town Pt, Maketu	Phizacklea (1993)	0.81	9.06	0.959	7.09	7.62
Pukehina	Phizacklea (1993)			0.189	7.09	21.27
Otamarakau	Phizacklea (1993)			0.20	7.09	20.69
Matata	Phizacklea (1993)			0.186	7.09	21.09
Town Pt, Maketu	Phizacklea (1993)	0.642	6.356	0.582	5.55	6.21
Pukehina	Phizacklea (1993)			0.180	5.55	11.78
Otamarakau	Phizacklea (1993)			0.188	5.55	11.55
Matata	Phizacklea (1993)			0.219	5.55	10.76
Ohope	Saunders (1999)	0.90	8.04	0.17	5.76	21.60

Table 4.3: Calculated Hallermeier Limits for the Bay of Plenty

These independent analyses for various beaches along the Bay of Plenty coast indicates an inner and outer depth limit for closure between 6 and 8 m for the inner limit and 10 and 15 m for the outer limit, with the most probable figures based on averaging being 6.5 and 13.2 respectively. However most of these determinations are based on data obtained during the period 1990 to 1995, a period that was known to fall in an extended El Nino or negative phase of the southern oscillation (ENSO) and the related phases of the Inter decadal Pacific Oscillation (De Lange and Gibb (2000).

It is known that this ENSO phase resulted in climatic conditions dominated by westerly wind patterns over the Bay of Plenty which tended

to promote accretional beach conditions under the dominance of westerly (offshore) winds and associated low energy wave regime typical of lee shores. It is possible that this may influence some of the results described in Table 4.3.

Cowell *et al.* (1999) noted that closure depths are very much a function of time and that depth of closure is known to increase with time scale (Nicholls *et al.*, 1998). Research documented by Lee *et al.* (1995), Nicholls and Birkemeier (1997), Capobianco *et al.* (1997), Lee *et al.* (1998), and Nicholls *et al.* (1998) developed the concepts of Hallermeier (1981b) and Kraus (1991) further using a high quality profile database available from the USACE Field Research Facility at Duck, North Carolina.

Lee *et al.* (1995) describe a conceptual fairweather-storm model of beach nearshore profile evolution whereby the beach-nearshore profile undergoes long term adjustments through time. Long-term (decadal) data indicated that under fairweather conditions the beach nearshore profile steepens towards a maximum as sand is moved onshore. The fairweather period is in the order of years to decades and includes less intense storms. The model predicts that if the fairweather period is long then the beach becomes primed and vulnerable to erosion and rapid recession is maximized.

The results of the profile analysis at Duck confirm important elements of this model and its usefulness for examining beach-nearshore behaviour, in particular over periods longer than annual time scales. The findings of this work has implications for the determination and interpretation of closure depth and the choice of inputs into the calculation of Hallermeier limits while recognising the time scales and phases of climate cycles such as ENSO and the IPO. This is particularly relevant as it could be argued that the data represented in Table 4.3 has been obtained during a fairweather El Nino dominated period (de Lange, 2000; Smith and Benson, 2000) whereby BoP beaches have been either largely static or accretional.

Nicholls and Birkemeier (1997) document a study to compare Depth of Closure (D_c) against the calculated Hallermeier inner limit (d_i - see equation 4.3) using 12 years of profiles from the Duck database. This analysis indicated that apart from extreme wave height, other factors can also affect or act to control closure depth at annual time scales. Their work showed that for erosional events with large waves, where d_i is greater than 7 m, pre event bar volume partly controlled closure.

Further they noted that the largest observed D_c is associated with a large single bar at about 400 m, while the smallest D_c is coupled with a smaller single bar located at 200 m offshore. Intermediate beach states are often associated with a two-bar configuration with the outer bar being intermediate in size and position (see Figure 4.9). The results of this work also demonstrated that Hallermeier's 'inner' limit d_i was equivalent to

observed depth of closures for profiles that were volumetrically constant, while d_i overestimated D_c for eroding profiles and under predicted D_c for accreting profiles.

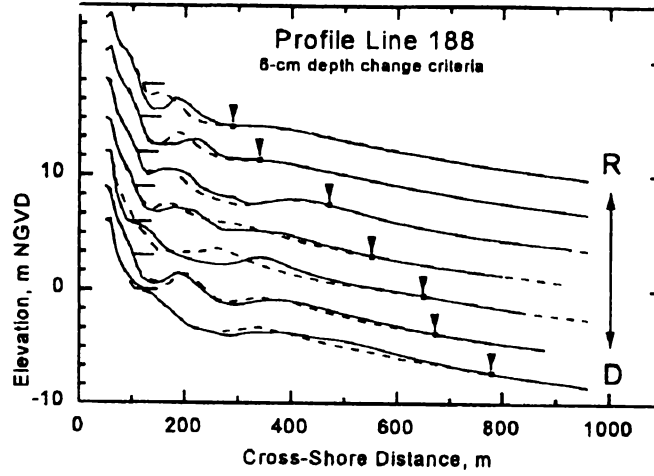


Figure 4.9: Pre and post storm morphology for the seven erosional events at Duck, North Carolina (Source: Nicholls and Birkemeier, 1997).

Nicholls *et al.* (1998) showed in general that D_c is also time scale dependent and will generally increase with time as suggested by the time dependent form of Hallermeier's annual limit d_i .

$$d_{i,t} = 2.8H_{e,t} - 68.5 \left(\frac{H_{e,t}^2}{gT_{e,t}^2} \right) \quad 4.14$$

where $d_{i,t}$ = the D_c over t years, $H_{e,t}$ = the non-breaking significant wave height that is exceeded 12 h per t years, (100/730t)% of the time, $T_{e,t}$ = the associated wave period, and g = the acceleration due to gravity (Nicholls *et al.*, 1998). Analysis of the Duck data indicates that equation 4.14 provides a reasonable estimate of depth of closure up to a time limit of at least 4 years. However the authors acknowledge that this may be due to a near balance of erosional and accretional processes at Duck. They suggest that sites that show either strong accretional or erosional trends may show different time interval characteristics for D_c than Duck.

These findings have relevance for the beaches of the Bay of Plenty given that they share many environmental characteristics with Duck including wave climate and tidal range characteristics. Nicholls and Birkemeier (1997) noted that different depth change criteria produced varying depth of closure estimates. For the Duck data closures were defined with 6, 10, 15 and 30 cm change criteria. Nicholls *et al.* (1997) determined that the larger change criteria produced estimates of closure that were landward of the smaller change criteria. When Closure Depth was plotted against the 6 cm change criteria the 10 and 15 cm change criteria data had similar properties to the 6 cm data but averaged about 90% and 80% of the 6 cm

depth of closure values, while the 30 cm data averaged only 53%. The BoP data has been measured to a lower degree of accuracy (± 0.2 m) to the Duck data and as a consequence it can be expected that estimates of depth of closure described above is likely to underestimate D_c by approximately 80% or less. This would increase the values for D_c indicated in Table 4.2 indicated as follows.

Profile Section	No. of Profiles	Average Depth of Closure (D_c)	Adjusted D_c	Average Depth of Change in Slope
Opape – Ohope	13	5	6.2	7
Whakatane - Pukehina	16	6	7.5	8
Maketu – Mount Maunganui	7	5.5	7.2	6.5
Matakana Island	4	5.5	7.2	7
Bowentown – Waihi Beach	5	6	7.5	7
Overall Average		5.5	7.1	7

Table 4.4: Indicative and adjusted Depth of Closure for Geomorphic Sections in the BoP. Systematic adjustment carried out to correct for (80%) under estimation in accordance to the results of Nicholls *et al.* (1997). Average depth of change in slope also shown for comparison purposes.

Repetitive analysis of detailed profile data combined with wave information obtained for Mangawhai Beach, New Zealand (Hicks *et al.*, 2002) showed closure depth results consistent with those derived for the Bay of Plenty as described above under similar morphological, climate and wave regimes. Hicks *et al.* calculated Hallermeier Limits varying between 8.0 and 8.9 m for d_i for the inner limit and between 10.7 and 10.8 m for the outer limits of sediment exchange (d_o). Morphological analysis of surveyed profiles from this study indicated surveyed 'closure depths' of between 7 and 8 m and approximately 10 m for the shoal zone confirm the predictions made using Hallermeier's formulae.

4.6 Determination of Scale and Shape Factors using Regression Analysis

The theoretical derivation of the Dean's equilibrium profile was discussed in Chapter 3. Dean (1977) confirmed the theoretical determination of the power curve exponent of $2/3$ by applying the technique of least squares regression analysis to 502 profiles located along the east coast of the United States between Long Island and the Texas-Mexico border. A similar analysis process was followed by the author in applying a 'blindfold' regression analysis to the 48 profiles contained in the 1992 BoP dataset. The object of this was to determine locally derived values for both scale and shape factors for comparison against those obtained by Dean (1977) and the values contained in the theoretical literature.

A sensitivity analysis was then carried out to determine the effect of closure depth on the values derived for the 'Dean' parameters and to also confirm the offshore limit for use in the model. Finally a further regression analysis was carried holding the shape factor ' m ' fixed while allowing the scale factor to vary. The results obtained from this analysis were then compared to the values obtained by Moore (1982) based on sediment grain size analysis and Dean (1987) based sediment fall velocity.

4.6.1 Blindfold Regression Analysis

As previously discussed a regression analysis was carried out to fit a power equation of the form described in equation 4.1. The regression analysis allowed for the power curve to be forced through zero (mean sea level) with both parameters left free to be determined by least squares regression. The result of this analysis using the 1992 data to the full depth (equivalent to the Hallermeier Outer Limit-HOL) of measurement is shown in Table 4.5 while the results obtained for closure depths approximating the Inner Limit are included in Table 4.6 (i.e. 6 and 8 m depths as discussed in section 4.5). The analysis was carried out using the curve-fitting program TABLECURVE 2D (Jandel Scientific, 1994). Examples of the regression curves produced showing the 95% confidence limits are included in Figure 4.10 (further sample plots from the analysis together with a summary table of Regression results for the BoP profile dataset are included in Appendix 4).

The regression derived values for both the scale (A) and shape (m) factors were then analysed using the statistical analysis package SYSTAT (SPSS, 1996) to determine in particular the dataset's statistical characteristics and relationship with Dean's (1977) theoretical value for the shape factor ' m ' (i.e. 0.67). The purpose of this analysis was to confirm or otherwise the utility of the shape factor based on uniform wave energy dissipation per unit volume for use in modeling the equilibrium status of the beaches within the Bay of Plenty.

Table 4.7 summarises the general statistics derived from the 'blindfold' regression analysis determining the shape factor ' m ' for various 'depths of closure'. The results presented in this table represent a standard set of measures that describe the statistical characteristics and normality of the datasets in terms of a Gaussian distribution.

Review of the values obtained in the analysis indicates that the data is normally distributed. In a symmetrical distribution the *mean* and the *median* are approximately the same. This is true in the above data although any agreement diverges slightly as the closure depth is decreased in the analysis, a fact that probably reflects an increased in profile variability as the closure depth is reduced.

Site No.	Scale Factor 'A'	Shape Factor 'm'	R ²	Fit std error (m)
1	0.1511	0.5922	0.9960	0.299
2	0.1380	0.6134	0.9961	0.298
3	0.0794	0.6824	0.9967	0.283
4	0.0708	0.7034	0.9920	0.457
5	0.1135	0.6347	0.9949	0.290
6	0.1640	0.5878	0.9954	0.324
7	0.1387	0.6046	0.9938	0.353
8	0.0414	0.7489	0.9805	0.553
9	0.0075	0.9691	0.9829	0.540
10	0.0507	0.7445	0.9981	0.191
11	0.0640	0.7084	0.9944	0.345
12	0.0923	0.6971	0.9898	0.486
13	0.1765	0.6076	0.9899	0.518
14	0.1004	0.6942	0.9927	0.488
15	0.0617	0.8053	0.9957	0.348
16	0.0494	0.8393	0.9972	0.261
17	0.0564	0.8251	0.9945	0.402
18	0.0188	0.9807	0.9914	0.428
19	0.0821	0.7409	0.9952	0.330
20	0.0911	0.7235	0.9873	0.459
21	0.1088	0.6860	0.9960	0.278
22	0.0898	0.7092	0.9936	0.351
23	0.057	0.7837	0.9940	0.343
24	0.102	0.7123	0.9925	0.418
25	0.0789	0.7548	0.9948	0.359
26	0.0794	0.7339	0.9938	0.386
27	0.0906	0.7283	0.9955	0.343
28	0.1147	0.6878	0.9968	0.295
29	0.0822	0.7337	0.9961	0.328
30	0.0772	0.7415	0.9857	0.720
32	0.2375	0.5216	0.9903	0.462
33	0.3564	0.4803	0.9832	0.538
34	0.0398	0.8344	0.9961	0.300
35	0.127	0.6366	0.9966	0.274
36	0.0503	0.8050	0.9972	0.246
38	0.0598	0.7755	0.9981	0.214
39	0.0379	0.8365	0.9949	0.343
40	0.144	0.6147	0.9924	0.468
41	0.3097	0.4531	0.9246	0.955
42	0.1346	0.6149	0.9941	0.403
43	0.0554	0.7505	0.9989	0.181
44	0.027	0.8449	0.9957	0.327
45	0.0347	0.8003	0.9906	0.478
46	0.0162	0.8636	0.9472	0.952
47	0.1195	0.5730	0.8900	0.951
48	0.1693	0.5737	0.9938	0.317
49	0.0573	0.7037	0.9976	0.186
51	0.0913	0.6362	0.9947	0.263

Table 4.5: Results of Blindfolded Regression Analysis to Profiles measured to HOL (N.B. Green shading indicates profiles affected by ebb tidal deltas).
Note: dimensions of 'A' are in metres^{1-m} and thus are variable.

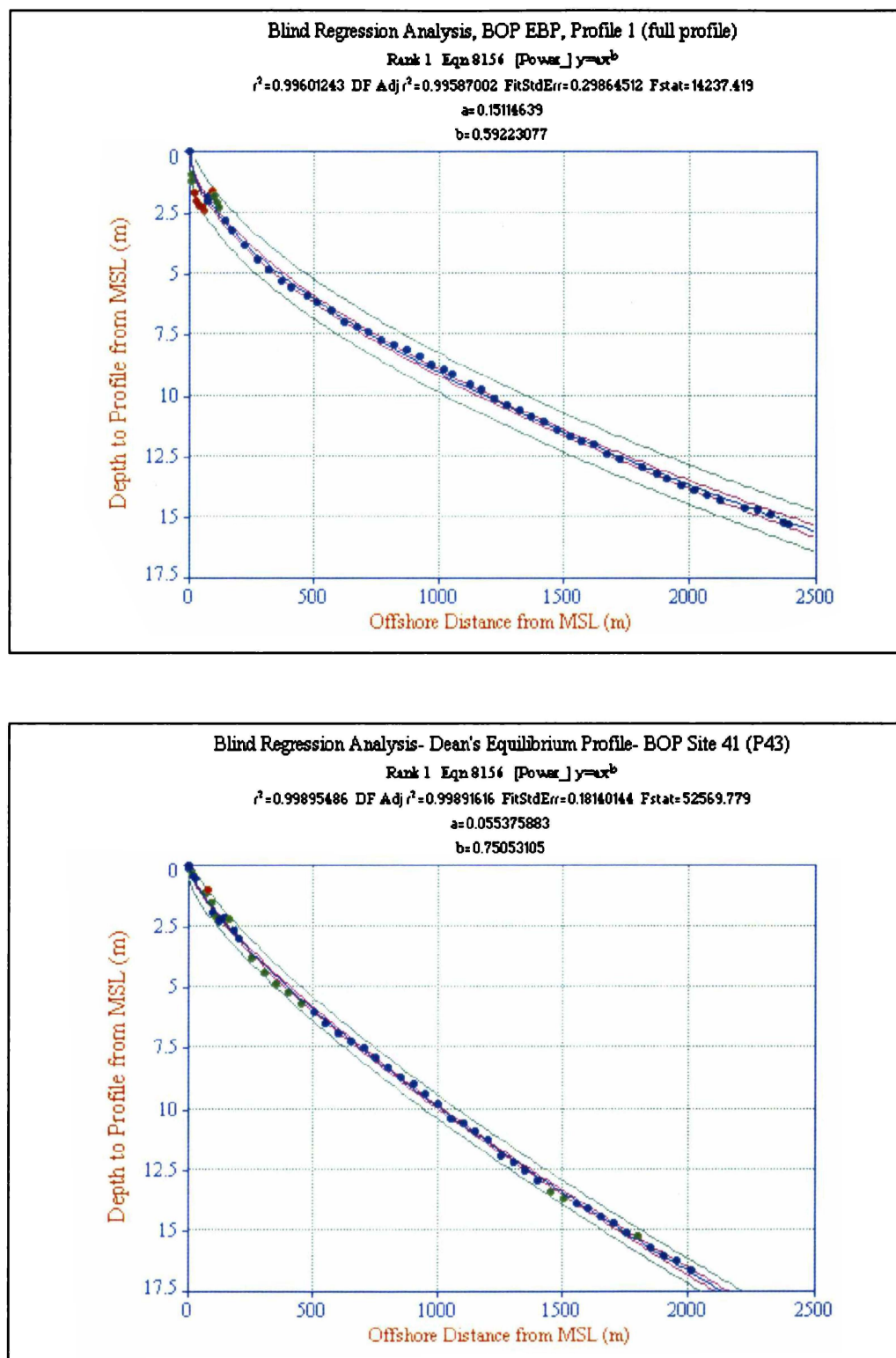


Figure 4.10: Regression Curves of the form $y=Ax^m$ for Profiles 1 (Opape) and 43 (Matakana Island)

Site No.	Scale Factor 'A'	Shape Factor 'm'	R ²	Fit std error (m)	Scale Factor 'A'	Shape Factor 'm'	R ²	Fit std error (m)	Site No.
	8m closure depth				6m closure depth				
1	0.1909	0.5548	0.9763	0.385	0.1951	0.5503	0.9359	0.442	1
2	0.1405	0.6146	0.9885	0.287	0.1065	0.6688	0.9763	0.289	2
3	0.0847	0.6757	0.9906	0.253	0.0609	0.7399	0.9815	0.227	3
4	0.0987	0.6537	0.9759	0.420	0.0620	0.7456	0.9535	0.402	4
5	0.0927	0.6706	0.9859	0.314	0.0765	0.7073	0.9628	0.336	5
6	0.1722	0.5835	0.9852	0.315	0.1662	0.5900	0.9530	0.353	6
7	0.1387	0.6046	0.9938	0.309	0.0758	0.7200	0.9761	0.295	7
8	0.1613	0.5393	0.9684	0.406	0.2089	0.4948	0.9553	0.405	8
9	0.0072	0.9737	0.9296	0.626	0.0184	0.8219	0.8770	0.607	9
10	0.0434	0.7712	0.9957	0.184	0.0315	0.8269	0.9921	0.178	10
11	0.066	0.7073	0.9886	0.284	0.0414	0.7958	0.9881	0.210	11
12	0.03	0.8966	0.9767	0.429	0.0073	1.1679	0.9663	0.318	12
13	0.0542	0.8279	0.9915	0.234	0.0396	0.8931	0.9889	0.201	13
14	0.0377	0.8641	0.9765	0.344	0.0382	0.8616	0.9450	0.360	14
15	0.0663	0.7895	0.9645	0.420	0.0842	0.7402	0.9376	0.427	15
16	0.0651	0.7863	0.9846	0.272	0.0789	0.7464	0.9671	0.275	16
17	0.0314	0.9295	0.9742	0.393	0.0419	0.8708	0.9475	0.398	17
18	0.0557	0.7867	0.9913	0.217	0.0695	0.7427	0.9905	0.178	18
19	0.1388	0.6477	0.9876	0.281	0.1521	0.6290	0.9749	0.301	19
20	0.1542	0.6279	0.9732	0.415	0.2209	0.5522	0.9419	0.404	20
21	0.1265	0.6597	0.9841	0.322	0.1336	0.6481	0.9594	0.355	21
22	0.0739	0.7446	0.9776	0.405	0.0590	0.7888	0.9320	0.451	22
23	0.0513	0.8053	0.9750	0.381	0.0350	0.8809	0.9395	0.397	23
24	0.1416	0.6546	0.9725	0.387	0.1530	0.6382	0.9260	0.424	24
25	0.1156	0.6863	0.9768	0.373	0.1348	0.6550	0.9578	0.386	25
26	0.1104	0.6790	0.9888	0.275	0.0794	0.7467	0.9796	0.255	26
27	0.1007	0.7100	0.9740	0.379	0.1059	0.6984	0.9301	0.403	27
28	0.1124	0.6950	0.9836	0.327	0.0919	0.7387	0.9611	0.337	28
29	0.0821	0.7374	0.9797	0.362	0.0689	0.7737	0.9504	0.383	29
30	0.0133	1.0612	0.9550	0.497	0.0055	1.2467	0.9293	0.428	30
32	0.3748	0.4489	0.9701	0.474	0.1898	0.5913	0.9673	0.370	32
33	0.2724	0.5371	0.9734	0.425	0.1114	0.7239	0.9715	0.272	33
34	0.0647	0.7523	0.9968	0.146	0.0579	0.7744	0.9917	0.154	34
35	0.1381	0.6259	0.9914	0.241	0.1058	0.6788	0.9839	0.222	35
36	0.0546	0.7926	0.9935	0.215	0.0415	0.8472	0.9888	0.199	36
38	0.0657	0.7618	0.9942	0.198	0.0508	0.8132	0.9902	0.181	38
39	0.0733	0.7262	0.9925	0.241	0.0598	0.7661	0.9839	0.253	39
40	0.0746	0.7316	0.9873	0.287	0.0605	0.7744	0.9788	0.279	40
41	0.5439	0.3556	0.9126	0.722	0.3932	0.4218	0.8253	0.812	41
42	0.0731	0.7216	0.9652	0.412	0.1013	0.6546	0.9305	0.392	42
43	0.0524	0.7669	0.9945	0.205	0.0361	0.8284	0.9910	0.182	43
44	0.0506	0.7453	0.9959	0.161	0.04	0.7888	0.9943	0.139	44
45	0.0896	0.6560	0.9970	0.150	0.0677	0.7071	0.9966	0.115	45
46	0.0722	0.6426	0.8526	0.930	0.2155	0.4853	0.6566	0.991	46
47	0.2277	0.4697	0.8329	0.936	0.5023	0.3230	0.7593	0.757	47
48	0.1093	0.6554	0.9900	0.219	0.0843	0.7099	0.9836	0.187	48
49	0.0611	0.6942	0.9961	0.159	0.0467	0.7433	0.9954	0.118	49
51	0.0987	0.6242	0.9910	0.257	0.0693	0.6898	0.9872	0.219	51

Table 4.6: Results of 'Blindfolded' Regression Analysis for Profiles measured to 8 and 6m depths being approximations of HIL (N.B. Green shading indicates profiles affected by ebb tidal deltas). Note: dimensions of 'A' are in metres^{1-m} and thus are variable.

	Shape Factor 'm' Statistics for various 'Depth of Closures'		
	Full Depth (HOL)	8m Depth (HIL)	6m Depth (HIL)
N of Cases	48	48	48
Minimum	0.453	0.356	0.323
Maximum	0.981	1.061	1.247
Range	0.528	0.706	0.924
Median	0.711	0.695	0.740
Mean	0.710	0.701	0.729
95% Upper Limit	0.742	0.738	0.774
95% Lower Limit	0.678	0.664	0.684
Std Error	0.016	0.019	0.022
Standard Deviation	0.111	0.129	0.156
Variance	0.012	0.017	0.024
Coefficient of Variation (CV)	0.156	0.184	0.213
Skewness(G1)	0.057	0.118	0.579
SE Skewness	0.343	0.343	0.343
Kurtosis (G2)	0.331	1.325	3.263
SE Kurtosis	0.674	0.674	0.674

Table 4.7: Summary Statistics for the least squares regression results shown in Tables 4.5 and 4.6 for Shape Factor 'm'

The *standard deviation* measures the spread of the values in each distribution. When data follows a normal distribution, we would expect roughly 95% of the values to fall within two standard deviations of the mean. The 95% confidence intervals (CI) described above adds further weight in confirming the normality of the data.

Two further important measures contained in the descriptive statistics provided in Table 4.7 are *skewness* (G1) and *kurtosis* (G2). Both of these measures are centred at 0 and measure the degree of symmetry and peakedness in the data. A positive value for skewness indicates a long right tail while a negative value indicates a long left tail. Likewise a positive value for kurtosis indicates that the tails of the distribution are longer than those belonging to a normal distribution while a negative value indicates a distribution with shorter tails suggesting a tendency to a box shaped uniform distribution.

Extreme values sufficient for rejection of normality are indicated by the values of the standard error. If the interval defined by plus or minus two times the standard error of G1 or G2 does not include 0, the measure is considered extreme and the hypothesis of normality can be rejected. Applying this test to the results contained in Table 4.7 indicates that the kurtosis values are extreme for the '6m' data and that the values in the range extend beyond that defined in a normal distribution. However skewness and kurtosis are sensitive to anomalies in the distribution of values contained in the dataset.

	Shape Factor 'm' Statistics for various 'Depth of Closures'		
	Full Depth (HOL)	8m Depth (HIL)	6m Depth (HIL)
N of Cases	42	41	41
Minimum	0.480	0.449	0.550
Maximum	0.981	0.929	0.893
Range	0.500	0.481	0.343
Median	0.711	0.695	0.740
Mean	0.709	0.700	0.733
95% Upper Limit	0.740	0.729	0.760
95% Lower Limit	0.678	0.671	0.706
Std Error	0.015	0.014	0.013
Standard Deviation	0.099	0.091	0.086
Variance	0.010	0.008	0.007
Coefficient of Variation (CV)	0.139	0.131	0.117
Skewness(G1)	0.088	-0.152	-0.207
SE Skewness	0.365	0.369	0.369
Kurtosis (G2)	0.413	0.834	-0.294
SE Kurtosis	0.717	0.724	0.724

Table 4.8: Summary Statistics for the LS regression results shown in Tables 4.5 and 4.6 for the Shape Factor 'm' omitting statistical outliers.

Review of the results identified in the regression analysis had previously identified a number of profiles whose shape were significantly affected by the proximity of ebb tidal deltas and whose derived shape factors were obvious outliers in the dataset. This was confirmed by carrying out a stem and leaf test and box plots in SYSTAT. Removal of these profiles from consideration in the statistical analysis led to an improved set of results with both G1 and G2 values meeting the test for normality. The results of this analysis are shown in Table 4.8.

Comparison with Dean's (1977) US East Coast Results

A one-sample 't' test was applied to the shape factor (m) results in order to determine whether they differed significantly from Dean's (1977) value as derived from the much larger US East Coast statistical population. Ideally it would have been more appropriate to have carried out a two-sample test; however the statistical data from Dean's (1977) analysis was not available to allow this. As a consequence the null hypothesis (H_0) was set at $m = 0.67$ with the alternative hypothesis (H_a) being that $m > 0.67$. The analysis using the full dataset including outliers (i.e. 48 profiles) yielded the results shown in Table 4.9.

This analysis indicates that two of the shape factor means (i.e. 'm' values derived from the 6 m and full depth analysis) are significantly different from Dean's value of 0.67 at the 95% confidence limit. However the average shape factor value derived from limiting the regression analysis to an 8 m closure depth confirms the utility of $m=0.67$ at the 95% and the 99% confidence level. This analysis perhaps suggests that there is statistical evidence to support the 8 m depth as the appropriate diabathic sediment exchange limit for use in the application of the Dean (1977) model in the

Bay of Plenty if the profile is based on the assumption of uniform energy dissipation per unit volume. Replication of the analysis removing the statistical outliers in the data due to profile proximity to the ebb tidal deltas did not change this conclusion (see Table 4.10).

One-sample t test for Closure Depth = HOL (full depth) with 48 cases; H_0 Mean = 0.67			
Mean = 0.710	90% CI = 0.683 to 0.737	t = 2.516	
SD = 0.111		DF = 47	Prob=0.015
cv(t_{47}) = 1.301, p= 0.10	95% CI = 0.678 to 0.742	t = 2.516	
cv(t_{47}) = 1.679, p= 0.05		DF = 47	Prob=0.015
cv(t_{47}) = 2.411, p= 0.01	99% CI = 0.667 to 0.753	t = 2.516	
H_0 rejected		DF = 47	Prob=0.015
One-sample t test for Closure Depth = 8m with 48 cases; H_0 Mean = 0.67			
Mean = 0.701	90% CI = 0.670 to 0.732	t = 1.666	
SD = 0.129		DF = 47	Prob=0.102
cv(t_{47}) = 1.301, p= 0.10	95% CI = 0.664 to 0.738	t = 1.666	
cv(t_{47}) = 1.679, p= 0.05		DF = 47	Prob=0.102
cv(t_{47}) = 2.411, p= 0.01	99% CI = 0.651 to 0.751	t = 1.666	
H_0 accepted		DF = 47	Prob=0.102
One-sample t test for Closure Depth = 6m with 48 cases; H_0 Mean = 0.67			
Mean = 0.729	90% CI = 0.692 to 0.767	t = 2.635	
SD = 0.156		DF = 47	Prob=0.011
cv(t_{47}) = 1.301, p= 0.10	95% CI = 0.684 to 0.774	t = 2.635	
cv(t_{47}) = 1.679, p= 0.05		DF = 47	Prob=0.011
cv(t_{47}) = 2.411, p= 0.01	99% CI = 0.669 to 0.790	t = 2.635	
H_0 rejected		DF = 47	Prob=0.011

Table 4.9: Student 't' test results at the 90%, 95% and 99% confidence levels for various 'Closure Depths'. The t values provided are those calculated as the test statistic. The critical values (c.v.) are determined from the Student's t distribution (Eton, 1980).

One-sample t test for Closure Depth = HOL with 42 cases; H_0 Mean = 0.67			
Mean = 0.709	90% CI = 0.684	to 0.735	
SD = 0.099	t = 2.572		
cv(t_{41}) = 1.303, p= 0.10	DF = 41	Prob=0.014	
cv(t_{41}) = 1.684, p= 0.05	95% CI = 0.678	to 0.740	
cv(t_{41}) = 2.423, p= 0.01	t = 2.572		
H_0 rejected	DF = 41	Prob=0.014	
	99% CI = 0.668	to 0.750	
	t = 2.572		
	DF = 41	Prob=0.014	
One-sample t test for Closure Depth = 8m with 41 cases; H_0 Mean = 0.67			
Mean = 0.700	90% CI = 0.676	to 0.724	
SD = 0.091	t = 2.115		
cv(t_{40}) = 1.303, p= 0.10	DF = 40	Prob=0.041	
cv(t_{40}) = 1.684, p= 0.05	95% CI = 0.671	to 0.729	
cv(t_{40}) = 2.423, p= 0.01	t = 2.115		
H_0 rejected at the 90 and	DF = 40	Prob=0.041	
95% CI but not at the 99%	99% CI = 0.662	to 0.739	
CI	t = 2.115		
	DF = 40	Prob=0.041	
One-sample t test for Closure Depth = 6m with 41 cases; H_0 Mean = 0.67			
Mean = 0.733	90% CI = 0.710	to 0.755	
SD = 0.086	t = 4.669		
cv(t_{40}) = 1.303, p= 0.10	DF = 40	Prob=0.000	
cv(t_{40}) = 1.684, p= 0.05	95% CI = 0.706	to 0.760	
cv(t_{40}) = 2.423, p= 0.01	t = 4.669		
H_0 rejected	DF = 40	Prob=0.000	
	99% CI = 0.696	to 0.769	
	t = 4.669		
	DF = 40	Prob=0.000	

Table 4.10: Student 't' test results at the 90%, 95% and 99% confidence levels for various 'Closure Depths' with statistical outliers removed. The critical values (c.v.) for a 95% CI are given by $t=1.684$ for a one tail test with $t=2.021$ for a two tail test.

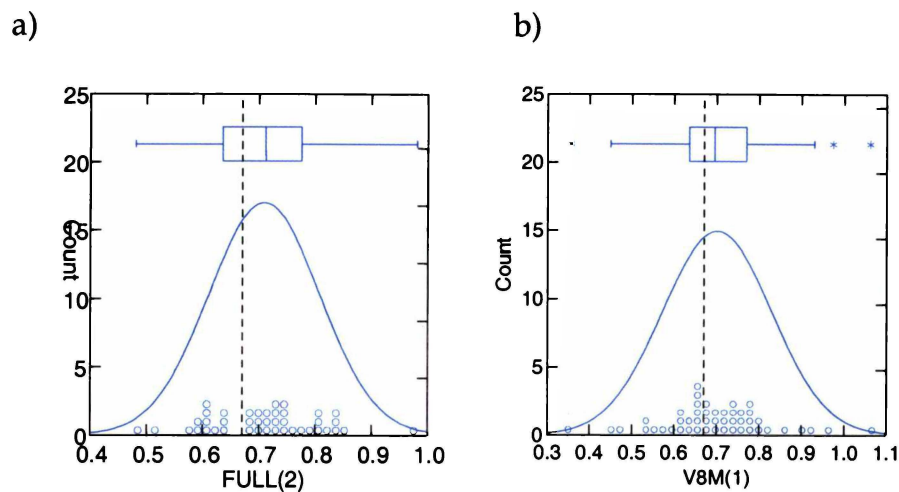


Figure 4.11: Two examples of t distributions and box plots showing the sample median, the quartiles and outliers where appropriate, and Dean's shape factor ' m ' = 0.67. Figure 4.11(a) indicates the t distribution for the full depth profile to approximately HOL with outlier values removed (see Table 4.10), while Figure 4.11(b) indicates the 8 m closure limit results for Dean's ' m ' without outliers removed. In Figure 4.11(a) the mean value of Dean's ' m ' value of 0.67 is significantly different from the derived value from the BoP data while in Figure 4.11(b) there is no significant difference with a closure depth limited to 8 metres.

4.6.2 Regression Analysis of the Dean Profile with fixed Shape and variable Scale Factor

Regression analysis was then applied to the 1992 BoP dataset while holding the shape factor in equation 4.1 fixed at 0.67 and allowing the scale parameter ' A ' to vary. This then allowed comparison of the results with the scale parameter-sediment size relationships defined by Moore (1982) and Dean (1987) using the sediment data gathered during the 1992 survey of the BOPRC profiles. The regression analysis was carried out to the three depth limits described in section 4.6.1 above. Table 4.11 summarises the results of this work.

Scatter plots of the respective regression and sediment derived values for A obtained for the various closure depths indicated some scatter with limited discernable trends or relationships evident from either visual assessment of the data or from regression curve fitting of the data (see Figure 4.12). However it is evident from the plots that the scatter is grouped around A values that fit reasonably well with the sand diameter derived data for A obtained by Moore (1982) thus indicating a reasonable relationship between the so called universal A values of Dean and sediment grain size data for the Bay of Plenty using a log transformation of the data (see Figure 4.13). This was obtained while retaining a good fit between the Dean model and the profile data as indicated by both the

Site Number	Regression derived Scale Factor A for varying depths			A values derived from profile averaged sediment dia. - Moore (1982) relationship		
	Full depth	8m depth	6m depth	Full Depth	8m depth	6m depth
1	0.0876	0.0948	0.1011	0.1020	0.1040	0.1064
2	0.0943	0.1021	0.1077	0.1050	0.1080	0.1092
3	0.0889	0.0896	0.0914	0.1035	0.1060	0.1096
4	0.0922	0.0910	0.0961	0.1000	0.1040	0.1080
5	0.0910	0.0949	0.0958	0.0987	0.1030	0.1060
6	0.0930	0.1037	0.1102	0.1020	0.1067	0.1096
7	0.0887	0.0984	0.1018	0.1012	0.1063	0.1092
8	0.0752	0.0692	0.0703	0.1092	0.1140	0.1148
9	0.0673	0.0555	0.0493	0.1050	0.1128	0.1130
10	0.0881	0.0847	0.0813	0.1000	0.1003	0.1003
11	0.0861	0.0853	0.0871	0.0964	0.0993	0.1016
12	0.1136	0.1146	0.1003	0.1010	0.1092	0.1164
13	0.1177	0.1319	0.1262	0.1067	0.1123	0.1172
14	0.1214	0.1146	0.1053	0.1105	0.1173	0.1224
15	0.1511	0.1291	0.1223	0.1075	0.1110	0.1132
16	0.1487	0.1252	0.1177	0.1122	0.1173	0.1216
17	0.1557	0.1321	0.1193	0.1092	0.1123	0.1148
18	0.1373	0.1105	0.1051	0.1107	0.1157	0.1172
19	0.1333	0.1245	0.1244	0.1205	0.1190	0.1124
20	0.1306	0.1232	0.1216	0.1167	0.1229	0.1267
21	0.1235	0.1214	0.1212	0.1142	0.1183	0.1228
22	0.1189	0.1168	0.1122	0.1152	0.1197	0.1232
23	0.1224	0.1133	0.1070	0.1191	0.1282	0.1354
24	0.1374	0.1323	0.1327	0.1255	0.1222	0.1282
25	0.1402	0.1291	0.1269	0.1186	0.1107	0.1128
26	0.1244	0.1187	0.1203	0.1124	0.1043	0.1084
27	0.1353	0.1281	0.1239	0.1163	0.1087	0.1120
28	0.1320	0.1318	0.1315	0.1092	0.1047	0.1056
29	0.1287	0.1229	0.1193	0.1122	0.1140	0.1184
30	0.1288	0.1147	0.0973	0.1512	0.1348	0.1278
32	0.0806	0.0930	0.1266	0.1274	0.1157	0.1100
33	0.0948	0.1271	0.1472	0.1087	0.1143	0.1204
34	0.1210	0.1074	0.1029	0.0987	0.1030	0.1060
35	0.1030	0.1081	0.1128	0.1055	0.1120	0.1168
36	0.1242	0.1139	0.1088	0.1027	0.1037	0.1030
38	0.1234	0.1142	0.1104	0.1025	0.1047	0.1052
39	0.1179	0.1049	0.1035	0.1062	0.1083	0.1092
40	0.0991	0.1091	0.1083	0.1217	0.1223	0.1148
41	0.0647	0.0637	0.0944	0.1433	0.1390	0.1380
42	0.0924	0.1007	0.0949	0.1177	0.1230	0.1276
43	0.1010	0.0934	0.0901	0.1115	0.1053	0.1064
44	0.0898	0.0829	0.0813	0.1017	0.1023	0.1036
45	0.0908	0.0837	0.0858	0.1025	0.1020	0.1024
46	0.0690	0.0614	0.0580	0.1156	0.1060	0.1240
47	0.0619	0.0603	0.0560	0.1250	0.1250	0.1300
48	0.0884	0.1022	0.1056	0.1111	0.1130	0.1200
49	0.0744	0.0731	0.0737	0.0991	0.1003	0.1012
51	0.0737	0.0746	0.0795	0.1000	0.1007	0.1016
Average	0.1067	0.1037	0.1035	0.1107	0.1118	0.1143
Std dev.	0.0250	0.0215	0.0208	0.0110	0.0091	0.0094

Table 4.11: Scale Factor values derived from Least Squares Regression analysis and separately from sediment analysis using the Moore (1982) relationship. Dimensions of 'A' are in (metres)^{1/3}.

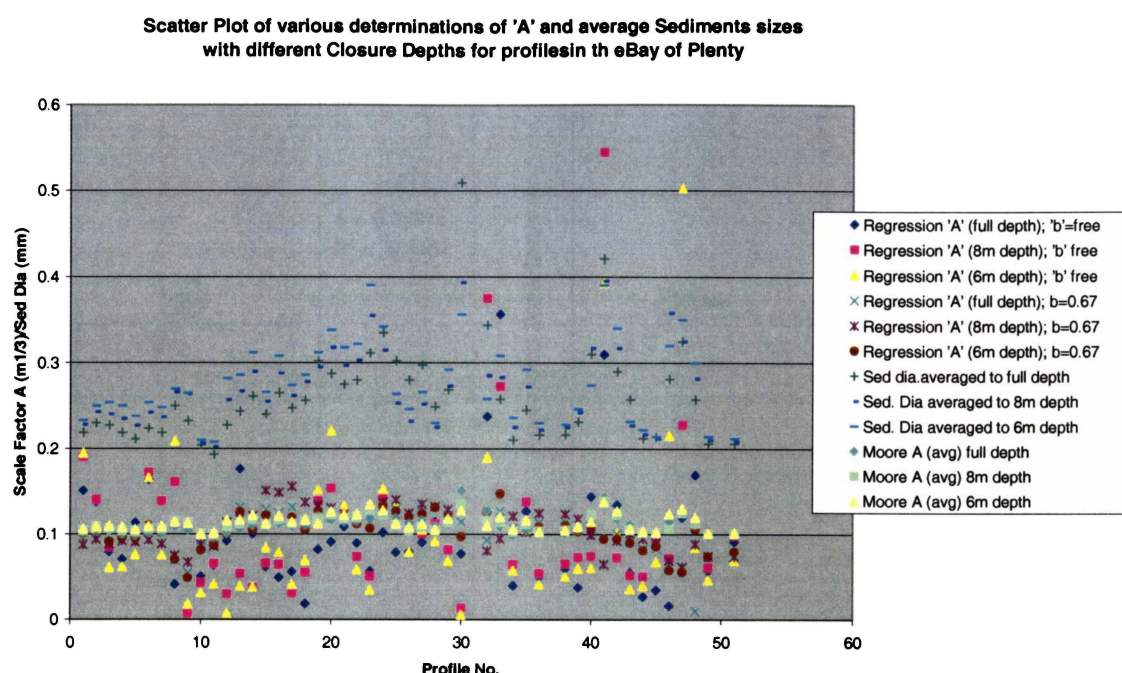


Figure 4.12: Scatter plot showing sediment data averaged to various closure depths together with Regression derived A and calculated A values derived from Moore's (1982) sediment relationship

coefficient of determination R^2 and the fit standard error evident from the regression analysis results contained in Appendix 4.

This relationship may be further explained by analysis of the data in Table 4.11 using two sample t tests. This showed that (with outlier profiles removed) there was no evidence to suggest any significant difference (at the 95% CI) between mean values for A obtained from regression fitting the Dean power curve (equation 4.1) to full and 8 m closure depths, and the scale factor values determined directly from the sediment diameter data using the Moore (1982) relationship shown in Figure 4.14 (Moore, 1982). However the null hypothesis was rejected for the same level of confidence for data obtained to 6 m closure depth. These t test results are shown graphically in Figure 4.14 with the results from SYSTAT (1996) included in Appendix 5.

To further demonstrate the relationship of the BoP data and the data of Dean (1977) the regression derived scale factors were then plotted against the average sediment diameters obtained from the field sampling using a log-log relationship as shown in Figure 4.13. These plots were then superimposed in Figure 4.15 over the data obtained by Moore (1982) as plotted by Dean (1987). While the plots indicate significant scatter in the data the greatest density of points are grouped around the line defined by Moore with the average values obtained for the various closure depths fitting the Moore relationship reasonably well.

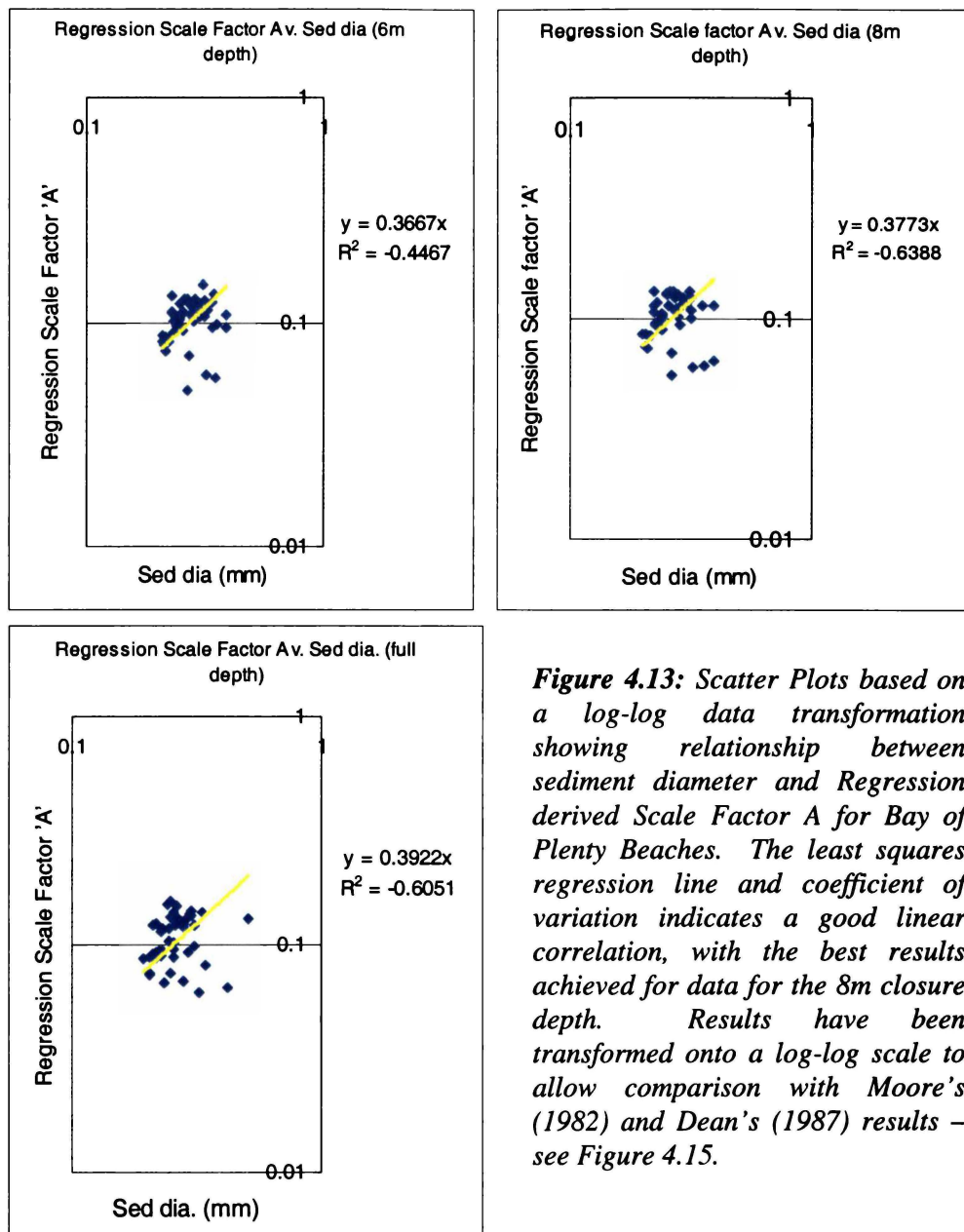
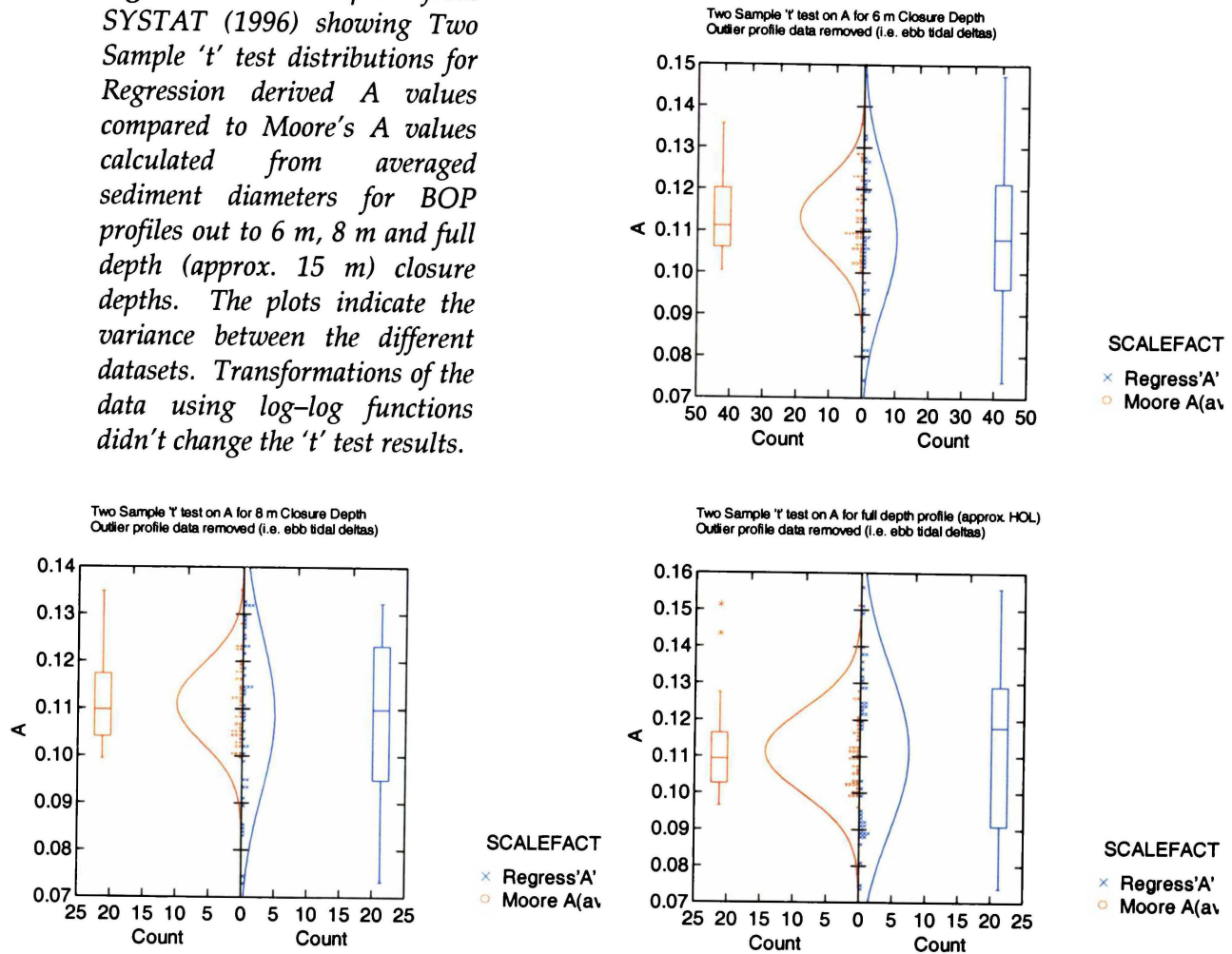
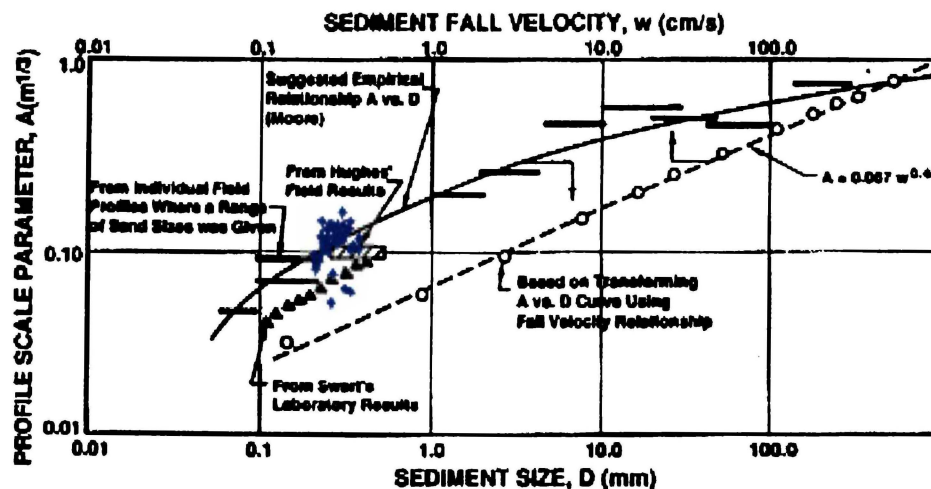


Figure 4.13: Scatter Plots based on a log-log data transformation showing relationship between sediment diameter and Regression derived Scale Factor A for Bay of Plenty Beaches. The least squares regression line and coefficient of variation indicates a good linear correlation, with the best results achieved for data for the 8m closure depth. Results have been transformed onto a log-log scale to allow comparison with Moore's (1982) and Dean's (1987) results – see Figure 4.15.

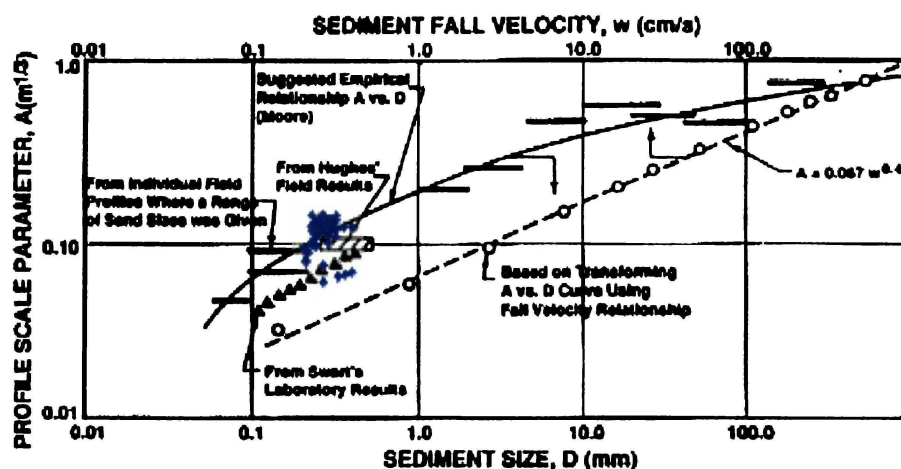
Figure 4.14: Graphs from SYSTAT (1996) showing Two Sample 't' test distributions for Regression derived A values compared to Moore's A values calculated from averaged sediment diameters for BOP profiles out to 6 m, 8 m and full depth (approx. 15 m) closure depths. The plots indicate the variance between the different datasets. Transformations of the data using log-log functions didn't change the 't' test results.



a) 6 m Closure depth



b) 8 m Depth



c) Full Depth

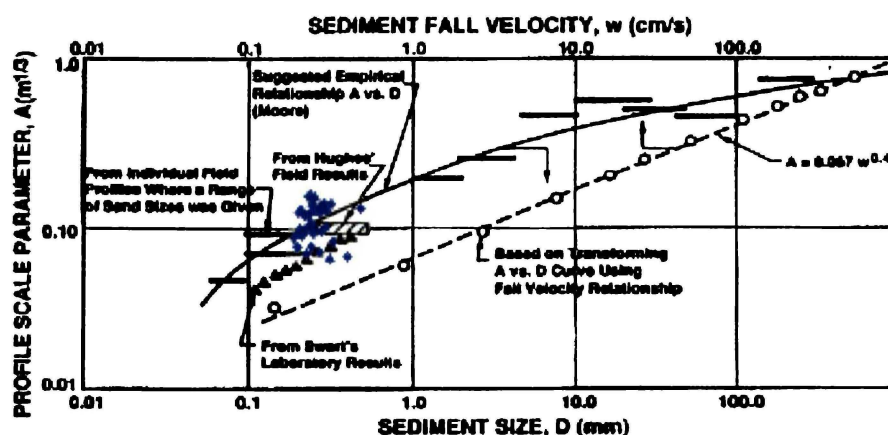


Figure 4.15, Regression derived Scale factor A for Bay of Plenty beaches plotted against average sediment values determined to various 'closure depths' for BOP Profiles. These values have then been superimposed on Moore's relationship (from Dean, 1987, Log-Log relationship).

4.6.3 Summary of results

In summary the foregoing analyses defines the following key results based on a 'blindfold' regression analysis carried out for three closure depths (6 m, 8 m and full HOL depth). This analysis indicated the following:

- That the power equation $y = Ax^{2/3}$ (equation 4.1) generally fitted the Bay of Plenty beach profiles very well irrespective of the closure

- depth chosen. This is reflected through the values obtained for the coefficient of determination, R^2 , values being located close to 1;
- R^2 reduces marginally with a reduction in the closure depth. This probably reflects the relatively high density of measurements in the nearshore compared to those offshore and the increasing influence that deviations from the 'Dean' profile associated with the offshore bars have on the process of fitting the model to the profile by the method of 'least squares';
 - The value of the exponent shape factor ' m ' determined from least squares regression analysis of the Bay of Plenty profiles confirms the utility of the value of $\frac{2}{3}$ as derived from linear wave theory for uniform wave energy dissipation per unit volume, so long as the profiles included in the analysis are limited to a closure depth, which for the Bay of Plenty beaches is 8 m;
 - The shape factor ' m ' values derived from the Bay of Plenty profile data were compared to Dean's value of $\frac{2}{3}$ by using one sample Student 't' tests at the 90, 95 and 99% confidence intervals for full (HOL) depth, 8 m and 6 m closure depths. The results of this analysis indicated that there was no evidence to reject the null hypothesis for the 8m closure depth (i.e. that there was no difference between the Dean's exponent value derived from the US data and that derived from the BoP data);
 - Dean's (1977) equilibrium profile $y = Ax^{2/3}$ was used to derive the scale factor for each BoP profile by solving for ' A ' using least squares regression analysis (see Appendix 4). This was repeated for the three closure limits described previously. These values were then compared to values obtained using Moore's relationship in order to determine ' A ' from the mean profile sediment diameter obtained from sampling carried out on all profiles out to the nominated closure depths. Two sample Student 't' tests were carried out to compare the results of the two relative datasets to see if any statistical relationship existed between the separately derived scale factor values. This analysis using a data set with outlier profiles removed showed that a relationship existed at the 95% level of confidence for data derived from profiles limited to full depth (approx. H.O.L. = 15 m) and 8 m closure depths, but this could not be replicated to 6 m depths, which may be a reflection of the complexity of geomorphic processes occurring within this inner surf zone;
 - Results of the comparison between regression and sediment derived scale factors indicate good correlations for the BoP data (see Figure 4.13). The data was analysed to see whether the results of Moore (1982) and Dean (1987) developed from the US coast could be replicated for the Bay of Plenty. This required plotting regression derived scale factor values against profile averaged sediment diameters using a log-log transformation as with Moore (1982) and Dean (1987). This was repeated for each of the three defined closure depths with good correlations established at all three depths (see

Figure 4.13). However the strongest correlation from the dataset was associated with the 8 m closure limit.

- Scatter plots of the various regression derived scale factors (A) versus profile averaged sediment diameters were then superimposed over the plot of Dean (1987) to visually assess whether any agreement existed with Dean and Moore's US dataset. These plots indicate a relatively good agreement between datasets although the scatter in the data indicates some weakness in this assertion.
- Irrespective, the overall results suggest that Dean's (1977) equilibrium beach profile model provides a good approximation of the sandy beach profiles found along the BoP coast. Additionally the results also indicate that profile averaged sediment diameter provides a good surrogate measure for determining scale factor ' A ' values for use in the model, and as a consequence the model can be used to assist in resolving beach equilibrium problems along the sandy beaches of the BoP coast.

4.7 Equilibrium Prediction using existing Profile Data

Because the Dean model is derived directly from wave energetics as described in Chapter 3 it is expected that beaches formed primarily from non cohesive sediment should respond in shape and form to changes in incident wave energy. Profile shapes should therefore reflect equilibrium with incident wave energy and related sediment and sediment supply characteristics. Consequently, with all other factors being equal the beach should either erode and flatten in response to increasing wave energy and offshore movement of sediment, or steepen and accrete under reducing energy conditions and onshore sediment transport (see Chapter 3). Comparison between measured beach profiles and predicted profiles using beach volume analysis should therefore indicate the equilibrium status of the beaches.

This section describes the application of the Dean (1977) model to predict beach equilibrium status using the 1993 Bay of Plenty beach profile dataset. The equilibrium status of each profile was determined by comparing the beach volume differences calculated between measured and predicted profile via routines developed in MATLAB. Results of the analysis showing differences between measured and predicted profile volumes (m^3 per m of beach) indicate either sediment surpluses in the nearshore system and therefore potential beach accretion, while negative differences indicate sediment deficits and potential erosion.

The methodology was tested for each profile using variations in closure depth and sediment scale factor values determined directly from the sediment characteristics of the beach. Scale factor for each assessment was determined in one of two ways. Firstly the scale factor ' A ' (Moore, 1982) was determined as a profile averaged constant calculated using Moore's

(1982) relationship for profile averaged sediment size determined from MSL out to closure depth (see Figure 4.15). Secondly 'A' was allowed to vary piecewise along the profile according to observed sediment size measured at various sampling points located along the profile. Again 'A' values for use in the Dean model were determined using Moore's relationship. Comparisons between results obtained between the differing approaches and different closure depths were measured by the root mean square residual error (rmsr) determined between the predicted and measured profiles.

Theoretically, piecewise determination of 'A' should provide a more realistic prediction of beach profile slopes than profile averaged 'A' values because piecewise determination should reflect the relationship (Moore, 1984) between ambient wave energy and sediment grain sizes. Consequently profile slope should vary directly with incident wave energy across the surf zone with coarser sediment occurring closer to shore resulting in steeper beach gradients which reflects the comparatively higher energy conditions found here while finer sediments and lower slopes dominate with increasing distances offshore (Hilton and Nichol, 2003).

The results of this analysis for the 48 profile BoP dataset for three closure depths (6, 7 and 8 m) are shown in the Table 4.13. The table shows the predicted erosion or accretion for each profile calculated to fit the equilibrium curve as described. The overall dataset average is also shown in the bottom row of the Table, the results of which indicate that the BoP beach system is generally either at equilibrium or slightly accretional. However greater variance occurs between individual profiles based on calculation method and closure depth, with results indicating that the Dean profile calculated with profile averaged Scale factor values provides profiles that more closely reflect those measured in the field.

Analysis of the profile plots and the goodness of fit criteria (as measured by the root mean square residual - rmsr) indicates that significant outliers occur for those profiles located adjacent to the ebb tidal deltas at profiles 8 and 9 (Ohiwa Harbour), profiles 41 and 42 (Tauranga Entrance - Matakana Bank) and profiles 46 and 47 (Bowentown Ebb Tidal delta and entrance). It is clear from the complex hydrodynamics reflected in the sedimentation patterns adjacent to these tidal inlets and associated deltas (Gibb, 1977; Richmond, 1977; Mathew, 1997; Hicks *et al.*, 1999; Hume, 2003) that a simple 2 dimensional numerical model such as Dean (1977) is not appropriate to fully explain beach profiles in such complex locations. As a consequence these profiles were consequently omitted from the analysis of means and rmsr included in Table 4.14 as a comparison to the full dataset results.

The results of this analysis clearly show that the Dean profile with profile averaged scale factor consistently minimizes the residual errors between

predicted and measured profiles when compared to the piecewise approach (i.e. rmsr of 0.65 m versus 0.96 m for the 6 m closure depth). These results are repeated when outlier profiles are removed (0.56 m versus 0.93 m results for the 6m closure depth) from the data. Similarly the 6 m closure depth from this data appeared to provide an appropriate boundary condition that generally minimized the residual errors between predicted and measured profiles within the overall dataset.

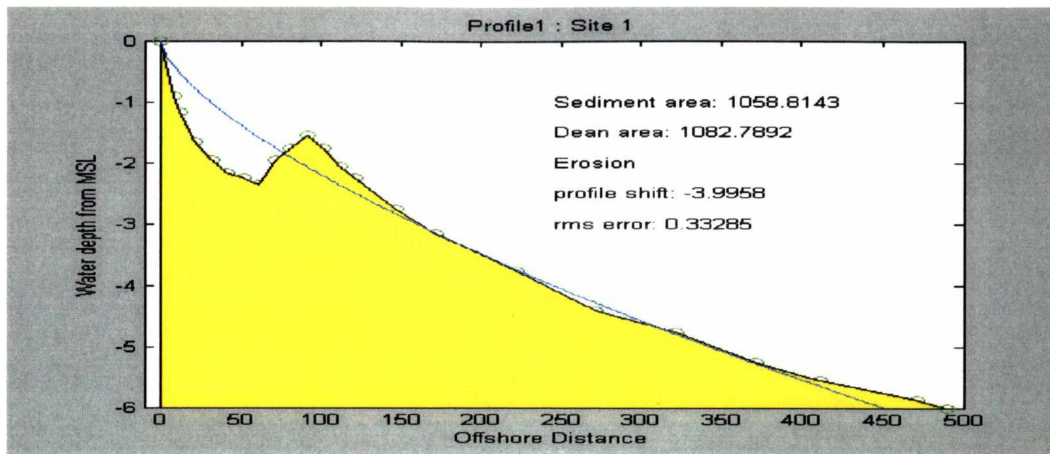
This interpretation was checked by arbitrarily choosing profiles from the dataset and calculating the standard errors using the Dean model for shallower closure depths. The results of this assessment are shown in the following table:

BoP Profile Number	Standard deviations (RMSR) for various closure depths				
	8 m	7 m	6 m	5 m	4 m
1	0.40431	0.3478	<i>0.3328</i>	0.37631	0.44235
11	0.53687	0.401	<i>0.3611</i>	0.37766	0.44388
23	<i>0.3433</i>	0.3791	0.4252	0.48658	0.57268
25	0.59236	0.487	<i>0.40876</i>	0.44569	0.38875
36	0.79663	0.6644	0.54859	0.43055	<i>0.3171</i>
39	<i>0.21865</i>	0.2388	0.26334	0.30053	0.34708
44	0.93665	0.8337	0.77747	0.75278	<i>0.73942</i>
51	1.0696	0.8505	0.66174	0.52332	<i>0.45132</i>

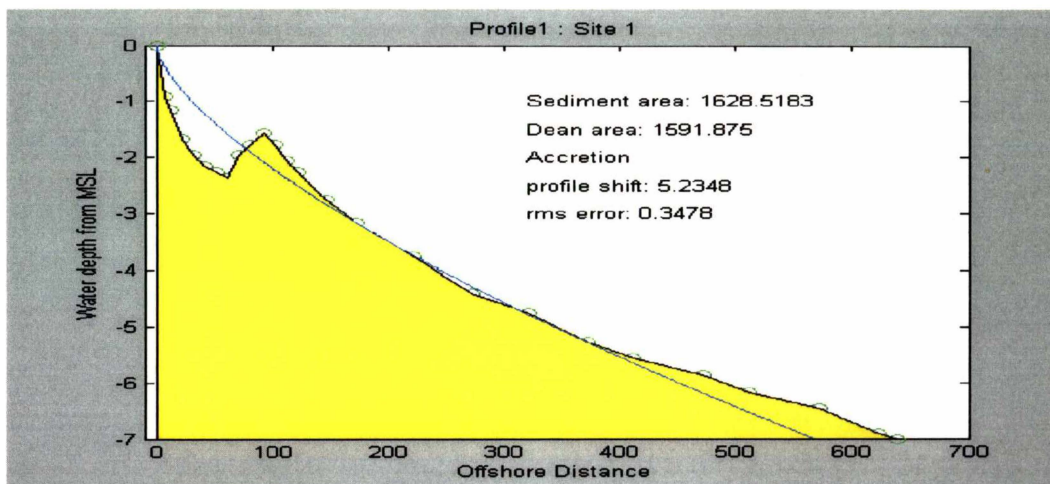
Table 4.12: Standard deviations of profile fits for various closure depths calculated using the Dean model with profile averaged Scale factor and a fixed Shape factor at $\frac{2}{3}$. The values shown in red italicized font represent the closure depth with the lowest standard deviation for each profile. No clear pattern is exhibited which would confirm a particular closure depth applicable generally to the BoP profile dataset.

It was anticipated that this analysis would confirm a consistent trend in closure depth for the dataset based on identifying depths that minimises standard errors (rmsr) for profiles, and that this would lie generally between the 6 and 8 m water depth. However the data showed much more variability at an individual profile level, which on reflection is as it should be. This is because profiles reflect amongst other things the variability in wave climate that they are exposed to, the role of geomorphic controls such as antecedent surfaces formed prior to the last marine transgression, its geotectonic setting (e.g. proximity to the Whakatane Graben and the northeast extension of the Taupo Volcanic Zone), the influence of nearshore bars and increased profile variability as closure depths are reduced, and the nature of sediment and sediment sources and inputs into the beach system. This perhaps emphasizes the limitations of two dimensional models as identified by Pilkey *et al.* (1993).

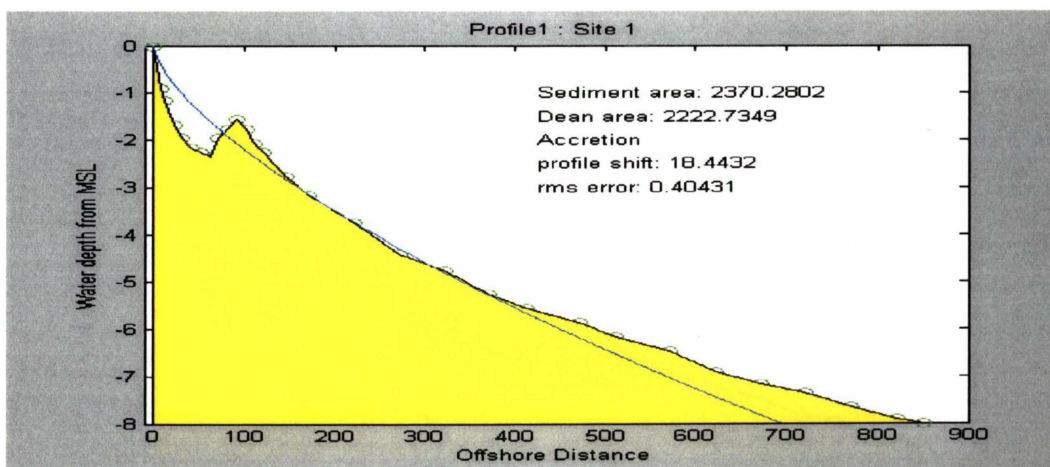
Comparison of the results shown in Table 4.12 together with the results of the information described in Table 4.1 indicates some limited agreement. However this is by no means conclusive and perhaps reflects the general and normative nature of the model.



a) Dean Profile for 6 m Closure Depth

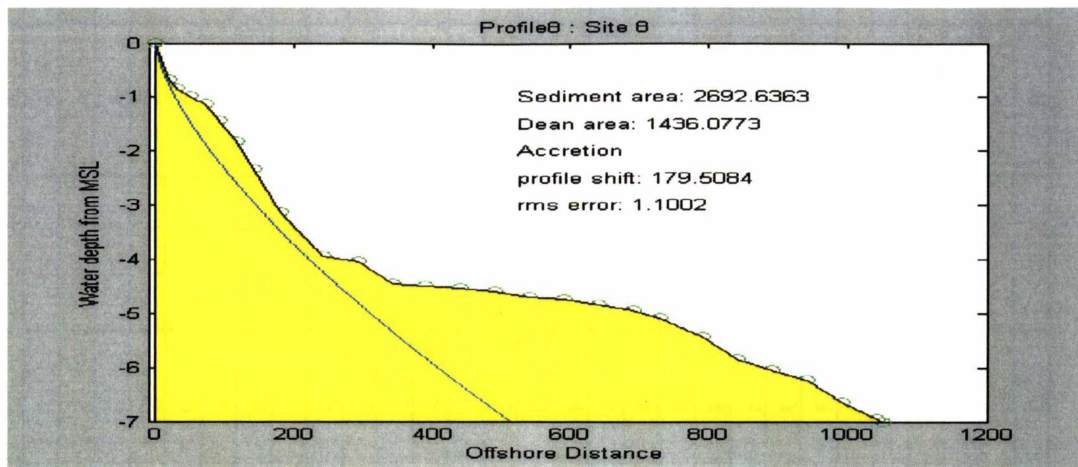


b) Dean Profile for 7 m Closure Depth

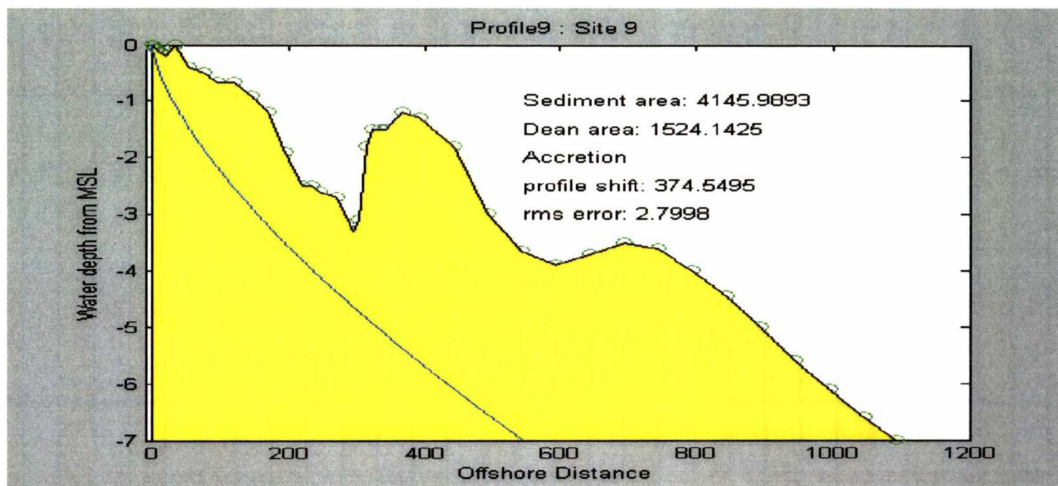


c) Dean Profile for 8 m Closure Depth

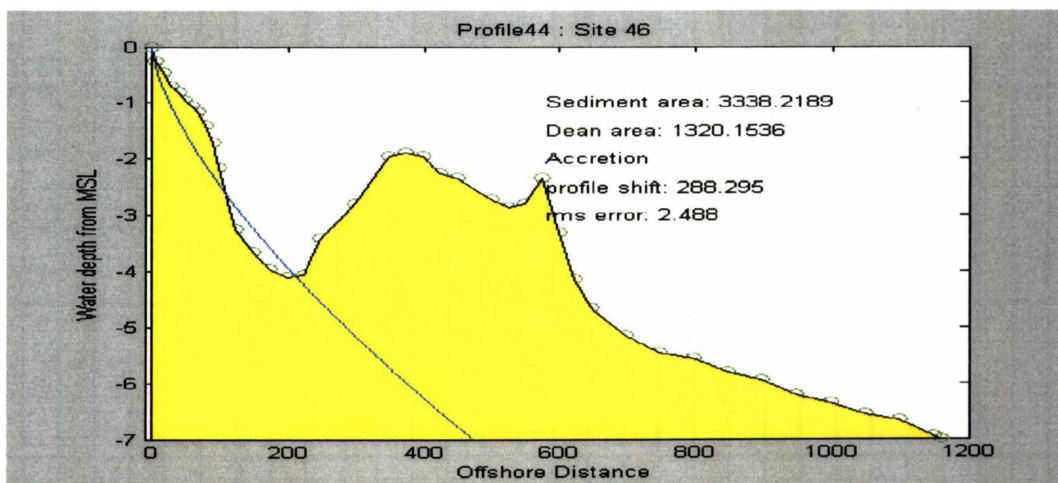
Figure 4.16: Plots of the Dean profile (blue line) plotted against the measured profile (yellow fill) for three closure depths, with the 7 m closure depth providing the preferred boundary condition for calculation as discussed in section 4.5. Profiles show equilibrium status as accretion or erosion together with profile adjustment (or shift) required to bring profile to equilibrium (NB vertical distortion in profiles)



a) Ohiwa Spit - Ohiwa Harbour, closure depth 7 m.



b) Ohope Spit



c) Bowentown ebb tidal delta

Figure 4.17: Plots for Dean (1977) profiles calculated with a profile averaged Scale Factor A for monitoring sites located on ebb tidal deltas showing the surplus sediments effect on profile equilibrium.

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
1	E	-19.83	E	-3.996	E	-20.51	A	5.235	E	-17.28	A	18.44
2	E	-25.6	E	-8.276	E	-31.18	E	-6.112	E	-27.33	A	1.77
3	A	24.47	A	31.5	A	14.73	A	40.36	A	13.25	A	56.93
4	E	-13.73	A	5.017	E	-23.29	A	15.18	E	-27.30	A	30.64
5	E	-0.89	A	6.996	E	-17.59	A	7.242	E	-26.47	A	12.00
6	E	-32.37	E	-17.08	E	-47.05	E	-18.84	E	-52.44	E	-13.49
7	A	10.02	E	-0.087	A	1.141	A	0.4028	E	-3.58	A	6.56
8	A	130.7	A	123.5	A	188.7	A	179.5	A	238.53	A	226.88
9	A	362.1	A	345.8	A	399.3	A	374.5	A	432.44	A	399.73
10	A	71.98	A	70.95	A	73.93	A	78.74	A	75.23	A	88.82
11	A	29.53	A	25.56	A	30.19	A	37.67	A	33.25	A	52.43
12	E	-66.73	E	-17.43	E	-118.6	E	-36.66	E	-165.13	E	-52.24
13	E	-53.8	E	-40.23	E	-90.91	E	-56.45	E	-128.41	E	-73.51
14	A	2.05	A	3.618	E	-29.3	E	-7.695	E	-60.18	E	-19.15
15	E	-32.74	E	-33.13	E	-62.05	E	-48.93	E	-95.13	E	-67.65
16	E	-21.6	E	-14.81	E	-44.14	E	-25.05	E	-67.84	E	-39.28
17	E	-31.48	E	-20.81	E	-55.88	E	-40.31	E	-83.65	E	-62.94
18	A	8.84	A	14.16	A	2.782	A	10.51	E	-17.46	A	1.16
19	E	40.53	E	-7.474	E	-52.87	E	-9.158	E	-62.99	E	-10.70
20	E	-21.42	E	-5.185	E	-34.61	E	-8.033	E	-57.38	E	-13.63
21	E	-43.81	E	-14.83	E	-61.34	E	-18.68	E	-76.94	E	-22.28
22	E	-36.56	E	-0.34	E	-48.52	E	-4.229	E	-59.24	E	-6.37
23	E	-9.32	A	13.39	E	-35.19	A	11.55	E	-59.86	A	10.62
24	E	-56.02	E	-13.21	E	-79.51	E	-15.1	E	-99.37	E	-17.06
25	E	-45.91	E	-14.25	E	-61.62	E	-17.56	E	-81.54	E	-24.63
26	E	-63.55	E	-17.66	E	-93.4	E	-22.99	E	-114.01	E	-23.98
27	E	-67.66	E	-19.94	E	-93.34	E	-28.43	E	-115.12	E	-35.06
28	E	-65.66	E	-43.79	E	-84.8	E	-56.04	E	-103.71	E	-66.33
29	E	-34.71	E	-18.27	E	-64.28	E	-26.49	E	-100.51	E	-33.50
30	A	4.83	A	39.73	A	12.8	A	41.23	A	25.49	A	43.63
32	E	-77.01	E	-5.233	E	-57.76	A	27.12	E	-17.89	A	73.84

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
33	E	-118.5	E	-62.67	E	-151.5	E	-76.01	E	-169.79	E	-77.02
34	E	-30.85	E	-14.11	E	-53.15	E	-22.31	E	-81.21	E	-32.68
35	E	-52.16	E	-18.39	E	-72.14	E	-21.58	E	-85.35	E	-17.67
36	E	-24.96	E	-16.76	E	-45.74	E	-27.29	E	-63.50	E	-39.01
38	E	-28.44	E	-19.82	E	-39.62	E	-30.83	E	-52.47	E	-40.60
39	A	3.967	A	7.108	A	1.354	A	7.339	E	-0.99	A	7.18
40	E	-1.925	A	19.43	A	12.56	A	28.15	A	28.99	A	34.66
41	A	61.85	A	89.22	A	174	A	202.5	A	291.01	A	318.41
42	A	79.47	A	63.04	A	36.94	A	65.35	A	62.75	A	64.97
43	A	39.12	A	56.28	A	41.1	A	64.6	A	43.65	A	75.09
44	A	64.32	A	68.58	A	76.02	A	83.44	A	85.34	A	98.48
45	A	49.99	A	55.18	A	62.1	A	72.78	A	76.73	A	93.35
46	A	256	A	234.4	A	321.2	A	288.3	A	389.72	A	347.70
47	A	308.7	A	287.2	A	377.6	A	346.6	A	441.70	A	402.06
48	A	10.02	A	3.441	A	31.75	A	11.99	A	36.00	A	22.72
49	A	90	A	100.4	A	111.8	A	127.8	A	142.10	A	162.22
51	A	61.11	A	69.6	A	92.33	A	103.2	A	132.14	A	143.75
Average Erosion/Accretion for dataset	A	11.49	A	26.80	A	8.18	A	32.79	A	7.80	A	41.78

Table 4.13: Equilibrium status of 48 beach profiles determined using Dean's (1977) profile calculated using either piecewise variation of the Scale Factor 'A' based on sediment sampling along the profile, or Profile averaged A values determined from the sediment sampling. Dataset averages for the 48 profiles are shown in the bottom row of the table.

BOPRC #	RMSR for 6m Closure Depth				RMSR for 7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed
1	0.3395	0.3395	0.3328	0.3328	0.3644	0.3644	0.3478	0.3478	0.33151	0.33151	0.40431	0.40431
2	0.5114	0.5114	0.237	0.237	0.4997	0.4997	0.2138	0.2138	0.46386	0.46386	0.24594	0.24594
3	0.4608	0.4608	0.435	0.435	0.4246	0.4246	0.4791	0.4791	0.38513	0.38513	0.5698	0.5698
4	0.4979	0.4979	0.2852	0.2852	0.4886	0.4886	0.3185	0.3185	0.45563	0.45563	0.42593	0.42593
5	0.5808	0.5808	0.2742	0.2742	0.6092	0.6092	0.2499	0.2499	0.59084	0.59084	0.25457	0.25457
6	0.6961	0.6961	0.3206	0.3206	0.6961	0.6961	0.299	0.299	0.69008	0.69008	0.27682	0.27682
7	0.4125	0.4125	0.2574	0.2574	0.4125	0.4125	0.2302	0.2302	0.37263	0.37263	0.23602	0.23602
8	0.7831		0.7253		1.136		1.1		1.5815		1.5534	
9	2.299		2.487		3.006		2.8		3.2972		2.9969	
10	0.8358	0.8358	0.823	0.823	0.7997	0.7997	0.8533	0.8533	0.74786	0.74786	0.88584	0.88584
11	0.4072	0.4072	0.3611	0.3611	0.3696	0.3696	0.401	0.401	0.35395	0.35395	0.53687	0.53687
12	2.157	2.157	0.9447	0.9447	2.378	2.378	1.015	1.015	2.6205	2.6205	1.0315	1.0315
13	1.87	1.87	1.118	1.118	2.145	2.145	1.327	1.327	2.2972	2.2972	1.397	1.397
14	1.11	1.11	0.555	0.555	1.553	1.553	0.6598	0.6598	1.8521	1.8521	0.7882	0.7882
15	1.352	1.352	1.025	1.025	2.343	2.343	1.401	1.401	2.8015	2.8015	1.8286	1.8286
16	1.191	1.191	0.5268	0.5268	1.682	1.682	0.8514	0.8514	2.2883	2.2883	1.2522	1.2522
17	1.675	1.675	1.196	1.196	2.143	2.143	1.681	1.681	2.75	2.75	2.1111	2.1111
18	0.252	0.252	0.2603	0.2603	0.4376	0.4376	0.2833	0.2833	1.9735	1.9735	0.63781	0.63781
19	0.8438	0.8438	0.2263	0.2263	0.9751	0.9751	0.2196	0.2196	1.0974	1.0974	0.23317	0.23317
20	0.5364	0.5364	0.3573	0.3573	0.907	0.907	0.379	0.379	1.4076	1.4076	0.40767	0.40767
21	1.064	1.064	0.3681	0.3681	1.199	1.199	0.3891	0.3891	1.3151	1.3151	0.40058	0.40058
22	1.04	1.04	0.3761	0.3761	1.061	1.061	0.3601	0.3601	1.1149	1.1149	0.34219	0.34219
23	1.171	1.171	0.4252	0.4252	1.358	1.358	0.3791	0.3791	1.5797	1.5797	0.3433	0.3433
24	1.434	1.434	0.3827	0.3827	1.657	1.657	0.377	0.377	1.8179	1.8179	0.37646	0.37646
25	1.087	1.087	0.4088	0.4088	1.373	1.373	0.487	0.487	1.7438	1.7438	0.59236	0.59236
26	1.381	1.381	0.4652	0.4652	1.555	1.555	0.4561	0.4561	1.6777	1.6777	0.42941	0.42941
27	1.616	1.616	0.605	0.605	1.827	1.827	0.67	0.67	2.0257	2.0257	0.68759	0.68759
28	1.411	1.411	0.9756	0.9756	1.537	1.537	1.039	1.039	1.7162	1.7162	1.103	1.103
29	1.146	1.146	0.5772	0.5772	1.588	1.588	0.6247	0.6247	2.0694	2.0694	0.66224	0.66224

BOPRC #	RMSR for 6m Closure Depth				RMSR for 7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed
30	0.7053	0.7053	0.9808	0.9808	0.7273	0.7273	0.9379	0.9379	0.82728	0.82728	0.90908	0.90908
32	1.128	1.128	0.3635	0.3635	1.065	1.065	0.4862	0.4862	1.0646	1.0646	0.71387	0.71387
33	2.042	2.042	1.283	1.283	1.975	1.975	1.213	1.213	1.8646	1.8646	1.1092	1.1092
34	0.8515	0.8515	0.3643	0.3643	1.237	1.237	0.4696	0.4696	1.6932	1.6932	0.63815	0.63815
35	1.001	1.001	0.3561	0.3561	1.03	1.03	0.3441	0.3441	1.0337	1.0337	0.31564	0.31564
36	0.8101	0.8101	0.5486	0.5486	1.082	1.082	0.6644	0.6644	1.2309	1.2309	0.79663	0.79663
38	0.7348	0.7348	0.5508	0.5508	0.7925	0.7925	0.64	0.64	0.98626	0.98626	0.73856	0.73856
39	0.3106	0.3106	0.2633	0.2633	0.2836	0.2836	0.2388	0.2388	0.27813	0.27813	0.21865	0.21865
40	0.4132	0.4132	0.3629	0.3629	0.4837	0.4837	0.4566	0.4566	0.68105	0.68105	0.5563	0.5563
41	0.9187		0.6121		1.34		1.189		1.8404		1.9248	
42	1.228	1.228	1.097	1.097	1.482	1.482	1.101	1.101	1.3803	1.3803	1.0379	1.0379
43	0.5331	0.5331	0.7632	0.7632	0.511	0.511	0.8022	0.8022	0.49398	0.49398	0.85419	0.85419
44	0.7272	0.7272	0.7775	0.7775	0.7606	0.7606	0.8337	0.8337	0.80665	0.80665	0.93656	0.93656
45	0.5611	0.5611	0.6337	0.6337	0.6046	0.6046	0.7216	0.7216	0.69035	0.69035	0.85682	0.85682
46	1.176		1.725		2.066		2.488		3.446		3.0536	
47	1.235		1.514		2.029		2.294		2.8991		2.8541	
48	0.2518	0.2518	0.1728	0.1728	0.4349	0.4349	0.2473	0.2473	1.082	1.082	0.35773	0.35773
49	0.8648	0.8648	0.9843	0.9843	0.94	0.94	1.112	1.112	1.0627	1.0627	1.2563	1.2563
51	0.5724	0.5724	0.6617	0.6617	0.7502	0.7502	0.8505	0.8505	0.96227	0.96227	1.0696	1.0696
Average rmsr	0.96	0.93	0.65	0.56	1.17	1.08	0.77	0.63	1.41	1.27	0.90	0.72
Std dev	0.50	0.48	0.44	0.30	0.65	0.59	0.58	0.36	0.81	0.70	0.70	0.42

Table 4.14: Table showing rmsr or standard error values derived from fitting Dean's model (1977) as shown in Table 4.12, to the BoP individual profiles with and without outlier profiles removed.

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
1	E	-19.83	E	-3.996	E	-20.51	A	5.235	E	-17.28	A	18.44
2	E	-25.6	E	-8.276	E	-31.18	E	-6.112	E	-27.33	A	1.77
3	A	24.47	A	31.5	A	14.73	A	40.36	A	13.25	A	56.93
4	E	-13.73	A	5.017	E	-23.29	A	15.18	E	-27.30	A	30.64
5	E	-0.89	A	6.996	E	-17.59	A	7.242	E	-26.47	A	12.00
6	E	-32.37	E	-17.08	E	-47.05	E	-18.84	E	-52.44	E	-13.49
7	A	10.02	E	-0.087	A	1.141	A	0.4028	E	-3.58	A	6.56
8												
9												
10	A	71.98	A	70.95	A	73.93	A	78.74	A	75.23	A	88.82
11	A	29.53	A	25.56	A	30.19	A	37.67	A	33.25	A	52.43
12	E	-66.73	E	-17.43	E	-118.6	E	-36.66	E	-165.13	E	-52.24
13	E	-53.8	E	-40.23	E	-90.91	E	-56.45	E	-128.41	E	-73.51
14	A	2.05	A	3.618	E	-29.3	E	-7.695	E	-60.18	E	-19.15
15	E	-32.74	E	-33.13	E	-62.05	E	-48.93	E	-95.13	E	-67.65
16	E	-21.6	E	-14.81	E	-44.14	E	-25.05	E	-67.84	E	-39.28
17	E	-31.48	E	-20.81	E	-55.88	E	-40.31	E	-83.65	E	-62.94
18	A	8.84	A	14.16	A	2.782	A	10.51	E	-17.46	A	1.16
19	E	-40.53	E	-7.474	E	-52.87	E	-9.158	E	-62.99	E	-10.70
20	E	-21.42	E	-5.185	E	-34.61	E	-8.033	E	-57.38	E	-13.63
21	E	-43.81	E	-14.83	E	-61.34	E	-18.68	E	-76.94	E	-22.28
22	E	-36.56	E	-0.34	E	-48.52	E	-4.229	E	-59.24	E	-6.37
23	E	-9.32	A	13.39	E	-35.19	A	11.55	E	-59.86	A	10.62
24	E	-56.02	E	-13.21	E	-79.51	E	-15.1	E	-99.37	E	-17.06
25	E	-45.91	E	-14.25	E	-61.62	E	-17.56	E	-81.54	E	-24.63
26	E	-63.55	E	-17.66	E	-93.4	E	-22.99	E	-114.01	E	-23.98
27	E	-67.66	E	-19.94	E	-93.34	E	-28.43	E	-115.12	E	-35.06
28	E	-65.66	E	-43.79	E	-84.8	E	-56.04	E	-103.71	E	-66.33
29	E	-34.71	E	-18.27	E	-64.28	E	-26.49	E	-100.51	E	-33.50
30	A	4.83	A	39.73	A	12.8	A	41.23	A	25.49	A	43.63

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A		Dean -Piecewise A		Dean -Profile Av. A	
32	E	-77.01	E	-5.233	E	-57.76	A	27.12	E	-17.89	A	73.84
33	E	-118.5	E	-62.67	E	-151.5	E	-76.01	E	-169.79	E	-77.02
34	E	-30.85	E	-14.11	E	-53.15	E	-22.31	E	-81.21	E	-32.68
35	E	-52.16	E	-18.39	E	-72.14	E	-21.58	E	-85.35	E	-17.67
36	E	-24.96	E	-16.76	E	-45.74	E	-27.29	E	-63.50	E	-39.01
38	E	-28.44	E	-19.82	E	-39.62	E	-30.83	E	-52.47	E	-40.60
39	A	3.967	A	7.108	A	1.354	A	7.339	E	-0.99	A	7.18
40	E	-1.925	A	19.43	A	12.56	A	28.15	A	28.99	A	34.66
41												
42	A	79.47	A	63.04	A	36.94	A	65.35	A	62.75	A	64.97
43	A	39.12	A	56.28	A	41.1	A	64.6	A	43.65	A	75.09
44	A	64.32	A	68.58	A	76.02	A	83.44	A	85.34	A	98.48
45	A	49.99	A	55.18	A	62.1	A	72.78	A	76.73	A	93.35
46												
47												
48	A	10.02	A	3.441	A	31.75	A	11.99	A	36.00	A	22.72
49	A	90	A	100.4	A	111.8	A	127.8	A	142.10	A	162.22
51	A	61.11	A	69.6	A	92.33	A	103.2	A	132.14	A	143.75
Average Erosion/Accretion for dataset	E	-13.21	A	4.80	E	-24.85	A	3.57	E	-33.00	A	7.22

Table 4.15: Replication of the data shown in Table 4.13 with outlier profiles removed

4.8 Application of Alternative EBP Models - Profile Equilibrium

Three alternative models or variations of the Dean 'Equilibrium Beach' model have been examined on a comparative basis to evaluate whether these offer any improvement to the predictive capability of the original Dean model (1977). These alternatives were described more fully in Chapter 3 and include:

- Introduction of a gravity term into the Dean model to eliminate the vertical profile at the shoreline. This model was applied using both average and piecewise-determined values for the scale factor A .
- Application of the Wang and Davis segmented model (1998) to characterise the offshore bar using Dean's (1977) power function.

4.8.1 Dean Model with Gravity Term

One of the variants suggested by Dean *et al.* (1993), and Dean (1991) as discussed in 3.5.1 and considered further here is described in the following equation:

$$x = \frac{y}{m} + \frac{y^{3/2}}{A^{3/2}} \quad (4.15)$$

where x is the offshore distance, y is the profile depth from sea level, A represents the scale factor as before, and m is the beach face slope. This modified profile is an attempt to create a more realistic composite profile to overcome difficulties associated with the infinite slope problem which equation 4.1 suggests as the profile approaches the origin.

This modified Dean profile involves both a linear component representing the beach face and a concave curve typical of the surf and offshore zone. This is similar to the approach taken in Kriebel's (1989) EDUNE model which can be used to predict short term cut and fill events (Pickett *et al.*, 1997). The form of the profile used in the MATLAB routine developed to apply this model to the BoP profile dataset integrated the equilibrium profile numerically is described in Dean *et al.* (1993) using the following:

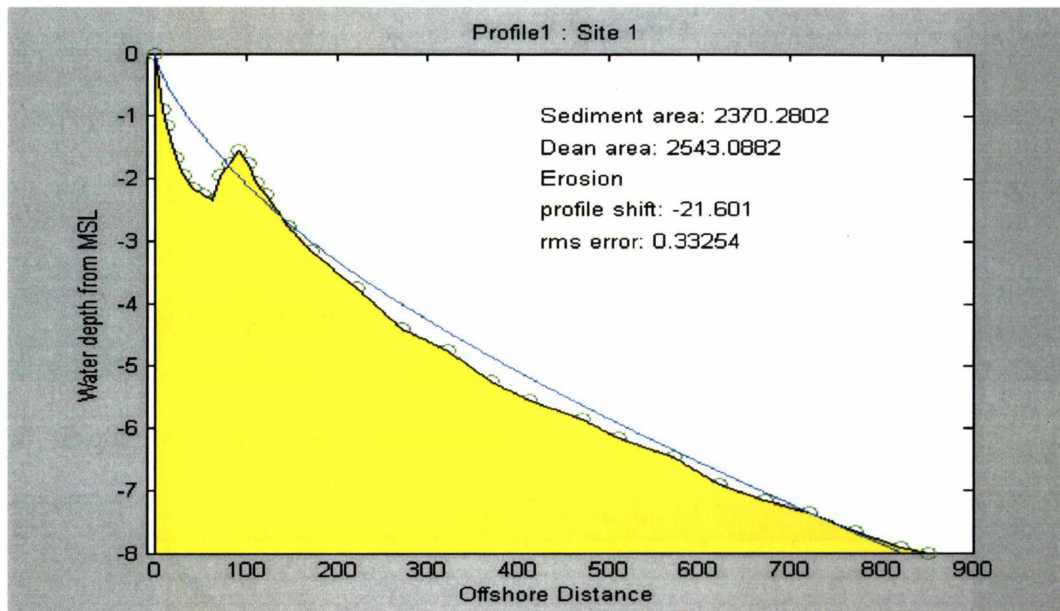
$$h(y+i) = h(y) + \left(\frac{1}{BSL} + \frac{3h_i^{1/2}}{2A^{3/2}} \right)^{-1} (y_{i+1} - y_i) \quad (4.16)$$

$$\bar{A} = A_n + \left(\frac{A_{n+1} - A_n}{y_{n+1} - y_n} \right) \left(\frac{y_{i+1} + y_i}{2} - y_n \right) \quad (4.17)$$

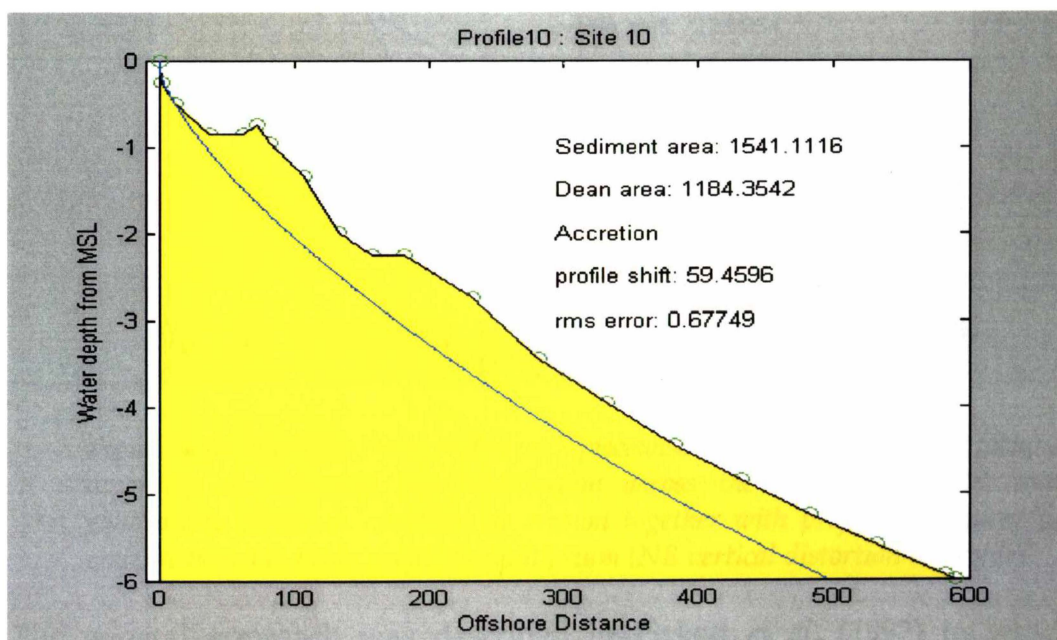
where y is the offshore distance, h is water depth and A is the scale factor.

As discussed previously, the modified Dean model conceptually offers the opportunity for an improved representation of the equilibrium beach profile. This together with a piecewise approach to the derivation of the scale factor from individual sediment samples should theoretically provide a realistic assessment of the stability of the beaches contained in the BOP dataset.

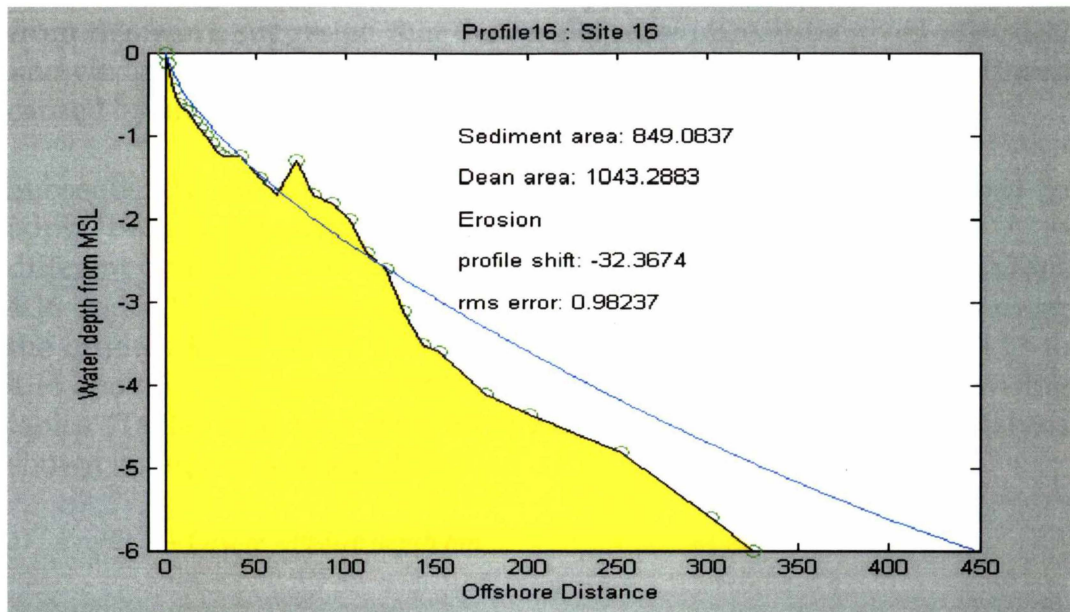
a) *Profile 1 – Opape, closure depth 8m*



b) *Profile 10 – Ohope Beach, closure depth 6m*



c) Profile 16 – Rangitaiki River mouth, closure depth 6m



d) Profile 48 – Bowentown, closure depth 6m

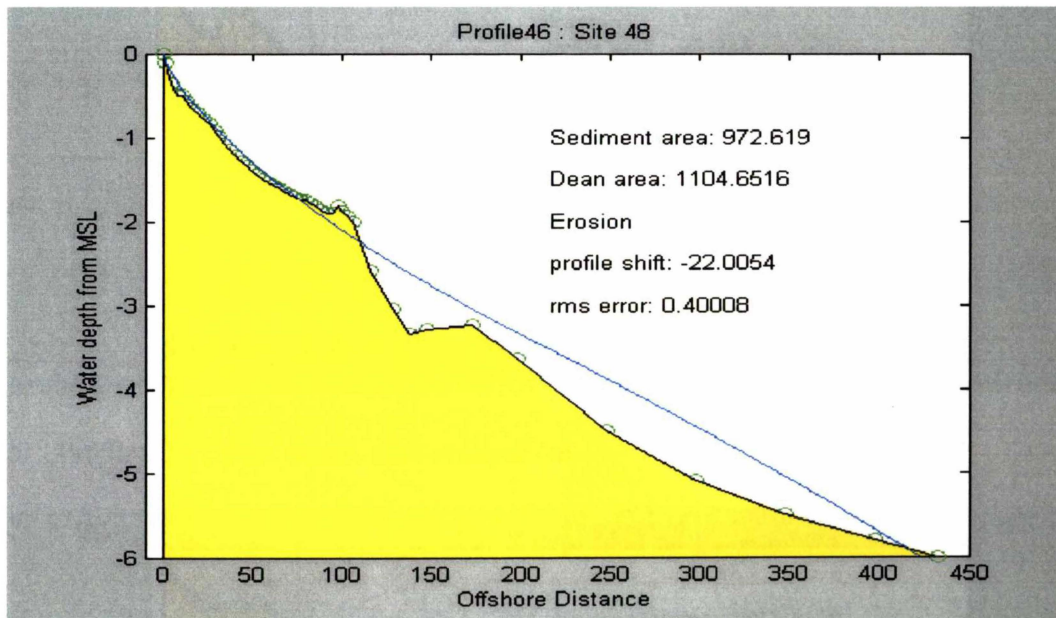


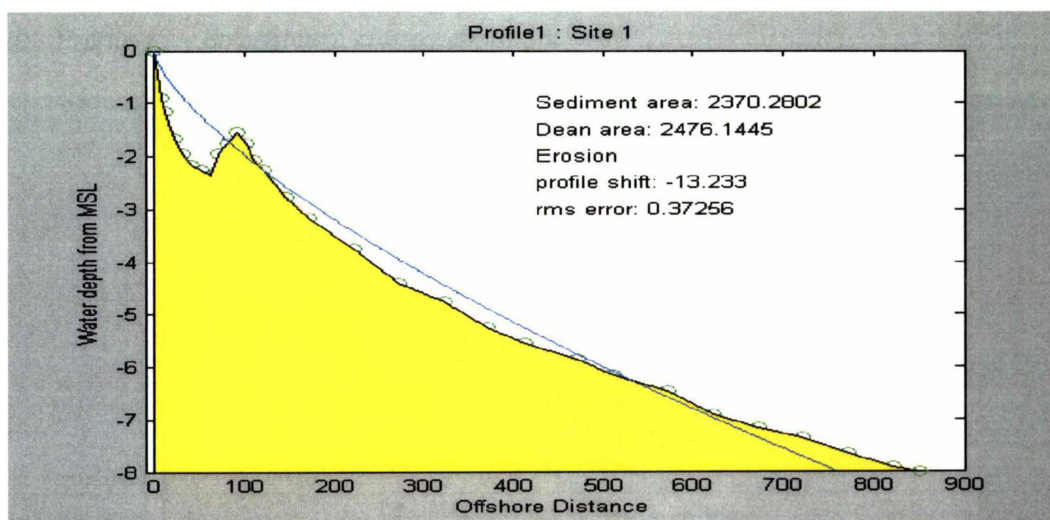
Figure 4.18: Modified Dean profile with piecewise application of the scale factor A according to sediment size distribution across the profile. Profiles show equilibrium status as accretion or erosion together with profile adjustment (or shift) required to bring profile to equilibrium (NB vertical distortion in profiles)

The general approach was described in Pickett *et al.* (1997) in which sediment balances were determined between the calculated and surveyed profiles measured to the beaches outer limits (-12 to -16 m, approximate Hallermeier Outer Limits or H.O.L). This analysis used a piecewise approach to determine the scale factor A based on sediment sampling

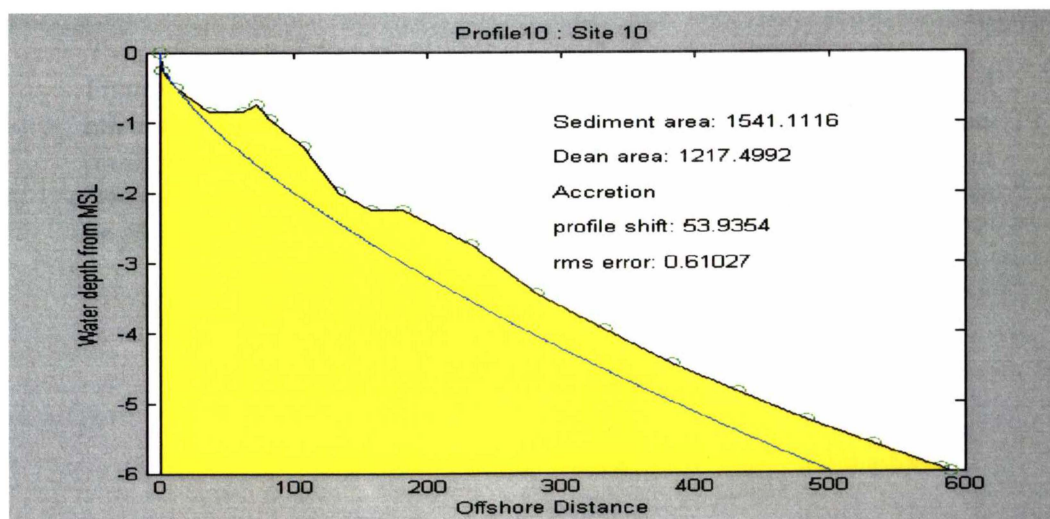
obtained from across the profile. The analysis indicated that of the total profiles considered, forty (83%) are susceptible to erosion while only eight contain a surplus of sediment and may therefore accrete. Conclusions from this work suggested that the results were unrealistic given historical knowledge concerning profile behaviour and that this could have been caused by an unrealistic choice of closure depths.

Subsequently the analysis has been repeated and further developed to apply both a piecewise and profile averaging determination of A to different closure depths using the modified schema described in equations 4.16 and 4.17 to provide a comparison with similar determinations using the original Dean (1977) power curve (see equation 4.1 and Table 4.13 to 4.15 above). The results of this analysis are summarised in the following tables (Tables 4.16 to 4.18) with typical plot outputs from this analysis shown in Figures 4.18 and 4.19.

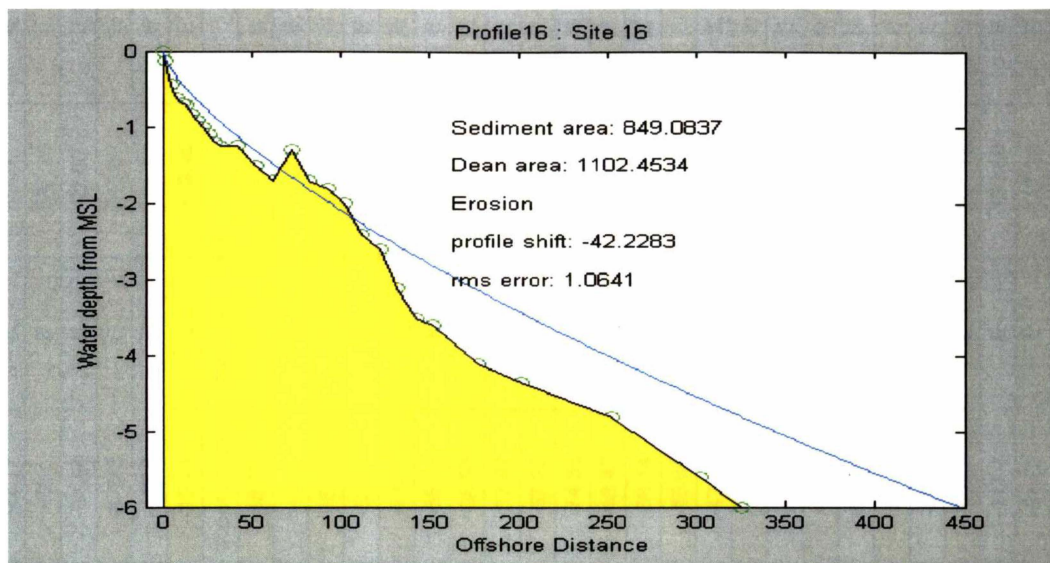
a) Profile 1 – Opape, closure depth 8m



b) Profile 10 – Ohope Beach, closure depth 6m



c) Profile 16 – Rangitaiki River mouth, closure depth 6m



d) Profile 48 – Bowentown, closure depth 6m

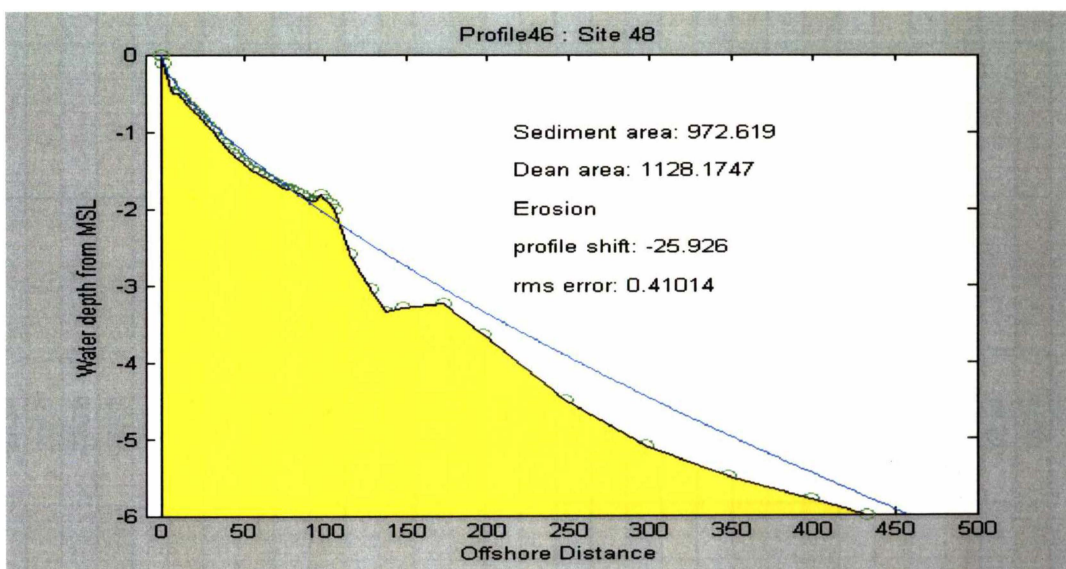


Figure 4.19: Modified Dean profile with profile averaged scale factor A calculated from sediment size sampling across the profile. Profiles show equilibrium status as accretion or erosion together with profile adjustment (or shift) required to bring profile to equilibrium (NB vertical distortion in profiles).

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A	
1	E	-24.59	E	-27.34	E	-24.42	E	-22.27	E	-21.60	E	-13.23
2	E	-217.7	E	-207.9	E	-252.9	E	-239	E	-282.26	E	-264.48
3	E	-65.14	E	-73.78	E	-81.31	E	-82.54	E	-92.00	E	-83.60
4	E	-162.8	E	-158.2	E	-191.1	E	-175.3	E	-215.07	E	-187.04
5	E	-123.8	E	-131	E	-154	E	-153.7	E	-181.30	E	-172.05
6	E	-99	E	-106.4	E	-122.5	E	-123.1	E	-139.96	E	-132.76
7	E	-771.9	E	-750	No closure depth for predicted profile							
8	A	53.06	A	45.3	A	97.87	A	88.13	A	134.36	A	122.37
9	A	4.473	E	-14.01	E	-25.23	E	-45.2	E	-61.21	E	-80.01
10	A	59.46	A	53.94	A	63.52	A	58.52	A	68.54	A	65.39
11	E	-42.21	E	-51.92	E	-45.61	E	-52.81	E	-48.18	E	-51.07
12	E	-105.7	E	-106.7	E	-157.4	E	-140.9	E	-209.02	E	-171.50
13	E	-51.02	E	-67.31	E	-76.61	E	-88.27	E	-106.66	E	-110.07
14	A	8.662	E	-21.24	E	-8.349	E	-36.93	E	-29.18	E	-52.77
15	E	55.94	E	-66.43	E	-76.26	E	-87.97	E	-108.18	E	-112.43
16	E	-32.37	E	-42.23	E	-50.6	E	-57.25	E	-74.53	E	-76.27
17	E	-44.5	E	-49.81	E	-72.25	E	-74.35	E	-103.65	E	-102.02
18	E	-25.72	E	-31.98	E	-39.08	E	-43.47	E	-59.67	E	-60.64
19	E	-62.92	E	-49.34	E	-80.8	E	-58.14	E	-98.85	E	-66.79
20	E	-42.42	E	-37.27	E	-56.05	E	-45.64	E	-74.56	E	-56.77
21	E	-29.55	E	-38.94	E	-45.6	E	-47.04	E	-63.00	E	-54.90
22	E	-4.474	E	-11.69	E	-19.51	E	-17.92	E	-33.30	E	-22.41
23	A	13.2	E	-12.86	A	1.161	E	-19.27	E	-14.28	E	-24.79
24	E	-28.7	E	-26.36	E	-43.89	E	-30.8	E	-62.35	E	-35.32
25	E	-115.5	E	-91.18	E	-141.4	E	-107.4	E	-169.95	E	-127.38
26	E	-88.06	E	-66.72	E	-116	E	-80.35	E	-141.63	E	-89.65
27	E	-89.47	E	-71.23	E	-120.1	E	-88.39	E	-149.69	E	-103.69
28	E	-138.4	E	-124.9	E	-170.7	E	-150.8	E	-201.78	E	-174.69
29	E	-90.89	E	-95.84	E	-120.9	E	-117.1	E	-153.66	E	-137.12
30	E	-92.31	E	-65.74	E	-105.8	E	-81.86	E	-117.29	E	-97.09

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Modified Dean	-Piecewise A	Modified Dean	-Profile Av. A	Modified Dean	-Piecewise A	Modified Dean	-Profile Av. A	Modified Dean	-Piecewise A	Modified Dean	-Profile Av. A
32	E	-76.25	E	-36.95	E	-66.5	E	-10.05	E	-40.25	A	31.22
33	E	-92.14	E	-83.19	E	-123.7	E	-100.2	E	-144.94	E	-104.95
34	E	-101.5	E	-103.9	E	-132.3	E	-127.2	E	-167.46	E	-152.60
35	E	-20.17	E	-36.65	E	-35.36	E	-43.21	E	-45.81	E	-42.68
36	E	-212.5	E	-205.2	E	-258.2	E	-247.2	No closure depth for predicted profile			
38	E	-133.2	E	-130.7	E	-165.1	E	-160.2	E	-196.60	E	-188.54
39	E	-328.8	E	-324.3	No closure depth for predicted profile							
40	E	-123.3	E	-108.7	E	-130.9	E	-121.4	E	-138.17	E	-136.28
41	A	11.69	A	35.38	A	111.8	A	139.6	A	215.84		
42	A	31.36	A	10.97	A	30.02	A	4.474	A	21.25	E	-4.70
43	E	-139.6	E	-123.3	E	-166.2	E	-145	E	-187.75	E	-164.49
44	E	-58.28	E	-59.46	E	-67.54	E	-66	E	-77.33	E	-72.37
45	E	-12.98	E	-12.64	E	-9.471	E	-6.456	E	-3.56	A	2.70
46	A	206.2	A	186.5	A	260.5	A	233.4	A	318.77	A	284.83
47	A	267.3	A	251.6	A	327.5	A	305	A	384.15	A	354.31
48	E	-22.01	E	-25.93	E	-12.04	E	-22.47	A	1.24	E	-16.84
49	E	-41.64	E	-39.67	E	-41.19	E	-35.68	E	-33.68	E	-24.72
51	E	-114.5	E	-110	E	-112.3	E	-106.3	E	-103.13	E	-95.78
Average Erosion/Accretion for dataset		-71.39		-71.15		-61.45		-57.17		-66.83		-63.72

Table 4.16: Equilibrium status of 48 beach profiles determined using Dean et al.'s modified profile (1993) profile and calculated using either piecewise variation of the Scale Factor 'A' based on sediment sampling along the profile or Profile averaged A values determined from the sediment sampling. Dataset averages for the 48 profiles are shown in the bottom row of the table.

BOPRC #	RMSR for 6m Closure Depth				RMSR for 7 m Closure Depth				8 m Closure Depth			
	Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A	
	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed
1	0.407	0.407	0.4336	0.4336	0.3683	0.3683	0.3891	0.3891	0.33254	0.33254	0.37256	0.37256
2	2.303	2.303	2.21	2.21	2.348	2.348	2.235	2.235	2.3723	2.3723	2.2395	2.2395
3	0.7846	0.7846	0.8366	0.8366	0.8107	0.8107	0.8114	0.8114	0.8182	0.8182	0.76605	0.76605
4	1.61	1.61	1.557	1.557	1.666	1.666	1.534	1.534	1.7507	1.7507	1.5171	1.5171
5	1.466	1.466	1.481	1.481	1.563	1.563	1.518	1.518	1.6318	1.6318	1.5249	1.5249
6	1.29	1.29	1.328	1.328	1.331	1.331	1.319	1.319	1.3354	1.3354	1.2781	1.2781
7	5.761	5.761	5.547	5.547	No closure depth for predicted profile							
8	0.5297		0.5434		0.8922		0.8881		1.2534		1.2064	
9	0.6329		0.6849		0.8256		0.8952		1.0285		1.0733	
10	0.6775	0.6775	0.6103	0.6103	0.6792	0.6792	0.6237	0.6237	0.67012	0.67012	0.63684	0.63684
11	0.5322	0.5322	0.623	0.623	0.5007	0.5007	0.5756	0.5756	0.47428	0.47428	0.53158	0.53158
12	2.212	2.212	2.021	2.021	2.551	2.551	2.144	2.144	2.9184	2.9184	2.2453	2.2453
13	1.447	1.447	1.61	1.61	1.751	1.751	1.783	1.783	1.9173	1.9173	1.8468	1.8468
14	0.6695	0.6695	0.8157	0.8157	0.9118	0.9118	1.034	1.034	1.2163	1.2163	1.2148	1.2148
15	1.563	1.563	1.699	1.699	2.178	2.178	2.179	2.179	2.8374	2.8374	2.6569	2.6569
16	0.9824	0.9824	1.064	1.064	1.603	1.603	1.507	1.507	2.2374	2.2374	1.9686	1.9686
17	1.909	1.909	1.843	1.843	2.508	2.508	2.371	2.371	3.0736	3.0736	2.8534	2.8534
18	0.6298	0.6298	0.6429	0.6429	1.22	1.22	1.144	1.144	2.1964	2.1964	1.9014	1.9014
19	1.178	1.178	0.8533	0.8533	1.431	1.431	0.9437	0.9437	1.7296	1.7296	1.0692	1.0692
20	0.8871	0.8871	0.7232	0.7232	1.113	1.113	0.8472	0.8472	1.4788	1.4788	1.0038	1.0038
21	0.7323	0.7323	0.7264	0.7264	0.9383	0.9383	0.7791	0.7791	1.1533	1.1533	0.83862	0.83862
22	0.6174	0.6174	0.4502	0.4502	0.7425	0.7425	0.4767	0.4767	0.86748	0.86748	0.48841	0.48841
23	0.4698	0.4698	0.4772	0.4772	0.5535	0.5535	0.501	0.501	0.75468	0.75468	0.52917	0.52917
24	0.7719	0.7719	0.5723	0.5723	1.042	1.042	0.6061	0.6061	1.3307	1.3307	0.63891	0.63891
25	2.174	2.174	1.686	1.686	2.662	2.662	1.937	1.937	3.0285	3.0285	2.2646	2.2646
26	1.508	1.508	1.14	1.14	1.728	1.728	1.171	1.171	2.0285	2.0285	1.2031	1.2031
27	1.864	1.864	1.42	1.42	2.221	2.221	1.523	1.523	2.6207	2.6207	1.6794	1.6794

BOPRC #	RMSR for 6m Closure Depth				RMSR for 7 m Closure Depth				8 m Closure Depth			
	Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A		Modified Dean -Piecewise A		Modified Dean -Profile Av. A	
	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed	Full dataset	Outliers removed
28	2.424	2.424	2.183	2.183	2.678	2.678	2.351	2.351	2.991	2.991	2.5491	2.5491
29	1.77	1.77	1.71	1.71	2.08	2.08	1.855	1.855	2.5172	2.5172	2.0022	2.0022
30	1.871	1.871	1.51	1.51	1.92	1.92	1.628	1.628	1.9128	1.9128	1.6866	1.6866
32	1.012	1.012	0.7196	0.7196	0.9178	0.9178	0.6735	0.6735	0.88835	0.88835	0.78237	0.78237
33	1.697	1.697	1.559	1.559	1.655	1.655	1.476	1.476	1.558	1.558	1.3594	1.3594
34	1.666	1.666	1.563	1.563	2.158	2.158	1.876	1.876	2.8336	2.8336	2.2874	2.2874
35	0.5609	0.5609	0.6072	0.6072	0.6128	0.6128	0.5893	0.5893	0.62399	0.62399	0.54275	0.54275
36	3.293	3.293	3.128	3.128	3.921	3.921	3.7	3.7	No closure depth for predicted profile			
38	2.116	2.116	2.05	2.05	2.46	2.46	2.347	2.347	2.9002	2.9002	2.7144	2.7144
39	4.416	4.416	4.292	4.292	No closure depth for predicted profile							
40	1.626	1.626	1.474	1.474	1.666	1.666	1.592	1.592	1.6611	1.6611	1.6488	1.6488
41	1.266		1.145		0.6236		1.479		1.5189			
42	0.6874	0.6874	0.4775	0.4775	1.774	1.774	0.4888	0.4888	0.56459	0.56459	0.48468	0.48468
43	1.624	1.624	1.434	1.434	0.6652	0.6652	1.552	1.552	1.9104	1.9104	1.6983	1.6983
44	0.6345	0.6345	0.6275	0.6275	0.1523	0.1523	0.6341	0.6341	0.75143	0.75143	0.67448	0.67448
45	0.1614	0.1614	0.159	0.159	2.426	2.426	0.1654	0.1654	0.16212	0.16212	0.21461	0.21461
46	1.815		1.924		2.245		2.423		2.9559		2.5715	
47	1.543		1.707		0.3931		2.249		2.7584		2.5963	
48	0.4001	0.4001	0.4101	0.4101	0.3542	0.3542	0.3681	0.3681	0.44451	0.44451	0.34153	0.34153
49	0.3837	0.3837	0.3626	0.3626	0.3542	0.3542	0.3288	0.3288	0.32563	0.32563	0.31508	0.31508
51	0.9127	0.9127	0.8853	0.8853	0.8456	0.8456	0.8167	0.8167	0.77791	0.77791	0.75031	0.75031
Average rmsr	1.41	1.43	1.32	1.34	1.44	1.49	1.31	1.28	1.62	1.59	1.38	1.33
Std dev	1.02	1.07	0.98	1.02	0.83	0.83	0.75	0.75	0.88	0.89	0.77	0.76

Table 4.17: Table showing rmsr or standard error values derived from fitting Dean et al's model (1993) as shown in Table 4.16 to the BoP individual profiles with and without outlier profiles removed.

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Modified Dean -Piecewise		Modified Dean -Profile Av.		Modified Dean -Piecewise		Modified Dean -Profile Av.		Modified Dean -Piecewise		Modified Dean -Profile Av.	
	A		A		A		A		A		A	
1	E	-24.59	E	-27.34	E	-24.42	E	-22.27	E	-21.60	E	-13.23
2	E	-217.7	E	-207.9	E	-252.9	E	-239	E	-282.26	E	-264.48
3	E	-65.14	E	-73.78	E	-81.31	E	-82.54	E	-92.00	E	-83.60
4	E	-162.8	E	-158.2	E	-191.1	E	-175.3	E	-215.07	E	-187.04
5	E	-123.8	E	-131	E	-154	E	-153.7	E	-181.30	E	-172.05
6	E	-99	E	-106.4	E	-122.5	E	-123.1	E	-139.96	E	-132.76
7	E	-771.9	E	-750	NO closure depth for predicted profile							
8												
9												
10	A	59.46	A	53.94	A	63.52	A	58.52	A	68.54	A	65.39
11	E	-42.21	E	-51.92	E	-45.61	E	-52.81	E	-48.18	E	-51.07
12	E	-105.7	E	-106.7	E	-157.4	E	-140.9	E	-209.02	E	-171.50
13	E	-51.02	E	-67.31	E	-76.61	E	-88.27	E	-106.66	E	-110.07
14	A	8.662	E	-21.24	E	-8.349	E	-36.93	E	-29.18	E	-52.77
15	E	-55.94	E	-66.43	E	-76.26	E	-87.97	E	-108.18	E	-112.43
16	E	-32.37	E	-42.23	E	-50.6	E	-57.25	E	-74.53	E	-76.27
17	E	-44.5	E	-49.81	E	-72.25	E	-74.35	E	-103.65	E	-102.02
18	E	-25.72	E	-31.98	E	-39.08	E	-43.47	E	-59.67	E	-60.64
19	E	-62.92	E	-49.34	E	-80.8	E	-58.14	E	-98.85	E	-66.79
20	E	-42.42	E	-37.27	E	-56.05	E	-45.64	E	-74.56	E	-56.77
21	E	-29.55	E	-38.94	E	-45.6	E	-47.04	E	-63.00	E	-54.90
22	E	-4.474	E	-11.69	E	-19.51	E	-17.92	E	-33.30	E	-22.41
23	A	13.2	E	-12.86	A	1.161	E	-19.27	E	-14.28	E	-24.79
24	E	-28.7	E	-26.36	E	-43.89	E	-30.8	E	-62.35	E	-35.32
25	E	-115.5	E	-91.18	E	-141.4	E	-107.4	E	-169.95	E	-127.38
26	E	-88.06	E	-66.72	E	-116	E	-80.35	E	-141.63	E	-89.65
27	E	-89.47	E	-71.23	E	-120.1	E	-88.39	E	-149.69	E	-103.69
28	E	-138.4	E	-124.9	E	-170.7	E	-150.8	E	-201.78	E	-174.69
29	E	-90.89	E	-95.84	E	-120.9	E	-117.1	E	-153.66	E	-137.12

BOPRC #	6m Closure Depth				7 m Closure Depth				8 m Closure Depth			
	Modified Dean -Piecewise		Modified Dean -Profile Av.		Modified Dean -Piecewise		Modified Dean -Profile Av.		Modified Dean -Piecewise		Modified Dean -Profile Av.	
	A		A		A		A		A		A	
30	E	-92.31	E	-65.74	E	-105.8	E	-81.86	E	-117.29	E	-97.09
32	E	-76.25	E	-36.95	E	-66.5	E	-10.05	E	-40.25	A	31.22
33	E	-92.14	E	-83.19	E	-123.7	E	-100.2	E	-144.94	E	-104.95
34	E	-101.5	E	-103.9	E	-132.3	E	-127.2	E	-167.46	E	-152.60
35	E	-20.17	E	-36.65	E	-35.36	E	-43.21	E	-45.81	E	-42.68
36	E	-212.5	E	-205.2	E	-258.2	E	-247.2	NO closure depth for predicted profile			
38	E	-133.2	E	-130.7	E	-165.1	E	-160.2	E	-196.60	E	-188.54
39	E	-328.8	E	-324.3	NO closure depth for predicted profile							
40	E	-123.3	E	-108.7	E	-130.9	E	-121.4	E	-138.17	E	-136.28
41												
42	A	31.36	A	10.97	A	30.02	A	4.474	A	21.25	E	-4.70
43	E	-139.6	E	-123.3	E	-166.2	E	-145	E	-187.75	E	-164.49
44	E	-58.28	E	-59.46	E	-67.54	E	-66	E	-77.33	E	-72.37
45	E	-12.98	E	-12.64	E	-9.471	E	-6.456	E	-3.56	A	2.70
46												
47												
48	E	-22.01	E	-25.93	E	-12.04	E	-22.47	A	1.24	E	-16.84
49	E	-41.64	E	-39.67	E	-41.19	E	-35.68	E	-33.68	E	-24.72
51	E	-114.5	E	-110	E	-112.3	E	-106.3	E	-103.13	E	-95.78
Average Erosion/Accretion for dataset		-92.31		-91.16		-87.79		-81.73		-99.98		-87.13

Table 4.18: Replication of the data shown in Table 4.16 with outlier profiles removed

The general results of the analysis summarised in Tables 4.16 to 4.18 above appear to predict an overall sediment deficit in the Bay of Plenty when aggregated sediment volumes are averaged over the dataset (see Average erosion/accretion values in the bottom row of Tables 4.16 and 4.18). Removal of outlier or anomalous profiles principally associated with ebb tidal deltas does not improve the results. In comparison, results obtained from fitting the Dean (1977) profile to the same profiles generally indicates that the overall profiles are more or less in equilibrium (see Tables 4.13 and 4.15) with the wave climate and sediment supply.

In terms of equilibrium theory this would be expected however the results obtained for the modified Dean profile indicate significant overall erosion potential which does not appear to be evident from the historical data (see Table 4.19). Analysis of the standard errors contained in Tables 4.14 and 4.17 indicate that the original Dean (1977) profile with profile averaged scale factor (with outlier profiles removed) best represents the profiles within the BoP dataset. The results obtained for the Dean profile (1977) with profile averaged scale factor and for 6 and 7 m closure depth which minimises the standard errors (see Table 4.14) of the Dean profile fit are shown in Table 4.19.

In general terms the results of fitting the Dean (1977) equilibrium curve to the BoP profiles generally reflect the historic accretion and erosion trends identified from BoP Regional Council profile monitoring (Hodges and Deely, 1997). However there is very little to choose from in the results obtained for the two closure depths with overall standard errors for the dataset averages being 0.56 m and 0.63 m for the 6 and 7 m depths respectively (see Table 4.14). Additionally the scatter plots of erosion and accretion for the various profiles when compared to the historic trends shown in Figure 4.20 show greater scatter for the 7 m closure depth when compared to the shallower depth while the 6 m closure depth more closely reflects the magnitudes of observed profile behaviour in the monitoring data, in particular for 1990-96 result which incorporate the 1993 survey data used here.

BOPRC#	Predicted Equilibrium status (Dean with profile averaged A) – 6 m closure depth	Predicted Equilibrium status (Dean with profile averaged A) – 7 m closure depth	1990-6 (Hodges and Deely, 1997)	Historic Rates (60-100yrs) (Hodges and Deely, 1997)
1	-3.996	5.235	20	-25
2	-8.276	-6.112	8	0
3	31.5	40.36	3	-20
4	5.017	15.18	-8	-25
5	6.996	7.242	12	30
6	-17.08	-18.84	4	20
7	-0.087	0.4028	2	0
8				
9				

BOPRC#	Predicted Equilibrium status (Dean with profile averaged A) – 6 m closure depth	Predicted Equilibrium status (Dean with profile averaged A) – 7 m closure depth	1990-6 (Hodges and Deely, 1997)	Historic Rates (60-100yrs) (Hodges and Deely, 1997)
10	70.95	78.74	-7	65
11	25.56	37.67	-11	15
12	-17.43	-36.66	26	25
13	-40.23	-56.45	3	55
14	3.618	-7.695	11	
15	-33.13	-48.93	1	
16	-14.81	-25.05	3	45 to 120
17	-20.81	-40.31	16	50
18	14.16	10.51	1	
19	-7.474	-9.158	9	55
20	-5.185	-8.033	3	0
21	-14.83	-18.68	1	
22	-0.34	-4.229	6	
23	13.39	11.55	-0.7	-20
24	-13.21	-15.1	-8	-25
25	-14.25	-17.56	-8	-15
26	-17.66	-22.99	-8	
27	-19.94	-28.43	-5	
28	-43.79	-56.04	0	-13
29	-18.27	-26.49	-4	-8
30	39.73	41.23		0 to -3
32	-5.233	27.12	6	-14
33	-62.67	-76.01	3	
34	-14.11	-22.31	1	
35	-18.39	-21.58	0	0
36	-16.76	-27.29	-0.4	
38	-19.82	-30.83	-0.4	
39	7.108	7.339	-1.5	2 to 60
40	19.43	28.15	9	
41				
42	63.04	65.35	-2	
43	56.28	64.6	-7	
44	68.58	83.44	-2	30
45	55.18	72.78	-9	
46				
47				
48	3.441	11.99	-2	-35
49	100.4	127.8	-1	-8
51	69.6	103.2	-5	0
Dataset average	4.80	3.57	1.38	5.48

Table 4.19: Results of beach equilibrium analysis using Dean (1977) profile with profile averaged 'A' values for two closure depths as compared to historic trends identified from monitoring investigations and results.

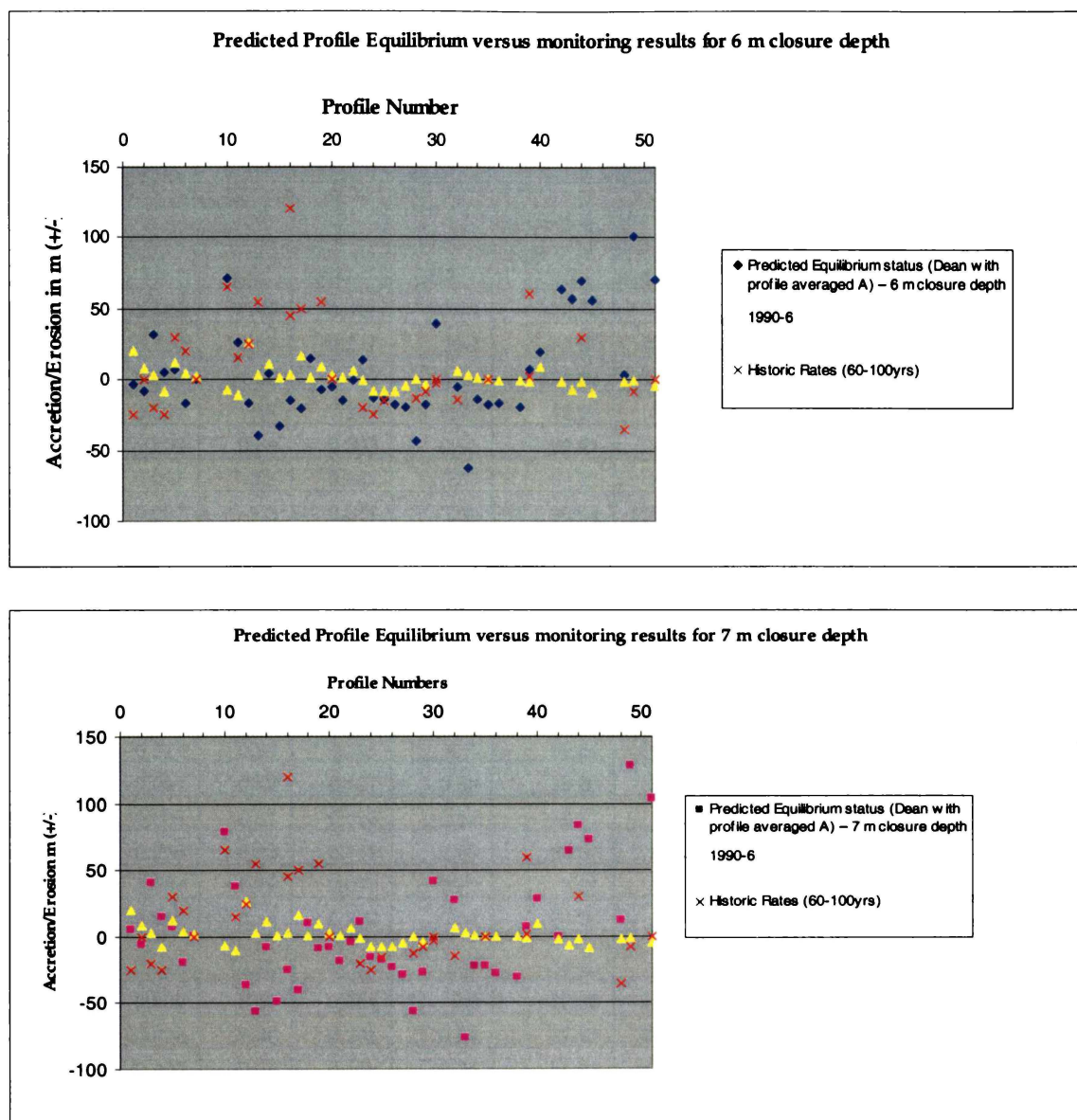


Figure 4.20: Scatter plots showing profile equilibrium status determined from the Dean (1977) model in comparison for results obtained from profile monitoring calculated for 6 and 7 m closure depths.

4.8.2 Wang Davis Segmented Model

The development and use of this segmented model for a barred Florida coast was originally described in Wang and Davis (1998), where it was depicted as a model incorporating three zones, an inner surf zone, a nearshore zone and a landward bar slope (see s.3.6.2).

A routine was developed in MATLAB to test this model's ability to replicate the BoP profiles in terms of equilibrium beach theory. The routine simulated Wang and Davis's (1998) initial work which involved fitting least square regression power curves to all the barred profiles to determine both the scale (A) and shape (m) factors for each of the two monotonic sections (i.e. the surf and the nearshore zones). The results of this analysis are shown in Table 4.20. Profiles where bars

are either not present or where profile morphology is significantly affected by the presence of offshore features such as ebb tidal deltas are not included in the analysis.

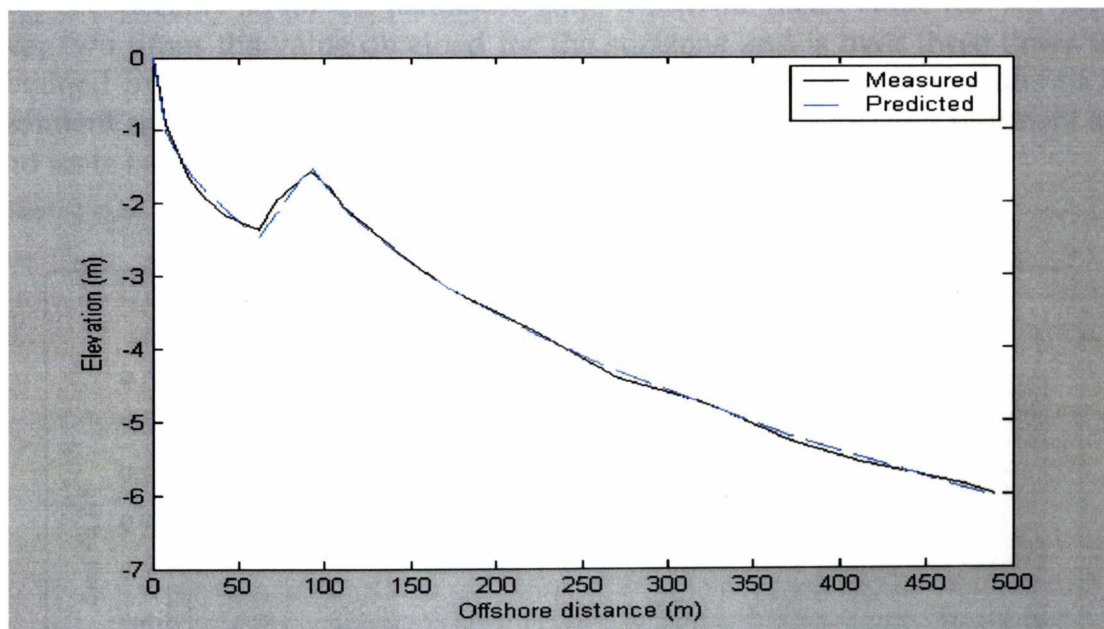
Results for Least Squares Regression fit of Wang and Davis 3 segment model to BoP Profile								
Profile No	Surfzone Section		Nearshore Section					Comments
	A1	M1	A2	M2	Intercept D (x2)	xbt	x2/xbt	
1	0.426	0.43	0.396	0.45	72.54	91.6	0.792	
2	0.024	1.14	0.247	0.54	49.02	86.12	0.569	
3	0.021	1.02	0.402	0.45	111.03	140.8	0.789	
4	0.004	1.46	0.652	0.37	112.06	127.6	0.878	
5	0.06	0.82	0.253	0.53	92.21	125.8	0.733	
6	0.295	0.5	0.261	0.53	39.71	53.6	0.741	
7	0.007	1.3	0.287	0.52	95.44	150.8	0.633	
8								Ohiwa spit – ebb tidal delta
9								Ohope Spit – ebb tidal delta
10	0.223	0.34	0.096	0.66	48.48	72.3	0.671	
11								No bar – dissipative beach
12	0.074	0.69	0.074	0.81	84.68	125.8	0.673	
13	0.106	0.84	0.063	0.81	8.7	10.05	0.866	
14	0.323	0.34	0.225	0.6	89.34	107.1	0.834	
15	0.091	0.87	0.127	0.69	39.83	70.2	0.567	
16	0.205	0.51	0.328	0.52	59.77	71.8	0.832	
17	0.225	0.48	0.141	0.69	63.97	98.6	0.649	
18	0.084	0.72	0.078	0.72	3.94	25.3	0.156	
19	0.382	0.44	0.272	0.54	34.04	59	0.577	
20	0.138	0.75	0.036	0.87	-18.23	81.8	0.450	100 added to ratio as a false origin
21	0.269	0.55	0.361	0.5	62.93	87.68	0.718	
22	0.298	0.46	0.295	0.54	72.91	82.88	0.880	
23	0.405	0.34	0.153	0.65	54.52	67.55	0.807	
24	0.605	0.33	0.278	0.55	34.78	50.5	0.689	
25	0.129	0.74	2.579	0.18	227.41	274.4	0.829	
26	0.037	1.03	0.125	0.68	24.01	59.88	0.401	
27	0.061	0.92	0.3	0.55	70.04	91	0.770	
28	0.014	1.32	0.373	0.51	56.53	78.5	0.720	
29	0.016	1.24	0.397	0.5	81.94	97.52	0.840	
30	0.06	0.59	0.069	0.81	41.6	42	0.990	
32	0.187	0.54	0.663	0.38	41.11	43.08	0.954	
33	0.347	0.47	0.154	0.68	17.75	46.4	0.383	
34	0.041	0.88	0.153	0.62	29.78	48.2	0.618	
35	0.123	0.85	0.046	0.82	-22.87	13.89	0.677	100 added to ratio as a false origin
36	0.02	1.02	0.744	0.38	117.39	130.27	0.901	
38	0.012	1.17	0.214	0.58	60.47	108.07	0.560	
39	0.01	1.25	0.644	0.38	104.29	116.8	0.893	
40								No bar present
41								Ebb tidal delta – Matakana Bank
42								Ebb tidal delta – Matakana Bank
43	0.021	0.93	0.124	0.63	43.99	82.94	0.530	
44	0.032	0.81	0.131	0.61	54.83	95.67	0.573	

Results for Least Squares Regression fit of Wang and Davis 3 segment model to BoP Profile								
Profile No	Surfzone Section		Nearshore Section					Comments
	A1	M1	A2	M2	Intercept D (x2)	xbt	x2/xbt	
45	0.14	0.52	0.154	0.58	40.51	79.2	0.511	
46								Ebb tidal delta -Bowentown
47								Ebb tidal delta -Bowentown
48	0.131	0.6	0.686	0.37	83.95	97.2	0.864	
49	0.034	0.82	0.327	0.46	131.81	175.8	0.750	
51								No bar present – dissipative beach
Mean	0.146	0.770	0.331	0.571	61.954	88.915	0.699	
Std dev	0.15	0.31	0.42	0.15	44.55	47.57	0.18	

Table 4.20: Results of least squares regression fitting of the Wang Davis (1998) three segment model to barred Bay of Plenty beach profiles to determine A1, A2, m1, m2 and the intercept distance ratio x2:xbt.

Examples of the plot outputs from the routine are shown in Figure 4.21 indicating that the model can replicate the measured profiles quite closely. However the results indicate considerable scatter (see Figure 4.22) and no clear relationship between the regression derived values for the scale factor 'A' and those determined from sediment grain size data using the original Moore (1982) relationship (see Table 4.11).

a) Profile 1 – Opape



b) Profile 26 – Pukehina Trig

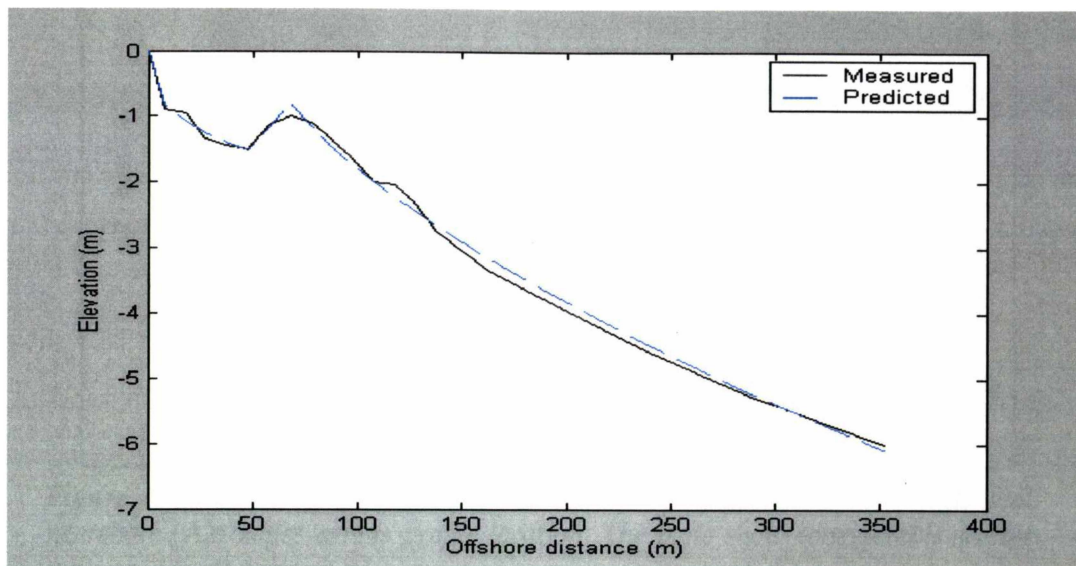
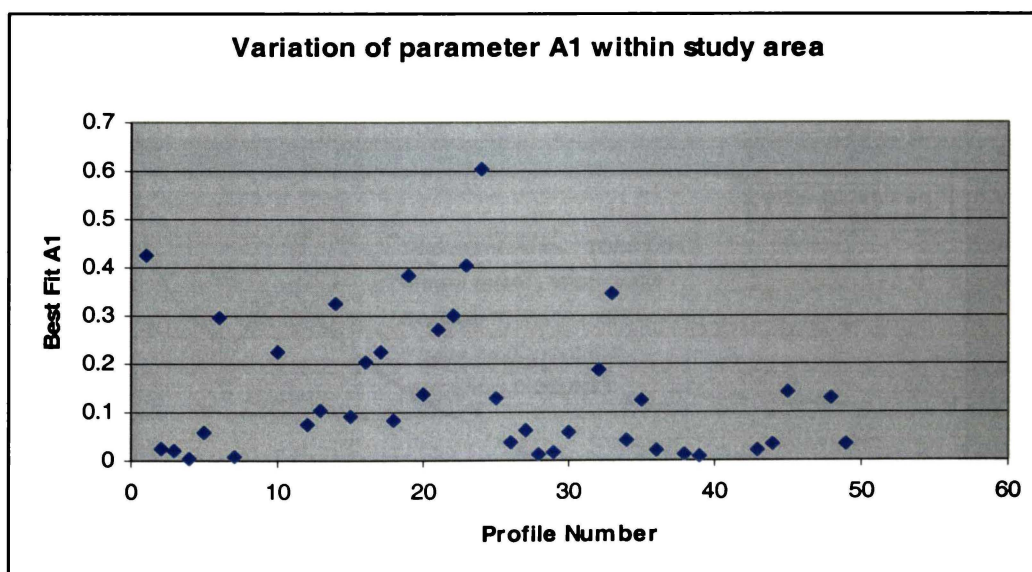


Figure 4.21: Least squares regression fit of the three segment model of Wang and Davis (1998) to two BoP profiles. Least squares regression curve shown in blue, measured profile in black.

The mean value of the scale factor 'A' for the nearshore segment indicates a scaling problem when compared to the results obtained for the Florida beaches. This is especially so for the nearshore zone where the mean value for 'A2' is just over two times the value obtained for the surfzone and is over three times that obtained by Wang and Davis (1998). This is also counter to the results of the sediment sampling along the profiles which indicates a decreasing sediment size and scale factor 'A' with increasing distance offshore.



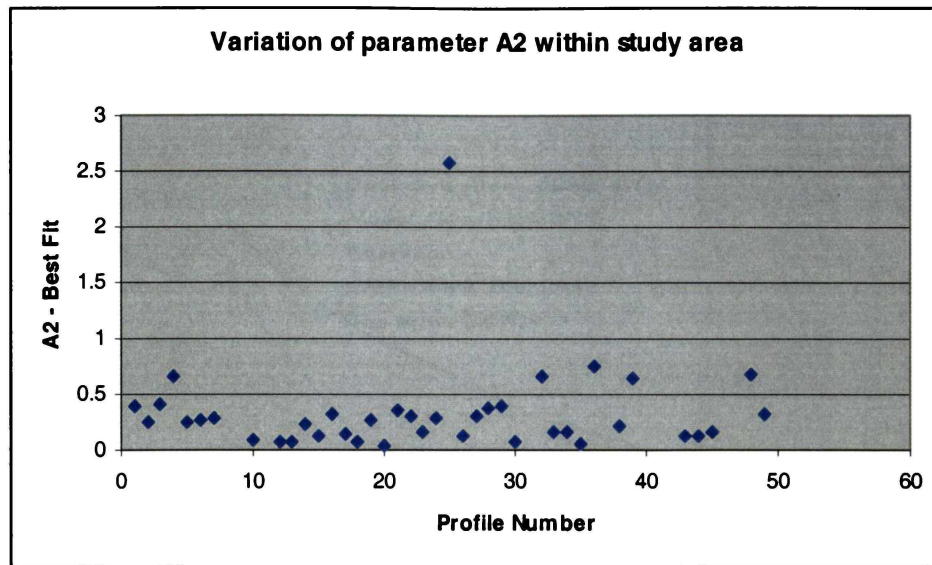
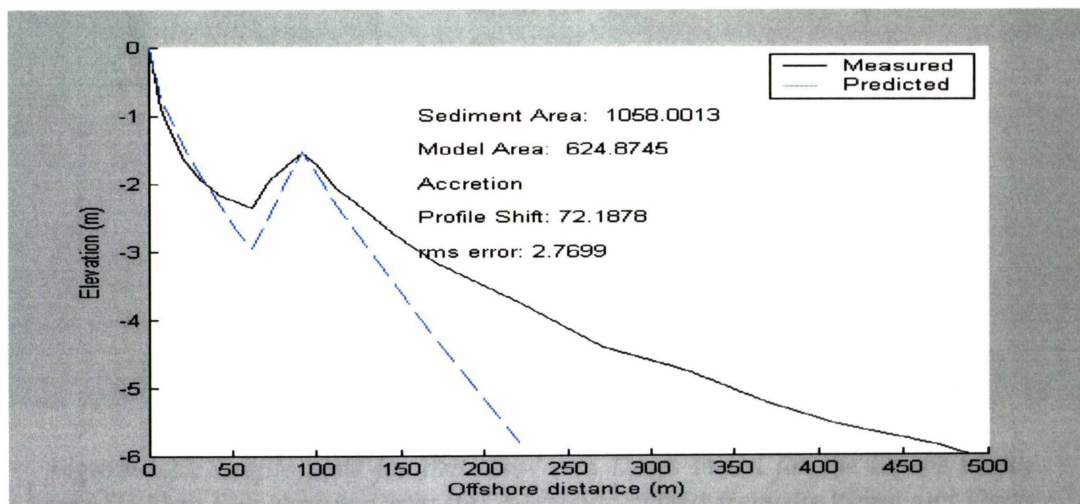
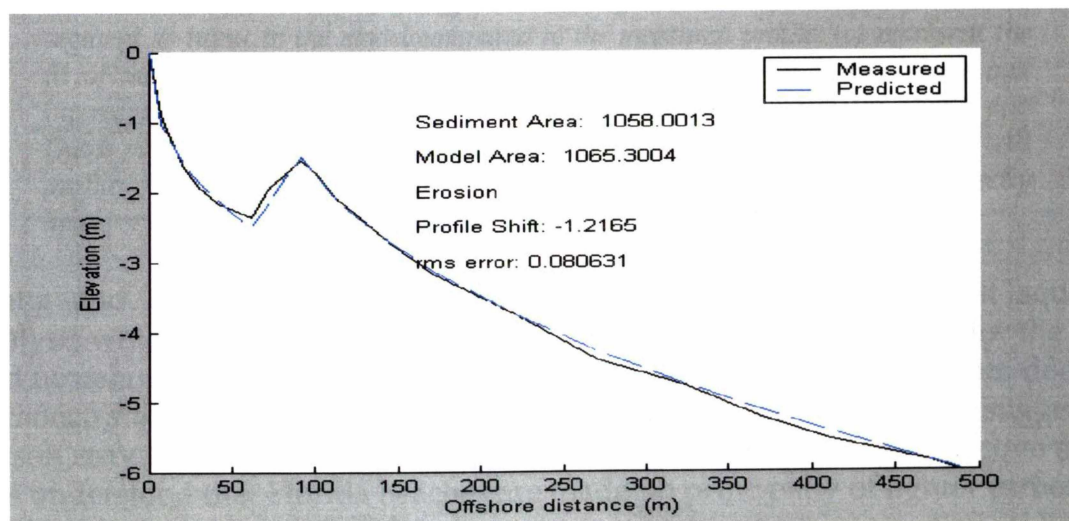


Figure 4.22: Scatter plots showing the scale factor for the surfzone (A1) and nearshore (A2) zones versus profile location. The plots show considerable scatter with no evident pattern.

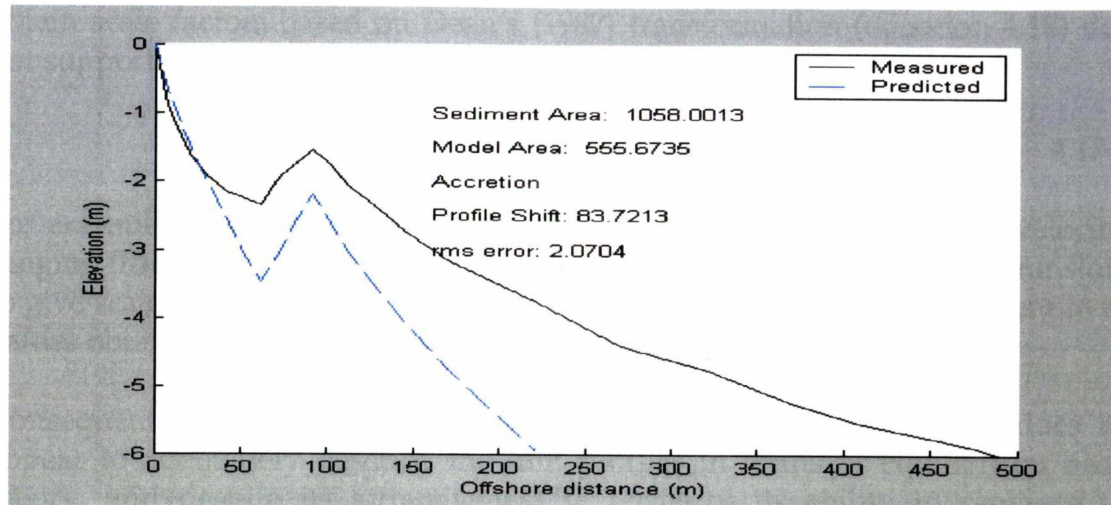
a)



b)



c)



d)

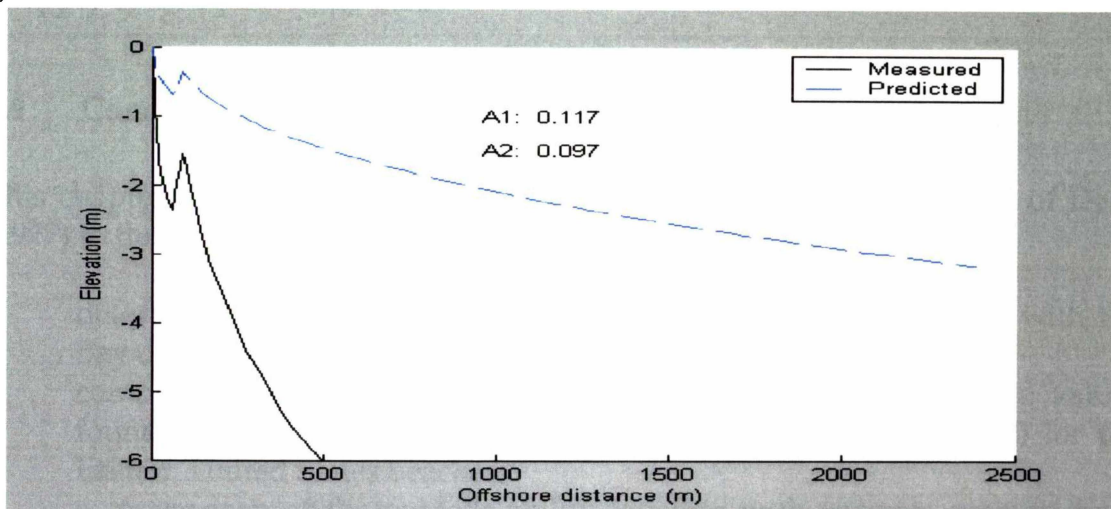


Figure 4.23: Profile plots for the Wang and Davis model for the Opape profile (profile 1) to 6 m closure depth: (a) represents output from the Wang and Davis (1998) model using the Florida input data described in the authors paper; (b) represents the plot obtained using the results of the least squares fit of the three segment as input to the model compared to the measured profile; (c) represent the fit of the Wang and Davis (1998) model using BoP averaged scale shape and intercept values shown in Table 4.20; and (d) shows the predicted Wang and Davis model using sediment derived scale factors ($A1$ and $A2$) for the profile. All profile plots except Figure 4.20 (b) replicate the overall profile shape correctly however there are significant scale problems with the model.

Wang and Davis (1998) obtained consistent results from the least squares analysis which enabled them to generate an overall descriptive model for the surf and nearshore zones (see equations 3.54 to 3.57). However the BoP data doesn't demonstrate any such consistency (see Figures 4.22 and 4.23). One suggested reason may be the differences in sediment density found at the respective sites. It is understood that Florida beaches are made up principally of lighter carbonate sands in comparison to BoP beaches which contain a high proportion of heavy

minerals as described in Chapter 3. However a quick check using sediment fall velocities (obtained from the rapid sediment analyser results for the BoP data) to obtain scale factors based on Dean's (1987) transformation (equation 4.18) does not support this hypothesis.

$$A = 0.067w^{0.44} \quad 4.18$$

For example sediment sampling along profile 1 provides sediment fall velocities ranging from 4.4 to 1.56 cms^{-1} . Using equation 4.17 these values would transform to give scale factors of 0.129 to 0.0815 $\text{m}^{1/3}$ respectively, which is equivalent to the values obtained using Moore's (1982) relationship.

Consequently based our current data the Wang and Davis model does not appear to adequately describe the BoP profiles in terms of equilibrium beach theory, and despite its attractiveness in terms of its ability to replicate the offshore bar, it suffers from considerable scale problems which make it difficult to apply as an equilibrium model.

4.9 Conclusions

This chapter describes the application of the equilibrium beach model of Dean (1977) to the Bay of Plenty profile dataset to achieve the following:

- determination of appropriate scale and shape factors for use in with the Bay of Plenty profile dataset;
- comparison of the derived scale and shape factors with typical values found by Bruun (1954), Dean (1977 and 1991) and Moore (1982) for the Eastern United States beaches;
- a comparison of the model's ability together with variants such as those described in Dean (1991), and Dean *et al.* (1993), to characterise the sandy beaches of the Bay of Plenty; and
- to assess the predictive ability of the model to determine the equilibrium status of these beaches.

The methodology employed to realise this is fully described in 4.1. In summary it included defining appropriate sediment exchange or closures limits as boundary conditions for the models, least squares regression curve fitting of the models to the BoP profile dataset in order to define appropriate scale and shape factors as a comparative study with current theory, and finally utilising developments of the models written in MATLAB to predict equilibrium status of the beaches in comparison with historic documented trends.

Several approaches were taken to resolving 'closure depths', including:

- estimating the limit of significant sediment exchange from geomorphic/geologic evidence;

- the determination of closure depth from time series profile survey data; utilising a routine developed in MATLAB; and
- estimation from theoretical closure depths using wave climate models.

Reasonable consistency was achieved from estimates derived from these three approaches, with the most probable estimate closure depth ranging between 6 and 8 m depth (from MSL) – see Table 4.4.

This depth range was then used as boundary conditions for the application of the described two dimensional equilibrium models to determine both scale and shape factors for the BoP beaches as a comparative study with U.S beaches as described by Dean (1977, 1987, 1991), Moore (1984), Dean *et al.* (1993). The initial analysis involved fitting the power curve by blindfold regression analysis to all forty eight profiles in the dataset. This analysis generally confirmed the appropriateness of the $\frac{2}{3}$ shape factor based on uniform wave energy dissipation per unit volume. One sample Student 't' test results for the 8 m closure depth indicated no significant differences between the mean shape factor obtained for the BoP profiles at the 90%, 95 % and 99% confidence limits and the shape factor reported in Dean (1977).

The regression analysis was then repeated holding the shape factor fixed at $\frac{2}{3}$ while allowing the Scale factor 'A' to vary in order to produce a best fit Dean (1977) power curve for each profile. The resultant scale factor values were then compared to those obtained directly from sediment sampling data using Moore's (1982) relationship to derive scale factor values for each profile. Two sample Student 't' tests indicated reasonable agreement between these two independent datasets although the variance of regression derived values showed a wider and flatter distribution when compared to sediment derived values (see Figure 4.1.4). Finally the regression derived values were plotted as a log –log relationship with sediment diameter based on Moore's relationship as described in Dean (1987). The results from this work indicated a good correlation between least squares regression analysis and sediment sampling for all three closure depths using Moore's (1982) relationship, with perhaps the strongest overall relationship associated with the 8m closure depth. As a consequence of this work it is argued that the Dean (1977) model provides a good approximation of the sandy beach profiles along the BoP coast.

The Dean (1977) model was then used to determine the equilibrium status of the BoP beaches for each of three closure depths. This analysis involved fitting the power curve using either a piecewise approach or profile averaged scale values derived directly from the sediment data for each profile in order to determine whether a surplus or deficit of sediment existed in each profile - or in other words whether a potential existed for individual profiles to either accrete or erode. The results of this analysis confirmed that the Dean (1977) profile limited to a 6 m closure depth with a profile averaged scale factor sourced directly from the sediment sampling, provided the best overall results when compared to the historic trends (Hodges and Deely, 1997) identified in the monitoring results (see Table 4.19), while also recognizing the need to minimise erosion/accretion

potential within the overall dataset (see Table 4.15) in order to conserve beach responses in terms of overall wave energy inputs.

Two evolutionary equilibrium models were subsequently tested. The first model included the addition of a gravity term to the basic Dean model as described in Kriebel and Dean (1986), Dean (1991) and Dean *et al.* (1993). The results showed no improvement over the predictive ability of the basic Dean model, especially when compared to historic trends recorded for the BoP profiles. The second model as proposed by Wang and Davis (1998) utilized a compound curve consisting of three zones describing the surf and nearshore zones and the landward bar slope. The model profile was fitted to each profile by least square regression to determine both shape and scale factors for both the surf and nearshore zones. This was carried out as a replication of the analysis reported in Wang and Davis (1998). However the consistency of results obtained for the Florida dataset could not be replicated in the BoP data. As a consequence the model has been discounted from further analysis and application.

In conclusion, the results of this work indicate that the Dean (1977) model can replicate active profiles in terms of equilibrium theory. It has been shown that the model can provide a reasonable estimate of a beaches equilibrium status and that this can be used to assess hazard potential. As a consequence the model will be further developed in the next two chapters to determine profile responses to both sea level rise and storm cut scenarios as elements in the determination of an overall hazard assessment of the beaches in the Bay of Plenty using a consistent application of equilibrium beach theory.

Chapter 5

Long Term Sea Level Change Scenarios, Equilibrium Beach Profiles and their Applicability to BOP Beaches

5.1 Introduction

This chapter investigates the implications of sea level change for the BoP coastline using equilibrium beach profile theory to determine sandy beach responses to changing sea levels, which in turn will form part of the overall erosion hazard analysis methodology developed in this study.

Because of the almost imperceptible changes associated with sea level rise this assessment focuses on a 100 year timeframe to incorporate those predictions made by the Intergovernmental Panel on Climate Change (IPCC) for climate change scenarios developed through to 2100 (IPCC, 2001a & b).

Various IPCC reports (1997, 2001) identify those coastal areas of greatest sensitivity to sea level rise. These include low lying areas such as deltas, coastal plains, and barrier coasts including sandy beaches, coastal wetlands, estuaries and lagoons. Many of these areas are occupied by cities, towns and urban areas and as a consequence they become vulnerable to the effects of sea level change.

The IPCC (2001) estimates that for the last 100 years approximately 70% of the world's sandy shorelines have been retreating, about 20-30% have been stable and less than 10% have been advancing. By comparison Gibb (1984) estimated that about 56% of New Zealand's 10,000 km coastline is static with 25% eroding while 19% is accreting. Of this 80% is classed by Gibb's as depositional (i.e. sandy or gravel coasts) of which 45% is erosional. With sea level rise it is suggested that there will be a tendency for these beaches to either erode further, become erosive or to stabilise, all subject of course to the vagaries of local sediment supply (Bird, 1993; Nicholls, 1998; Bell *et al.*, 2001).

The work documented in this chapter identifies the potential effects that sea level rise will have on the BoP coastline and includes the following:

- a review of literature relevant to climate change scenarios considered likely over the next 100 hundred years;
- an analysis of historical sea level rise assessments documented in the literature to identify the most probable predictions for sea level rise both world wide and at a regional level for New Zealand;
- a review of the derivation of the Bruun Rule as a basis for predicting sea level rise using equilibrium beach profiles;
- a determination of sea level rise predictions for the 48 BoP profiles using a two dimensional model incorporating the Bruun Rule; and
- a review of these predictions in the light of geomorphic and sediment budget information in order to determine whether the two dimensional predictions provide realistic predictions of coastal change caused by sea level rise ;

5.2 Sea Level Rise and the Bay of Plenty: Tectonics and Global Warming

Sea level change is an important consequence of climate change. Every 5 years since 1990 the IPCC have produced assessment reports on the state of climate change. Collectively the latest set of investigations published in 2001 is known as the Third Assessment Report (TAR). The work underlying the TAR is backed by new and stronger evidence strengthening the contention of earlier reports that global temperatures are increasing and that most of the warming observed over the last 50 years is attributable to human activities (see Figure 5.1).

Projections of temperature and associated sea level changes have been made using several Atmosphere-Ocean General Circulation Models (AOGCMs) which represents an overall improvement to the earlier models used in the Second Assessment Report (SAR) (IPCC, 2001a &b). These coupled models incorporating mechanisms to provide for deep oceanic heat flux were used to process climate change simulations assessed for the period 1990 to 2100 based on a range of scenarios for projected changes in greenhouse gas concentrations and sulphate aerosol loadings.

In summary the work of the TAR identified that:

- temperatures are rising as a result of 'Greenhouse Gas' emissions such as CO₂, NO_x, and CH₄. As a consequence global average temperatures are predicted to increase under various IPCC scenarios by between 1.4 and 5.8° C by the year 2100. This range is shown graphically in Figures 5.2 and 5.3;

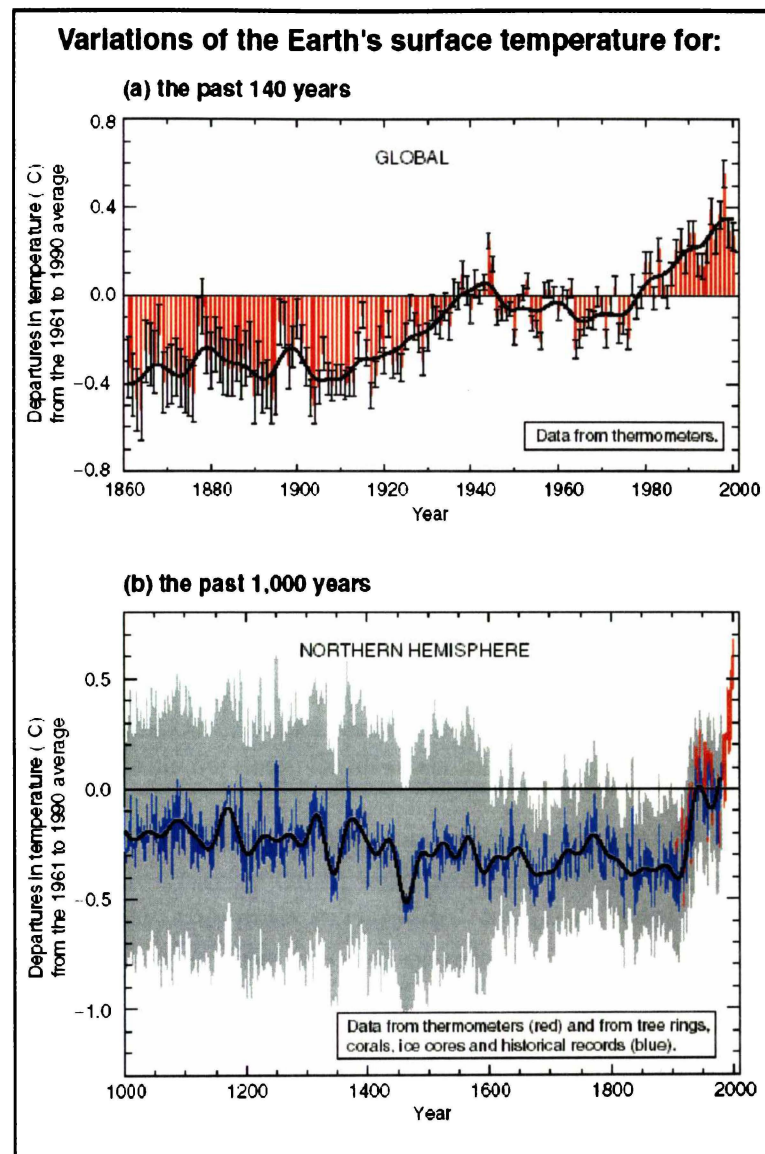


Figure 5.1: Variations of the Earth's surface temperature over the last 140 years and the last millennium. (a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line). The uncertainties in the annual data are indicated by the thin whisker bars (95% C.I.). Over the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by $0.6 \pm 0.2^\circ \text{C}$. (b) This graph shows for the northern hemisphere the annual (blue curve) and 50 year average temperature departures from the 1961 to 1990 average for the last 1000 years. This data has been 'reconstructed' from "proxy" data calibrated against thermometer data. The 95% confidence range in the annual data is represented by the grey region. Despite the large uncertainties associated with this data which increases over time from present the record shows that the rate and duration of warming over the 20th century has been much greater than in any other century. Similarly it is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium (Source: IPCC 2001b).

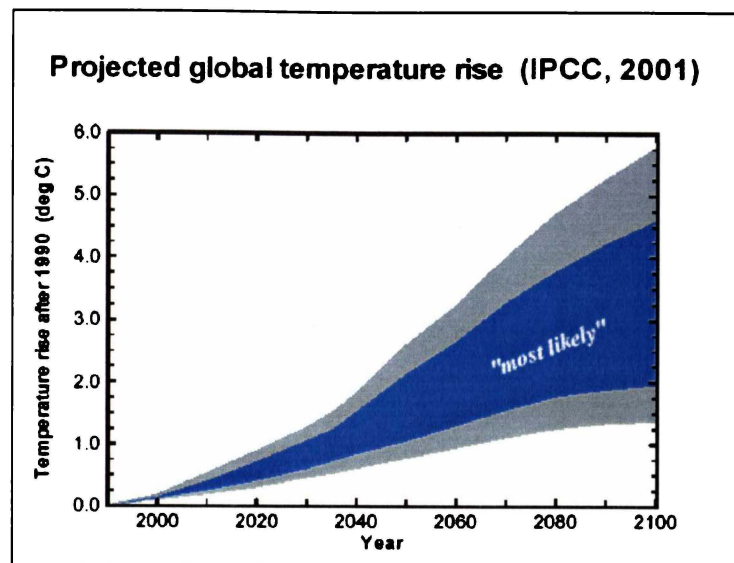


Figure 5.2: IPCC (2001b) global temperature projections. This figure shows global mean air temperature increase sourced from Bell et al. (2002) as generalised temperature trends for the period 1990 to 2100. The most likely zone (blue) shows the range of the average of seven ocean climate model simulations for 35 socio-economic emission scenarios. The grey shaded regions show the range for all seven models for all 35 scenarios.

- as a result of this atmospheric warming, worldwide mean sea level is expected to change due principally to either heat absorption and consequential thermal expansion and/or total mass increases through ice melt. The amount of relative sea level rise will depend largely of regional and local tectonic conditions and isostatic changes. However IPCC modelling based on a full set of 6 illustrative climate scenarios (IPCC, 2001b) indicates that global mean sea level is projected to rise by between 0.09 and 0.88 m between 1990 and 2100 (see Figures 5.3 and 5.4). The central value is 0.48 m which IPCC (2001b) says corresponds to an average rate of about two to four times the observed rate over the 20th century. If the scenario is restricted to IS92a (i.e. business as usual emission scenario) utilising a range of AOGCMs then the range lies between 0.11 to 0.77 m which reflects the systematic uncertainty associated with the modelling. The main contributions to this are:
 - thermal expansion of 0.11 to 0.43 m;
 - glacier contributions of 0.01 to 0.23 m;
 - Greenland contribution of -0.02 to 0.09 m; and an
 - Antarctica contribution of -0.17 to 0.02 m.

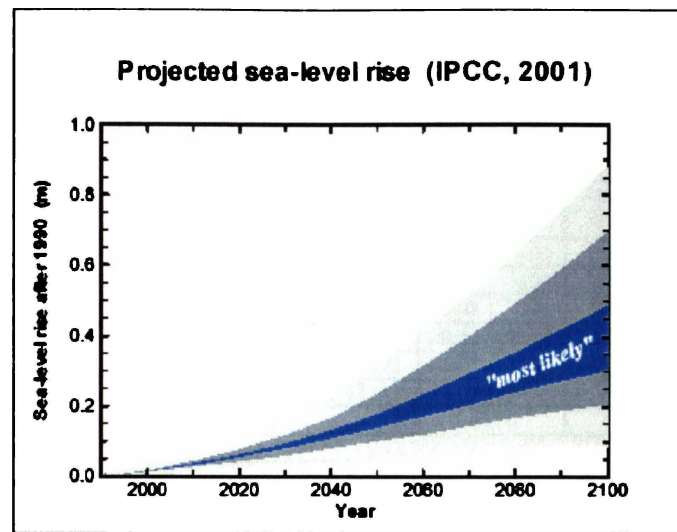


Figure 5.3: These figures show the global mean sea level rise for the period 1990-2100 corresponding to the projected temperature increases documented in Figure 5.2. (a) Shows the most likely global sea level rise is shown as a range shaded dark blue and is again based on a range of average values obtained from 35 socio-economic scenarios (see Figure 5.2). Visual interpretation of this graph indicates a mid range value of 0.4 m with a range of approximately ± 0.2 m (Bell et al., 2002). The outer light grey zone includes model results with an allowance made for uncertainties in land-ice changes, permafrost changes and sediment deposition, but excludes any allowance for changes in the Antarctic Ice Sheet.

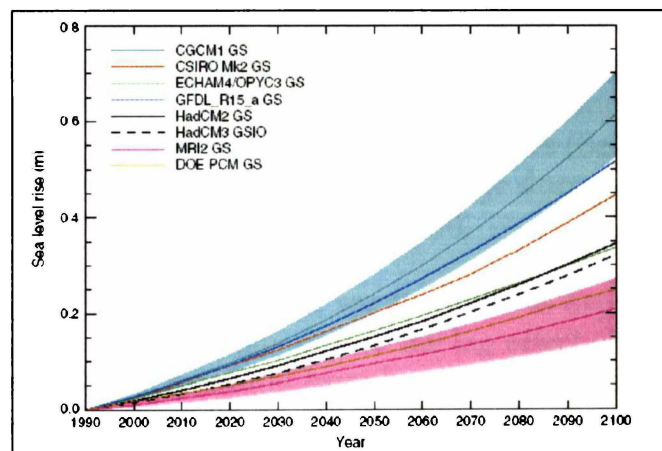


Figure 5.4: This figure shows the global average sea level rise for the period 1990 to 2100 for the IS92a (the so called 'business as usual scenario') including the direct effect of sulphate aerosols. Thermal expansion and land ice changes were calculated from the AOGCM experiments, and contributions from changes in permafrost, the effect of sediment deposition and the long-term adjustment of the ice sheets to past climate change were added (IPCC, 2001b). The colour shading indicates the uncertainties for predictions obtained for the two models predicting the least and greatest changes and these represent uncertainty associated with land-ice changes, permafrost changes and sediment deposition. Uncertainties associated with other models are shown in Table 5.1 below (Source: IPCC, 2001b)

Experiment	Sea level rise (m) 1990 to 2100									
	Expansion		Glaciers		Greenland		Antarctica ^a		Sum ^b	
	min	max	min	max	min	max	min	max	min	max
CGCM1 GS	0.43		0.03	0.23	0.00	0.07	-0.07	0.02	0.45	0.77
CSIRO Mk2 GS	0.33		0.02	0.22	-0.01	0.08	-0.12	-0.04	0.29	0.60
ECHAM4/OPYC3 GS	0.30		0.02	0.18	-0.02	0.03	-0.17	-0.06	0.19	0.48
GFDL_R15_a GS	0.38		0.02	0.19	-0.01	0.09	-0.09	-0.01	0.37	0.67
HadCM2 GS	0.23		0.02	0.17	-0.01	0.05	-0.09	0.00	0.21	0.48
HadCM3 GSIO	0.24		0.02	0.18	0.00	0.05	-0.13	-0.03	0.18	0.46
MRI2 GS	0.11		0.01	0.11	0.00	0.03	-0.04	0.00	0.11	0.31
DOE PCM GS	0.19		0.01	0.13	-0.01	0.06	-0.13	-0.04	0.12	0.37
Range	0.11	0.43	0.01	0.23	-0.02	0.09	-0.17	0.02	0.11	0.77
Central value	0.27		0.12		+0.04		-0.08		0.44	
SAR	Best estimate		0.28		0.16		+0.06		-0.01	
7.5.2.4	Range								0.20	0.86

Table 5.1: Sea level rise 1990 to 2100 due to climate change derived from AOGCM experiments following the IS92a scenario, including the direct effect of sulphate aerosols. For comparison the projection of the Second Assessment Report (SAR) (Warrick et al., 1996) is also included. IPCC (2001b) note that the minimum of the sum of the components is not identical with the sum of the of the minima because the smallest values of the components do not all come from the same AOGCM, and because for each model the land ice uncertainties have been combined in quadrature; similarly for maxima, which also contain non-zero contributions from smaller terms (Source: IPCC, 2001b).

Hannah (1988, 1990) has analysed sea level records (see also 2.3) and has described a linear increase of $+1.7 \text{ mm yr}^{-1}$ (range 1.3 to 2.3 mm yr^{-1}) in mean sea level over the period 1900-1988 from tide gauge information obtained from gauges located at the countries four main ports of Auckland, Wellington, Lyttelton and Port Chalmers (Bell et al., 1999). This lies within the historical annual mean and range documented by the IPCC of $+1.8 \text{ mm}$ and $1\text{-}2.5 \text{ mm yr}^{-1}$ (Bell et al., 1999).

As indicated in Figures 5.3 and 5.4, sea level rise is expected to accelerate over the next century principally due to the lag effect observed in thermal expansion of the oceans resulting from heat transfer from the atmosphere. As a consequence eustatic sea level is anticipated to continue to rise over the next few hundred years to millennia irrespective of the stabilisation of greenhouse gas emissions (IPCC, 2001b).

The IPCC Third Assessment Reports (2001) indicate both global and regional impacts from the documented increase in atmospheric temperatures and sea level rise. Regional variations are likely to be substantial although effects in the case of New Zealand are likely to be significant (Bell et al., 2001). As pointed out by Bell et al. (2001), "The processes of translating IPCC global predictions to likely regional climate and coastal responses is a difficult technical and socio-economic exercise." The process of translation involved the running of more detailed climate

models at regional scales using statistical downscaling techniques to provide the detailed scenario results.

This work was carried out principally by the National Institute of Water and Atmospheric Research (NIWA) and is described in MfE (2001) and more generally in Bell *et al.* (2001). It involved the use of two emission scenarios and global general circulation models (GCMs). The downscaling was then interpreted locally to take into account factors such as historical trends and topography. No specific details are provided in the literature associated with this work however it is presumed that the methodology employed generally follows that described in Chapter 10 of IPCC (2001b). Additionally it is presumed that some of the systematic problems associated with empirical-statistical downscaling documented in IPCC (2001b) such as requirements for long and homogenous data series spanning the range of observed variance over time, and presumptions that current linkages will prevail under different climate conditions apply in this instance.

Irrespective, the work done by the Ministry for the Environment (MfE, 2001; Bell *et al.*, 2001), Bell *et al.* (1999) and IPCC (2001a) represents the only relevant work of its type concerning sea level change projections available for New Zealand and as a consequence the climate scenarios and sea level rise assessments have been generally adopted as the basis for the sea level rise investigations described here.

Bell *et al.* (1999) note the IPCC (1995) projections for “best estimate” sea level rises for three greenhouse emission scenarios. These values are shown in Table 5.2 for the IS92 scenarios adopting low, mid and high ice melt allowances (IPCC, 1994).

Scenario	Climate factors	2050	2100
IS92e/high	High ice melt + 4.5°C climate sensitivity	39 cm	94 cm
IS91a/mid	Moderate ice melt +2.5°C climate sensitivity	20 cm	49 cm
IS92c/low	Low ice melt + 1.5°C climate sensitivity	7 cm	13 cm

Table 5.2: IPCC projections for sea level rise for the years 2050 and 2100 for three different greenhouse gas emission scenarios (Source: Bell *et al.*, 1999).

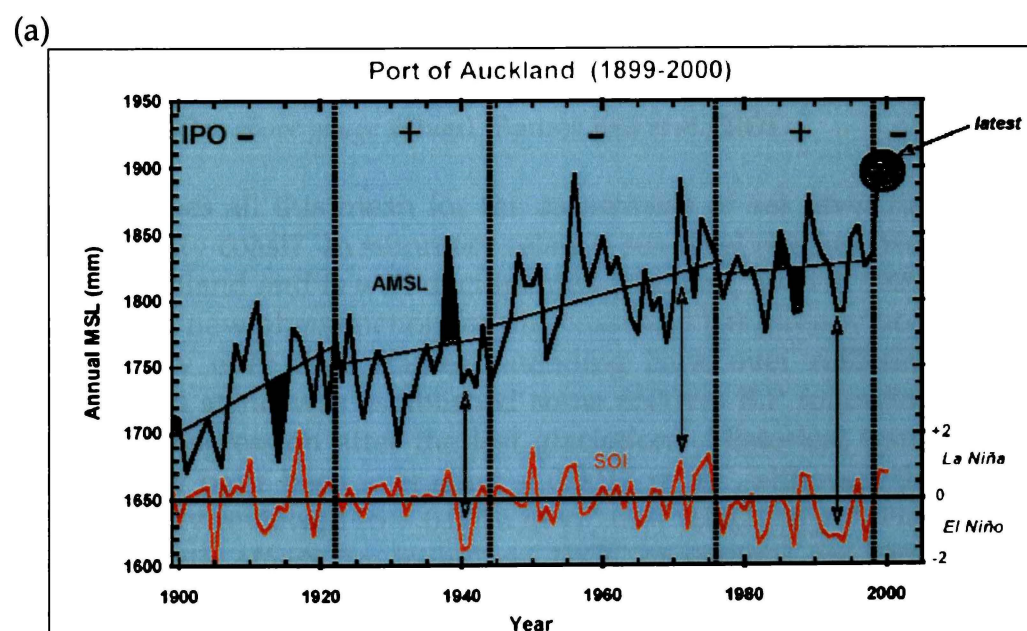
They identify that while the projections identify an acceleration of sea level rise over the 21st century with 3.6 mm yr⁻¹ up to 2050 and 4.7 mm yr⁻¹ up to 2100, the information derived from New Zealand tide gauges

currently show no evidence of this (Bell *et al.*, 1999). However as already discussed it is expected that rises in sea level will lag behind temperature increases due to the complexity of the heat transfer mechanisms involved and the thermal properties of the ocean, compared to the more reactive nature of the atmosphere.

Bell *et al.* (2001) note that global climate models may produce different results from those developed using regional modelling due principally to the extra layer of complexity introduced by local terrain and the limited spatial resolution. As a consequence the use of scenarios allows the evaluation of a range of plausible future changes (Bell *et al.*, 2001).

In summary Bell *et al.*'s work concludes that if greenhouse emissions continue to increase that, "projected sea level-rise around New Zealand is expected to match the global projections of 0.25 to 0.36 m by 2080, except in areas where significant vertical landmass movements exaggerate or mitigate the absolute rise in sea level." It also concludes that there may be a dominance of El Nino conditions over the country resulting from a more 'El Nino' like mean state of the tropical Pacific which is also reflected in some of the result obtained from the AOGCMs (IPCC 2001a & b). If this is true then such effects may act to counter or occasionally reinforce the climate impacts (including sea level changes and cycles around the New Zealand coast) associated with the Interdecadal Pacific Oscillation (IPO) (Goring *et al.*, 1999; Bell *et al.*, 1999, Smith and Benson, 2000).

Figure 5.5(a) below shows both historical sea level rise data obtained from the Auckland tide gauge together with superimposed ENSO and IPO cycles while Figure 5.5(b) splices the IPCC (2001a) scenarios onto the current sea level trends (Bell *et al.*, 2001).



(b)

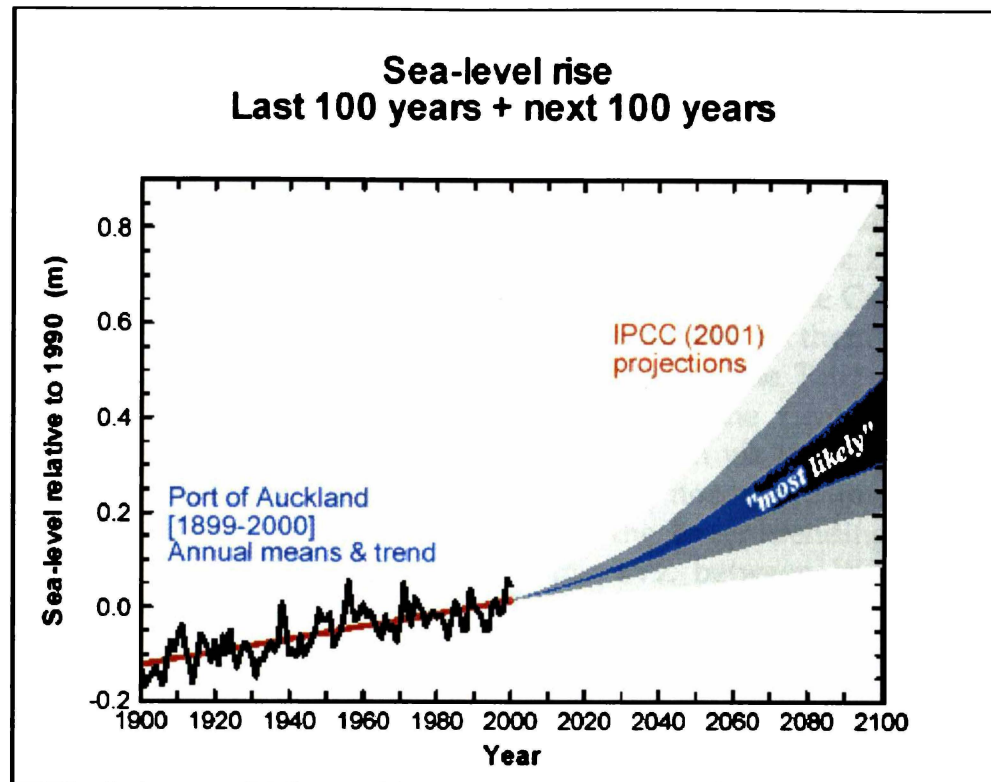


Figure 5.5: (a) shows the annual mean sea-level (amsl) for the Port of Auckland since 1899 and the annual mean Southern Oscillation Index (SOI). The transitions between phases of the Interdecadal Pacific Oscillation (IPO) are marked by the vertical dotted lines. During El Nino events (SOI is negative), sea level is lower than normal, and vice versa for La Nina events (see arrows). During the negative phase of the longer 20-30 year IPO episodes, sea level rises more steeply compared with episodes when IPO is positive; (b) shows the relative sea level trend for Auckland since 1899 and the annual variability in mean sea level (Hannah, 1990; Bell et al., 2001) is spliced with the predicted IPCC (2001) projections in "global" sea level rise up to 2100. Note sea level has been plotted relative to the 1990 values (which for Auckland is 1.840 m above gauge datum). Source Bell et al., 2001.

So what does all this mean for the assessment of sea level rise along the Bay of Plenty coast? In summary relative sea level rise has been occurring in New Zealand and is well documented (Hannah, 1988 & 1990). Sea level rise is not a new phenomenon for this coast and has already been occurring dynamically over time frames extending back over millennia to when relative still stand was established some 6500yrs B.P following the major marine transgression after the last glaciation. Historical trends over the last century have been averaging $+ 0.0017 \text{ m yr}^{-1}$, although this has been subsequently reviewed to $+ 0.0016 \text{ m yr}^{-1}$ or $+ 0.0021 \text{ m yr}^{-1}$ (Hannah, 2004) when isostatic effects are included. IPCC projections are backed by well founded scientific investigation and generally predict sea level rises in the order of 0.49 m (best estimate) by 2100 with a range of between 0.1 and 0.9

m. Consequently these figures will be used to determine the coastal offset required to accommodate the anticipated coastal transgression.

The investigations described in Chapter 2 indicate that the BoP has generally been tectonically stable over the last 5-6000 years although there are some areas that are obviously subject to ongoing deformation. The most significant of these is the Whakatane Graben (Nairn and Beanland (1989) which is an associated feature of the Taupo Volcanic Zone (TVZ). As already noted the TVZ extends some 250 km across the Central North Island (Nairn and Beanland, 1989) and is interpreted by them as a < 1Ma volcanic arc and ensialic marginal basin related to the Taupo-Hikurangi subduction system. The 20 km wide Whakatane Graben has been physically linked to the Taupo-Rotorua depression via the Haroharo vent zone and its associated faulting which extends northward to merge with the western margin of the Graben and to the linear trending volcanoes delineating the south east margin of the TVZ between Waiotapu and Kawerau (Nairn and Beanland, 1989).

The Graben represents part of a zone of crustal extension and subsidence where horizontal extension and subsidence amounts to secular rates of 7 mm yr⁻¹ and 0.4 to 2 mm yr⁻¹ respectively (Nairn and Beanland, 1989; Beanland and Berryman, 1992). Subsidence is also noted at other sites by Wigley (1990) at eastern Papamoa (0.25 mm yr⁻¹) and 2-4 mm yr⁻¹ in the Aongatete – Bowentown area west of Tauranga by Schofield (1968), Cole (1978), Abrahamson (1987) and Briggs *et al.* (1996). Despite this subsidence coastal sedimentation and progradation has continued over the Holocene throughout much of the BoP. The effects of this are discussed further below.

5.3 Computation of Sea Level Rise from EBPs – Theoretical Concepts and derivations

The forces which affect equilibrium of the nearshore will affect the beach profile in a manner that tends to restore equilibrium (Dean and Maurmeyer, 1984). That is the basic tenet of the Equilibrium beach concept. These forces act over varying time scales and include mean water level and wave characteristics, forces acting to create longshore sediment transport, and in some cases anthropogenic forcing caused by activities such as sand mining. The equilibrium profile models discussed here are based on normative concepts of wave energy dissipation in a two dimensional setting (Dean, 1977).

As pointed out by Dean and Maurmeyer (1984) these models include both kinematic and dynamic elements. The kinematic requires conservation of mass or sediment while the dynamic elements concern beach shape and associated forces. Usually the kinematic elements of a model are exact

while the dynamic part is empirical, approximate and based on observations or intuitive concepts (Dean and Maurmeyer, 1984).

In the case of a shoreline change model the kinematic elements simply ensures the conservation of sediment volume. For example the rate of change in volume of sand volume in a beach profile may be expressed as,

$$\frac{\partial V}{\partial t} = - \left(\frac{\partial Q_{sx}}{\partial x} + Q_{syo} - Q_{sys} \right) \quad (5.1)$$

where ∂V represents the change in sand volume over time (∂t), and the various other variables represent the quantity of sediment inputs and outputs (or sediment transport components) to the representative profile section as shown in Figure 5.6. The transport components (i.e. inputs and outputs) could include wind-blown sediment to the dunes, or loss of sediment due to littoral drift or diabathic exchange resulting from storm effects.

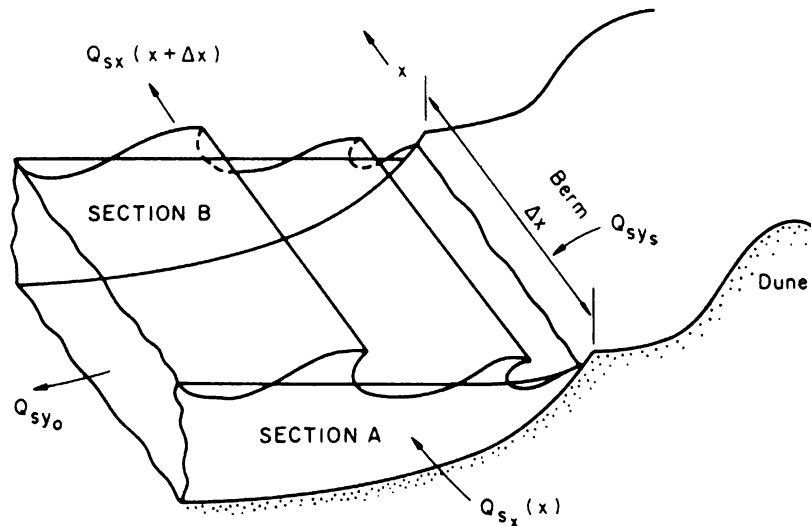


Figure 5.6: Volumetric changes through the gradients in longshore transport
(Source: Dean and Maurmeyer, 1984).

As Dean and Maurmeyer point out equation 5.1 is exact. Should $Q_{sys} = Q_{syo} = 0$ (i.e. diabathic exchange is negligible or in equilibrium) then in order to conserve sediment the profile response is translated perpendicular to the shoreline without change in form out to a nominated boundary or closure depth. This case is represented by,

$$\Delta V = \Delta y(B + h_*) \quad (5.2)$$

where ΔV is the change in volume resulting from additional sediment input to the profile, Δy is the resultant profile shift, B is the berm height,

and h_* is the closure depth. Converting this to profile shift rates over time Equation 5.2 then becomes,

$$\frac{\partial y}{\partial t} = -\frac{1}{B + h_*} \left(\frac{\partial Q_{sx}}{\partial x} \right). \quad (5.3)$$

An example of a dynamic element of the model is represented by the effects sea level rise on beach profiles. In this case the so called Bruun Rule is considered.

Under this rule Bruun (1954) considered that the shoreline should retreat (R) under the forcing action of a rise in sea level (S). The assumptions here include a requirement for the profile shape to remain constant relative to the actual sea level, that there is a limit to the active profile h_* , and that the gradient in longshore sediment transport $\partial Q_{sx} / \partial x$ is not important (Dean and Maurmeyer, 1984). Using equation 5.2 and applying these assumptions equation 5.2 becomes (see Figure 5.7 (a)),

$$\Delta V = (B + h_*)R. \quad (5.4)$$

An alternative form of this equation based on the geometrics described Figure 5.7 (b) gives,

$$\Delta V = LS \quad (5.5)$$

Equating equations 5.4 and 5.5 provides a determination of the profile shift R

$$R = \frac{L}{(B + h_*)} S \quad (5.6)$$

or

$$R = \frac{1}{\tan \theta} S \quad (5.7)$$

where $\tan \theta$ is the average slope of the beach over the active beach width L .

In Dean (1991) a different approach to the same problem (with a similar outcome) is described whereby beach response to sea level rise is derived from the familiar Dean (1977) profile of equilibrium $h = Ay^{2/3}$ (see Chapter 3 for derivation) where h is the water depth, y is the offshore distance and A is the scale factor. Integrating this relationship across the full profile to closure depth allows the determination of profile volume both prior to and after sea level rise. To determine profile shift so as to retain

equilibrium with incoming wave energy it is assumed that beach profile volume is conserved such that $V_E = V_D$ where V_E is the sand volume eroded and V_D equals the volume sand deposited. When this requirement is combined with the Dean profile of equilibrium the following implicit equation for shoreline change is obtained (Dean, 1991).

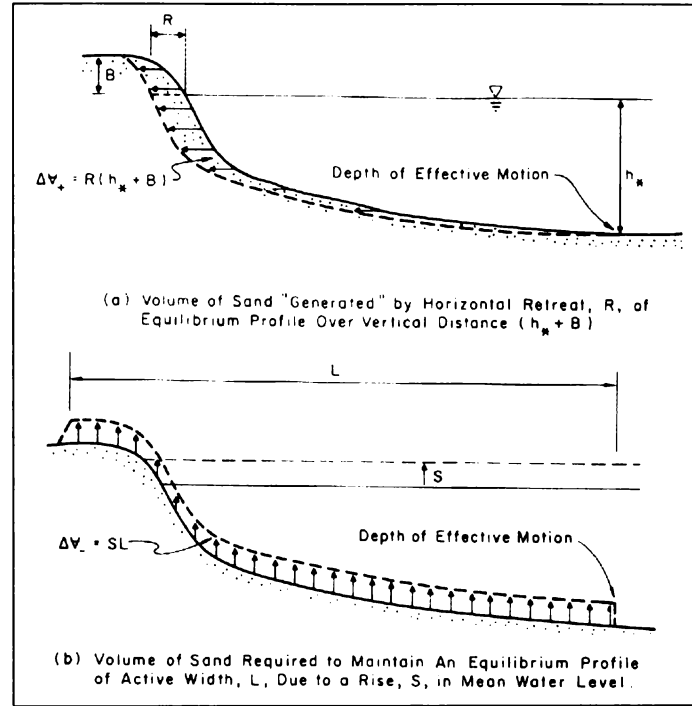


Figure 5.7: Components of sand volume balance due to sea level rise and associated profile retreat (Source: Dean and Maurmeyer 1984)

The initial profile volume (Figure 5.8) before sea level rise can be described as,

$$V_1 = \int Aw_o'^{2/3} dw + w_o' B \quad (5.8)$$

$$V_1 = \frac{3}{5} Aw_o'^{5/3} + w_o' B \quad (5.9)$$

$$V_1 = \frac{3}{5} A(w_o - \Delta y)^{5/3} + (w_o - \Delta y) B \quad (5.10)$$

where $w_o' = w_o - \Delta y$ and w_o' represents the initial surfzone width out to closure depth (or seaward limit of the active profile), w_o the final active profile width following profile adjustment, B is the beach berm height and Δy is the profile shift required to accommodate the sea level rise.

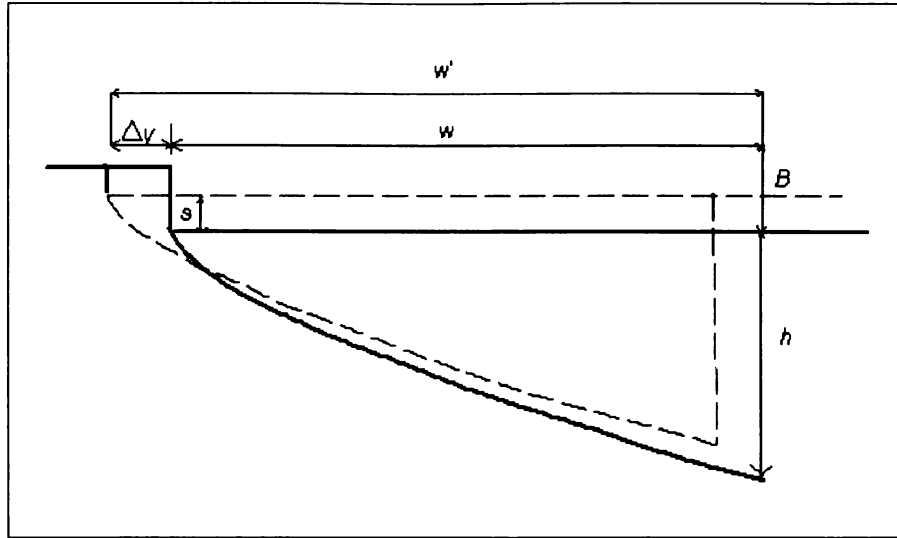


Figure 5.8: Beach profile showing Sea Level Rise and associated dimension notation used in Bruun Rule derivation.

The adjusted profile volume following sea level rise is determined by integrating the adjusted Dean profile of equilibrium as follows,

$$V_2 = \int A w_o^{2/3} + w_o (B - S) \quad (5.11)$$

$$V_2 = \frac{3}{5} A w_o + w_o (B - S) \quad (5.12)$$

where S represents the Sea Level rise. The Dean profile at the limit of the active profile may be defined as,

$$h_o = A w_o^{2/3} \quad (5.13)$$

$$A = \frac{h_o}{w_o^{2/3}} \quad (5.14)$$

Substituting equation 5.14 into equations 5.10 and 5.12 gives,

$$V_1 = \frac{3}{5} \frac{h_o}{w_o^{2/3}} (w_o - \Delta y)^{5/3} + (w_o - \Delta y) B \quad (5.14)$$

$$V_2 = \frac{3}{5} \frac{h_o}{w_o^{2/3}} w_o^{5/3} + w_o (B - S) \quad (5.15)$$

As discussed $V_1 = V_2$ in order to conserve sediment therefore equating and rearranging equations 5.14 and 5.15 leads to,

$$\frac{3}{5} \frac{h_o}{w_o^{2/3}} (w_o - \Delta y)^{5/3} + B w_o - B \Delta y = \frac{3}{5} h_o w_o + w_o B - w_o S \quad (5.16)$$

$$\Delta y - \frac{3}{5} \frac{h_o}{B w_o^{2/3}} (w_o - \Delta y)^{5/3} = \frac{3}{5} \frac{h_o w_o}{B} - \frac{w_o S}{B} \quad (5.17)$$

$$\Delta y + \frac{3}{5} \frac{h_o w_o}{B} \left(1 + \frac{\Delta y}{w_o}\right)^{5/3} = \frac{3}{5} \frac{h_o w_o}{B} - \frac{w_o S}{B} \quad (5.18)$$

where $w_o = \left(\frac{H_b}{\kappa A}\right)^{2/3}$ and $\Delta y < 0$. Equation 5.18 can be rewritten in a non dimensional form (Dean, 1991) by carrying out the following,

$$\Delta y = -\frac{3}{5} \frac{h_o w_o}{B} \left(1 + \frac{\Delta y}{w_o}\right)^{5/3} + \frac{3}{5} \frac{h_o w_o}{B} - \frac{w_o S}{B} \quad (5.19)$$

and substituting $\Delta y' = \frac{\Delta y}{w_o}$, $B' = \frac{B}{h_o}$, and $S' = \frac{S}{B}$. Equation 5.19 is then divided by w_o to yield Dean's (1991) non dimensional form for determining the profile shift due to sea level rise, this being

$$\Delta y' = \frac{3}{5B'} \left(1 - (1 + \Delta y')^{5/3}\right) - S' \quad (5.20)$$

or

$$\Delta y' - \frac{3}{5B'} \left(1 - (1 + \Delta y')^{5/3}\right) + S' = 0 \quad (5.21)$$

Equation 5.21 requires iterative solution however graphical solutions have been calculated as shown in Figure 5.8 (Dean, 1991). For relatively small values of $\Delta y'$ this can be simplified into a dimensional form to yield,

$$\Delta y = -\frac{w_o S}{h + B} \quad (5.22)$$

which of course is the Bruun Rule as derived previously. This agrees with recent kinematic assessments by Cowell *et al.* (2003), Stive (2004) and Zhang *et al.* (2004) who derive the Bruun Rule directly from the three dimensional kinematics as described by Dean and Maurmeyer (1984). In this derivation Stive (2004) and Cowell *et al.* (2003) relate sediment balances in the upper shoreface back to the Bruun Rule (Bruun, 1962). Following Cowell *et al.*'s derivation whereby sediment-volume conservation for profile kinematics requires that

$$\frac{\partial h}{\partial t} + c_p \frac{\partial h}{\partial x} = 0 \quad (5.23)$$

where h is the depth from mean sea level to a concave up profile with a depth limit of h , and a corresponding profile length L , in which x is the

distance from shore, and c_p is the horizontal translation rate of the shoreline. Equation 5.23 may be rewritten in the following form substituting for h where $h=MSL-z_b$,

$$\frac{\partial z_b}{\partial t} + c_p \frac{\partial z_b}{\partial x} = \frac{\partial MSL}{\partial t} \quad (5.24)$$

A key assumption here is that “the upper shoreface ... to a first approximation is form invariant relative to mean sea level over time periods greater than 1 year based on work by Nicholls et al. (1998)” (Cowell et al., 2003; Stive, 2004).

Based on gross coastal kinematics (Dean & Maurmeyer, 1984; Cowell et al., 2003, Stive, 2004) the sediment-transport balance may be written as,

$$\frac{\partial z_b}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + s = 0 \quad (5.25)$$

where $q_{x,y}$ are the cross shore and alongshore sediment transport, and s is a local source or sink. Equations 5.23 to 5.24 can be combined to provide a relationship for the horizontal translation rate c_p ,

$$c_p = -\frac{\partial MSL}{\partial t} \left(\frac{\partial h}{\partial x} \right)^{-1} - \frac{\partial q_x}{\partial h} - \frac{\partial q_y}{\partial y} \left(\frac{\partial h}{\partial x} \right)^{-1} - s \left(\frac{\partial h}{\partial x} \right)^{-1} \quad (5.26)$$

Integrating this with respect to the cross shore over the profile length L yields,

$$c_p h_* = -\frac{\partial MSL}{\partial t} L_* - (q_{x,sea} - q_{x,dune}) - \frac{\partial Q_y}{\partial y} - s \quad (5.27)$$

In the absence of littoral transport gradients and other sources or sinks which act in the sense of gross losses to the offshore and onshore system then equation 5.27 can be rewritten to give the two dimensional Bruun rule with the negative sign indicating a transgression of the profile shoreward with increasing sea levels.

$$c_p = -\frac{\partial MSL}{\partial t} \left(\frac{L_*}{h_*} \right) \quad (5.28)$$

Zhang et al. (2004) address the uncertainties associated with the definition of terms in the Bruun Rule. They confirmed the general applicability of the formula deriving it from the assumption that sediment eroded from the upper beach is equal to that deposited on the nearshore bottom with no net sediment exchange occurring between the active beach profile and

the outer shoreface. While this is similar to the approach described previously using the Dean formula, this derivation has been carried out independent of any profile defining shape function such as Dean's power curve, $y=Ax^b$.

This assumption can be expressed in the following equation with $f(x)$ and $f'(x)$ representing the initial and subsequent profiles following sea level rise.

$$\begin{aligned} & \int_{x_1}^{x_2} [g'(x) - f'(x)] dx + \int_{x_2}^{x_3} [f(x) - f'(x)] dx \\ &= \int_{x_3}^{x_4} [f'(x) - f(x)] dx + \int_{x_4}^{x_5} [g(x) - f(x)] dx \end{aligned} \quad (5.29)$$

Referring to Figure 5.9 where s is shoreline recession, D_b is the elevation of the shoreline above MSL (such as berm height), D_c is the depth of closure, a is the rise in sea level, and l is the distance offshore of the closure depth (or active profile width), it can be seen that $f'(x) = f(x + s) + a$. Also assuming that the function $g(x)$ and $g'(x)$ follow the same function, it follows that $g'(x) = g(x + l) + (D_b + D_c)$.

Substituting these equations into Equation 5.29, integrating with respect to constants and summing the integral terms provide the following formulation for deriving the profile shift:

$$\begin{aligned} & \int_{x_1}^{x_2} g(x + l) dx + \int_{x_2}^{x_3} f(x) dx + (D_b + D_c)(x_2 - x_1) = \\ & \int_{x_1}^{x_4} f(x + s) dx + \int_{x_4}^{x_5} g(x) dx + a(x_4 - x_1). \end{aligned} \quad (5.30)$$

Since $x_4 - x_1 = x_5 - x_2 = l$ and $x_2 - x_1 = x_5 - x_4 = s$ Equation 5.30 can be evolved following substitution of terms and consideration of the integrals involved to obtain the following,

$$s(D_b + D_c) = al \quad \text{or} \quad (5.31)$$

$$s = \frac{al}{D_b + D_c} \quad (5.32)$$

which of course is the Bruun Rule.

The purpose of carrying out this analysis is to demonstrate the Bruun Rule's general robustness as a model for determining sea level rise, its equivalency in terms of equilibrium beach theory and therefore its relevance in determining the sea level rise calculations to follow; while also acknowledging the required assumptions concerning negligible

littoral drift, the dominance of diabathic exchange from within the upper shoreface, and onshore contributions from dune erosion as a means of simplifying the information requirements. However the derivation of equation 5.28 acts to highlight the importance of these contributions in terms of mitigating, offsetting or in some cases reversing profile transgression caused by sea level rise (Cowell & Thom, 1994; Roy *et al.* 1994; Cowell *et al.*, 2003; Stive (2004); Zhang *et al* (2004))

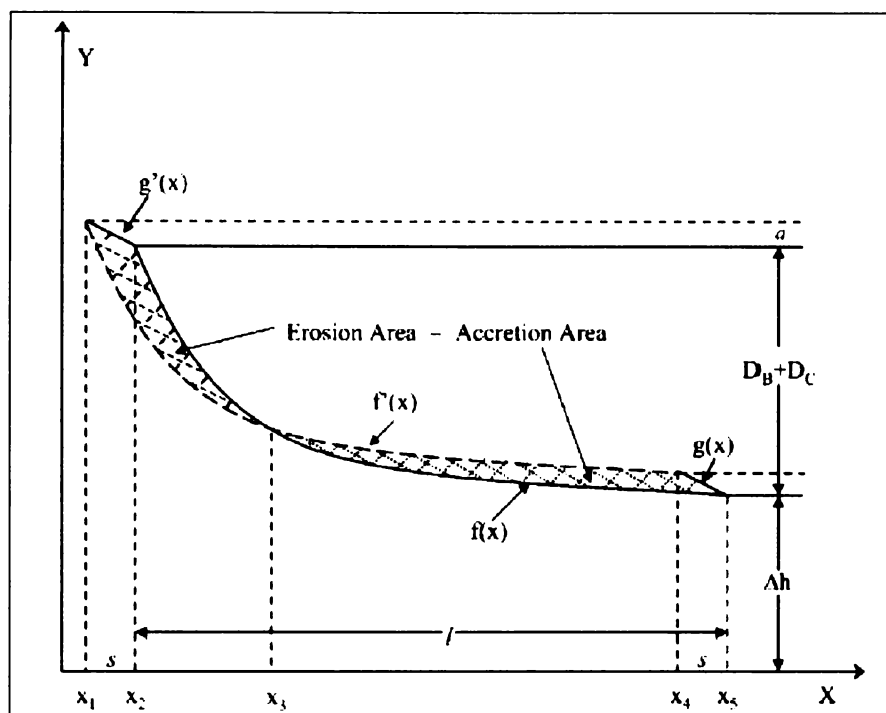


Figure 5.9: Active cross-shore beach profile geometry for derivation of the two-dimensional Bruun Rule of beach erosion due to sea level rise (Source : Zhang *et al.*, 2004)

5.4 Determination of Sea Level Rise Impacts for the Bay of Plenty

The theoretical analysis described above confirms the appropriateness of the Bruun Rule for determining the two dimensional effects of sea level rise. This section describes the application of the rule and the results obtained for the forty eight profiles contained in the Bay of Plenty dataset. In order to achieve this, a routine based on Bruun's Rule and the Dean profile of equilibrium was written for use in MATLAB.

The required inputs included sea level rise, berm height, and the depth limit of the active profile (or closure depth). The accepted scenario used as input is based on the work described here with a uniform closure depth of 6 meters below mean sea level and a sea level rise limit S at year 2100 of 0.5 m (0.49 m rounded) based on the mid range best estimate of IPCC

(2001), while the offshore distance of the active profile is calculated individually for each profile directly from the profile data.

The remaining variable in equation 5.6 is the berm height (B). Komar (1998) defines the berm as the near horizontal portion of the exposed beach formed by sediment brought ashore during low wave conditions. Komar notes that the berm elevation is largely determined by wave runup and consequently that the run up distance in part is dependent on the wave height. Komar (1998: p.290) notes Takeda and Sunamura's relationship for bar elevation B_h as,

$$B_h = 0.125 H_b^{5/8} (gT^2)^{3/8} \quad (5.33)$$

in which H_b is the breaking wave height and T is the wave period. This relationship is based on laboratory and field measurements and is shown graphically in Figure 5.10.

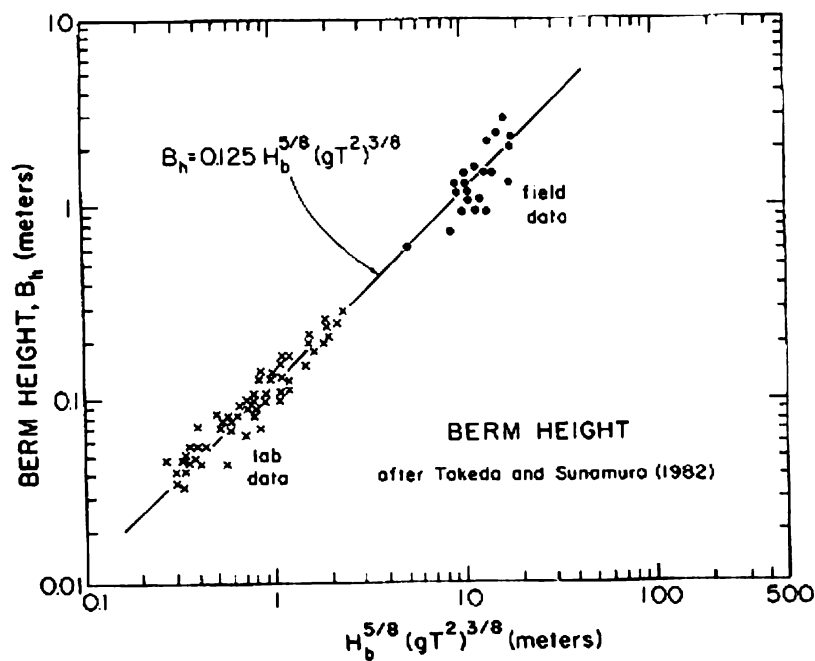


Figure 5.10: Measurements of berm elevations that confirm equation 5.33, based on considerations of wave run-up levels (Source Komar, 1998 after Sunamura)

The field data were obtained from beaches located along the Japanese Pacific coast where the mean tidal range is approximately 1 m, berm height was measured relative to mean sea level, and sediment sizes ranged from 0.2 to 1.3 mm without showing differences in berm elevation, which demonstrate general equivalency with the BoP beaches (see Chapter 2).

As a consequence this relationship was used to determine a generic berm height for use in the sea level rise analysis, which was subsequently checked by inspection of the plotted profiles to determine its appropriateness. The input data was taken from the wave information described generally in Chapter 2. To initiate the calculations de Lange's (1991) mean significant wave height of 0.5 m and a period of 10 s was used from wave data obtained from 'A' beacon at the Tauranga Entrance.

A sensitivity analysis was then carried out to determine a likely range of berm heights resulting from a range of wave heights (see Table 5.3). To do this deep water wave buoy data from Macky *et al.* (1996) and data from de Lange (1991 & 1993) was reviewed which indicated typical significant wave heights varying from a height of 0.8 m and a period (T) of 6 s to maximum significant wave heights during storms of 4.3 m and 9.7 s for the Katikati data (Macky *et al.*, 1996) and mean significant wave heights 0.5 m and periods of 9 s to a maximum significant wave height of 3.9 m for the data recorded at the Tauranga entrance (de Lange, 1991).

Where appropriate deep water wave heights have been converted to breaking wave height using the formula of Komar and Gaughan (see Equation 5.24) as described in Komar (1998, p216).

$$H_b = 0.39g^{1/5} (TH_\infty^2)^{2/5} \quad (5.34)$$

The analysis indicated that the likely berm height above mean sea level would be approximately 1.0 to 1.5 m above mean sea level under typical wave conditions, with berm heights ranging up to approximately 4.5m or higher under storm conditions.

$H_s (m)$	$T (s)$	$H_b (m)$	$B_s (m)$
0.5	10	0.89	1.5
0.44	10.9	0.83	1.6
0.48	7.3	0.75	1.1
	6.0	0.8	1.0
4.3	9.7	4.91	4.4

Table 5.3: Sample of various reported wave height data for the Bay of Plenty together with calculated breaking wave height and berm height relative to MSL.

Inspection of the profile plots from the BoP dataset confirms that berms, if present or detectable, generally lie in the region of 1 to 2 m above mean sea level thus confirming the calculations. Reference to the Bruun Rule indicates that the sea level rise set back will be greater for lower berm heights because of the need to conserve sand volume across the profile. This intuitive assessment was confirmed by choosing a profile randomly and running the Bruun rule calculation over a range of berm heights. Consequently a 1 m berm height was used to provide the conservatism necessary when applying the approach to coastal hazard assessment.

The results of the sea level rise calculations derived from the MATLAB routine are included in Table 5.4. The output from the routine includes a sea level rise calculation, a beach equilibrium assessment as discussed in Chapter 4 and a summation of the two. The summation is required in order to take into account any existing beach disequilibrium profile adjustment which will result in short term profile relocation at time frames generally in the order of days, weeks and months before applying sea level rise calculations which will apply over multi decadal timeframes up to 2100.

Profile Shift Calculations: Sea Level Rise effect on Dean Equilibrium Beach Profile						
Closure Depth: 6 m				Sea level rise: 0.5 m		
Method: Profile averaged A, Dean model				Berm height: 1.0 m		
BOPRC #	rmsr error	Erosion/ Accretion	EBP shift (m)	Sea level rise shift (m)	Total shift (m)	Remarks
1	0.33	E	-4.00	-32.22	-36.22	
2	0.24	E	-8.28	-30.85	-39.13	
3	0.43	A	31.50	-31.53	-0.02	
4	0.28	A	5.02	-33.2	-28.18	
5	0.27	A	6.97	-33.83	-26.86	
6	0.32	E	-17.08	-32.22	-49.31	
7	0.26	E	-0.09	-32.58	-32.67	
8	0.72	A	123.55	-29.07	94.48	Ohiwa spit – ebb tidal delta
9	2.49	A	345.75	-30.58	314.9	Ohope spit – ebb tidal delta
10	0.82	A	70.95	-33.2	37.75	
11	0.36	A	25.55	-35.05	-9.49	
12	0.94	E	-17.43	-32.68	-50.11	
13	1.12	E	-40.23	-30.1	-70.33	
14	0.55	A	3.62	-28.58	-24.96	
15	1.02	E	-33.13	-29.78	-62.91	
16	0.53	E	-14.81	-27.91	-42.72	
17	1.2	E	-20.81	-29.07	-49.88	
18	0.26	A	14.16	-28.48	-14.32	
19	0.23	E	-7.47	-25.1	-32.57	
20	0.36	E	-5.18	-26.34	-31.52	
21	0.37	E	-14.83	-27.18	-42.01	
22	0.38	E	-0.34	-26.83	-27.17	
23	0.42	A	13.39	-25.53	-12.14	
24	0.38	E	-13.21	-23.59	-36.8	
25	0.41	E	-14.25	-25.69	-39.94	
26	0.46	E	-17.66	-27.86	-45.52	
27	0.61	E	-19.94	-26.46	-46.4	
28	0.98	E	-43.79	-29.07	-72.86	
29	0.58	E	-18.27	-27.91	-46.18	
30	0.98	A	39.73	-17.86	21.87	
32	0.36	E	-5.23	-23.09	-28.33	
33	1.29	E	-62.67	-29.27	-91.95	
34	0.3643	E	-1411	-33.83	-47.94	
35	0.3561	E	-18.39	-30.64	-49.03	
36	0.5486	E	-16.76	-31.87	-48.63	

Profile Shift Calculations: Sea Level Rise effect on Dean Equilibrium Beach Profile						
Closure Depth: 6 m				Sea level rise: 0.5 m		
Method: Profile averaged A, Dean model				Berm height: 1.0 m		
BOPRC #	rmsr error	Erosion/ Accretion	EBP shift (m)	Sea level rise shift (m)	Total shift (m)	Remarks
38	0.5508	E	-19.82	-31.99	-51.81	
39	0.2633	A	7.11	-30.31	-23.2	
40	0.3629	A	19.43	-24.72	-5.296	
41	0.61	A	89.22	-19.36	69.86	Ebb tidal delta – Matakana Bank
42	1.1	A	63.04	-25.98	37.06	Ebb tidal delta – Matakana Bank
43	0.76	A	56.28	-28.2	28.09	
44	0.78	A	68.58	-32.34	36.24	
45	0.63	A	55.18	-31.99	23.19	
46	1.72	A	233.42	-26.72	206.69	Ebb tidal delta – Bowentown
47	1.51	A	287.22	-23.75	263.47	Ebb tidal delta – Bowentown
48	0.17	A	3.44	-28.33	-24.89	
49	0.98	A	100.44	-33.63	66.81	
51	0.66	A	69.61	-33.2	36.41	

Table 5.4: Sea level rise calculations for BoP profiles incorporating Dean Equilibrium assessment (see Chapter 4). Total profile shift calculated as sum of existing profile disequilibrium calculated using the Dean profile with profile averaged Scale factor A and sea level rise calculation using the Bruun Rule. This provides for total potential profile shift excluding any allowance for the effects of storm surge events.

5.5 Discussion – Sea Level Rise and its Implications for long term Beach Management

Table 5.4 summarises the results of the application of the Bruun rule to the 48 profiles in the BoP profile dataset as a two dimensional assessment with all the limitations that this brings. That is, it does not attempt to take into account sediment dynamics external to the profile which may have significant impacts on either reinforcing or offsetting erosional and accretional patterns.

While it may be argued that there is a reasonable heuristic understanding of the BoP coastal system, current knowledge does not provide good quantifiable estimates of sediment input and distribution within the BoP sedimentary system in a manner that allows widespread morphological assessment of the adjoining beaches sufficient to generally adopt the modelling approaches suggested by Cowell and Thom (1984), Cowell *et al.* (2003), and Stive (2004). That information simply does not exist or at best only partly exists for Matata, Pukehina and Ohope as described in the work of Phizacklea (1993), Saunders (1999), and Easton (2002).

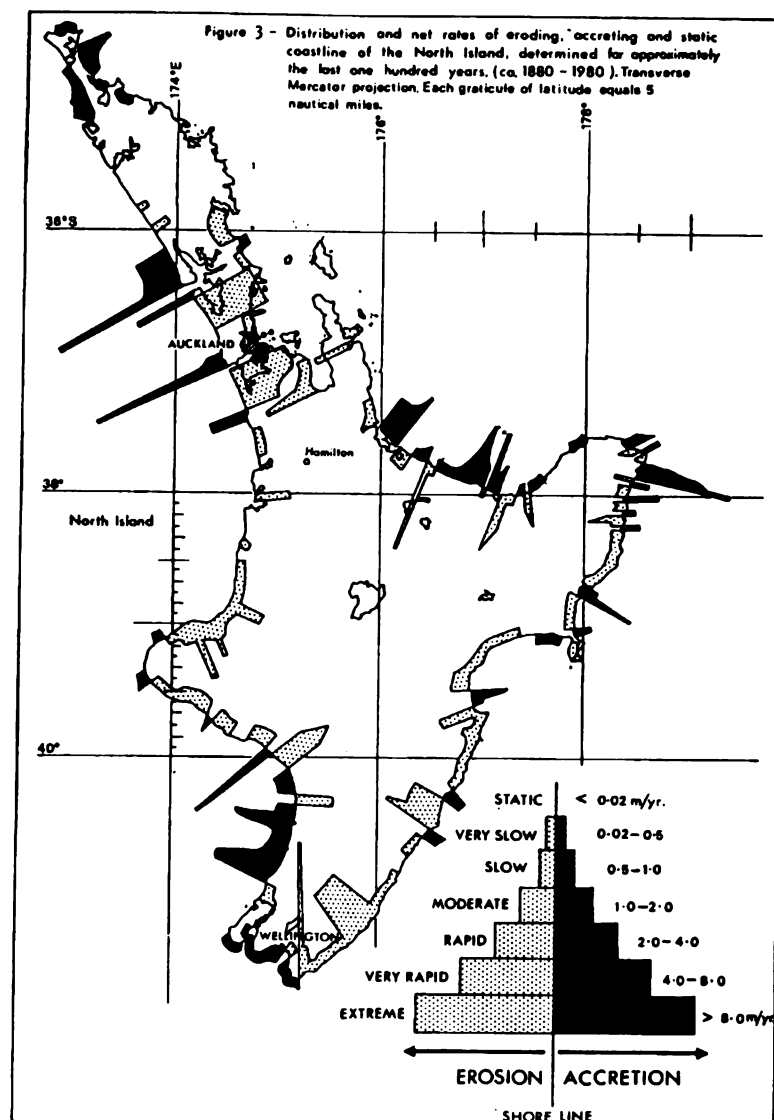
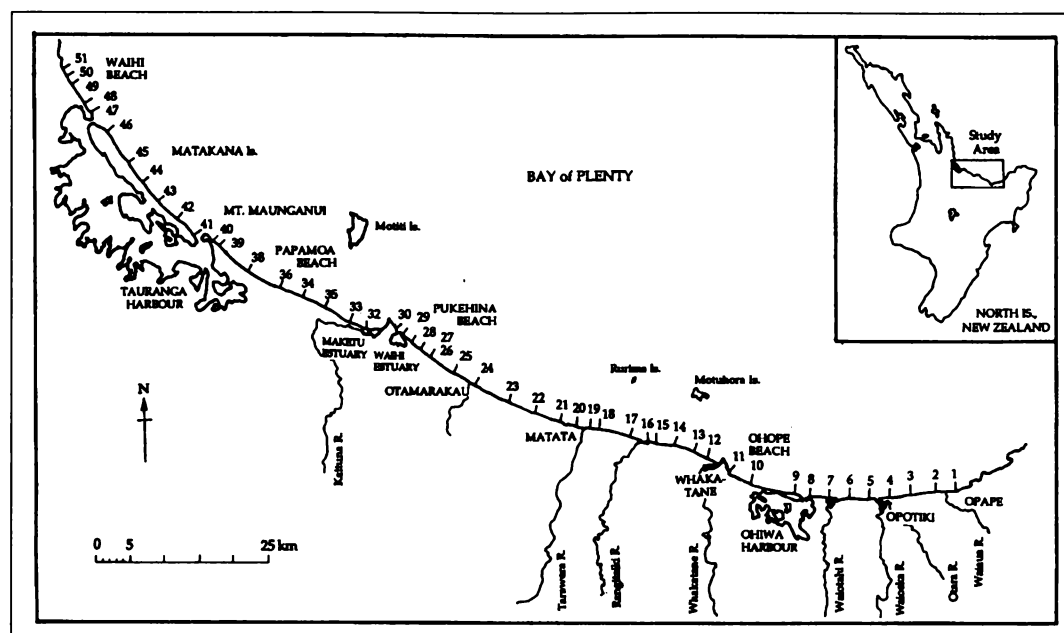


Figure 5.11: Historic rates of open-coast erosion and accretion around the North Island of New Zealand (Source Gibb, 1984).

Bell *et al.* (2001) recognised this problem when discussing Gibb's (1984) morphological analysis of historical trends of erosion and accretion around New Zealand (see Figure 5.11) suggesting that an urgent updating of this sort of analysis is required. That reassessment work has not been carried out here. Inspection of Gibb's (1984) work as it relates to the Bay of Plenty indicates widespread coastal progradation rates along the coastline varying from 0.5 m up to 4 m per annum over the last 100 years based on various sources of information including cadastral records dating from the mid 19th century, hydrographic charts dating from 1842, and aerial photographs dating from 1938. Gibb in particular notes areas of rapid erosion located around Opape in the eastern bay and in the vicinity of Pukehina and Papamoa in the central Bay of Plenty (see Figures 5.11 & 5.12). Gibb (1994) and Hodges and Deely (1997) document areas sensitive to erosion which builds on Healy *et al.* (1977) original work for the Bay of Plenty.



Cowell and Thom (1994), Cowell *et al.* (2003), Stive (2004), Zhang *et al.* (2004) identify the need to provide quantitative inputs in terms of sediment budgets for littoral drift, diabathic contributions plus sedimentary sinks, and onshore sources such as dunes in order to provide realistic predictions of future long term coastal change. The analysis carried out in Chapters 2 and 4 indicate profile changes in a two dimensional sense that are likely to occur over periods generally of days, weeks and months up to annual timeframes. Principally this is because the modelling carried out was defined in relation to the active profile affected by the surfzone that was observed at a particular instance in time.

Irrespective of this, the impacts on profile morphology due to factors acting over periods longer than annual timeframes (i.e. over decadal and interdecadal periods) are treated as large scale coastal change and this is more appropriately addressed by the coastal change documented in this chapter, i.e. Sea Level Rise. This being the case and if Cowell and Thom's (1994) thesis concerning *Large Scale Coastal Behaviour* (LSCB) is accepted then the sea level rise assessment detailed in Table 5.4 will require adjustment or further interpretation in order to accommodate long term sedimentation patterns occurring within the Bay of Plenty.

At this stage given the limitations of our current knowledge concerning sediment budgets and process in the BoP, such a task can only be carried out in a rudimentary manner. This can be demonstrated by way of examples covering areas where known long term progradation or regression has occurred or where sediment budget information is available. This is discussed as follows using the long term coastal trend data sourced from Healy *et al.* (1977), Gibb, (1984, 1994, 1997) and Hodges and Deely (1997) and geological information from Healy (1967), Pullar and Selby (1971), Nairn and Beanland (1989), Beanland and Berryman (1992), Saunders (1999), and Easton (2000).

In general terms the study area can be described as containing four distinct geomorphic units described by historical and long term coastal change behaviour (i.e. over decadal, centennial to millennial timeframes). These general states are shown in Figure 5.11 and described in Table 2.5. Starting from the eastern end of the study area at Opape, long term beach state based on the trends identified by Hodges and Deely (1997) and geologic evidence from the Holocene period (since stillstand) indicates that most of the beaches extending westward from Opape through to Ohope have been in a state of advance as evidenced by the morphologic features present (i.e. strand plains, lagoons, barrier spits and dune ridge sequences).

Likewise west of Whakatane the extensive progradational features of the Rangitaiki Plains extending through to Matata (despite tectonic down warping of the surface associated with the Whakatane Graben – see Chapter 2) confirms extensive sediment inputs into the coastal system over the last 5-6000 years. This progradation has been occurring at an average rate of 1.3 m yr^{-1} from the Tarawera eruption (1886) through to the present but ranging from 0.5 to 0.7 m yr^{-1} since the end of the post glacial marine transgression some 6000 years ago. This progradation has been episodic and strongly correlated to volcanic eruptions from Taupo and the volcanoes of the Okataina Volcanic Centre (Pullar and Selby, 1971).

West of Matata the beach morphology changes from a strand plain to a mainland beach (Roy *et al.*, 1994) reflecting a steeper offshore substrate and a reducing sediment supply. This supply decreases to such an extent

that the beach becomes long term erosional from Pikowai (Phizacklea, 1993; Gibb 1994; Hodges and Deely, 1997) through to Pukehina Beach where a steep nearshore profile and a net sediment loss (Easton, 2000) affects the overall stability of the spit (Figure 5.13).

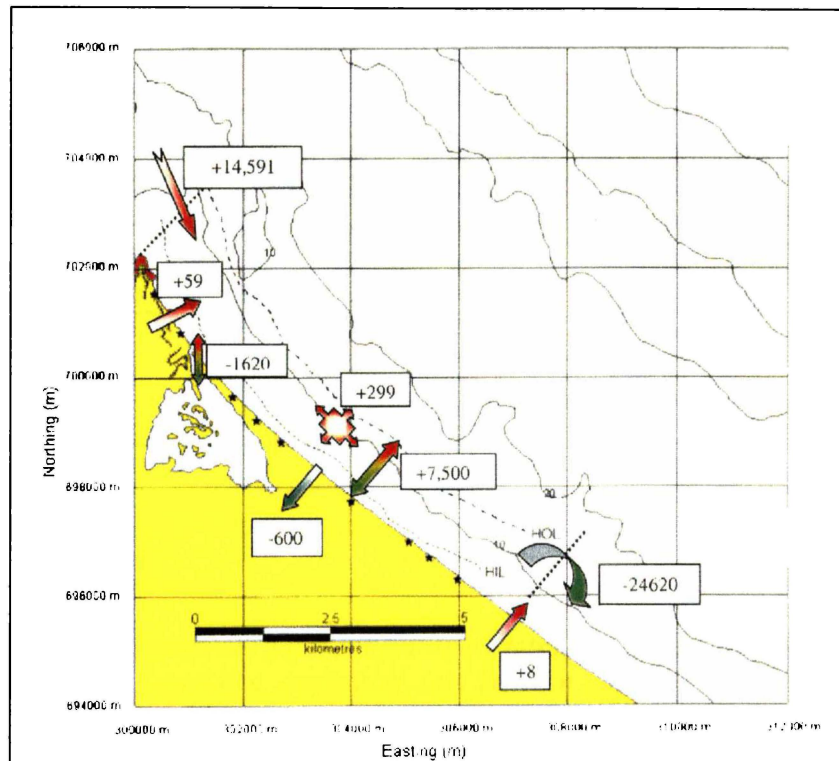


Figure 5.13: Net annual credits and debits to the sediment budget along the Pukehina coastal sector with units in $m^3 yr^{-1}$ (Source: Easton, 2000)

West of Okurei Point, Maketu, the beach is erosional reflecting perhaps the influence of the Point, the Maketu spit and estuary, Motiti Island, and the relocated Kaituna River outlet on sedimentation and hydrodynamic patterns in this vicinity. The coastline becomes regressive and long term accretional again west of the 'Kaituna Cut' through to eastern Papamoa reflecting significant sediment supply sourced principally from the Kaituna catchment but also supplemented by littoral and diabathic contributions from the offshore system (see Figure 5.14).

The beach extending from Papamoa through to Mount Maunganui is in a more finely balanced state being near equilibrium over the decadal period but over the longer term has been accretional, while Matakana Island remains generally in a long term accretional state. Waihi Beach and the connected tombolo to Bowentown Heads are erosional over the long term reflecting a limitation in sediment supply with most of this being supplied via diabathic exchange from the offshore (*pers. com.* Healy, T.R.). However this can be extremely variable and subject to episodic accretional phases, being driven largely by wave and regional climate conditions causing reversals in littoral drift patterns which may result in 'slugs' of sediment

moving from the Katikati ebb tidal delta into the beach system and westward towards Waihi Beach (Hicks *et al.*, 1999).

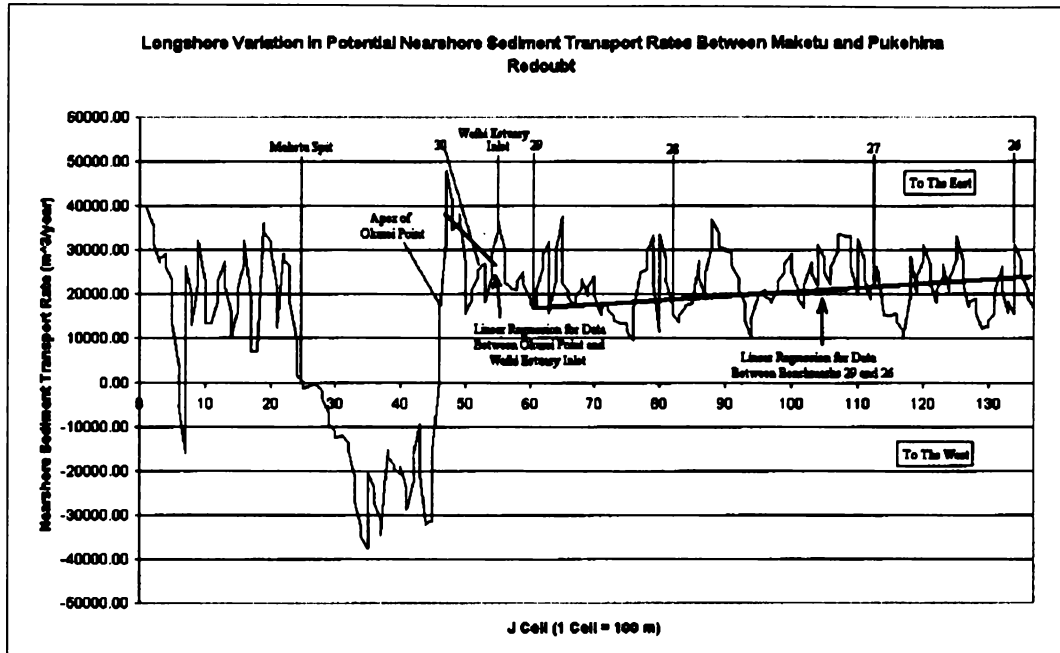


Figure 5.14: Nearshore sediment transport rates, as calculated by WBEND simulation. Regression analysis of data between Okurei Point and Waihi Estuary, illustrated a negative relationship, and therefore this region would be expected to have a tendency towards accretion. The converse is true between profiles 29 and 26 where a positive relationship indicates erosion. (Source: Easton, 2000).

It has been suggested that most of the progradation occurring within the Bay of Plenty has occurred as a result of the post glacial marine transgression and that this was substantially completed by about two thousand years ago (Gibb, 1997, Gibb and Aburn, 1986 Shepherd *et al.*, 1997). This is also evidenced by the position of a relict Taupo sourced pumice berm at Waihi beach and ash deposits within the Papamoa dunes located some 75m behind the current beach (*pers. comm.*, Healy, T.R., 2004).

This agrees with estimates made from the Pakiri sand study (*pers. comm.*, Healy, T.R.) and analyses of beach ridge sequences in South East Australia (Thom *et al.*, 1981). Based on Healy's observations this equates to an accumulation of approximately $0.25\text{--}0.3 \text{ m}^3\text{m}^{-1}$ of beach sediment per annum ($+0.04 \text{ m yr}^{-1}$) which is considered by Healy as reflecting a long term (approx. 1800 years) general diabathic "lee shore" contribution to the Bay of Plenty beaches from offshore sand sources derived largely from reworked Pleistocene marine sediments under offshore winds with concomitant upwelling.

As already noted there are areas where significant progradation has occurred and is still occurring. Pullar and Selby (1971) identified variable rates of progradation on the Rangitaiki Plains while Wigley (1990) describes a similar evolutionary sequence for the Te Puke lowlands and the eastern Papamoa beach system. Rates of progradation in these areas over the post marine transgression period have been highly variable, cumulative and largely related to pulses of fluvial sediment inputs into the coastal system driven principally by Central North Island volcanism occurring over timeframes varying from hundreds to thousands of years.

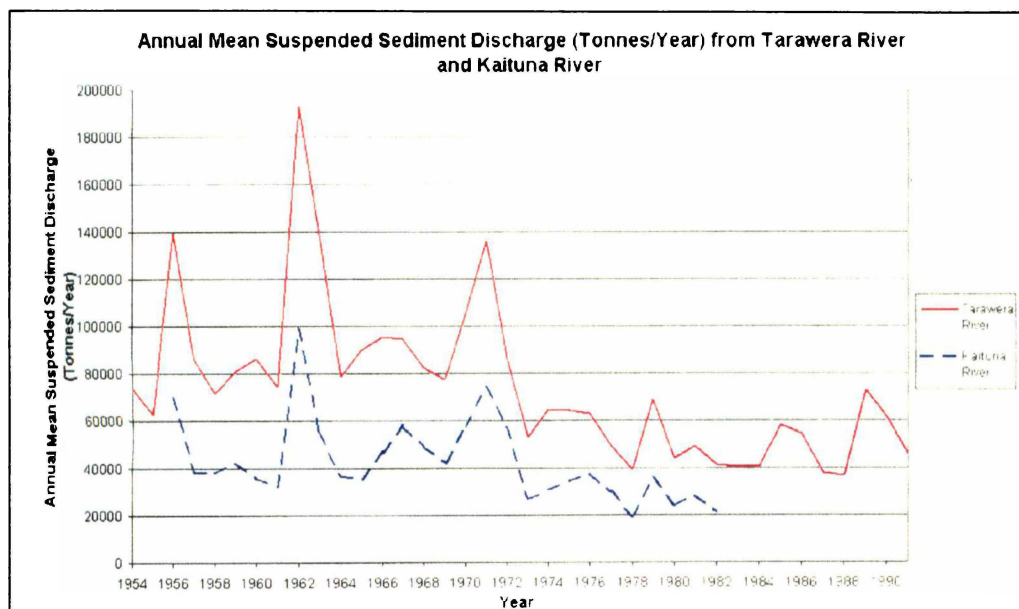


Figure 5.15: Annual mean suspended sediment discharge (tonnes yr⁻¹) from the Tarawera and Kaituna Rivers (Source: Easton, 2000)

Currently the principal terrestrial sediment supplies fuelling the coastal system are thought to be sourced from the last Tarawera (1886) and Taupo eruptions (186 AD) and that these will be time limited. However sediment supply trends are not generally available over a sufficient time period to quantify this. Easton (2000) notes a reduction of river load from NIWA sourced data for the Tarawera and Kaituna Rivers based on data accumulated from 1954 through to 1991. However it is possible that this may be more related to climate factors such as IPO and ENSO cycles than reflecting a true reduction in sediment supply from these catchments (see Figure 5.15).

5.6 Application of LSCB to Sea Level Rise Prediction in the BoP

Recollect that Dean (1991) described equilibrium profile equations that allow for the correction of sea level rise predictions where sedimentary inputs are known. Profile shift due to sea level rise corrected for these sediment inputs are described by Dean (1991) in the following equations.

$$\Delta y = \Delta y_s + \Delta y_N \quad (5.35)$$

where Δy_s is the recession due to sea level rise while Δy_N represents the advancement or recession resulting from either sediment surpluses or deficits occurring within the coastal system out to a nominated closure depth. Δy_s is defined by equation 5.22 while Δy_N is defined by the following equation,

$$\Delta y_N = \frac{\Delta V}{h_o + B} \quad (5.36)$$

where ΔV represents the surplus or deficit of sediment inputs expressed as volume per unit length of beach. Combining equations 5.22 and 5.36 as provided for in equation 5.35 gives,

$$\Delta y = \frac{1}{h_o + B} [\Delta V - S w_o] \quad (5.37)$$

This may be expressed in rates by rewriting to provide

$$\frac{\partial y}{\partial t} = \frac{1}{(h_o + B)} \left[\frac{\partial V}{\partial t} - w_o \frac{\partial S}{\partial t} \right] \quad (5.38)$$

where S is the sea level rise, h_o is the closure depth, w_o is the active profile width, and B is the berm height as described previously.

Stive (2004) and Cowell and Thom (1994) confirm the robustness and validity of the Bruun Rule while also recognising the need to incorporate time related sediment budgets into the calculation in order to obtain realistic retreat based upon sea level rise predictions. Stive (2004) suggest that the Bruun Rule be modified to provide for these sedimentary components as follows,

$$c_p h_* = \frac{\partial MSL}{\partial t} L_* - (q_{x,sea} - q_{x,dune}) - \frac{\partial Q_y}{\partial y} - s \quad (5.39)$$

where h_* is the width of the active profile, c_p is the horizontal profile shift, $q_{x,sea} - q_{x,dune}$ represents the net contribution from sediment sources normal to the shoreline, while Q_y is the alongshore transport integrated over the longshore length of the coastal sector. Equation 5.39 can be shown to be equivalent in two dimensions to equation 5.38.

To illustrate the application of these equations for the BoP they have been applied to areas where either progradation rates or sediment budgets are reasonably known. These areas include Ohope Beach, Rangitaiki Plains, Pukehina Beach, Papamoa and Waihi Beach. The examples are described as follows.

Ohope Beach

Saunders (1999) determined a sediment budget for western Ohope Beach, (see Figure 5.16). This indicates an annualised net loss to the Ohope system of $-29,000 \text{ m}^3 \text{ yr}^{-1}$ or approximately $8.1 \text{ m}^3 \text{ m}^{-1}$ of beach. However Saunders also notes that the western sector of the beach has been accreting historically over time since 1868 with a major phase of accretion (+203 m) occurring up until 1976, while erosion (approximately -180 m) has occurred since then.

Only one of the 48 BoP dataset profiles (Profile 11) is located within this budget area. The sea level rise shift predicted for this profile (profile 11) indicated a -35 m adjustment resulting from a 0.5 m rise in sea level over the next 100 years (see Table 5.4). If this is adjusted to incorporate the profiles current disequilibrium of + 25.5 m (to account for the apparent sediment surplus in the profile) then the predicted shift becomes -9.5 m or 0.9 m yr^{-1} .

If equation 5.38 is applied to West End Ohope using Saunders predicted sediment loss from this coastal sector of $-8.1 \text{ m}^3 \text{ m}^{-1} \text{ yr}^{-1}$ then the calculation yields the following.

$$\frac{\partial V}{\partial t} = -8.1 \text{ m}^3 \text{ m}^{-1} \text{ yr}^{-1}, \quad \frac{\partial S}{\partial t} = 0.005 \text{ m yr}^{-1}, \quad w_o = 650 \text{ m} \quad \text{and} \quad h_o + B = 7 \text{ m}.$$

$$\frac{\partial y}{\partial t} = \frac{1}{7} [-8.1 - 0.005(650)]$$

$$\frac{\partial y}{\partial t} = -1.6 \text{ m yr}^{-1}.$$

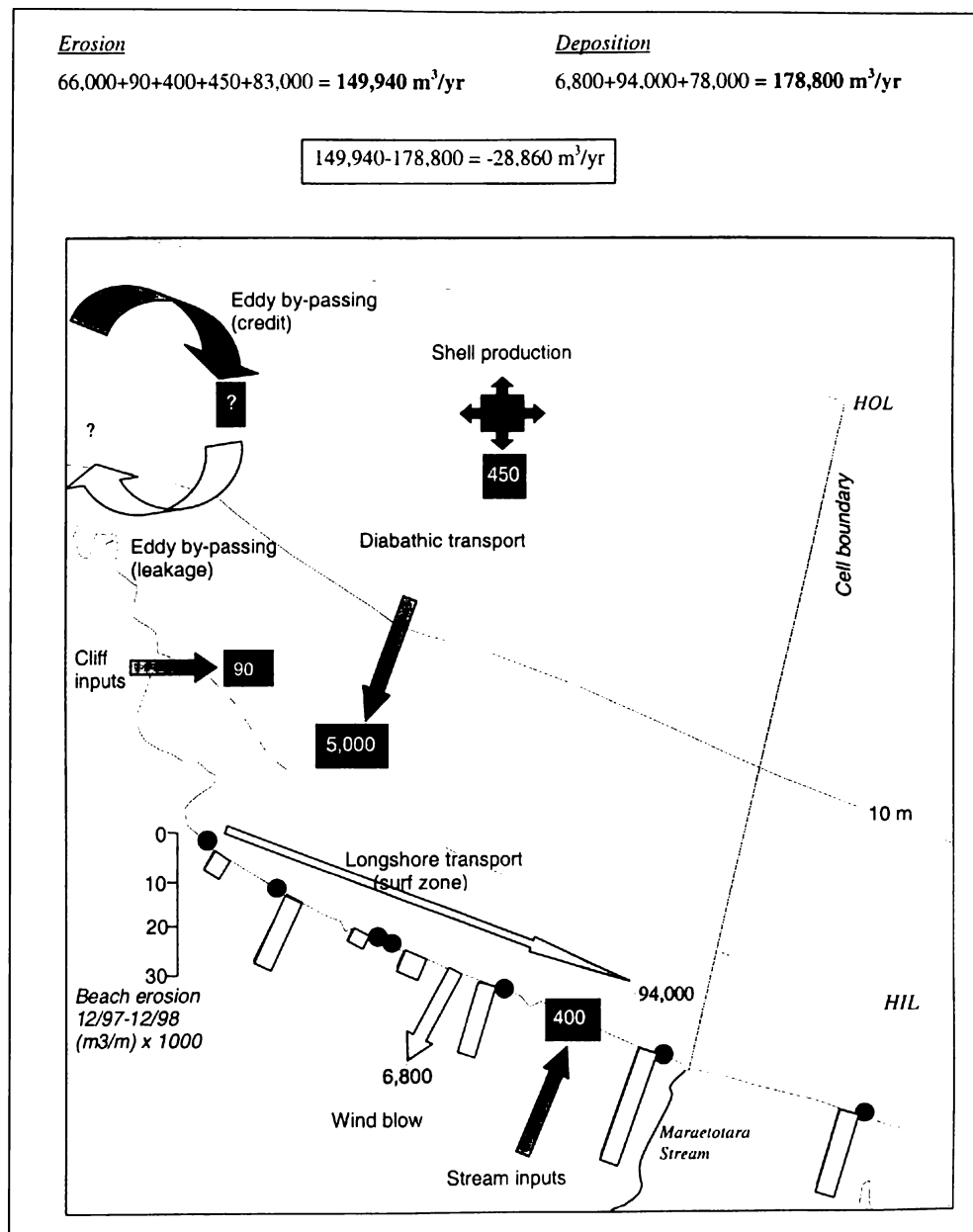


Figure 5.16: Net annual credits and debits to the sediment budget, along with net annual sediment transport at Ohope Beach in $\text{m}^3 \text{yr}^{-1}$. (Source: Saunders, 1999)

This represents a predicted retreat of the beach of 161 m over the next century which appears counter intuitive as historical beach accretion has occurred at West End over the last 100 years. Saunders (1999) notes that this is cyclical at inter decadal timeframes with the retreat noted since 1976 which may reflect the effects of climate cycles and an identified change in the IPO that occurred around that time (Goring *et al.*, 1999; Bell *et al.*, 1999). Irrespective of this the potential for accretion is reflected in the surplus of sediment located offshore for profiles 10 and 11 as shown by the equilibrium profile calculations described in Chapter 4 and shown in Table 5.4.

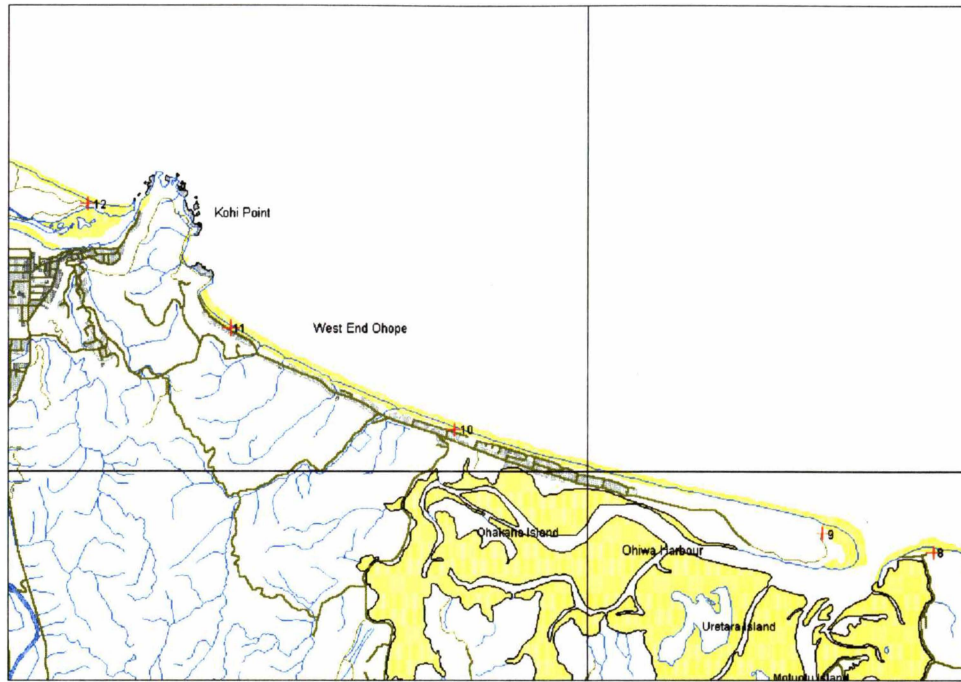


Figure 5.17: Locality Map of West End Ohope showing location of profile monitoring sites

If the sea level rise profile shift values predicted in Table 5.4 adjusted for this surplus sediment is substituted back into equation 5.38 with $\frac{\partial y}{\partial t} = -0.09 \text{ m yr}^{-1}$, the equation yields the following result for beach volume change.

$$\begin{aligned} -0.09 &= \frac{1}{7} \left[\frac{\partial V}{\partial t} - 0.005(650) \right] \\ \frac{\partial V}{\partial t} &= -0.63 + 2.5 \\ \frac{\partial V}{\partial t} &= +2.6 \text{ m}^3 \text{m}^{-1} \text{ year}^{-1} \end{aligned}$$

If we look at other trend rates documented in the literature Gibb (1994) identifies +15 m of accretion for the period (1924- 1994) at West End Ohope, while Healy *et al.* (1977) identified approximately 25 m of accretion over a shorter period (1944-1977) for the same sector. Taking Gibb's observed rate translated to an annualised accretion rate of +0.3 m and a historical sea level rise of +0.002 m yr⁻¹ (Hannah, 2004) this yields a predicted change in beach volume using Equation 5.38 of +3.4 m³m⁻¹yr⁻¹ while using Healy *et al.*'s (1977) figures yields +6.9 m³m⁻¹yr⁻¹.

Gibb's observation agrees reasonably well with the predicted value from the equilibrium profile calculations show in Table 5.4. However there is

an apparent anomaly when the geomorphology of the beach sector is considered. The beach at Ohope West End is a mainland beach (using the nomenclature of Roy *et al.*, 1994) which is located at the base of cliffs with no evidence of substantial progradation occurring post during the stillstand. Yet profile 11 shows a sediment surplus of $153 \text{ m}^3 \text{m}^{-1}$ located in the offshore profile (see Figure 5.18). It may be that a significant component of this sediment presumably arriving from updrift of Kohi Point (Saunders, 2000) is not being transferred by diabathic exchange onto the beach but is being moved either longshore by littoral drift towards Ohiwa and/or is being accumulated in a sink, or alternatively is being lost offshore.

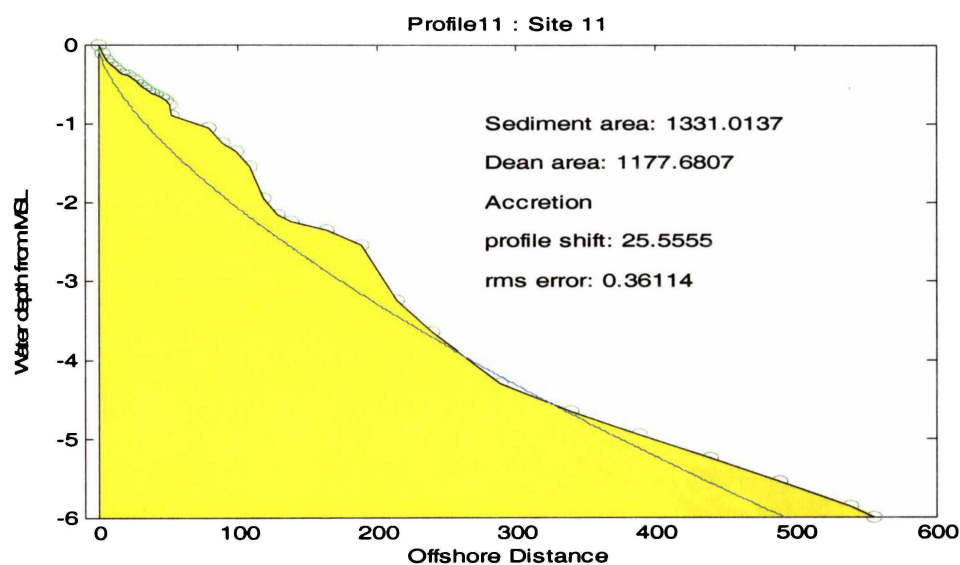


Figure 5.18: Dean (1977) profile fitted to Profile 11 at West End Ohope showing surplus sediment in the offshore profile.

An objective of Saunders (2000) was to identify why erosion was occurring at the western end of Ohope Beach over the period. Using budgeted sediment loss from this beach sector and allowing for a sea level rise of 0.002 m yr^{-1} yields a profile shift of -1.3 m yr^{-1} , which over 10 years would result in approximately 13 m of erosion. Gibb (1994) notes that fluctuations of this order can be expected so it is possible that the sediment deficit documented in Saunder's work reflects a short term erosional episode but does not fully explain the sedimentary dynamics at work in this area.

Rangitaiki Plains

A detailed sediment budget is not available for this coastal sector although river sediment inputs and foredune accumulation are discussed in Healy (1983) indicating progradation rates in the lee of Motuhora Island of approximately 1 m yr^{-1} . Additionally a geological description of the evolutionary history of this strand plain is available (Pullar and Selby, 1971; Beanland and Berryman, 1992), which provides progradation rates

for the Rangitaiki Plains assessed from the stratigraphic record. This information can be used as an indication of the net sediment budget applicable to this coastal sector and therefore allows Equations 5.36 and 5.38 to be used to determine the effects that these inputs will have on coastal adjustments predicted from the sea level rise formula (see Table 5.4). Given the generalised nature of such information profile shift rates have been averaged in the following assessment.

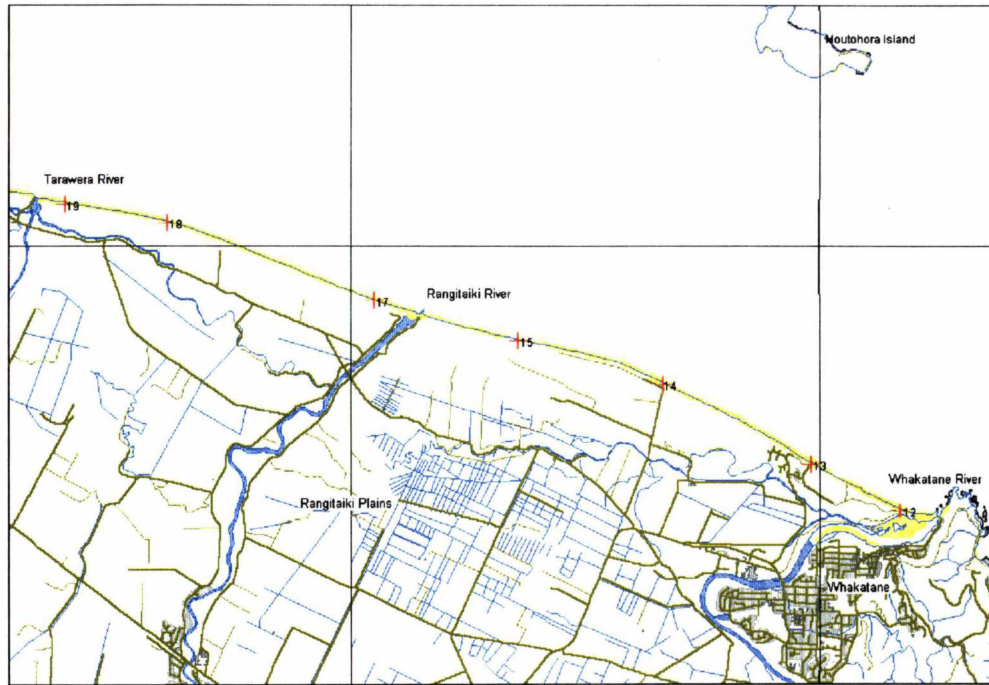


Figure 5.19: Locality Map of the Rangitaiki Plains showing the location of profile monitoring sites

The average predicted profile adjustment for sea level rise, adjusted for profile disequilibrium, derived from Table 5.4 for eight profiles (profiles 12 to 19) located within the Rangitaiki Plain sector over the next 100 years is -43.47 m. This represents an annualised profile shift rate of -0.44 m yr^{-1} for a sea level rise of 0.5 m over next 100 years. Substituting these values into equation 5.38 for the various terms provides the following solution of the virtual sediment volumes involved:

$$\frac{\partial y}{\partial t} = -0.44 \text{ m yr}^{-1}, \quad \frac{\partial S}{\partial t} = 0.005 \text{ m yr}^{-1}, \quad \text{and } h_o + B = 7 \text{ m.}$$

$$-0.44 = \frac{1}{7} \left[\frac{\partial V}{\partial t} - 0.005(500) \right]$$

$$\frac{\partial V}{\partial t} = -3.08 + 2.5$$

$$\frac{\partial V}{\partial t} = -0.58 \text{ m}^3 \text{m}^{-1} \text{ year}^{-1}$$

This tells us that to maintain the shoreline in its present position requires the addition of 0.58 m³ of sediment per m of beach in order to offset the effects of a sea level rise of 0.5 m. Pullar and Selby (1971) identified that the Rangitaiki Plains have been prograding at an average rate of 0.5m per year over the last 2000 years. On this basis assuming that sea level for the period has remained relatively stable at the same level as today, then the annualised rate of sediment addition to the coastline (calculated using equation 5.36) must have averaged approximately 3.5 m³m⁻¹yr⁻¹ of beach over this period.

Consequently there should be sufficient sediment to not only maintain the current shoreline but to continue to prograde it, the difference between the two being + 2.9 m³m⁻¹ of beach. Assuming that this overall rate of sediment accumulation is maintained and substituting the 3.5 m³m⁻¹yr⁻¹ back into equation 5.38 yields a shift value of +0.14 m yr⁻¹ being the averaged amount of annual progradation expected for this coastal sector over the next 100 years. This is potentially available to continue coastal progradation on the two cusate forelands in the lee of Motuhora and Rurima Islands. The consequences of this for coastal management are obvious however whether this prediction is realised will be highly dependent on the continuance of past sedimentation patterns within the river catchments and the quantities of sub aerial sediment contributed to the transgressive coastal dunes found in this sector.

Pukehina Beach

Easton (2000) in his sediment budget for Pukehina Beach considered a range of inputs and outputs to the beach system (see Figure 5.13). He noted an overall sediment deficit of -4,400 m³ per year for the nine kilometres coastal sector extending eastward from Okurei Point towards Otamarakau (profiles 26 to 30). This sediment deficit represents an annualised average loss of 0.49 m³ m⁻¹ yr⁻¹ of sand to the beach. Averaging the profile shift predictions from Table 5.4 for a sea level rise of +0.5 m results in a predicted profile shift of -0.38 m yr⁻¹ for this beach sector over the next 100 years. Applying the same sea level rise scenario as previously with an averaged offshore distance to closure depth of 470 m provides the following volumetric solution from equation 5.38,

$$\frac{\partial y}{\partial t} = -0.38 \text{ m yr}^{-1}, \quad \frac{\partial S}{\partial t} = 0.005 \text{ m yr}^{-1}, \quad \text{and } h_o + B = 7\text{m}.$$

$$-0.38 = \frac{1}{7} \left[\frac{\partial V}{\partial t} - 0.005(470) \right]$$

$$\frac{\partial V}{\partial t} = -0.31 \text{ m}^3 \text{ m}^{-1} \text{ yr}^{-1}$$

This compares reasonably well with the figure of sediment loss calculated in Easton's (2000) sediment budget although the results are sensitive to the rate of sea level rise and the closure depth chosen.

Historically Pukehina spit is noted as having a long term trend for erosion averaging approximately -8 m for the period 1912-1994 with ranges from -2 to -14 m (Gibb, 1994). This equates to an annualised average rate of -0.1 m yr⁻¹ ranging from -0.02 through to -0.17 m yr⁻¹ for this period.

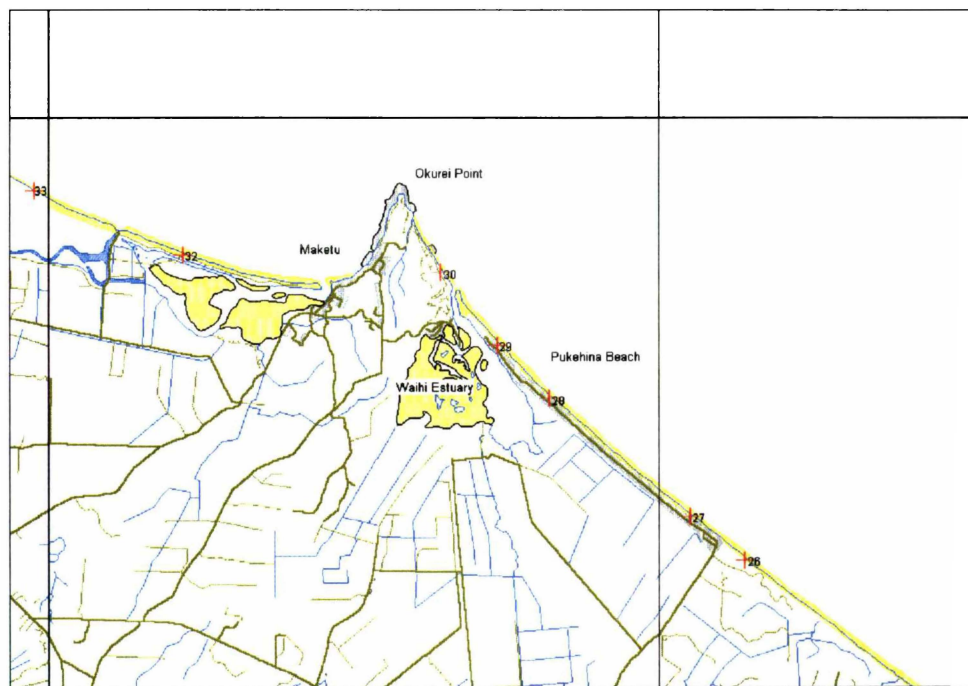


Figure 5.20: Locality Map of Pukehina showing the location of Pukehina Spit and profile monitoring sites

Substituting Easton's annual sediment loss of $-0.49 \text{ m}^3 \text{ m}^{-1}$ for the coastal sector back into equation 5.38 provides an estimate of the annualised trend rate for the beach using a sea level rise value of 0.002 m yr^{-1} for this period (Hannah, 2004). On this basis the solution yields an averaged virtual erosion loss due to sea level rise of -16.75 m for the period or -0.2 m of beach per year, which is more than the average value of -0.1 m determined by Gibb (1994) but is in general agreement with Gibb's upper range value of -0.17 m. As a consequence it would be prudent for coastal management purposes to use the higher figure of -0.2 m yr^{-1} of beach assuming current sea level rise trends but this should be increased over the next 100 years to 0.38 m yr^{-1} to provide for the anticipated sea level rise.

Papamoa – Te Puke lowland

Wigley (1990) notes an average progradation rate of 0.2 m yr⁻¹ for Papamoa since the deposition of Taupo Pumice (Tp) immediately following the Taupo eruption of 186 AD. Applying the same methodology as for the Rangitaiki Plains the average predicted sea level rise shift adjusted for profile disequilibrium for the five profiles (profiles 32 to 36) located within the Te Puke lowland sector (eastern Papamoa) for the next 100 years is -53.18 m. This represents an annualised profile shift rate of -0.53 m yr⁻¹ for a sea level rise of 0.5m over the next 100 years yielding a virtual sediment loss calculated as follows.

$$\frac{\partial y}{\partial t} = -0.53 \text{ m yr}^{-1}, \quad \frac{\partial S}{\partial t} = 0.005 \text{ m yr}^{-1}, \quad \text{and } h_o + B = 7\text{m.}$$

$$-0.53 = \frac{1}{7} \left[\frac{\partial V}{\partial t} - 0.005(400) \right]$$

$$\frac{\partial V}{\partial t} = -3.08 + 2.0$$

$$\frac{\partial V}{\partial t} = -1.1 \text{ m}^3\text{m}^{-1} \text{ year}^{-1}$$

Using equation 5. 36 and Wigley's (1990) progradation rate of 0.2 m yr⁻¹, and assuming that mean sea level has been more or less constant over this period yields a long term sediment contribution rate of 1.4 m³m⁻¹yr⁻¹ of beach. This indicates a sediment excess over that predicted of +0.3 m³m⁻¹. In order to determine whether this additional sediment is sufficient to offset the effects of sea level rise involves substituting the 1.4 m³m⁻¹ sediment input value back into equation 5.38 to yield a reduced annual erosion rate (over that predicted directly from the sea level rise calculations detailed in Table 5.4) of -0.09 m yr⁻¹ or -8.6 m of 'accumulated erosion' over the next 100 years.

Interestingly if Healy's sediment accumulation rate of +0.25 m³m⁻¹ per year (+0.04 m yr⁻¹) of beach (identified at the western margin of this coastal sector) is substituted into equation 5.38 this yields an annualised virtual erosion rate of -0.32 m yr⁻¹ or -32 m erosion for a predicted sea level rise of 0.5 m over the next 100 years. This site is located updrift (i.e. close to the Mount Maunganui sewer outfall and one kilometre southeast of profile 38) and well outside of the main progradation area described by Wigley (1990). Therefore this site is more likely to reflect lower rates of sediment accumulation than that observed at eastern Papamoa. Additionally the planform in this locality is more closely aligned with Mount Maunganui than Papamoa, and is concave compared to the convex shaped cusate foreland of the Te Puke Lowland, reflecting the island's influence on wave refraction, wave focussing and a more 'active' beach in this coastal sector.

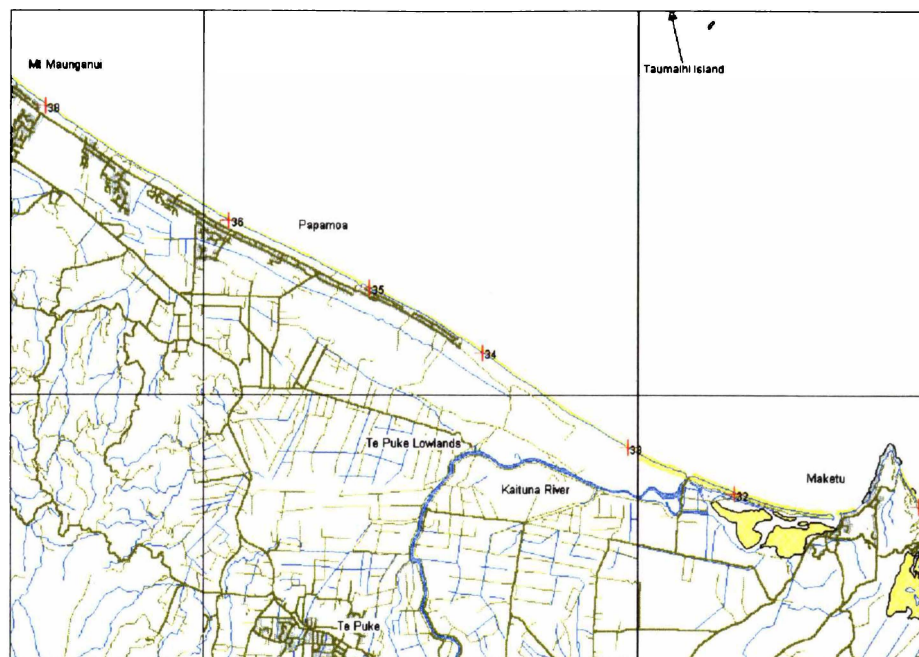


Figure 5.21: Locality Map of the Te Puke lowlands showing profile sites.

Waihi Beach

Waihi Beach has been described as a long term erosional barrier beach-tombolo extending some 8 km southeast from the main settlement of Waihi Beach to Bowentown Head. Healy *et al.* (1977) identified erosion trends ranging from between 10 and 60 m for the period 1948 to 1977 while Gibb (1994) notes long term shoreline retreat of approximately 35 m at the eastern end of the beach decreasing to approximately 8 m.

In a broader sense little evidence exists documenting the recent Holocene evolution of the Waihi Beach tombolo but as already noted related evidence exists on Matakana Island (Shepherd *et al.*, 1997) and at Pauanui (Gibb and Aburn, 1986) which indicates perhaps a regional progradational history for the Holocene. At Pauanui these rates decreased from $+0.39 \text{ m yr}^{-1}$ (5060-4120 yrs B.P.) to 0.12 m yr^{-1} (4120-2020 yrs B.P.) to 0.06 m yr^{-1} (2020 to present). Similarly on Matakana Island (Shepherd *et al.*, 1997) progradational rates indicate a similar reducing trend from 0.42 m yr^{-1} (6,000-3500 yrs B.P.), to 0.13 m yr^{-1} (3,500-1750 yrs B.P.) to 0.13 m yr^{-1} (1,750-present). Healy (1993) notes that Waihi Beach has advanced approximately $+0.04 \text{ m yr}^{-1}$ over the last 2000 years. This equates to observations of Taupo tephra deposits some 75m behind the current foredune (Healy, 1976.) leading Healy to conclude that progradation rates to the beach have averaged approximately $0.25 \text{ m}^3 \text{ m}^{-1}$ over this period.

It seems likely therefore that annualised long term progradational rates for this coastal sector have averaged around $+0.04$ to 0.06 m yr^{-1} since the time of the Taupo eruption about 1800 years ago. Substituting this value into

equation 5.36 and assuming a constant sea level over this period yields a sediment contribution of $+0.25 \text{ m}^3 \text{m}^{-1}$ of beach. Substituting this value back into Equation 5.38 yields the following change in volume occurring as a result of an anticipated sea level rise of $+0.5 \text{ m}$ over the next 100 years.

$$\frac{\partial V}{\partial t} = +0.25 \text{ m}^3 \text{m}^{-1} \text{ yr}^{-1}, \quad \frac{\partial S}{\partial t} = 0.005 \text{ m yr}^{-1}, \quad \text{and } h_o + B = 7 \text{ m}.$$

$$\frac{\partial y}{\partial t} = \frac{1}{7} [0.25 - 0.005(500)]$$

$$\frac{\partial y}{\partial t} = -0.32 \text{ m yr}^{-1}.$$

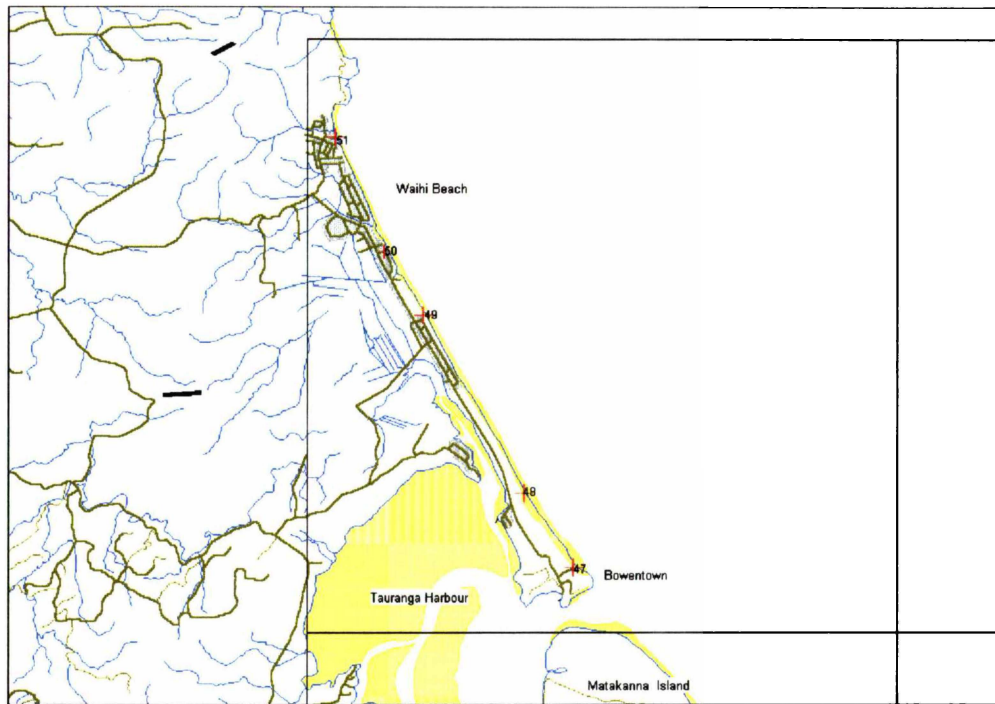


Figure 5.22: Locality Map of Waihi Beach showing Bowentown Head and Matakana Island.

This result represents a profile shift of -32 m due to sea level rise over the next 100 years. However there is considerable variance in the width of the active profiles at Waihi Beach. These range from approximately 500 m at profile 48 increasing to 800 m at profiles 49 and 51. As a consequence this will increase the shift rate predicted using equation 5.38 from -0.32 m to -0.54 m yr^{-1} . If sea level rise remains at its current observed rate of $+0.002 \text{ m yr}^{-1}$ then the predicted profile shift reduces to -11 m for profile 48 and -19 m for profiles 49 and 51.

These profile shift values are similar to those predicted in Table 5.4. However profiles 49 and 51 also contain considerable sediment surpluses determined from the equilibrium profile calculations summarised in Table

5.4, which should theoretically act to offset the effects of sea level rise. This is reflected by the profiles dissipative state (which probably mirrors the fine grained nature of the beach sediments rather than any high energy erosional environment) but whether this sediment can be or is activated for diabathic exchange can only be determined through further work.

It is suggested work that future research will need to incorporate a systems approach to resolving contemporary sediment budgets extended to include the palaeo-evolutionary history of the beach. This will then allow for the application of methodologies and modelling such as those described in Roy *et al.* (1994), Cowell and Thom (1994), Cowell *et al.* (1995), Cowell *et al.* (2003), Stive (2004), Zhang *et al.* (2004).

5.7 Conclusion

This chapter describes the implications of sea level rise on the Bay of Plenty coastline using the 48 profiles of the BoP coastal dataset. This has involved:

- a review of literature relevant to climate change scenarios considered likely over the next 100 hundred years;
- an analysis of historical sea level rise assessments documented in the literature and the most probable predictions for sea level rise both world wide and in a regional context for New Zealand;
- a review of the derivation of the Bruun Rule from Dean's (1977) equilibrium profile using equilibrium profile theory and use of this model as the basis for predicting sea level rise;
- determining sea level rise predictions for the 48 BoP profiles using a two dimensional MATLAB model incorporating the Bruun Rule; and
- a review of the predictions in light of geomorphic and sediment budget information available for some coastal sectors to determine whether the two dimensional predictions provide realistic predictions of sea level rise predictions;

The literature indicated that the likely sea level rise predicted for the next 100 years will be +0.49 m (rounded to +0.5 m for the purposes of this assessment). It is anticipated that this will not occur as a linear increase but will accelerate from the current 0.002 m yr⁻¹ to 0.004 m yr⁻¹ by 2050 and to 0.005 m yr⁻¹ by 2001. Applying the Bruun Rule to the profiles in the BoP dataset produces the results described in Table 5.4. If these results are then adjusted to account for observed historical coastline changes (Healy *et al.*, 1977; Gibb, 1994; Deely and Hodges, 1997) using the general hindcast methodology described in 5.6 to calculate sediment input volumes for the Papamoa coastal sector (assuming a sea level rise of +0.002 m yr⁻¹ for the

historical period) then this will result in the adjusted sea level rise forecast shown in Table 5.5.

BOPRC #	Sea level rise shift (m)	Total shift (m)	Historical coastline trend rate (m/yr)	Adjusted prediction of SLR shift (m rounded)
1	-32.22	-36.22	-0.22	-48
2	-30.85	-39.13	0	-24
3	-31.53	-0.02	-0.12	-38
4	-33.2	-28.18	-0.22	-48
5	-33.83	-26.86	+0.56	31
6	-32.22	-49.31	+0.23	1.6
7	-32.58	-32.67	0	-21
8	-29.07	94.48	-1.11	-154
9	-30.58	314.9	+4.0	348
10	-33.2	37.75	+1.3	100
11	-35.05	-9.49	+0.3	4
12	-32.68	-50.11	+0.5	33
13	-30.1	-70.33	+1.1	93
14	-28.58	-24.96	+1.3	111
15	-29.78	-62.91	+0.8	63
16	-27.91	-42.72	+1.7	153
17	-29.07	-49.88	+1.0	83
18	-28.48	-14.32	+1.5	129
19	-25.1	-32.57	+1.1	93
20	-26.34	-31.52	0	-17
21	-27.18	-42.01	0	-17
22	-26.83	-27.17	+0.8	63
23	-25.53	-12.14	-0.26	-44
24	-23.59	-36.8	-0.33	-50
25	-25.69	-39.94	-0.22	-39
26	-27.86	-45.52	0	-17
27	-26.46	-46.4	0	-17
28	-29.07	-72.86	-0.16	-33
29	-27.91	-46.18	-0.1	-55
30	-17.86	21.87	-0.06	-27
32	-23.09	-28.33	-0.15	-31
33	-29.27	-91.95	+0.77	60
34	-33.83	-47.94	+1.15	96
35	-30.64	-49.03	0	-14
36	-31.87	-48.63	-0.43	-62
38	-31.99	-51.81	+0.54	36
39	-30.31	-23.2	+0.6	42
40	-24.72	-5.296	0	-20
41	-19.36	69.86	+1.6	136
42	-25.98	37.06	+2	177
43	-28.2	28.09	+0.9	60
44	-32.34	36.24	+1.1	86
45	-31.99	23.19	+1.0	73
46	-26.72	206.69	+0.4	11
47	-23.75	263.47	-1.4	-167
48	-28.33	-24.89	-0.7	-111
49	-33.63	66.81	-0.15	-45
51	-33.2	36.41	0	-34

Table 5.5: This table contains a summary of the equilibrium shift calculations for the BoP profile dataset (i.e. the erosion or accretion potential in the profile), related sea level rise predictions based on (cont .overleaf)

Bruun Rule calculations, the annualised trend rate in $m\ yr^{-1}$ based on historical data such as cadastral records and aerial photographs, and the adjusted sea level rise prediction calculated incorporating the historic trend data as a surrogate measure for sediment budget inputs.

From these results it is clear that there are a number of sites where sea level rise may be offset by progradation effects due to sediment inputs into the respective coastal sectors.

Chapter 6

Storm Modelling - Application of the Dean Kriebel EBP Model (EDUNE) to Short Term Cut and Fill Events in the Bay of Plenty.

6.1 Introduction

Chapters 4 and 5 document the application of equilibrium beach profile theory to coastal change behaviour at timeframes ranging from short term (i.e. generally less than a year up) to inter decadal timeframes of up to a century. This chapter focuses on short term beach changes resulting from storm systems impacting on the Bay of Plenty (BoP) to complete the hazard assessment for this coastal system utilising equilibrium profile theory.

This will involve:

- A discussion of the theoretical concepts behind the model EDUNE (Kriebel, 1989).
- A summary of the wave characteristics applicable under storm conditions for the BoP and the derivation of a 'design' storm for use in the modeling process.
- The application of the model EDUNE to all 48 profiles in the BoP dataset.
- A discussion of the implications of the modeling results for the Bay of Plenty coastline in the light of the results obtained from the assessments contained in Chapters 4 and 5.

6.2 Theoretical Concepts associated with EDUNE

Kriebel (1989) documents a two dimensional numerical model (EDUNE) to simulate storm surge and beach and dune erosion (Pickett *et al.*, 1997). This model or its precursor EBEACH has been applied to the Florida coast for that state (Chiu and Dean, 1984; National Research Council, 1990).

The EDUNE model (Kriebel 1989) is based on equilibrium profile theory (Dean 1977). As discussed previously in Chapter 3 Dean (1977) analysed several mechanisms for equilibrium profile development and concluded that the profile form was determined by the mechanism of uniform dissipation of wave energy per unit volume in the surf zone. Kriebel (1989) points out that based on this assumed forcing mechanism, and the assumption of spilling breaking waves, a power equation (Dean 1977) can be derived to represent the equilibrium beach form:

$$y = Ax^b, \quad (6.1)$$

where y = is the water depth, x is the distance offshore from the still water shoreline (mean sea level in this case), and A is the scale factor governing the steepness of the profile. Dean (1977) also related the scale factor A to a unique value of energy dissipation across the profile which is equivalent to the energy dissipation per unit volume. This unique variable (D_{eq}) exists when the energy dissipation equates to the profile of equilibrium.

Least squares fit of equation 6.1 by Dean (1977) and Moore (1982) to over 500 profiles has resulted in the development of an empirical relationships between “ A ” (or D) and sediment size and fall velocity. This work has been generally replicated in the BoP as described in Chapter 4 confirming Moore (1982) and Dean’s (1987) original work in this area.

Kriebel (1986) has suggested that during a severe storm, elevated water levels permit waves to break closer to shore. This results in greater energy dissipation to occur over all points within the surf zone and creates a situation where the profile will be out of equilibrium with storm wave energy dissipation. The beach profile responds to this disequilibrium by redistributing sand across the profile so that the depth adjusts to a point where the depth is equivalent to the wave energy dissipation per unit volume.

Based on these concepts and using linear wave theory, the sediment transport rate, Q_s , may be determined at each contour level across the profile in the surf zone by:

$$Q_s = K (D - D_{eq}) \quad (6.2)$$

Where Q_s is the offshore sediment flux (i.e. volume of sediment passing through a unit area per unit time), K is a transport rate parameter determined by calibration carried out on data from Saville (1957) and Hurricane Eloise data as described in Kriebel (1986 & 1989), D is the incident wave energy dissipation per unit volume and D_{eq} is the equilibrium wave energy. The default value of the transport rate parameter K was used for this modelling exercise (i.e. $0.0045 \text{ ft}^4\text{lb}^{-1}$ or

$8.7 \times 10^{-6} \text{ m}^4 \text{N}^{-1}$) giving a 25 to 40% level of confidence which Kriebel (1989) noted provided no biases either toward over or under predicting.

D_{eq} is solved by resolving the equation (Dean 1977).

$$A = \left[\frac{24}{5} \frac{D_{eq}}{\gamma \kappa^2 g^{\frac{1}{2}}} \right]^{\frac{2}{3}} \quad (6.3)$$

where κ = ratio of spilling breaker height into depth (approximated by the value 0.78), γ is the specific weight of water, and g is the gravitational constant.

The energy dissipation per unit volume, D , is defined as

$$D = \frac{1}{h} \frac{dF}{dx}; \quad (6.4)$$

where F is the wave energy flux across the surf zone. Based on the linear assumption of shallow water spilling breaking waves, energy flux may be written as a function of water depth only as:

$$F = \frac{1}{8} \rho g^{\frac{3}{2}} \kappa^2 h^{\frac{5}{2}} = \frac{\partial (EC_s)}{\partial x}, \quad (6.5)$$

where the values are as before for equation 6.3 and h is water depth.

In the model the off shore boundary condition is defined by the breaker index multiplied by wave height. However the driving forces in the model are the resultant water level increase from storm surge coincident with incident wave height.

Finally the model is two dimensional in that the total sand volume across the profile must be conserved. As a consequence the model is only applicable where the sand exchange is essentially diabathic as expressed in the equation:

$$\frac{dx}{dt} = - \frac{dQ_s}{dh}, \quad (6.6)$$

where x represents distance along the profile, t the specified time period over which adjustment occurs, and h represents water depth to the profile from sea level.

To solve these equations Kriebel and Dean (1985) and Kriebel (1989) describe a finite difference scheme used to solve the energy dissipation equation (6.2) and the conservation of mass required by equation 6.6. The model employs a numerical double sweep routine to achieve this as described by Kriebel (1989) that ensures continuity in terms of the eroded and deposited volumes and links the underwater profile with the eroding beach face.

6.3 Wave and Storm Characteristics of the BoP

EDUNE allows for data input to cover either individually or collectively the following wave and surge characteristics:

- Wave height - Kriebel (1989) recommends the use of H_{rms} (root mean-square wave height) since it represents a single wave height (m) that contains the same energy density as the complete wave spectrum.
- Runup - vertical distance (m) from still-water flood level to the limit of wave runup.
- Surge Level (Selev) - maximum storm surge level. For the purpose of this study, storm surge components incorporated into this variable included wave set up, barometric set up, wind set up, and tidal surge (spring tide).

The wave height data used for determining input to the model was derived from the extremal significant wave analysis for the Tauranga Harbour Entrance by de Lange (1993). Predictions of significant wave height in this report are based on a Weibull distribution with the upper 90% used for a 100 year return period system. This figure has been rounded to the nearest whole metre to provide an h_s value of 8 m. By comparison the maximum 20 year hindcast significant wave height derived by Gorman *et al.* (2003) using the WAM model was 7 m. Using the formula of Komar and Gaughan (1973) from Healy (1993) and Frisby and Goldberg (1981), the H_{rms} was calculated as 5.66 m. This again was rounded up to the nearest whole metre following its conversion to breaker height (i.e. 6 m). The formulae used are shown below.

$$H_{rms} = \frac{H_s}{\sqrt{2}} \quad (6.7)$$

$$H_{br} = \frac{0.563H_{\infty}}{\sqrt[5]{H_{\infty}/L_{\infty}}} \quad (6.8)$$

where $T = 7.6s$ (Frisby and Goldberg, 1981).

The components of storm surge were then calculated as follows:

- Wave set-up,

$$h_b = 0.19 \left[1 - 2.82 \sqrt{\frac{H_b}{gT^2}} \right] H_b; \quad (6.9)$$

- Wave run-up,

$$h_r = \sqrt{H_b L_\infty} \tan \beta, \quad (6.10)$$

where β is the gradient of the offshore bar;

- Barometric setup

$$h_{\Delta p} = 0.010(1014 - P) \quad (6.11)$$

where P is the storm system minimum pressure in mb.

- Wind setup

$$h_w = \frac{kh_1 u^2 W}{gh_1^2 (1 - h_2/h_1)} \ln \left(\frac{h_1}{h_2} \right) \quad (6.12)$$

Where $k = \text{constant} = 3 \times 10^{-6}$
 $u = \text{wind speed (m/s)}$
 $w = \text{width of the continental shelf}$
 $h_1 = \text{the depth at shelf break}$
 $h_2 = \text{the depth at the shore or point of interest (Healy, 1993).}$

The detailed results of this analysis yielded the following results (see Table 6.2) for a storm with average winds of 80 km/h. The data used in this quantification is based on observations from the 1967 so called “Wahine” storm (10th April 1967) otherwise known as cyclone Gisele (Revell and Gorman, 2003; de Lange and Gibb, 2000), and the July 1978 storm described by Frisby and Goldberg (1981).

The 1978 storm had a central pressure of approximately 979 hPa near East Cape with winds of up to 36 m s⁻¹ while Cyclone Gisele is noted as having winds gusting to 40 m s⁻¹ with sustained winds of 36 m s⁻¹ when passing over Tauranga. By the time ‘Gisele’ had reached Wellington the central pressure had dropped to c. 964 hPa with winds of approximately 50 m s⁻¹ gusting to 73 m s⁻¹. Surge generated as a result of this storm comprised an inverse barometric wind stress effect of c. 0.9 m (Revell & Gorman, 2003).

This information was then used to define a design storm for use in the storm erosion modelling as follows:

- $H_s = 8.0$ m;
- $H_{rms} = 5.66$ m; and
- $H_{br} = 5.54$ m ≈ 5.5 m.

H_b	T	H_{rms}	h_b	h_p	h_w	h_r	h_r
6.0	7.6	5.7	0.75	0.35	0.55	1.14	0.55

Table 6.2: Storm surge input parameters for modelling

The surge elevation (Selev) was then calculated as follows with the figures then rounded up to the nearest metre to provide a more conservative output from the model. The tidal component calculated for secondary ports around the BOP coast was deduced using the methodology described in Lamont (1996) and this was added in as a constant in order to increase the conservatism of the scenario, however it is recognised that this would not normally be done in this fashion because of the cyclical nature of the tide over the storm's duration.

$$\begin{aligned}
 \text{Selev} &= 0.75 + 0.35 + 0.55 + 1.14 \\
 &= +2.79\text{m} \\
 &\cong +3.0\text{m} \\
 \text{Runup}(h_r) &= +0.55\text{m} \\
 &\cong +1.0\text{m}
 \end{aligned}$$

The default value dune face slope of 1:1 was used for the dune cut face based on Vellinga 1983 while the beach geometry was defined with a general berm height of 1.0 m amsl and an equilibrium slope below run up of 7° or 0.07, and the appropriateness of this was checked by visually comparing model output with the existing profile morphology.

6.4 Application of EDUNE Modeling to the BoP Profiles

As described above the model relies on a relatively simple approximation of beach responses to storm surge effects. This simplicity offers some advantages for coastal management in that the level of information required to apply it, compared to say more complex models, is relatively low, so long as measured profiles, sediment data and some tidal and wave climate information is available.

These storm scenario characteristics were then applied to 47 profiles of the Bay of Plenty dataset (see Figure 6.1).

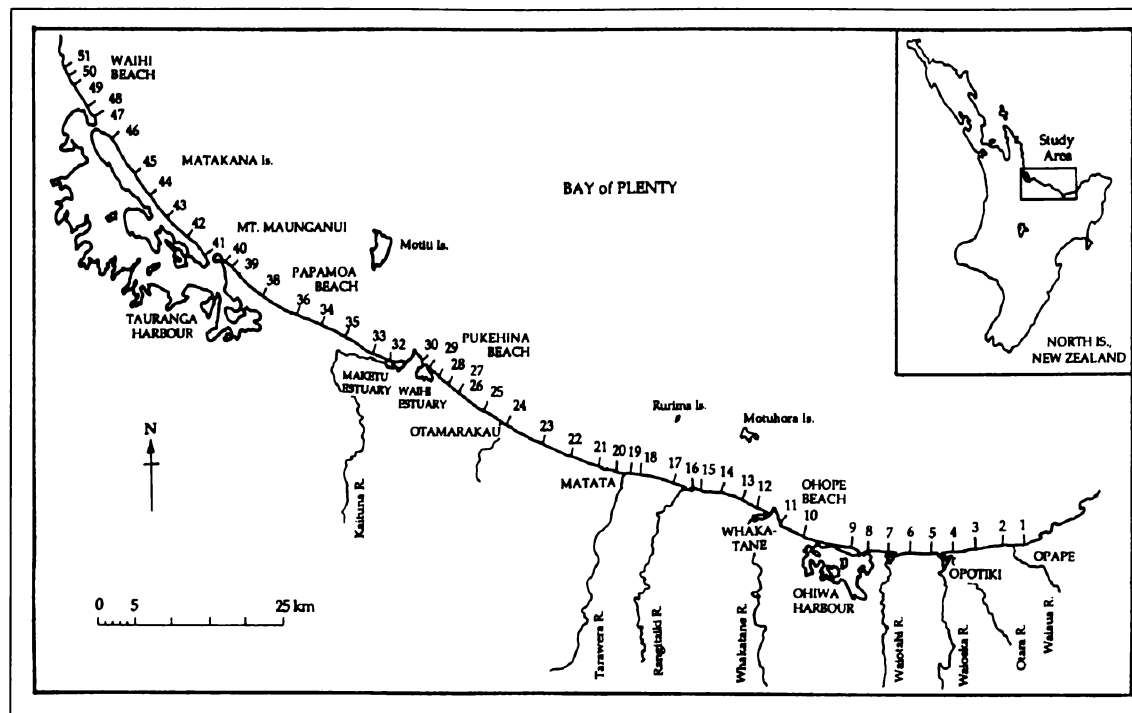


Figure 6.1: BOP Profile Sites (Source Healy et al., 1977)

The summary results of this analysis for a 24 hr storm are shown in Table 6.3 and include the following output variables where:

- VMAX, is the maximum volume eroded above MSL expressed as m^3/m of beach;
- VSWFL, is the maximum volume eroded above the peak flood level;
- DXSWFL, represents the maximum horizontal change in the position of the peak still water flood level of the storm;
- DXDUNE, is the horizontal erosion determined by the modelling for the foredune crest;
- TIME, in the table represents the time of maximum erosion over the storm duration period (i.e. 24hr).

Table 6.3 summarises some of the key outputs calculated from the modelling exercise. These have been statistically analysed to provide the following observations:

- The mean maximum profile erosion above MSL for all the profiles in the dataset is $72.8 \text{ m}^3\text{m}^{-1}$;
- The maximum profile erosion was $161.0 \text{ m}^3\text{m}^{-1}$ which occurred at Profile 33 (Kaituna West);
- The 95 percentile upper and lower limits for VMAX are 85.5 and $60.1 \text{ m}^3\text{m}^{-1}$;
- The mean erosion (profile retreat) at the still water flood level for all the profiles (VSWFL) is $34.2 \text{ m}^3/\text{m}$;

Site No.	VMAX m ³ m ⁻¹	VSWFL m ³ m ⁻¹	DXSWFL m	DXDUNE m	TIME hr
1	52.2	7.1	0.3	-3.6	18.88
2	68.4	39.7	-7.4	-10.0	19.00
3	63.9	43.3	-8.2	-0.63	18.13
4	50.1	36.7	-7.1	0.0	18.88
5	58.8	17.3	-14.4	0.0	19.00
6	132.9	0.0	-0.6	-34.0	20.0
7	49.3	34.1	-7.6	0.0	17.5
8	42.2	0.1	-5.1	0.0	18.0
9	43.9	33.5	-11.9	-8.7	15.25
10	21.9	18.7	-6.1	-4.5	14.88
12	60.0	9.8	-18.6	0.0	18.13
13	84.0	15.2	-24.0	0.0	19.63
14	79.8	30.9	-14.9	0.0	18.25
15	92.1	32.3	-23.3	0.0	19.50
16	89.4	11.7	-15.4	-2.1	19.13
17	77.9	24.4	-9.3	-4.1	19.38
18	87.6	45.4	-23.8	0.0	18.38
19	112.0	17.9	-39.7	-3.0	19.50
20	134.9	66.2	-28.2	-12.5	19.50
21	129.9	58.9	-30.6	-24.4	19.63
22	101.2	24.7	-32.5	-18.6	19.38
23	51.4	28.1	-7.7	0.0	17.13
24	155.6	81.7	-29.9	-11.5	19.88
25	113.6	56.7	-18.3	-3.8	19.63
26	137.4	115.9	-11.2	-2.1	18.75
27	121.4	85.9	-13.4	-6.6	20.88
28	82.4	48.5	-13.3	0.0	19.50
29	101.7	60.6	-11.9	-0.6	19.63
30	46.6	23.9	-6.4	0.0	19.38
32	132.7	72.5	-22.3	-20.5	19.88
33	161.0	97.1	-23.8	-6.0	20.00
34	76.5	52.7	-15.6	-12.9	17.25
35	120.2	72.4	-25.3	0.0	18.88
36	70.2	60.5	-6.4	-3.5	16.88
38	68.4	52.7	-9.6	0.0	17.25
39	24.9	18.6	-0.3	0.0	16.63
40	40.6	18.3	-1.5	-1.5	19.00
41	0.0	-11.7	18.4	0.0	16.7
42	0.0	-13.7	16.8	0.0	17.00
43	0.0	-14.6	13.1	0.0	16.63
44	0.0	-20.4	21.9	0.0	16.63
45	0.0	-17.8	17.9	0.0	16.63
46	33.5	5.5	-1.5	0.0	17.00
47	93.6	63.5	-14.0	-5.5	18.75
48	75.9	34.8	-21.1	-27.1	19.25
49	61.0	50.9	-10.6	-14.1	16.00
51	22.4	17.0	-5.6	-4.2	16.5

*Table 6.3: Outputs from EDUNE model for 24hr Storm surge for 47
Profiles from the BOP dataset*

- The maximum dune crest erosion is -34.0 m (profile 6 - Waiwhakatoitoi) with the mean being -5.2 m. However this result is influenced significantly by limited profile information landward of the reference mark resulting in excessive dune lowering due to 'sea wall' boundary effect;
- The 95 percentile upper and lower limits for DXDUNE (dune crest erosion) are -2.9 and -7.6 m respectively; and
- The mean time to maximum erosion (VMAX) is 18.33 hrs for the 24 hour design storm

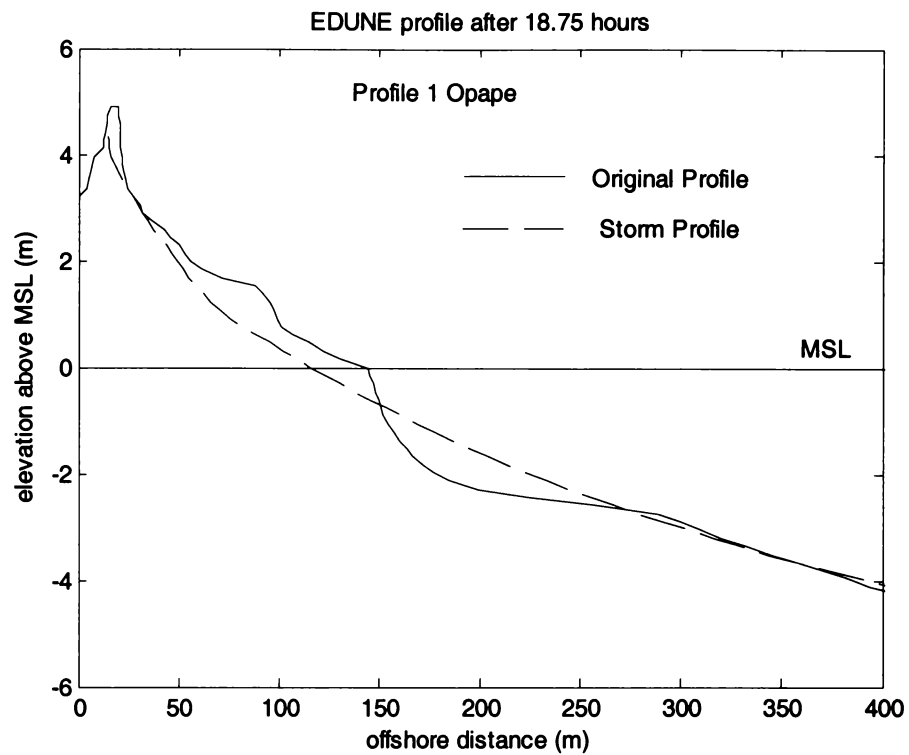
These statistics are contained in the following table

	VMAX	VSWFL	DXSWFL	DXDUNE	TIME
No	47	47	47	47	47
Min.	0.0	-20.4	-39.7	-34.0	14.88
Max.	161.0	115.9	21.90	0.0	20.88
Range	161.0	136.3	61.6	34.0	6.00
Sum	3423.0	1607.5	-510.0	-246.03	861.57
Median	70.20	32.30	-11.20	-1.5	18.88
Mean	72.84	34.20	-10.85	-5.24	18.33
U.95%	85.51	43.29	-6.87	-2.86	18.75
L.95%	60.16	25.12	-14.83	-7.61	17.92
Std error	6.30	4.51	1.98	1.18	0.21
Std Dev.	43.17	30.94	13.56	8.10	1.41

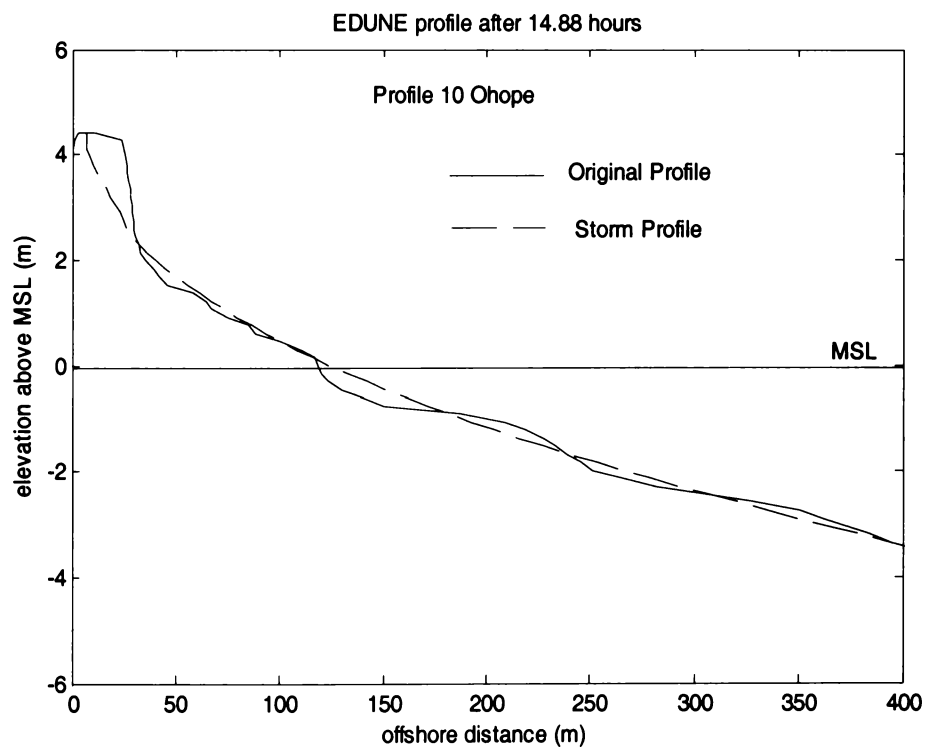
Table 6.4: Statistical analysis of results obtained from running EDUNE (shown in Table 6.3) using the design storm for the BoP profile dataset.

The EDUNE model also provides data output in a time series form. As part of the study this output was processed through a routine developed in MATLAB to plot the time series data contained in the output file EDUNE.DAT. This routine produces plots spaced at six equal time intervals during the storm cycle with the final profile plot produced representing the profile achieved at the time of maximum erosion. Examples of representative plots produced from BOP data are shown in the following diagrams. The original profile is shown as a solid line while the pecked line represents the profile obtained at the time of maximum erosion.

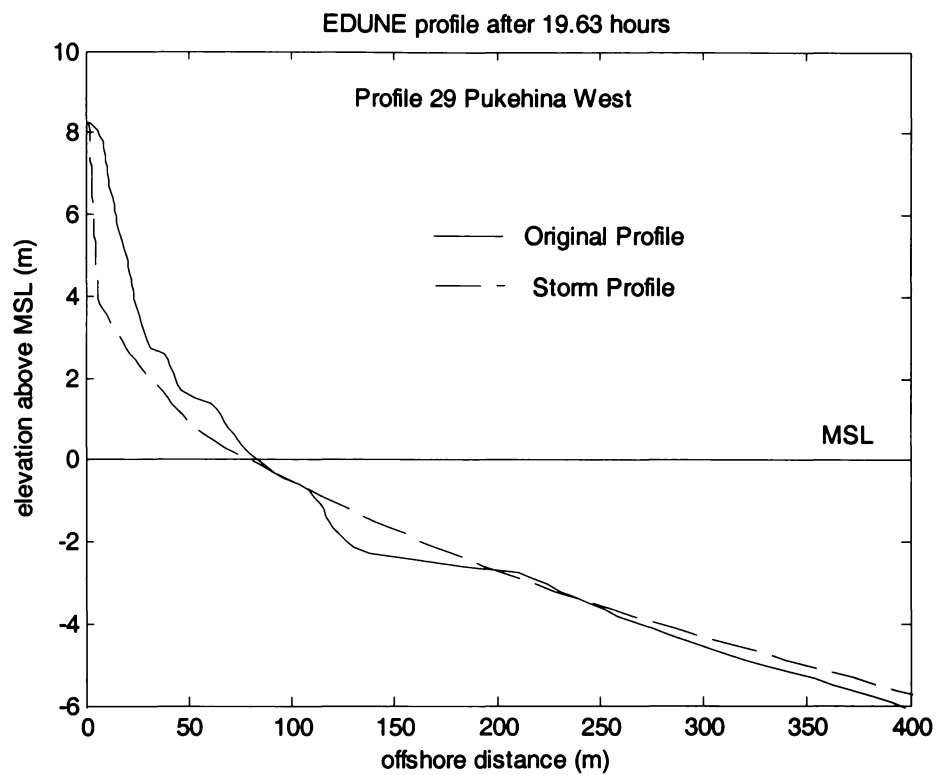
(a) Profile 1



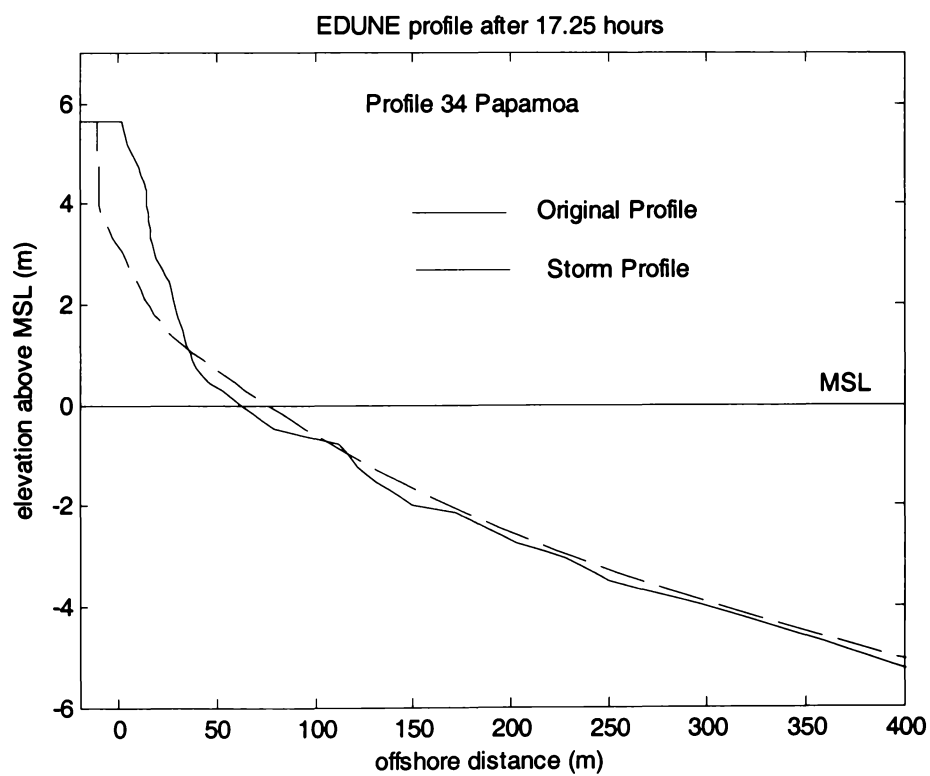
(b) Profile 10



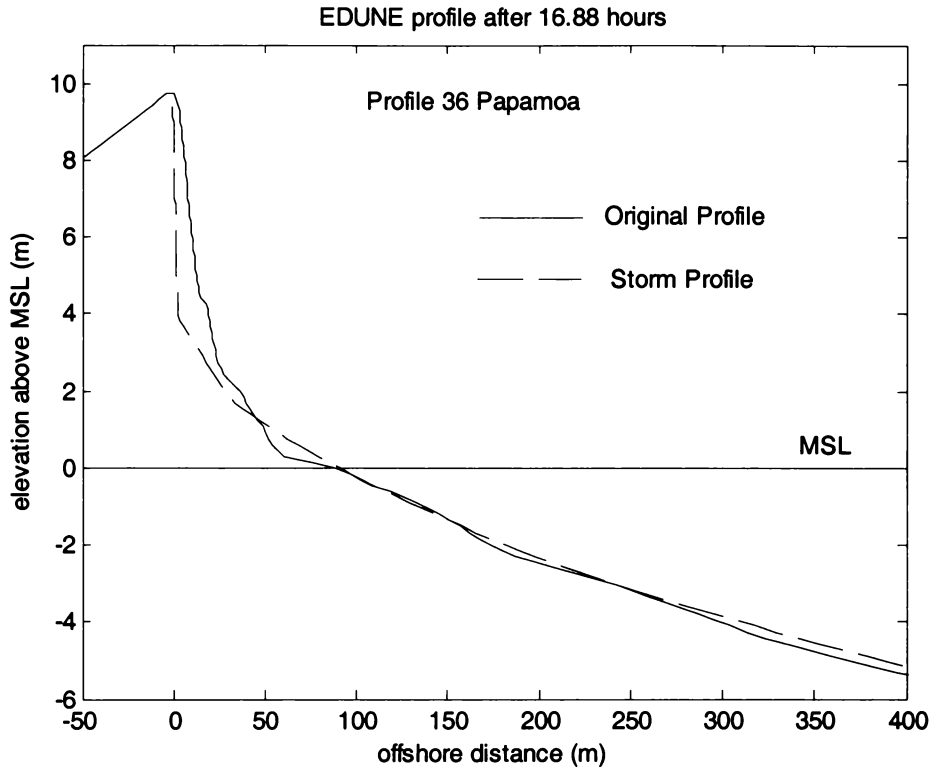
(c) Pukehina West



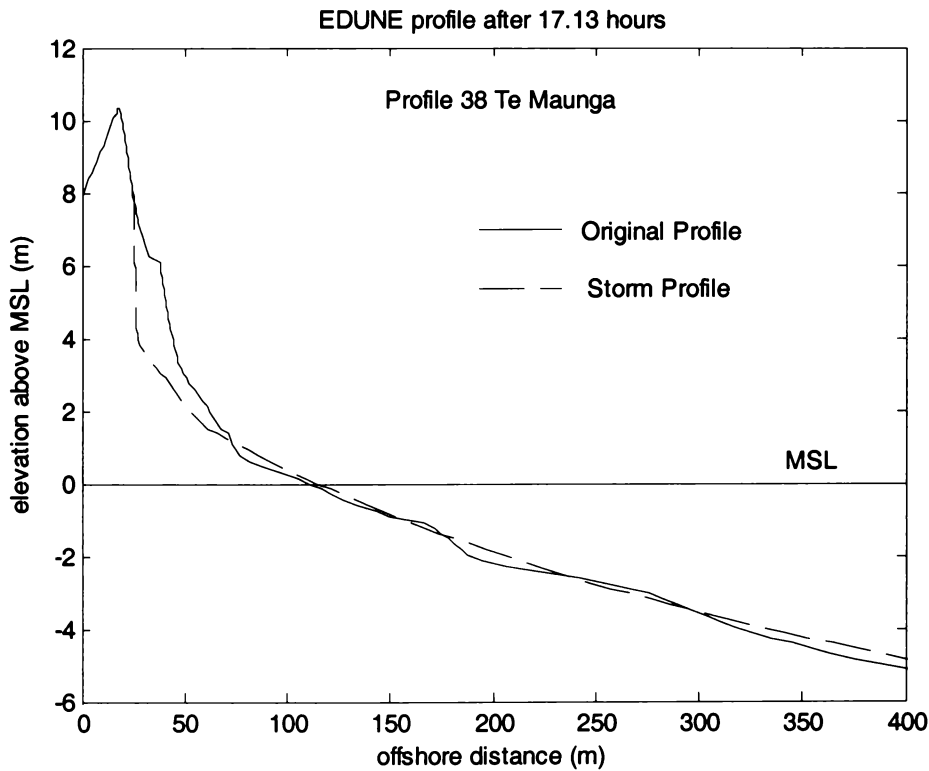
(d) Profile 34 (Taylor Street)



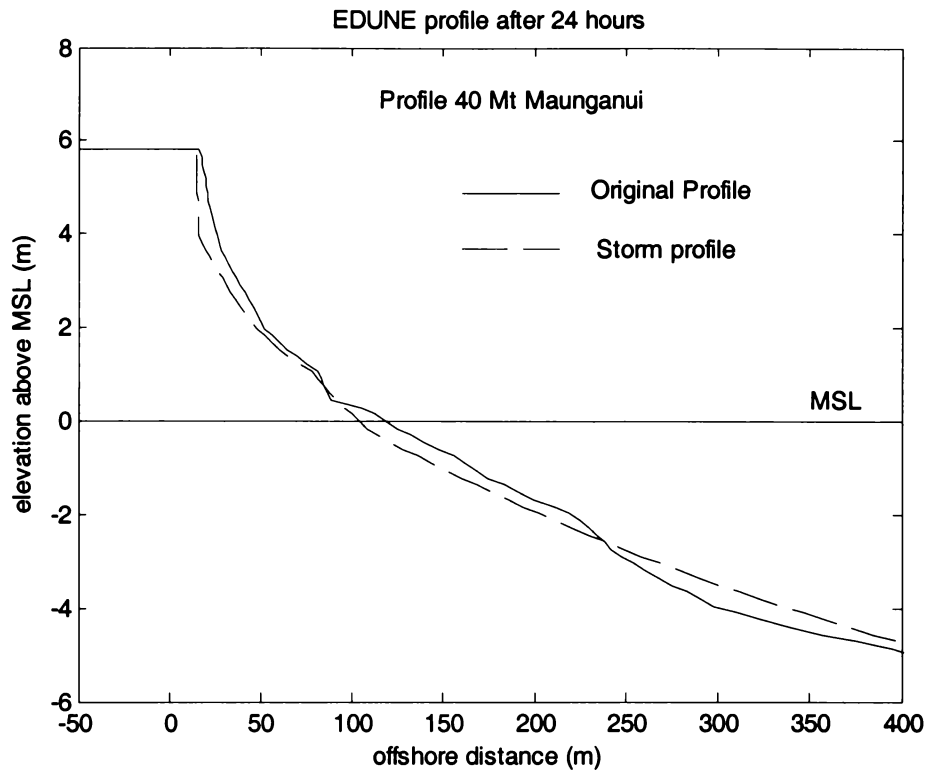
(e) Profile 36 (Papamoa Domain)



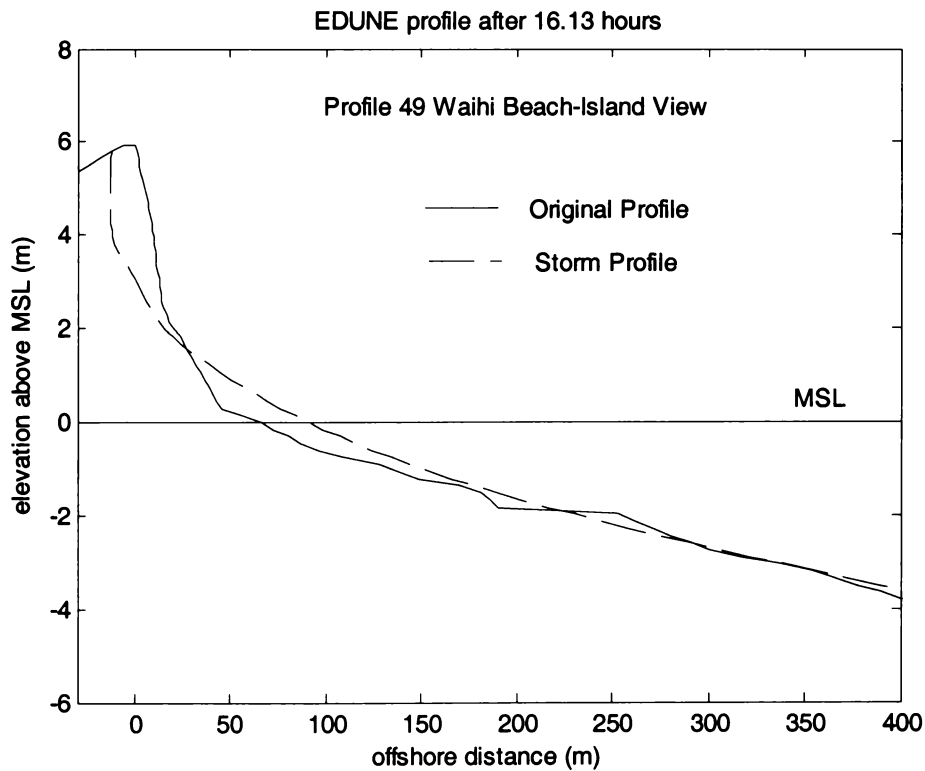
(f) Profile 38 (Te Maunga)



(g) Profile 40



(h) Profile 49



(i) Profile 51

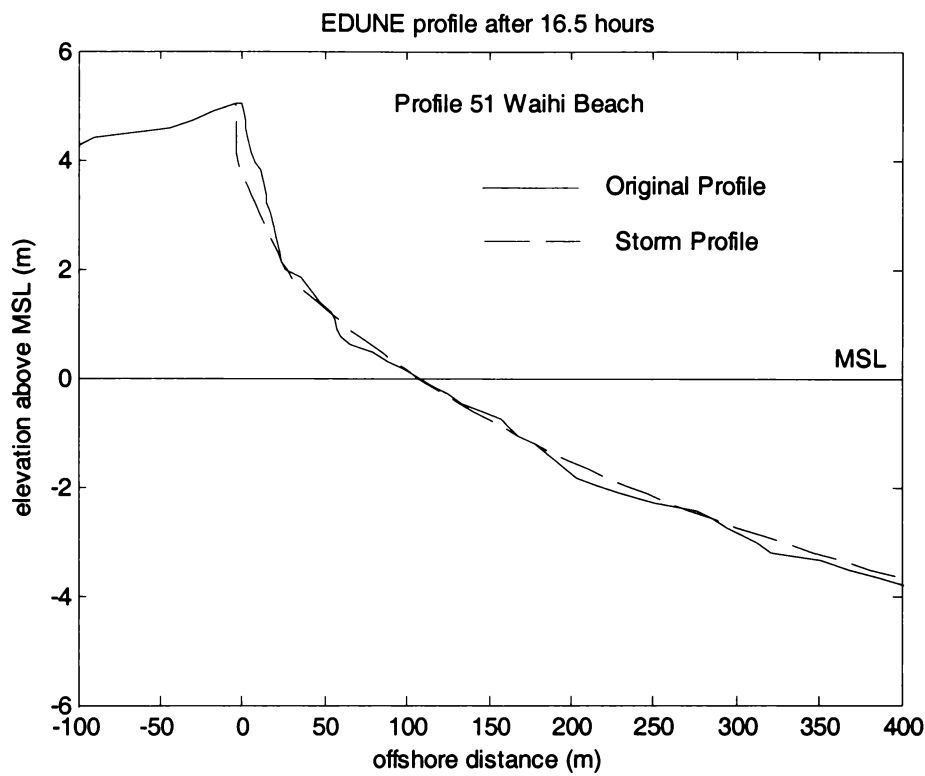


Figure 6.2: Examples of Plots from EDUNE showing profiles at time of maximum erosion (distances in metres) for the following profile sites: (a). Profile 1 (Opape), (b) Profile 10 (Ohope), Profile 29 (Pukehina West), (d) Profile 34 (Papamoa – Taylor St), (e) Profile 36 (Papamoa), (f) Profile 38 (Te Maunga), (g) Profile 40 (Mt Maunganui), (h) Profile 49 (Waihi Beach– Island View) (i) Profile 51 (Waihi Beach)

This 2 dimensional dune erosion modelling exercise has demonstrated the following:

1. That the mean cut out achieved above MSL for a storm of 24 hours duration is $72.8 \text{ m}^3\text{m}^{-1}$ of beach with a standard deviation of $43.17 \text{ m}^3\text{m}^{-1}$.
2. 26 of the 46 profiles are subject to erosion sufficient to remove the dune crest.
3. The model plots show that there are localised areas that will suffer flooding due to erosion and overtopping of the foredune. Areas at risk appear to be Opape-Hukuwai, Ohope, Piripai-Matata, Papamoa, and Bowentown-Waihi Beach. It is interesting to note that at Pukehina Beach the modelling depicted large erosion cuts but no or limited dune-crest erosion.

4. Maximum dune erosion for the conditions simulated in the modelling occurred along the Maketu - Papamoa coastal sector at profiles 32-34. Additionally large erosion values were also obtained for Bowentown at profile 47.
5. Maximum dune cut out occurs after about 18 hours.
6. Maximum dune crest erosion occurred in areas where there is limited urban or residential development. These include profiles located between Matata and Otamarakau (profiles 20 to 24). Dune crest erosion of between -11.5 and -24.4 m is predicted for these sites.

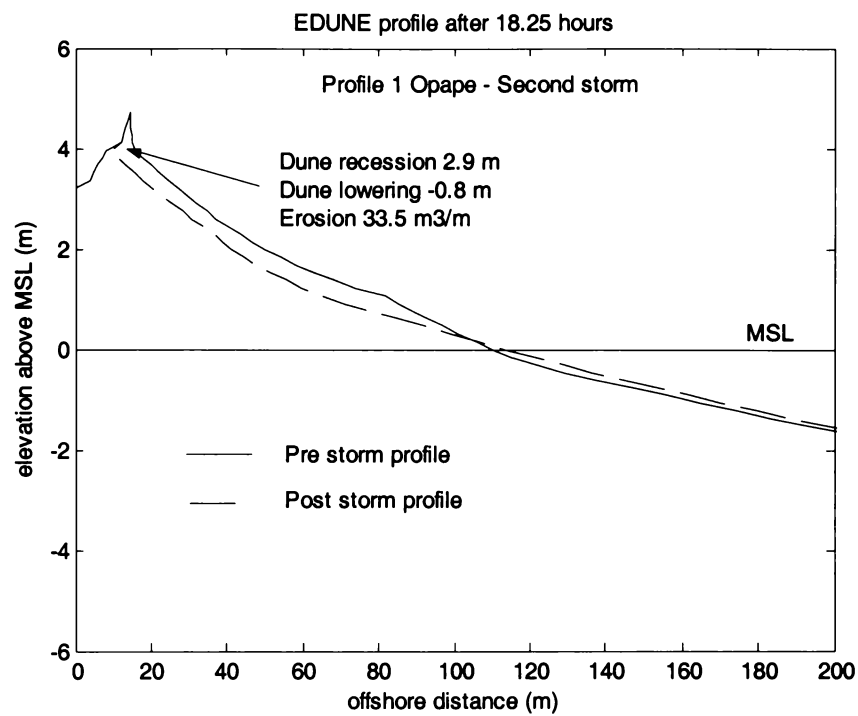
The above findings are considered consistent with historical and anecdotal evidence of episodic dune erosion in the BOP (Harray 1976; Healy 1993).

For technical reasons the model will not accept offshore bars within the simulation routines as no more than two locations along the measured profile can have the same elevation. For these cases the measured profiles required smoothing. This is considered only a minor disadvantage as the major forcing mechanisms in the model in determining the erosion profile are storm surge and run up elevations, and these principally affect the sub aerial beach. The offshore profile is then used to redistribute the sediment eroded from the beachface based on wave energy dissipation across the profile.

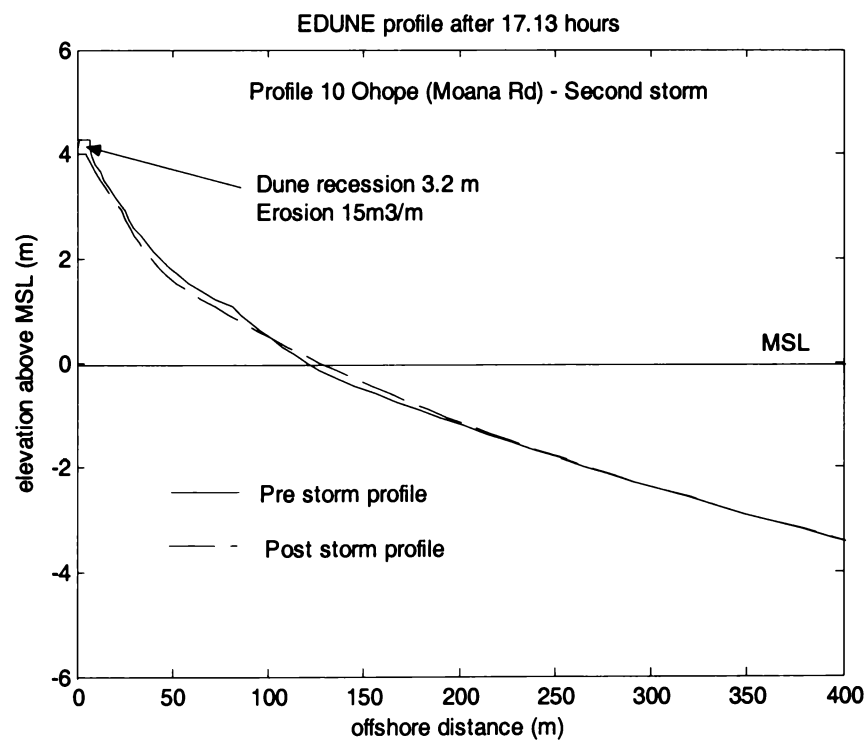
Effect of Multiple Storms

EDUNE was then run again to test the effects of two consecutive storms of similar duration and intensity without sufficient time for beach and foredune recovery. This represents a situation where two sub tropical cyclones affect the area within a 1 to 2 month period as occurred in December 1996 and January 1997 (cyclones Fergus and Drena - Blackwood, 1997). The approach was tested at Opape (Profile 1) and further tested on profiles at Ohope (Profile 10), Pukehina (Profile 29), Papamoa Profiles 36 and 38) and Waihi Beach (Profiles 49 and 51) as being representative profiles of those sites located adjacent to residential areas. The storm wave surge inputs were retained as previously described with the output plots shown in Figure 6.3.

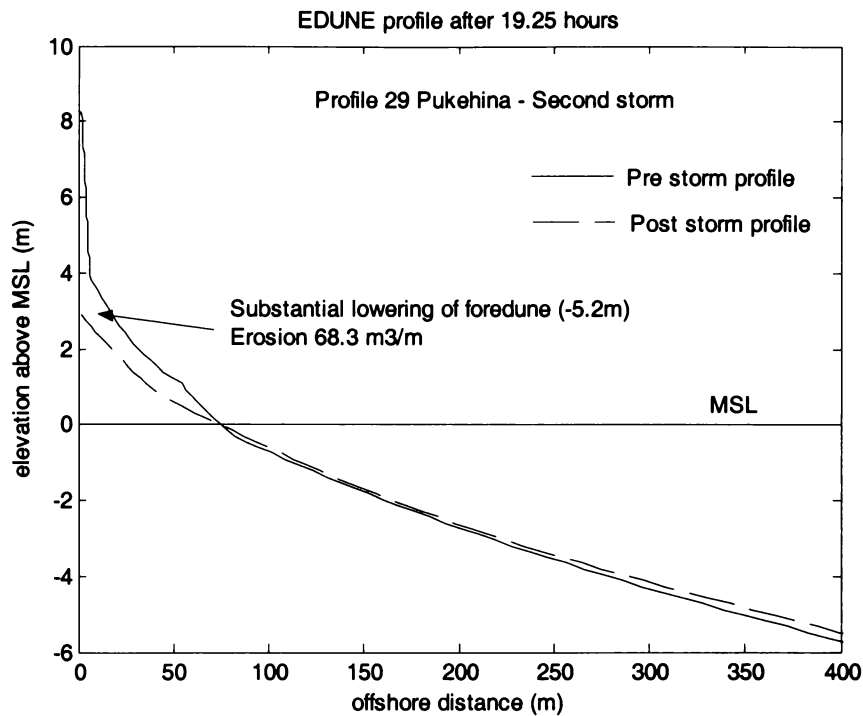
(a) Profile 1



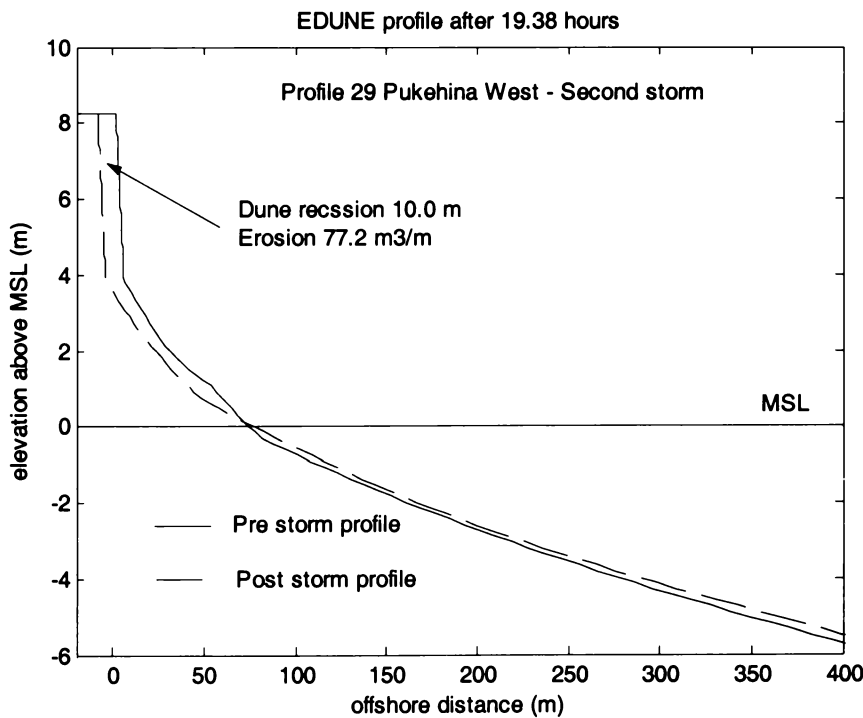
(b) Profile 10



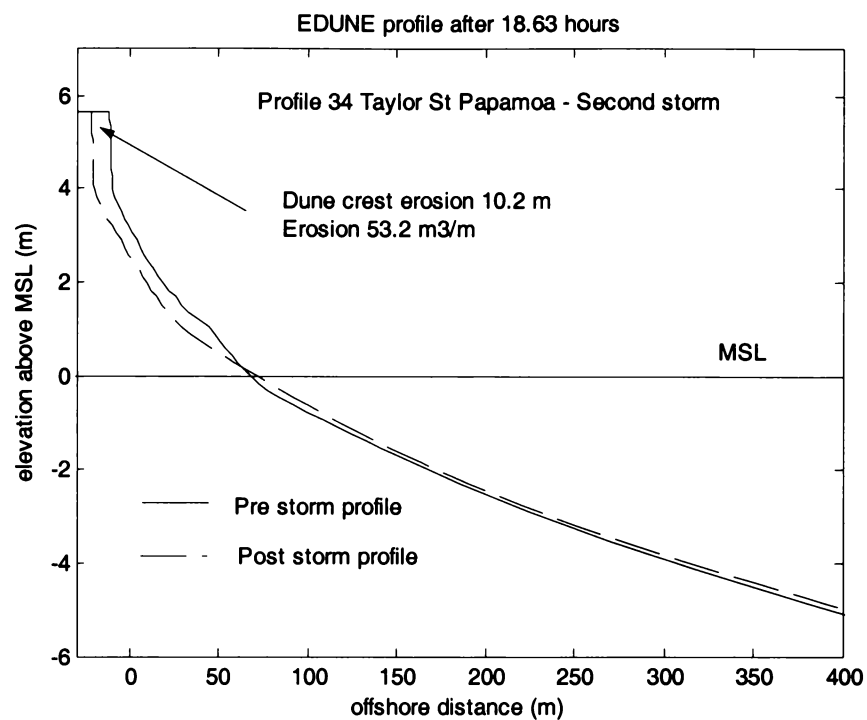
(c) Profile 29



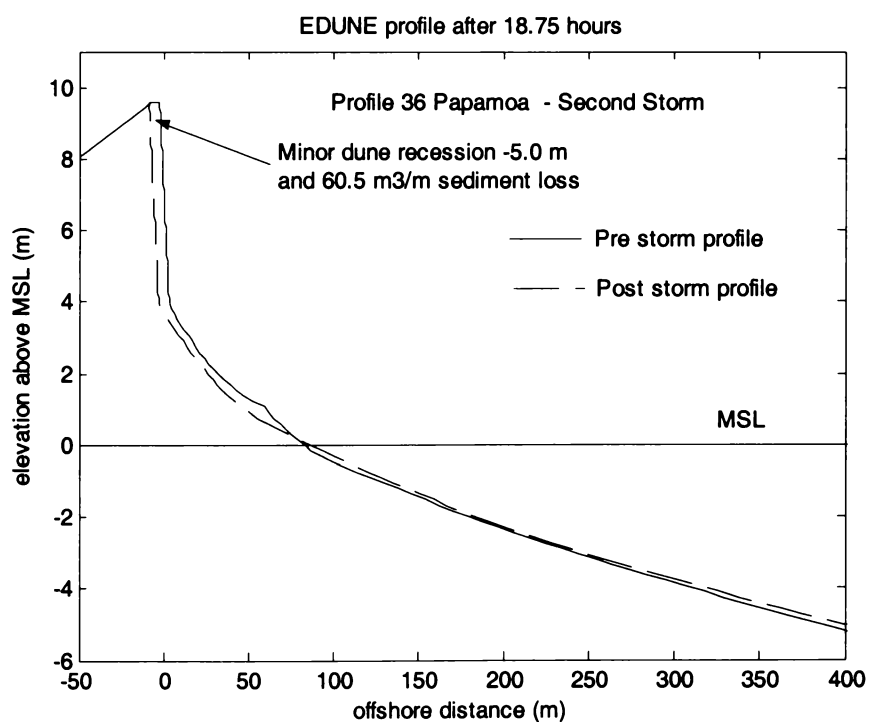
(d) Profile 29



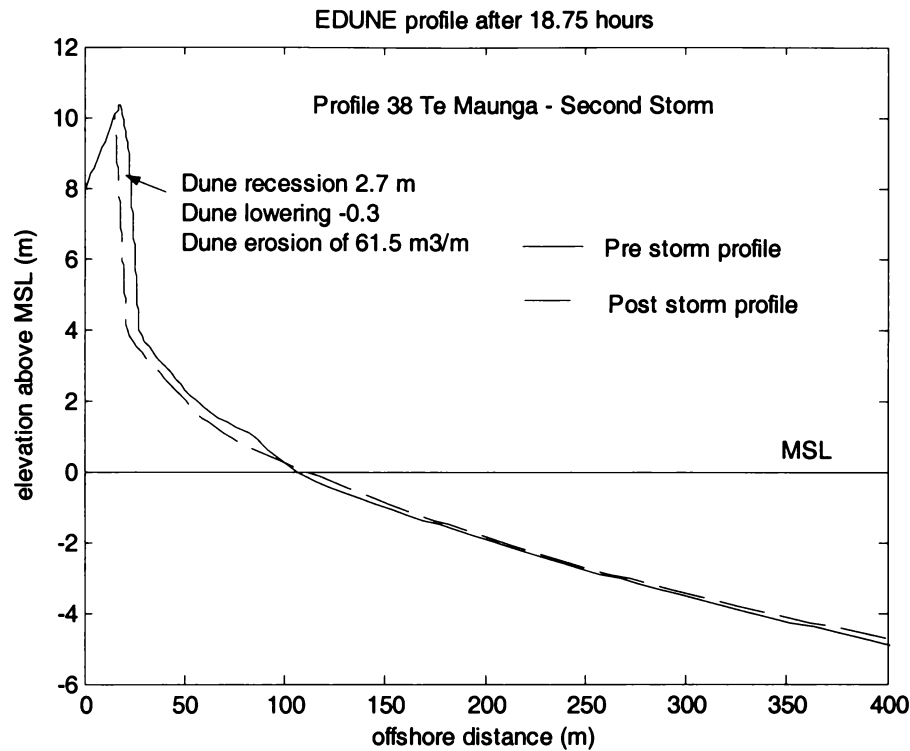
(e) Profile 34



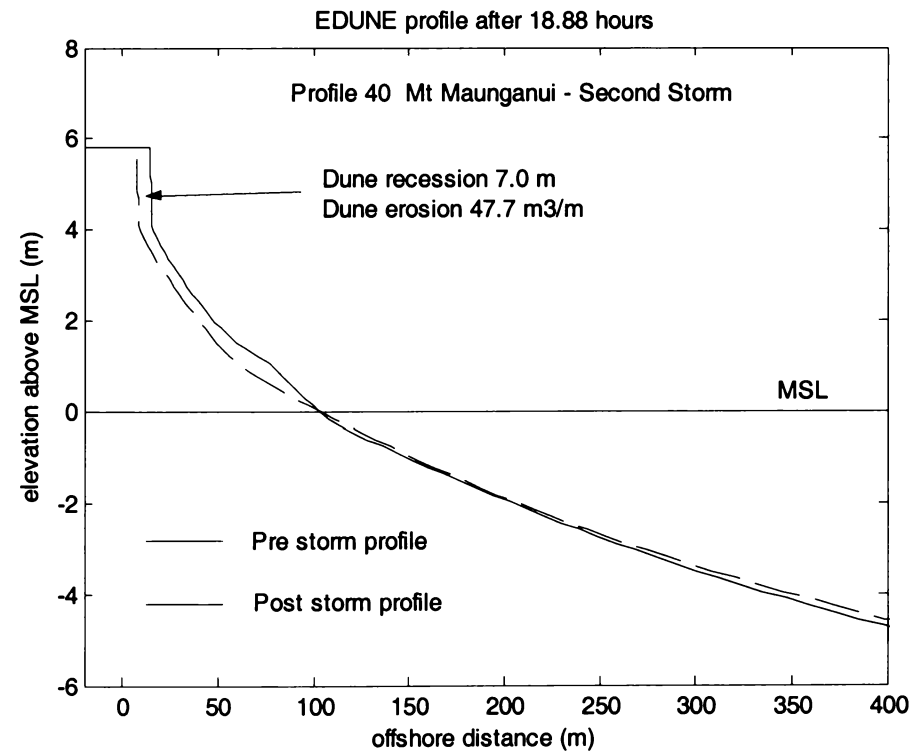
(f) Profile 36



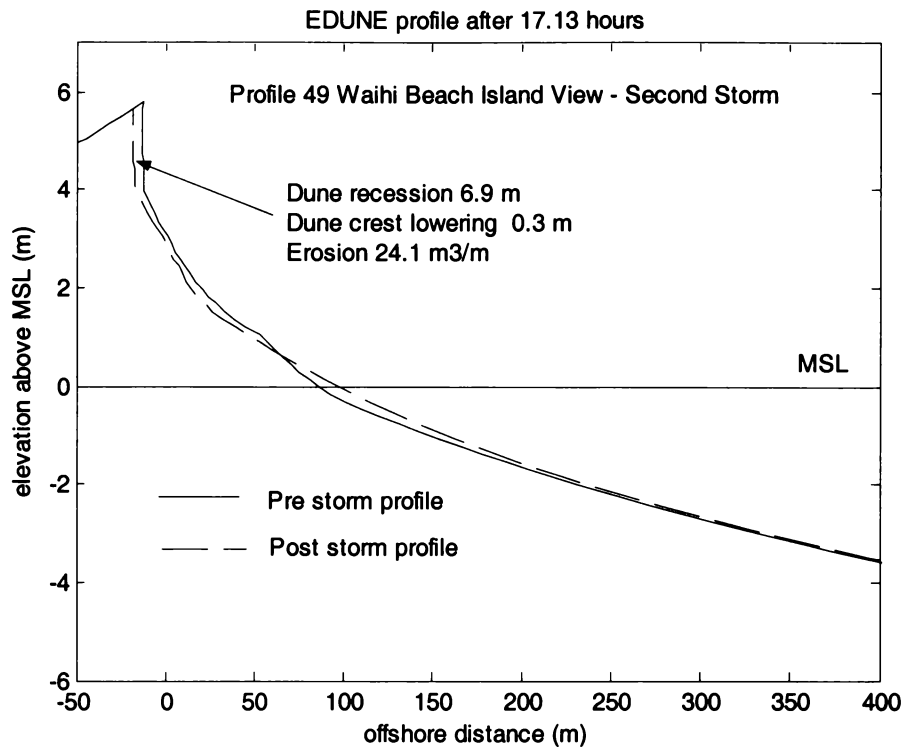
(g) Profile 38



(h) Profile 40



(i) Profile 49



(j) Profile 51

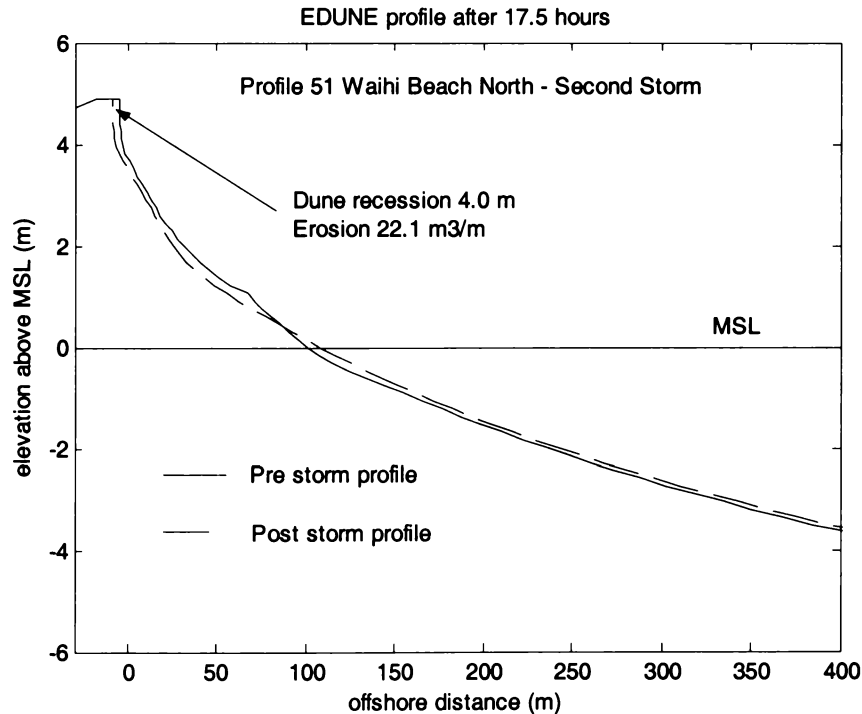


Figure 6.3: Profiles showing the effects of a second consecutive storm for the profiles shown in Figure 6.2: (a). Profile 1 (Opape), (b) Profile 10 (Ohope), (c) Profile 29 (Pukehina West) – seawall effect (d) Profile 29 (Pukehina West) (e) Profile 34 (Papamoa – Taylor St), (f) Profile 36 (Papamoa), (g) Profile 38 (Te Maunga), (h) Profile 40 (Mt Maunganui), (i) Profile 49 (Waihi Beach– Island View) (j) Profile 51 (Waihi Beach). All profiles show further erosion across the subaerial beach which in all cases resulted in dune crest erosion.

A summary of the results from this analysis is shown in Table 6.5 below.

Site No.	VMAX m ³ m ⁻¹	VSWFL m ³ m ⁻¹	DXSWFL m	DXDUNE m	Crest reduction m	TIME hr
1	33.5	7.5	-6.6	-2.9	-0.8	18.25
10	15.0	3.0	-1.7	-3.2	0.0	17.13
29	77.2	51.6	-8.8	-10.0	0.0	19.38
34	53.2	26.2	-8.9	-10.2	0.0	18.63
36	68.3	40.2	-5.5	-5.0	0.0	18.75
38	61.5	41.8	-5.4	-2.7	-0.3	18.75
40	47.7	19.6	-7.1	-7.0	0.0	18.88
49	24.1	12.5	-2.9	-6.9	-0.3	17.13
51	21.1	6.8	-2.9	-4.0	0.0	17.5
Sum	401.6	209.2	-49.83	-51.9	-1.4	164.0
No.	9	9	9	9	9	9
Min.	15.0	3.0	-8.9	-1.7	0.0	17.13
Max.	77.2	51.6	-1.7	-10.2	0.8	19.38
Range	62.2	48.6	7.2	7.5	0.8	2.25
Median	47.7	19.6	-5.5	-5.0	0.0	18.63
Mean	44.6	23.2	-5.5	-5.8	-0.2	18.27

Table 6.5: Result summary of EDUNE results for Second Storm for nominated profile sites in the BOP together with their descriptive statistics.

These results indicate the following:

- That all profiles underwent significant erosion as a consequence of the second storm.
- The average maximum volume eroded from the nine profiles was 44.6 m³m⁻¹ with a maximum 77.2 and a minimum of 15.0 m³m⁻¹ of beach.
- All beaches suffered dune crest erosion as a result of the second storm. The mean value of this crest erosion was -5.8m with a maximum of -10.2 and a minimum of -1.7 m.
- Three of the nine profiles were affected by dune crest lowering of up to 0.8 m.

These results are cumulative to the erosion incurred as a result of the first storm. Table 6.6 contains the aggregated values of the relevant erosion statistics to provide an overall picture for the nine profiles examined.

All nine profiles included in this analysis exhibited significant foredune erosion from consecutive applications of the design storm. While only three profiles showed foredune lowering, all were substantially eroded as described in Figures 6.2 and 6.3. The profiles suffering the most erosion were those with higher and more substantial foredunes such as sites located at Pukehina, Papamoa, Te Maunga and Mount Maunganui. These include areas where substantial urban settlement has occurred to a point

where houses located close to and immediately behind foredunes will be under threat from wash-over and avulsion. This reinforces known risks in these areas. Likewise while erosion volumes predicted for Waihi Beach are comparatively low the effects on the protective foredune are significant with threats of dune lowering reinforced by relatively low foredune heights with risks of significant wash-over effects from storm surge and wave run up.

Site No.	VMAX storm 1 (m ³ m ⁻¹)	VMAX storm 2 (m ³ m ⁻¹)	Total VMAX (m ³ m ⁻¹)	DXDUNE storm 1 (m)	DXDUNE storm 2 (m)	Total DXDUNE (m)	Crest height reduction storm 1 (m)	Crest height reduction storm 2 (m)	Total crest height reduction (m)
1	52.2	33.5	85.7	-3.6	-2.9	-6.5	-0.3	-0.8	-1.1
10	21.9	15.0	36.9	-4.5	-3.2	-7.7	0.0	0.0	0
29	101.7	77.2	178.9	-0.6	-10.0	-10.6	0.0	0.0	0
34	76.5	53.2	129.7	-12.9	-10.2	-23.1	0.0	0.0	0
36	70.2	68.3	138.5	-3.5	-5.0	-8.5	0.0	0.0	0
38	68.4	61.5	129.9	0.0	-2.7	-2.7	0.0	-0.3	-0.3
40	40.6	47.7	88.3	-1.5	-7.0	-8.5	0.0	0.0	0
49	61.0	24.1	85.1	-14.1	-6.9	-21.0	-0.3	-0.3	-0.6
51	22.4	21.1	43.8	-5.6	-4.0	-9.6	0.0	0.0	0

Table 6.6: Aggregated storm erosion values after two storms for nominated profiles where VMAX, is the maximum volume eroded above MSL expressed as m³/m of beach, DXDUNE is the horizontal erosion determined by the modelling for the foredune crest measured in m, and crest height reduction is a measure of foredune lowering in m.

6.5 Conclusion

EDUNE modelling has been carried out to determine the effects of significant storm (≥ 100 yr ARI) impacts on the coastal BoP. These impacts including erosion and inundation from dune overwash, often provide the most dramatic evidence of the power of the sea and storms. They provide the images that make 'news bulletins' but are often the things that people forget quickly, partly because they are relatively rare events within the scale of a human lifetime, but also because beaches often repair themselves quickly (i.e. in the order of months) so that any evidence of erosion and flooding is lost. However the reality is that the event will be repeated again sometime. Modelling of the type carried out here therefore provides us with an opportunity to replicate storms and their impacts in a demonstrable way.

The exercise described here has been carried out to forecast potential storm impacts. To ensure realism the relevant characteristics of significant storms have been reviewed and described from existing scientific literature (Frisby & Goldberg 1981; de Lange 1993; Revell & Gorman, 2003; de Lange & Gibb, 2000) and a design storm has been defined based on these characteristics. The design storm has been conservatively described

in order to adequately represent the risks involved to human property and life and to incorporate the vagaries of storm and wave energy variations (such as wave focussing) impacting at all the numerous locations along the coast.

The design storm has been applied to 47 of the profiles in the BoP dataset. Additionally a consecutive design storm has been applied to selected profiles both to test the beach susceptibility to increased storm frequency envisaged under regional climate change scenarios, climate cycles such as IPO and ENSO (de Lange and Gibb; 2000; Goring and Bell 1999), and as a sensitivity analysis to cover the implications of such events on shoreline recession and erosion should a second storm impact the area. The results of these assessments are shown in Tables 6.3, 6.5 and 6.6 with the second storm resulting in an averaged 43% increase in sand erosion volumes, and further erosion and lowering of the dune crests leaving the back dune areas susceptible to inundation from storm surge and wave runup effects.

So how do we know that the results provided by the modelling are reasonable? Pullar (1978) documents the impacts of the 1968 storm (Cyclone Gisele) on the Bay of Plenty. These included the following (see also Figure 6.4):

- *“Erosion of the storm-beach berm and up to half of the foredune some of which was fern vegetated. East of Opotiki hangi stones and the skeleton of a horse were seen in the resultant cliff face of 4 m to 6 m high. The sand, however, was replaced after a short interval. No evidence of sea erosion was seen after a period of five months;*
- *Sea water flooding in swales behind the foredune. The sea water poured through gaps in the foredune (walkways) and left behind tell-tale flotsam and jetsam;*
- *Sea water overtopped the foredunes at Matata and at Maketu near the mouth of Kaituna River. At the former place the sea water has been known to cascade over the foredune 1906 and 1926. Sea water also flowed over the dunes between Matata and Otamarakau and encroached on the railway;*
- *Sea rafted logs of timber and driftwood cast high up on the beach was a common reminder of the storm on the Bay of Plenty coast. The logs were thrown as high as 5.6 m at Whakatane Heads and at the mouth of the Rangitaiki River, and about 3.3 m at Piripai midway between the above mentioned points on the coast. At Piripai the logs became hidden by wind blown sand...At Ohope Beach settlement logs were deposited on the road and the domain at the foot of Ohope Hill;*
- *Sea water flooding ... in river and stream estuaries and on associated low lying pasture ... at Te Tumu near the mouth of the Kaituna River, at Matata on the eastern side of the Rangitaiki River mouth.” (Pullar, 1978)*

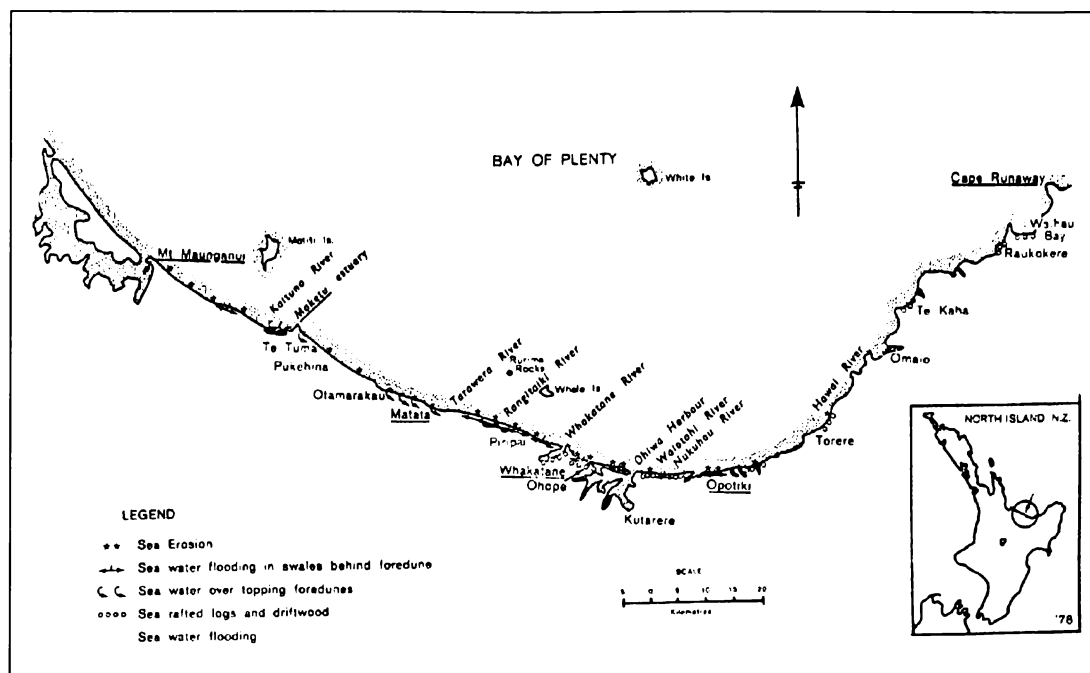


Figure 6.4: Locality showing coastal storm effects from Cyclone Gisele (Pullar, 1978)

Healy (1993) describes a maximum recorded storm cut in the Bay of Plenty with a dune retreat of 18 to 20 m recorded at Bowentown in 1978 with a profile sweep of 130 -140 m² sweep above MSL. He also calculated design wave run up values based on a maximum breaking wave height of 11.5 m of approximately 4 m at Waihi Beach (north) to about 5.4 m at the Bowentown end. These are higher values than those used in the EDUNE modelling, because the model uses time varying wave energy dissipation as a means of determining profile response where H_{rms} more closely reflects the total incoming wave energy (Kriebel, 1989).

Gibb (1997) and De Lange and Gibb (2000) noted also that the largest storm surges were associated with extra tropical cyclones with Gibb (1997) noting maximum sea levels between 2.3 and 2.5 m above MSL within the relatively sheltered Tauranga Harbour during three cyclone events on the 2 February 1936, 6-8 March 1954, and 9-10 April 1968 (Cyclone Gisele). This relates to storm surges of approximately 1.1 to 1.7 m after tidal elevations are eliminated. Gibb (1997) notes that both the 1936 and 1968 events occurred during neap tides and the 1954 event during spring tides. Had these storm occurred at spring tide it is likely that maximum sea levels would have been closer to 3 m above MSL. If wave set up and run up are added to this then the water level reached by waves could have been 1 to 1.3 m higher than those recorded within Tauranga Harbour sufficient to produce the sort of problems identified by Pullar above.

De Lange and Gibb (2000) have noted both seasonal, interannual and decadal cycles in the storm surge database for the Bay of Plenty. They note that storm surge magnitude and frequency vary over decadal

timeframes and that recent research suggesting that the IPO has changed states in the North Pacific and by teleconnections this can be expected to affect the climate of the South Pacific. As a consequence the conditions that were associated with larger and more frequent storm surges during the period 1960-76, may be expected to prevail for the next few decades, implying that the beaches of the BoP will reflect such influences and show more erosive tendencies.

As a consequence of this discussion the inputs and results obtained from the modelling are considered to be appropriate and of the right scale to identify storm erosion hazards at the various beach monitoring sites located around the Bay of Plenty.

Chapter 7

Coastal Hazard Identification and EBP Modelling – Conclusions, Major Findings and Further Research

7.1 Introduction

The overall aim of this thesis was to apply two dimensional parametric modelling utilising Equilibrium Beach Profile (EBP) theory to coastal hazard assessment. Three broad scale objectives were set to achieve this aim. These were stated in Chapter 1 and included the following:

- 1) Investigation of a number of Bay of Plenty Beaches to determine how well the EBP concept characterised these sandy beaches. This analysis took into account the effects of sediment variation along the beach profiles, and used this information to predict the equilibrium status of these beaches and their potential to erode or accrete. The following specific analyses were undertaken:
 - to determine representative values of the scale parameter, A , and the shape parameter, m , for the measured beach profile using least square analysis;
 - to evaluate the relationship between the A parameter and sediment grain sizes and fall velocities in order to compare these with the established relationships for grain size (Moore, 1982) and fall velocity (Dean, 1987); and
 - to ascertain the influence of additional terms or alternative forms of the EBP equation to represent realistic shoreline slopes, cross-shore grain size variation and shoreline response characteristics.
- 2) Application of the EBP concept to various sea level rise scenarios to predict long-term (50 to 100 year) beach responses to eustatic sea level change by applying a variation of the basic Dean/Bruun model to the profiles contained in the Bay of Plenty dataset.

- 3) Application of EBP for the prediction of short-term coastline responses to changes in relevant forcing conditions including tides, storm surge and wave climate. This has involved the development of various design storm scenarios for use as input into the Kriebel (1989) model EDUNE to forecast short term dune cut responses to various design storm events.

Chapters 4, 5 and 6 document the application of equilibrium beach profile theory to coastal change behaviour at timeframes ranging from instantaneous and short term events (i.e. generally less than a year up) through to inter decadal timeframes ranging up to a century. Chapter 4 focused on short term profile adjustments caused by profile disequilibrium; Chapter 5 discussed profile changes over the long term (i.e. years to decades) caused by future sea level rise; while Chapter six describes the modelled profile responses to sudden increases in incident wave energy caused by significant storm events forcing profile change over event scales of days to weeks.

This final chapter draws together the research findings described in the previous chapters in order to document alternative elements for use in defining coastal hazard zones (CHZ) using Bay of Plenty (BoP) data. Additionally it documents the significant research findings, and provides suggested directions for further research or investigations required to resolve identified inconsistencies, limitations or problems arising from the research results.

7.2 Coastal Hazard Zones

Coastal hazards are essentially a human perception of impacts associated with natural phenomena (e.g. storms, waves, storm surge, sea level rise, flooding). Often they can be problematic for human settlement. One way of dealing with them is to quantify their impacts so as to provide for them in coastal management decision-making - one example being the delineation of coastal hazard zones or construction control lines. As already stated one principal objective of this research was to investigate the application of and contribution of EBP theory to CHZ definition and assessment, and to quantify where possible the nature of impact involved.

Coastal Hazard Zones in New Zealand were originally defined by Gibb (1981) “...as an adequate width of land between any development and the beach”. As Healy (2002) points out the hazard zone was by implication defined by the potential of identified risks to damage or destroy beachfront property and assets. Healy (2002) further defines the zone as, “...a sector of coastal terrain that is subject to hazards from the marine environment. Mainly the hazards become manifest as storm wave erosion of the frontal dune, storm surge

and flooding of coastal lowland, wind erosion of the dunes, or tsunami wave damage and wash over flooding."

Coastal hazard zones and building set backs involve the determination of distance (i.e. from the coastline) with distance often equating to safety. However as Kaufmann and Pilkey (1983) state, "*What protects a building is not its distance from the sea, but the volume of sand between it and the sea.*" Healy (1993) recognised this in his CHZ formulation which incorporates an allowance for foredune 'bulk' where he adopted the Dutch minimum dune reservoir volume of $400 \text{ m}^3\text{m}^{-1}$ as a minimum test condition to be met for the calculation of any CHZ. Additionally Coastal Hazard Zones should also recognise and provide for coastal inundation and the effects of tsunamis as well as wave erosion and sea level rise in order comprehensively address hazard, something which falls beyond the scope of EBPs and this thesis.

7.3 Significant Research Findings

The work described here has applied Equilibrium Beach Profile theory to the beaches of the BoP principally to assess the effects of waves and sea level rise on shoreline location. It has done so from varying perspectives and includes the following of relevance to coastal hazard zone definition.

Application of Wright and Short beach morphodynamic model to the BOP dataset

The Wright and Short (1983) morphodynamic beach model was reviewed as part of the initial work carried out for this thesis. Conceptually the model provided a useful reference point from which to describe the coastal geomorphology and to introduce a three dimensional element into what is essentially a two dimensional assessment. Additionally the model introduced a temporal component into the process of beach and profile evolution, varying as beach state and wave energy inputs to the beach system change over time.

The beaches represented in the BoP profile dataset were classified using Dean's parameter Ω (Equation 2.1) which utilises sediment fall velocities and breaking wave height as a means of determining Beach State. The beach states covering the dataset are shown in Table 2.3 with the majority of beaches being classified as Intermediate. Accordingly these beaches will be quite responsive to changes in the forcing environment and will therefore change their beach state relatively rapidly as incoming wave energy and water level changes (~ 0.5 beach state per day). However the amount of energy required to achieve significant changes for beaches that lie at the extremes of the model spectrum (e.g. Dissipative and Reflective) are shown to require sustained wave energy inputs over time (in the order of several days to weeks) in order to achieve significant changes of beach state (see Figure 2.22). This is unlikely given the wave climate of the BoP.

Hence significant changes to beach morphology are unlikely to occur at northern Waihi and West End Ohope beaches, both of which are classified as dissipative beaches.

On the other hand it can be expected that the majority of the intermediate beaches with their apparent profile disequilibrium (see Table 4. 15 and 4.19) will be in a constant state of flux, changing their beach state and morphology over periods of days in response to changes in the wave climate.

Closure depth analysis and determination for the BoP

The analysis of profile and wave data using a range of methods was carried out to determine an appropriate closure depth for use in the EBP modelling. This was assessed independently for each profile in three ways, all of which gave generally consistent results. The methods included estimation from geologic and geomorphic evidence; determination of closure depth from time series data, and estimation of theoretical closure depths using wave climate models. The range of observed closure depths (or the limit of significant sediment exchange) obtained from profile comparison measured in this way ranged between 6 and 8 m depth from MSL thus further confirming the observations of other writers and researchers.

The utility of the Dean Equilibrium Beach Profile

The theoretical derivation of the power equation was considered in terms of linear wave theory and uniform wave energy dissipation per unit volume as described by Dean (1977). This derivation was replicated (see Chapter 3) using the work of Larson *et al.* (1996a), which indicated that the curve and its parameters have a robust and rational foundation within linear wave theory.

The power form of the Dean (1977) equation was then fitted to all profiles by least squares 'blindfold' analysis allowing both the scale (A) and the shape factors (m) to vary freely so as to minimise the residual error. This analysis confirmed the utility of Dean's exponent value of $\frac{2}{3}$ based on uniform wave energy dissipation per unit volume. Additionally applying Students t tests for the 8m closure depth indicated no significant differences between the mean shape factor obtained from the BoP profiles at the 90, 95 and 99 % confidence limits and the shape factor determined by Dean (1977).

This process was then repeated holding the shape factor m (Equation 3.1) at $\frac{2}{3}$ while allowing the scale factor A to vary accordingly. The resulting scale factors were then compared to those obtained directly from the sediment sampling. This indicated a reasonable correlation based on a log-log relationship as found by Dean (1987). Scatter plots of the results

were then overlaid against the plot of Dean (1987) with results from the 6 and 8 m closure depths providing the best agreement with Dean's work.

Application of EBP in predicting beach equilibrium state.

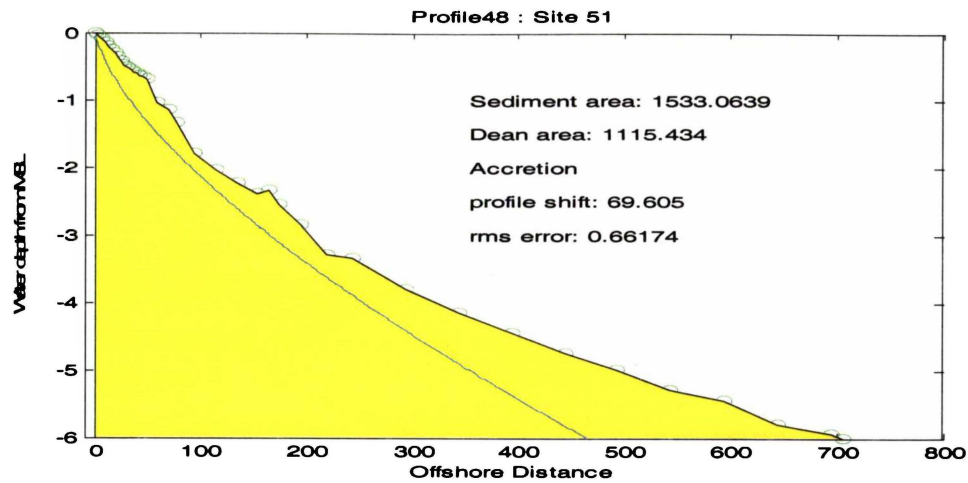
Initially four different variations of the Dean (1977) profile were fitted to the 1993 BoP dataset to assess the equilibrium status of individual profiles contained in the BoP dataset. This was carried out using routines developed in MATLAB. The model variations included:

- the Dean equation with profile averaged scale factor derived directly from the sediment sampling for the profile;
- the Dean profile with piecewise variation of the scale factor according to the sediment sampling;
- the Kriebel and Dean (1985) modified profile incorporating a gravity term to address the infinite slope problem at the shoreline with profile averaged scale factor; and
- the Kriebel and Dean model with piecewise variation of the scale factor as described previously.

The results of this analysis are shown in Tables 4.13 to 4.19, with examples of the output plots from the MATLAB shown in Figures 4.16 to 4.19. Tables 4.15 and 4.18 describe the predicted profile equilibrium responses with the outlier profile removed (i.e. the profiles containing ebb tidal deltas) for three closure depths (6, 7 and 8 m). Generally the results of the analysis indicate that Dean's (1977) profile with a profile averaged scale factor best represents the dataset as measured by the residuals (Table 4.14) and produces an overall result indicating that the BoP dataset is very close to equilibrium (see Table 4.15). Table 4.19 then compares the Dean model's predictions for two closure depths with historical beach erosion data for the BoP indicating that the results are generally consistent with the recorded survey data of erosion and accretion.

However despite this there are some anomalous results in particular those relating to the dissipative beaches at northern Waihi and West End Ohope (see Table 2.3). It is noted that both beaches are situated to the southeast or east of significant headlands which act as large scale natural groynes. Both beaches have relatively shallow gradients in comparison to the dominant intermediate beaches of the BoP. Both have suffered equally from historical erosion, although the evidence appears somewhat equivocal on this when considered over longer timeframes (Healy, 1993; Gibb & Reinen-Hamill, 1997; Hodges and Deely, 1997). Both beaches are also fine grained and if the Wright and Short beach state model is accepted as proposed, then the profiles will display the physical characteristics of an eroded beach while being relatively stable under a low wave energy environment. They will also be notoriously resistant to morphological change (Wright and Short, 1983) irrespective of the presence of surplus sediment.

a)



b)

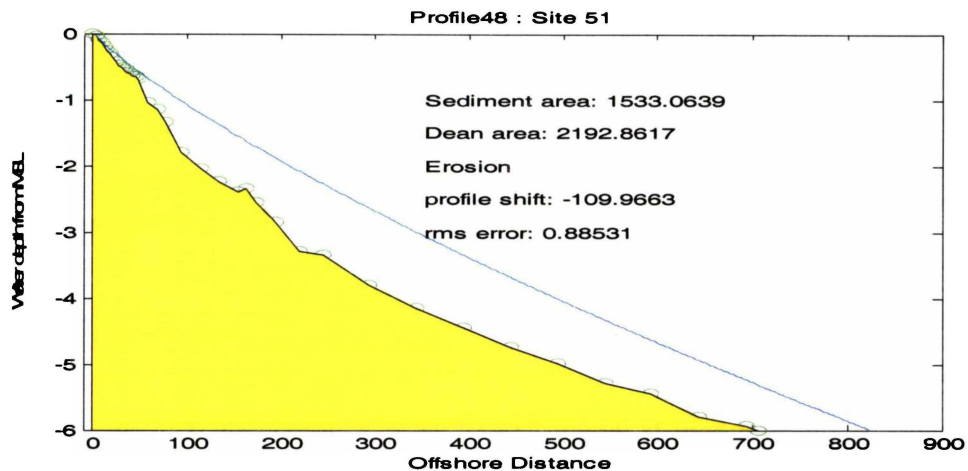


Figure 7.1: Profile equilibrium predictions for Profile 51 at Waihi Beach (North). Figure a) is the equilibrium prediction profile using Dean's (1977) equation with profile averaged shape factor "A". Figure b) is the same profile predicted using Kriebel and Dean's (1985) profile with gravity term

If this proposition is accepted and the equilibrium status of both beaches is in fact accretional as predicted by the Dean (1977) model (see Figure 7.1(a)) then it leaves open the question as to why an apparent surplus of sediment exists offshore as predicted by the model. It may be that this sediment surplus represents a sink or low energy zone; or alternatively it could result from littoral drift or "sediment cycling" associated with ENSO cycles as proposed by Hicks *et al.* (1999). It is interesting to note that these authors observed accretion at the north end of Waihi Beach at the time of profile measurement for the BoP dataset which they associated with an ENSO driven three year cycle of accretion and erosion occurring at Waihi.

Bradshaw (1991) and Bradshaw *et al.* (1991, 1994) also offer a further explanation in terms of identified currents and sediment transport

patterns operating offshore of Waihi Beach (see Figure 7 2), while Gibb and Reinen-Hamill (1997) note a net transport rate to the NW of $72,000 \text{ m}^3 \text{ yr}^{-1}$ based on work by Macky *et al.* (1995) from data obtained during an exceptionally long El Nino phase between 1991 and 1993. Therefore their data are biased to winds from a south-south westerly direction (i.e. an offshore direction).

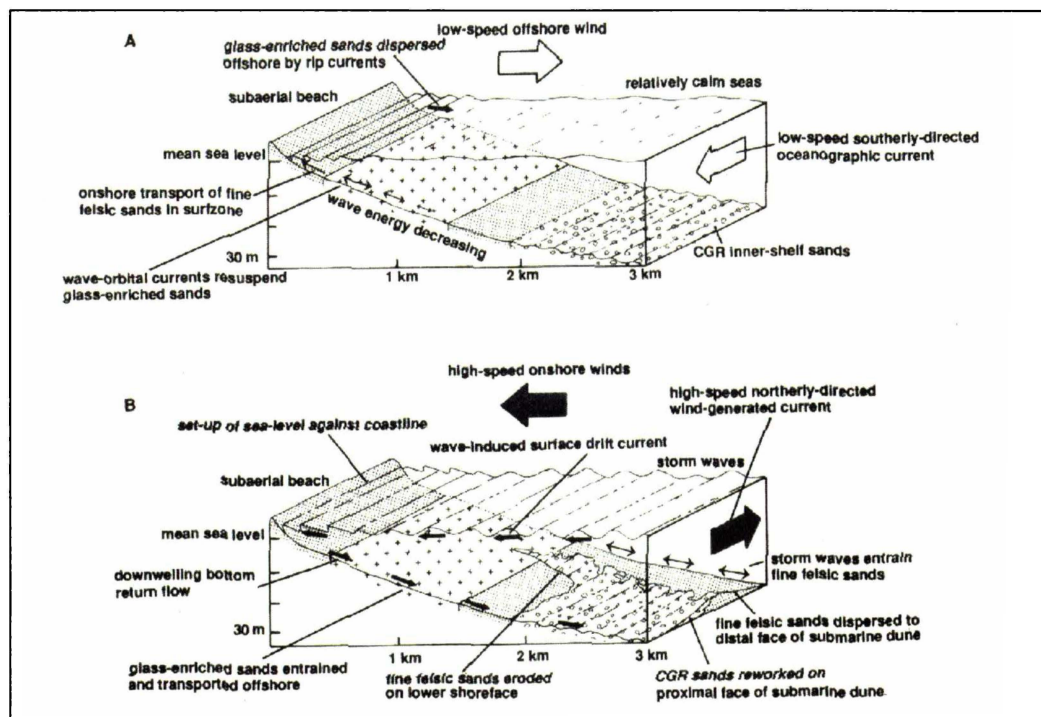


Figure 7.2: Bradshaw *et al.*'s (1994) conceptual model for inner-shelf dynamics and sediment dispersal on the east Coromandel shelf. (A) Calm weather periods are dominated by upper shoreface deposition of very fine glass- enriched sands. (B) Episodic stormy periods are characterised by erosion and offshore transport of shoreface sediments by downwelling currents, and intense shore-parallel northerly directed transport of coarse-grained ripple sands (CGR) and fine felsic sands into submarine dunes by wind generated currents (Source: Bradshaw *et al.*, 1994)

Wang and Davis (1998) describe an evolutionary equilibrium beach profile model consisting of a compound curve with three zones described as the surf, nearshore and landward bar slope. While the model replicated the BoP beaches extremely well when both the shape and scale factors were allowed vary to meet least squares criteria, the model failed to replicate the success of Wang and Davis when the model was applied to the BoP data using fixed scale and shape parameters derived directly from the local data. Consequently the model was discounted from further analysis and application.

Sea Level Rise

The derivation of the Bruun Rule in terms of Equilibrium Beach Profile theory was derived in section 5.3 directly from Dean's (1977) profile of equilibrium thus confirming Dean's (1991) assertion of equivalency with the Bruun rule. Therefore Bruun's Rule was subsequently used to determine the sea level rise (SLR) response to the IPCC "business as usual" sea level rise scenario. This was calculated using a routine developed in MATLAB for the purpose and applied to the 1992 BoP profiles with the results of this assessment shown in Table 5.4.

It is recognised that these results represent a two dimensional assessment of the beach states. However ideally there is a need to improve such assessments to take into account the three dimensional morphodynamics of the coast over time. Reference to some of the literature on Large Scale Coastal Behaviour (LSCB) (Cowell & Thom, 1994; Cowell *et al.*, 2003; Stive, 2004; and Zhang *et al.*, 2004) led to the application of equivalent approaches to sections of the BoP coast where sediment budget information either exists or where surrogate long term progradation rates are known.

Two coastal sectors were identified from the stratigraphic and geologic record as exhibiting significant long term progradation. The two areas (the Rangitaiki Plains and the Te Puke Lowlands) were analysed by applying littoral sediment inputs (as annual rates) as budgetary input into the SLR assessments. In the case of the Rangitaiki Plains this led to the inescapable conclusion that the coastline in this sector would continue to prograde over the 100 year prediction period thus negating the need to consider SLR as a coastal hazard so long as current or past progradation rates were maintained. That is providing the rivers continue to contribute sediment to the coastal system as they have in the past.

Similarly long term progradation of the Te Puke Lowlands also affects the SLR assessment. While rates of progradation in this sector were not as high as for the Rangitaiki Plains the rates were sufficient to potentially offset the effects of any SLR effect over this coastal sector. However this trend is spatially limited to the extent that progradation rates may fall below the self limiting threshold further to the west (Te Maunga – Profile 38). Applying a similar methodology to Waihi Beach where low progradation rates apply, results in a predicted beach retreat or coastline transgression caused principally by limitations in sediment supply in this coastal sector.

At Ohope and at Pukehina Beach recent work by Saunders (1999) and Easton (2000) quantified sediment budgets for the respective sedimentary systems. This allowed the full implementation of the LSCB schema to determine SLR response for these coastal sectors. In both cases coastline retreat is predicted although as at Waihi Beach the offshore profile shows

a sediment surplus which may indicate a significant littoral component which is likely to cycle over time as noted by Saunders (1999). If this is the case then a similar sedimentary regime may operate here as at Waihi Beach.

Storm Erosion Modelling - EDUNE

The application of the model EDUNE to BoP profiles implements an equilibrium profile model to storm driven beach and dune erosion and thus allows the prediction of storm forced erosion activity in the Bay of Plenty. A design storm was developed for the purpose based on a significant storm (e.g. Cyclone Gisele) with an estimated Annual Return Interval (ARI) of 100 years (de Lange 1996, de Lange and Gibb 1999). The model was then applied to all of the profiles in the dataset producing responses that represented observed behaviour reasonably well.

As discussed above, the results of the modelling reinforces the need to retain or enhance foredune volume as a protection measure against property loss and inundation due to storms.

7.4 Application of EBP to CHZ definition

It is possible to use the information derived from this study to define the core elements of a coastal hazard zone (i.e. from coastal storm erosion and sea level rise). Ideally this requires acceptance of the equilibrium profile position for MSL, which as described is determined by adding the predicted equilibrium beach profile shift distance obtained from the Dean model to the measured MSL position, as shown in Table 5.5.

Table 7.1 is presented for selected profiles to indicate how this information can be used to define a Coastal Hazard Zone or to confirm an existing Zone prepared by other methods. The calculations involved are as follows:

$$\text{CHZ} = \text{SLR} + \text{EBP} + \text{EDX}, \quad (7.1)$$

where SLR is the predicted Sea Level Rise shift, EBP is the equilibrium beach profile correction resulting from profile disequilibrium, and EDX is the distance from mean sea level to the limit of dune erosion obtained from the EDUNE output file EDUNE.DAT. Care needs to be exercised when using this methodology in cases where long term coastal progradation acts to offset sea level rise. In these situations consideration needs to be given to excluding progradation effects from the CHZ calculations, so as to provide for storm erosion effects.

The following offset calculation is then performed for each profile so as to calculate an offset distance from the survey reference mark for each profile so that setback limit may be plotted on a map (see Figure 7.3):

$$\text{Offset (ODX)} = \text{XMSL} + \text{SLR} + \text{EBP} + \text{EDX}(1.4), \quad (7.2)$$

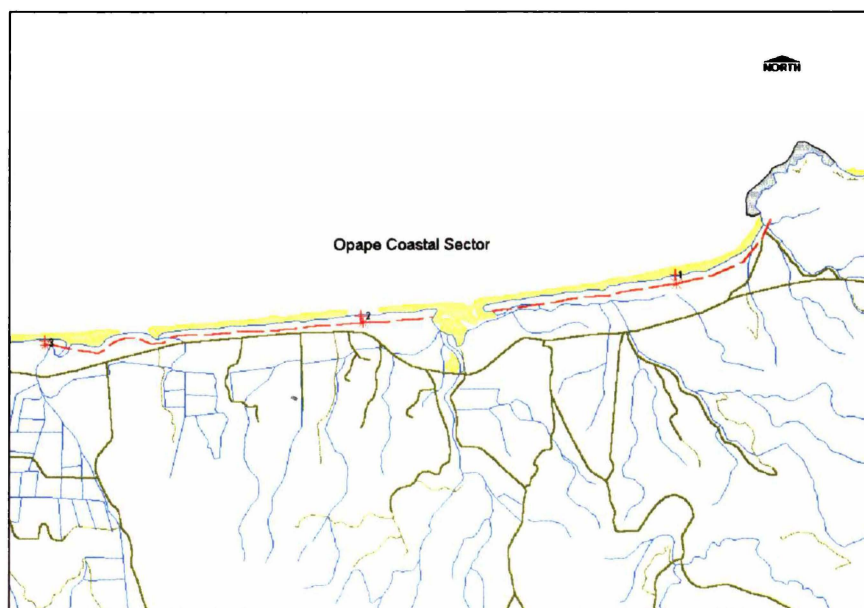
where XMSL is the distance from the profile reference mark to MSL obtained from EDUNE.DAT, and 1.4 represents an upper error limit to the predictions obtained from EDUNE (Kriebel, 1989).

BOPRC #	EBP shift (m)	Adjusted SLR shift (m) (Table 5.5)	Storm Erosion Distance from MSL or EDX (m)	S.F.	Corrected EDX	CHZ width	Distance from ref. mark to MSL or XMSL	Offset from ref mark - ODX (m)
1	-4	-48	-130	1.4	-182	-230	144.3	-85.7
2	-8.28	-24	-94	1.4	-131.6	-155.6	93.8	-61.8
3	31.5	-38	-86	1.4	-120.4	-158.4	88	-70.4
4	5.02	-48	-96.8	1.4	-135.52	-183.52	201.1	17.58
5	6.97	31	-92.4	1.4	-129.36	-98.36	111.7	13.34
6	-17.08	1.6	-97.9	1.4	-137.06	-135.46	98	-37.46
7	-0.09	-21	-94.3	1.4	-132.02	-153.02	100.6	-52.42
27	-19.94	-17	-77.4	1.4	-108.36	-125.36	70.7	-54.66
28	-43.79	-33	-100.1	1.4	-140.14	-173.14	113.2	-59.94
29	-18.27	-55	-81.3	1.4	-113.82	-168.82	83	-85.82

Table 7.1: Coastal Hazard Line determination using equation 7.2. N.B. Where profiles are prograding long term then SLR effects should be discounted from the calculation.

Figure 7.3 illustrates examples of hazard lines prepared for the Opape and Pukehina coastal sectors using this data.

a)



b)

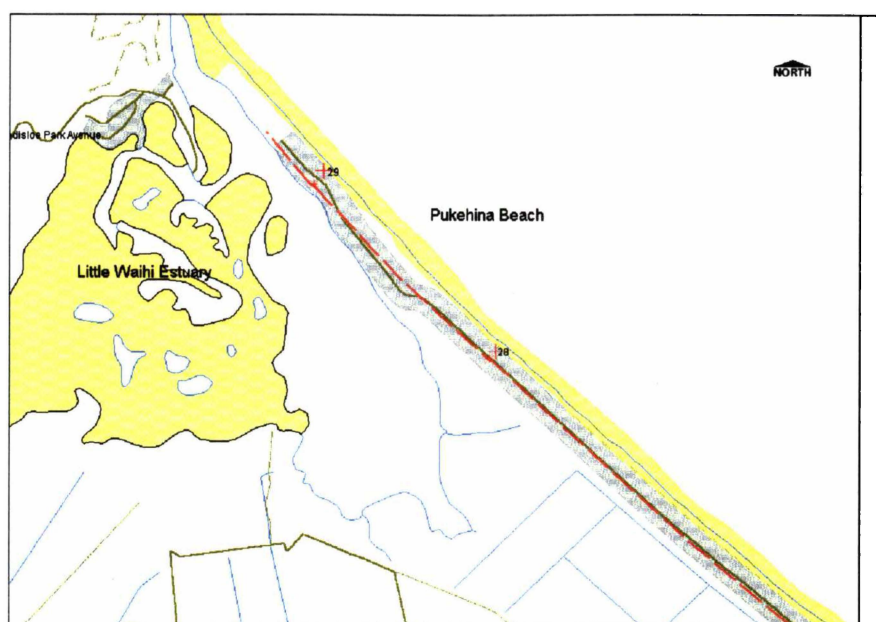


Figure 7.3: Map showing potential CHZs at: a) Opape beach showing profile locations 1 to 3 and b) Pukehina Beach. The red line indicates a possible set back line for development based on the assessment summarised in Table 7.1. The offset lines have been measured in MAPINFO as the offset distance from the survey reference mark.

7.5 Further Research

There are a number of areas identified from this research where further work would improve our understanding of the BoP coastal environment. These suggestions include:

- Further storm modelling using different storm scenarios and actual storm data as input into improved 2 dimensional diabathic models such as SBEACH. This could be combined with 2 dimensional littoral drift models in order to provide a better understanding of the morphodynamics of coastal sectors. Alternatively the application of three dimensional morphodynamic modelling could be considered for key areas where coastal hazards are considered significant.
- The work of Bradshaw (1991) could be extended to cover nearshore and inner shelf sedimentation in the wider Bay of Plenty. For example stratigraphic knowledge derived from seismic survey combined with sonar survey of the nearshore areas would allow assessment of the sediment available for reworking.
- More extensive work is suggested to apply Large Scale Coastal Behaviour (LSCB) modelling to the BoP so as to improve long term predictions concerning climate change effects and evolutionary coastal behaviour based on systems analysis of sediment movement. This will involve a number of research streams

including modelling using shoreface translation models or STMs (Cowell, *et al.*, 2003 –see Figures 7.4 & 7.6), sediment budget assessments for defined coastal sectors over time (see Figure 7.5), and stratigraphic and geological analysis.

- Ongoing coastal monitoring surveys to identify trends in beach behaviour, in particular as this relates to climate cycles and extreme weather events so as to identify long term trends in coastal behaviour. Consideration should also be given to extending the beach monitoring profiles further landward to provide sufficient depth for erosion modelling. A number of profiles in the current dataset are limited in this way.
- The linkage between sediment inputs and beach behaviour needs to be provided for in the coastal monitoring programmes. This includes recognition of the importance of monitoring sediment inputs of principal rivers into the BoP littoral system and the identification of other component inputs and sinks such as headlands and estuaries.

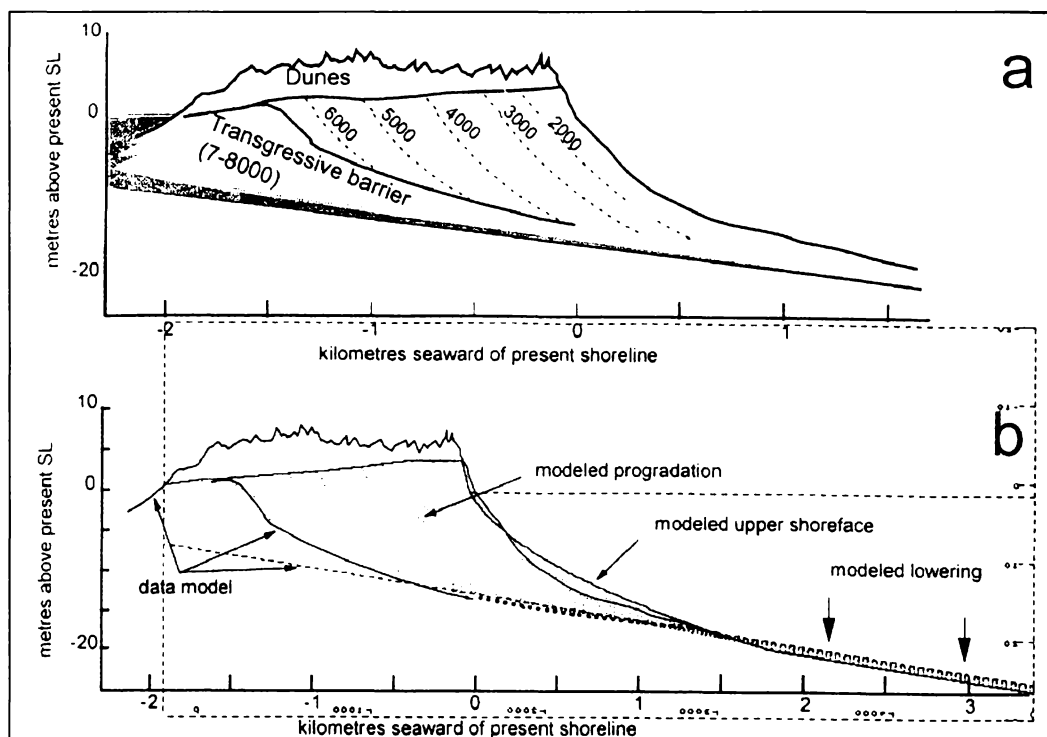


Figure 7.4: Example of STM output for Truncurry Coast, SE Australia: a) data-model based on radiometric dating of cores sample and ground penetrating radar, with isochrones labelled in years BP ; and b) STM simulation output overlaid on data model. (Source: Cowell *et al.*, 2003)

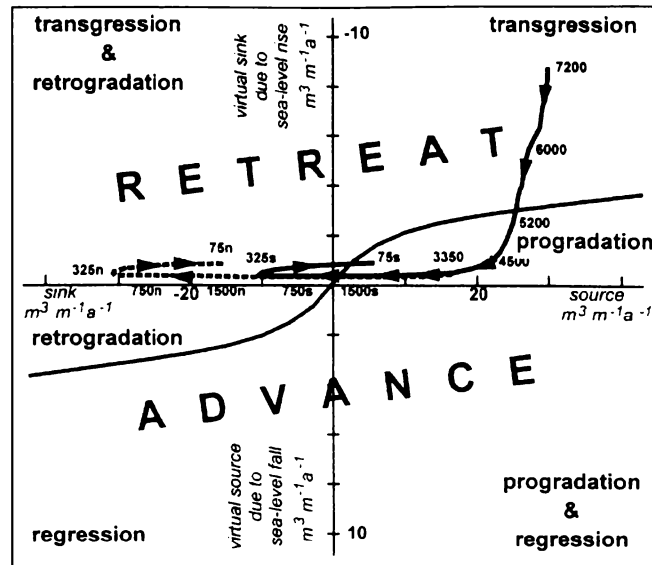


Figure 7.5: Evolution of the central Netherlands Coast as a time trajectory in sediment supply/accommodation phase space (abscissa and ordinate respectively scaled in cubic meters per year per meter of shoreline). Numbers along the trajectory indicate time (years BP); suffixes n and s denote north and south Haarlem respectively. (Source: Stive, 2004; Cowell et al., 2003).

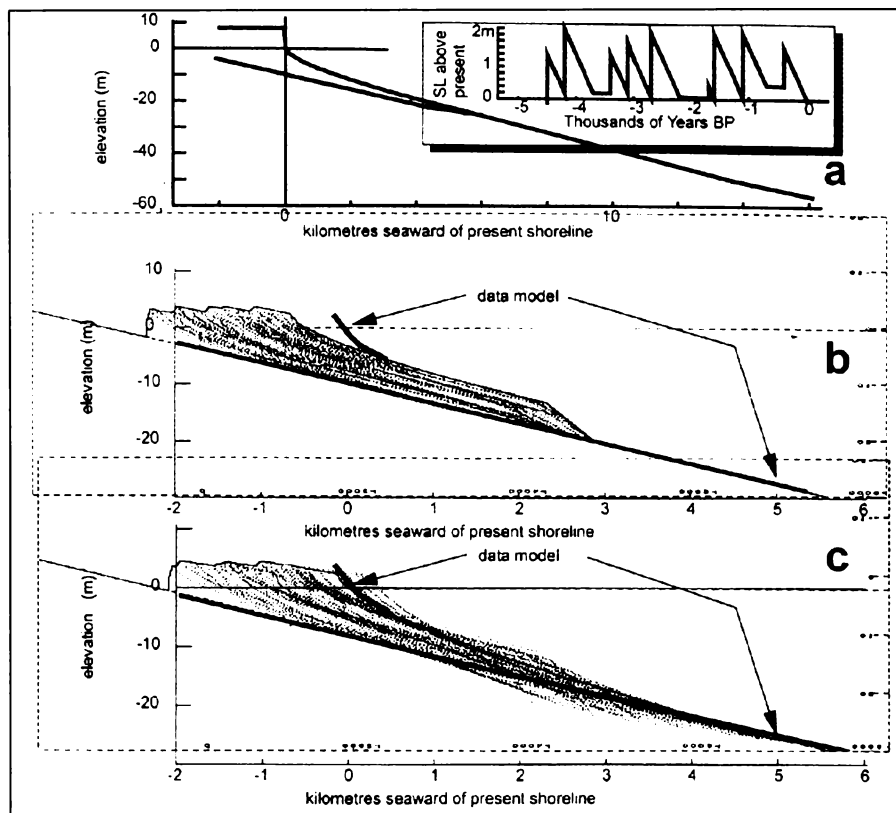


Figure 7.6: STM prediction for Columbia coastal tract, SW Washington, USA subject to seismically induced sea level variations and littoral sediment feed: a) data model, b) STM simulation without shoreface deepening, and c) STM simulation with shoreface deepening between earthquake events. (Source: Cowell et al., 2003)

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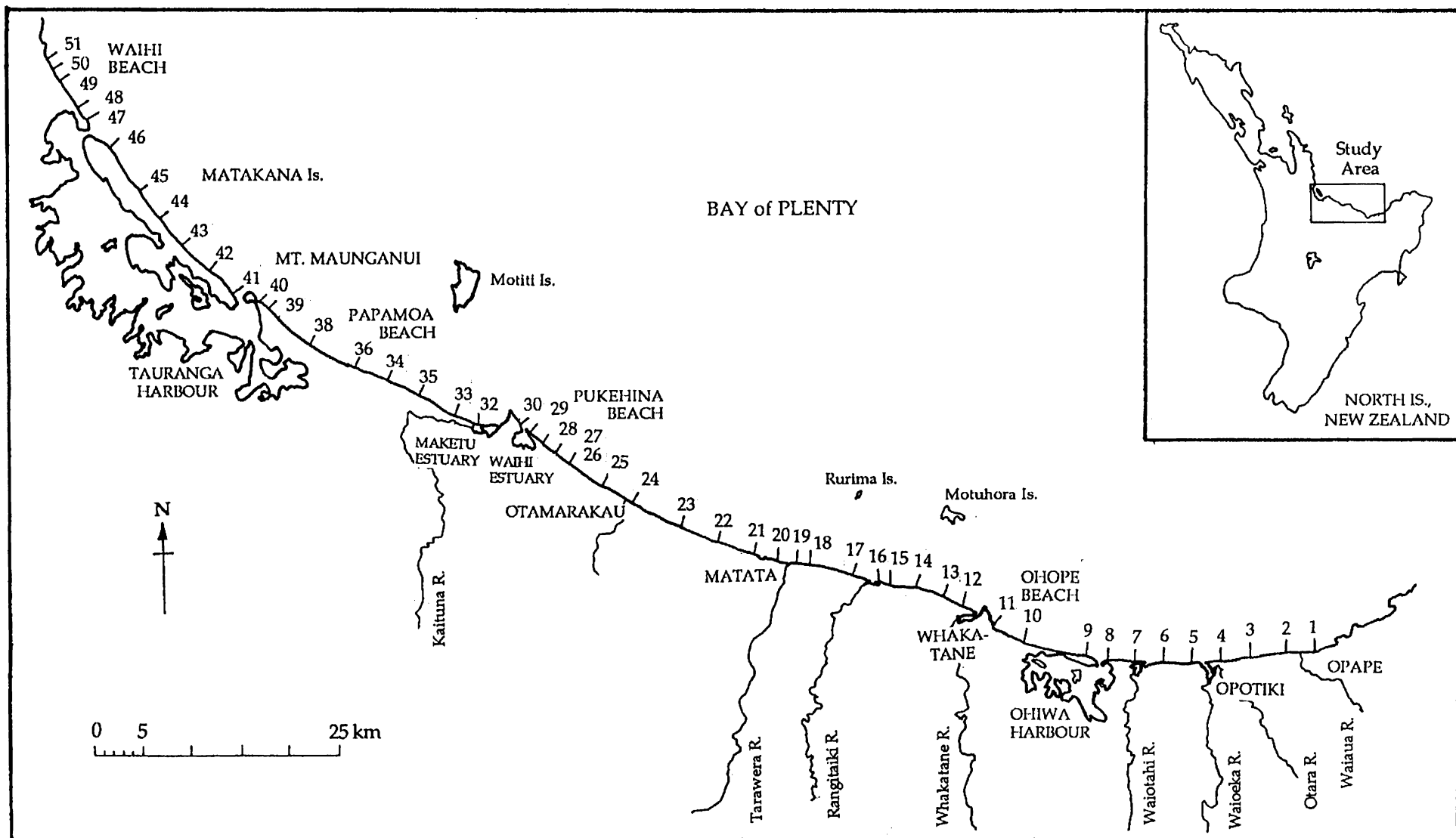
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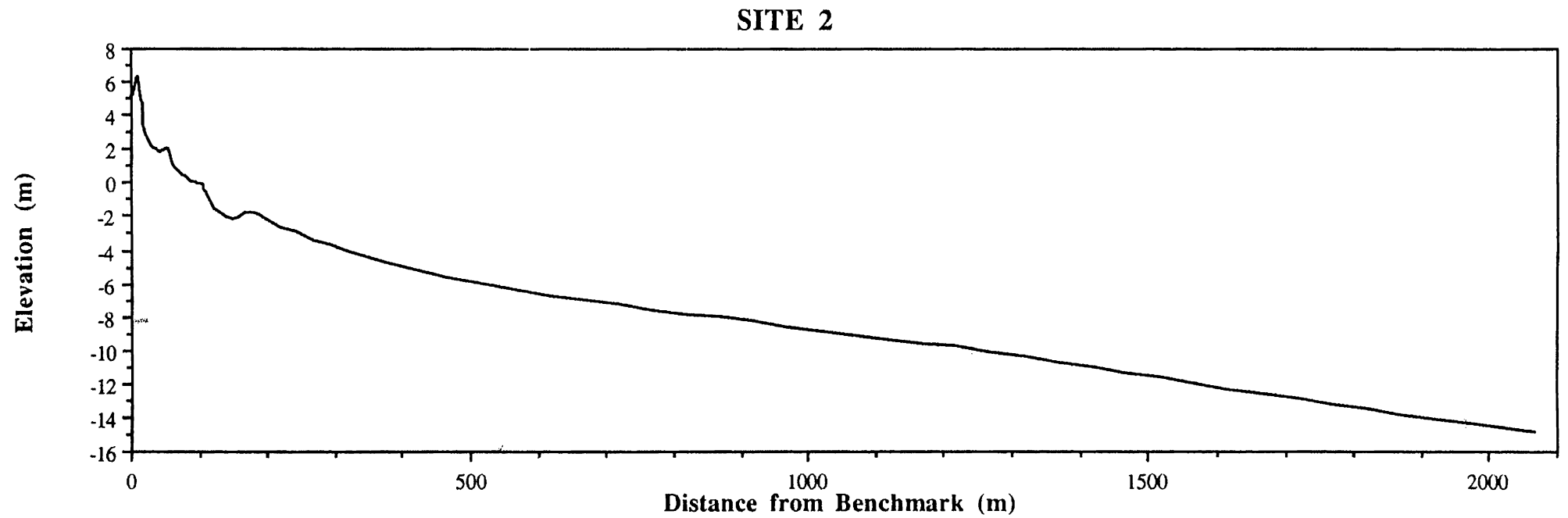
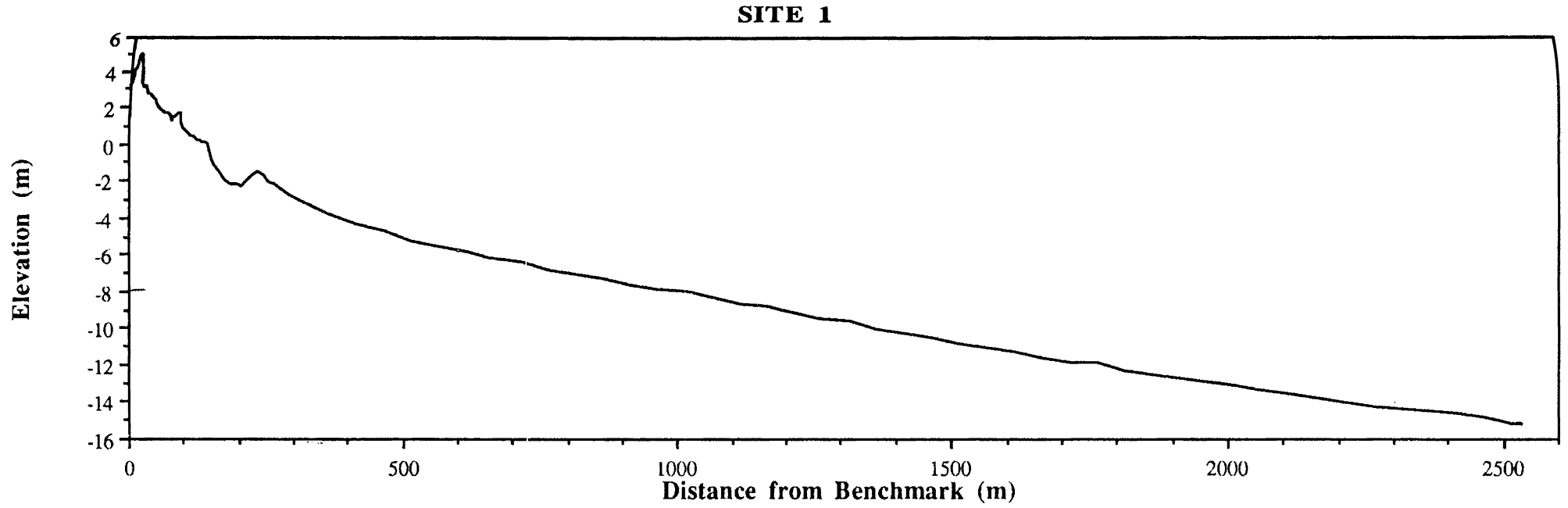
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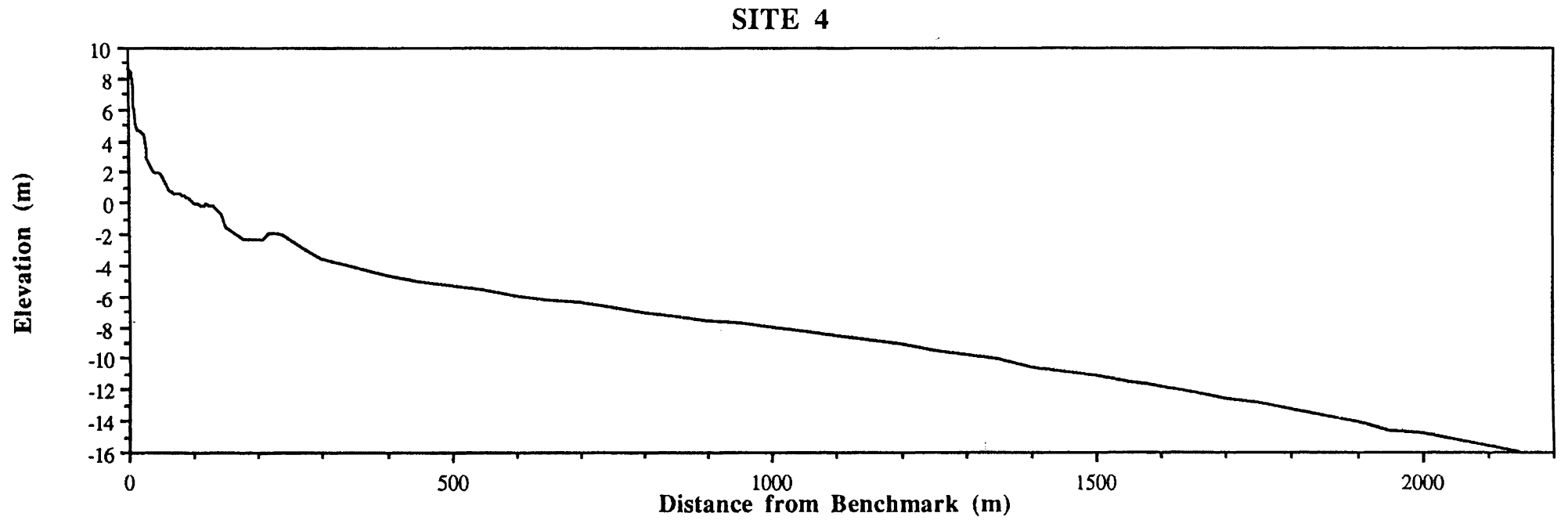
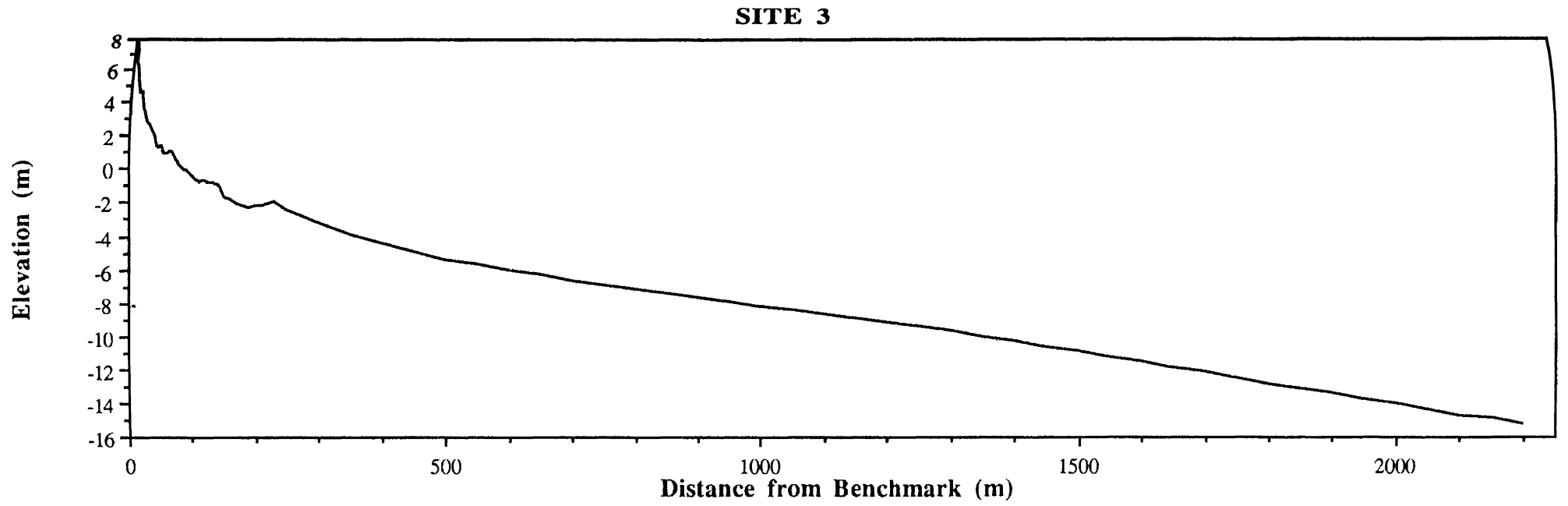
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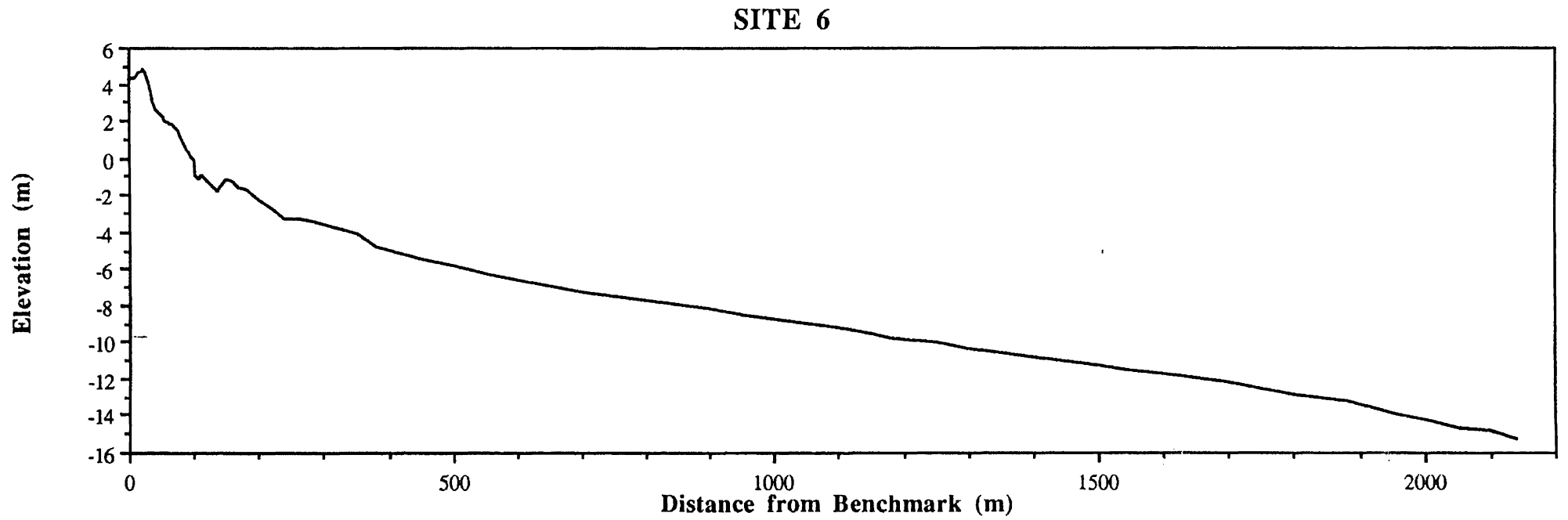
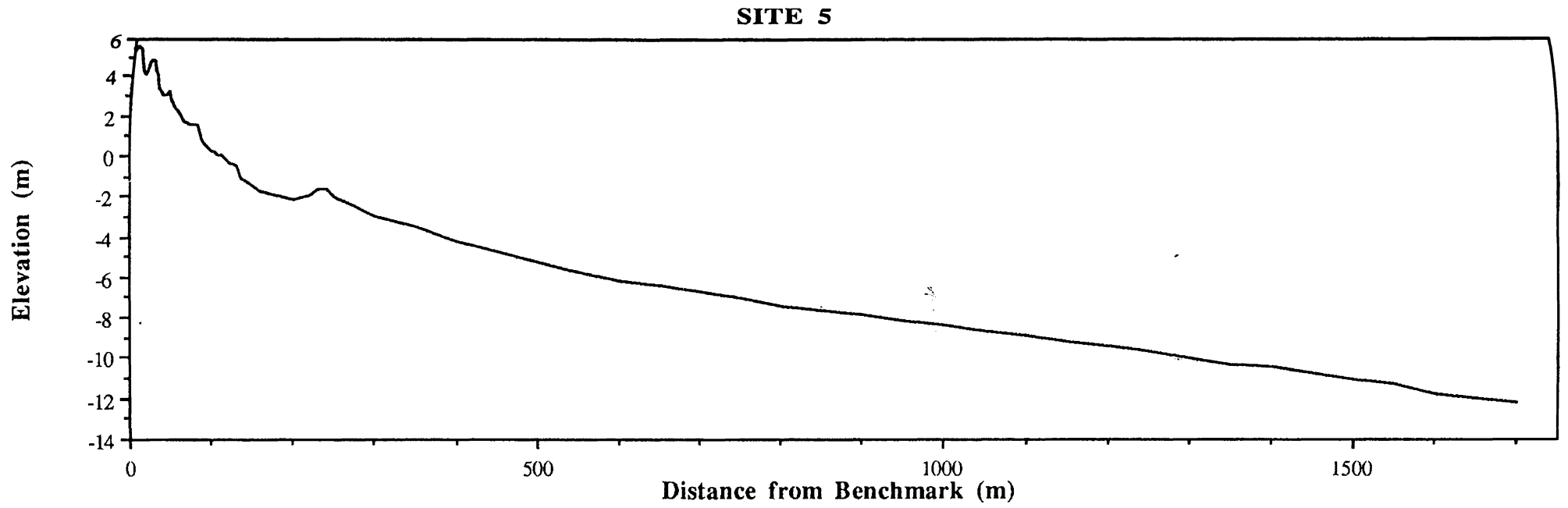
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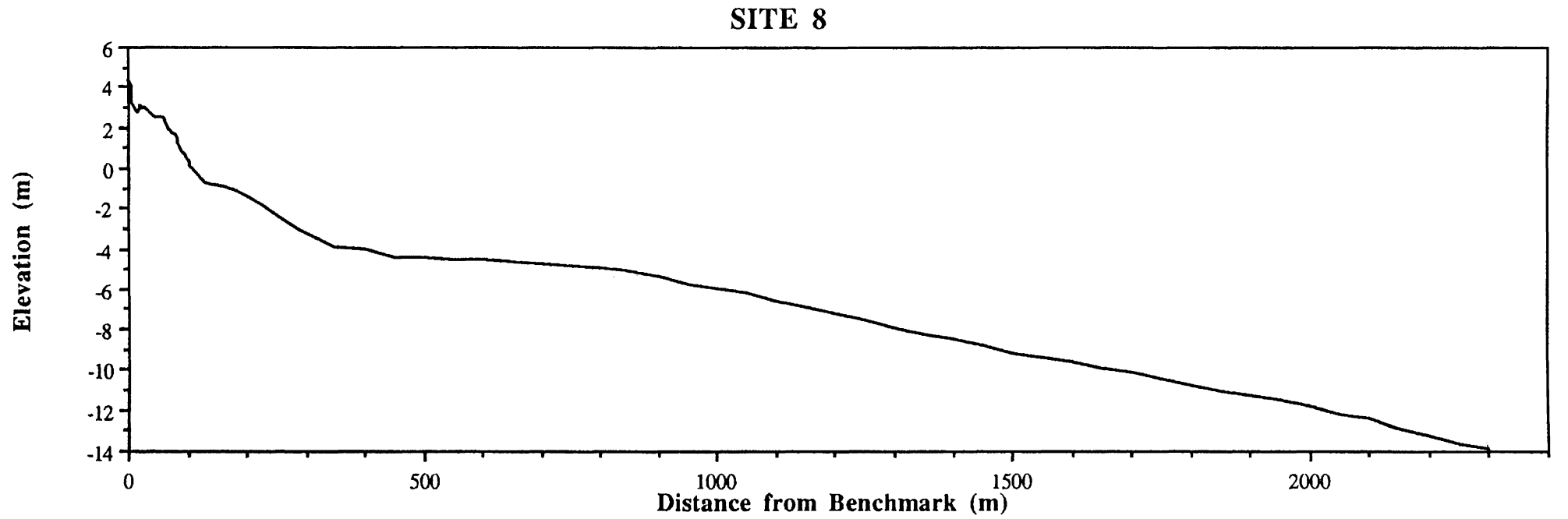
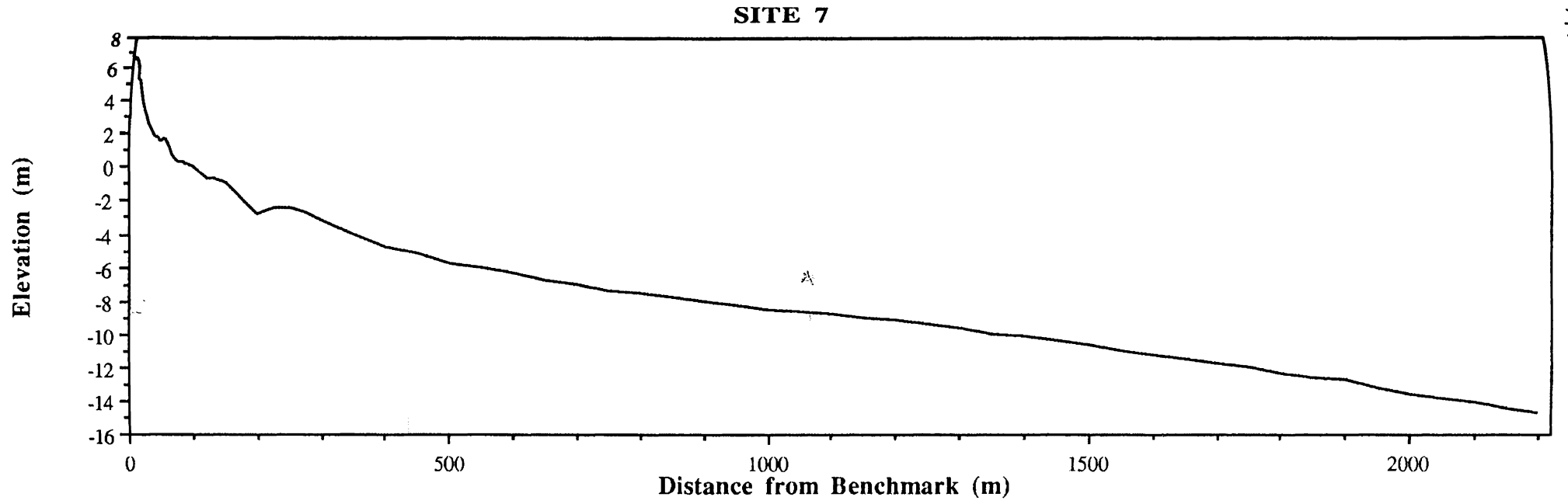


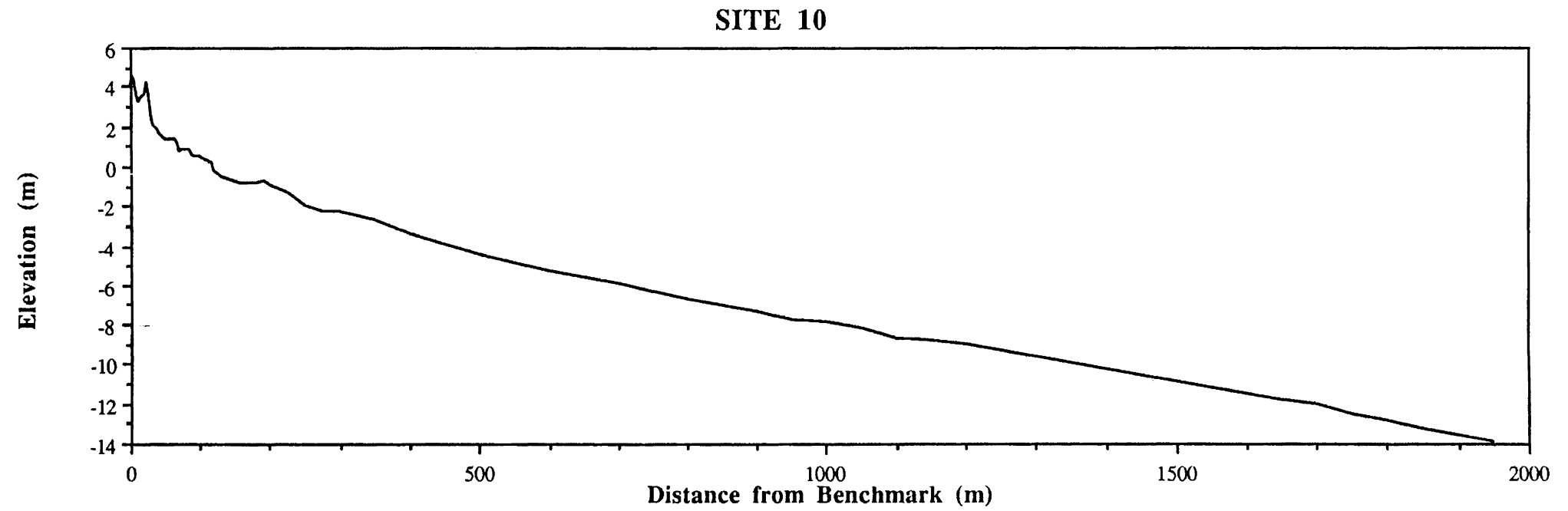
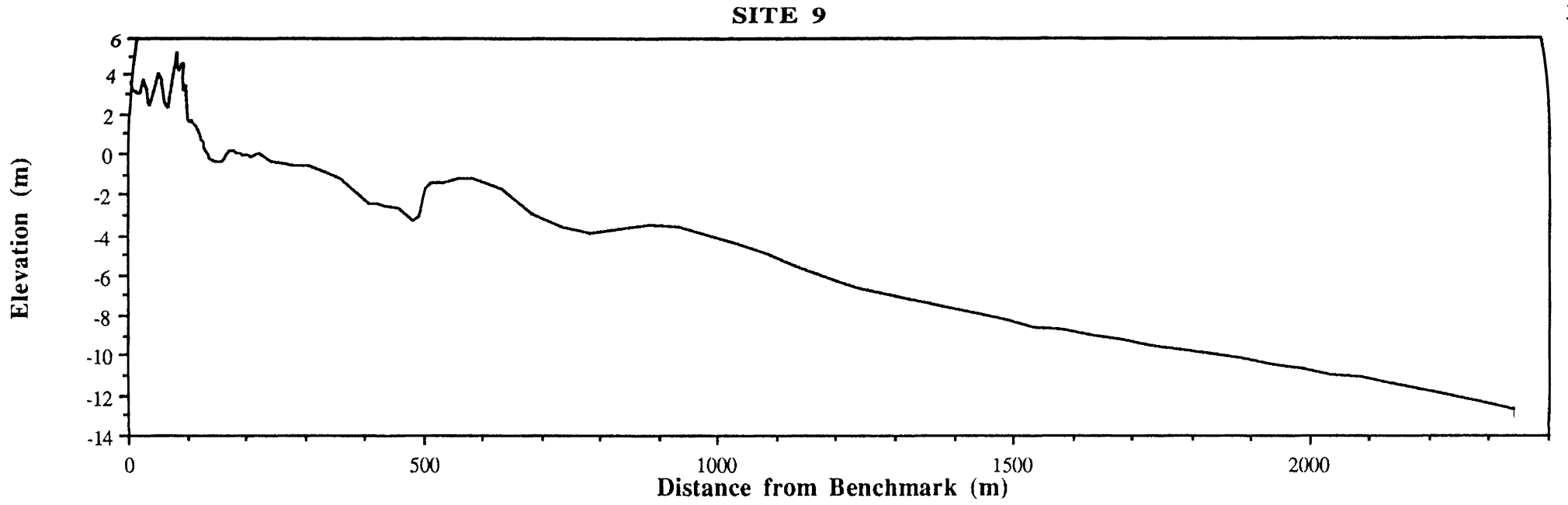
Bay of Plenty profile sites. (Modified from Healy (1978a)).

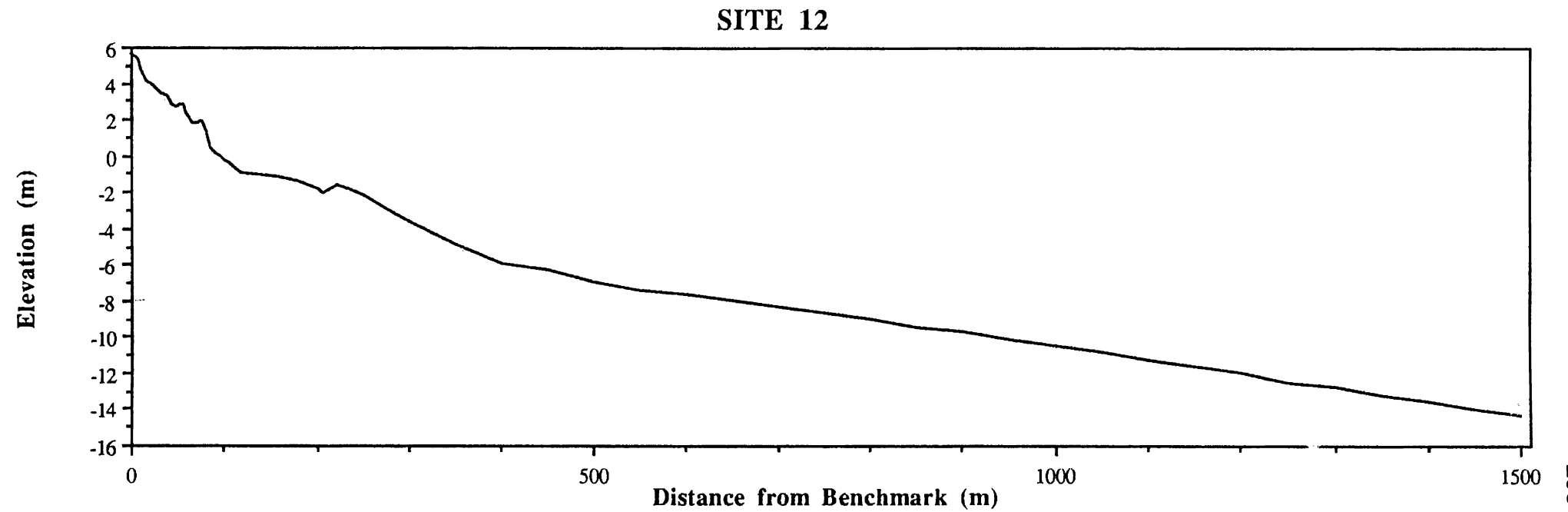
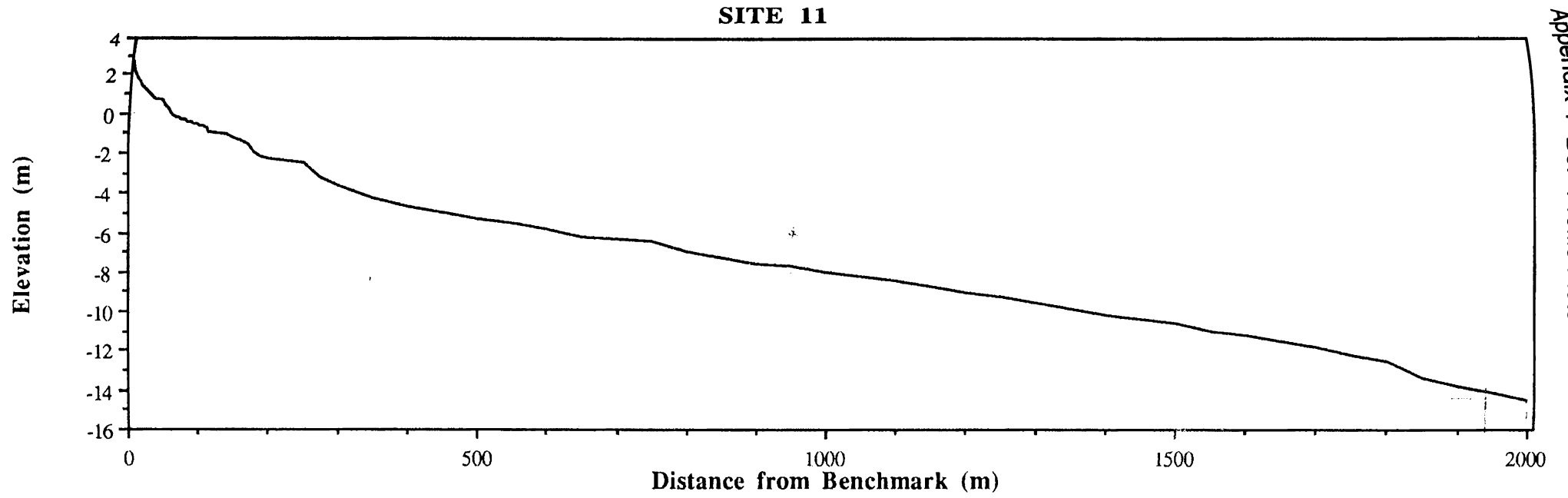


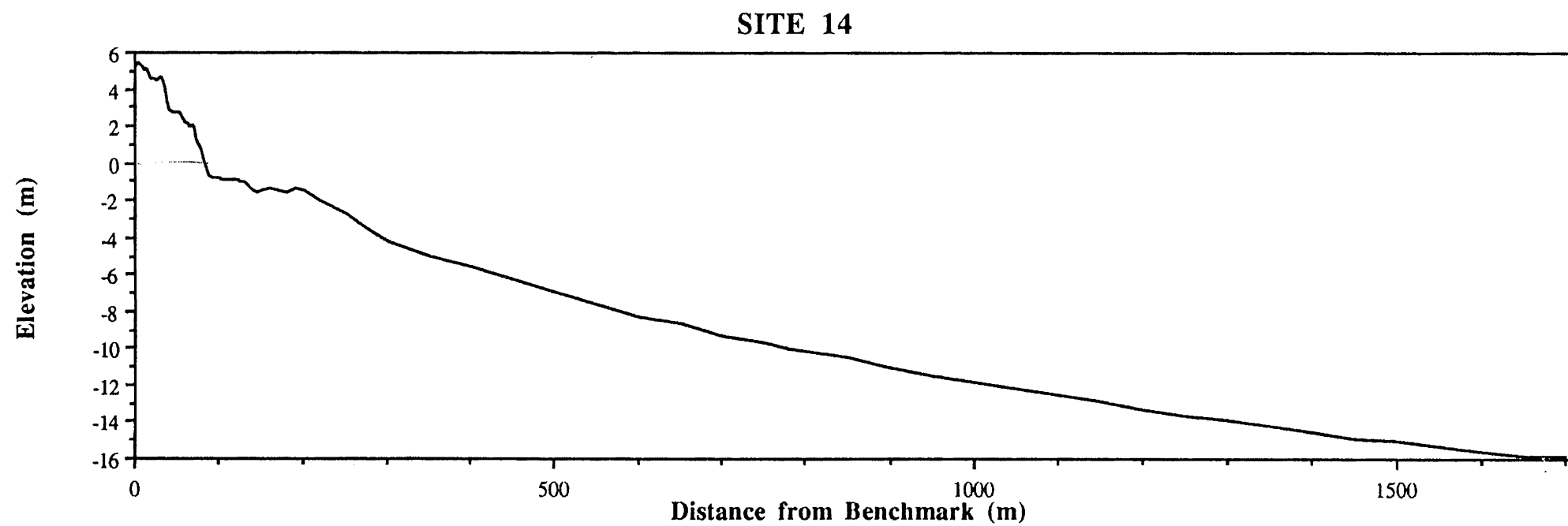
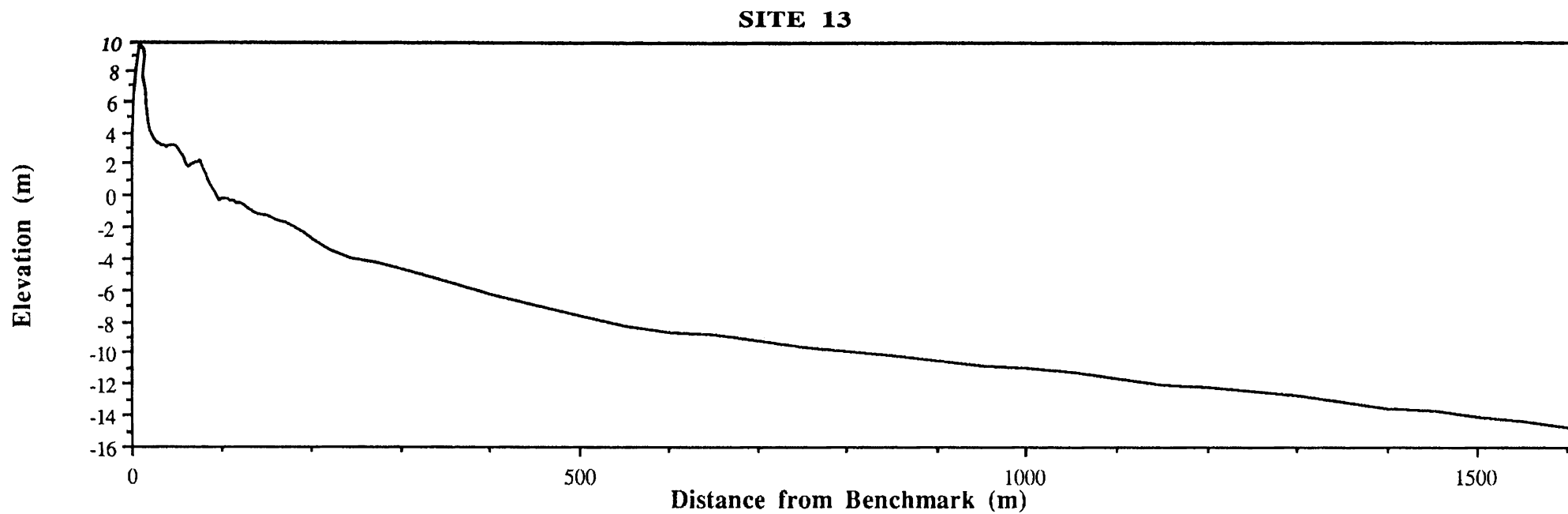


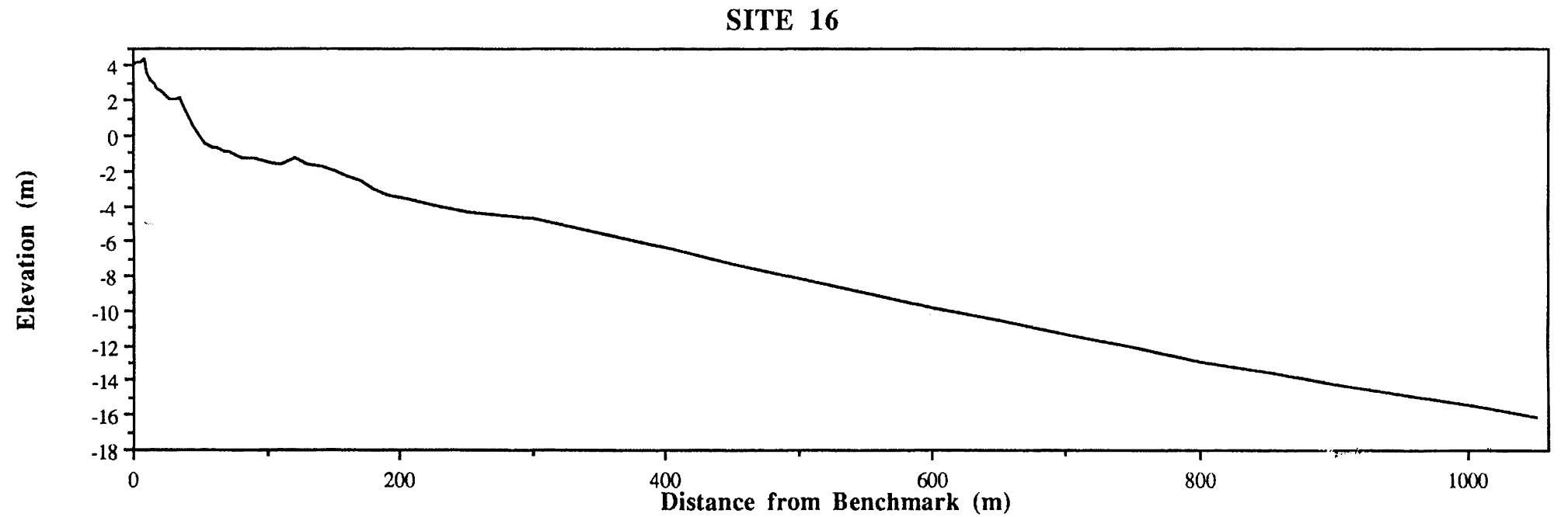
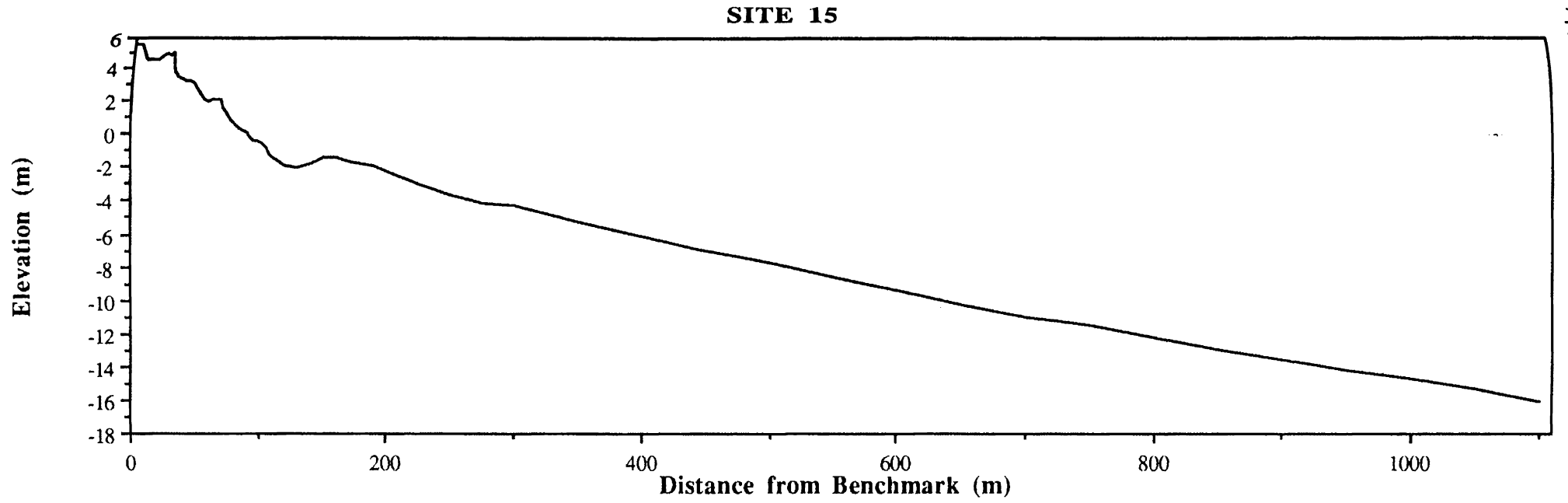


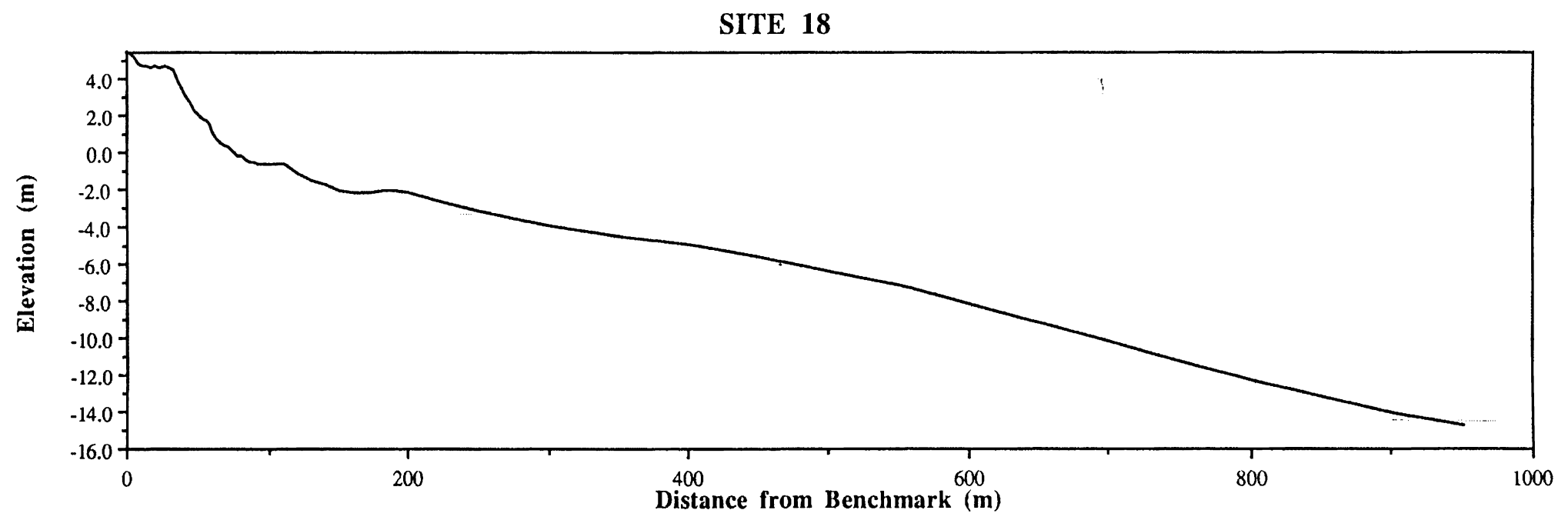
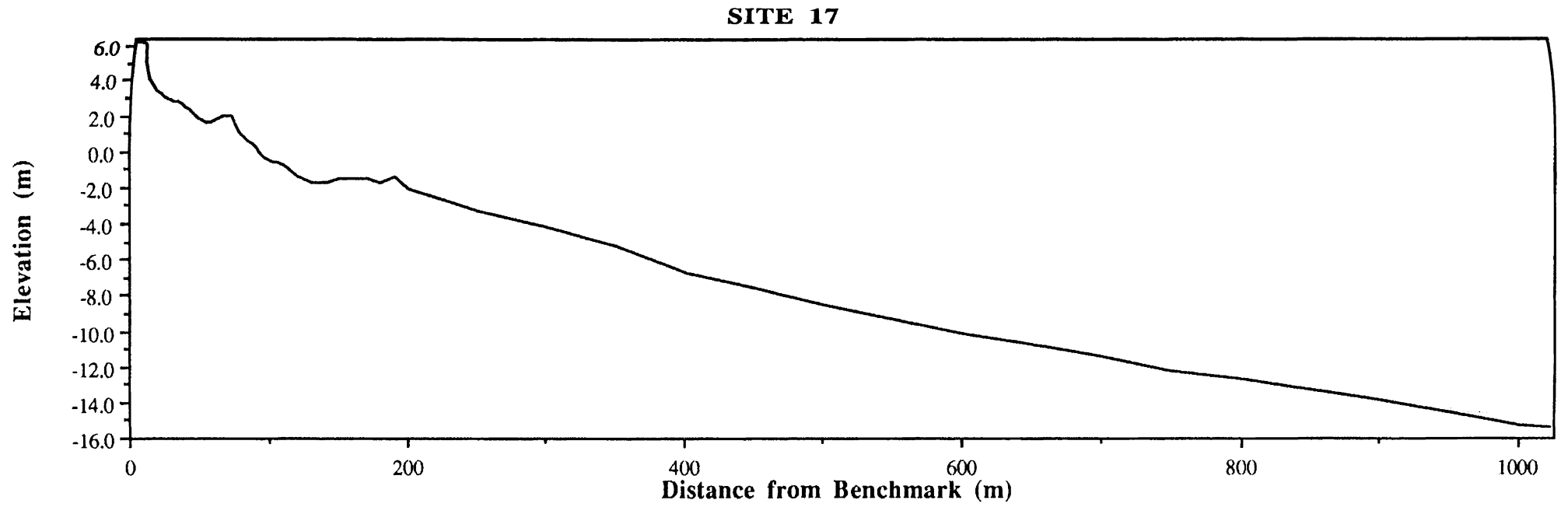


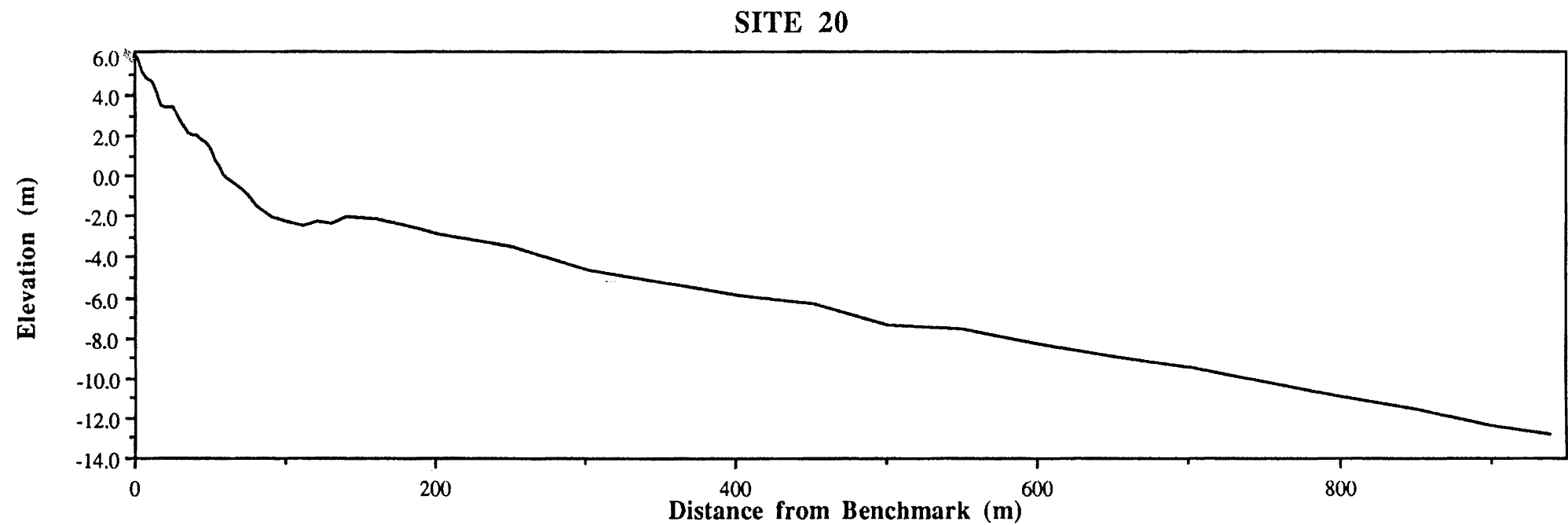
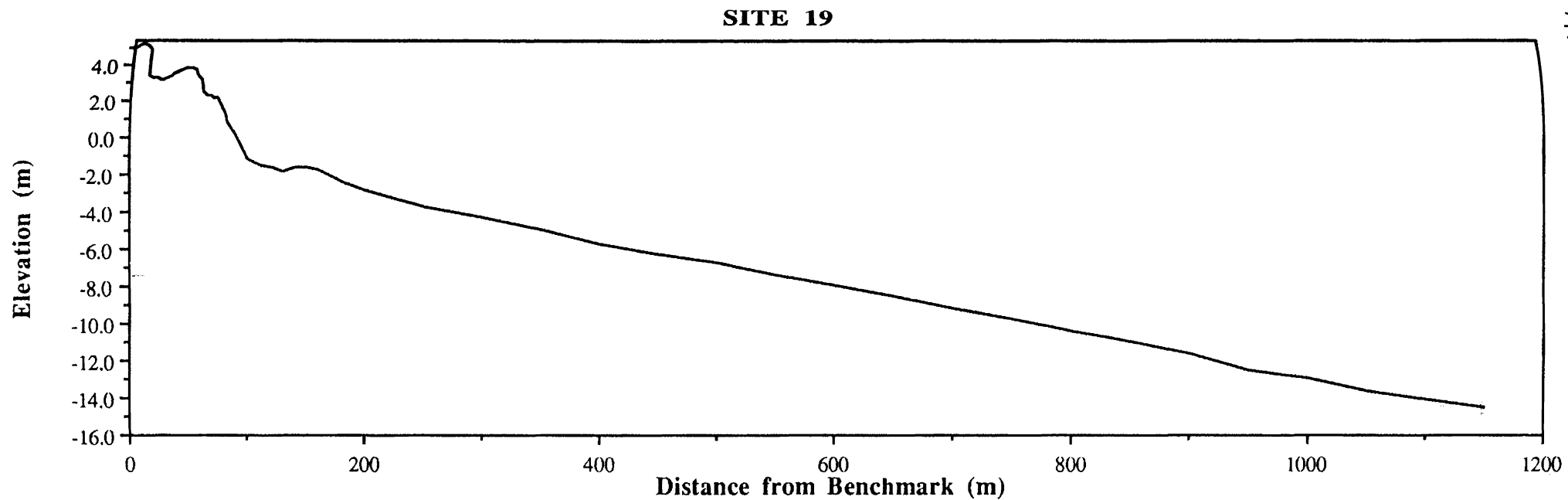


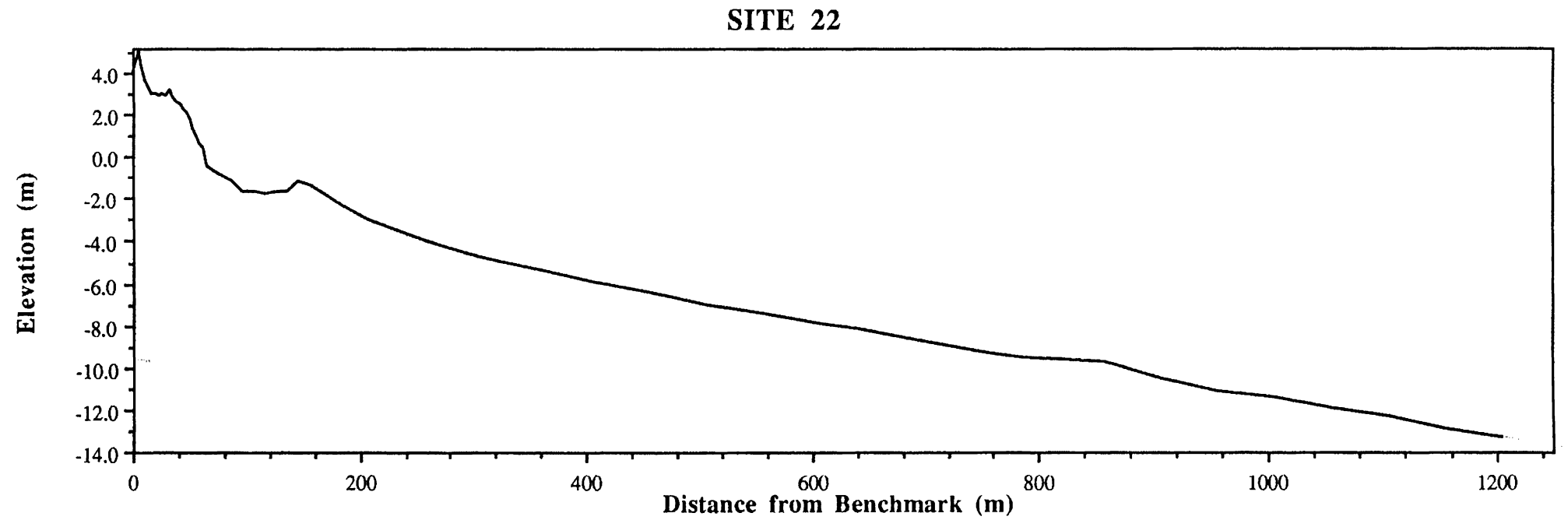
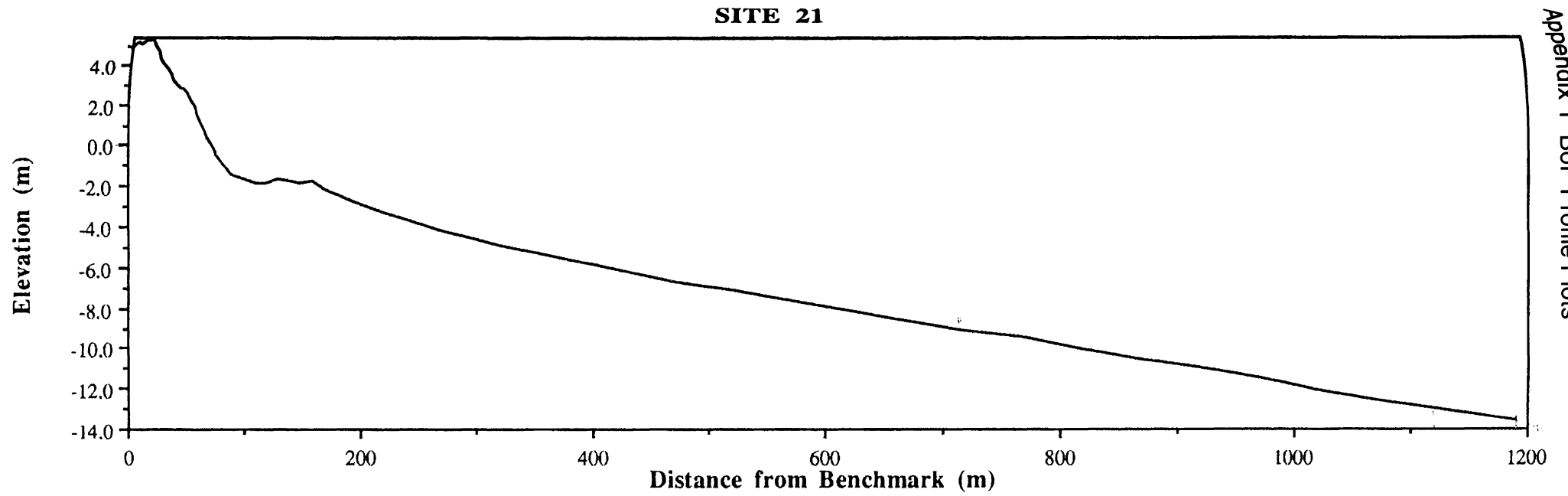


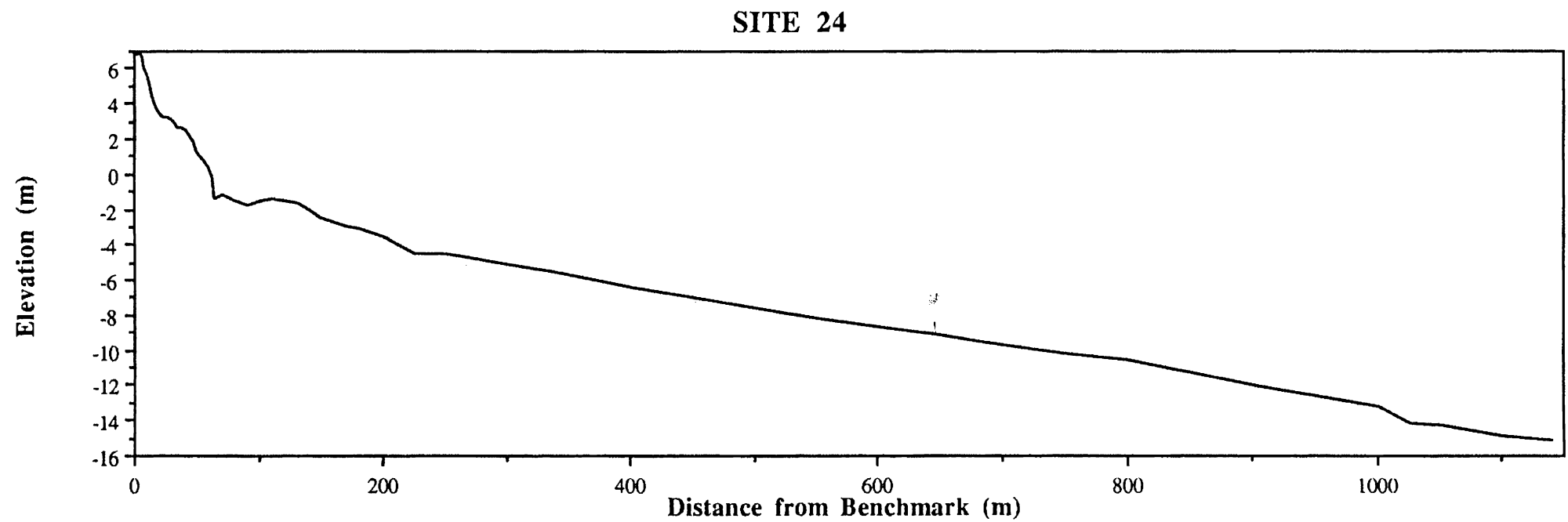
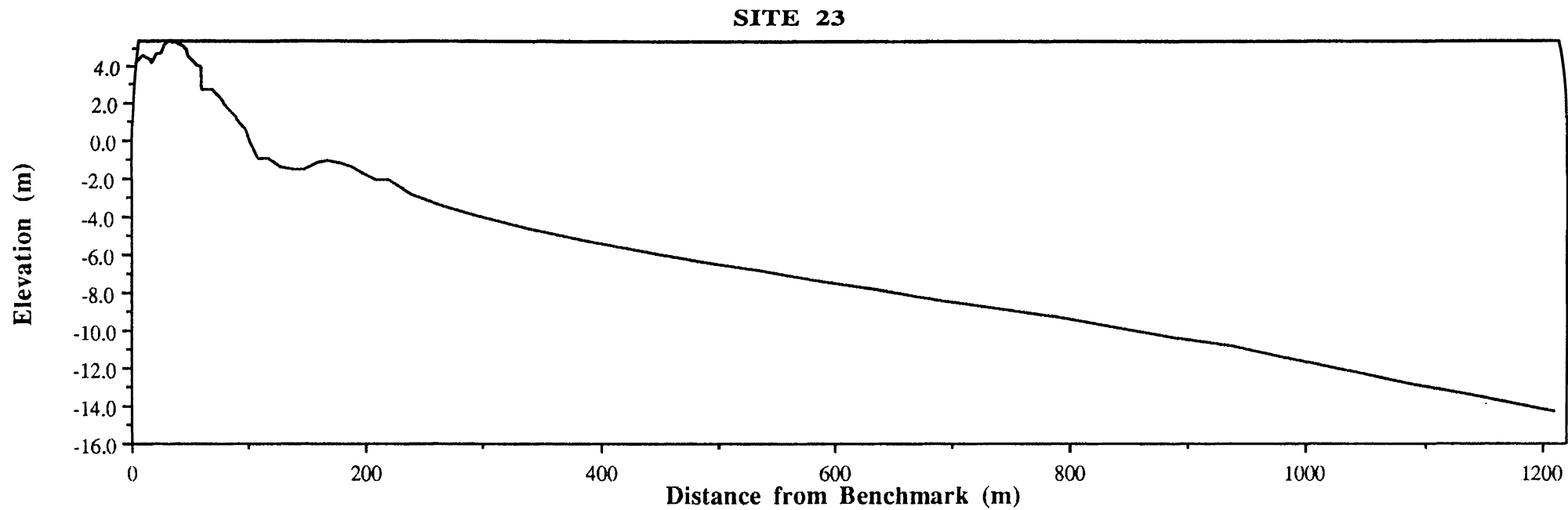


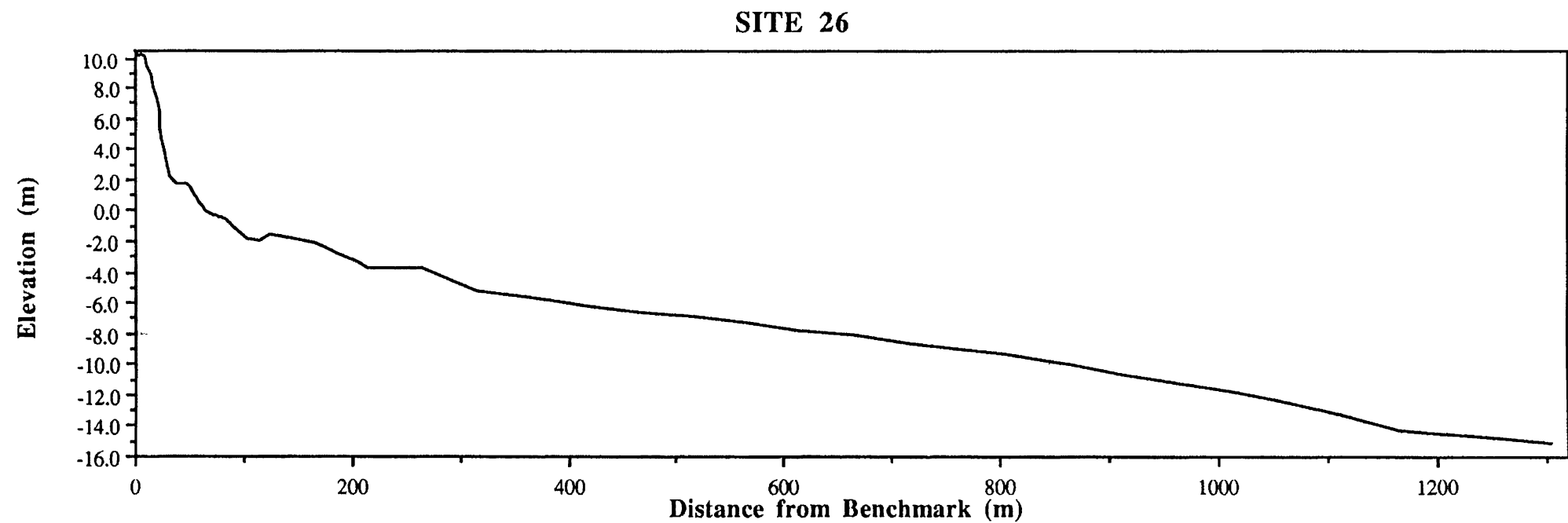
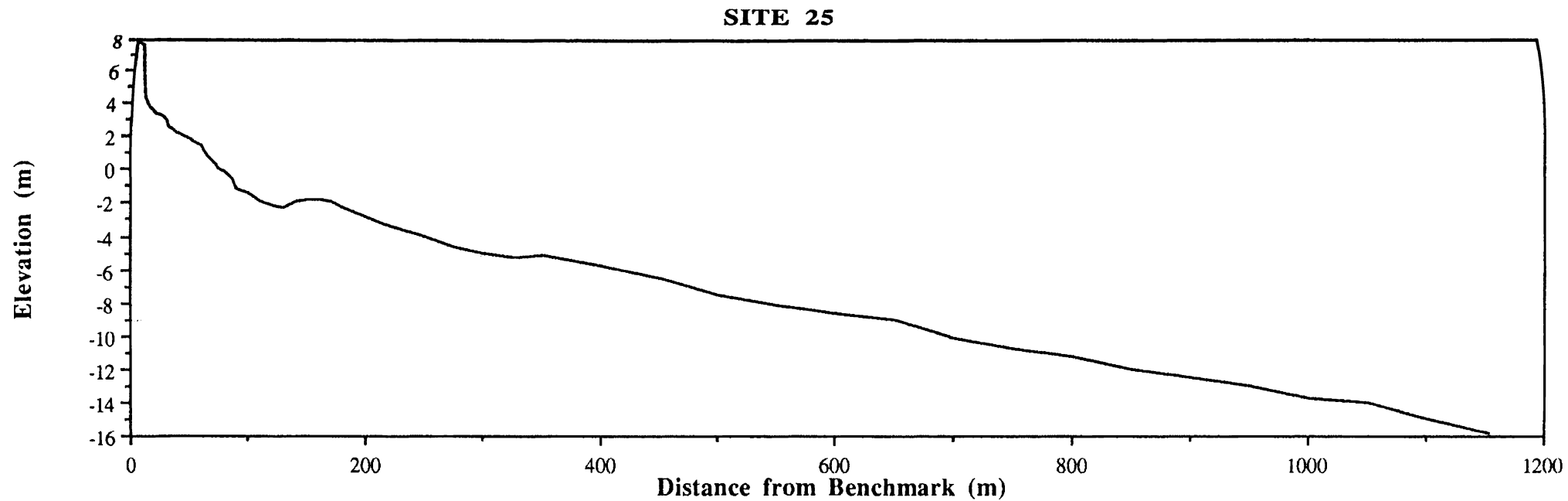


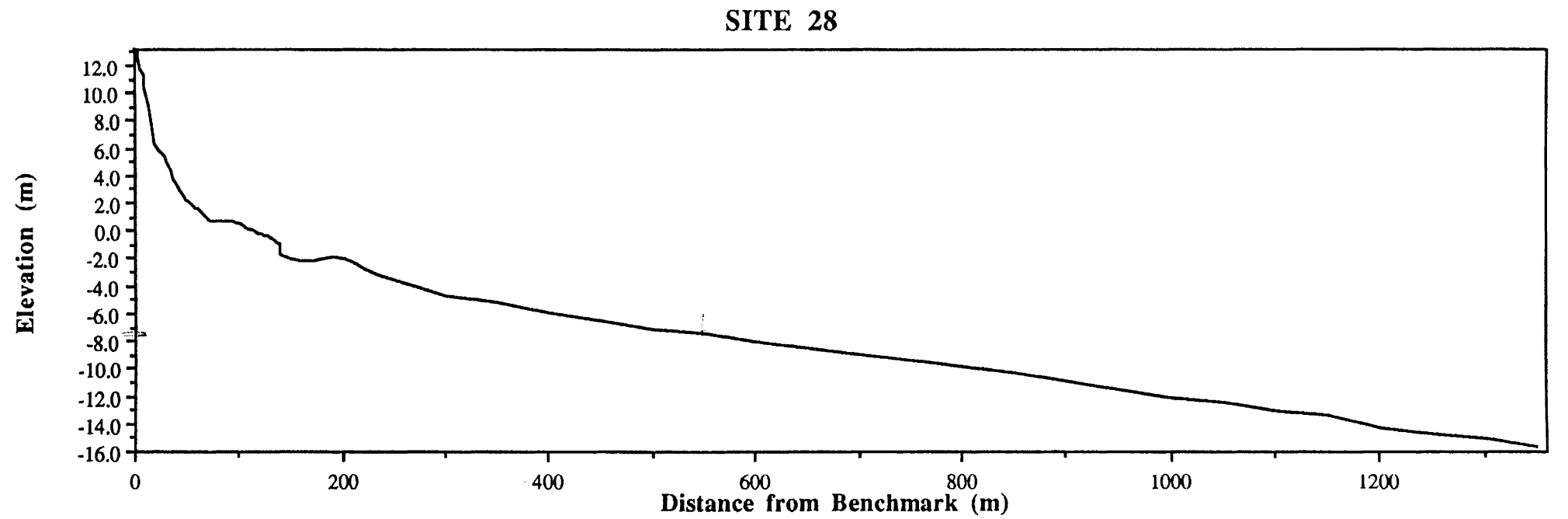
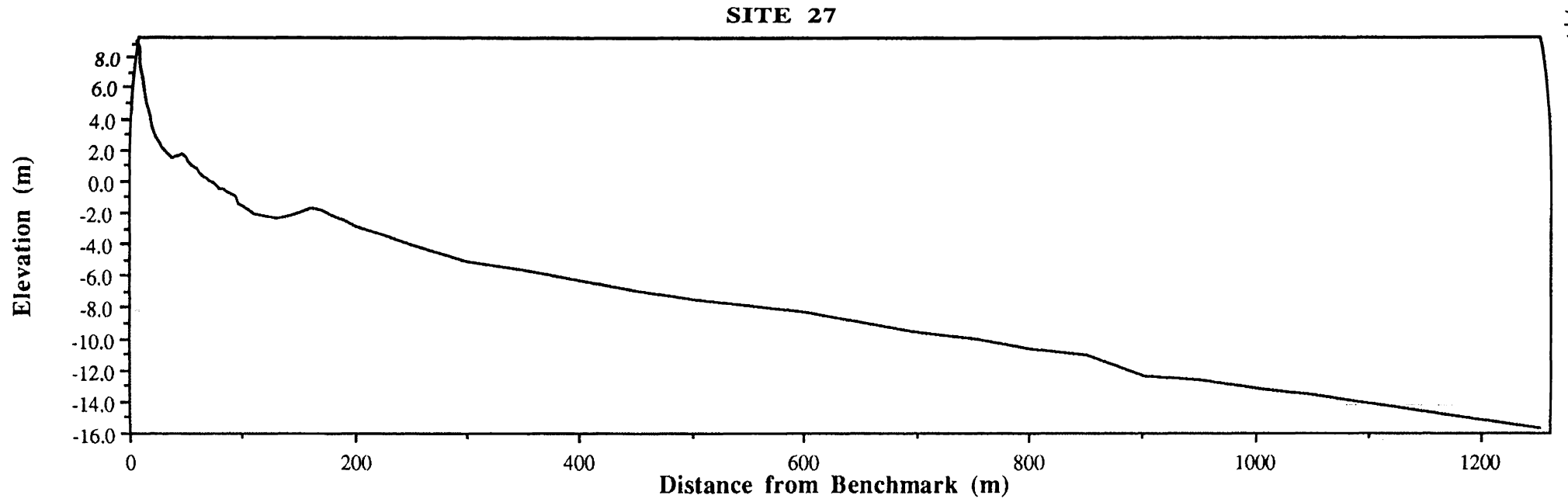


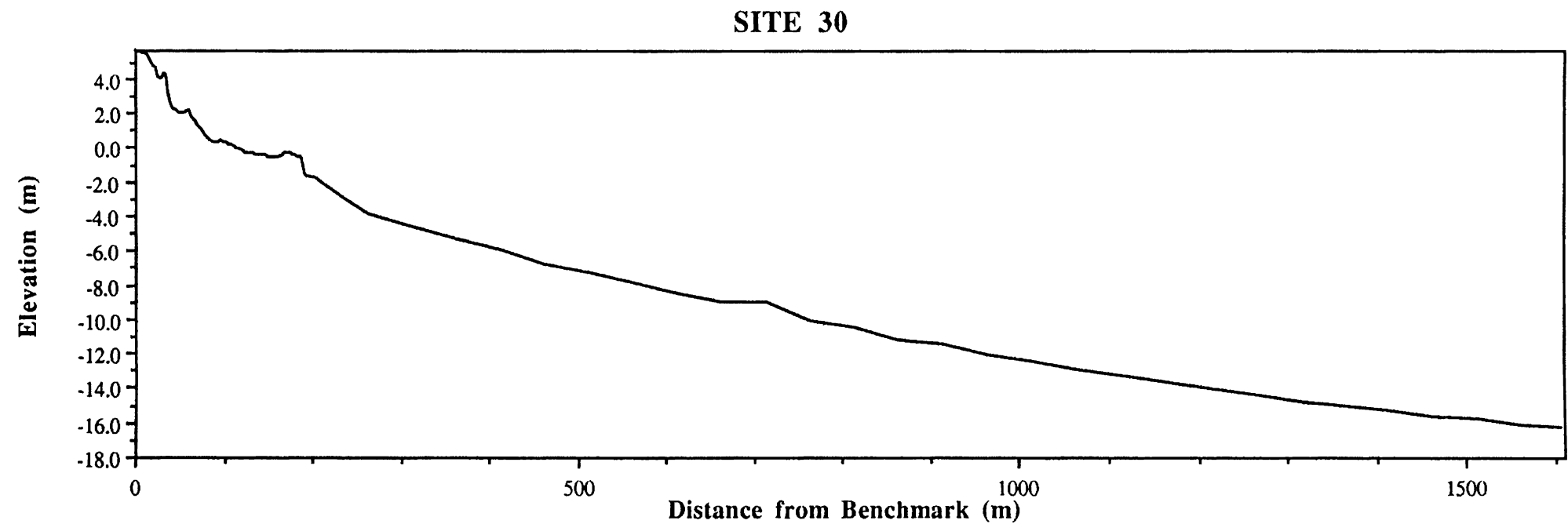
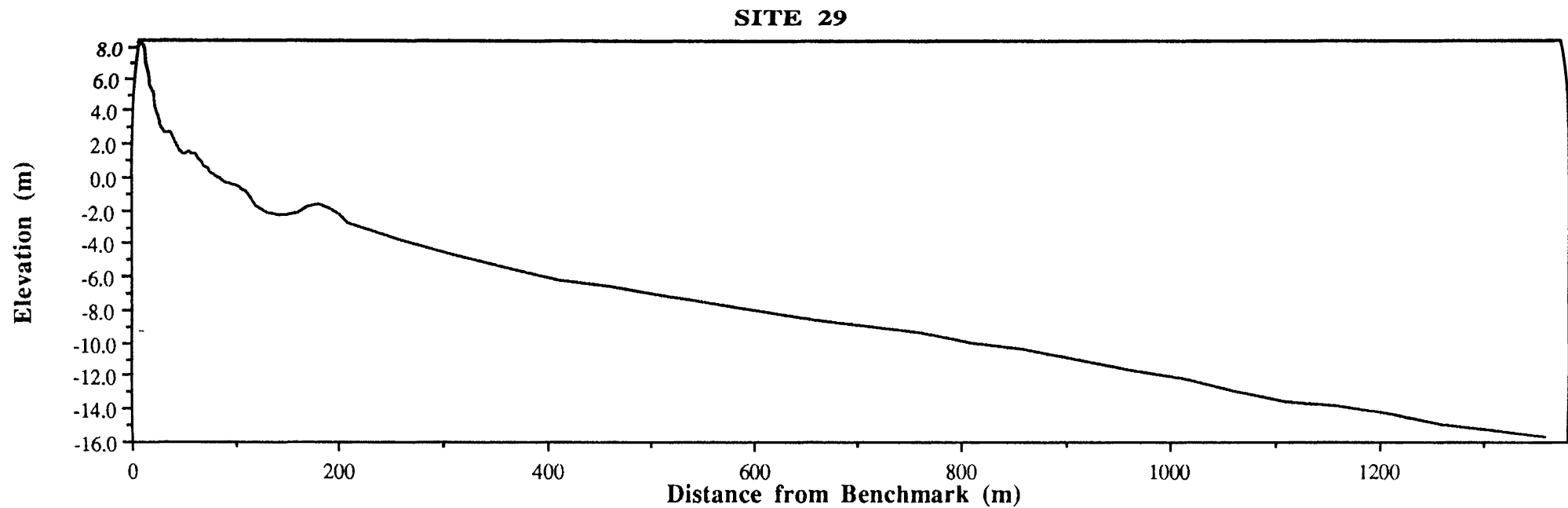


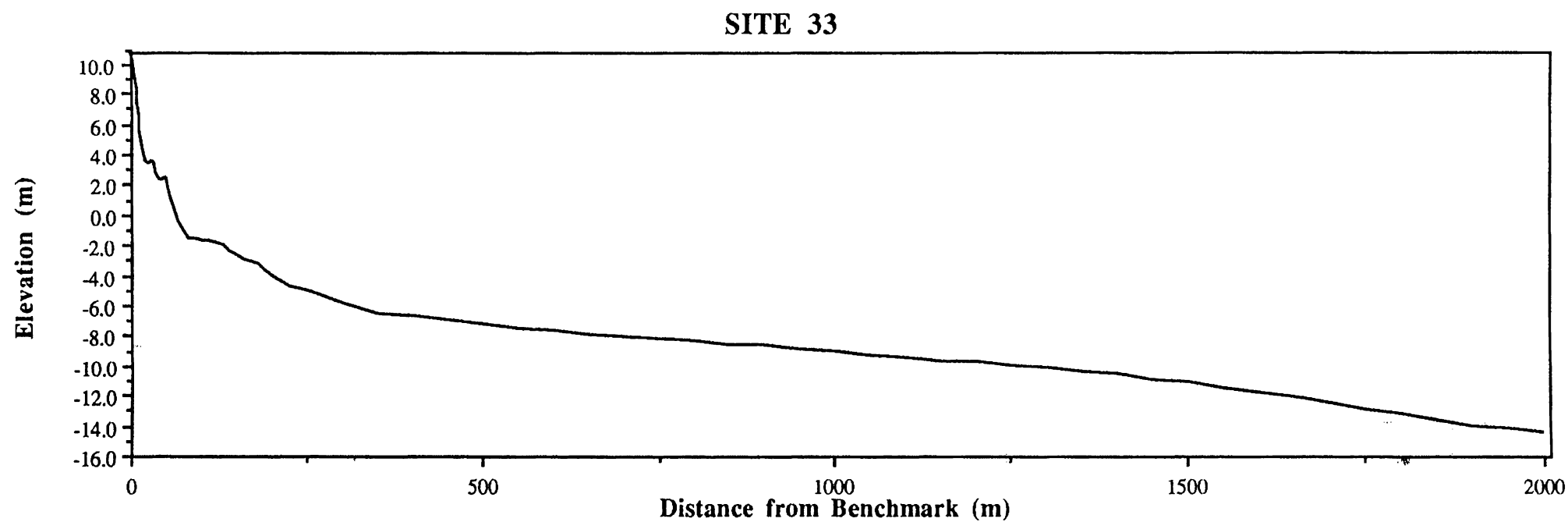
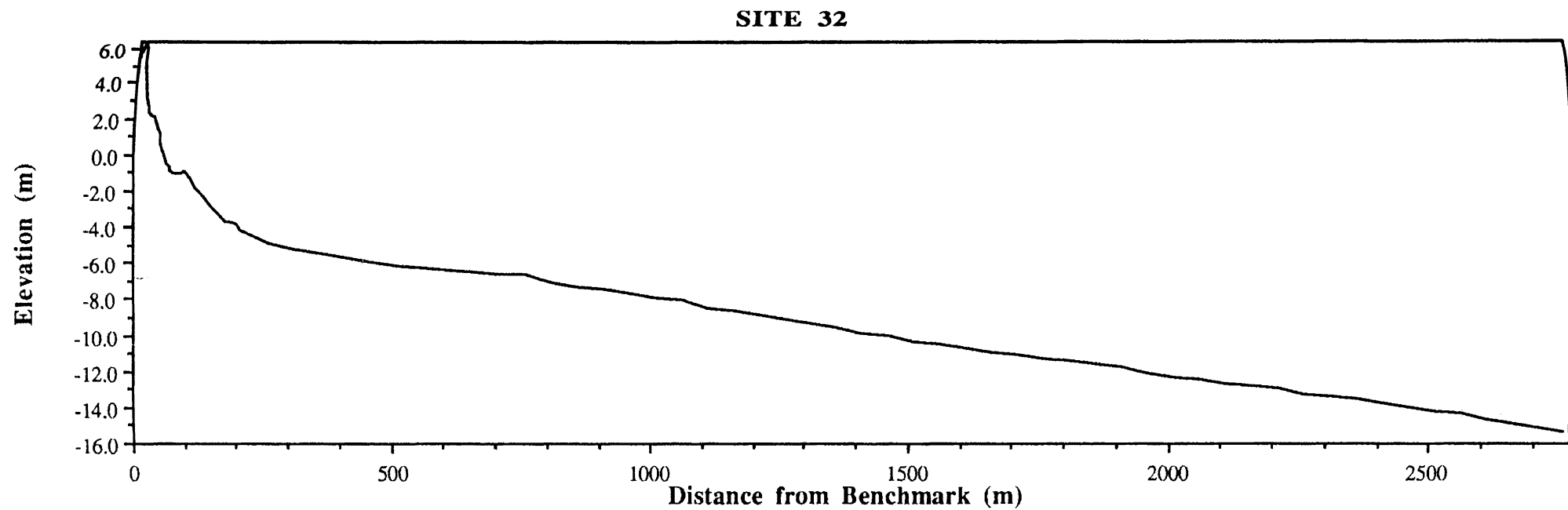


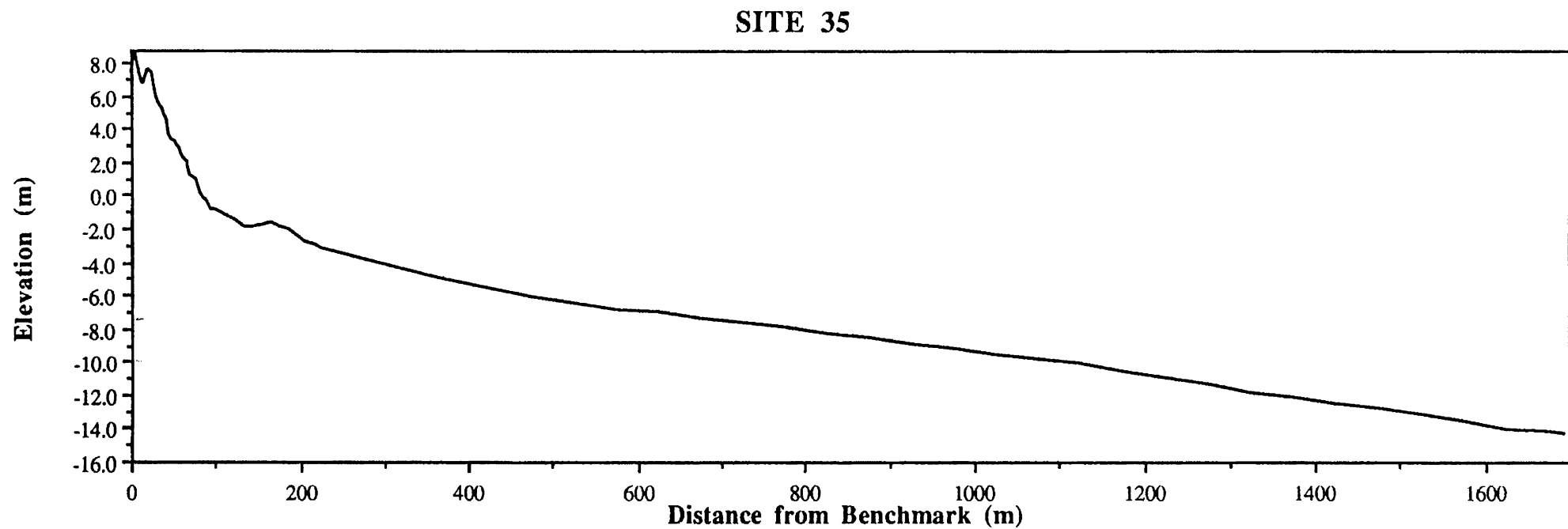
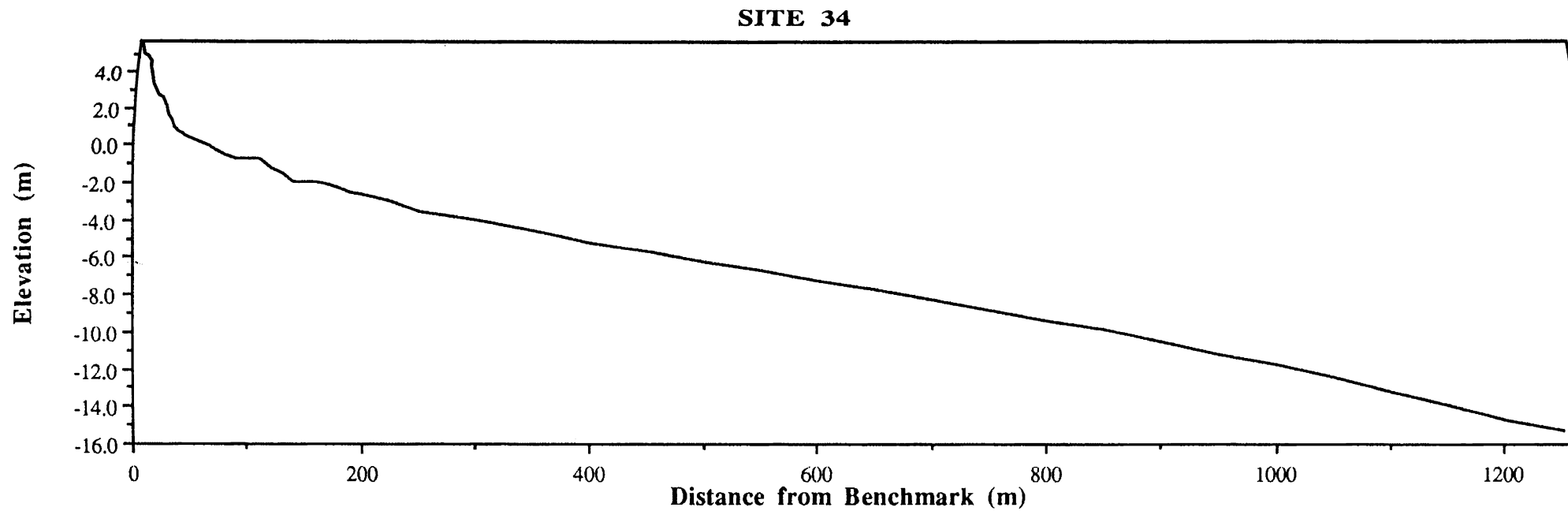


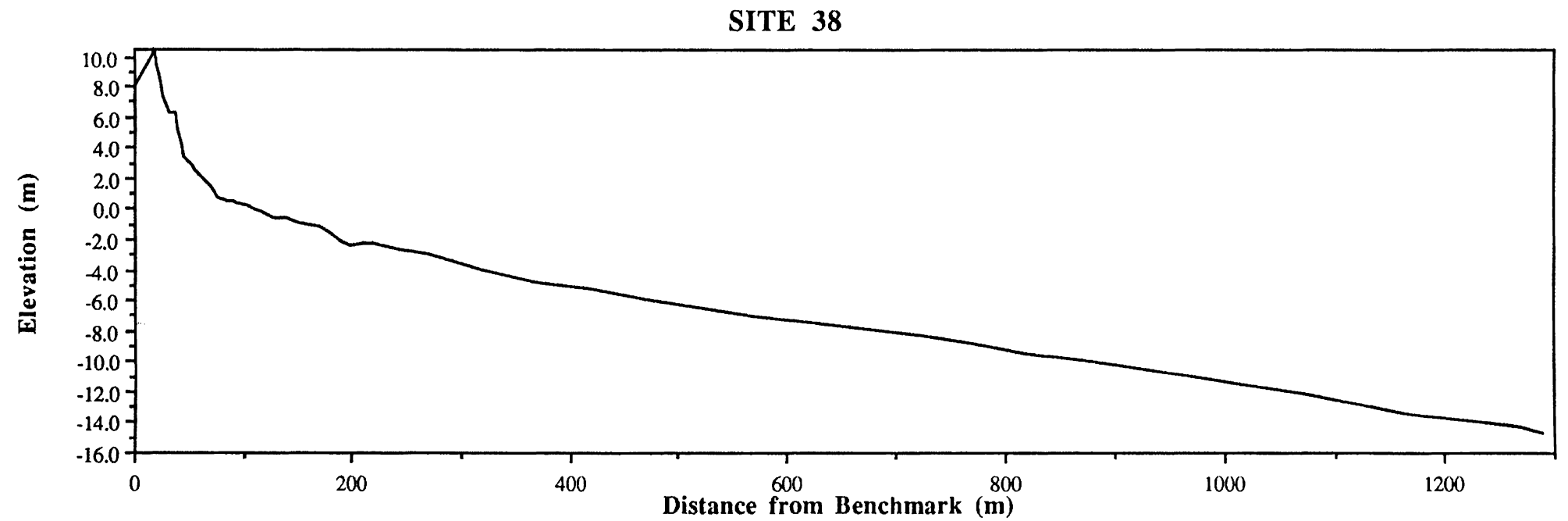
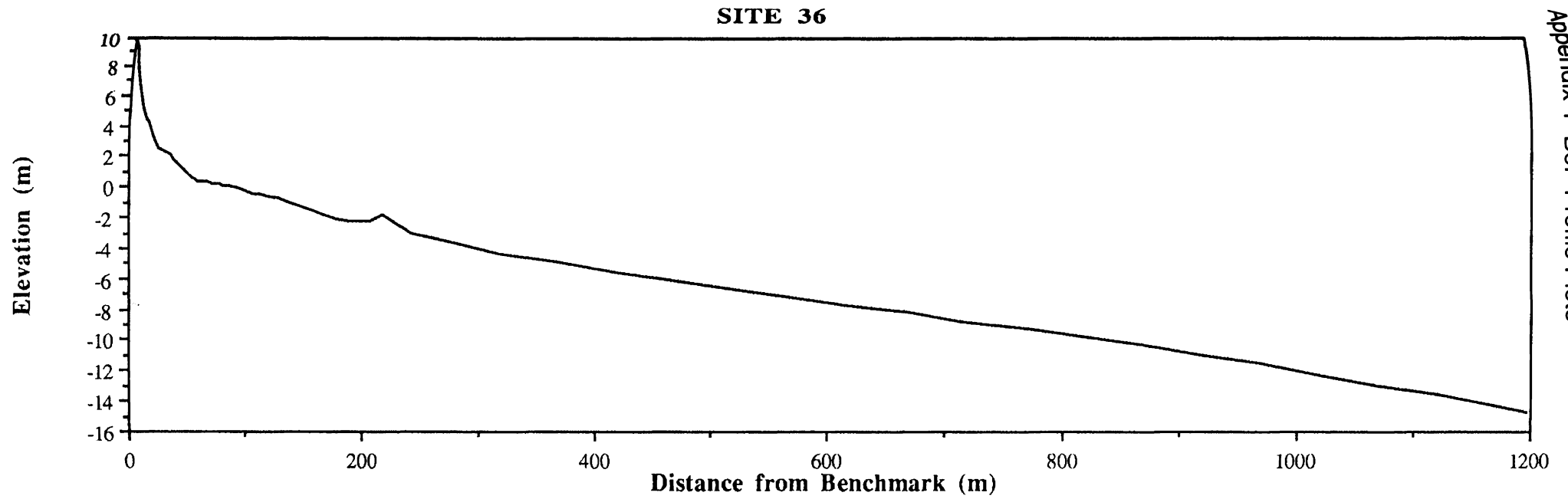


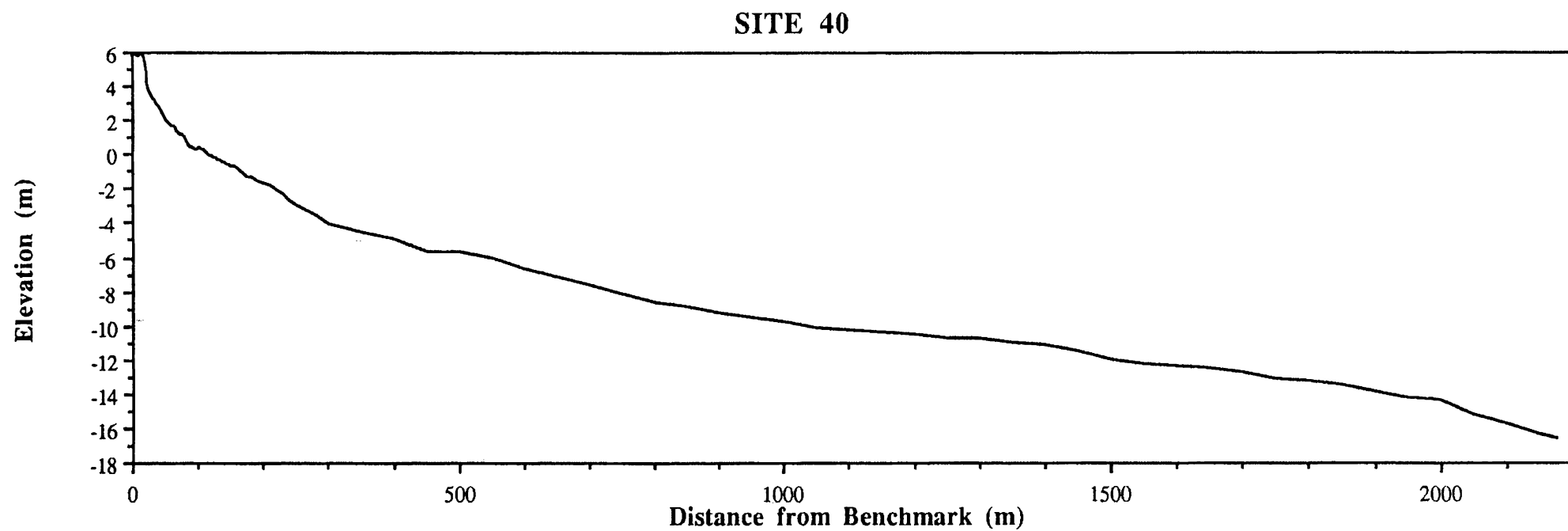
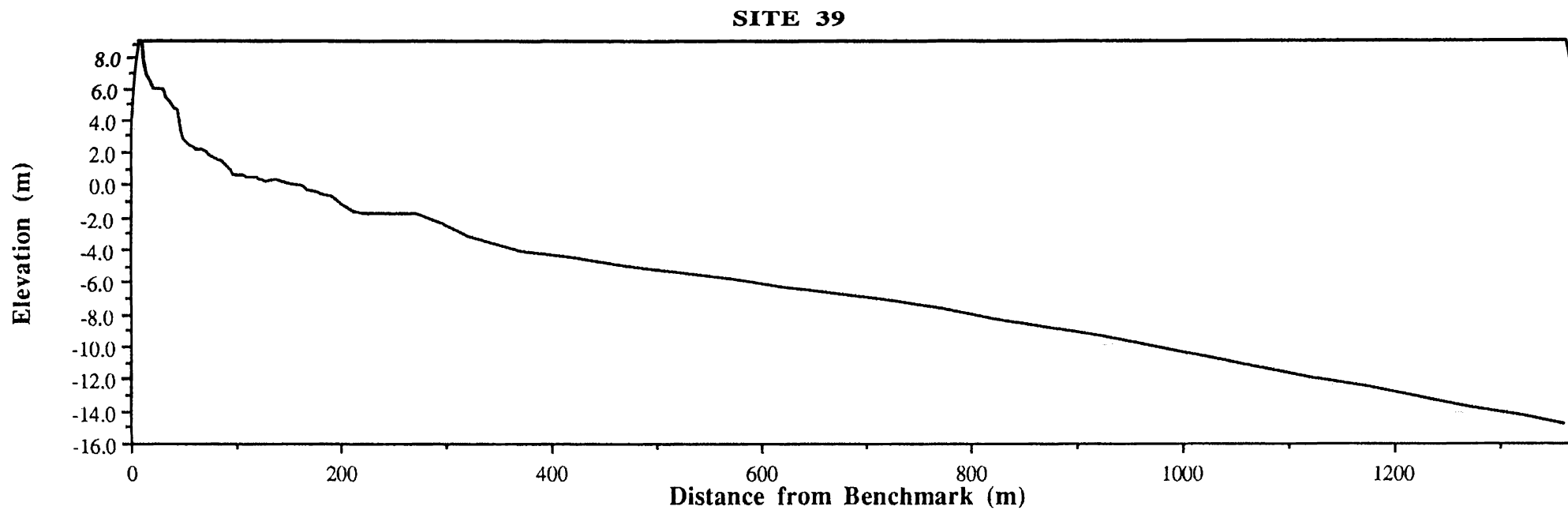


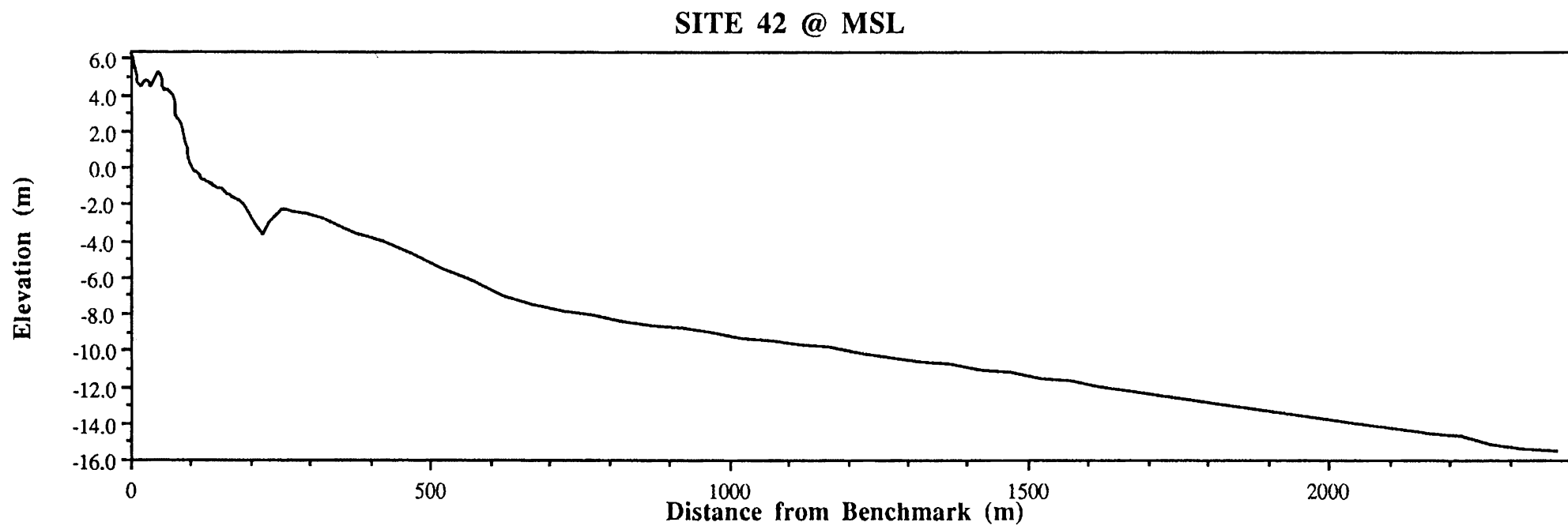
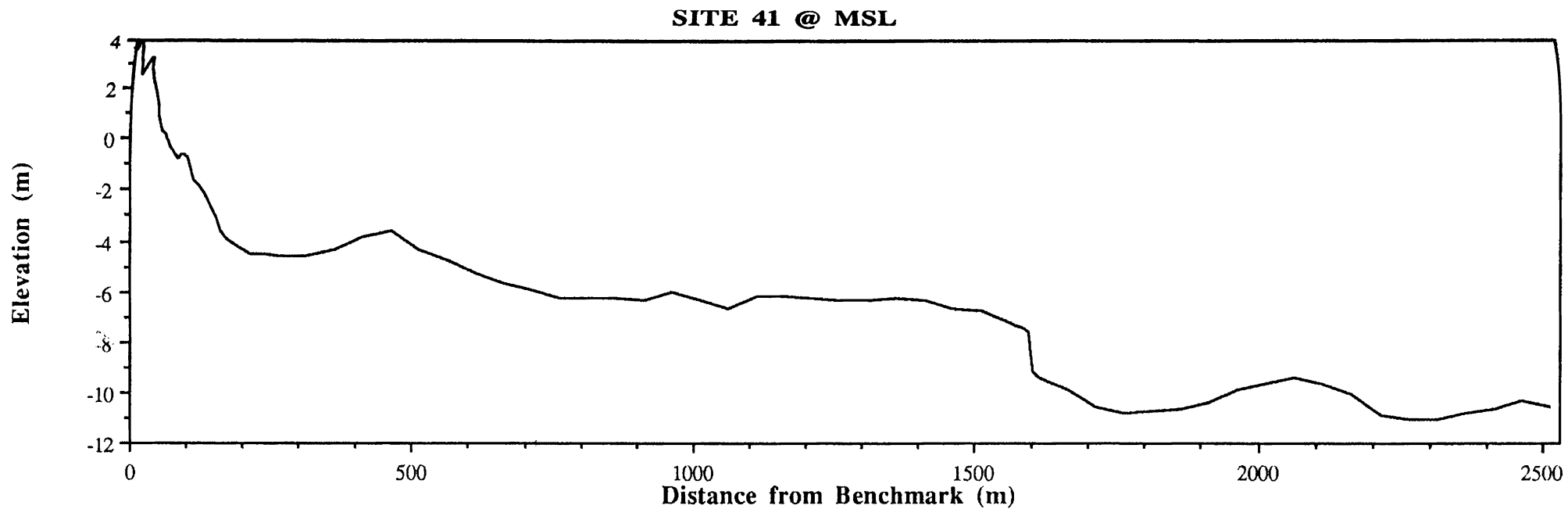


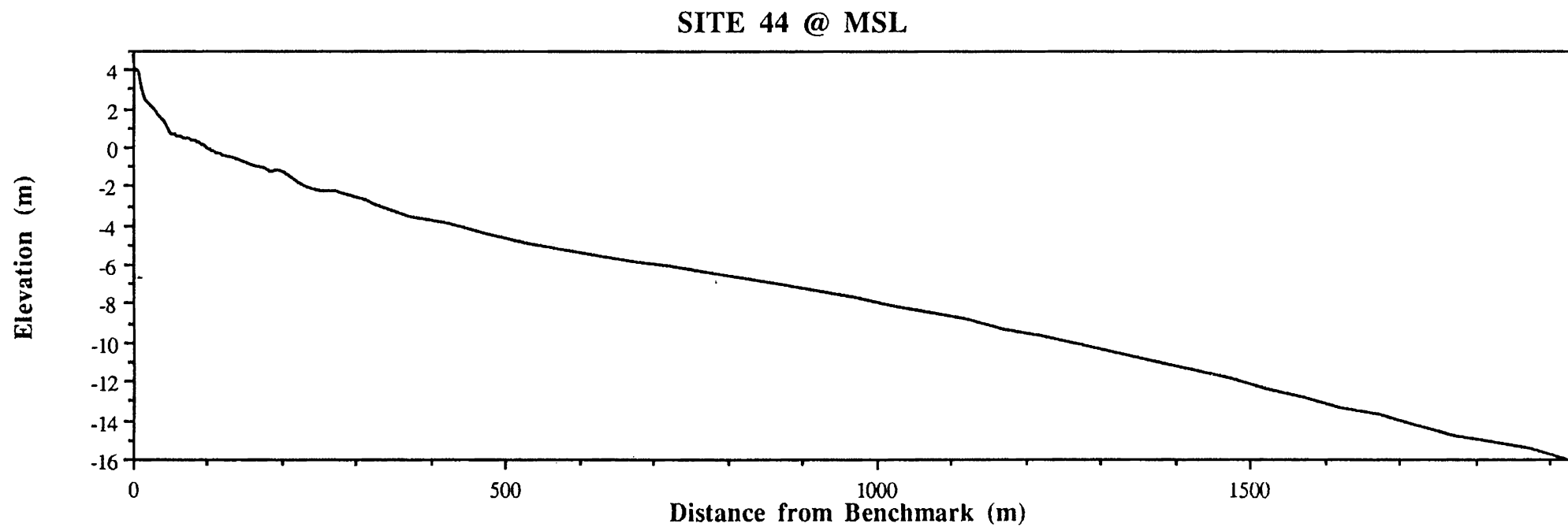
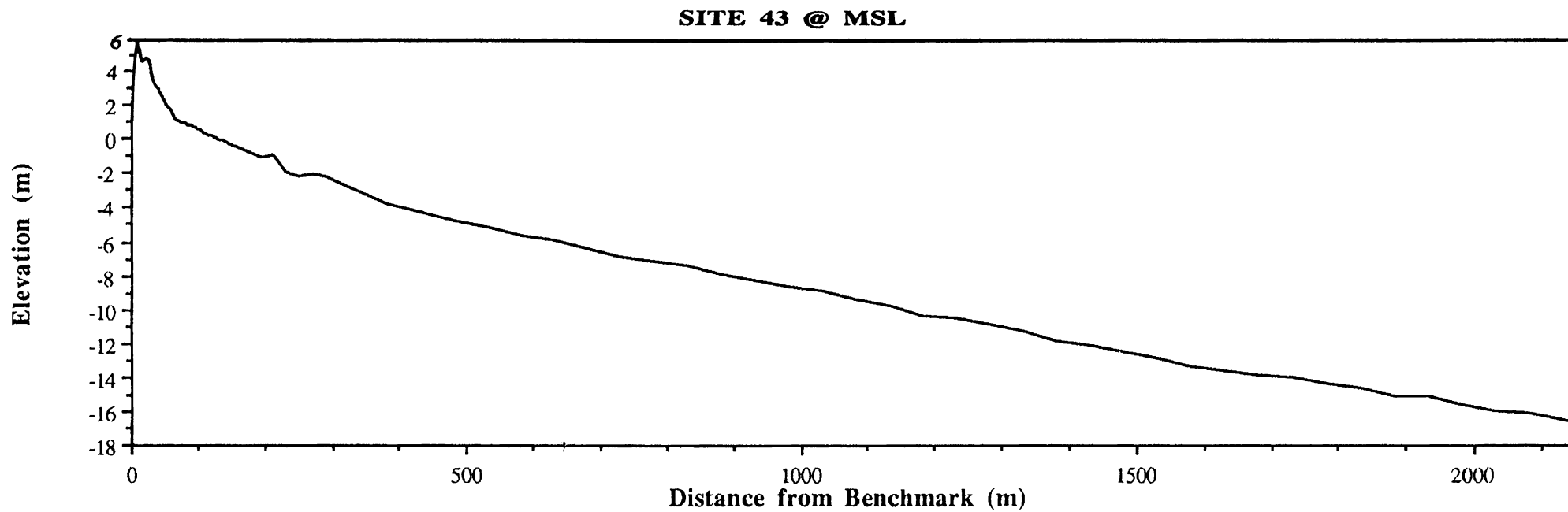


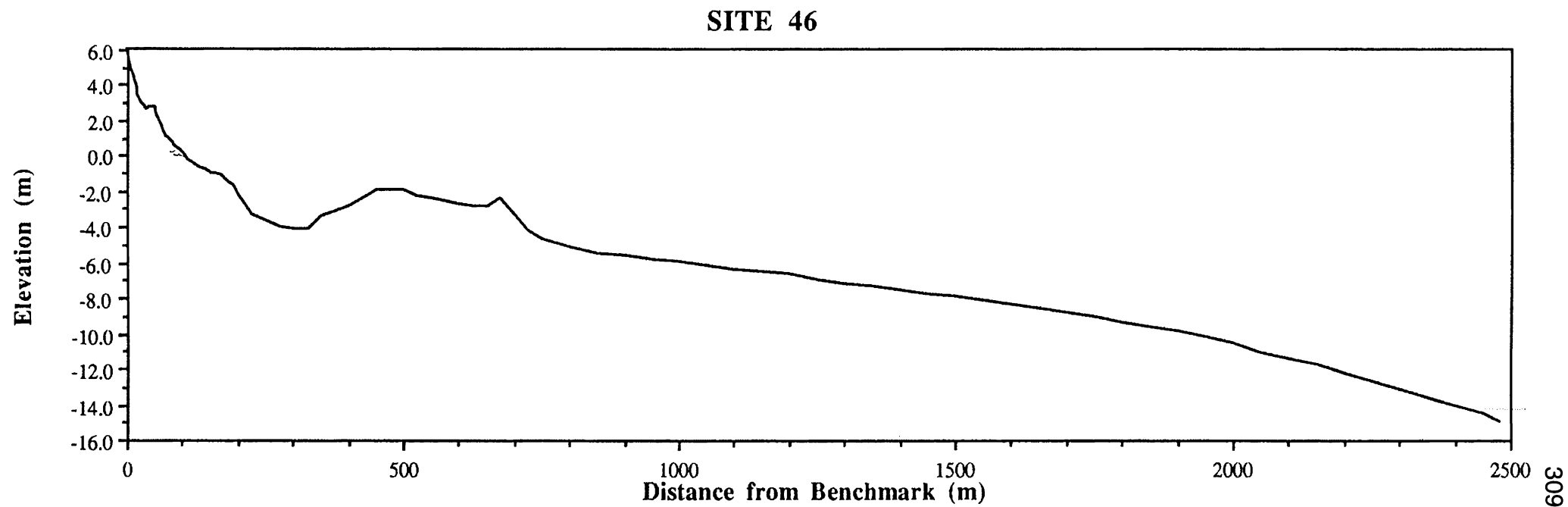
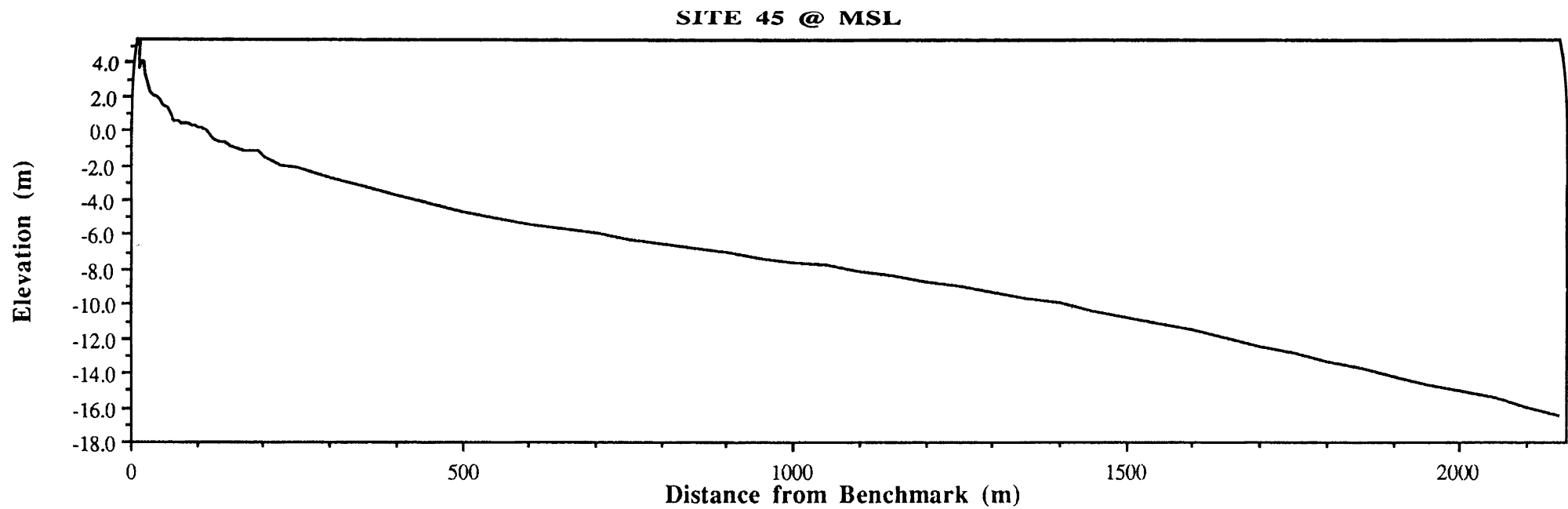


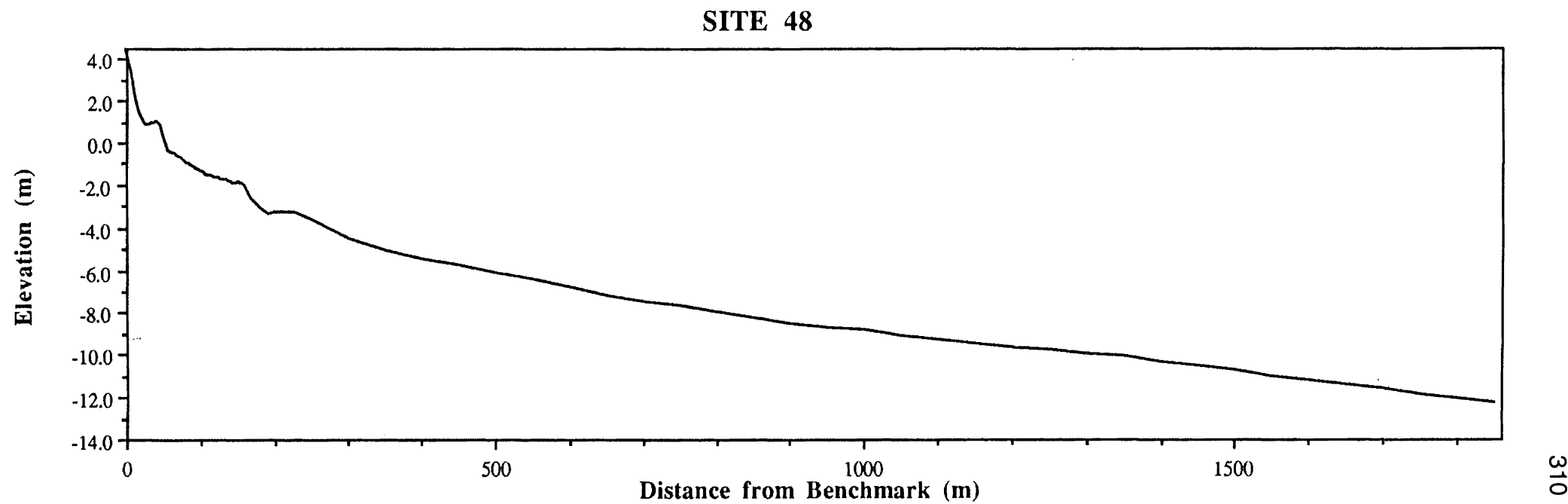
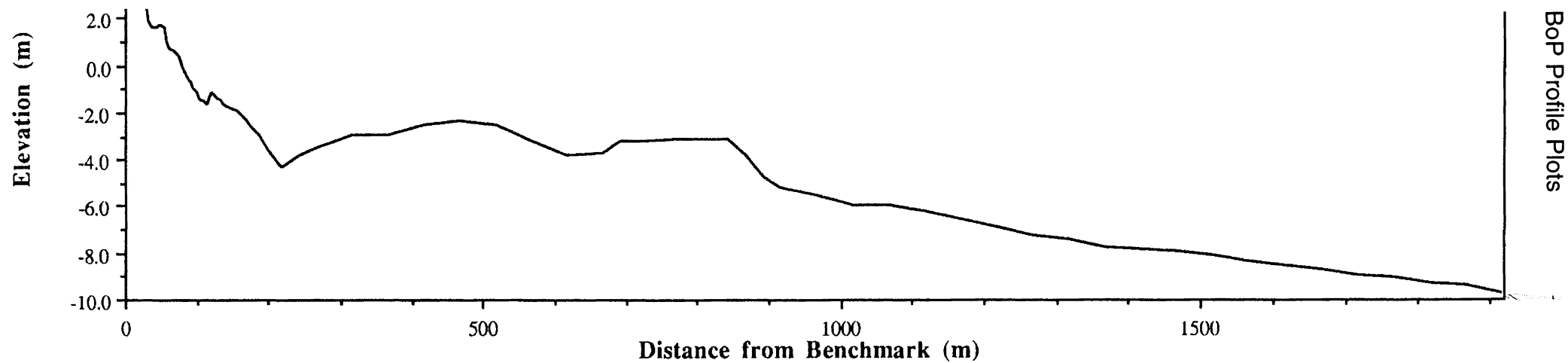


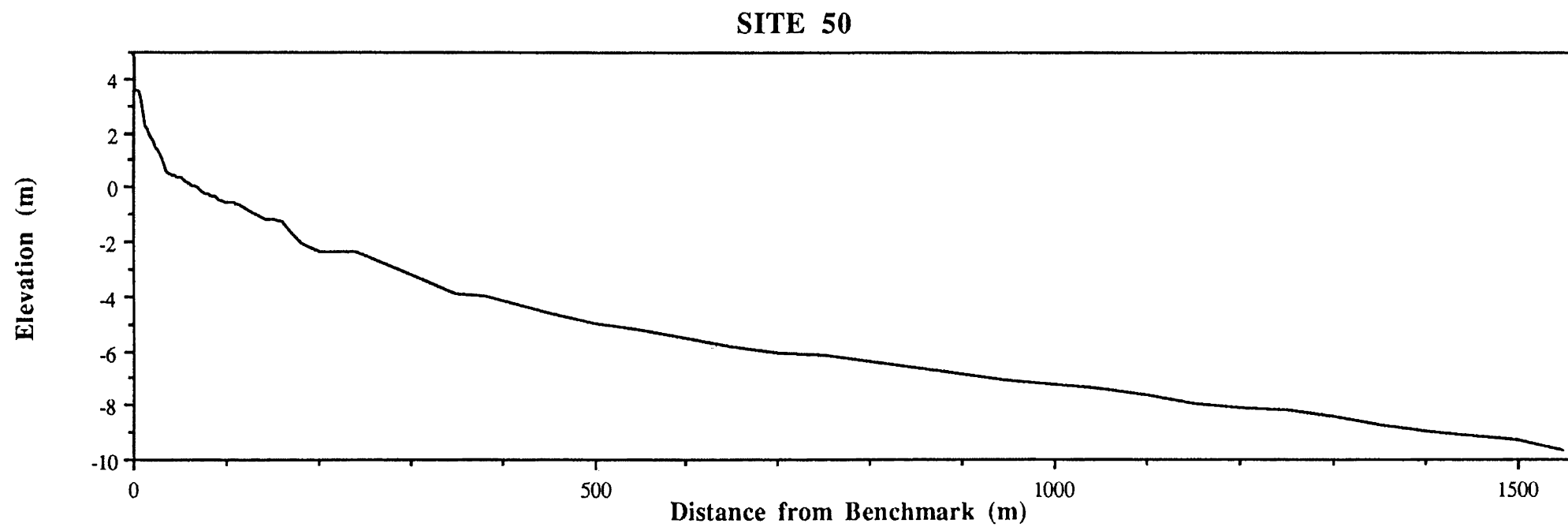
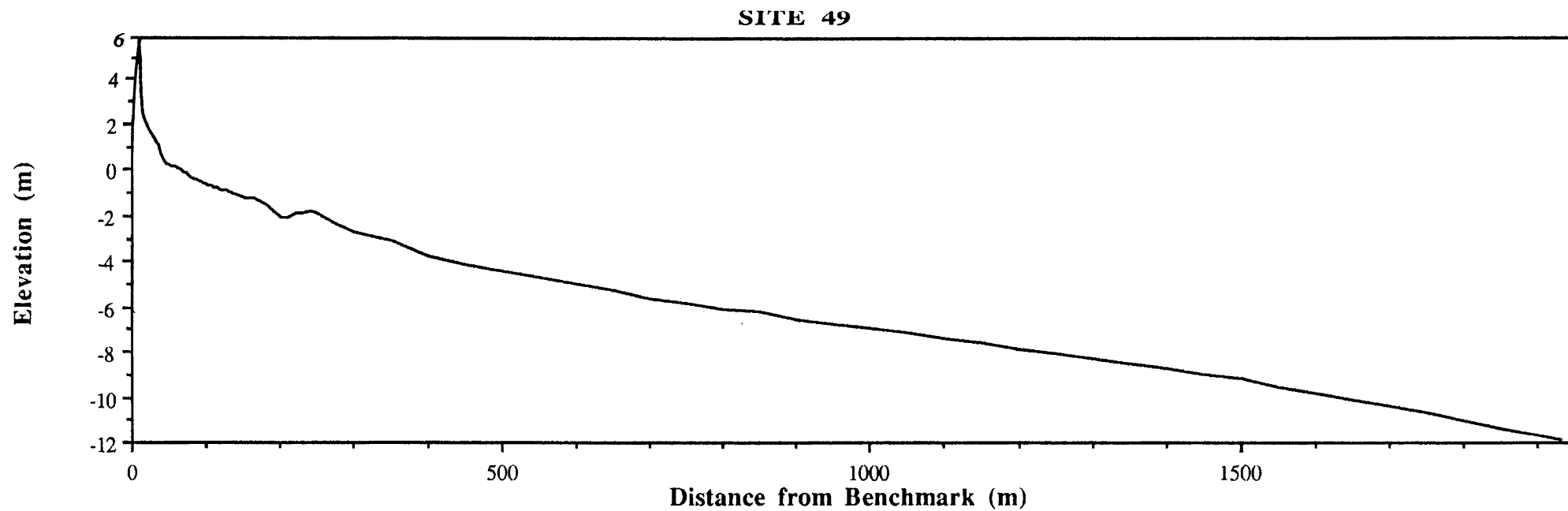


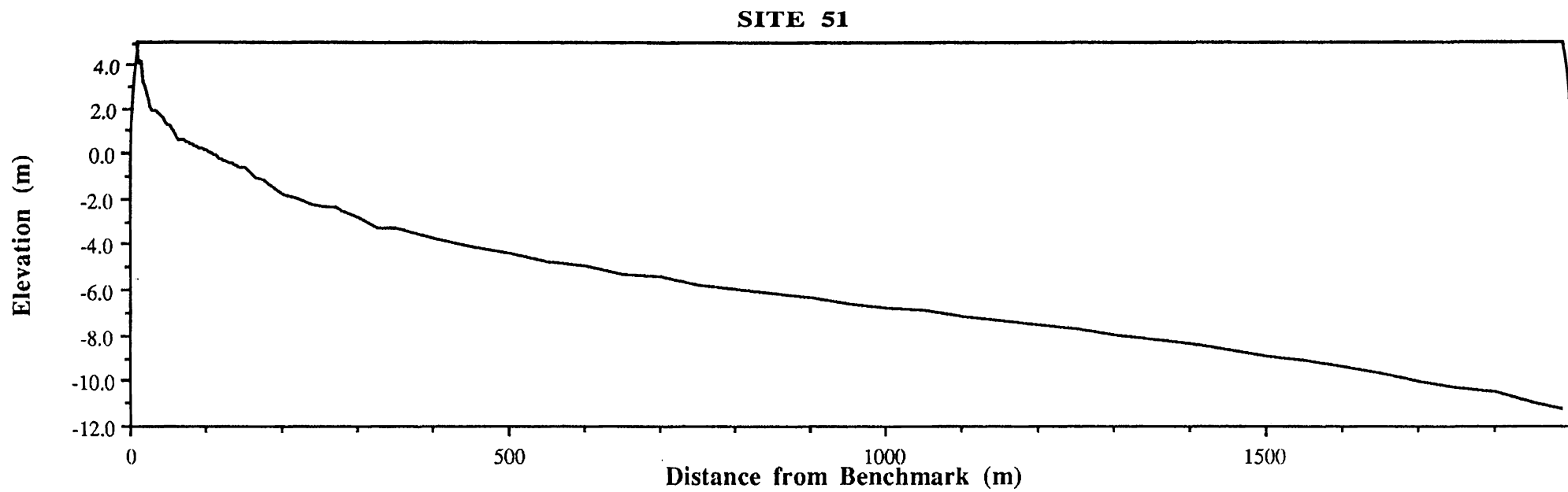












Appendix 2

Examples of Rapid Sediment Analyser Results
and Summary Spreadsheets showing profile and
mean grain size data, and Sediment derived Scale Factor
(*A*) values.

Appendix 2 – Notes

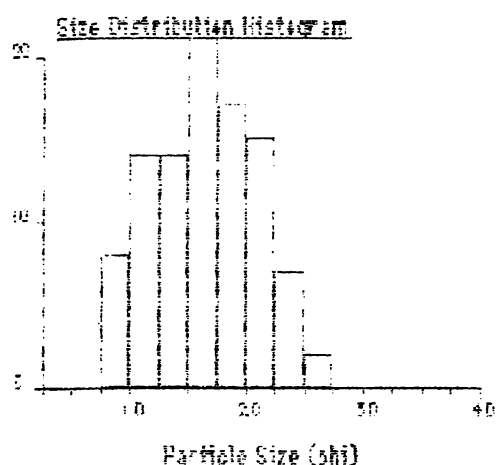
The following information is contained in this appendix:

1. Examples of output from the rapid sediment analyser is provided for profile 1. Similar output is available for all other profiles in the dataset (pp 313 – 331).
2. Sediment data together with offshore distance and Scale Factor A are shown in the first of two EXCEL spreadsheets (full, 8m and 6m depth, sed, A – pages). The column headers are shown in the top row of the first sheet (pp 332- 337).
3. Copies of profile data contained in an EXCEL spreadsheet is provided for all profile in the dataset together with profile plots. Offshore distances (m) from MSL are contained in column 1 while depths below MSL are shown in column two. Sediment data is shown at the bottom of each sheet with distance in the left hand column and mean grain diameter in mm in the right (pp 338 –385).

Particle Size Analysis

Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site 1700000



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.00% Sand= 100.00% Silt= 0.00% Clay= 0.00%
Gravel free detrital sediment
Sand

Moment Method Parameters

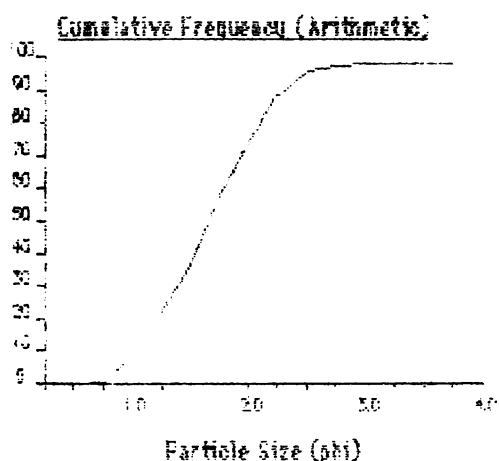
Mean= 1.62 Sorting= 0.46 Skewness= 0.32 Kurtosis= 2.50

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 1.66 Sorting= 0.50 Skewness= 0.31 Kurtosis= 0.91
Median= 1.67 σ = 0.77 σ_{35} = 1.48 σ_{65} = 1.87

Textural Description

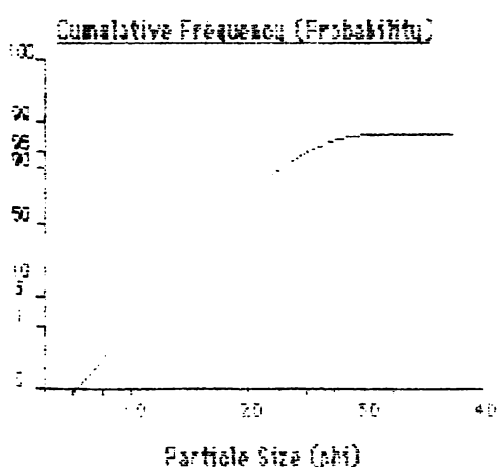
Moderately well sorted, Near symmetrical, Mesokurtic



Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
0.50	7.07e-1	0.01	0.03	0.03
0.75	5.95e-1	0.17	0.41	0.44
1.00	5.00e-1	3.26	8.16	8.61
1.25	4.20e-1	9.37	13.50	22.11
1.50	3.54e-1	13.65	13.92	36.03
1.75	2.97e-1	21.57	20.82	56.84
2.00	2.50e-1	27.81	16.56	73.41
2.25	2.10e-1	33.36	14.66	88.06
2.50	1.77e-1	36.03	7.06	95.13
2.75	1.49e-1	36.66	2.17	97.30
3.00	1.25e-1	36.99	0.35	97.65
3.25	1.05e-1	37.01	0.06	97.71
3.50	8.64e-2	37.03	0.04	97.75
3.75	7.47e-2	37.03	0.00	97.75

Total Weight = 37.88 g



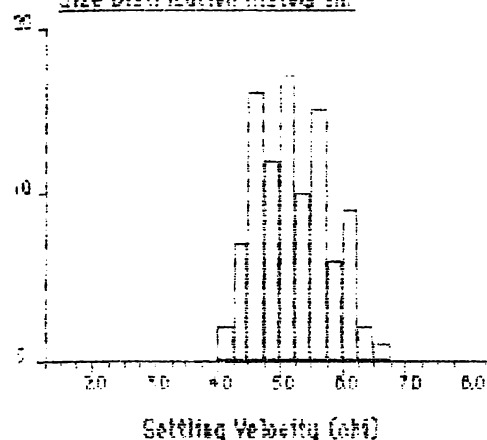
University of Waikato
Rapid Sediment Analyser
Operating System Version 5.5

Settling Velocity Analysis

Marine Geosciences (University of Waikato) - BOPRC

Sample Identification: Site 1 LWH

Size Distribution Histogram



Settling Velocity (chi) Results Summary

Moment Method Parameters

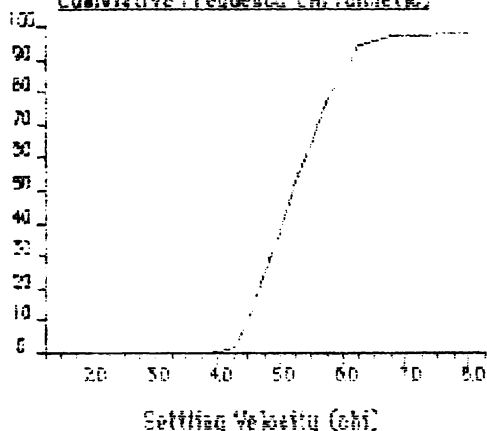
Mean= 5.12 Sorting= 0.61 Skewness= 0.90 Kurtosis= 3.58

Data Summary

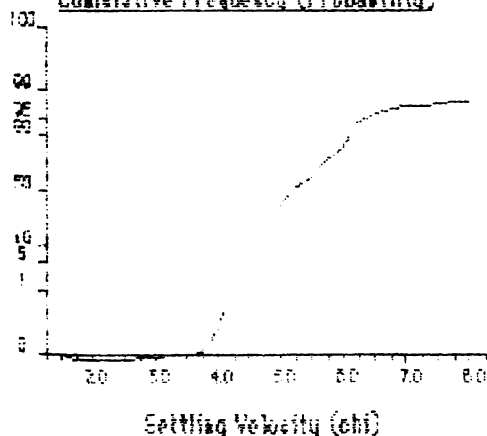
Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.50	3.54e-1	0.00	0.01	0.01
1.75	2.97e-1	0.01	0.01	0.02
2.00	2.50e-1	0.01	0.00	0.02
2.25	2.10e-1	0.01	0.00	0.02
2.50	1.77e-1	0.01	0.00	0.02
2.75	1.49e-1	0.01	0.01	0.03
3.00	1.25e-1	0.02	0.02	0.05
3.25	1.05e-1	0.02	0.01	0.06
3.50	8.94e-2	0.02	0.00	0.06
3.75	7.43e-2	0.03	0.03	0.09
4.00	6.25e-2	0.13	0.30	0.40
4.25	5.26e-2	0.77	1.92	2.32
4.50	4.42e-2	3.05	6.99	9.21
4.75	3.72e-2	8.25	15.65	24.85
5.00	3.12e-2	12.06	11.51	36.36
5.25	2.63e-2	17.66	16.86	53.22
5.50	2.21e-2	21.12	10.42	63.64
5.75	1.86e-2	26.03	14.80	78.45
6.00	1.56e-2	28.05	6.10	84.55
6.25	1.31e-2	31.17	9.38	93.93
6.50	1.10e-2	31.80	1.91	95.84
6.75	9.29e-3	32.12	0.96	96.80
7.00	7.91e-3	32.24	0.37	97.17
7.25	6.87e-3	32.24	0.01	97.18
7.50	5.92e-3	32.37	0.33	97.56
7.75	4.85e-3	32.41	0.13	97.69
8.00	3.91e-3	32.41	0.00	97.69

Total Weight = 33.13 g

Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



University of Waikato

Rapid Sediment Analyser

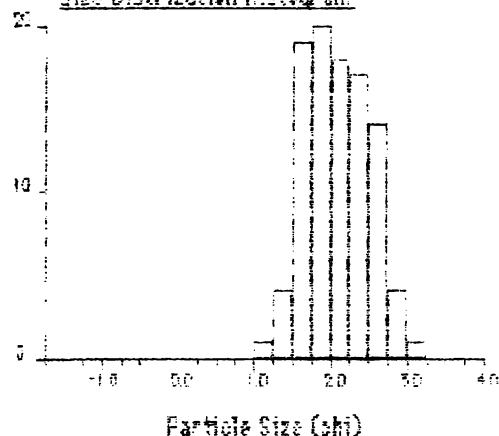
Operating System Version 5.5

Particle Size Analysis

Marine Geosciences (University of Waikato) - BOPRC

Sample Identification: Site 1 L177

Size Distribution Histogram



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.02% Sand= 99.98% Silt= 0.00% Clay= 0.00%
Gravel bearing detrital sediment
Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.04 Sorting= 0.43 Skewness= 0.38 Kurtosis= 3.76

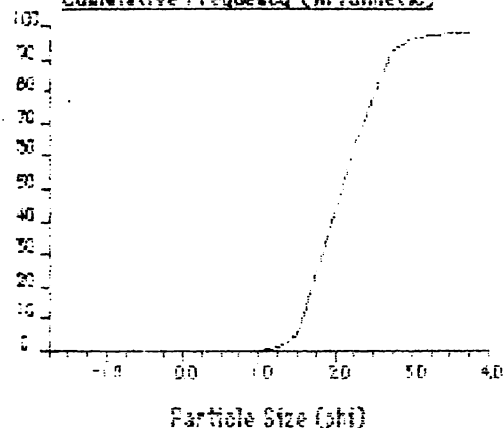
Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.11 Sorting= 0.46 Skewness= 0.12 Kurtosis= 0.66
Median= 2.05 D= 1.24 Q35= 1.89 Q85= 2.30

Textural Description

Well sorted, Fine skewed, Platykurtic

Cumulative Frequency (Arithmetic)

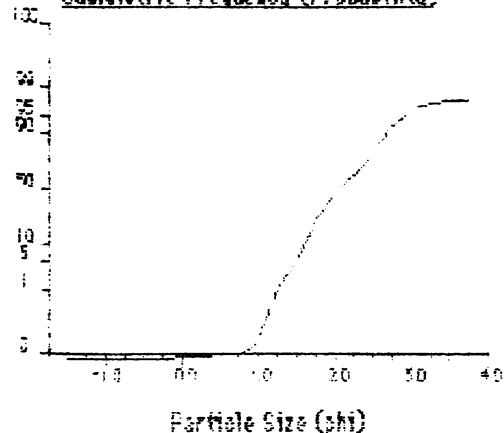


Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.01	0.02	0.02
-1.25	2.38e+0	0.01	0.02	0.02
-1.00	2.00e+0	0.01	0.02	0.02
-0.75	1.68e+0	0.01	0.02	0.02
-0.50	1.41e+0	0.01	0.02	0.02
-0.25	1.19e+0	0.01	0.01	0.03
0.00	1.00e+0	0.01	0.00	0.03
0.25	7.41e-1	0.02	0.02	0.05
0.50	7.07e-1	0.02	0.00	0.06
0.75	5.95e-1	0.02	0.00	0.06
1.00	5.00e-1	0.07	0.15	0.21
1.25	4.20e-1	0.34	0.93	1.04
1.50	3.54e-1	1.81	4.41	5.44
1.75	2.97e-1	8.00	18.65	24.12
2.00	2.50e-1	14.61	19.93	44.05
2.25	2.10e-1	20.48	17.58	61.72
2.50	1.77e-1	26.03	16.72	78.45
2.75	1.49e-1	30.56	13.67	92.11
3.00	1.25e-1	31.93	4.12	96.23
3.25	1.05e-1	32.24	0.95	97.17
3.50	8.84e-2	32.37	0.38	97.56
3.75	7.43e-2	32.37	0.00	97.56

Total Weight = 33.19 g

Cumulative Frequency (Probability)

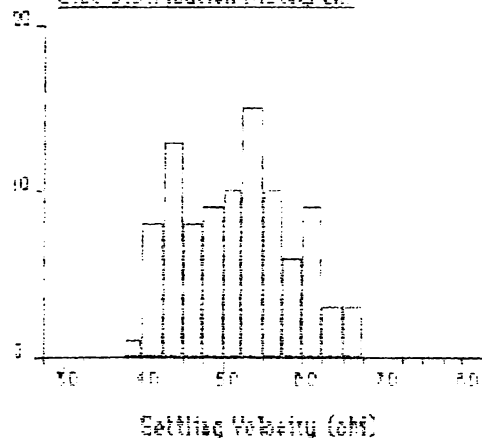


Settling Velocity Analysis

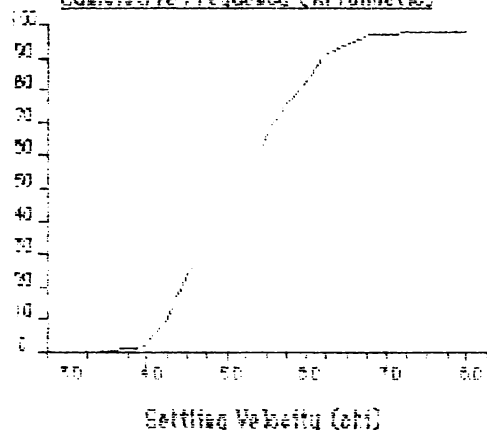
Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site 1 - #2

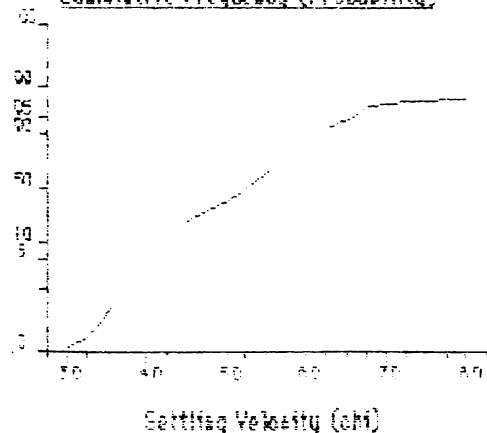
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.06 Sorting= 0.74 Skewness= 0.62 Kurtosis= 2.77

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
3.00	1.25e-1	0.04	0.12	0.12
3.25	1.05e-1	0.09	0.16	0.27
3.50	9.84e-2	0.19	0.26	0.54
3.75	7.43e-2	0.35	0.45	1.03
4.00	6.25e-2	0.75	1.14	2.17
4.25	5.26e-2	3.53	6.07	10.24
4.50	4.42e-2	8.09	13.23	23.47
4.75	3.72e-2	10.69	6.13	31.60
5.00	3.12e-2	13.95	9.92	40.48
5.25	2.63e-2	17.42	10.05	50.53
5.50	2.21e-2	22.72	15.38	65.91
5.75	1.86e-2	26.22	10.14	76.06
6.00	1.56e-2	28.34	6.17	82.23
6.25	1.31e-2	31.41	6.93	91.12
6.50	1.10e-2	32.47	3.09	94.20
6.75	9.29e-3	33.37	2.61	96.81
7.00	7.91e-3	33.92	0.42	97.24
7.25	6.87e-3	33.97	0.16	97.40
7.50	5.92e-3	33.90	0.09	97.49
7.75	4.85e-3	33.70	0.27	97.76
8.00	3.91e-3	33.70	0.00	97.76

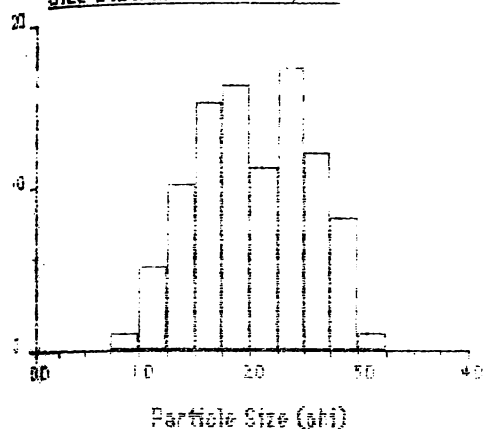
Total Weight = 34.47 g

Particle Size Analysis

Marine Geosciences (University of Waikato) - BOPRC

Sample Identification: Site 1 / #2

Size Distribution Histogram



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.00% Sand= 100.00% Silt= 0.00% Clay= 0.00%
Gravel free detrital sediment
Sand

Moment Method Parameters

Mean= 1.99 Sorting= 0.57 Skewness= 0.15 Kurtosis= 2.55

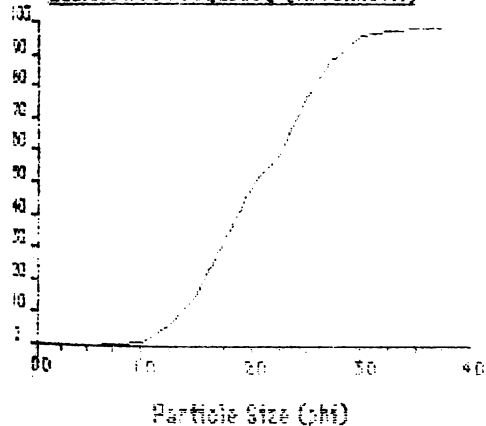
Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.07 Sorting= 0.57 Skewness= 0.04 Kurtosis= 0.86
Median= 2.05 σ = 0.65 D55= 1.60 D85= 2.34

Textural Description

Modestly well sorted, Near symmetrical, Platykurtic

Cumulative Frequency (Arithmetic)

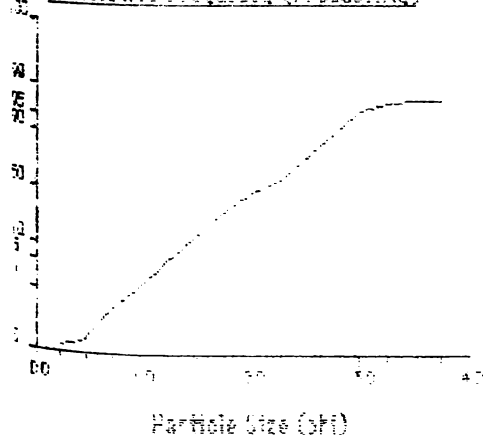


Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
0.25	8.41e-1	0.06	0.16	0.16
0.50	7.07e-1	0.09	0.10	0.27
0.75	5.95e-1	0.23	0.40	0.67
1.00	5.00e-1	0.59	1.05	1.72
1.25	4.20e-1	2.26	4.66	6.60
1.50	3.54e-1	5.57	9.56	16.16
1.75	2.97e-1	10.69	15.44	31.60
2.00	2.50e-1	16.53	10.34	47.95
2.25	2.10e-1	20.35	11.06	59.03
2.50	1.77e-1	26.21	17.03	76.06
2.75	1.49e-1	30.32	11.69	87.95
3.00	1.25e-1	33.01	7.95	95.80
3.25	1.05e-1	33.52	1.44	97.24
3.50	9.94e-2	33.60	0.25	97.49
3.75	7.43e-2	33.60	0.00	97.49

Total Weight = 34.47 g

Cumulative Frequency (Probability)

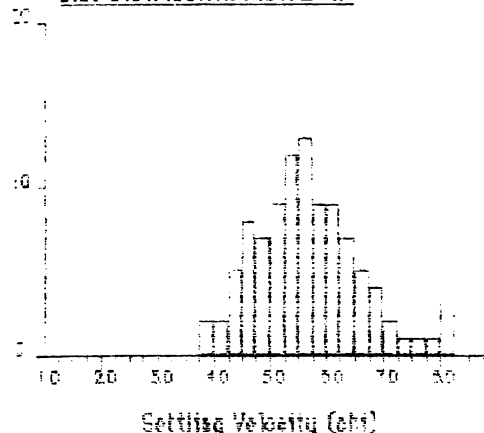


Settling Velocity Analysis

Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site #3

Size Distribution Histogram



Settling Velocity (chi) Results Summary

Moment Method Parameters

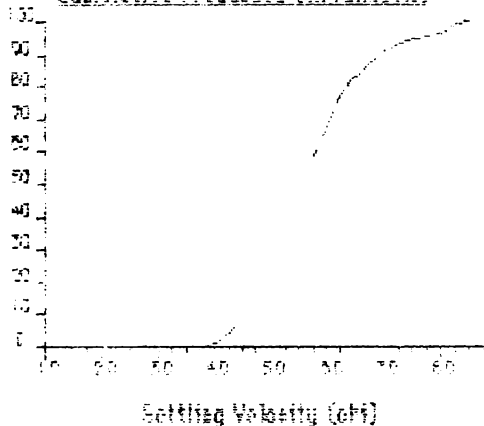
Mean = 5.00 Sorting = 0.95 Skewness = 0.47 Kurtosis = 3.82

Data Summary

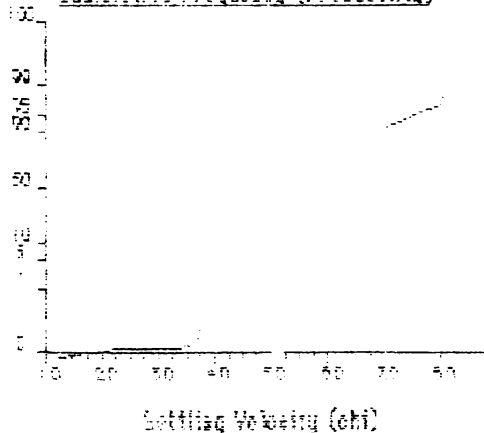
Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.25	4.20e-1	0.01	0.02	0.02
1.50	3.54e-1	0.02	0.03	0.05
1.75	2.97e-1	0.02	0.02	0.07
2.00	2.50e-1	0.03	0.05	0.10
2.25	2.10e-1	0.04	0.01	0.11
2.50	1.77e-1	0.04	0.00	0.11
2.75	1.49e-1	0.04	0.00	0.11
3.00	1.25e-1	0.04	0.00	0.11
3.25	1.05e-1	0.04	0.00	0.11
3.50	8.84e-2	0.06	0.06	0.17
3.75	7.43e-2	0.09	0.11	0.28
4.00	6.25e-2	0.50	1.56	1.86
4.25	5.26e-2	1.31	2.22	4.09
4.50	4.42e-2	2.91	4.93	9.05
4.75	3.72e-2	5.59	9.31	17.37
5.00	3.12e-2	7.73	6.74	24.11
5.25	2.63e-2	10.52	9.40	32.73
5.50	2.21e-2	14.36	11.94	44.67
5.75	1.86e-2	19.64	13.32	57.99
6.00	1.56e-2	21.55	5.07	63.06
6.25	1.31e-2	24.50	9.24	76.50
6.50	1.10e-2	25.62	6.51	82.81
6.75	9.29e-3	29.14	4.80	97.61
7.00	7.81e-3	29.37	3.77	91.39
7.25	6.57e-3	29.99	1.94	93.32
7.50	5.52e-3	30.44	1.40	94.72
7.75	4.65e-3	30.79	1.04	95.76
8.00	3.91e-3	31.05	0.84	96.59
8.25	3.28e-3	32.02	3.03	99.63
8.50	2.78e-3	32.14	0.37	100.00

Total weight = 32.14 g

Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)

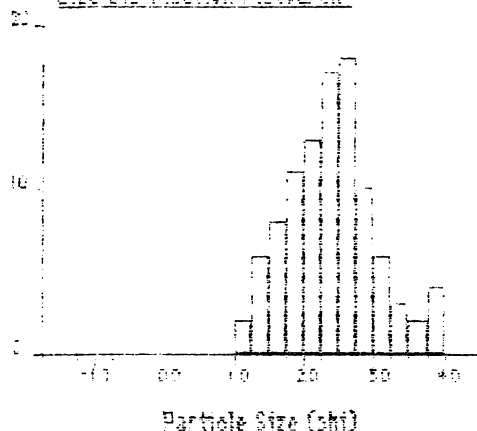


Particle Size Analysis

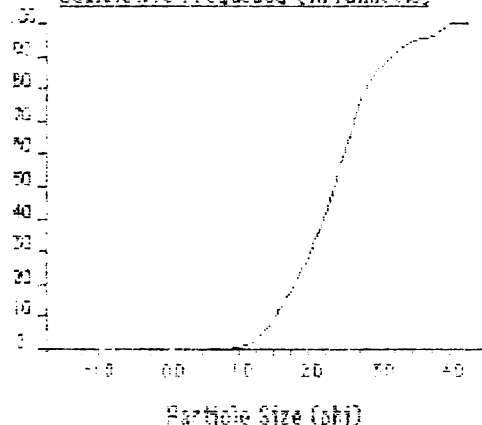
Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site = 50

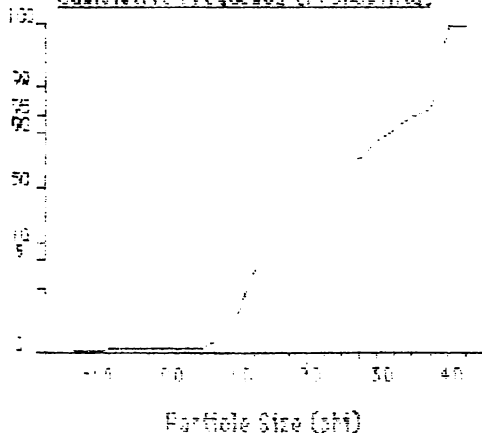
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probabilistic)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.00% Sand= 55.60% Silt= 0.00% Clay= 0.00%

Gravel bearing detrital sediment

Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.35 Sorting= 0.64 Skewness= 0.00 Kurtosis= 4.11

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.35 Sorting= 0.65 Skewness= -0.01 Kurtosis= 4.14

Median= 2.35 σ_1 = 1.04 σ_{85} = 2.15 σ_{65} = 2.60

Textural Description

Moderately well sorted, Near symmetrical, Leptokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.02	0.06	0.06
-1.25	2.38e+0	0.03	0.02	0.08
-1.00	2.00e+0	0.03	0.02	0.10
-0.75	1.68e+0	0.04	0.01	0.11
-0.50	1.41e+0	0.04	0.00	0.11
-0.25	1.19e+0	0.04	0.00	0.11
0.00	1.00e+0	0.04	0.00	0.11
0.25	0.41e-1	0.04	0.00	0.11
0.50	7.07e-1	0.04	0.00	0.11
0.75	5.95e-1	0.03	0.12	0.24
1.00	5.00e-1	0.19	0.34	0.58
1.25	4.20e-1	0.27	0.45	1.03
1.50	3.54e-1	2.86	5.65	6.69
1.75	2.97e-1	5.53	0.49	17.37
2.00	2.50e-1	5.03	10.74	28.11
2.25	2.11e-1	17.70	17.29	45.39
2.50	1.77e-1	18.66	16.67	58.05
2.75	1.49e-1	24.51	18.25	76.30
3.00	1.25e-1	27.59	5.54	85.84
3.25	1.05e-1	29.77	5.55	91.39
3.50	8.64e-2	30.37	3.09	94.48
3.75	7.47e-2	30.04	10	96.28
4.00	6.25e-2	32.11	5.63	99.91
4.25	5.28e-2	32.11	0.00	99.91

Total Weight = 32.14 g

University of Waikato

Rapid Sediment Analyser

Operating System Version 5.5

Particle Size Analysis

Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site 1 - #2

Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 1.01% Sand= 96.71% Silt= 0.00% Clay= 0.00%

Gravel bearing detrital sediment

Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.56 Sorting= 0.90 Skewness= -1.58 Kurtosis= 7.20

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.63 Sorting= 0.75 Skewness= -0.15 Kurtosis= 1.19

Median= 2.71 $D_{-1.0}$ 0.35= 2.43 D_{+5} 2.93

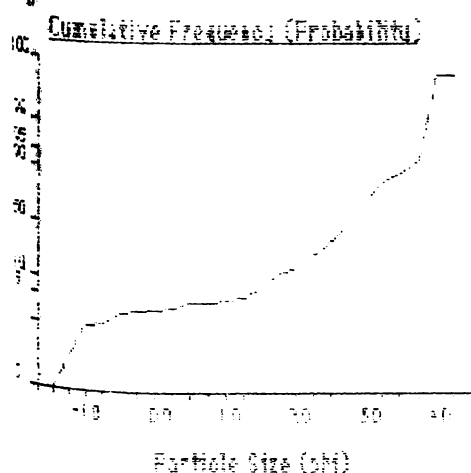
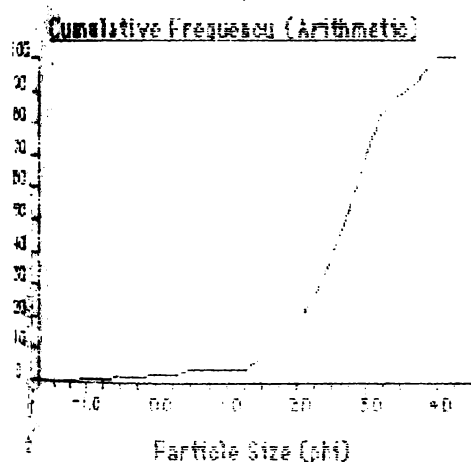
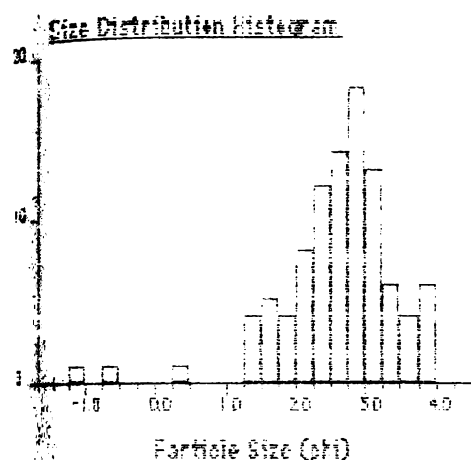
Textural Description

Moderately sorted, Coarse skewed, Leptokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.02	0.07	0.07
-1.25	2.38e+0	0.14	0.29	0.47
-1.00	2.00e+0	0.29	0.54	1.01
-0.75	1.68e+0	0.37	0.26	1.28
-0.50	1.41e+0	0.66	0.99	2.26
-0.25	1.18e+0	0.76	0.34	2.60
0.00	1.00e+0	0.82	0.21	2.80
0.25	8.41e-1	0.92	0.01	3.01
0.50	7.07e-1	1.17	1.01	4.02
0.75	5.95e-1	1.17	0.01	4.02
1.00	5.00e-1	1.29	0.42	4.45
1.25	4.20e-1	1.43	0.48	4.92
1.50	3.54e-1	2.58	5.94	6.86
1.75	2.97e-1	4.05	5.06	13.92
2.00	2.50e-1	5.31	4.51	16.23
2.25	2.10e-1	7.01	7.92	26.14
2.50	1.77e-1	11.11	12.04	38.18
2.75	1.49e-1	15.24	14.19	52.37
3.00	1.25e-1	20.35	17.55	69.91
3.25	1.05e-1	24.77	12.95	80.86
3.50	8.84e-2	25.84	5.54	86.41
3.75	7.47e-2	27.17	4.43	93.24
4.00	6.25e-2	29.02	6.49	99.73
4.25	5.26e-2	29.02	1.00	99.73

Total Weight= 29.02 g



University of Waikato

Rapid Sediment Analyser

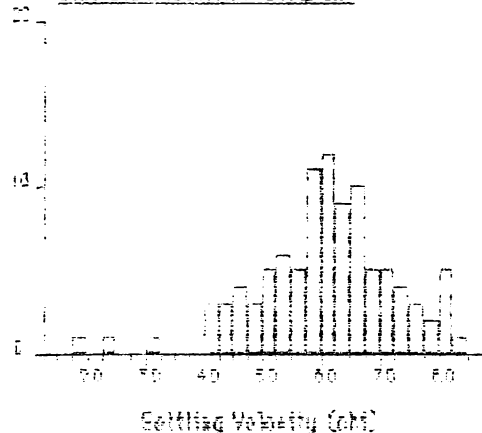
Operating System Version 5.5

Settling Velocity Analysis

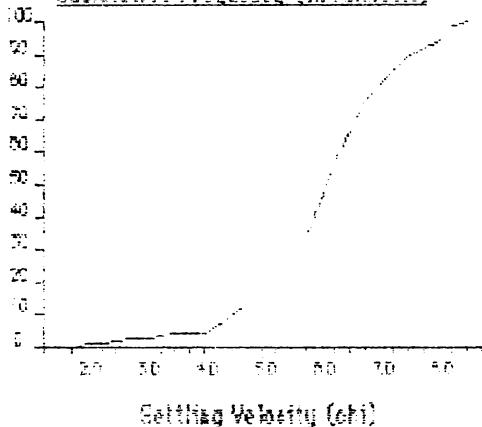
Marine Geosciences (University of Waikato) – BOPRC

Sample Identification: Site 1 #1

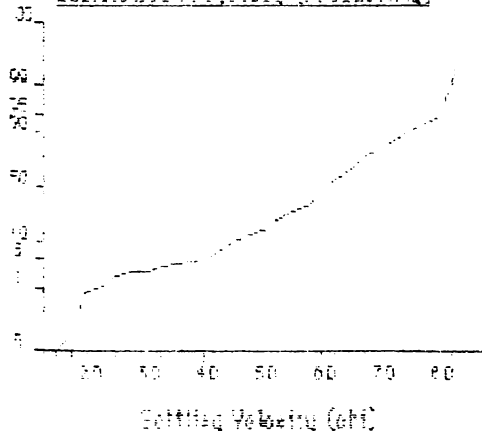
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (cm) Results Summary

Moment Method Parameters

Mean = 6.01 Sorting = 1.25 Skewness = -0.73 Kurtosis = 4.17

Data Summary

Velocity (cm)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.50	3.54e-1	0.00	0.00	0.00
1.75	2.97e-1	0.03	0.28	0.28
2.00	2.50e-1	0.29	0.71	0.99
2.25	2.10e-1	0.37	0.29	1.28
2.50	1.77e-1	0.68	1.05	2.32
2.75	1.49e-1	0.81	0.47	2.80
3.00	1.25e-1	0.92	0.04	2.87
3.25	1.05e-1	1.10	0.98	3.79
3.50	8.94e-2	1.17	0.23	4.02
3.75	7.43e-2	1.29	0.42	4.45
4.00	6.25e-2	1.29	0.00	4.45
4.25	5.26e-2	2.30	3.44	7.69
4.50	4.42e-2	3.06	2.62	10.50
4.75	3.72e-2	4.10	3.58	14.08
5.00	3.12e-2	4.95	2.97	17.05
5.25	2.63e-2	6.56	3.46	22.33
5.50	2.21e-2	8.28	5.91	28.44
5.75	1.86e-2	9.85	5.39	33.63
6.00	1.55e-2	12.94	10.64	44.47
6.25	1.31e-2	16.50	12.28	56.70
6.50	1.10e-2	19.10	8.92	65.62
6.75	9.29e-3	22.09	10.29	75.92
7.00	7.81e-3	23.41	4.54	80.45
7.25	6.57e-3	24.67	5.02	85.47
7.50	5.53e-3	25.99	3.87	89.30
7.75	4.68e-3	26.74	2.58	91.89
8.00	3.91e-3	27.39	2.24	94.12
8.25	3.28e-3	28.78	4.71	98.63
8.50	2.75e-3	29.10	1.17	100.00

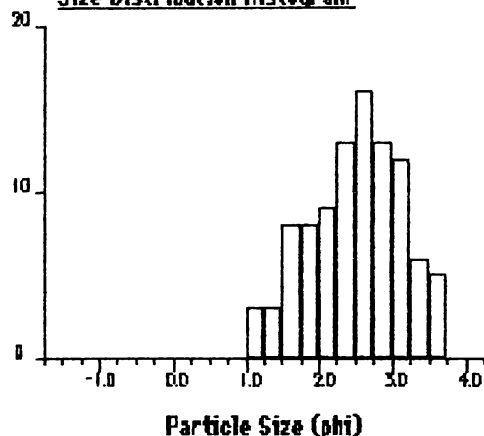
Total Weight = 29.10 g

Particle Size Analysis

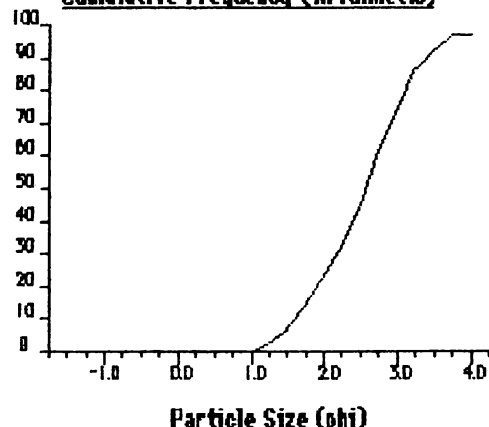
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #46

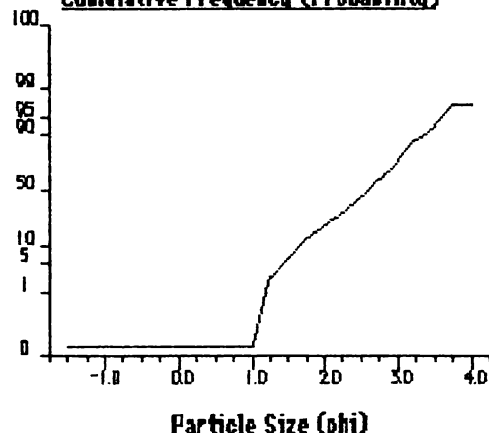
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.18% Sand= 97.13% Silt= 0.00% Clay= 0.00%

Gravel bearing detrital sediment

Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.43 Sorting= 0.64 Skewness= -0.36 Kurtosis= 4.89

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.52 Sorting= 0.69 Skewness= -0.09 Kurtosis= 0.95

Median= 2.58 C= 1.08 D35= 2.32 D65= 2.83

Textural Description

Moderately well sorted, Near symmetrical, Mesokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.03	0.18	0.18
-1.25	2.38e+0	0.03	0.00	0.18
-1.00	2.00e+0	0.03	0.00	0.18
-0.75	1.68e+0	0.03	0.00	0.18
-0.50	1.41e+0	0.03	0.00	0.18
-0.25	1.19e+0	0.03	0.00	0.18
0.00	1.00e+0	0.03	0.00	0.18
0.25	8.41e-1	0.03	0.00	0.18
0.50	7.07e-1	0.03	0.00	0.18
0.75	5.95e-1	0.03	0.00	0.18
1.00	5.00e-1	0.03	0.00	0.18
1.25	4.20e-1	0.46	2.68	2.86
1.50	3.54e-1	1.00	3.37	6.23
1.75	2.97e-1	2.32	8.24	14.47
2.00	2.50e-1	3.65	8.31	22.79
2.25	2.10e-1	5.05	8.78	31.56
2.50	1.77e-1	7.15	13.10	44.66
2.75	1.49e-1	9.76	16.37	61.03
3.00	1.25e-1	11.87	13.14	74.17
3.25	1.05e-1	13.87	12.49	86.66
3.50	8.84e-2	14.81	5.90	92.56
3.75	7.43e-2	15.57	4.75	97.32
4.00	6.25e-2	15.57	0.00	97.32

Total Weight = 16.00 g

University of Waikato

Rapid Sediment Analyser

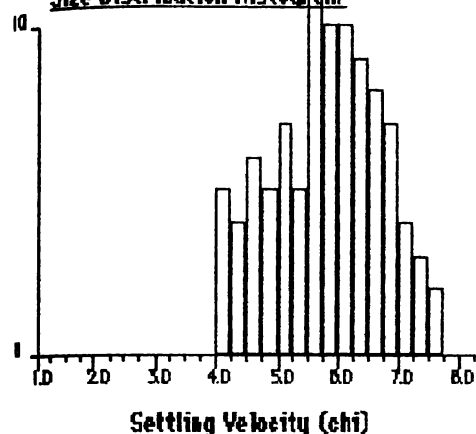
Operating System Version 5.5

Settling Velocity Analysis

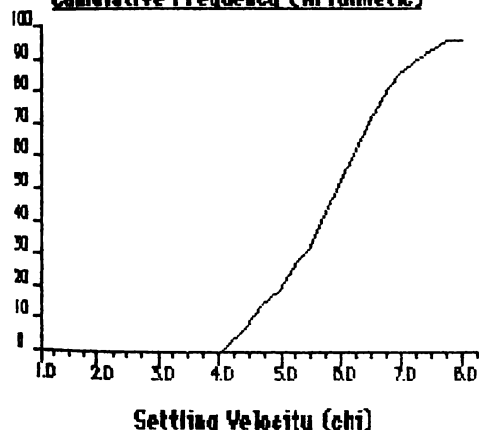
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #4b

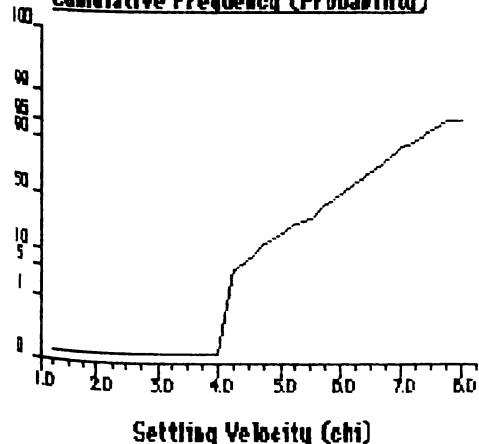
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.57 Sorting= 0.94 Skewness= 0.49 Kurtosis= 3.04

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.25	4.20e-1	0.03	0.18	0.18
1.50	3.54e-1	0.03	0.00	0.18
1.75	2.97e-1	0.03	0.00	0.18
2.00	2.50e-1	0.03	0.00	0.18
2.25	2.10e-1	0.03	0.00	0.18
2.50	1.77e-1	0.03	0.00	0.18
2.75	1.49e-1	0.03	0.00	0.18
3.00	1.25e-1	0.03	0.00	0.18
3.25	1.05e-1	0.03	0.00	0.18
3.50	8.84e-2	0.03	0.00	0.18
3.75	7.43e-2	0.03	0.00	0.18
4.00	6.25e-2	0.03	0.00	0.19
4.25	5.26e-2	0.78	4.70	4.89
4.50	4.42e-2	1.43	4.04	8.92
4.75	3.72e-2	2.41	6.12	15.05
5.00	3.12e-2	3.21	5.02	20.07
5.25	2.63e-2	4.28	6.69	26.76
5.50	2.21e-2	5.15	5.45	32.22
5.75	1.86e-2	6.84	10.55	42.77
6.00	1.56e-2	8.40	9.71	52.48
6.25	1.31e-2	9.92	9.53	62.00
6.50	1.10e-2	11.38	9.09	71.10
6.75	9.29e-3	12.68	8.13	79.22
7.00	7.81e-3	13.77	6.87	86.09
7.25	6.57e-3	14.38	3.78	89.87
7.50	5.52e-3	14.90	3.24	93.12
7.75	4.65e-3	15.30	2.48	95.60
8.00	3.91e-3	15.30	0.00	95.60

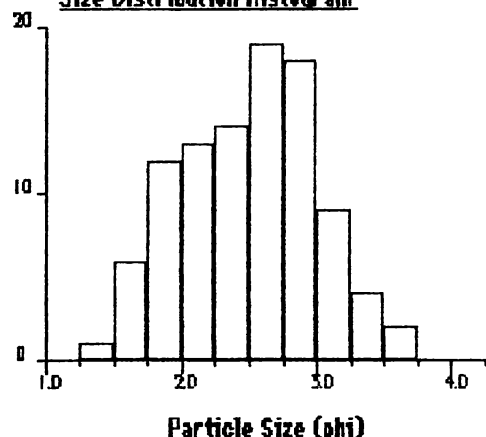
Total Weight = 16.00 g

Particle Size Analysis

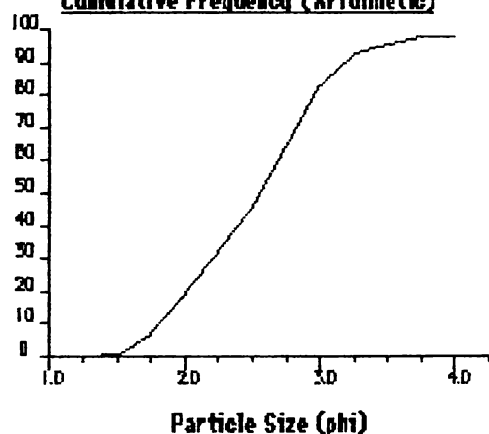
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #5

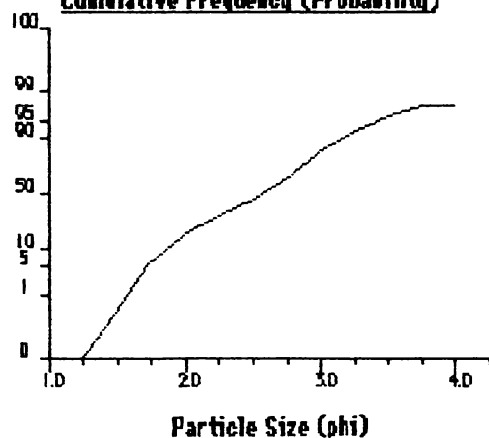
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.00% Sand= 97.50% Silt= 0.00% Clay= 0.00%

Gravel free detrital sediment

Sand

Moment Method Parameters

Mean= 2.44 Sorting= 0.49 Skewness= 0.33 Kurtosis= 2.40

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.51 Sorting= 0.54 Skewness= -0.06 Kurtosis= 0.93

Median= 2.56 C= 1.51 D35= 2.31 D65= 2.75

Textural Description

Moderately well sorted, Near symmetrical, Mesokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.25	4.20e-1	0.01	0.06	0.06
1.50	3.54e-1	0.12	0.63	0.69
1.75	2.97e-1	1.10	5.83	6.53
2.00	2.50e-1	3.16	12.28	18.81
2.25	2.10e-1	5.33	12.94	31.75
2.50	1.77e-1	7.69	14.05	45.80
2.75	1.49e-1	10.87	18.90	64.70
3.00	1.25e-1	13.96	18.39	83.09
3.25	1.05e-1	15.49	9.08	92.17
3.50	8.84e-2	16.11	3.72	95.89
3.75	7.43e-2	16.38	1.61	97.50
4.00	6.25e-2	16.38	0.00	97.50

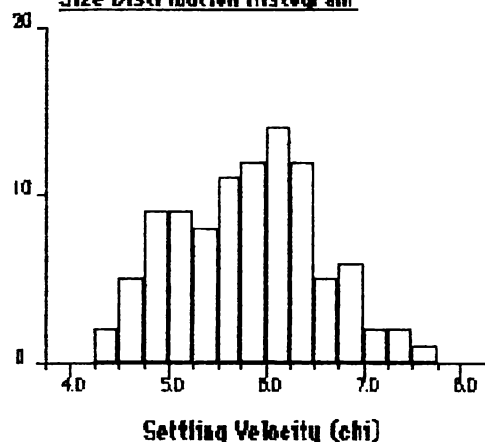
Total Weight = 16.80 g

Settling Velocity Analysis

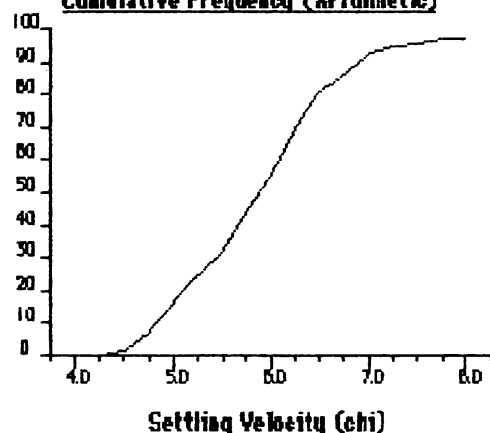
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #5

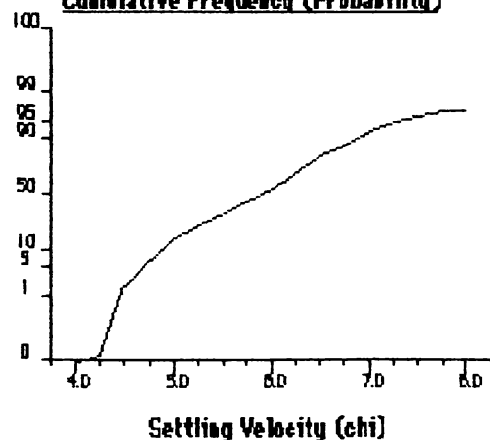
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.65 Sorting= 0.74 Skewness= 0.74 Kurtosis= 2.58

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
4.00	6.25e-2	0.01	0.04	0.04
4.25	5.26e-2	0.02	0.11	0.14
4.50	4.42e-2	0.31	1.70	1.85
4.75	3.72e-2	1.18	5.15	7.00
5.00	3.12e-2	2.62	8.59	15.59
5.25	2.63e-2	4.12	8.95	24.54
5.50	2.21e-2	5.46	7.95	32.49
5.75	1.86e-2	7.28	10.86	43.34
6.00	1.56e-2	9.27	11.82	55.16
6.25	1.31e-2	11.58	13.75	68.91
6.50	1.10e-2	13.51	11.52	80.44
6.75	9.29e-3	14.41	5.31	85.75
7.00	7.81e-3	15.49	6.42	92.17
7.25	6.57e-3	15.89	2.39	94.56
7.50	5.52e-3	16.14	1.53	96.10
7.75	4.65e-3	16.30	0.93	97.03
8.00	3.91e-3	16.30	0.00	97.03

Total Weight = 16.80 g .

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Rapid Sediment Analyser

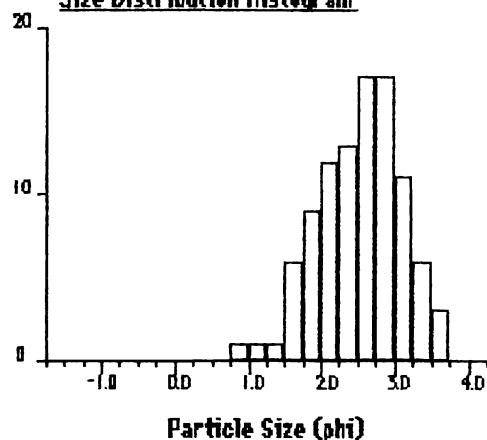
Operating System Version 5.5

Particle Size Analysis

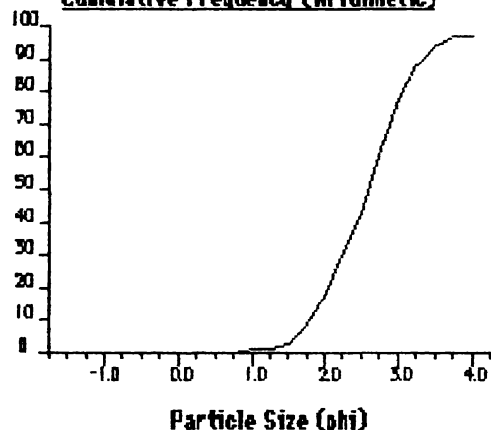
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #6

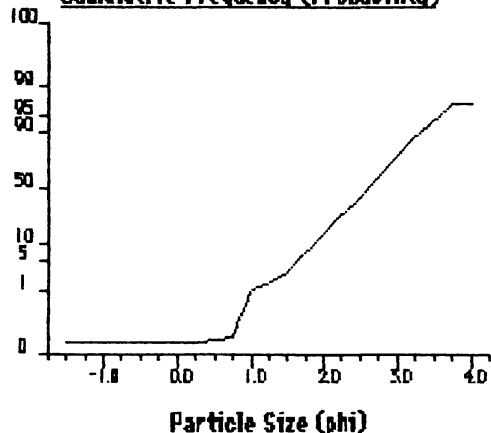
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.21% Sand= 97.09% Silt= 0.00% Clay= 0.00%
Gravel bearing detrital sediment
Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.46 Sorting= 0.59 Skewness= -0.65 Kurtosis= 7.13

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.58 Sorting= 0.60 Skewness= -0.05 Kurtosis= 1.00
Median= 2.61 C= 0.93 D35= 2.36 D65= 2.82

Textural Description

Moderately well sorted, Near symmetrical, Mesokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.04	0.21	0.21
-1.25	2.38e+0	0.04	0.00	0.21
-1.00	2.00e+0	0.04	0.00	0.21
-0.75	1.68e+0	0.04	0.00	0.21
-0.50	1.41e+0	0.04	0.00	0.21
-0.25	1.19e+0	0.04	0.00	0.21
0.00	1.00e+0	0.04	0.00	0.21
0.25	8.41e-1	0.04	0.00	0.21
0.50	7.07e-1	0.05	0.04	0.25
0.75	5.95e-1	0.06	0.04	0.29
1.00	5.00e-1	0.27	1.01	1.30
1.25	4.20e-1	0.40	0.59	1.89
1.50	3.54e-1	0.64	1.13	3.02
1.75	2.97e-1	1.83	5.61	8.64
2.00	2.50e-1	3.65	8.65	17.28
2.25	2.10e-1	6.21	12.11	29.39
2.50	1.77e-1	8.99	13.14	42.53
2.75	1.49e-1	12.67	17.40	59.93
3.00	1.25e-1	16.29	17.13	77.06
3.25	1.05e-1	18.64	11.10	88.16
3.50	8.84e-2	19.90	5.98	94.14
3.75	7.43e-2	20.57	3.15	97.30
4.00	6.25e-2	20.57	0.00	97.30

Total Weight = 21.14 g

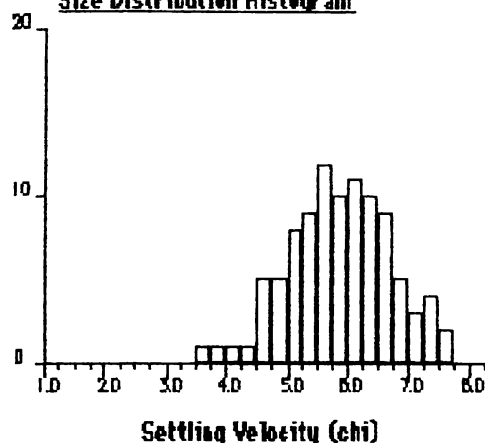
University of Waikato
Rapid Sediment Analyser
Operating System Version 5.5

Settling Velocity Analysis

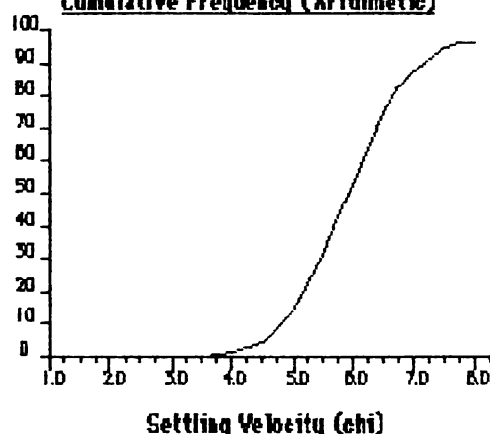
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Sample Identification: Site 1 / #6

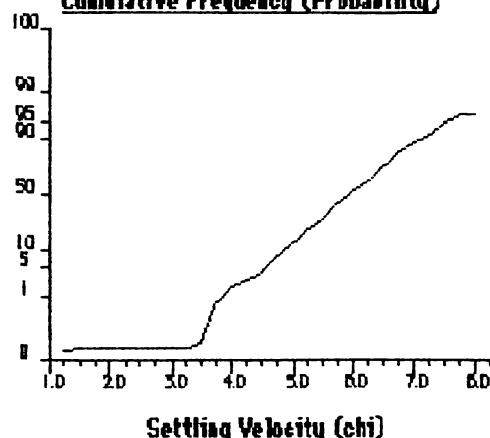
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.66 Sorting= 0.86 Skewness= 0.29 Kurtosis= 3.98

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.25	4.20e-1	0.04	0.19	0.19
1.50	3.54e-1	0.04	0.01	0.21
1.75	2.97e-1	0.04	0.00	0.21
2.00	2.50e-1	0.04	0.00	0.21
2.25	2.10e-1	0.04	0.00	0.21
2.50	1.77e-1	0.04	0.00	0.21
2.75	1.49e-1	0.04	0.00	0.21
3.00	1.25e-1	0.04	0.00	0.21
3.25	1.05e-1	0.04	0.00	0.21
3.50	8.84e-2	0.06	0.08	0.29
3.75	7.43e-2	0.18	0.57	0.86
4.00	6.25e-2	0.37	0.91	1.77
4.25	5.26e-2	0.61	1.11	2.88
4.50	4.42e-2	0.84	1.07	3.95
4.75	3.72e-2	1.92	5.11	9.06
5.00	3.12e-2	3.05	5.37	14.43
5.25	2.63e-2	4.71	7.84	22.27
5.50	2.21e-2	6.51	8.55	30.82
5.75	1.86e-2	8.98	11.68	42.50
6.00	1.56e-2	11.13	10.14	52.63
6.25	1.31e-2	13.45	10.99	63.62
6.50	1.10e-2	15.61	10.22	73.84
6.75	9.29e-3	17.53	9.09	82.93
7.00	7.81e-3	18.52	4.69	87.62
7.25	6.57e-3	19.24	3.37	90.99
7.50	5.52e-3	20.02	3.73	94.71
7.75	4.65e-3	20.38	1.67	96.38
8.00	3.91e-3	20.38	0.00	96.38

Total Weight = 21.14 g

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Rapid Sediment Analyser

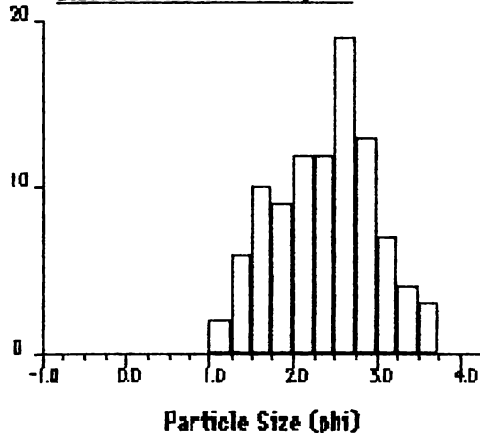
Operating System Version 5.5

Particle Size Analysis

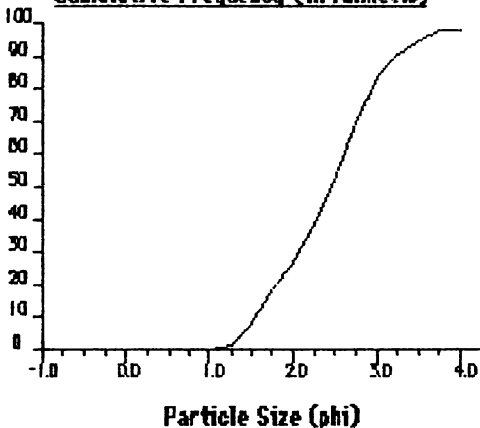
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Sample Identification: Site 1 / #7

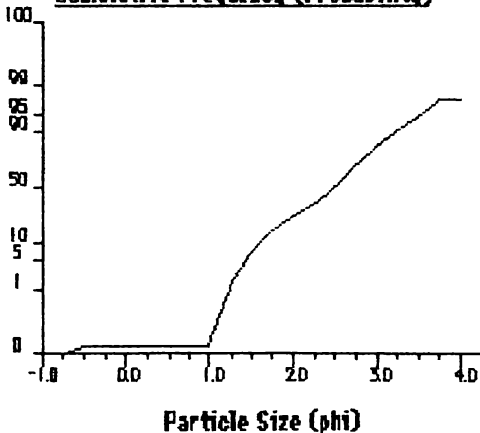
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.00% Sand= 97.43% Silt= 0.00% Clay= 0.00%
Gravel free detrital sediment
Sand

Moment Method Parameters

Mean= 2.33 Sorting= 0.60 Skewness= 0.03 Kurtosis= 3.23

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.41 Sorting= 0.66 Skewness= -0.09 Kurtosis= 0.99
Median= 2.48 C= 1.13 D35= 2.18 D65= 2.69

Textural Description

Moderately well sorted, Near symmetrical, Mesokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-0.75	1.68e+0	0.01	0.06	0.06
-0.50	1.41e+0	0.03	0.10	0.16
-0.25	1.19e+0	0.03	0.01	0.17
0.00	1.00e+0	0.03	0.00	0.17
0.25	8.41e-1	0.03	0.00	0.17
0.50	7.07e-1	0.03	0.00	0.17
0.75	5.95e-1	0.03	0.00	0.17
1.00	5.00e-1	0.03	0.00	0.17
1.25	4.20e-1	0.35	1.56	1.72
1.50	3.54e-1	1.65	6.33	8.06
1.75	2.97e-1	3.62	9.66	17.72
2.00	2.50e-1	5.46	8.97	26.68
2.25	2.10e-1	7.88	11.83	38.51
2.50	1.77e-1	10.42	12.45	50.96
2.75	1.49e-1	14.24	18.69	69.65
3.00	1.25e-1	16.96	13.30	82.95
3.25	1.05e-1	18.47	7.35	90.30
3.50	8.84e-2	19.31	4.14	94.44
3.75	7.43e-2	19.92	3.00	97.43
4.00	6.25e-2	19.92	0.00	97.43

Total Weight = 20.45 g

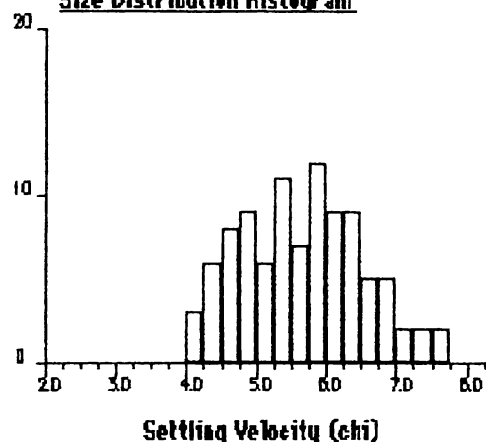
University of Waikato
Rapid Sediment Analyser
Operating System Version 5.5

Settling Velocity Analysis

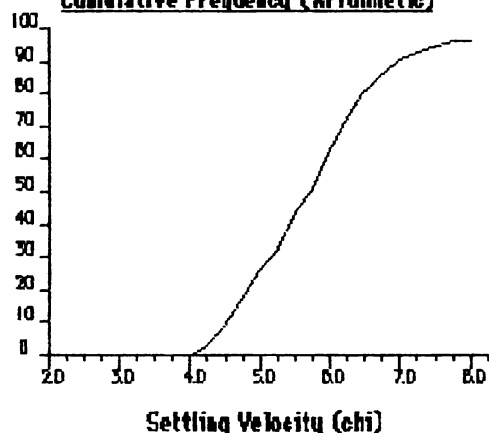
Earth Sciences – University of Waikato

Sample Identification: Site 1 / #7

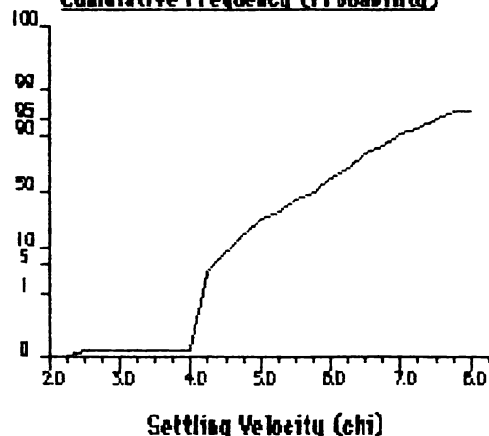
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.45 Sorting= 0.87 Skewness= 0.74 Kurtosis= 2.80

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
2.25	2.10e-1	0.02	0.10	0.10
2.50	1.77e-1	0.03	0.06	0.16
2.75	1.49e-1	0.03	0.00	0.17
3.00	1.25e-1	0.03	0.00	0.17
3.25	1.05e-1	0.03	0.00	0.17
3.50	8.84e-2	0.03	0.00	0.17
3.75	7.43e-2	0.03	0.00	0.17
4.00	6.25e-2	0.03	0.00	0.17
4.25	5.26e-2	0.60	2.78	2.95
4.50	4.42e-2	1.90	6.36	9.30
4.75	3.72e-2	3.62	8.41	17.72
5.00	3.12e-2	5.40	8.71	26.43
5.25	2.63e-2	6.65	6.06	32.49
5.50	2.21e-2	8.94	11.23	43.73
5.75	1.86e-2	10.30	6.62	50.35
6.00	1.56e-2	12.79	12.22	62.56
6.25	1.31e-2	14.72	9.44	72.00
6.50	1.10e-2	16.53	8.80	80.81
6.75	9.29e-3	17.51	4.80	85.60
7.00	7.81e-3	18.47	4.70	90.30
7.25	6.57e-3	18.96	2.39	92.69
7.50	5.52e-3	19.41	2.23	94.92
7.75	4.65e-3	19.72	1.53	96.45
8.00	3.91e-3	19.72	0.00	96.45

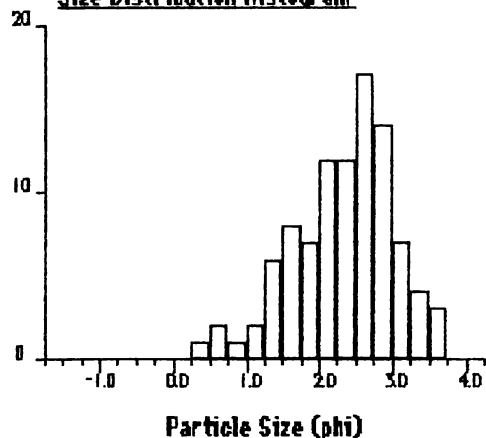
Total Weight = 20.45 g

Particle Size Analysis

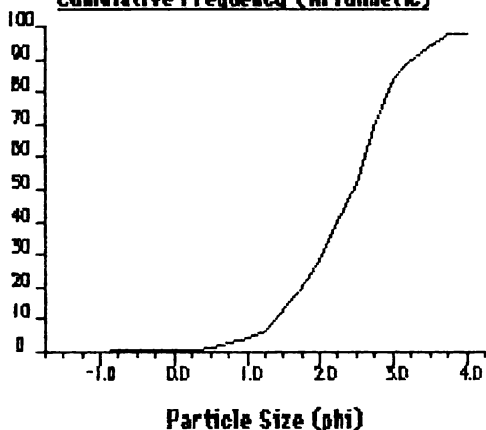
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Sample Identification: Site 1 / #7b.

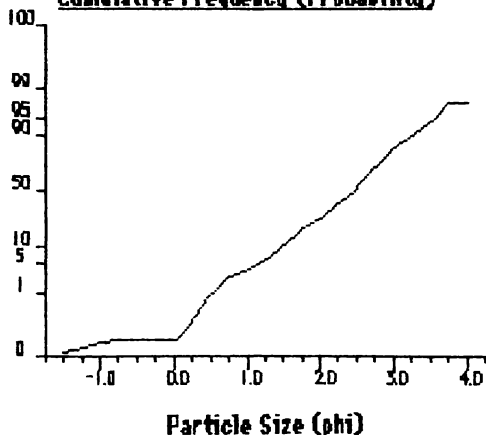
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Particle Size (phi) Results Summary

Textural Size Classes

Gravel= 0.28% Sand= 97.20% Silt= 0.00% Clay= 0.00%

Gravel bearing detrital sediment

Slightly Gravelly Sand

Moment Method Parameters

Mean= 2.27 Sorting= 0.71 Skewness= -0.59 Kurtosis= 4.65

Graphical Method Parameters (Folk & Ward, 1957)

Mean= 2.37 Sorting= 0.73 Skewness= -0.15 Kurtosis= 1.07

Median= 2.46 C= 0.42 D35= 2.15 D65= 2.69

Textural Description

Moderately sorted, Coarse skewed, Mesokurtic

Data Summary

Size (phi)	Size (mm)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
-1.50	2.83e+0	0.03	0.13	0.13
-1.25	2.38e+0	0.04	0.07	0.20
-1.00	2.00e+0	0.05	0.07	0.28
-0.75	1.68e+0	0.06	0.03	0.31
-0.50	1.41e+0	0.06	0.00	0.31
-0.25	1.19e+0	0.06	0.00	0.31
0.00	1.00e+0	0.06	0.00	0.31
0.25	8.41e-1	0.10	0.22	0.52
0.50	7.07e-1	0.25	0.72	1.24
0.75	5.95e-1	0.55	1.54	2.78
1.00	5.00e-1	0.83	1.38	4.16
1.25	4.20e-1	1.29	2.32	6.48
1.50	3.54e-1	2.44	5.78	12.26
1.75	2.97e-1	4.02	7.95	20.21
2.00	2.50e-1	5.51	7.49	27.70
2.25	2.10e-1	7.88	11.92	39.62
2.50	1.77e-1	10.32	12.31	51.93
2.75	1.49e-1	13.78	17.36	69.29
3.00	1.25e-1	16.53	13.83	83.12
3.25	1.05e-1	17.88	6.83	89.95
3.50	8.84e-2	18.76	4.39	94.35
3.75	7.43e-2	19.38	3.13	97.48
4.00	6.25e-2	19.38	0.00	97.48

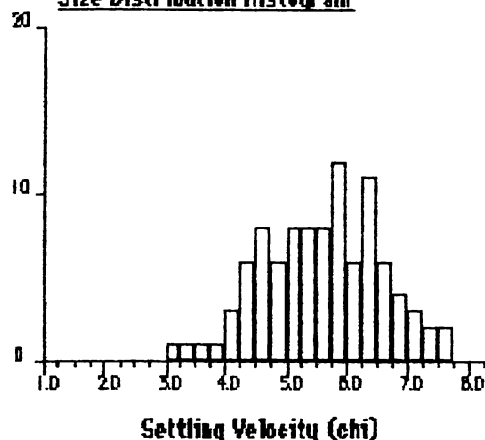
Total Weight = 19.88 g

Settling Velocity Analysis

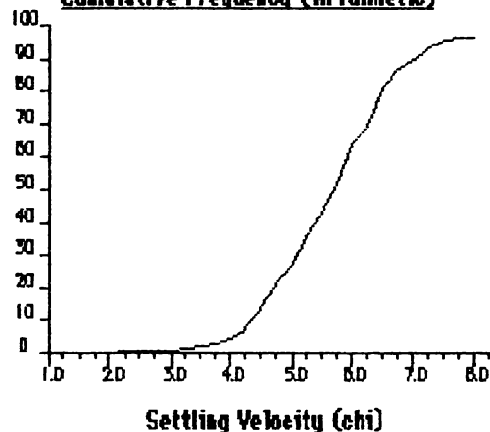
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Sample Identification: Site 1 / #7_c

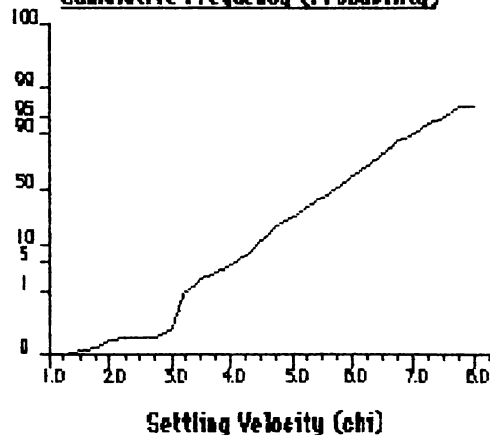
Size Distribution Histogram



Cumulative Frequency (Arithmetic)



Cumulative Frequency (Probability)



Settling Velocity (chi) Results Summary

Moment Method Parameters

Mean= 5.41 Sorting= 0.98 Skewness= 0.22 Kurtosis= 3.09

Data Summary

Velocity (chi)	Velocity (m/s)	Cumulative Weight (g)	Interval Frequency (%)	Cumulative Frequency (%)
1.25	4.20e-1	0.02	0.08	0.08
1.50	3.54e-1	0.02	0.04	0.12
1.75	2.97e-1	0.03	0.05	0.17
2.00	2.50e-1	0.05	0.10	0.27
2.25	2.10e-1	0.06	0.03	0.31
2.50	1.77e-1	0.06	0.00	0.31
2.75	1.49e-1	0.06	0.00	0.31
3.00	1.25e-1	0.08	0.10	0.41
3.25	1.05e-1	0.24	0.78	1.19
3.50	8.84e-2	0.47	1.17	2.36
3.75	7.43e-2	0.64	0.87	3.22
4.00	6.25e-2	0.88	1.19	4.41
4.25	5.26e-2	1.43	2.80	7.21
4.50	4.42e-2	2.58	5.74	12.96
4.75	3.72e-2	4.11	7.73	20.68
5.00	3.12e-2	5.35	6.23	26.91
5.25	2.63e-2	6.98	8.20	35.11
5.50	2.21e-2	8.56	7.96	43.07
5.75	1.86e-2	10.19	8.18	51.26
6.00	1.56e-2	12.52	11.71	62.97
6.25	1.31e-2	13.78	6.33	69.29
6.50	1.10e-2	15.93	10.83	80.13
6.75	9.29e-3	17.15	6.12	86.25
7.00	7.81e-3	17.88	3.71	89.95
7.25	6.57e-3	18.54	3.32	93.28
7.50	5.52e-3	18.92	1.88	95.16
7.75	4.65e-3	19.23	1.58	96.74
8.00	3.91e-3	19.23	0.00	96.74

Total Weight = 19.88 g

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Rapid Sediment Analyser

Operating System Version 5.5

Site 1 (dist)	A	Sed dia (mm)	Site 2	A	Sed dia (mm)	Site 3	A	Sed dia (mm)	Site 4	A	Sed dia (mm)
0	0.126	0.33	0	0.122	0.31	0	0.122	0.31	0	0.126	0.33
0.0058	0.108	0.24	0.0197	0.126	0.33	0.021	0.126	0.33	0.0406	0.122	0.31
0.0916	0.11	0.25	0.1121	0.106	0.23	0.1476	0.112	0.26	0.1324	0.112	0.26
0.2346	0.096	0.19	0.2521	0.1	0.2	0.2986	0.1	0.2	0.2374	0.096	0.19
0.4856	0.092	0.18	0.4301	0.092	0.18	0.5476	0.088	0.17	0.5344	0.084	0.16
0.8786	0.092	0.18	0.7701	0.102	0.21	0.9476	0.088	0.17	0.9304	0.084	0.16
1.3546	0.092	0.18	1.3971	0.1	0.2	1.4376	0.092	0.18	1.3834	0.092	0.18
2.3466	0.1	0.2	1.9651	0.092	0.18	2.0526	0.1	0.2	1.9124	0.084	0.16
Av.	0.102	0.21875	Av.	0.106	0.23	Av.	0.1035	0.2275	Av.	0.1	0.21875
Std Dev	0.012048	0.052763	Std Dev	0.012694	0.058064	Std Dev	0.014919	0.064087	Std Dev	0.017534	0.070799
Site 5			Site 6			Site 7			Site 8		
0	0.114	0.27	0	0.118	0.29	0	0.112	0.26	0	0.122	0.31
0.024	0.12	0.3	0.0053	0.124	0.32	0.0308	0.114	0.27	0.0182	0.112	0.26
0.1248	0.112	0.26	0.0946	0.118	0.29	0.0708	0.112	0.26	0.1023	0.114	0.27
0.2638	0.1	0.2	0.2276	0.1	0.2	0.2258	0.112	0.26	0.1983	0.112	0.26
0.5258	0.084	0.16	0.4326	0.088	0.17	0.4298	0.096	0.19	0.8123	0.114	0.27
0.8508	0.088	0.17	0.8136	0.092	0.18	0.8318	0.092	0.18	1.1353	0.11	0.25
1.3718	0.084	0.16	1.3256	0.088	0.17	1.4458	0.084	0.16	1.6793	0.102	0.21
1.6268	0.088	0.17	1.9336	0.088	0.17	2.0448	0.088	0.17	2.1313	0.088	0.17
Av.	0.09875	0.21125	Av.	0.102	0.22375	Av.	0.10125	0.21875	Av.	0.10925	0.25
Std Dev	0.014772	0.056679	Std Dev	0.015529	0.064573	Std Dev	0.01251	0.047641	Std Dev	0.010195	0.042426
Site 9			Site 10			Site 11			Site 12		
0	0.116	0.28	0	0.104	0.22	0	0.102	0.21	0	0.134	0.37
0.119	0.11	0.25	0.0265	0.104	0.22	0.045	0.102	0.21	0.0175	0.132	0.36
0.164	0.108	0.24	0.0763	0.102	0.21	0.1048	0.102	0.21	0.1148	0.108	0.24
0.419	0.118	0.29	0.1943	0.102	0.21	0.1808	0.102	0.21	0.1808	0.108	0.24
0.877	0.112	0.26	0.2623	0.102	0.21	0.2738	0.1	0.2	0.2528	0.1	0.2
1.035	0.1	0.2	0.5163	0.096	0.19	0.6178	0.088	0.17	0.4888	0.0732	0.13
1.606	0.092	0.18	0.7903	0.092	0.18	0.9758	0.088	0.17	0.8818	0.0765	0.14
2.186	0.084	0.16	1.3653	0.102	0.21	1.5208	0.092	0.18	1.3918	0.0766	0.14
Av.	0.105	0.2325	Av.	0.1	0.204444	Av.	0.096444	0.193333	Av.	0.10105	0.2275
Std Dev	0.012	0.047434	Std Dev	0.004243	0.013887	Std Dev	0.006364	0.018077	Std Dev	0.024239	0.095431
Site 13			Site 14			Site 15			Site 16		
0	0.126	0.33	0	0.134	0.37	0	0.116	0.28	0	0.142	0.41
0.031	0.13	0.35	0.006	0.152	0.46	12.8	0.118	0.29	13.3	0.13	0.35
0.0808	0.12	0.3	0.1581	0.116	0.28	110.2	0.114	0.27	103.8	0.114	0.27
0.1988	0.104	0.22	0.2441	0.11	0.25	196.2	0.11	0.25	214.8	0.114	0.27
0.2958	0.106	0.23	0.4041	0.1	0.2	296.2	0.108	0.24	343.8	0.108	0.24
0.4858	0.088	0.17	0.5431	0.092	0.18	446.2	0.1	0.2	441.8	0.096	0.19
0.9988	0.088	0.17	0.8611	0.092	0.18	650.2	0.092	0.18	640.8	0.102	0.21
1.5618	0.092	0.18	1.6001	0.088	0.17	935.2	0.102	0.21	931.8	0.092	0.18
Av.	0.10675	0.24375	Av.	0.1105	0.26125	Av.	0.1075	0.24	Av.	0.11225	0.265
Std Dev	0.016968	0.073278	Std Dev	0.022697	0.10494	Std Dev	0.008928	0.04	Std Dev	0.016918	0.08
Site 17			Site 18			Site 19			Site 20		
0	0.118	0.29	0	0.128	0.34	0	0.136	0.38	0	0.136	0.38
16.4	0.134	0.37	35.3	0.138	0.39	0.0052	0.154	0.47	11.8	0.1675	0.56
83.6	0.11	0.25	100.3	0.106	0.23	0.059	0.116	0.28	35.8	0.114	0.27
195.6	0.106	0.23	213.3	0.108	0.24	0.202	0.106	0.23	168.8	0.106	0.23
245.6	0.106	0.23	382.3	0.106	0.23	0.305	0.1	0.2	304.8	0.11	0.25
367.6	0.1	0.2	500.3	0.108	0.24	0.48	0.102	0.21	473.8	0.104	0.22
575.6	0.104	0.22	640.3	0.1	0.2	0.727	0.108	0.24	676.8	0.096	0.19
886.6	0.096	0.19	857.3	0.092	0.18	1.044	0.142	0.41	877.8	0.1	0.2
Av.	0.10925	0.2475	Av.	0.11075	0.25625	Av.	0.1205	0.3025	Av.	0.116688	0.2875
Std Dev	0.011949	0.058248	Std Dev	0.014964	0.071502	Std Dev	0.020612	0.10306	Std Dev	0.02387	0.1251
Site 21			Site 22			Site 23			Site 24		
0	0.134	0.37	0	0.144	0.42	0	0.138	0.39	0	0.136	0.38
0.0058	0.16	0.5	0.0076	0.154	0.47	0.0057	0.175	0.62	2.5	0.1612	0.51
0.0907	0.112	0.26	0.0859	0.12	0.3	0.0775	0.122	0.31	72.5	0.13	0.35
0.1617	0.116	0.28	0.1569	0.11	0.25	0.1576	0.15	0.45	130.5	0.11	0.25
0.3337	0.092	0.18	0.3289	0.088	0.17	0.2976	0.092	0.18	298.5	0.104	0.22
0.5237	0.096	0.19	0.5189	0.102	0.21	0.5086	0.092	0.18	469.5	0.092	0.18
0.8357	0.1	0.2	0.8309	0.1	0.2	0.7726	0.092	0.18	736.5	0.1	0.2
1.1257	0.104	0.22	1.1209	0.104	0.22	1.0325	0.092	0.18	998.5	0.1712	0.59
Av.	0.11425	0.275	Av.	0.11525	0.28	Av.	0.119125	0.31125	Av.	0.12555	0.335
Std Dev	0.022764	0.110065	Std Dev	0.022852	0.109545	Std Dev	0.032476	0.164615	Std Dev	0.0292	0.151469
Site 25			Site 26			Site 27			Site 28		
0	0.132	0.36	0	0.126	0.33	0	0.118	0.29	0	0.11	0.25
11	0.112	0.26	0.0195	0.112	0.26	0.0162	0.144	0.42	0.021	0.11	0.25
94.4	0.112	0.26	0.0999	0.108	0.24	0.105	0.11	0.25	0.0905	0.108	0.24
179.4	0.106	0.23	0.1739	0.104	0.22	0.207	0.096	0.19	0.1965	0.104	0.22
341.4	0.102	0.21	0.3699	0.092	0.18	0.356	0.092	0.18	0.3575	0.096	0.19
393.4	0.1	0.2	0.5859	0.084	0.16	0.537	0.092	0.18	0.5505	0.1	0.2
710.4	0.1	0.2	0.8809	0.092	0.18	0.779	0.096	0.19	0.8305	0.096	0.19
980.4	0.185	0.7	1.1959	0.1813	0.67	1.104	0.1825	0.68	1.1805	0.15	0.45
Av.	0.118625	0.3025	Av.	0.112413	0.28	Av.	0.116313	0.2975	Av.	0.10925	0.24875
Std Dev	0.02879	0.168925	Std Dev	0.030848	0.166733	Std Dev	0.032066	0.17499	Std Dev	0.017434	0.085094
Site 29			Site 30			Site 32			Site 33		
0	0.118	0.29	0	0.114	0.27	0	0.114	0.27	0	0.154	0.47
0.024	0.154	0.47	0.0727	0.112	0.26	0.011	0.122	0.31	0.0064	0.13	0.35

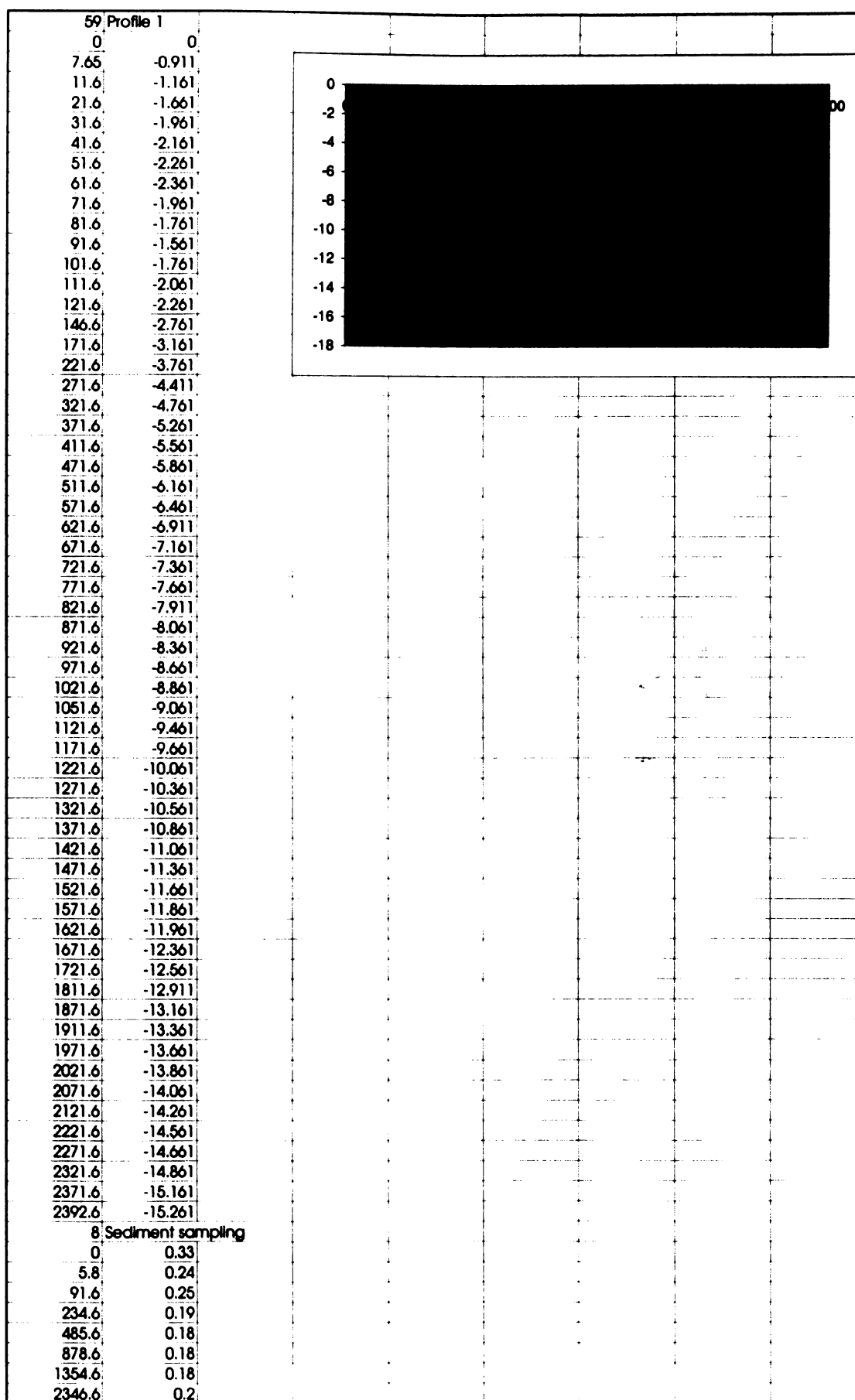
0.1175	0.116	0.28	0.0952	0.118	0.29	0.0551	0.126	0.33	0.0584	0.118	0.29
0.2165	0.104	0.22	0.1852	0.104	0.22	0.1431	0.104	0.22	0.1294	0.112	0.26
0.3635	0.1	0.2	0.3332	0.191	0.74	0.3881	0.084	0.16	0.2004	0.088	0.17
0.5605	0.092	0.18	0.5252	0.17	0.58	0.9341	0.144	0.42	0.5154	0.084	0.16
0.8635	0.084	0.16	0.7902	0.208	0.96	1.6351	0.16	0.5	1.3224	0.096	0.19
1.2505	0.13	0.35	1.3772	0.1925	0.75	2.5741	0.165	0.54	1.8664	0.088	0.17
Av. A	0.11225	0.26875	Av. A	0.151188	0.50875	Av. A	0.127375	0.34375	Av. A	0.10875	0.2575
Std Dev A	0.022461	0.103156	Std Dev A	0.043293	0.285479	Std Dev A	0.027759	0.13341	Std Dev A	0.024587	0.109642
Site 34			Site 35			Site 36			Site 38		
0	0.116	0.28	0	0.128	0.34	0	0.114	0.27	0	0.114	0.27
0.0249	0.116	0.28	0.0075	0.154	0.47	0.0345	0.108	0.24	0.0281	0.11	0.25
0.0712	0.11	0.25	0.0872	0.118	0.29	0.0823	0.108	0.24	0.0731	0.106	0.23
0.2022	0.1	0.2	0.1782	0.096	0.19	0.1703	0.1	0.2	0.1911	0.1	0.2
0.3632	0.088	0.17	0.3752	0.088	0.17	0.3423	0.1	0.2	0.3351	0.096	0.19
0.5742	0.088	0.17	0.6752	0.088	0.17	0.5673	0.092	0.18	0.5271	0.102	0.21
0.8172	0.084	0.16	1.1172	0.088	0.17	0.8163	0.1	0.2	0.8001	0.096	0.19
1.0982	0.088	0.17	1.5082	0.084	0.16	1.0053	0.1	0.2	1.0931	0.096	0.19
Av. A	0.09875	0.21	Av. A	0.1065	0.245	Av. A	0.10275	0.21625	Av. A	0.1025	0.21625
Std Dev A	0.013562	0.051824	Std Dev A	0.025315	0.112631	Std Dev A	0.00684	0.030208	Std Dev A	0.006908	0.030677
Site 39			Site 40			Site 41			Site 42		
0	0.11	0.25	0	0.114	0.27	0	0.142	0.41	0	0.136	0.38
0.031	0.118	0.29	0.036	0.11	0.25	0.013	0.16	0.5	0.021	0.136	0.38
0.0878	0.11	0.25	0.1098	0.108	0.24	0.0821	0.11	0.25	0.2329	0.12	0.3
0.1858	0.106	0.23	0.2268	0.102	0.21	0.4841	0.146	0.43	0.3579	0.15	0.45
0.4018	0.102	0.21	0.4588	0.14	0.4	1.0791	0.132	0.36	0.5049	0.096	0.19
0.6118	0.104	0.22	0.6688	0.1638	0.53	1.4561	0.144	0.42	0.8549	0.1	0.2
0.8508	0.1	0.2	1.3418	0.11	0.25	2.0331	0.1688	0.57	1.5029	0.102	0.21
1.1198	0.1	0.2	1.8788	0.126	0.33				2.2559	0.102	0.21
Av. A	0.10625	0.23125	Av. A	0.121725	0.31	Av. A	0.143257	0.42	Av. A	0.11775	0.29
Std Dev A	0.006182	0.030909	Std Dev A	0.020821	0.107305	Std Dev A	0.01904	0.101325	Std Dev A	0.020686	0.10198
Site 43			Site 44			Site 45			Site 46		
0	0.11	0.25	0	0.11	0.25	0	0.106	0.23	0	0.124	0.32
0.0387	0.114	0.27	0.0495	0.116	0.28	0.0234	0.108	0.24	0.0278	0.126	0.33
0.1629	0.102	0.21	0.2017	0.096	0.19	0.1432	0.102	0.21	0.0898	0.122	0.31
0.3179	0.104	0.22	0.4277	0.1	0.2	0.3272	0.1	0.2	0.3778	0.14	0.4
0.5409	0.102	0.21	0.7087	0.096	0.19	0.6272	0.096	0.19	0.6018	0.114	0.27
0.7729	0.1	0.2	1.0057	0.096	0.19	1.0232	0.1	0.2	0.9288	0.118	0.29
1.2259	0.152	0.46	1.3517	0.1	0.2	1.4272	0.102	0.21	1.4298	0.106	0.23
1.7809	0.108	0.24	1.7977	0.1	0.2	1.8862	0.106	0.23	1.8928	0.102	0.21
Av. A	0.1115	0.2575	Av. A	0.10175	0.2125	Av. A	0.1025	0.21375	Av. A	0.115556	0.281111
Std Dev A	0.017029	0.085147	Std Dev A	0.007363	0.0337	Std Dev A	0.003964	0.017678	Std Dev A	0.015257	0.069901
Site 47			Site 48			Site 49			Site 51		
0	0.126	0.33	0	0.114	0.27	0	0.11	0.25	0	0.108	0.24
0.0121	0.126	0.33	0.0192	0.116	0.28	0.036	0.112	0.26	0.048	0.108	0.24
0.2664	0.15	0.45	0.2078	0.104	0.22	0.2128	0.096	0.19	0.1658	0.096	0.19
0.4714	0.144	0.42	0.426	0.146	0.43	0.4238	0.092	0.18	0.4258	0.096	0.19
0.7684	0.12	0.3	0.66	0.102	0.21	0.8738	0.096	0.19	0.8768	0.1	0.2
0.9704	0.114	0.27	1.226	0.096	0.19	1.3188	0.096	0.19	1.3688	0.096	0.19
1.1153	0.106	0.23	1.738	0.1	0.2	1.7998	0.092	0.18	1.7228	0.096	0.19
1.4193	0.114	0.27									
Av. A	0.125	0.325	Av. A	0.111143	0.257143	Av. A	0.099143	0.205714	Av. A	0.1	0.205714
Std Dev A	0.015194	0.07597	Std Dev A	0.017004	0.083609	Std Dev A	0.008315	0.034087	Std Dev A	0.005657	0.023705

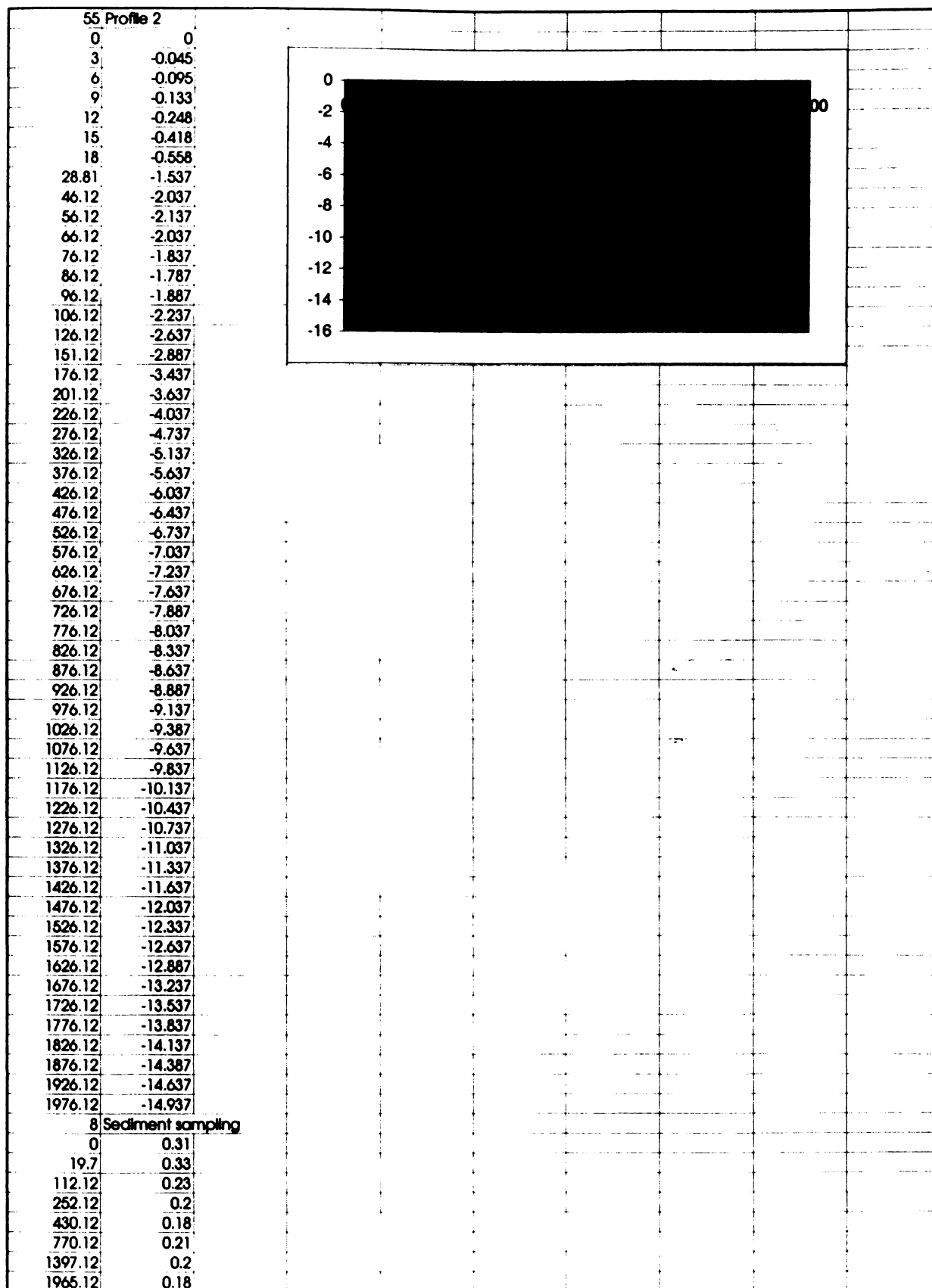
Site 1 (dist)	A	Sed dia (mm)	Site 2	A	Sed dia (mm)	Site 3	A	Sed dia (mm)	Site 4	A	Sed dia (mm)
0	0.126	0.33	0	0.122	0.31	0	0.122	0.31	0	0.126	0.33
0.0058	0.108	0.24	0.0197	0.126	0.33	0.021	0.126	0.33	0.0406	0.122	0.31
0.0916	0.11	0.25	0.1121	0.108	0.23	0.1476	0.112	0.26	0.1324	0.112	0.26
0.2346	0.096	0.19	0.2521	0.1	0.2	0.2986	0.1	0.2	0.2374	0.096	0.19
0.4856	0.092	0.18	0.4301	0.092	0.18	0.5476	0.088	0.17	0.5344	0.084	0.16
0.8786	0.092	0.18	0.7701	0.102	0.21	0.9476	0.088	0.17	0.9304	0.084	0.16
Av.	0.104	0.228333	Av.	0.108	0.243333	Av.	0.106	0.24	Av.	0.104	0.235
Std Dev.	0.013327	0.053359	Std Dev.	0.013266	0.05647	Std Dev.	0.016589	0.064291	Std Dev.	0.018633	0.068981
Site 5			Site 6			Site 7			Site 8		
0	0.114	0.27	0	0.118	0.29	0	0.112	0.26	0	0.122	0.31
0.024	0.12	0.3	0.0053	0.124	0.32	0.0308	0.114	0.27	0.0182	0.112	0.26
0.1248	0.112	0.26	0.0946	0.118	0.29	0.0708	0.112	0.26	0.1023	0.114	0.27
0.2638	0.1	0.2	0.2276	0.1	0.2	0.2258	0.112	0.26	0.1983	0.112	0.26
0.5258	0.084	0.16	0.4326	0.088	0.17	0.4298	0.096	0.19	0.8123	0.114	0.27
0.8508	0.088	0.17	0.8136	0.092	0.18	0.8318	0.092	0.18	1.1353	0.11	0.25
Av.	0.103	0.226667	Av.	0.106667	0.241667	Av.	0.106333	0.236667	Av.	0.114	0.27
Std Dev.	0.014738	0.05785	Std Dev.	0.015267	0.065549	Std Dev.	0.009668	0.040332	Std Dev.	0.004195	0.020976
Site 9			Site 10			Site 11			Site 12		
0	0.116	0.28	0	0.104	0.22	0	0.102	0.21	0	0.134	0.37
0.119	0.11	0.25	0.0265	0.104	0.22	0.045	0.102	0.21	0.0175	0.132	0.36
0.164	0.108	0.24	0.0763	0.102	0.21	0.1048	0.102	0.21	0.1148	0.108	0.24
0.419	0.118	0.29	0.1943	0.102	0.21	0.1808	0.102	0.21	0.1808	0.108	0.24
0.877	0.112	0.26	0.2623	0.102	0.21	0.2738	0.1	0.2	0.2528	0.1	0.2
Av.	0.1128	0.264	Av.	0.1063	0.096	Av.	0.106333	0.201667	Av.	0.1092	0.256667
Std Dev.	0.004147	0.020736	Std Dev.	0.004536	0.015119	Std Dev.	0.009333	0.016021	Std Dev.	0.022443	0.093095
Site 13			Site 14			Site 15			Site 16		
0	0.126	0.33	0	0.134	0.37	0	0.116	0.28	0	0.142	0.41
0.031	0.13	0.35	0.006	0.152	0.46	12.8	0.118	0.29	13.3	0.13	0.35
0.0808	0.12	0.3	0.1581	0.116	0.28	110.2	0.114	0.27	103.8	0.114	0.27
0.1988	0.104	0.22	0.2441	0.11	0.25	196.2	0.11	0.25	214.8	0.114	0.27
0.2958	0.106	0.23	0.4041	0.1	0.2	296.2	0.108	0.24	343.8	0.108	0.24
0.4858	0.088	0.17	0.5431	0.092	0.18	446.2	0.1	0.2	441.8	0.096	0.19
Av.	0.112333	0.266667	Av.	0.117333	0.29	Av.	0.111	0.255	Av.	0.117333	0.288333
Std Dev.	0.01587	0.070616	Std Dev.	0.022259	0.106958	Std Dev.	0.006542	0.032711	Std Dev.	0.01633	0.079099
Site 17			Site 18			Site 19			Site 20		
0	0.118	0.29	0	0.128	0.34	0	0.136	0.38	0	0.136	0.38
16.4	0.134	0.37	35.3	0.138	0.39	0.0052	0.154	0.47	11.8	0.1675	0.56
83.6	0.11	0.25	100.3	0.106	0.23	0.059	0.116	0.28	35.8	0.114	0.27
195.6	0.106	0.23	213.3	0.108	0.24	0.202	0.106	0.23	168.8	0.106	0.23
245.6	0.106	0.23	382.3	0.106	0.23	0.305	0.1	0.2	304.8	0.11	0.25
367.6	0.1	0.2	500.3	0.108	0.24	0.48	0.102	0.21	473.8	0.104	0.22
Av.	0.112333	0.261667	Av.	0.115667	0.278333	Av.	0.119	0.295	Av.	0.122917	0.318333
Std Dev.	0.01216	0.0608	Std Dev.	0.013823	0.069113	Std Dev.	0.021643	0.108213	Std Dev.	0.024695	0.131669
Site 21			Site 22			Site 23			Site 24		
0	0.134	0.37	0	0.144	0.42	0	0.138	0.39	0	0.136	0.38
0.0058	0.16	0.5	0.0076	0.154	0.47	0.0057	0.175	0.62	2.5	0.1612	0.51
0.0907	0.112	0.26	0.0859	0.12	0.3	0.0775	0.122	0.31	72.5	0.13	0.35
0.1617	0.116	0.28	0.1569	0.11	0.25	0.1576	0.15	0.45	130.5	0.11	0.25
0.3337	0.092	0.18	0.3289	0.088	0.17	0.2976	0.092	0.18	298.5	0.104	0.22
0.5237	0.096	0.19	0.5189	0.102	0.21	0.5086	0.092	0.18	469.5	0.092	0.18
Av.	0.118333	0.296667	Av.	0.119667	0.303333	Av.	0.128167	0.355	Av.	0.1222	0.315
Std Dev.	0.025375	0.121106	Std Dev.	0.025216	0.11894	Std Dev.	0.032927	0.169558	Std Dev.	0.025157	0.122434
Site 25			Site 26			Site 27			Site 28		
0	0.132	0.36	0	0.126	0.33	0	0.118	0.29	0	0.11	0.25
11	0.112	0.26	0.0195	0.112	0.26	0.0162	0.144	0.42	0.021	0.11	0.25
94.4	0.112	0.26	0.0999	0.108	0.24	0.105	0.11	0.25	0.0905	0.108	0.24
179.4	0.106	0.23	0.1739	0.104	0.22	0.207	0.096	0.19	0.1965	0.104	0.22
341.4	0.102	0.21	0.3699	0.092	0.18	0.356	0.092	0.18	0.3575	0.096	0.19
393.4	0.1	0.2	0.5859	0.084	0.16	0.537	0.092	0.18	0.5505	0.1	0.2
Av.	0.110667	0.253333	Av.	0.104333	0.231667	Av.	0.108667	0.251667	Av.	0.104667	0.225
Std Dev.	0.01157	0.05785	Std Dev.	0.014882	0.0608	Std Dev.	0.020265	0.093684	Std Dev.	0.00575	0.025884
Site 29			Site 30			Site 32			Site 33		
0	0.118	0.29	0	0.114	0.27	0	0.114	0.27	0	0.154	0.47
0.024	0.154	0.47	0.0727	0.112	0.26	0.011	0.122	0.31	0.0064	0.13	0.35
0.1175	0.116	0.28	0.0952	0.118	0.29	0.0551	0.126	0.33	0.0584	0.118	0.29
0.2165	0.104	0.22	0.1852	0.104	0.22	0.1431	0.104	0.22	0.1294	0.112	0.26
0.3635	0.1	0.2	0.3332	0.191	0.74	0.3881	0.084	0.16	0.2004	0.088	0.17
0.5605	0.092	0.18	0.5252	0.17	0.58	0.9341	0.144	0.42	0.5154	0.084	0.16
Av.	0.114	0.273333	Av.	0.134833	0.393333	Av.	0.115667	0.285	Av.	0.114333	0.283333
Std Dev.	0.021909	0.105767	Std Dev.	0.036279	0.213885	Std Dev.	0.020452	0.090499	Std Dev.	0.026273	0.116562

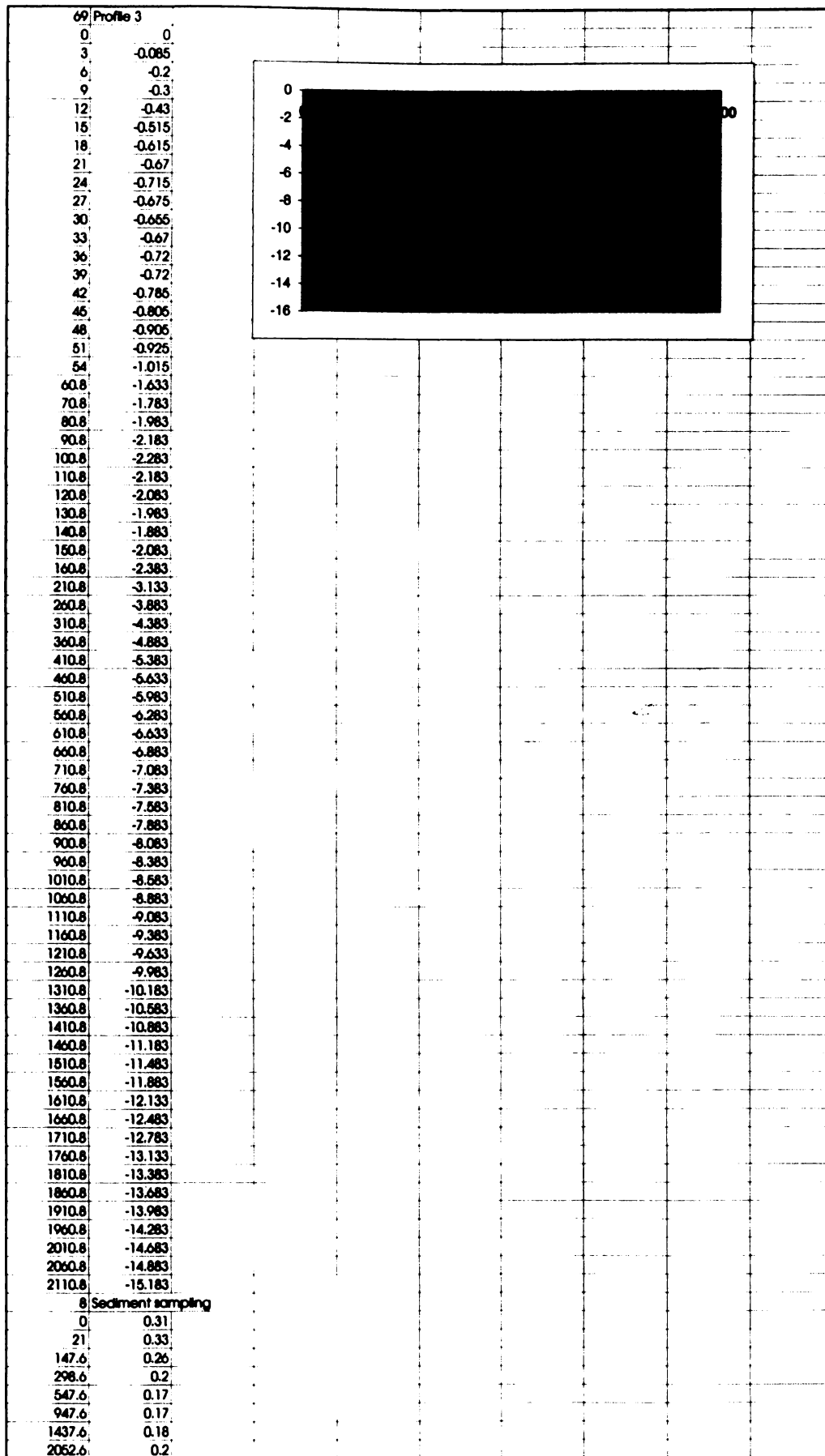
Site 34			Site 35			Site 36			Site 38		
0	0.116	0.28	0	0.128	0.34	0	0.114	0.27	0	0.114	0.27
0.0249	0.116	0.28	0.0075	0.154	0.47	0.0345	0.108	0.24	0.0281	0.11	0.25
0.0712	0.11	0.25	0.0872	0.118	0.29	0.0823	0.108	0.24	0.0731	0.106	0.23
0.2022	0.1	0.2	0.1782	0.096	0.19	0.1703	0.1	0.2	0.1911	0.1	0.2
0.3632	0.088	0.17	0.3752	0.088	0.17	0.3423	0.1	0.2	0.3351	0.096	0.19
0.5742	0.088	0.17	0.6752	0.088	0.17	0.5673	0.092	0.18	0.5271	0.102	0.21
Av.	0.103	0.225	Av.	0.112	0.271667	Av.	0.103667	0.221667	Av.	0.104667	0.225
Std Dev.	0.013008	0.051672	Std Dev.	0.026321	0.119736	Std Dev.	0.00784	0.033714	Std Dev.	0.006653	0.030822
Site 39			Site 40			Site 41			Site 42		
0	0.11	0.25	0	0.114	0.27	0	0.142	0.41	0	0.136	0.38
0.031	0.118	0.29	0.036	0.11	0.25	0.013	0.16	0.5	0.021	0.136	0.38
0.0678	0.11	0.25	0.1098	0.108	0.24	0.0821	0.11	0.25	0.2329	0.12	0.3
0.1858	0.106	0.23	0.2268	0.102	0.21	0.4841	0.146	0.43	0.3579	0.15	0.45
0.4018	0.102	0.21	0.4588	0.14	0.4	1.0791	0.132	0.36	0.5049	0.096	0.19
0.6118	0.104	0.22	0.6688	0.1638	0.53	1.4561	0.144	0.42	0.8549	0.1	0.2
Av.	0.108333	0.241667	Av.	0.122967	0.316667	Av.	0.139	0.395	Av.	0.123	0.316667
Std Dev.	0.005715	0.028577	Std Dev.	0.023957	0.123558	Std Dev.	0.016817	0.084083	Std Dev.	0.021606	0.105578
Site 43			Site 44			Site 45			Site 46		
0	0.11	0.25	0	0.11	0.25	0	0.106	0.23	0	0.124	0.32
0.0387	0.114	0.27	0.0495	0.116	0.28	0.0234	0.108	0.24	0.0278	0.126	0.33
0.1629	0.102	0.21	0.2017	0.096	0.19	0.1432	0.102	0.21	0.0898	0.122	0.31
0.3179	0.104	0.22	0.4277	0.1	0.2	0.3272	0.1	0.2	0.3778	0.14	0.4
0.5409	0.102	0.21	0.7087	0.096	0.19	0.6272	0.096	0.19	0.6018	0.114	0.27
0.7729	0.1	0.2	1.0057	0.096	0.19	1.0232	0.1	0.2	0.9288	0.118	0.29
Av.	0.105333	0.226667	Av.	0.102333	0.216667	Av.	0.102	0.211667	Av.	0.121429	0.307143
Std Dev.	0.005465	0.027325	Std Dev.	0.008618	0.038816	Std Dev.	0.004382	0.019408	Std Dev.	0.010628	0.05314
Site 47			Site 48			Site 49			Site 51		
0	0.126	0.33	0	0.114	0.27	0	0.11	0.25	0	0.108	0.24
0.0121	0.126	0.33	0.0192	0.116	0.28	0.036	0.112	0.26	0.048	0.108	0.24
0.2664	0.15	0.45	0.2078	0.104	0.22	0.2128	0.096	0.19	0.1658	0.096	0.19
0.4714	0.144	0.42	0.426	0.146	0.43	0.4238	0.092	0.18	0.4258	0.096	0.19
0.7684	0.12	0.3	0.66	0.102	0.21	0.8738	0.096	0.19	0.8768	0.1	0.2
0.9704	0.114	0.27	1.226	0.096	0.19	1.3188	0.096	0.19	1.3688	0.096	0.19
1.1153	0.106	0.23	Av.	0.113	0.266667	Av.	0.100333	0.21	Av.	0.100667	0.208333
1.4193	0.114	0.27	Std Dev.	0.017833	0.087331	Std Dev.	0.00843	0.035214	Std Dev.	0.005888	0.024833
Av.	0.125	0.325									
Std Dev.	0.015194	0.07597									

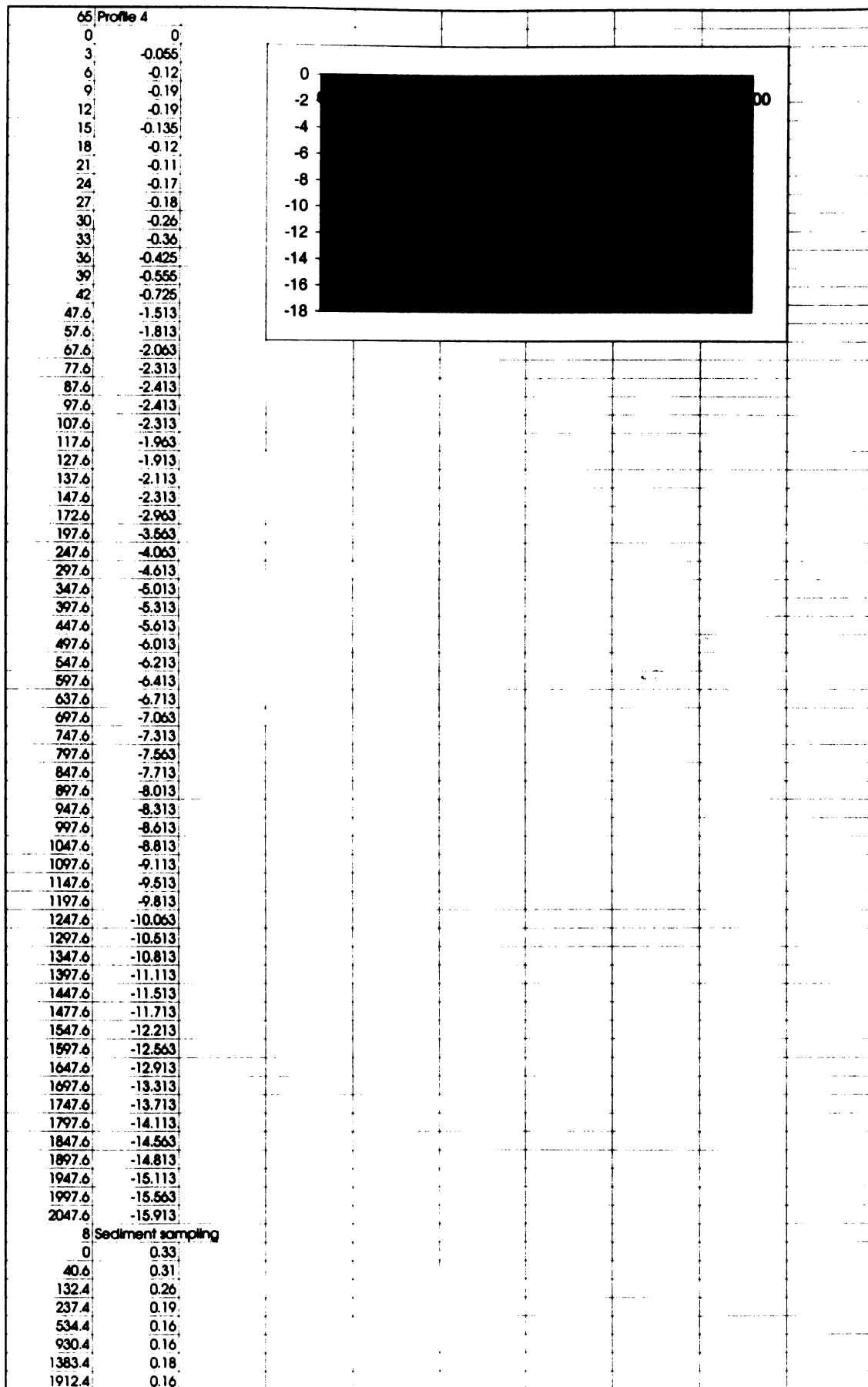
Site 1 (dist)	A	Sed dia (mm)	Site 2	A	Sed dia (mm)	Site 3	A	Sed dia (mm)	Site 4	A	Sed dia (mm)
0	0.126	0.33	0	0.122	0.31	0	0.122	0.31	0	0.126	0.33
0.0058	0.108	0.24	0.0197	0.126	0.33	0.021	0.126	0.33	0.0406	0.122	0.31
0.0916	0.11	0.25	0.1121	0.106	0.23	0.1476	0.112	0.26	0.1324	0.112	0.26
0.2346	0.096	0.19	0.2521	0.1	0.2	0.2986	0.1	0.2	0.2374	0.096	0.19
0.4856	0.092	0.18	0.4301	0.092	0.18	0.5476	0.088	0.17	0.5344	0.084	0.16
Av.	0.1064	0.238	Av.	0.1092	0.25	Av.	0.1096	0.254	Av.	0.108	0.25
Std Dev.	0.013372	0.053442	Std Dev.	0.014464	0.059666	Std Dev.	0.01571	0.061514	Std Dev.	0.01772	0.06603
Site 5			Site 6			Site 7			Site 8		
0	0.114	0.27	0	0.118	0.29	0	0.112	0.26	0	0.122	0.31
0.024	0.12	0.3	0.0053	0.124	0.32	0.0308	0.114	0.27	0.0182	0.112	0.26
0.1248	0.112	0.26	0.0946	0.118	0.29	0.0708	0.112	0.26	0.1023	0.114	0.27
0.2638	0.1	0.2	0.2276	0.1	0.2	0.2258	0.112	0.26	0.1983	0.112	0.26
0.5258	0.084	0.16	0.4326	0.088	0.17	0.4298	0.096	0.19	0.8123	0.114	0.27
Av.	0.106	0.238	Av.	0.1096	0.254	Av.	0.1092	0.248	Av.	0.1148	0.274
Std Dev.	0.014283	0.056745	Std Dev.	0.01506	0.065038	Std Dev.	0.00743	0.032711	Std Dev.	0.004147	0.020736
Site 9			Site 10			Site 11			Site 12		
0	0.116	0.28	0	0.104	0.22	0	0.102	0.21	0	0.134	0.37
0.119	0.11	0.25	0.0265	0.104	0.22	0.045	0.102	0.21	0.0175	0.132	0.36
0.164	0.108	0.24	0.0763	0.102	0.21	0.1048	0.102	0.21	0.1148	0.108	0.24
0.419	0.118	0.29	0.1943	0.102	0.21	0.1808	0.102	0.21	0.1808	0.108	0.24
Av.	0.113	0.265	0.2623	0.102	0.21	0.2738	0.1	0.2	0.2528	0.1	0.2
Std Dev.	0.004761	0.023805	0.5163	0.096	0.19	Av.	0.1016	0.208	Av.	0.1164	0.282
			0.7903	0.092	0.18	Std Dev.	0.000894	0.004472	Std Dev.	0.015518	0.077589
			Av.	0.100285	0.203333						
			Std Dev.	0.004536	0.015119						
Site 13			Site 14			Site 15			Site 16		
0	0.126	0.33	0	0.134	0.37	0	0.116	0.28	0	0.142	0.41
0.031	0.13	0.35	0.006	0.152	0.46	12.8	0.118	0.29	13.3	0.13	0.35
0.0808	0.12	0.3	0.1581	0.116	0.28	110.2	0.114	0.27	103.8	0.114	0.27
0.1988	0.104	0.22	0.2441	0.11	0.25	196.2	0.11	0.25	214.8	0.114	0.27
0.2958	0.106	0.23	0.4041	0.1	0.2	296.2	0.108	0.24	343.8	0.108	0.24
Av.	0.1172	0.286	Av.	0.1224	0.312	Av.	0.1132	0.266	Av.	0.1216	0.308
Std Dev.	0.011713	0.058566	Std Dev.	0.020659	0.103296	Std Dev.	0.004147	0.020736	Std Dev.	0.014029	0.070143
Site 17			Site 18			Site 19			Site 20		
0	0.118	0.29	0	0.128	0.34	0	0.136	0.38	0	0.136	0.38
16.4	0.134	0.37	35.3	0.138	0.39	0.0052	0.154	0.47	11.8	0.1675	0.56
83.6	0.11	0.25	100.3	0.106	0.23	0.059	0.116	0.28	35.8	0.114	0.27
195.6	0.106	0.23	213.3	0.108	0.24	0.202	0.106	0.23	168.8	0.106	0.23
245.6	0.106	0.23	382.3	0.106	0.23	0.305	0.1	0.2	304.8	0.11	0.25
Av.	0.1148	0.274	Av.	0.1172	0.286	Av.	0.1224	0.312	Av.	0.1267	0.338
Std Dev.	0.011798	0.058992	Std Dev.	0.014873	0.074364	Std Dev.	0.022334	0.111669	Std Dev.	0.025592	0.137004
Site 21			Site 22			Site 23			Site 24		
0	0.134	0.37	0	0.144	0.42	0	0.138	0.39	0	0.136	0.38
0.0058	0.16	0.5	0.0076	0.154	0.47	0.0057	0.175	0.62	2.5	0.1612	0.51
0.0907	0.112	0.26	0.0859	0.12	0.3	0.0775	0.122	0.31	72.5	0.13	0.35
0.1617	0.116	0.28	0.1569	0.11	0.25	0.1576	0.15	0.45	130.5	0.11	0.25
0.3337	0.092	0.18	0.3289	0.088	0.17	0.2976	0.092	0.18	298.5	0.104	0.22
Av.	0.1228	0.318	Av.	0.1232	0.322	Av.	0.1354	0.39	Av.	0.12824	0.342
Std Dev.	0.025597	0.122147	Std Dev.	0.02648	0.12276	Std Dev.	0.031029	0.163554	Std Dev.	0.022748	0.115195
Site 25			Site 26			Site 27			Site 28		
0	0.132	0.36	0	0.126	0.33	0	0.118	0.29	0	0.11	0.25
11	0.112	0.26	0.0195	0.112	0.26	0.0162	0.144	0.42	0.021	0.11	0.25
94.4	0.112	0.26	0.0999	0.108	0.24	0.105	0.11	0.25	0.0905	0.108	0.24
179.4	0.106	0.23	0.1739	0.104	0.22	0.207	0.096	0.19	0.1965	0.104	0.22
341.4	0.102	0.21	0.3699	0.092	0.18	0.356	0.092	0.18	0.3575	0.096	0.19
Av.	0.1128	0.264	Av.	0.1084	0.246	Av.	0.112	0.266	Av.	0.1056	0.23
Std Dev.	0.011541	0.057706	Std Dev.	0.012361	0.055498	Std Dev.	0.020736	0.097108	Std Dev.	0.005899	0.025495
Site 29			Site 30			Site 32			Site 33		
0	0.118	0.29	0	0.114	0.27	0	0.114	0.27	0	0.154	0.47
0.024	0.154	0.47	0.0727	0.112	0.26	0.011	0.122	0.31	0.0064	0.13	0.35
0.1175	0.116	0.28	0.0952	0.118	0.29	0.0551	0.126	0.33	0.0584	0.118	0.29
0.2165	0.104	0.22	0.1852	0.104	0.22	0.1431	0.104	0.22	0.1294	0.112	0.26
0.3635	0.1	0.2	0.3332	0.191	0.74	0.3881	0.084	0.16	0.2004	0.088	0.17
Av.	0.1184	0.292	Av.	0.1278	0.356	Av.	0.11	0.258	Av.	0.1204	0.308
Std Dev.	0.021326	0.10663	Std Dev.	0.035696	0.216171	Std Dev.	0.016793	0.069065	Std Dev.	0.024224	0.111445
Site 34			Site 35			Site 36			Site 38		
0	0.116	0.28	0	0.128	0.34	0	0.114	0.27	0	0.114	0.27
0.0249	0.116	0.28	0.0075	0.154	0.47	0.0345	0.108	0.24	0.0281	0.11	0.25
0.0712	0.11	0.25	0.0872	0.118	0.29	0.0823	0.108	0.24	0.0731	0.106	0.23
0.2022	0.1	0.2	0.1782	0.096	0.19	0.1703	0.1	0.2	0.1911	0.1	0.2
0.3632	0.088	0.17	0.3752	0.088	0.17	0.3423	0.1	0.2	0.3351	0.096	0.19
Av.	0.106	0.236	Av.	0.1168	0.292	Av.	0.106	0.23	Av.	0.1052	0.228
Std Dev.	0.012	0.049295	Std Dev.	0.026329	0.121737	Std Dev.	0.006	0.03	Std Dev.	0.007294	0.033466

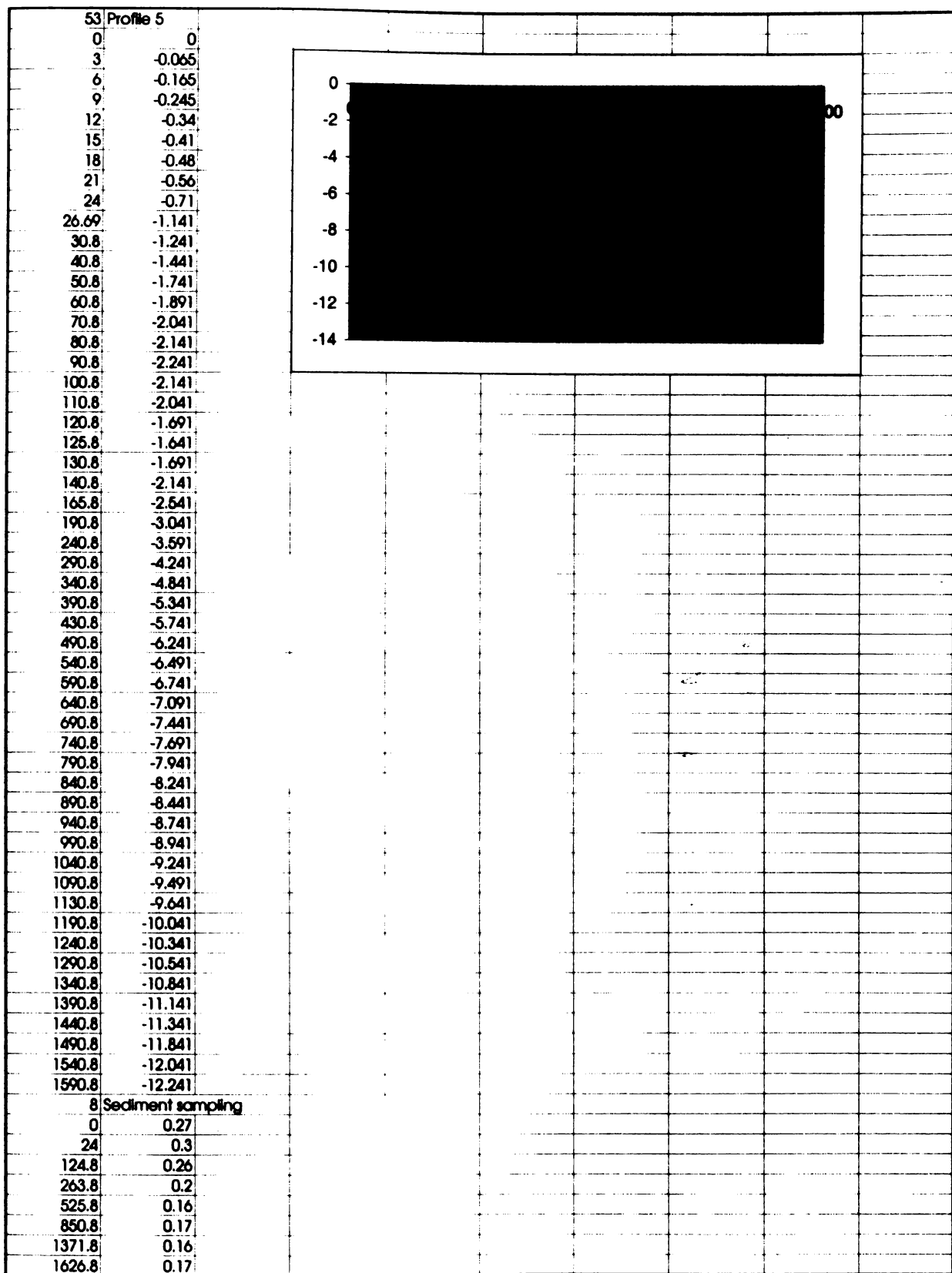
Site 39			Site 40			Site 41			Site 42		
0	0.11	0.25	0	0.114	0.27	0	0.142	0.41	0	0.136	0.38
0.031	0.118	0.29	0.036	0.11	0.25	0.013	0.16	0.5	0.021	0.136	0.38
0.0878	0.11	0.25	0.1098	0.108	0.24	0.0821	0.11	0.25	0.2329	0.12	0.3
0.1858	0.106	0.23	0.2268	0.102	0.21	0.4841	0.146	0.43	0.3579	0.15	0.45
0.4018	0.102	0.21	0.4588	0.14	0.4	1.0791	0.132	0.36	0.5049	0.096	0.19
Av.	0.1092	0.246	Av.	0.1148	0.274	Av.	0.138	0.39	Av.	0.1276	0.34
Std Dev.	0.005933	0.029665	Std Dev.	0.014738	0.073689	Std Dev.	0.018601	0.093005	Std Dev.	0.020611	0.099247
Site 43			Site 44			Site 45			Site 46		
0	0.11	0.25	0	0.11	0.25	0	0.106	0.23	0	0.124	0.32
0.0387	0.114	0.27	0.0495	0.116	0.28	0.0234	0.108	0.24	0.0278	0.126	0.33
0.1629	0.102	0.21	0.2017	0.096	0.19	0.1432	0.102	0.21	0.0898	0.122	0.31
0.3179	0.104	0.22	0.4277	0.1	0.2	0.3272	0.1	0.2	0.3778	0.14	0.4
0.5409	0.102	0.21	0.7087	0.096	0.19	0.6272	0.096	0.19	0.6018	0.114	0.27
Av.	0.1064	0.232	Av.	0.1036	0.222	Av.	0.1024	0.214	Av.	0.1288	0.29
Std Dev.	0.005367	0.026833	Std Dev.	0.008989	0.040866	Std Dev.	0.004775	0.020736	Std Dev.	0.008944	0.044721
Site 47			Site 48			Site 49			Site 51		
0	0.126	0.33	0	0.114	0.27	0	0.11	0.25	0	0.108	0.24
0.0121	0.126	0.33	0.0192	0.116	0.28	0.036	0.112	0.26	0.048	0.108	0.24
0.2664	0.15	0.45	0.2078	0.104	0.22	0.2128	0.096	0.19	0.1658	0.096	0.19
0.4714	0.144	0.42	0.426	0.146	0.43	0.4238	0.092	0.18	0.4258	0.096	0.19
0.7684	0.12	0.3	Av.	0.12	0.3	0.8738	0.096	0.19	0.8768	0.1	0.2
0.9704	0.114	0.27	Std Dev.	0.018111	0.090554	Av.	0.1012	0.214	Av.	0.1016	0.212
Av.	0.13	0.35				Std Dev.	0.009121	0.037815	Std Dev.	0.006066	0.025884
Std Dev.	0.014029	0.070143									

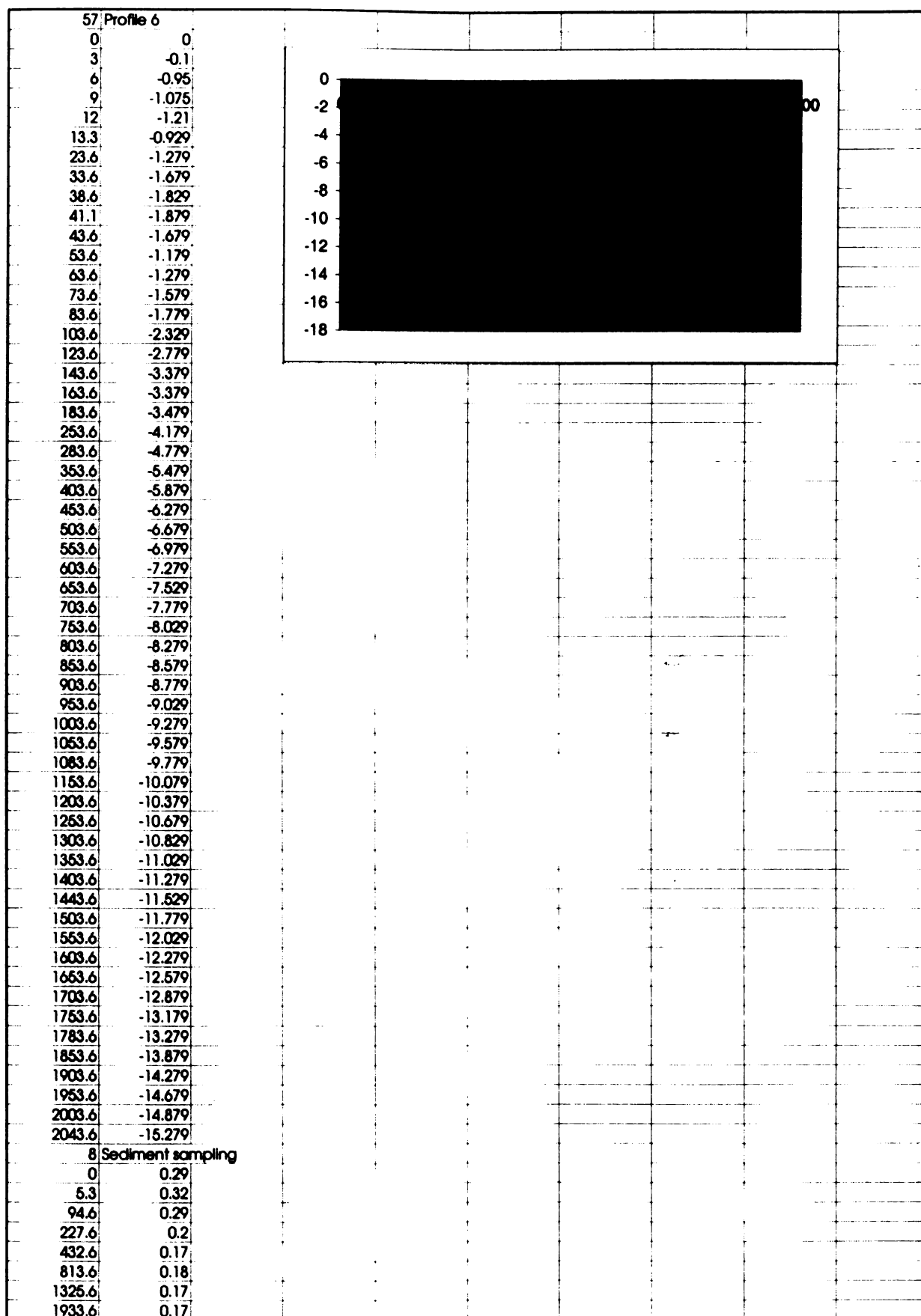


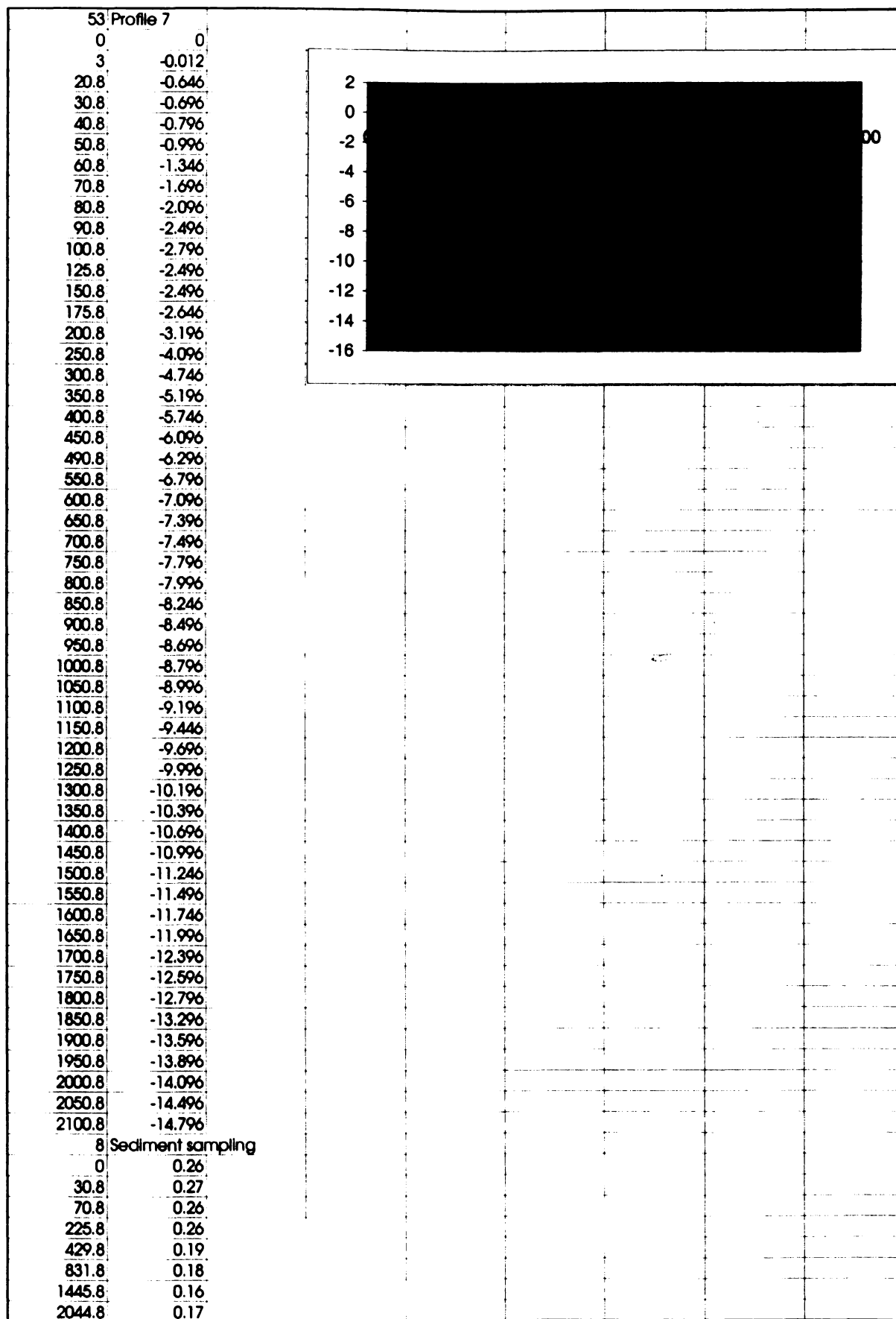


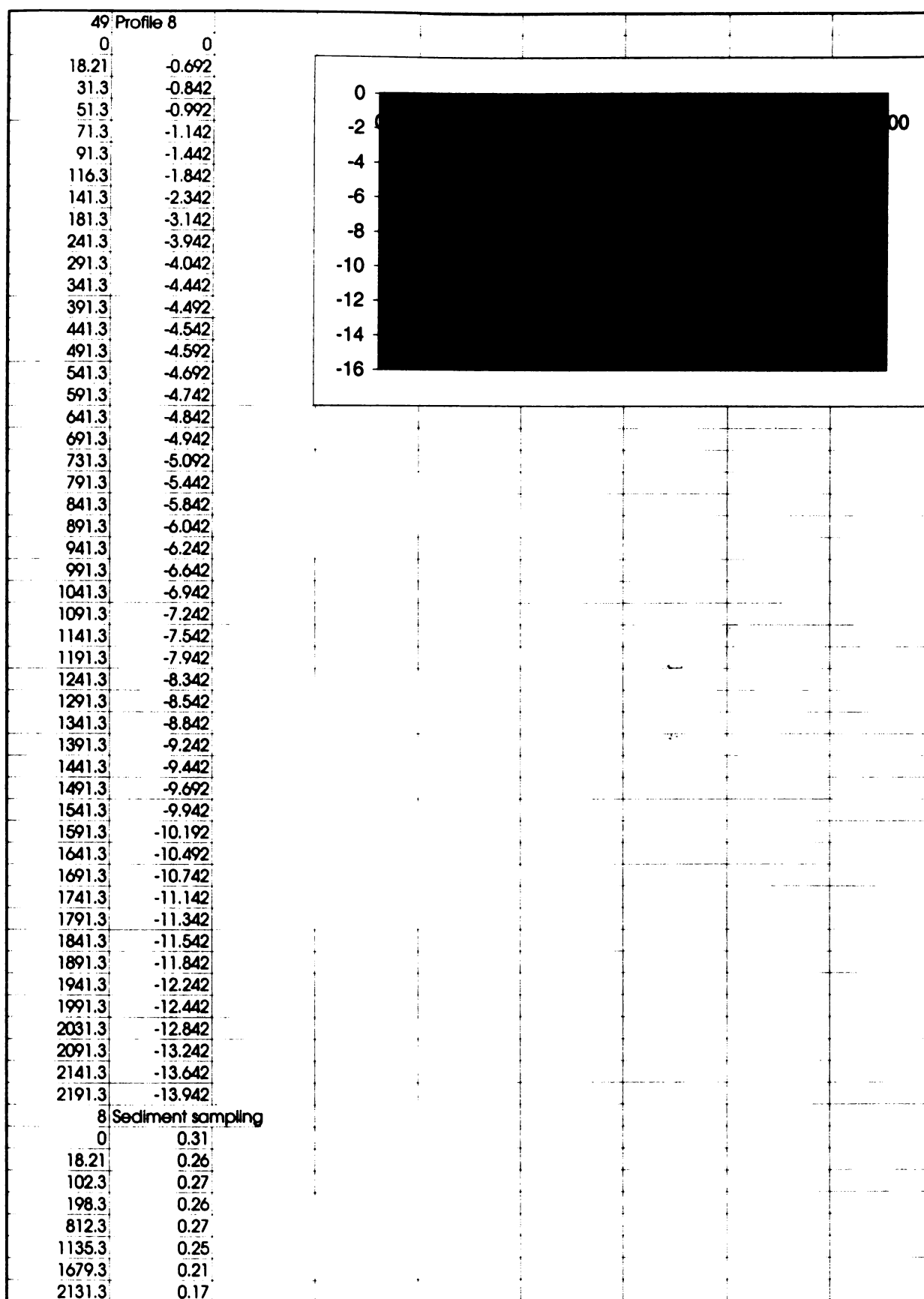


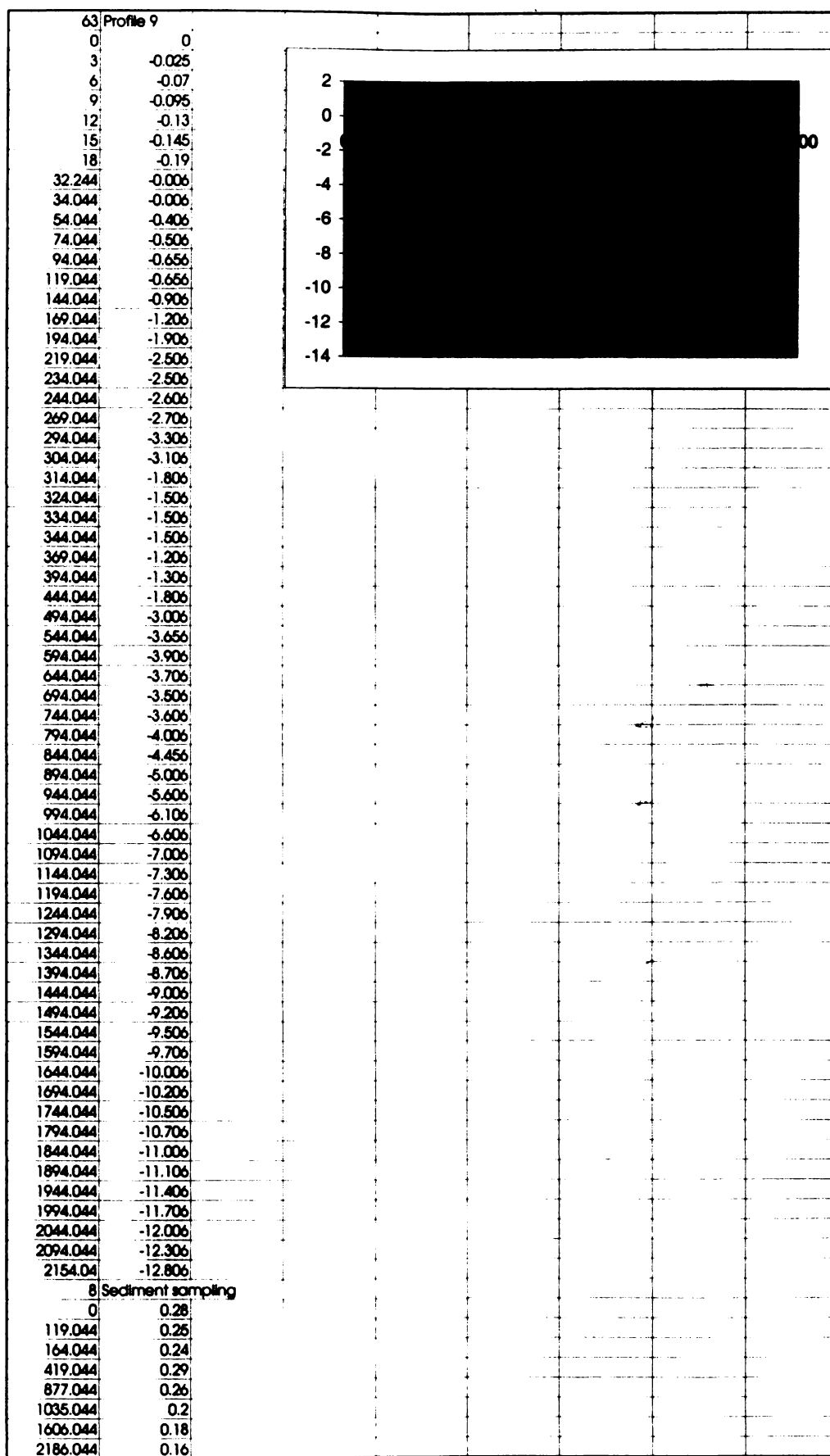


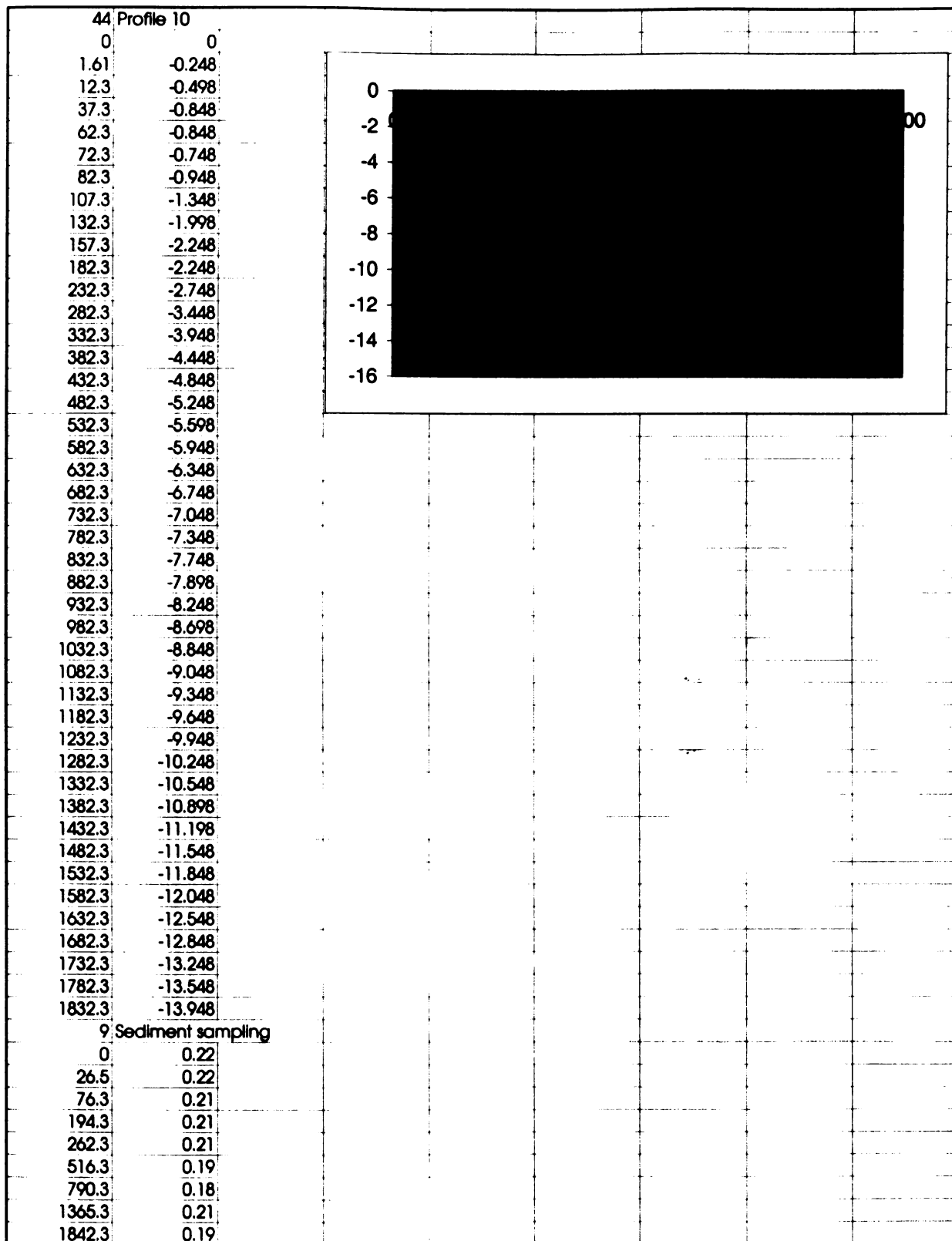


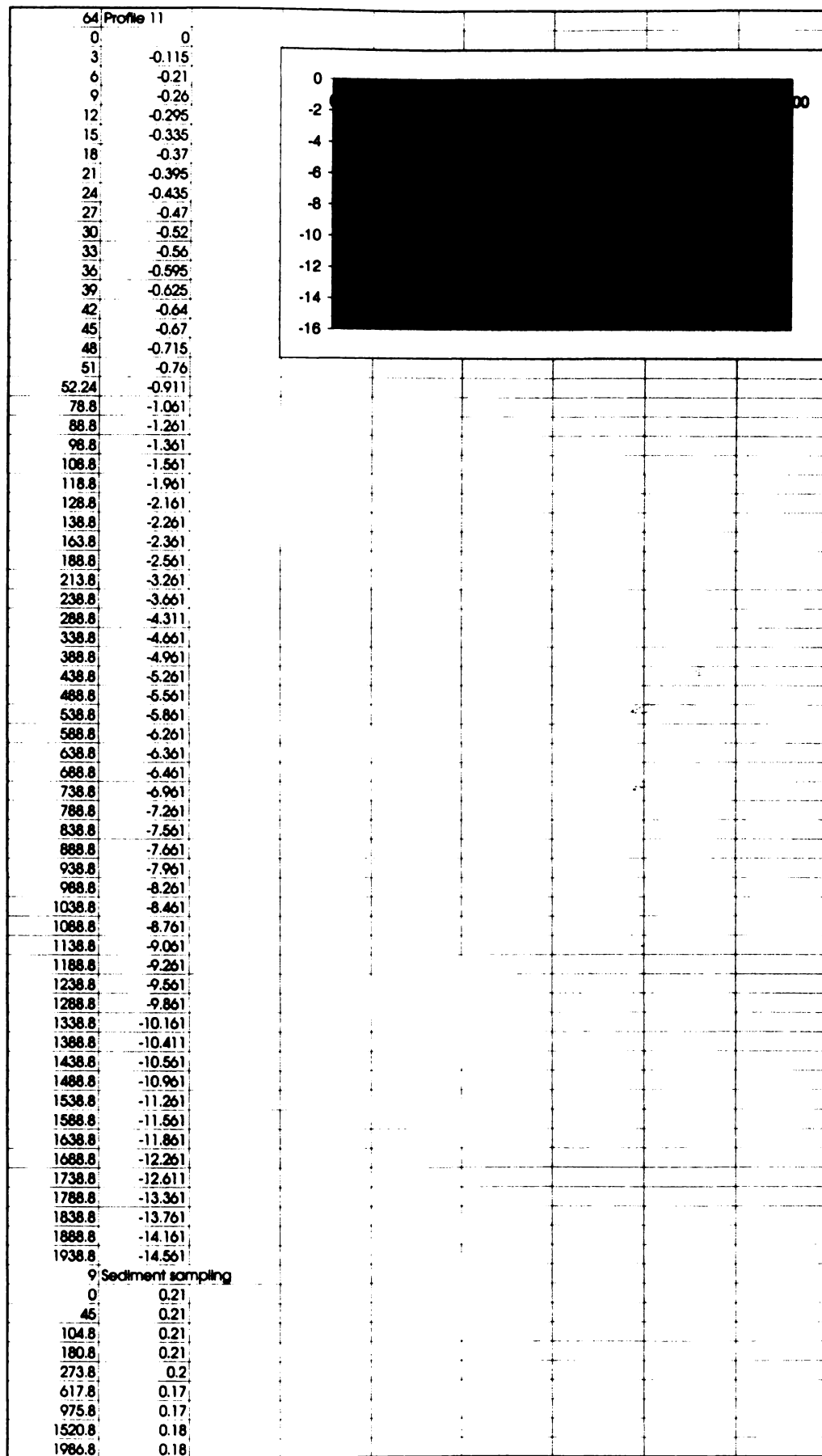


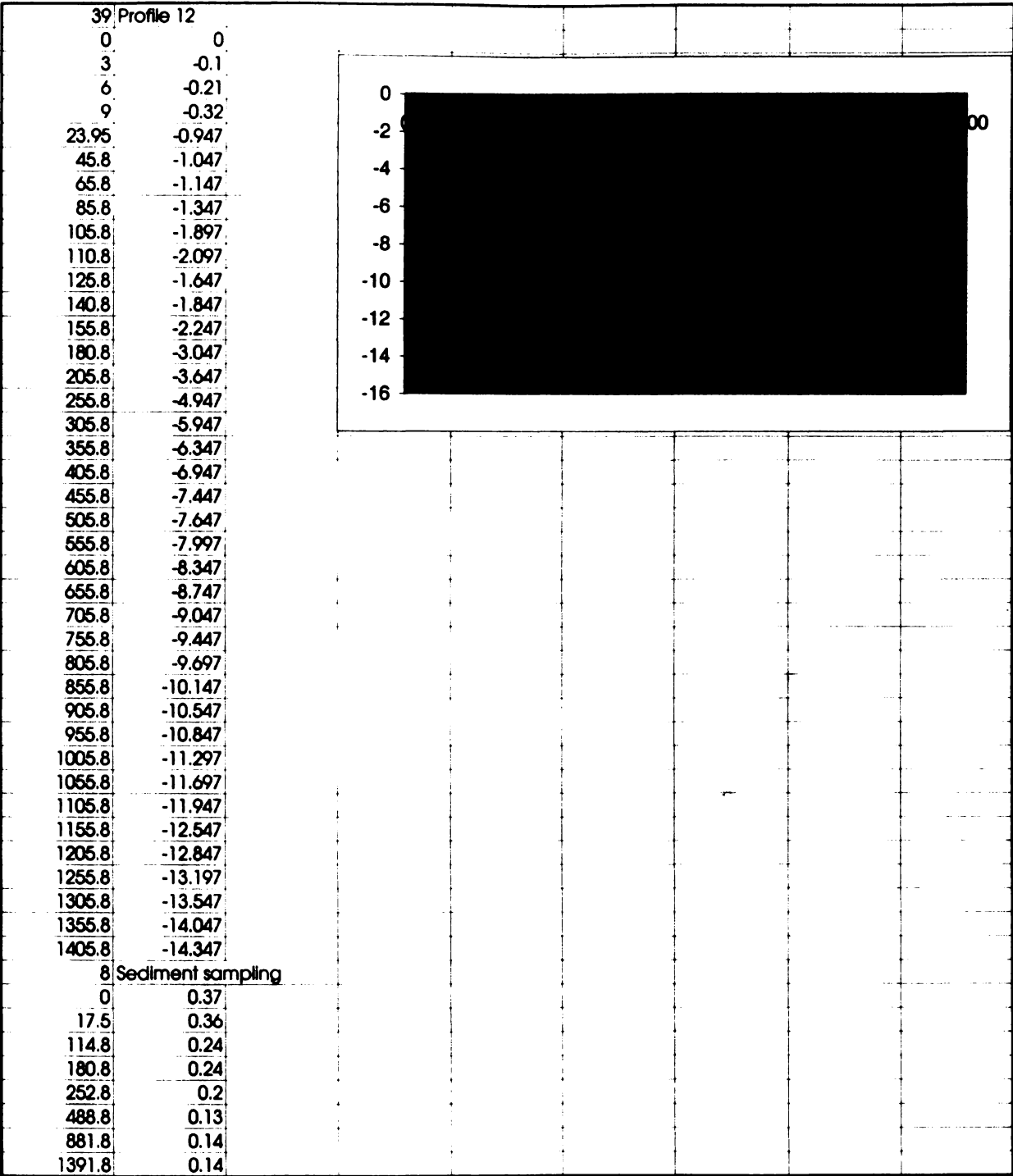


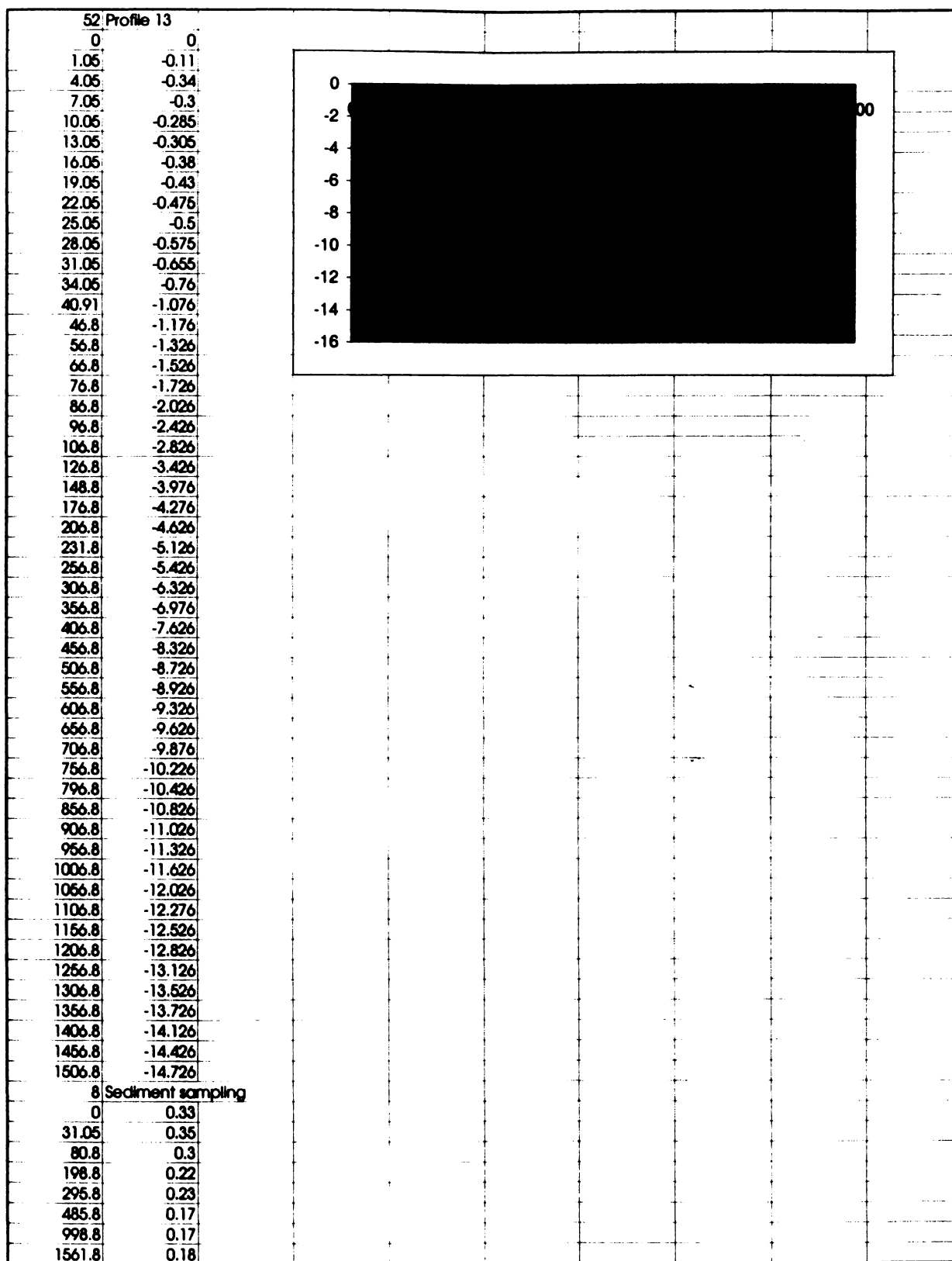


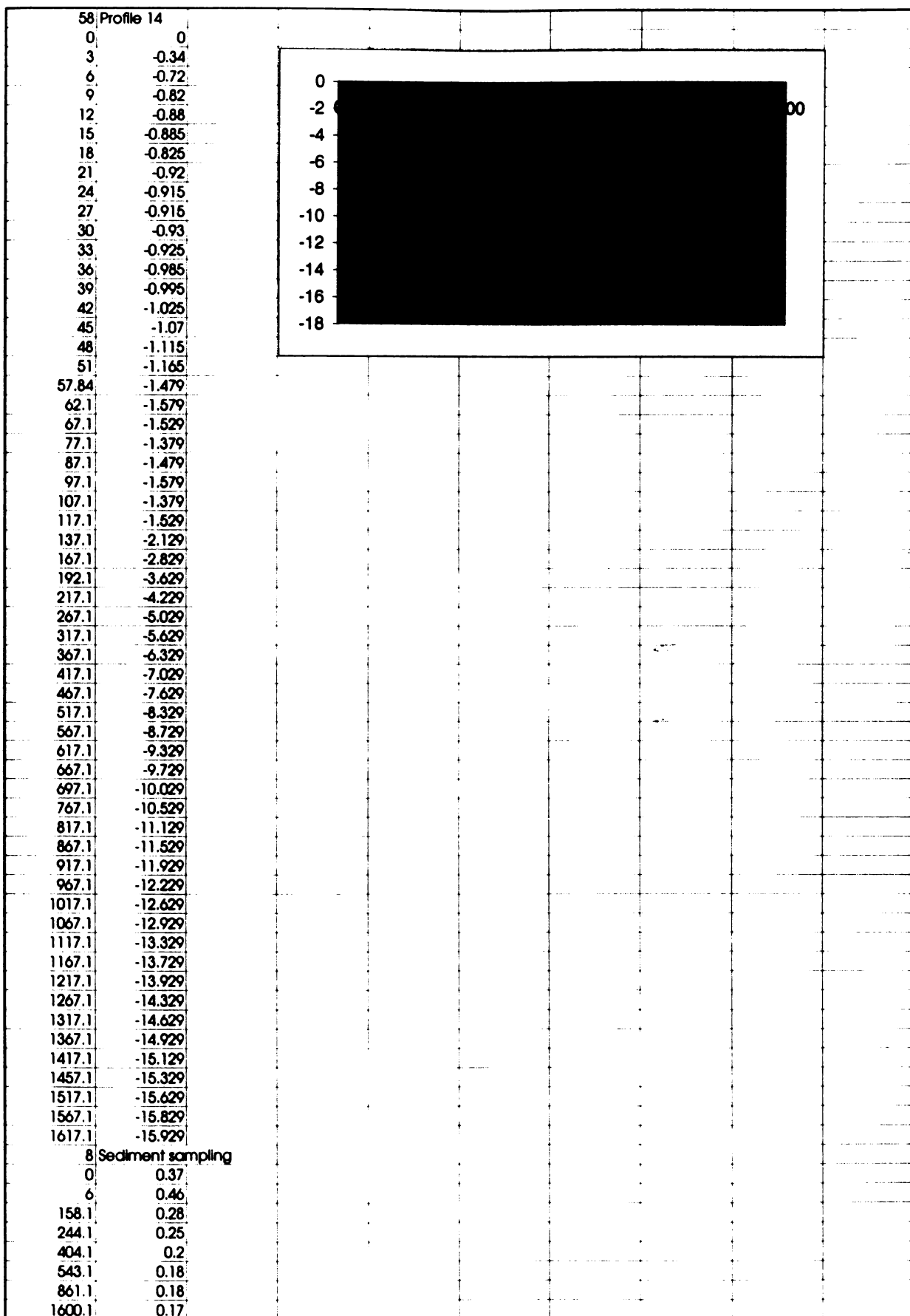


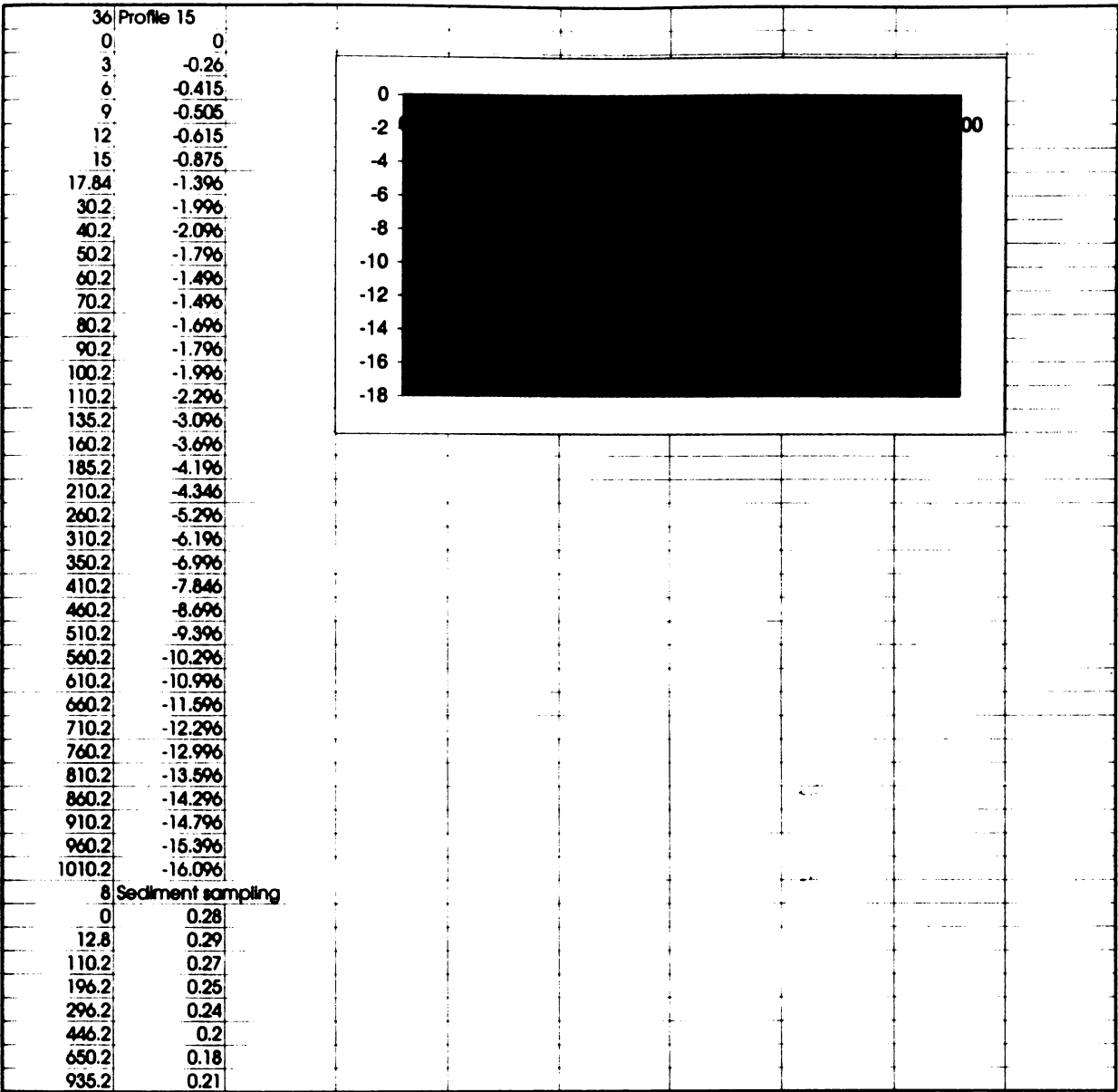


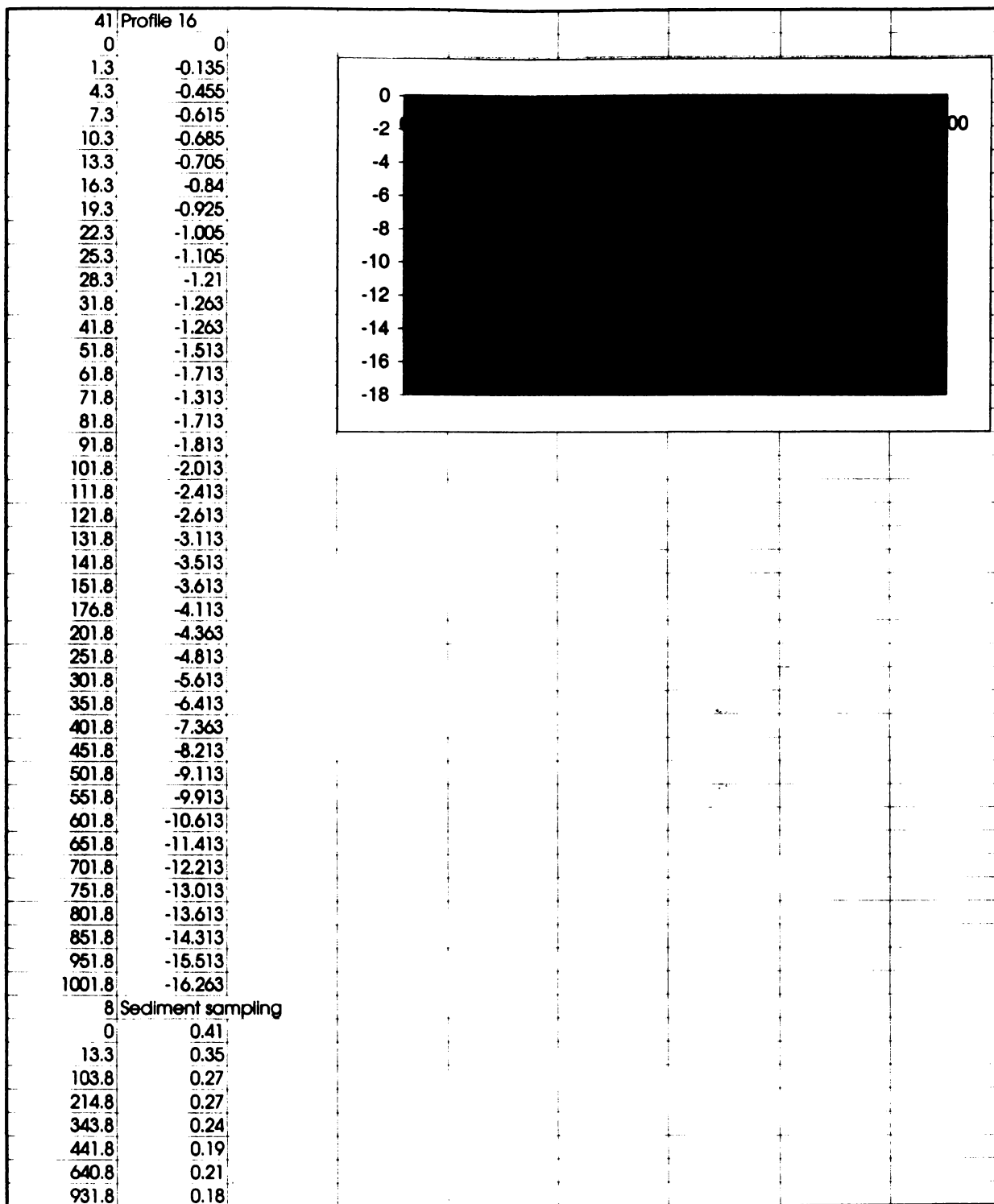


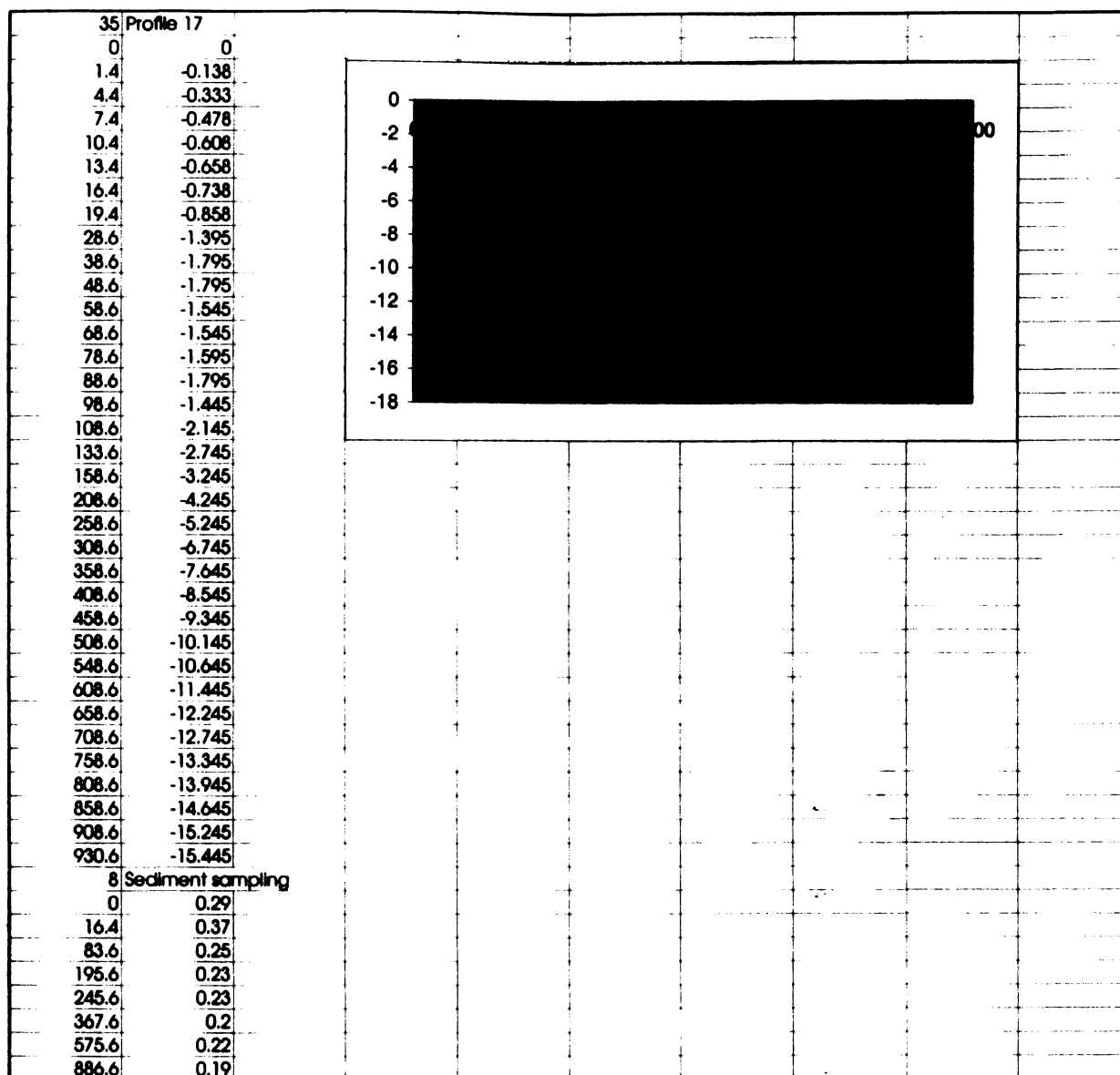


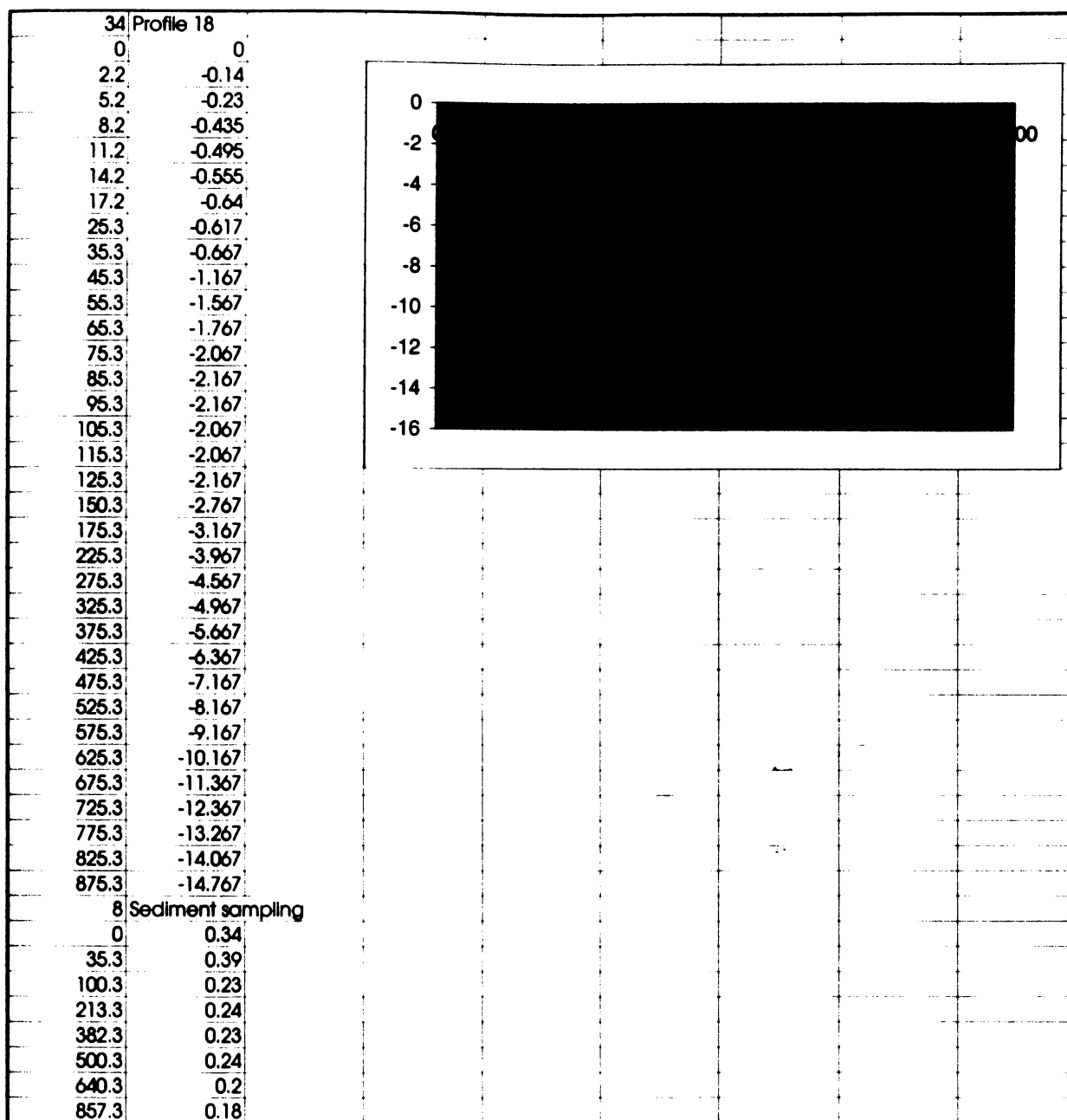


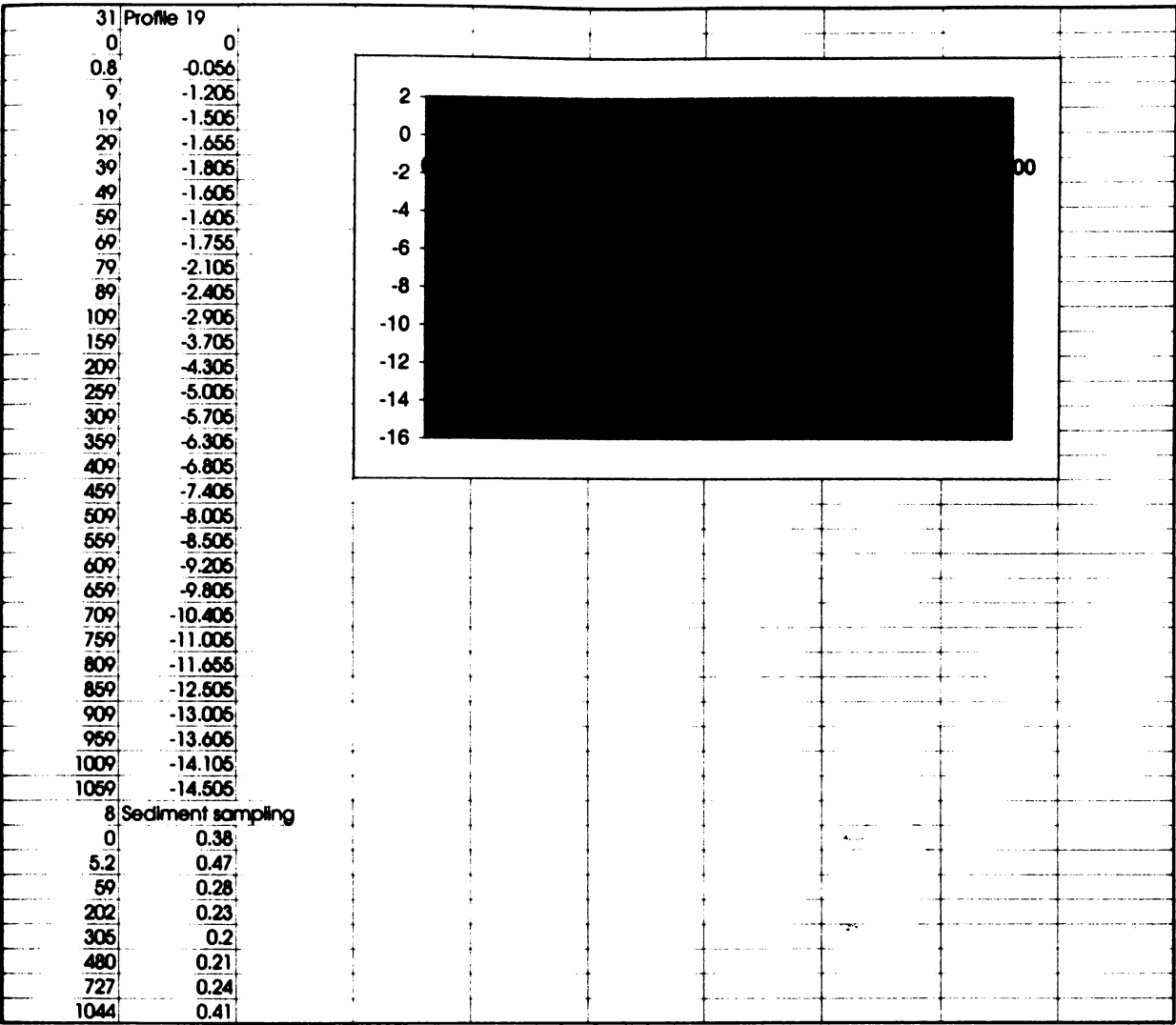


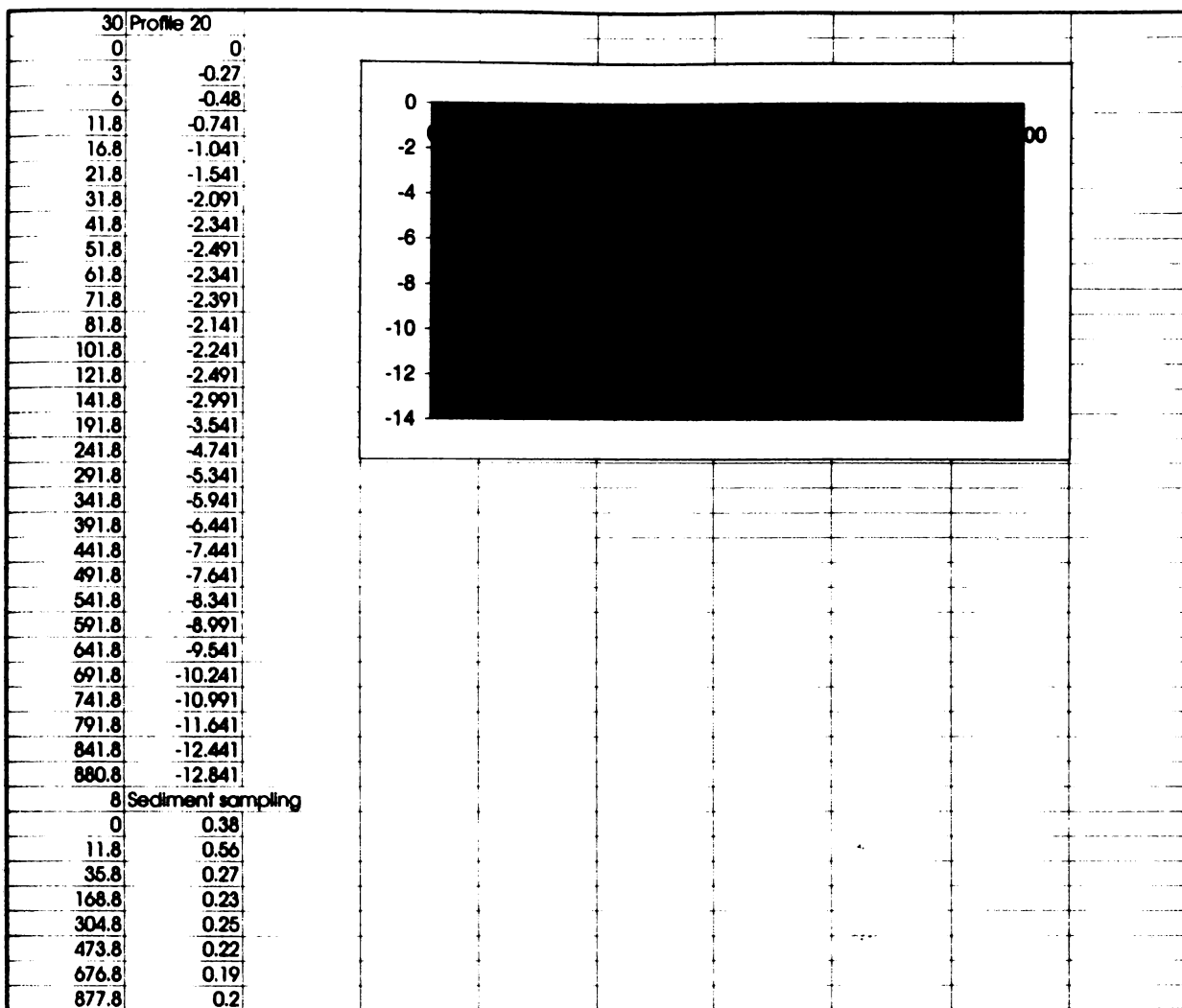


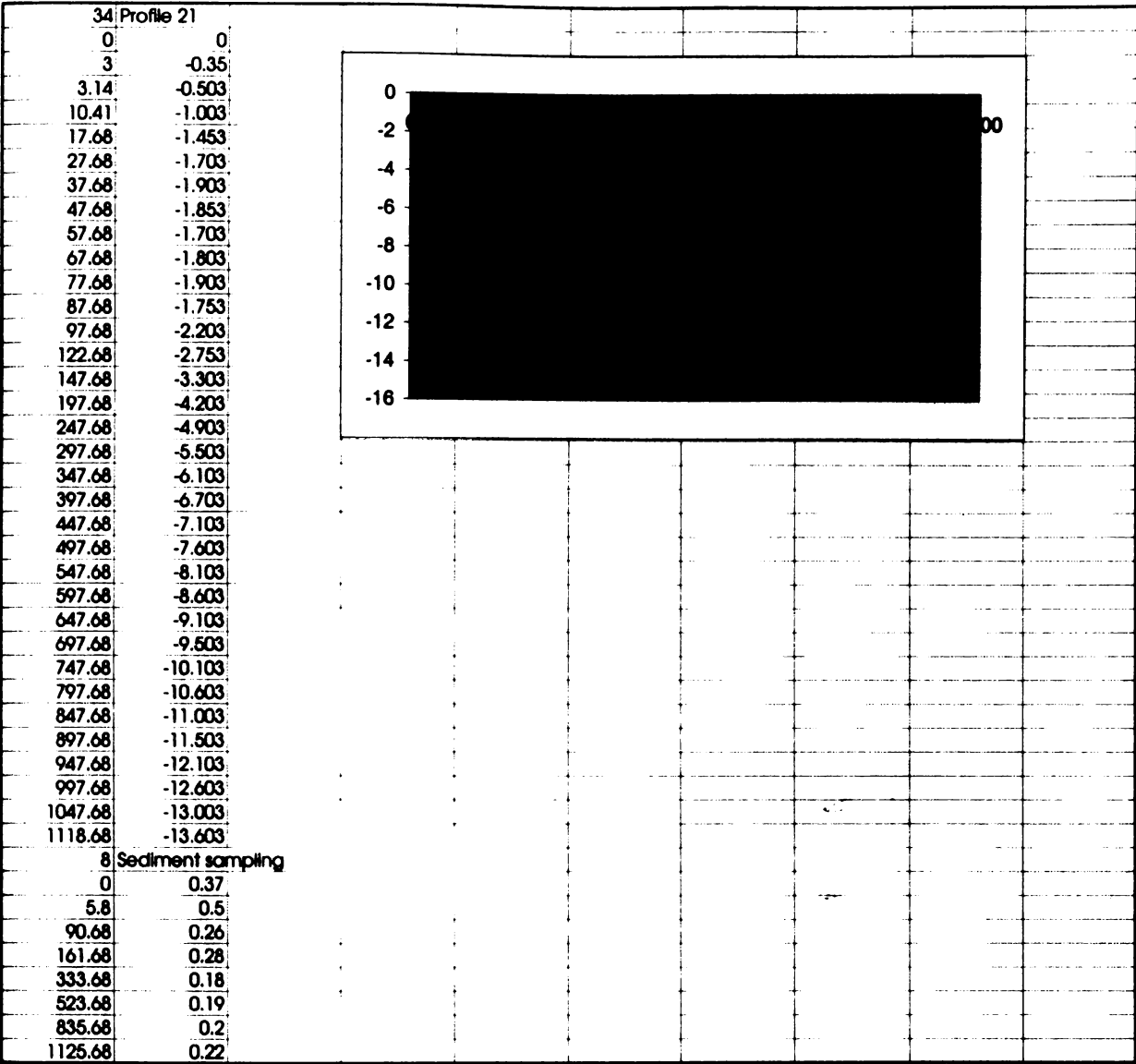


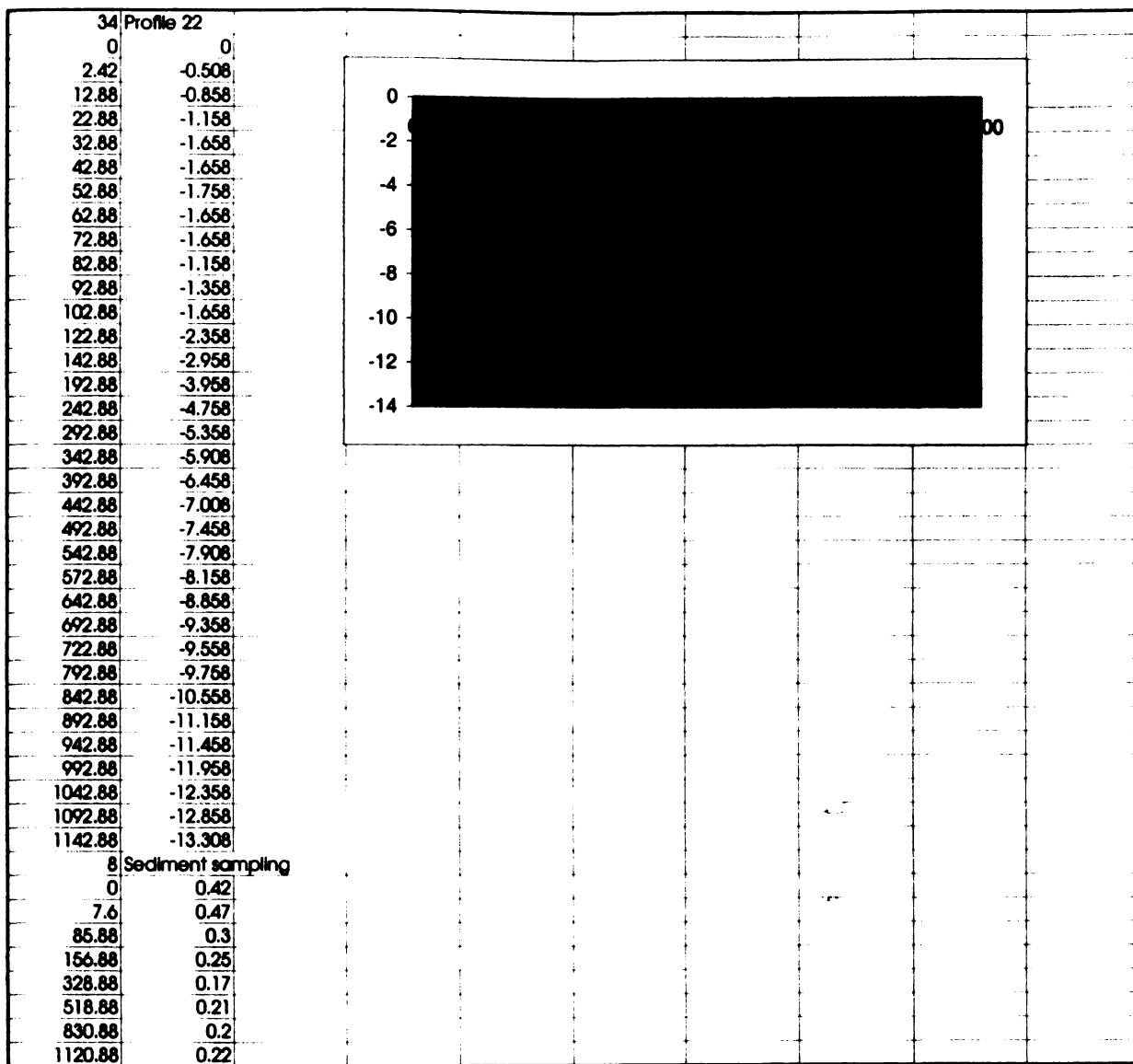


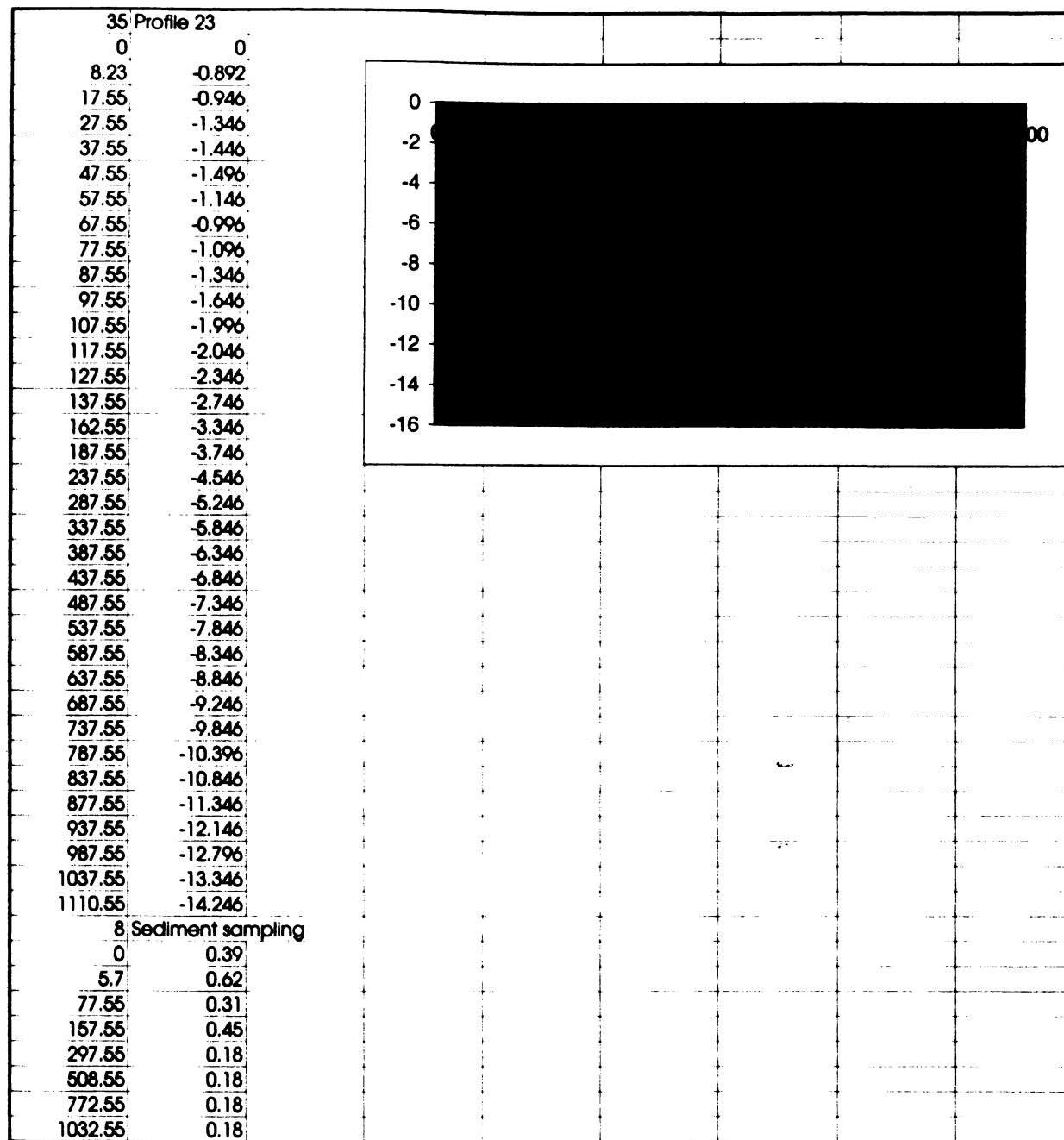


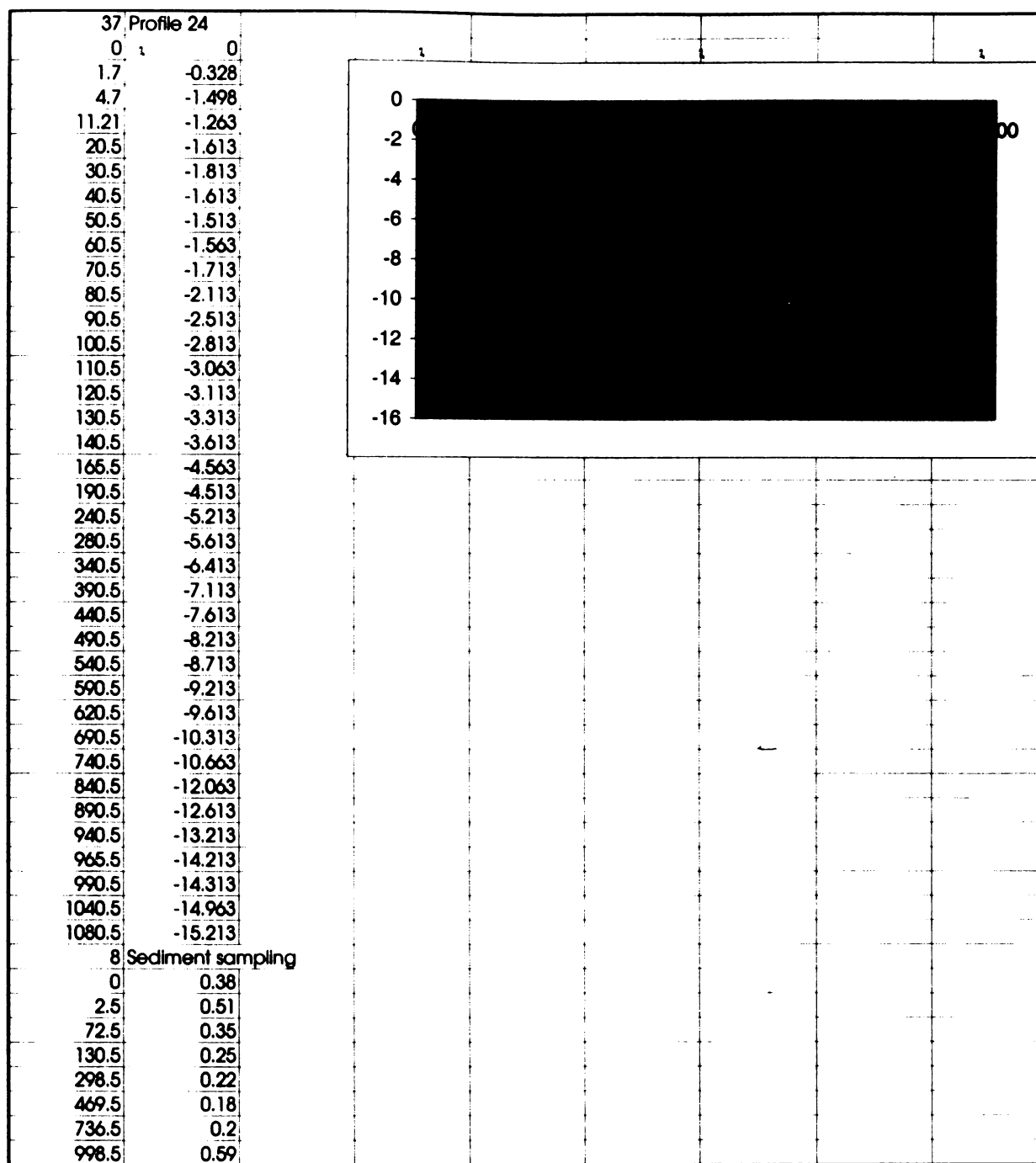


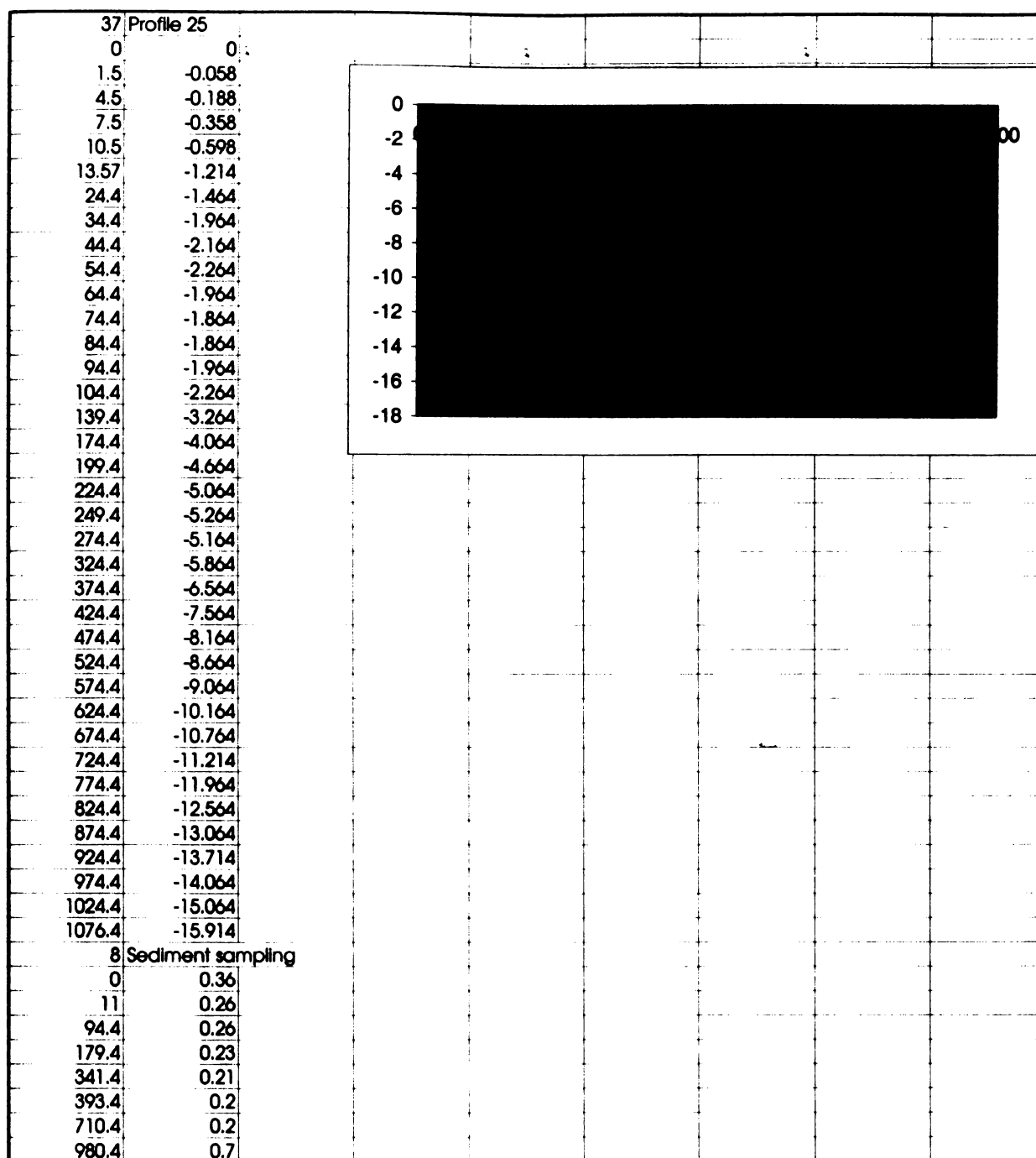


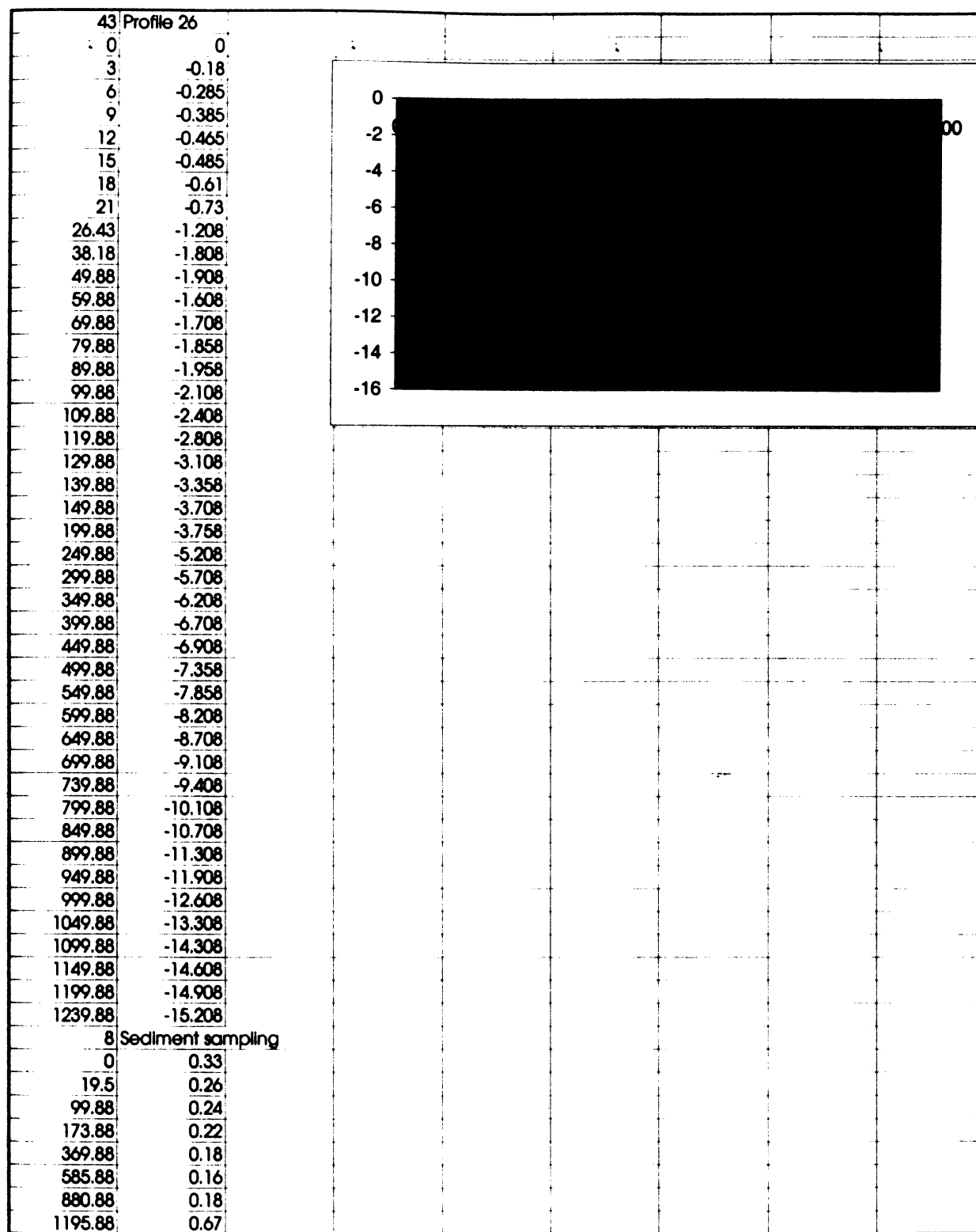


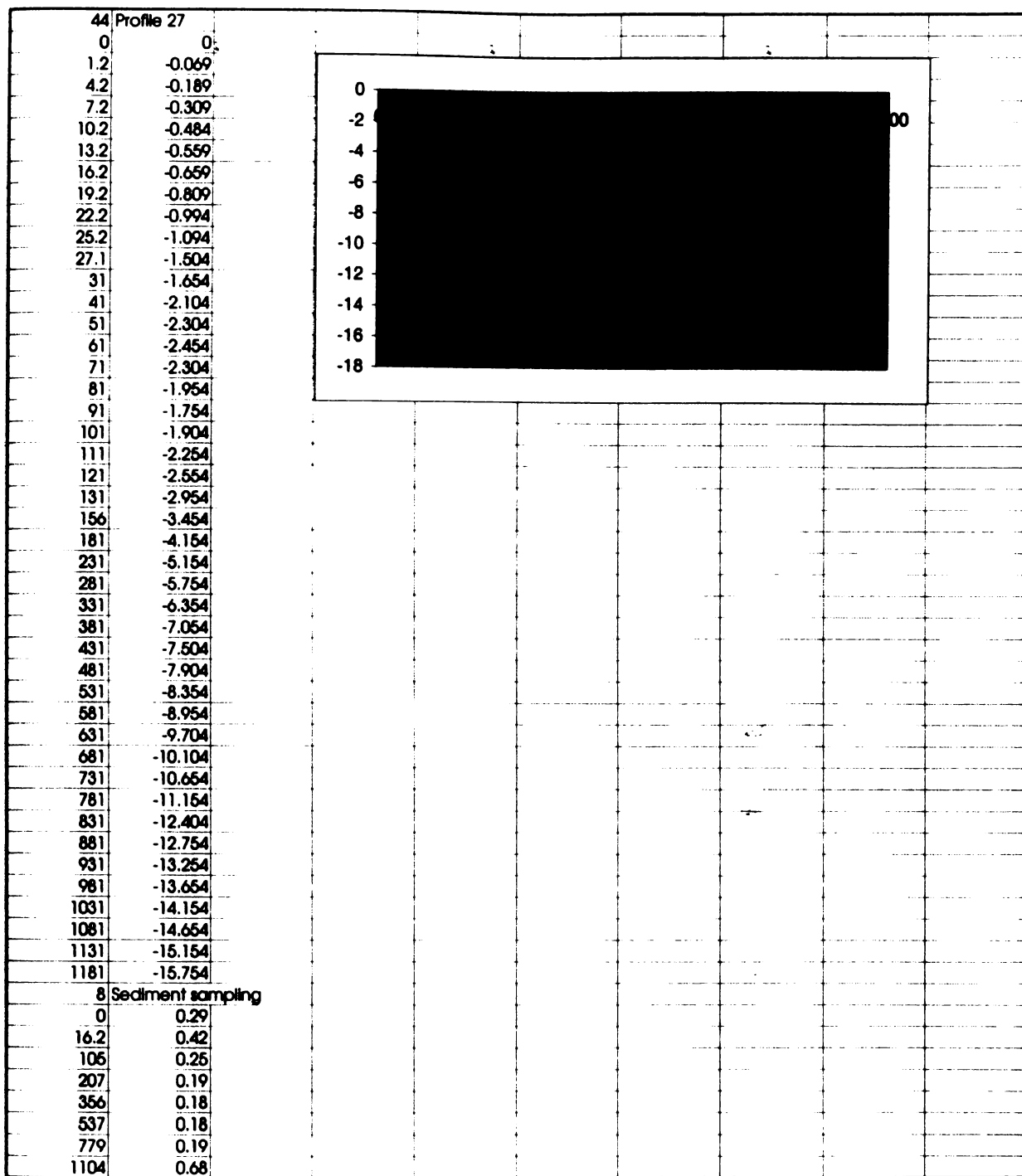


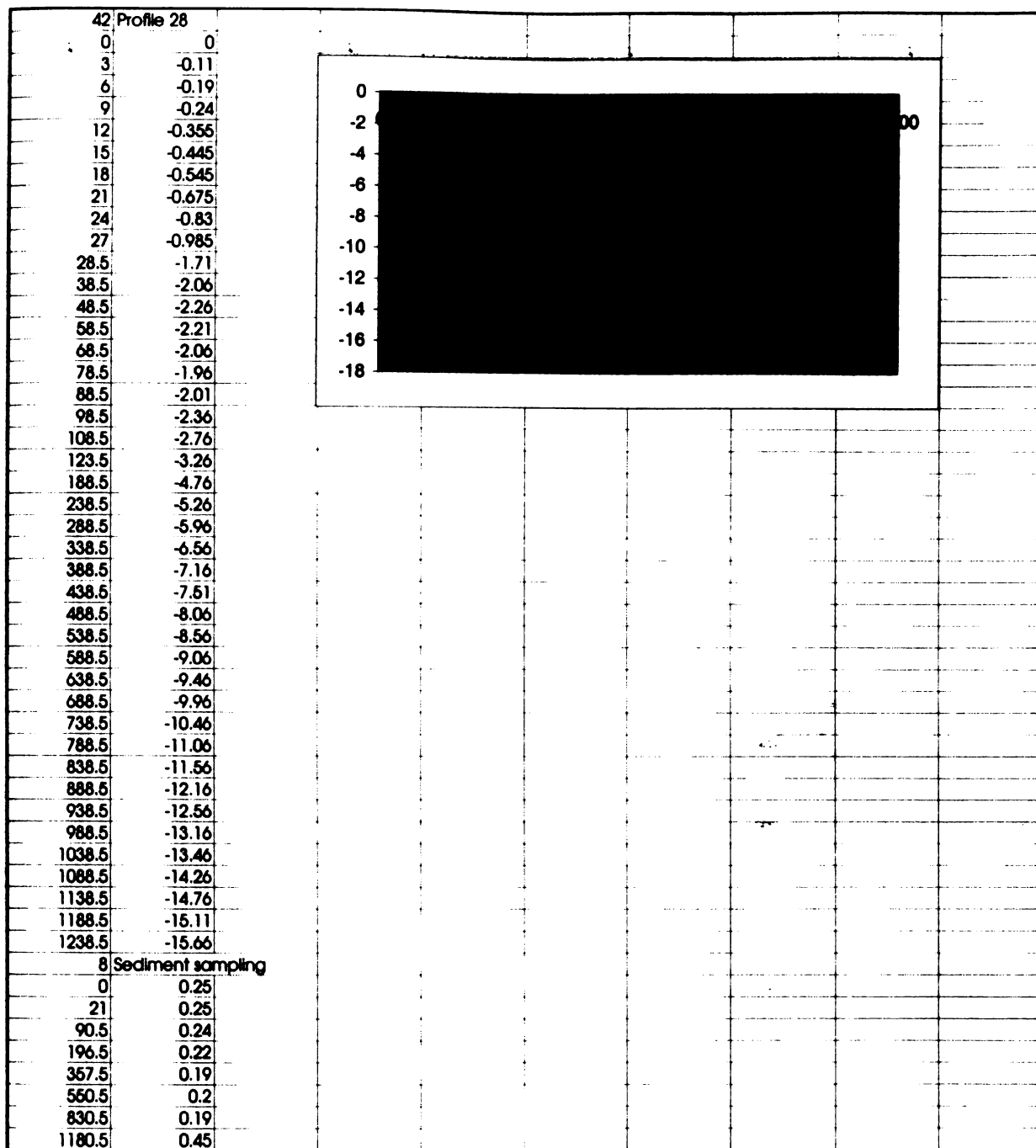




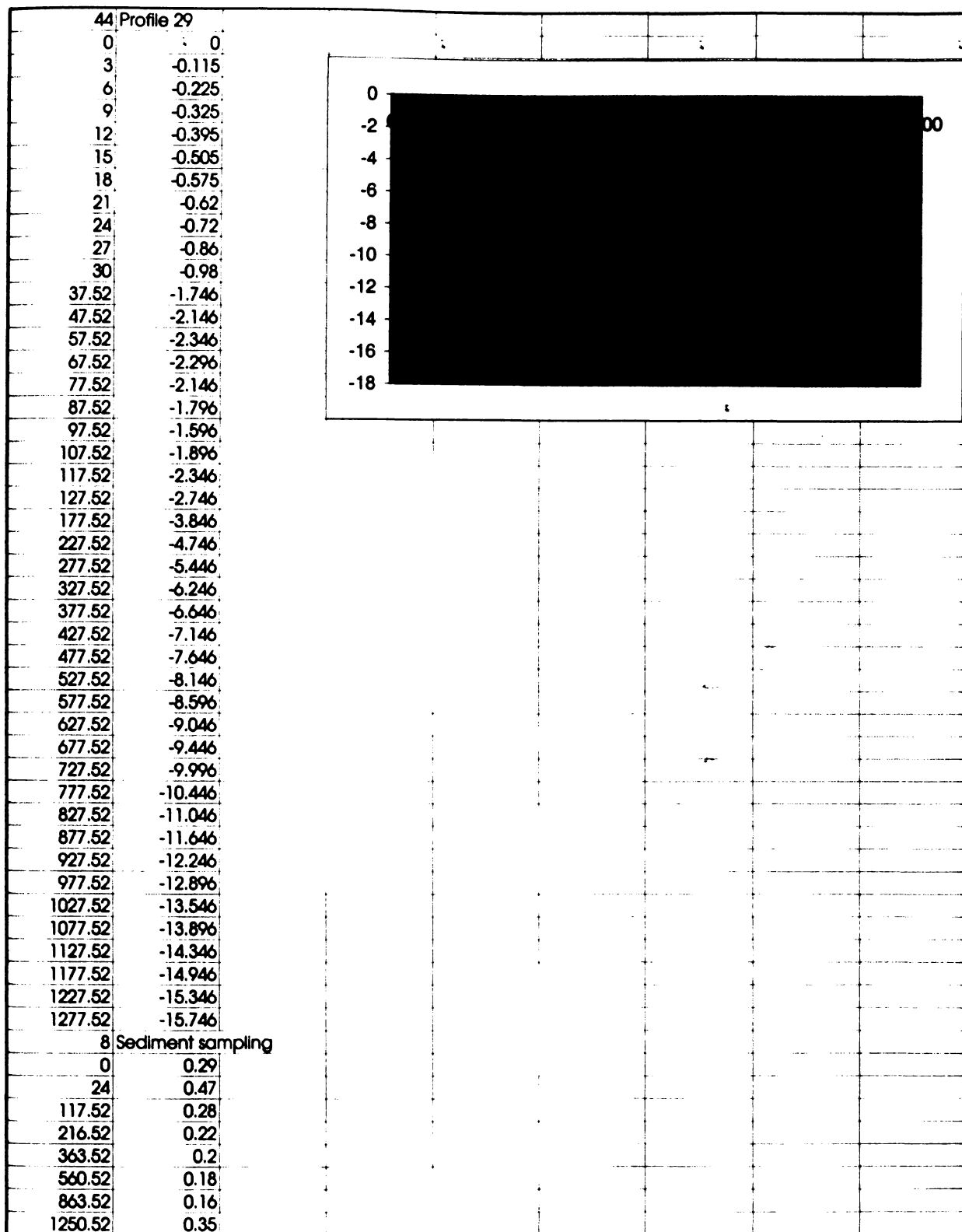




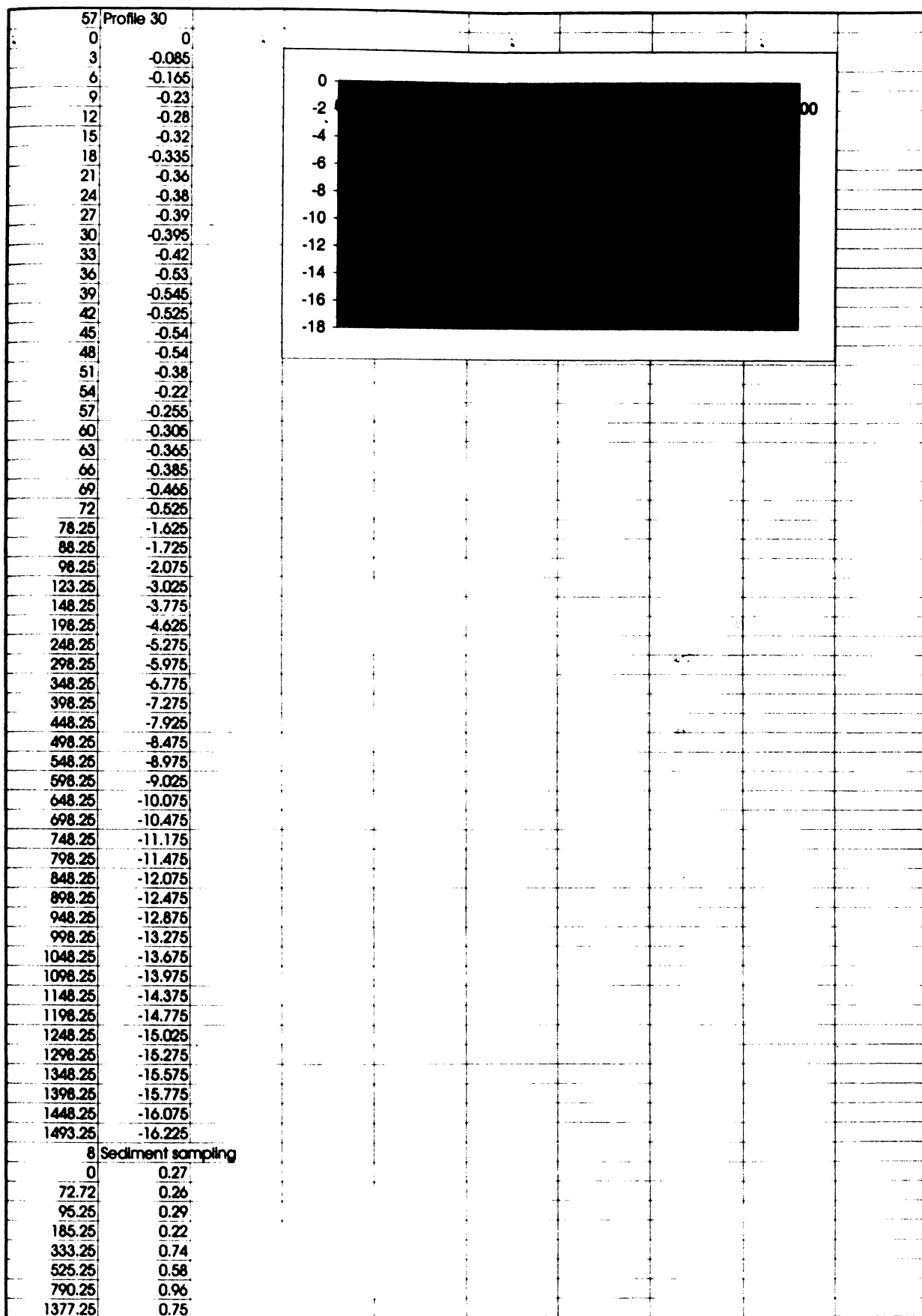


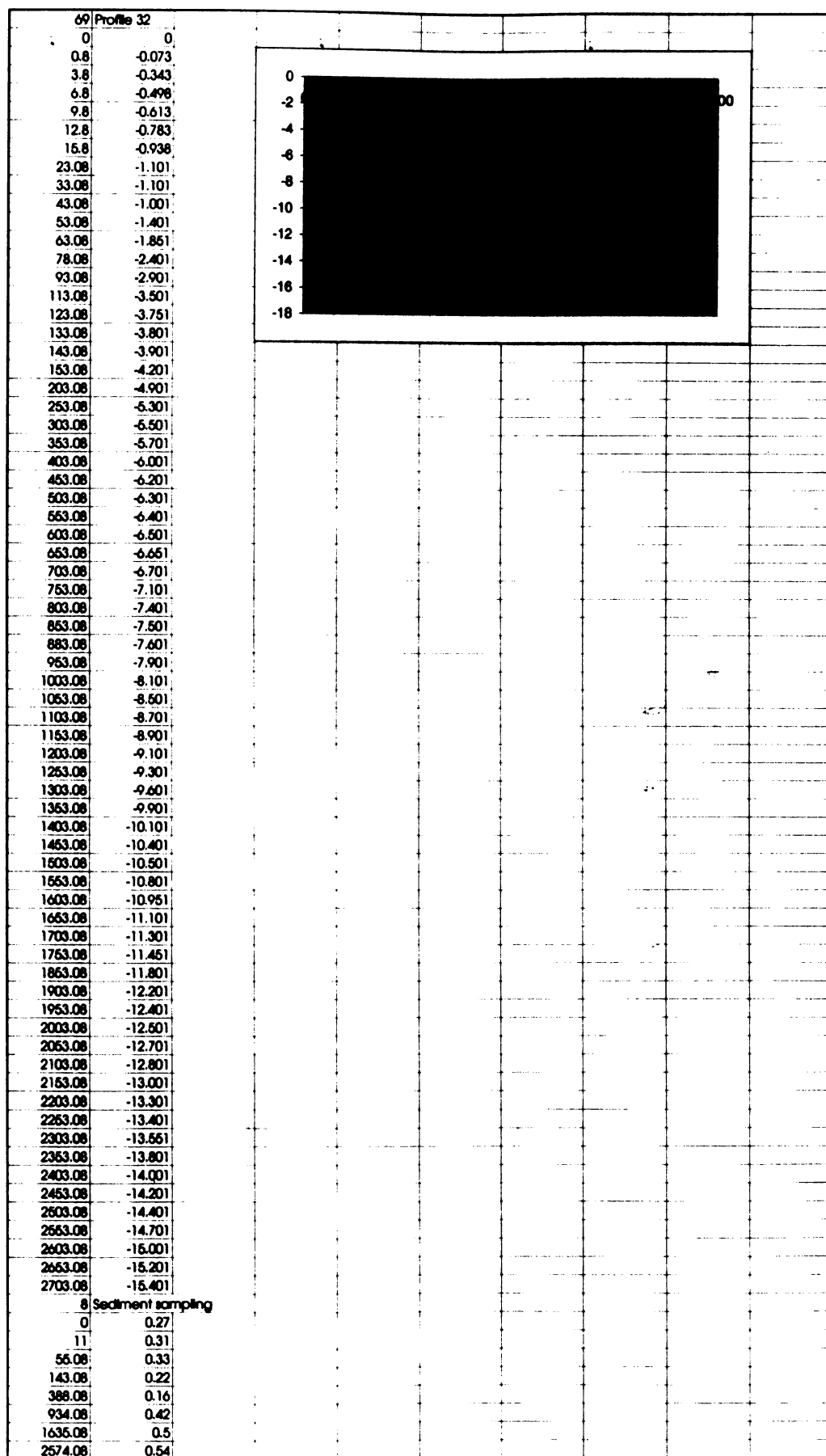


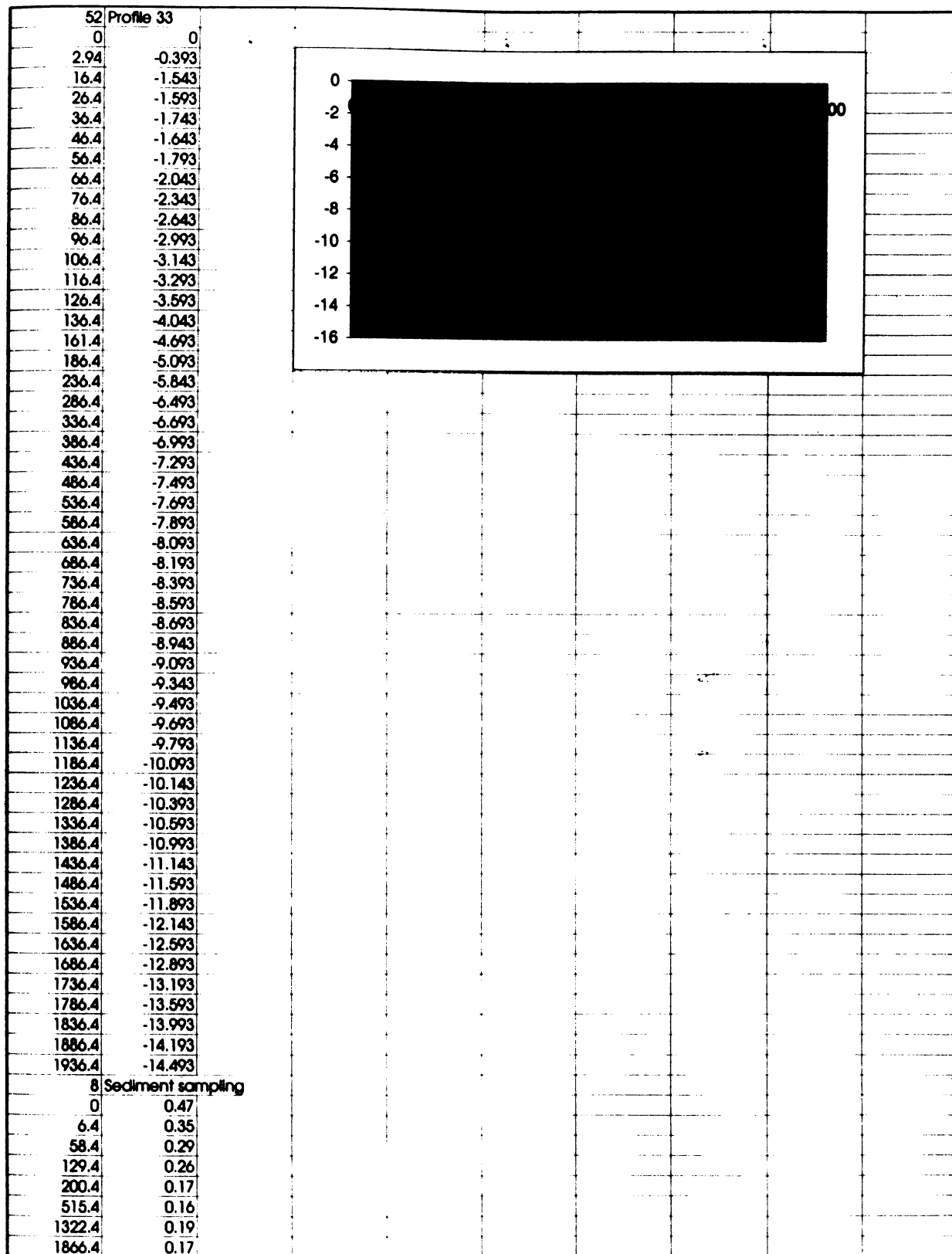
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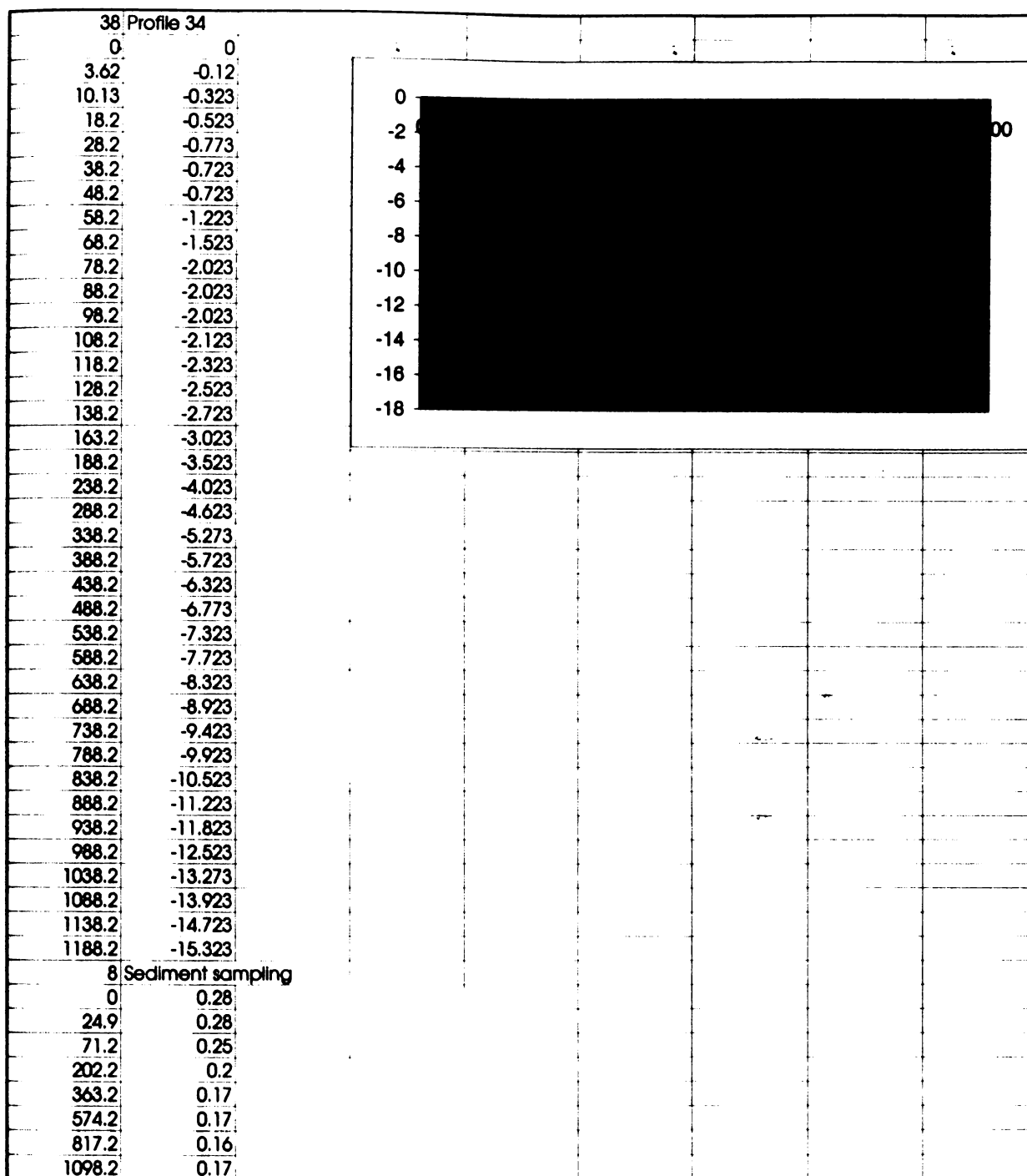


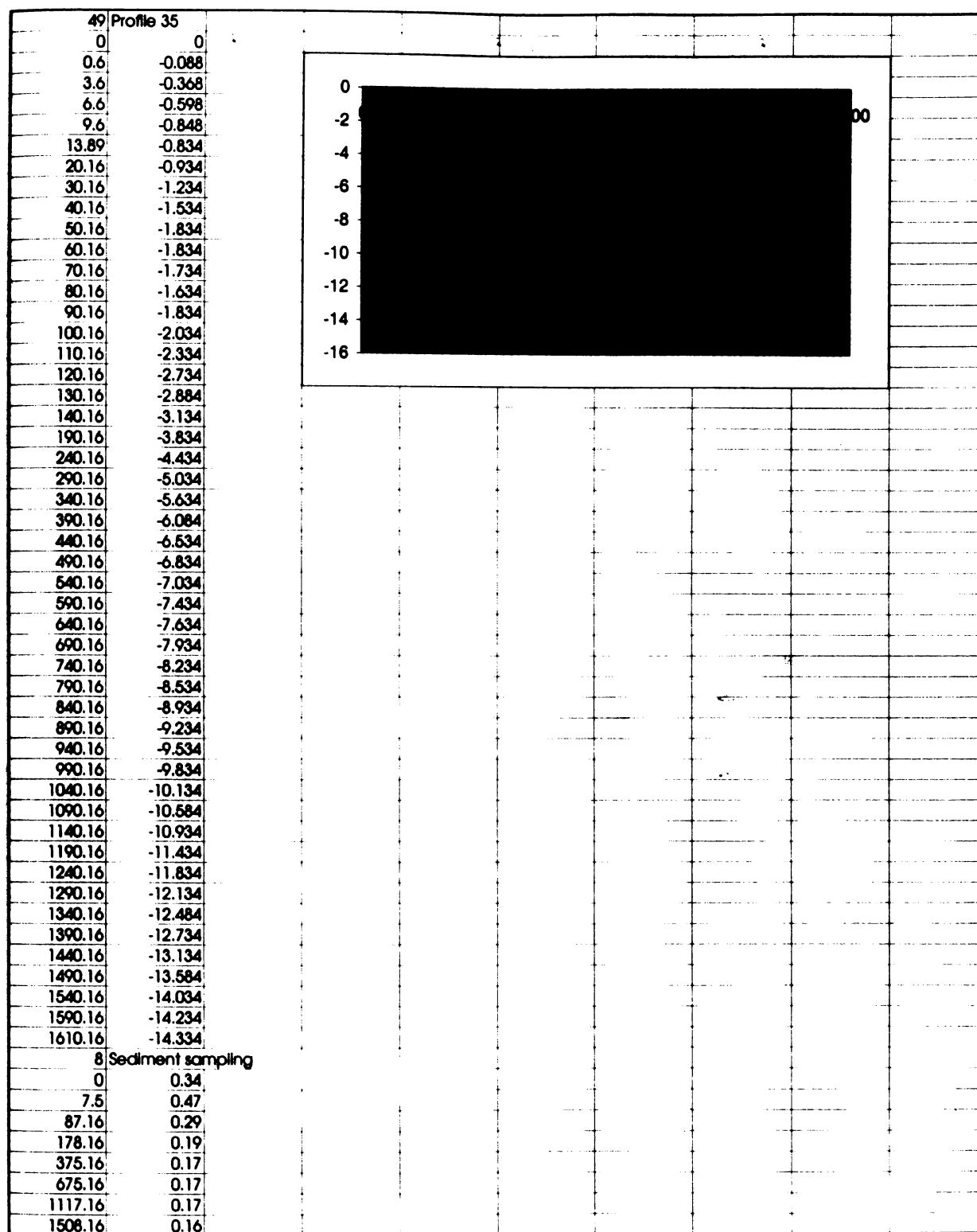
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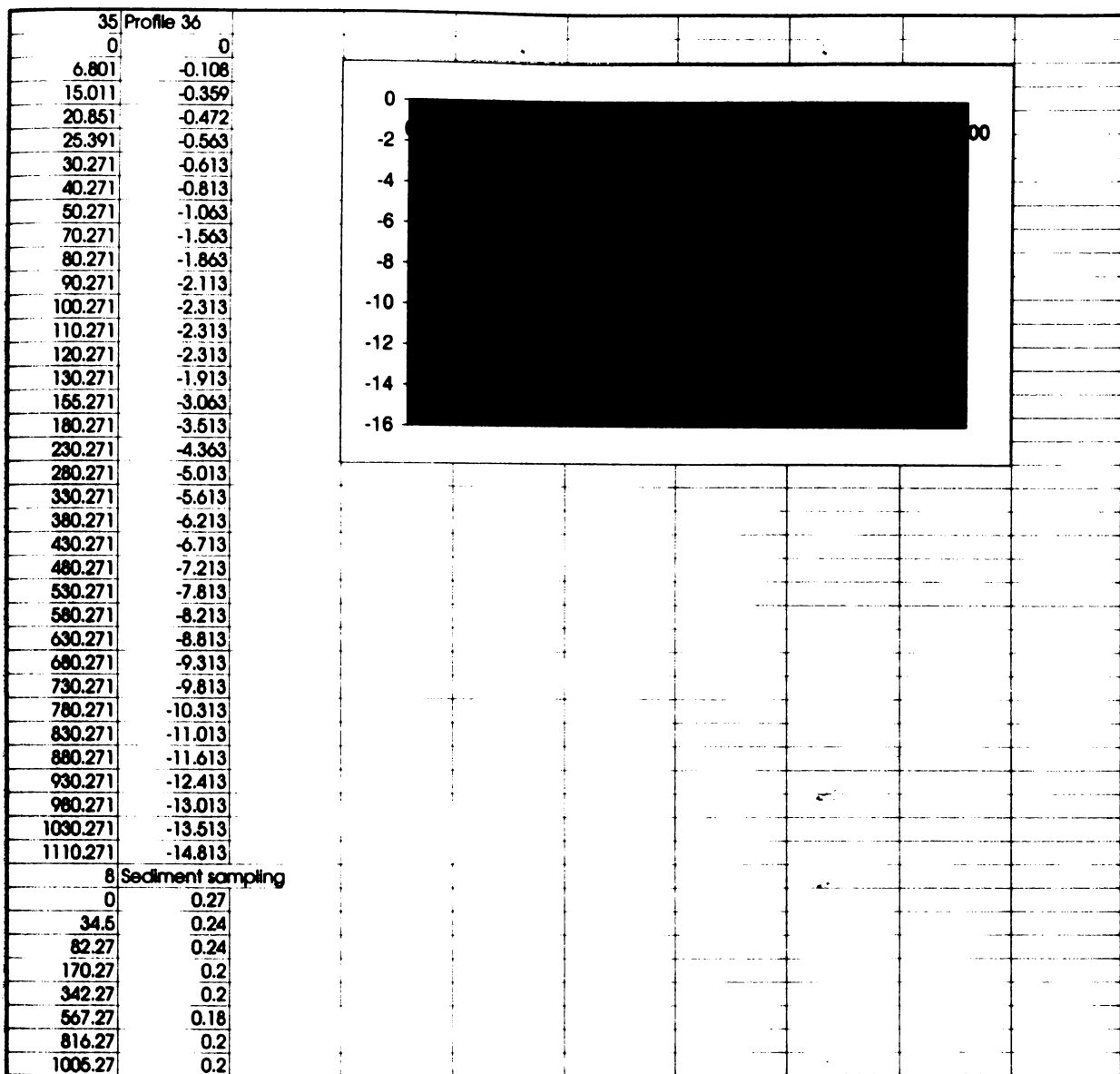




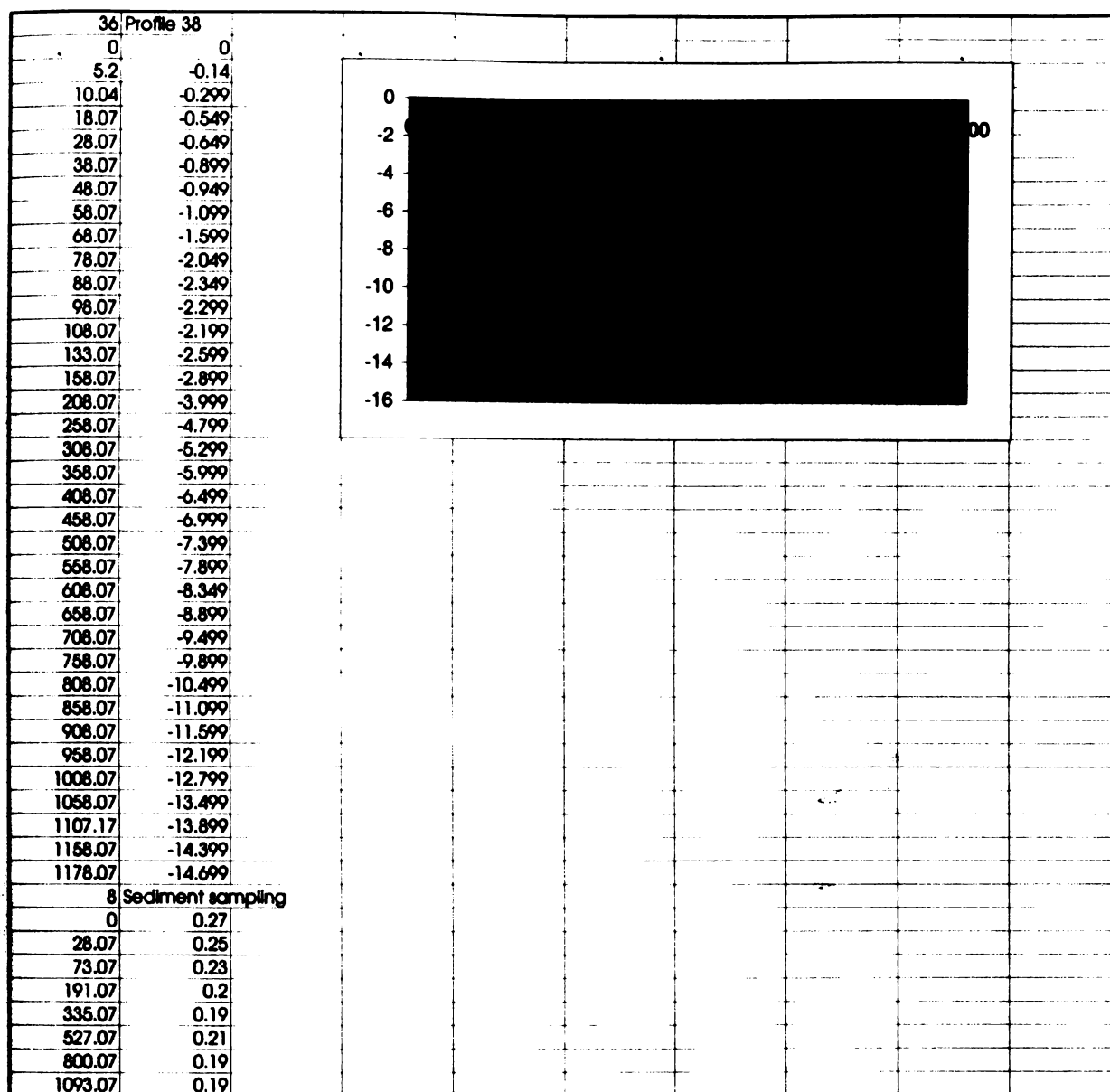


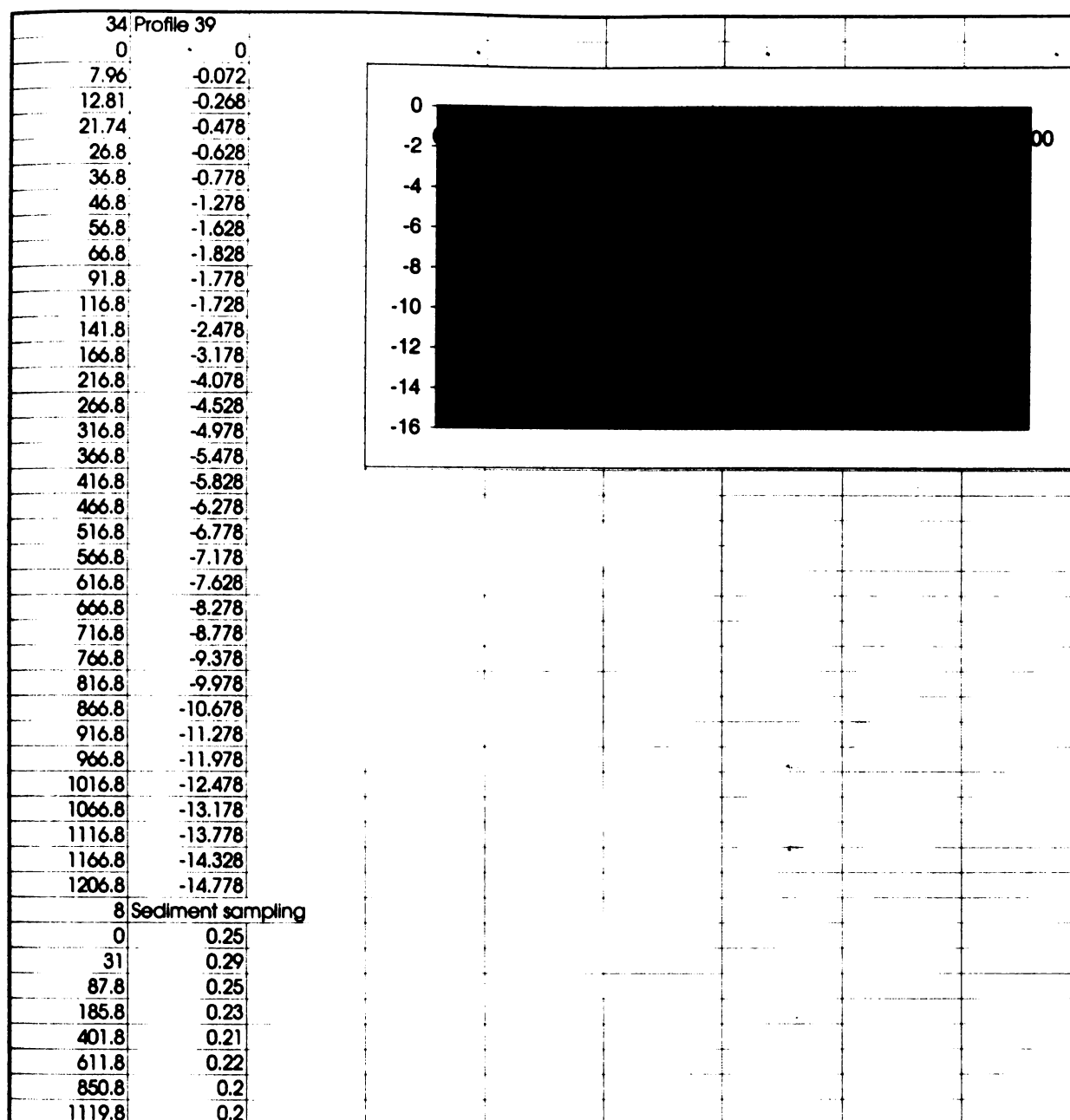


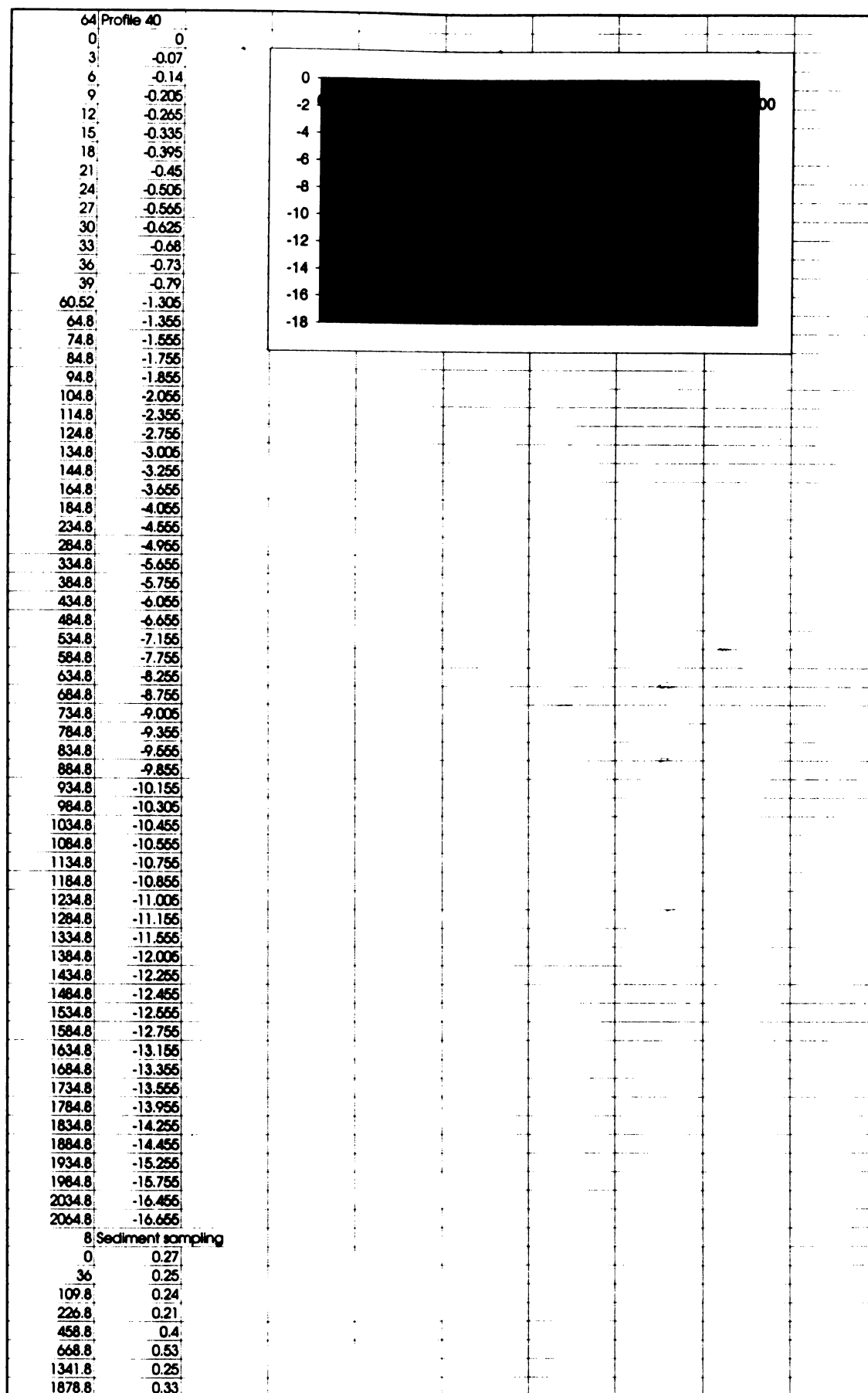


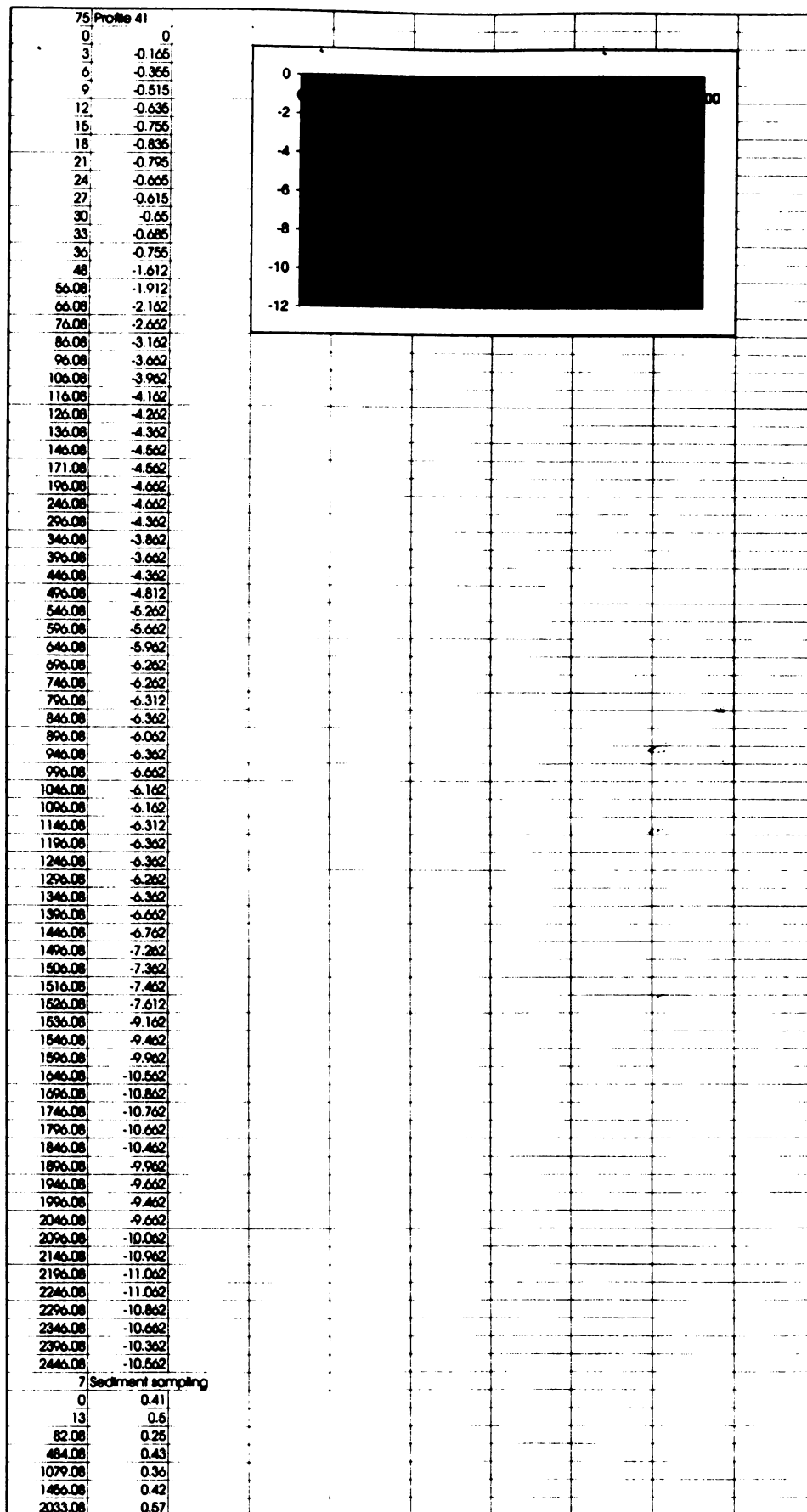


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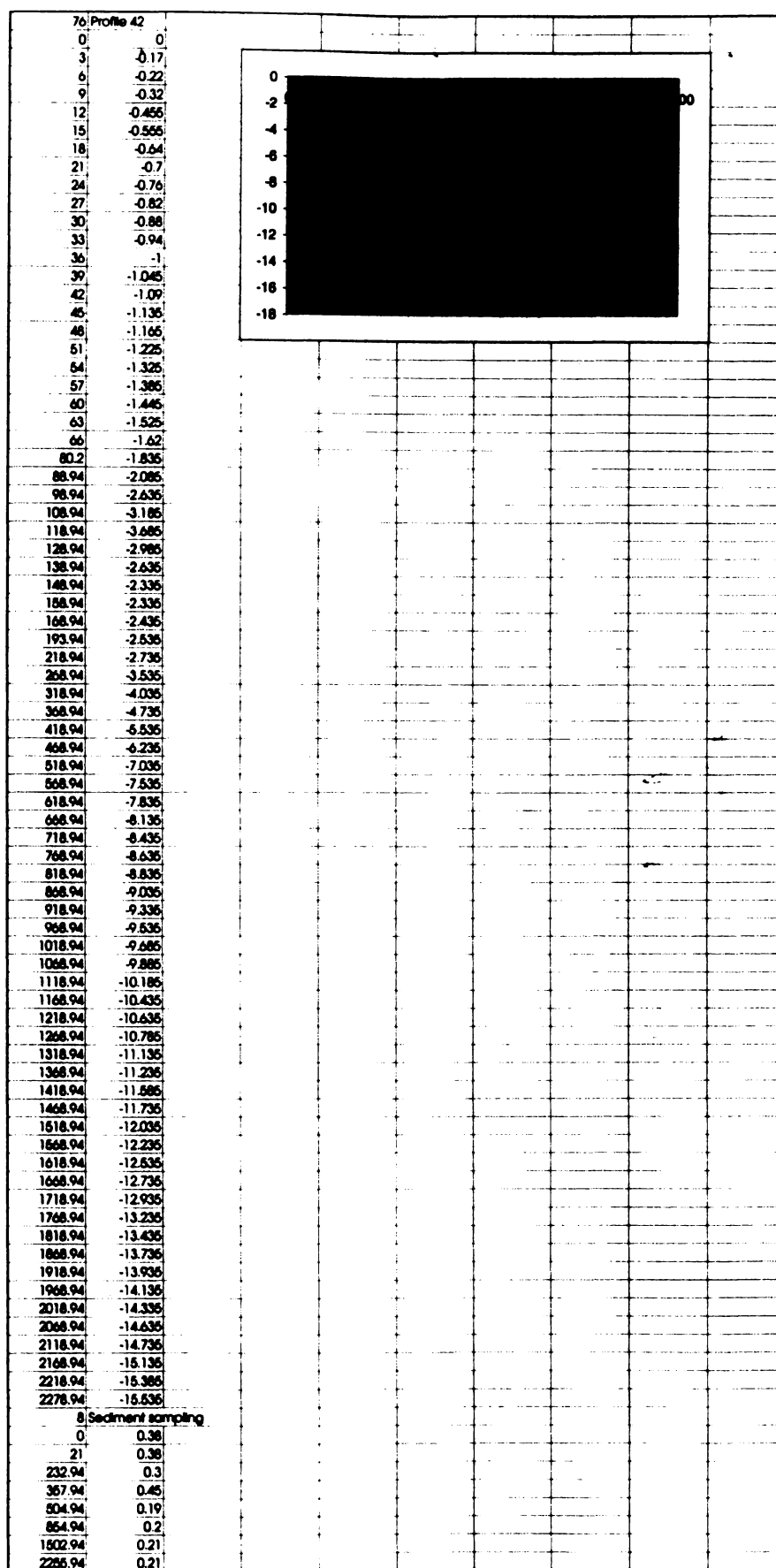


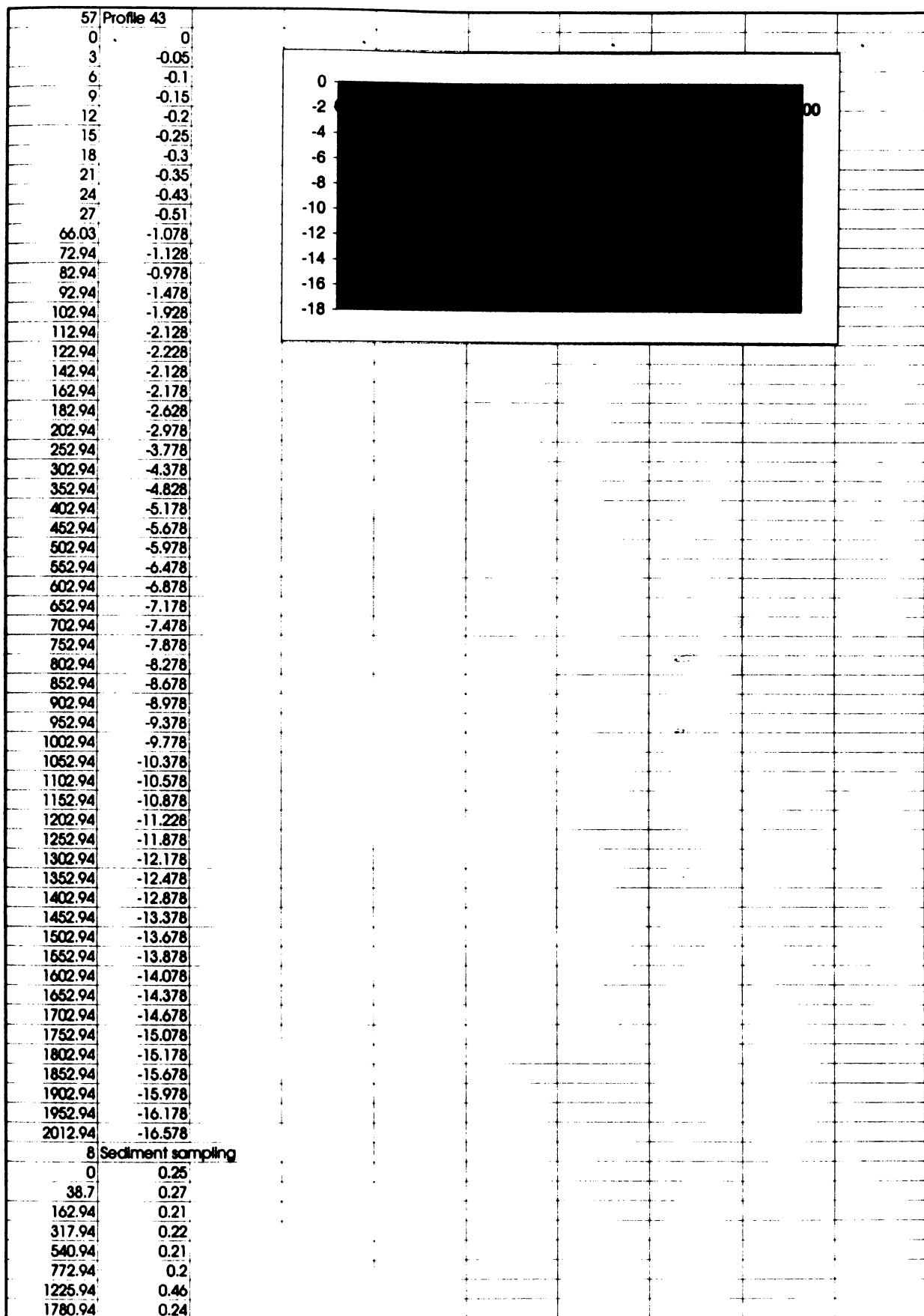


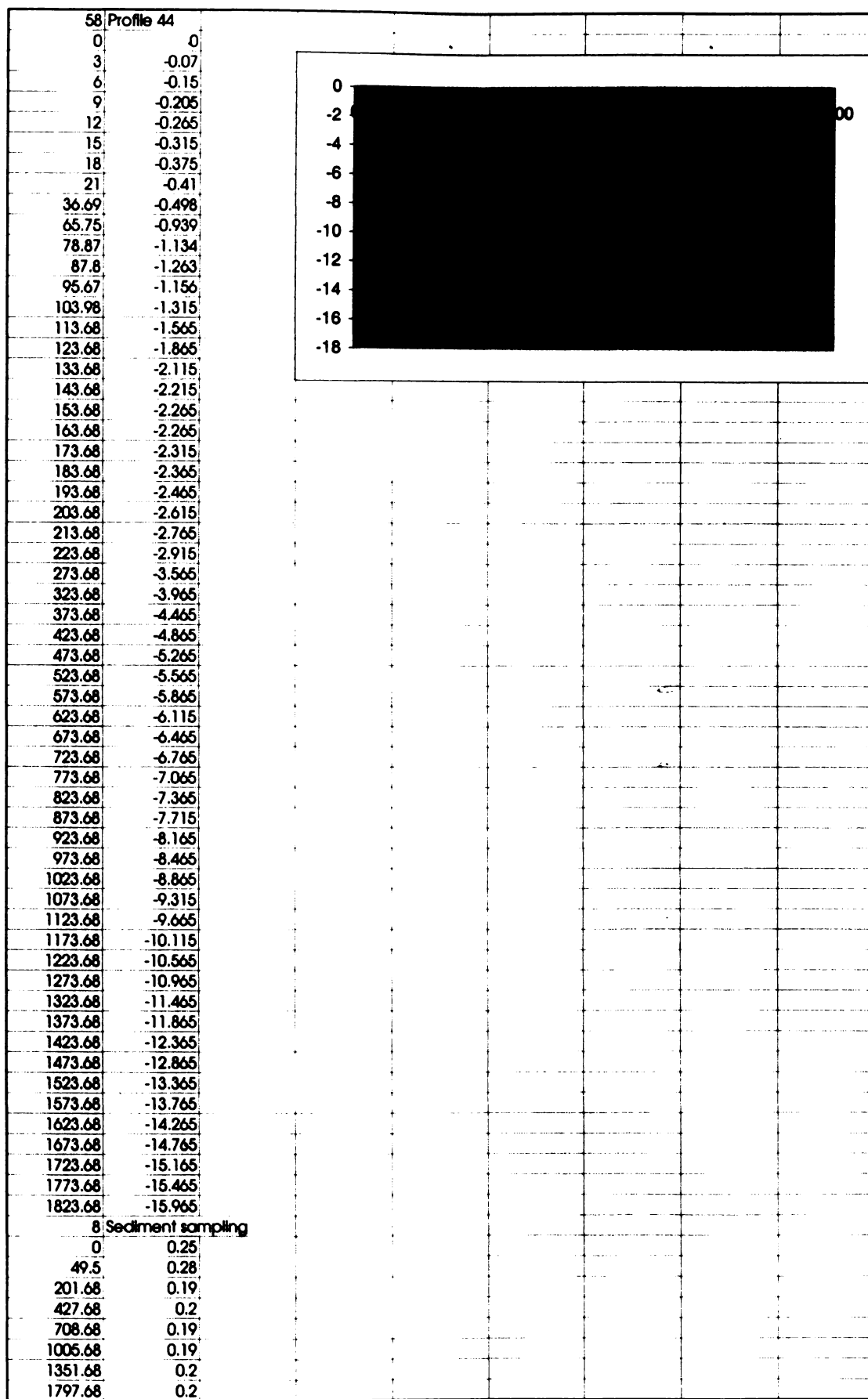


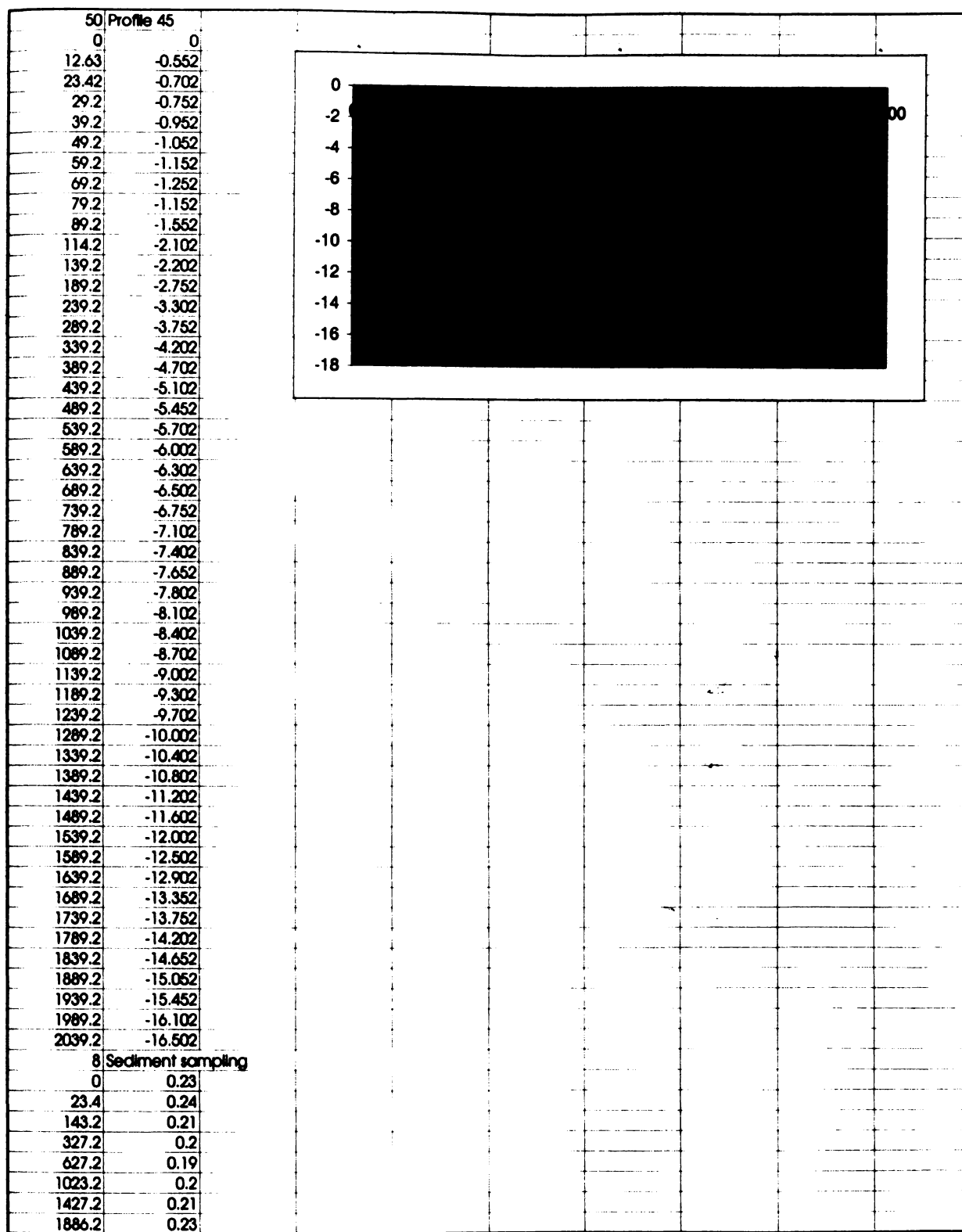


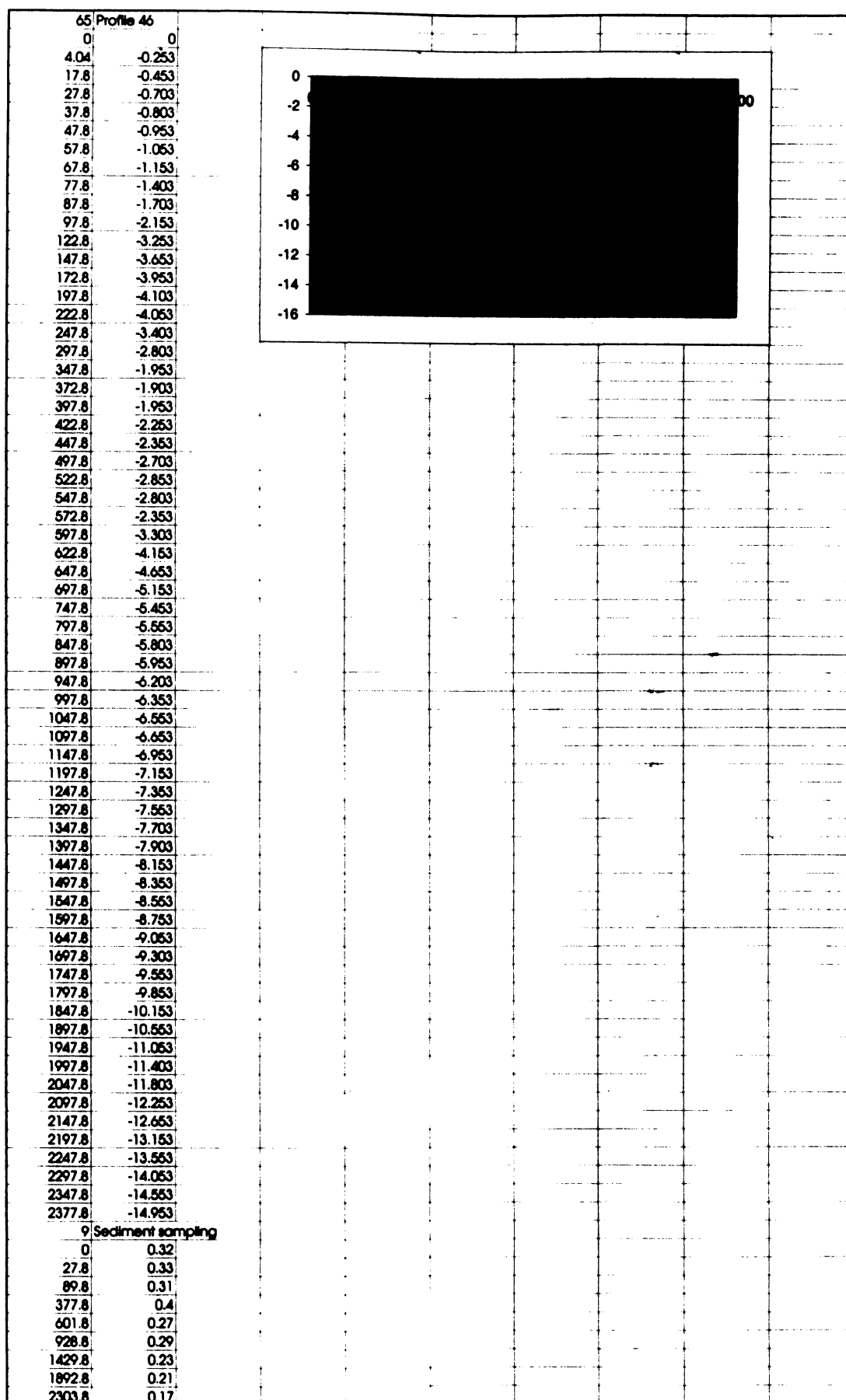
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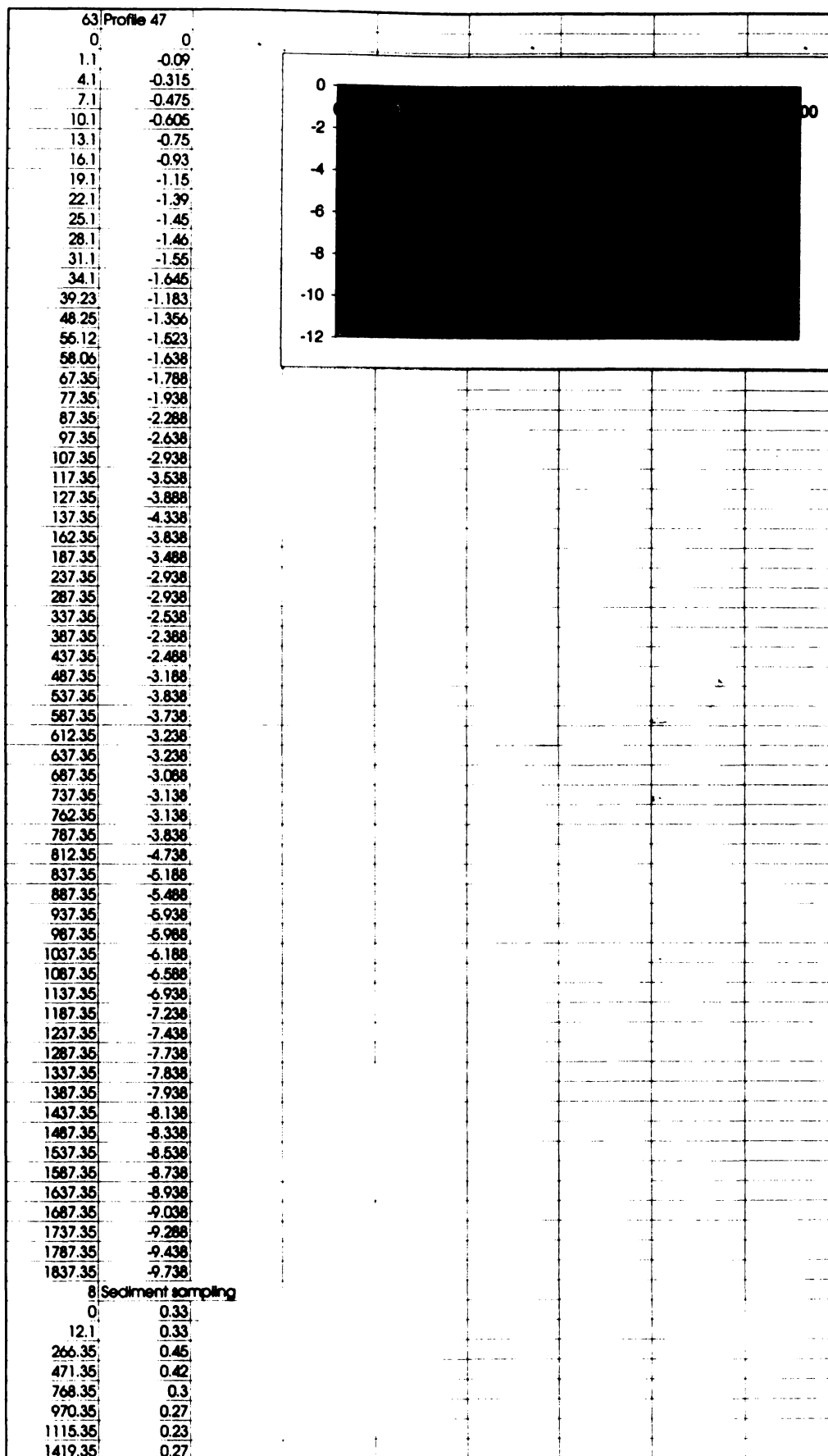




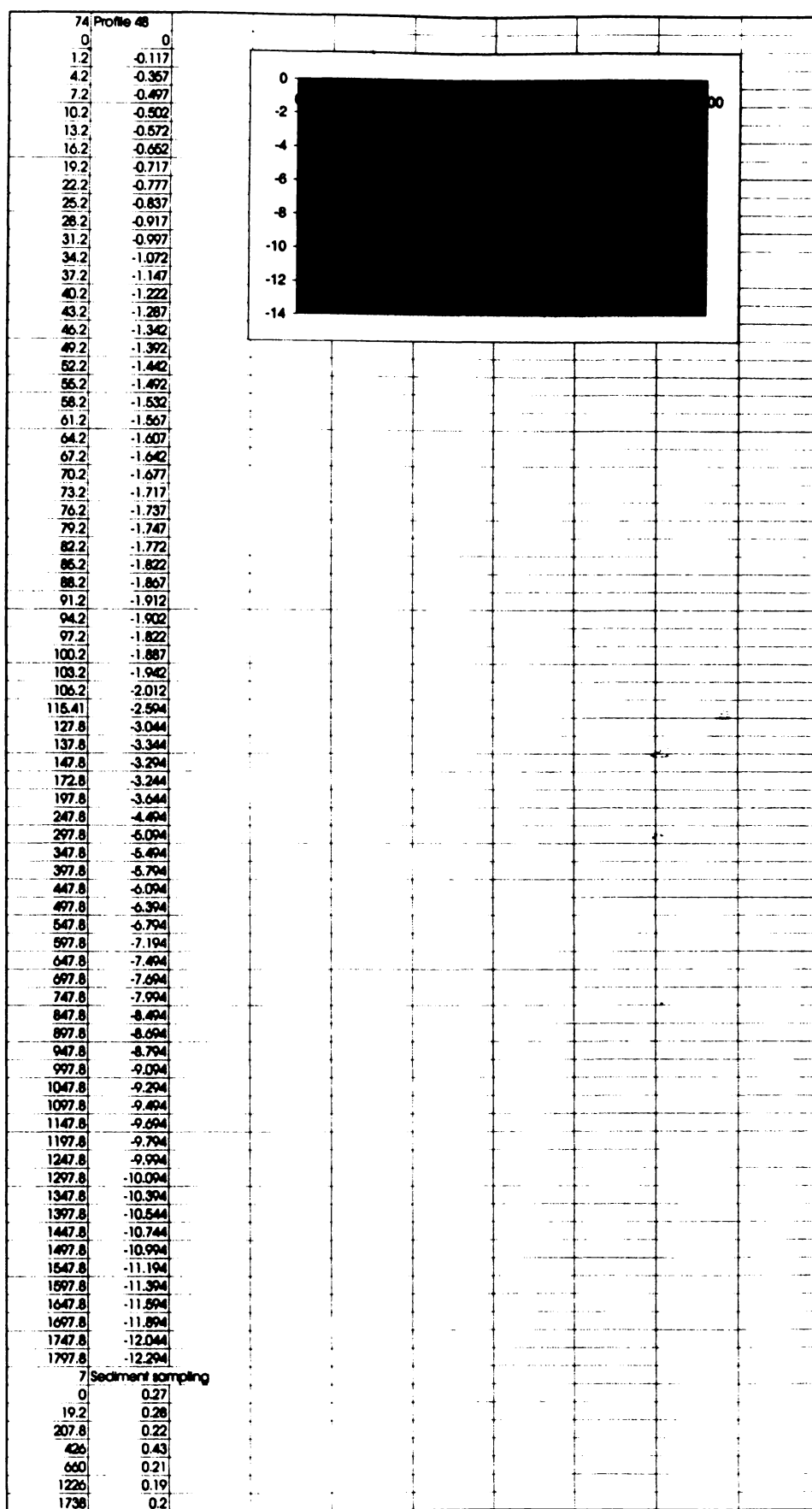


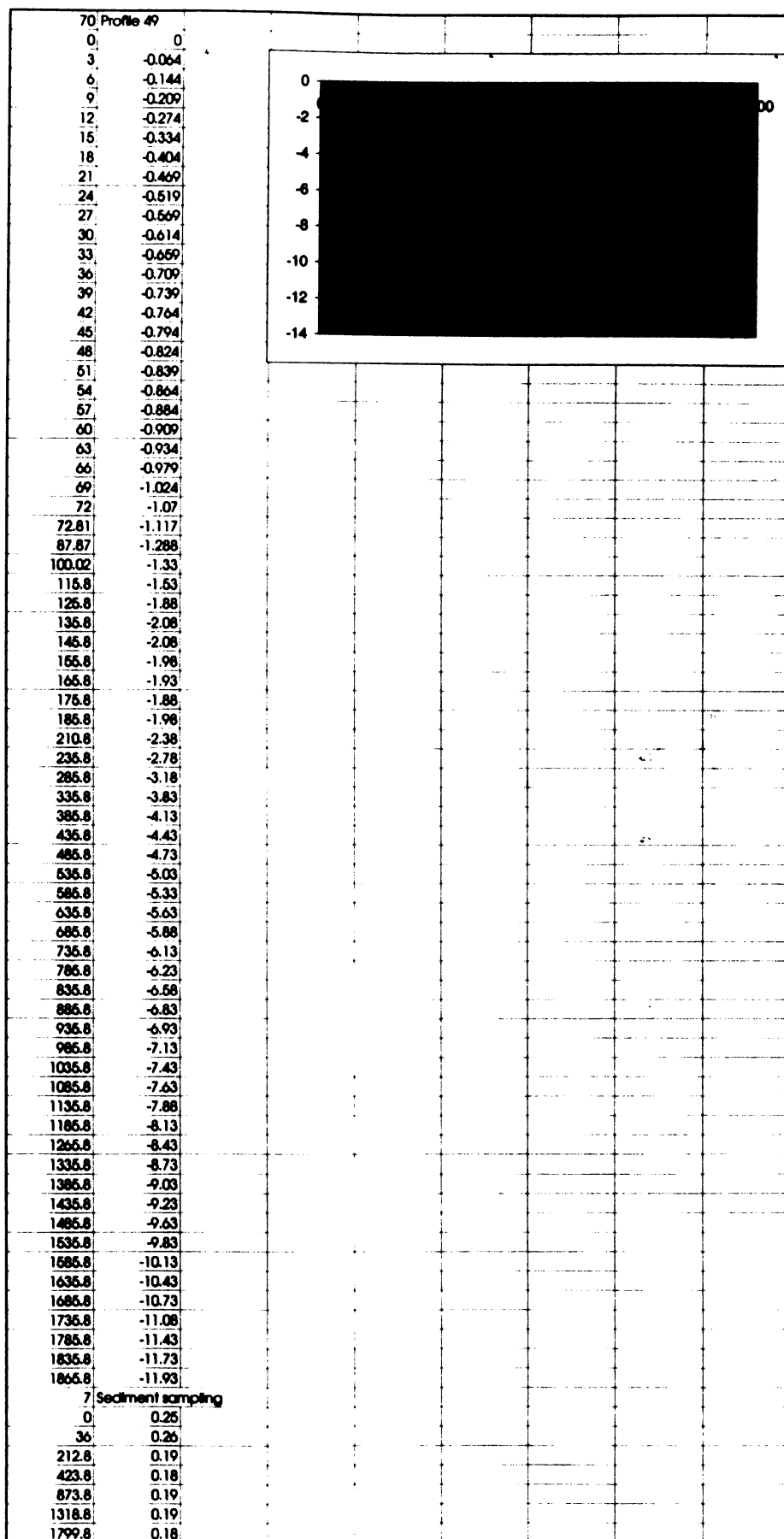




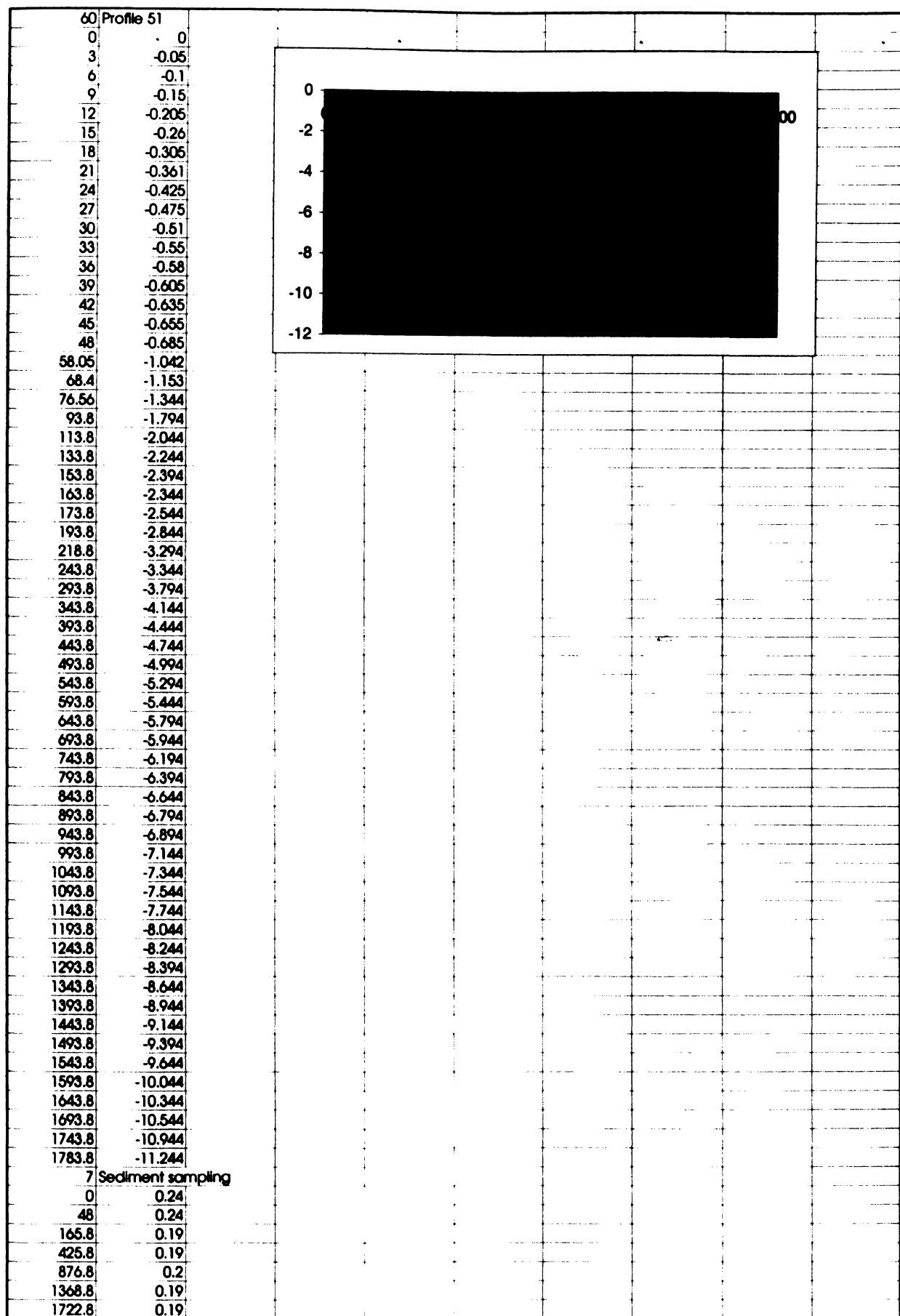


48





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Appendix 3

Summary Table and MATLAB Plots showing Closure
Depth Estimates

Appendix 3 – Notes

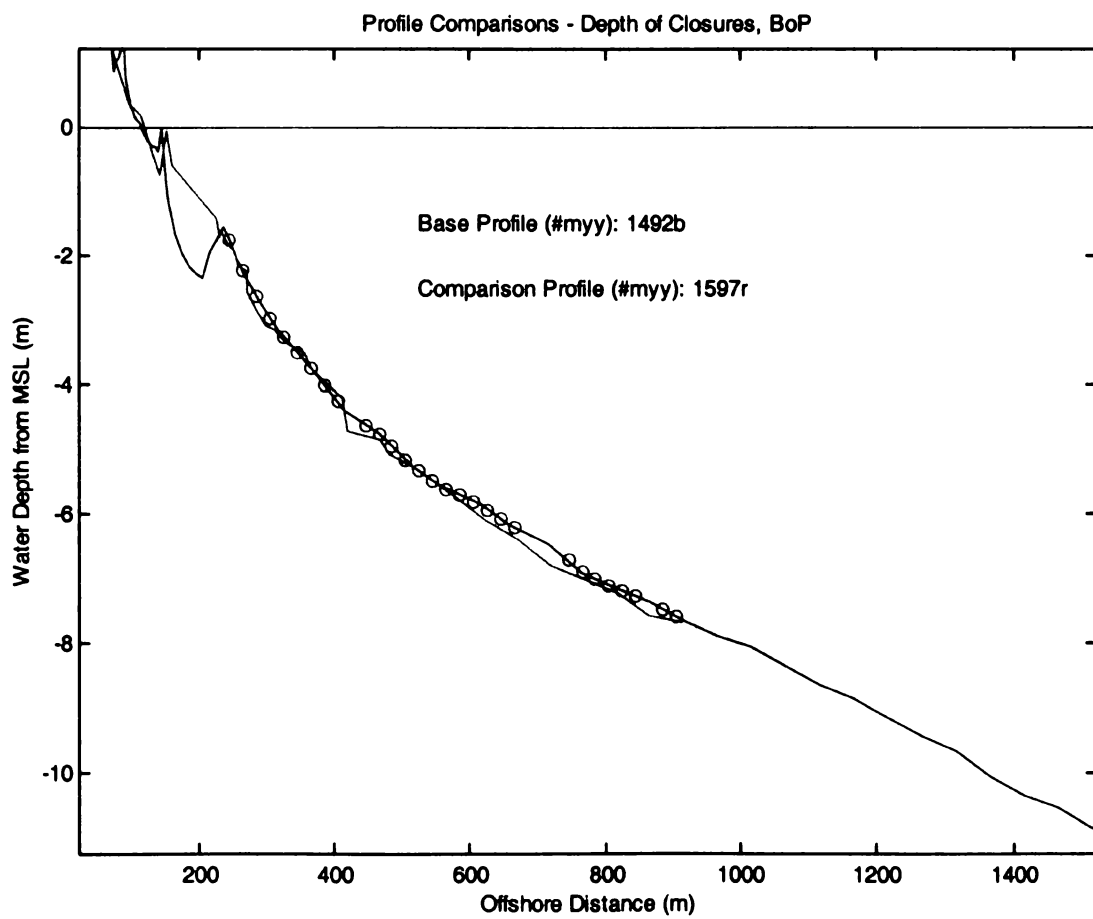
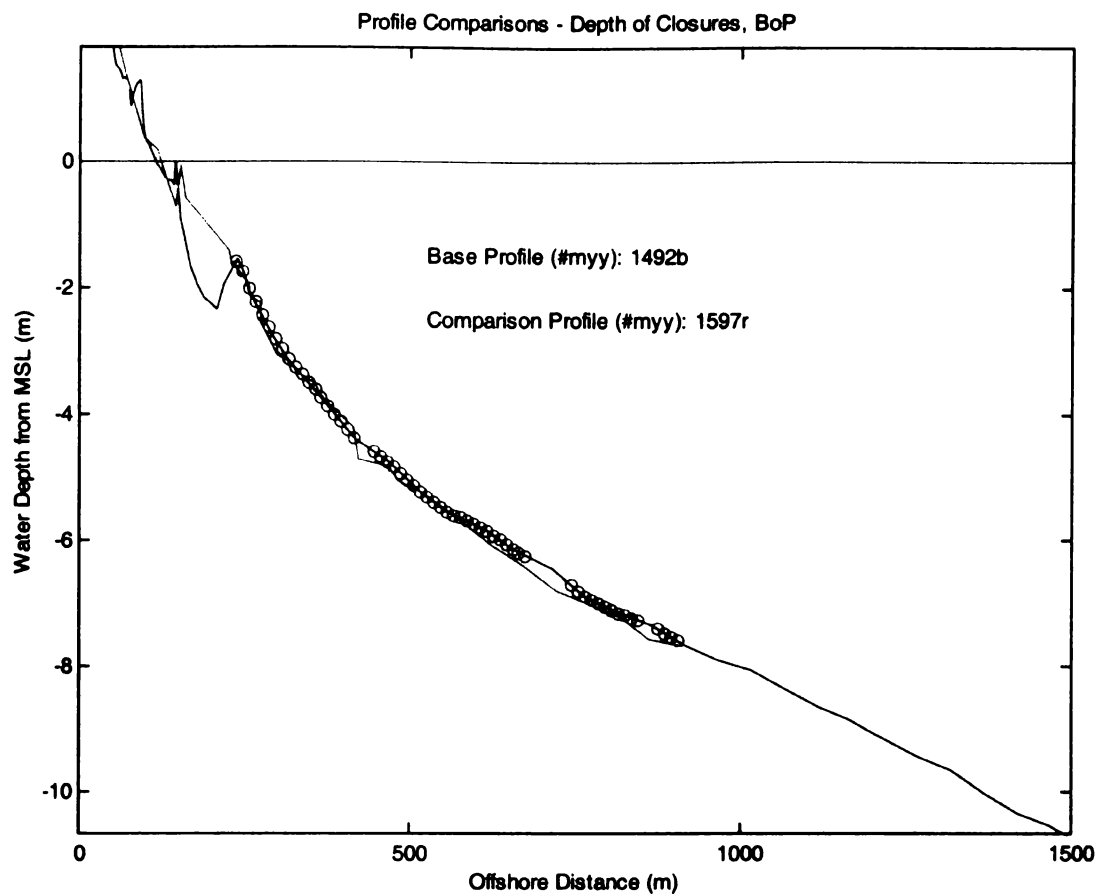
Appendix three contains a summary table of closure depth analysis for all profiles together with profile plots for all monitoring sites. Green circles demonstrate where the two profiles are coincident indicating potential closure depths. The profile number and date of survey are shown on the plots. For example 10597 indicates profile no. 10, surveyed in May 1997.

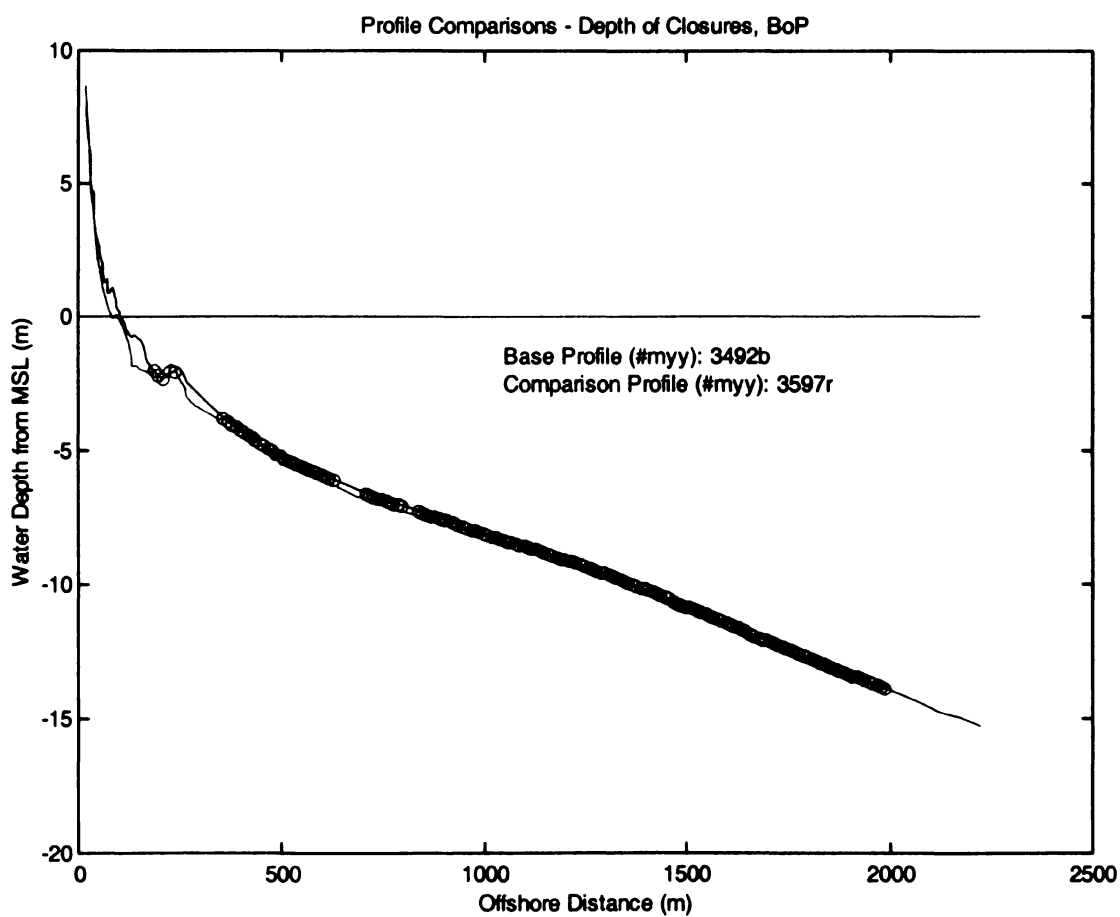
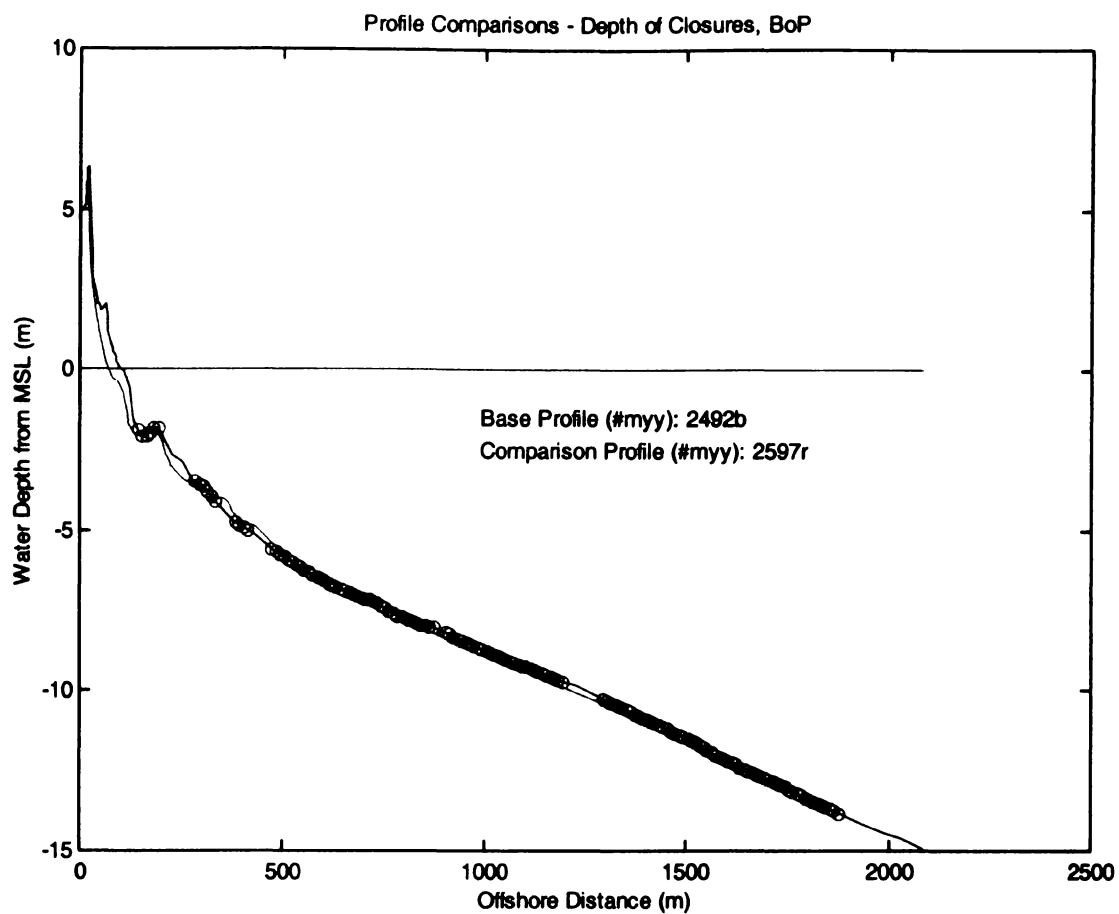
Profile No.	Dates of profile surveys (m/y)	Estimated Depth of Closure (m)	Depth of change in slope (m)	Profile Convergence with depth	Comment
Oape to Ohope					
1	4/92 6/97	4-6	7	Y	Profiles Converge
2	4/92 6/97	4	7	N	Parallel profiles indicate minor overestimation of closure depth.
3	4/92 6/97	4-6	7	N	Parallel profiles indicates minor overestimation of closure depth
4	4/92 6/97	Indeterminable		N	Parallel profile
5	4/92 6/97	6	6-7	Y	Profiles converge
6	4/92 6/97	Indeterminable		N	Parallel profile
7	4/92 6/97	8 & 12	7-8	Y	Profiles converge at depth – possible outer Hallermeier Limit?
8	4/92 6/97	Indeterminable		N	Ebb tidal delta?
9	4/92 6/97	Indeterminable		N	Ebb tidal delta?
10	4/92 6/97	5	7	N	
10	4/92 6/97	Indeterminable	8	N	3 profiles available No change in profile form
11	4/92 6/97	4 & 14	6	Y	Profiles converge at depth – possible outer Hallermeier Limit?
11	4/92/ 5/97	4 & 14	6	Y	
Average for Profiles in section		5	7		
Whakatane Spit to Pukehina					
12	4/92 5/97	6	7		Pronounced change in profile slope evident – profiles steeper than previous section

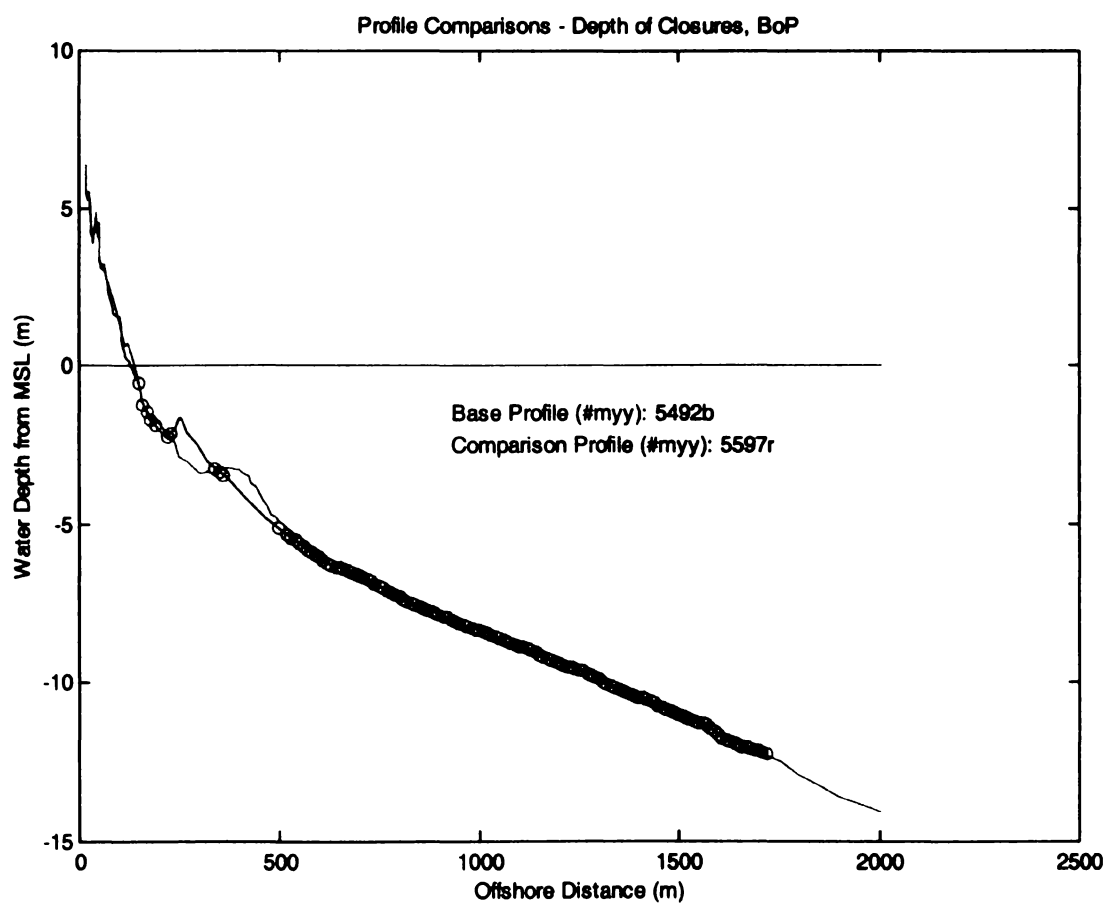
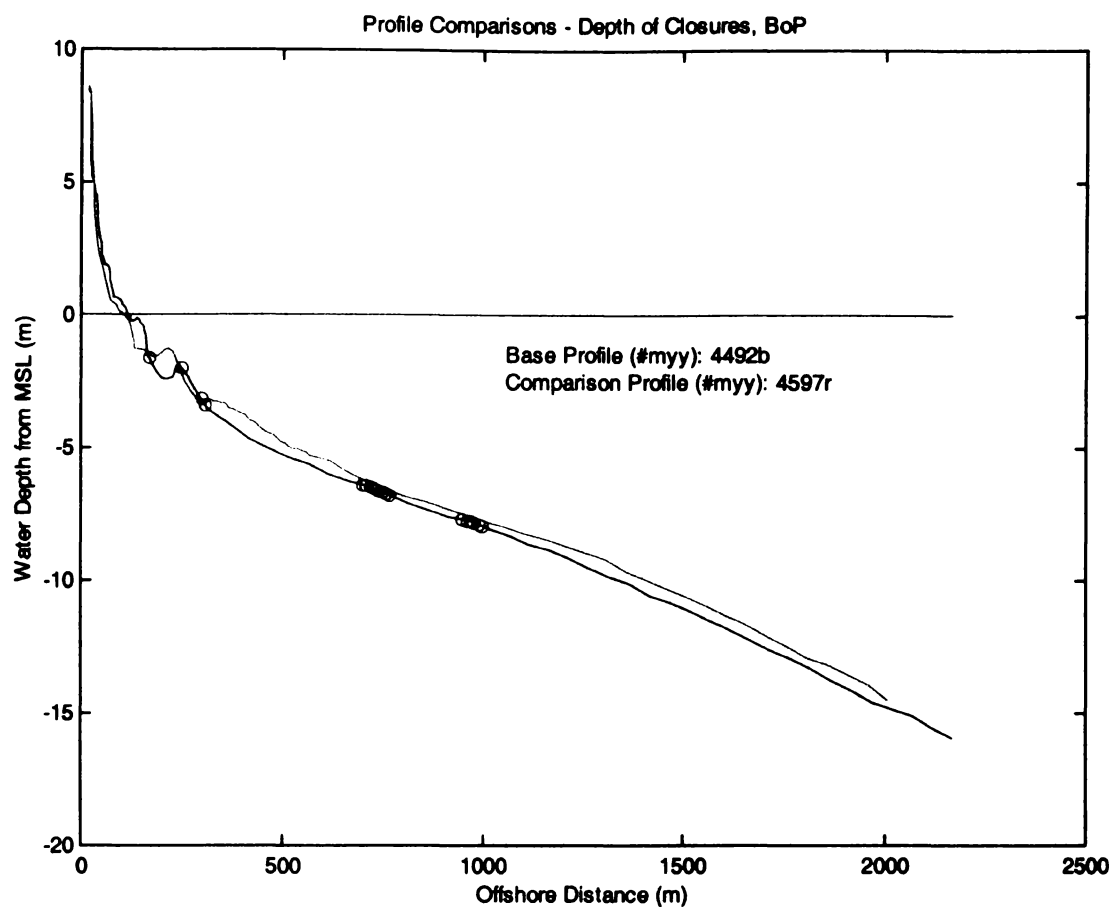
13	4/92 5/97	10	10	Y	Pronounced change in slope evident. Major bar development at 5m depth possibly from effects of cyclones Fergus, Drena, and Gavin
14	4/92 5/97	8.5	9	N	Profiles converge then strongly divergent below 14m in depth – suggests that either parts of the profile or whole profile line not coincident
15	4/92 5/97	6	8	N	Profiles parallel at depth
16	4/92 5/97	8	9	Y	
17	4/92 5/97	5	9	N	Minor coincidence of profile lines possible
20	4/92 5/97	4	4	N	Minor coincidence of profile lines possible
22	4/92 5/97	5	7	N	
23	4/92 6/97	Indeterminate	9	N	Profiles strongly divergent and separated in depth
24	4/92 6/97	5.5	8	Y	
25	4/92 6/97	6	8?	Y	Second bar evident at 5m
26	4/92 6/97	5 & 14	6	Y	
27	4/92 6/97	7 & 12	7	Y	
28	5/92 6/97	6 & 11.5	8	Y	
29	5/92 6/97	6	6	Y	
30	5/92 6/97	6	6	Y	
Average for Profiles in section		6	8		
Maketu Spit to Mt Maunganui					
32	5/92 6/97	6	6	N	Profiles slightly divergent at depths greater than 10m

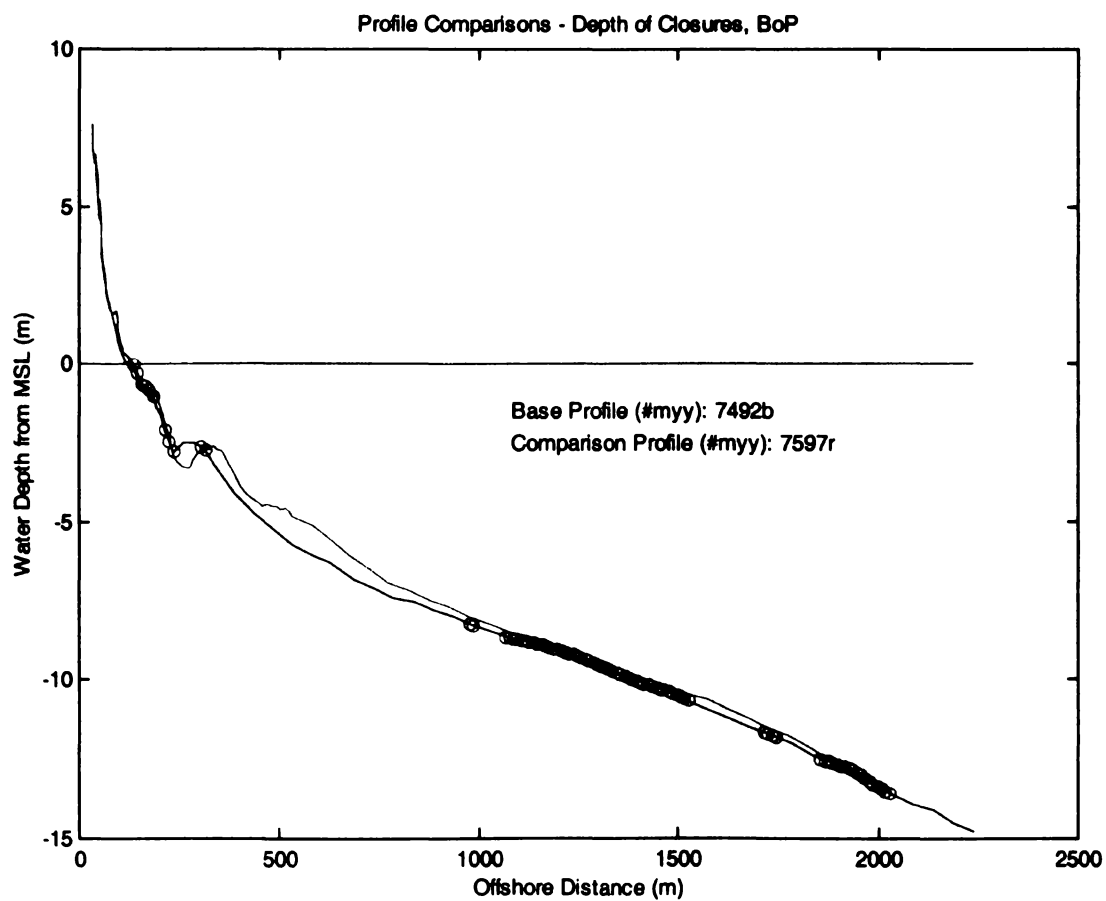
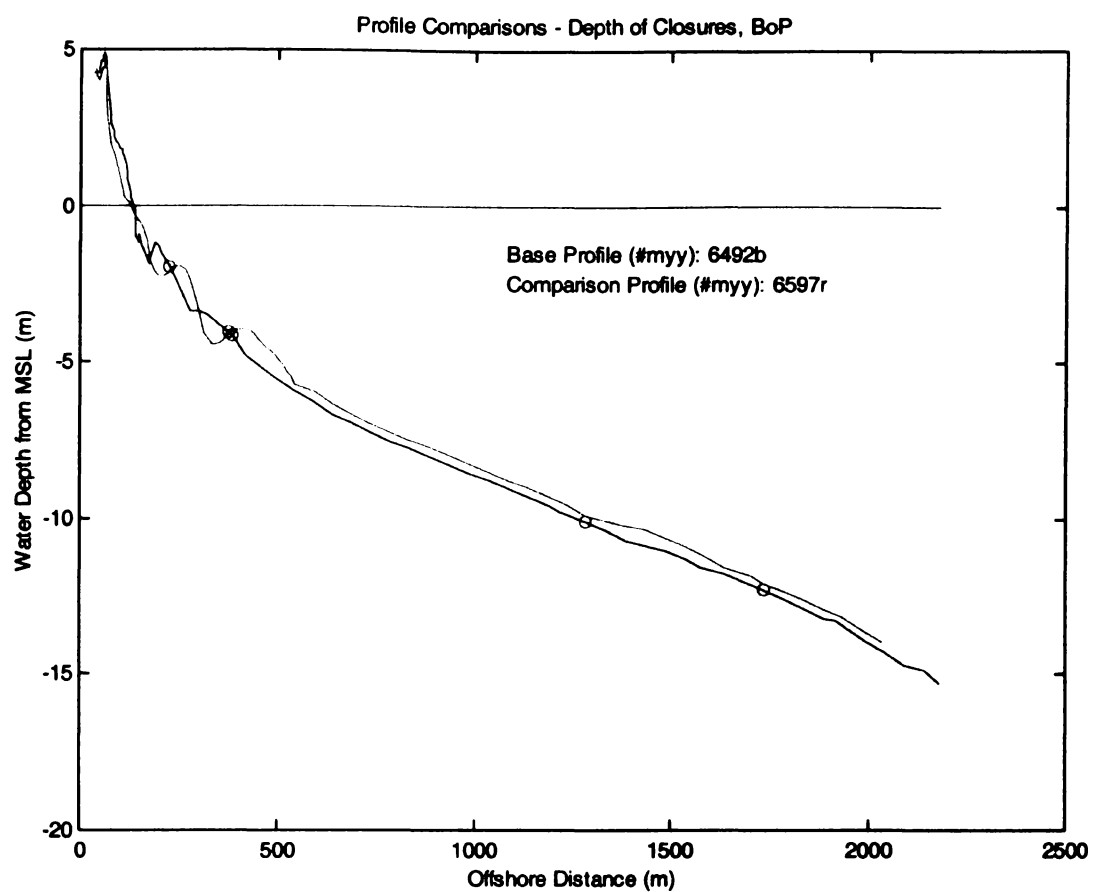
34	5/92 6/97	5-7	5	No	
35	5/92 6/97	Indeterminate	6	No	Profiles strongly divergent – suggests non coincidence of profiles
36	5/92 6/97	6	6-8	N	
38	5/92 6/97	5	6	N	Profiles strongly divergent at depth – suggests that survey diverges offline from 700m offshore
39	5/92 6/97	5	5	N	Profiles strongly divergent below depths of 6m and strongly convex below this depth
40	5/92 6/97	5-6	10	N	No significant difference in profiles – Parallel profile could indicate slight profile divergence.
Average for Profiles in section		5.5	6.5		
Matakana Island					
43	5/92 6/97	6 & 11	7	N	Parallel profiles at depth may indicate slight divergence of survey lines especially from 1km offshore (-10m)
44	5/92 6/97	4	5-6	N	Profiles strongly divergent from 600m offshore (-6m)
45	5/92 6/97	6	8-9	N	See above
46	5/92 6/97	6	Indeterminate	N	Profile effected by ebb tidal delta, Katikati entrance
Average for Profiles in section		5.5	7		
Bowentown to Waihi Beach					
47	5/92 6/97	6	Indeterminate	N	Profile effected by ebb tidal delta, Katikati entrance
48	5/92 6/97	Indeterminate	7-8	N	No coincidence of profile – either profile has been affected by significant sediment inputs from the delta and/or profile lines not coincident
49	5/92 6/97	5?	7	N	See above
50	5/92 6/97	6?	7	N	Profiles same from 3m to 6m depth (600m offshore). Profile divergence beyond this point suggests non coincidence of profile
51	5/92	7	8	Y	

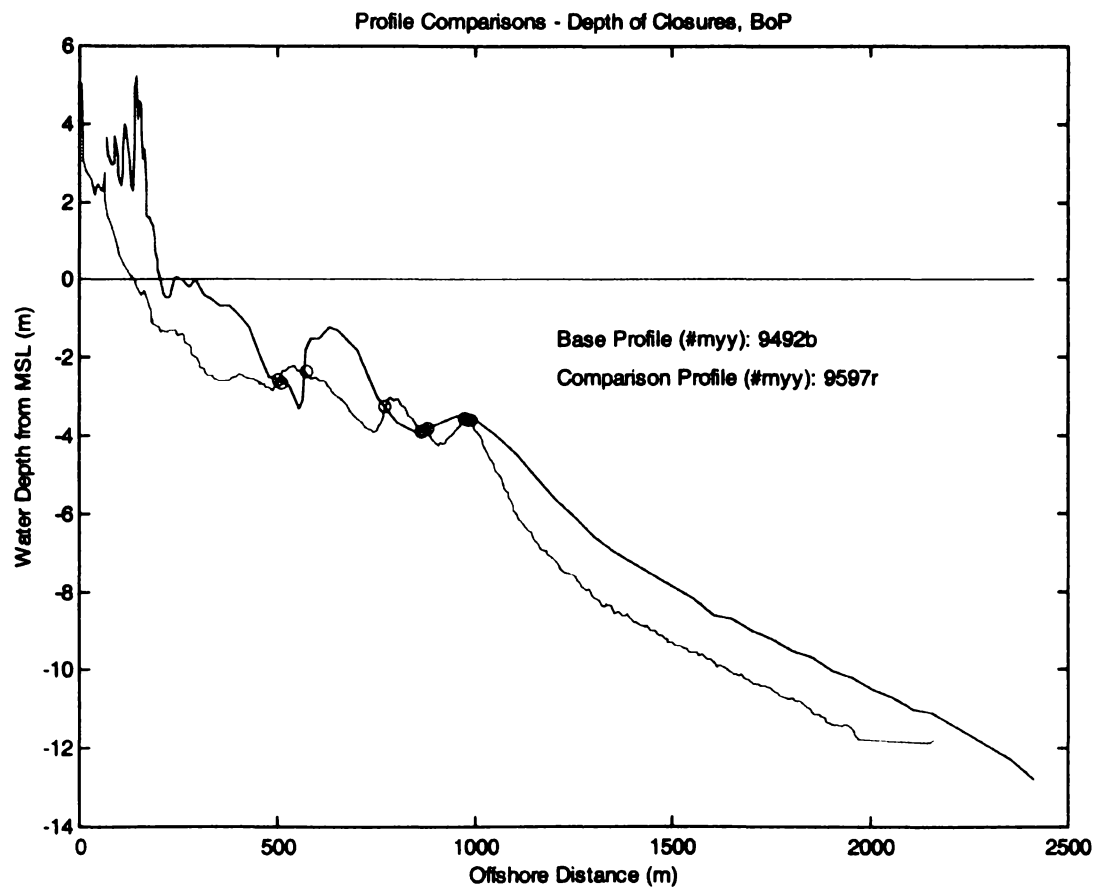
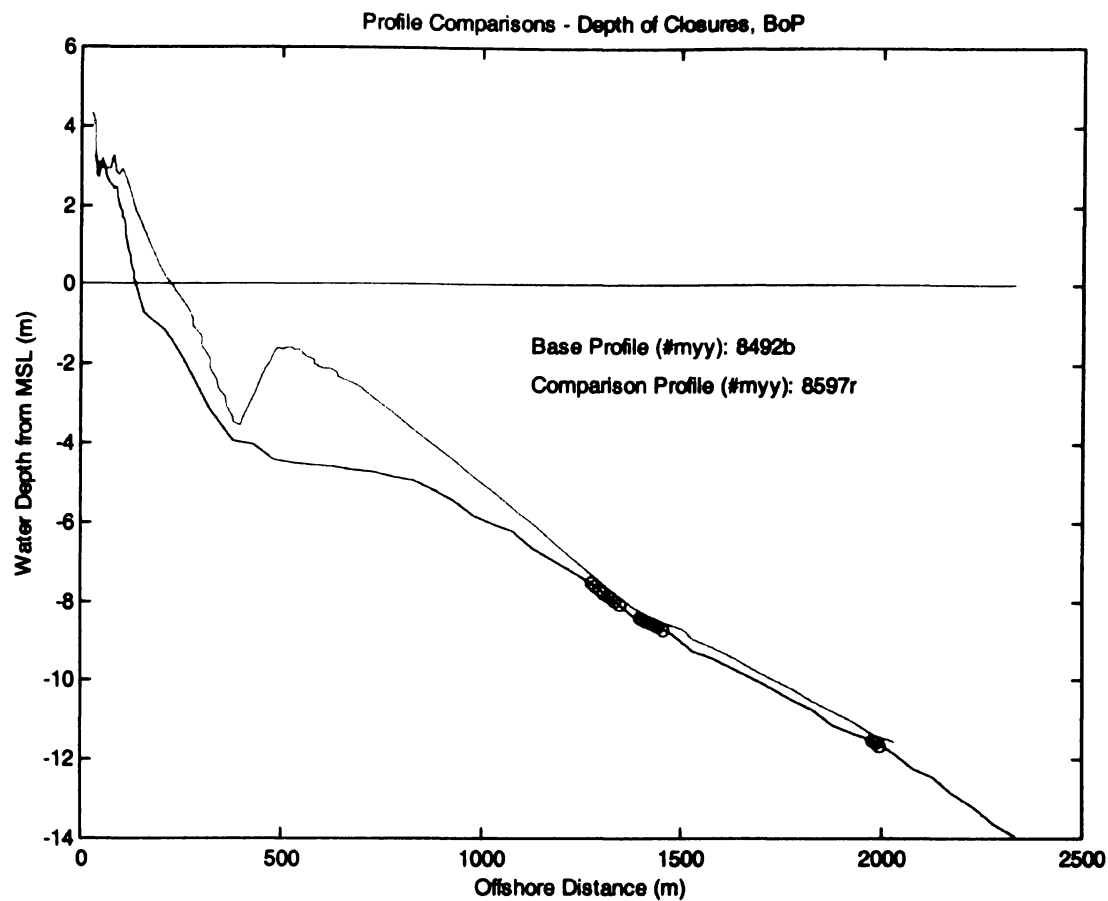
	6/97				
Average for Profiles in section		6	7		
Overall Average for BoP Coastline		5.5			

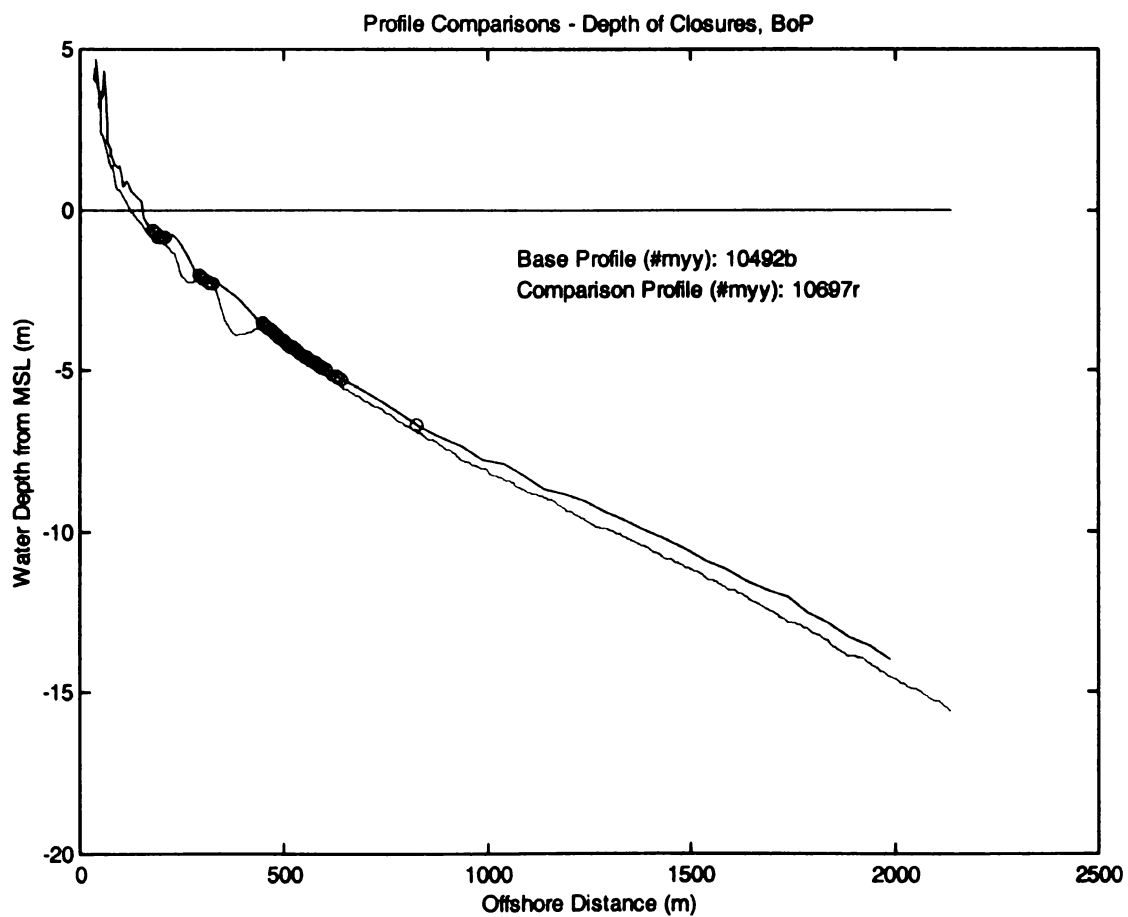
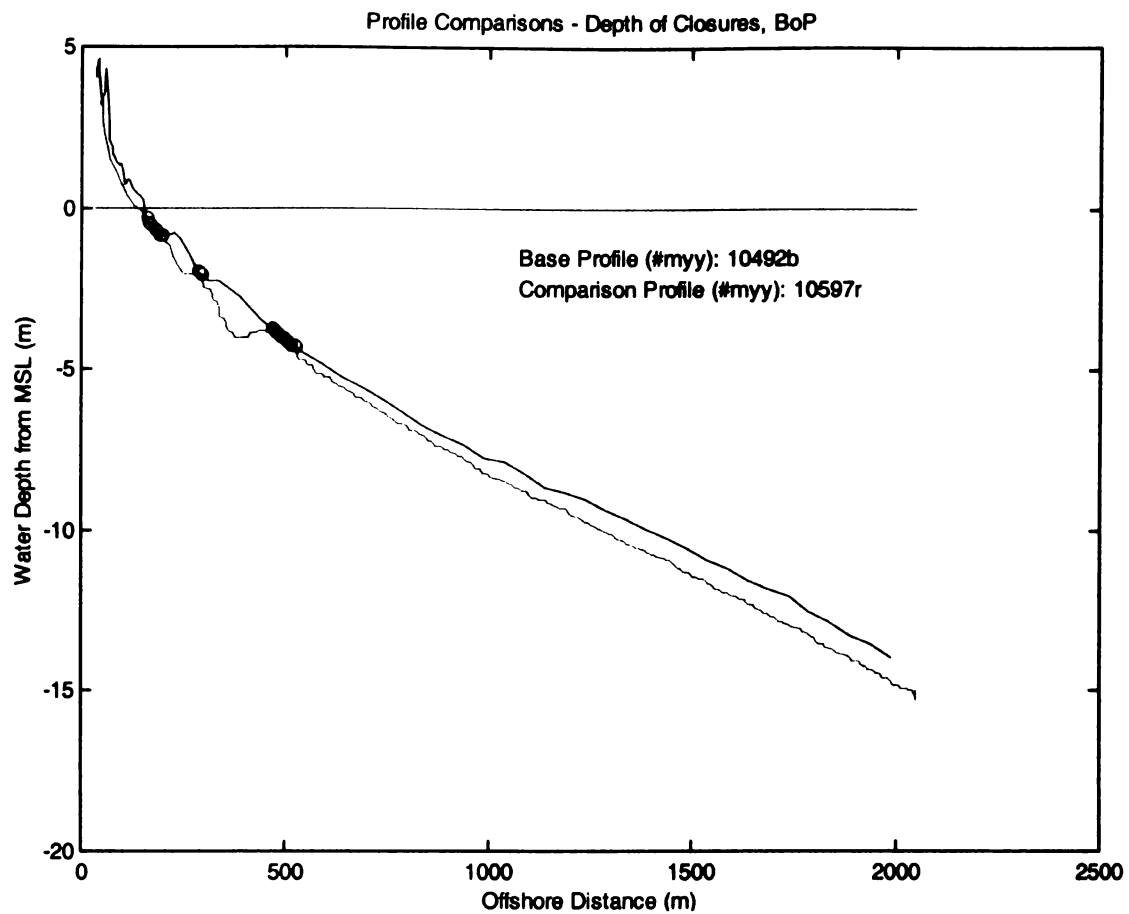


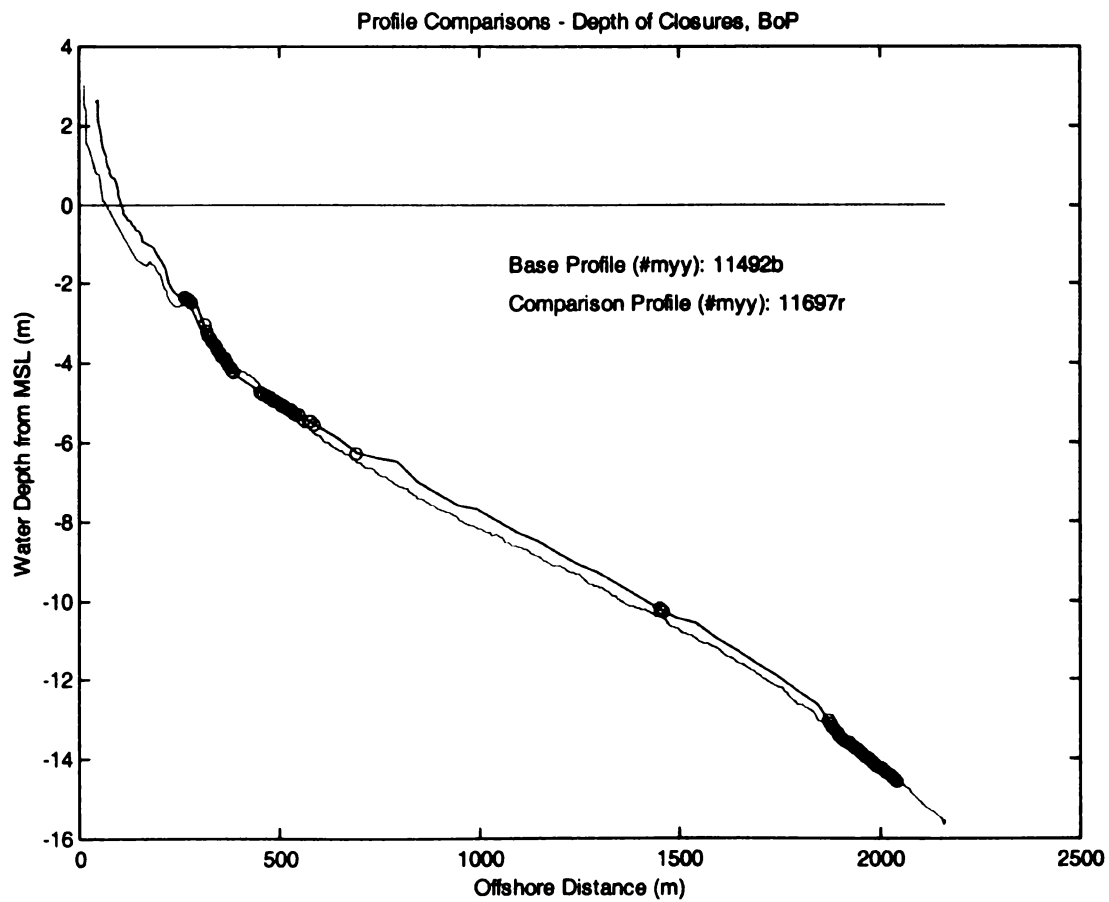
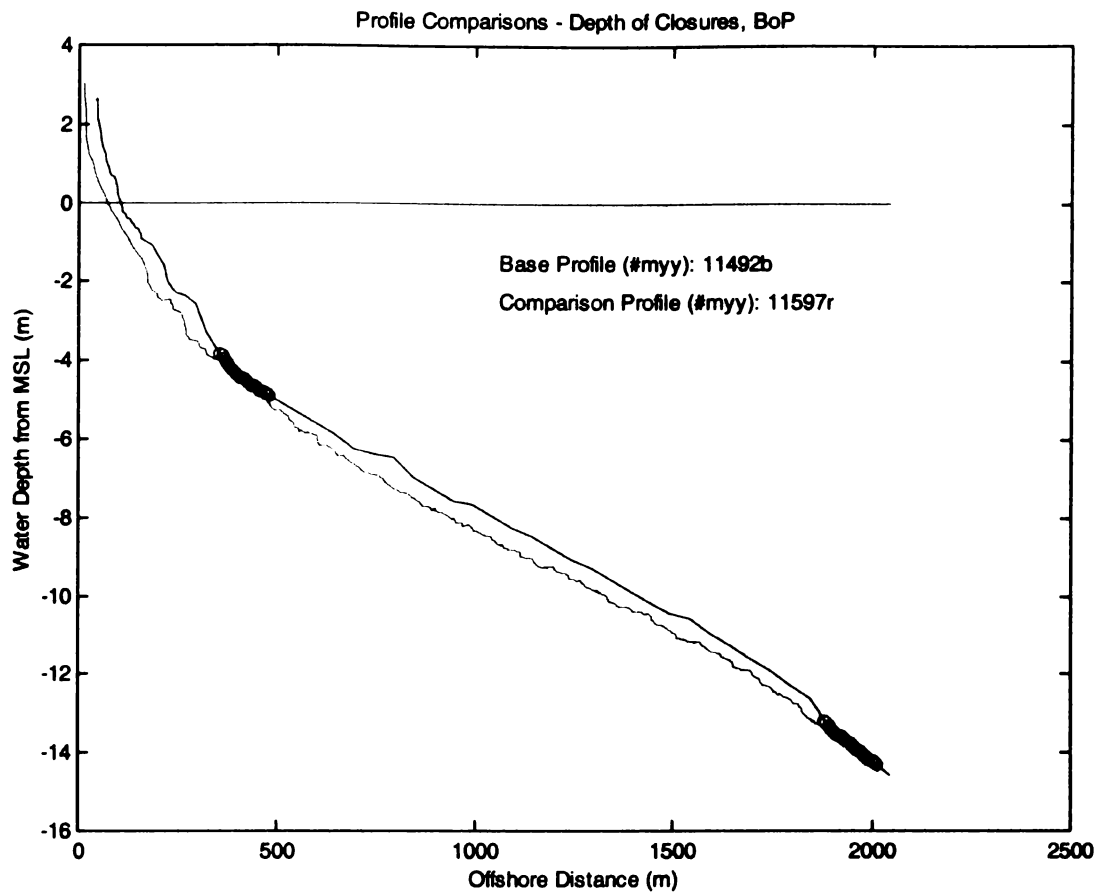


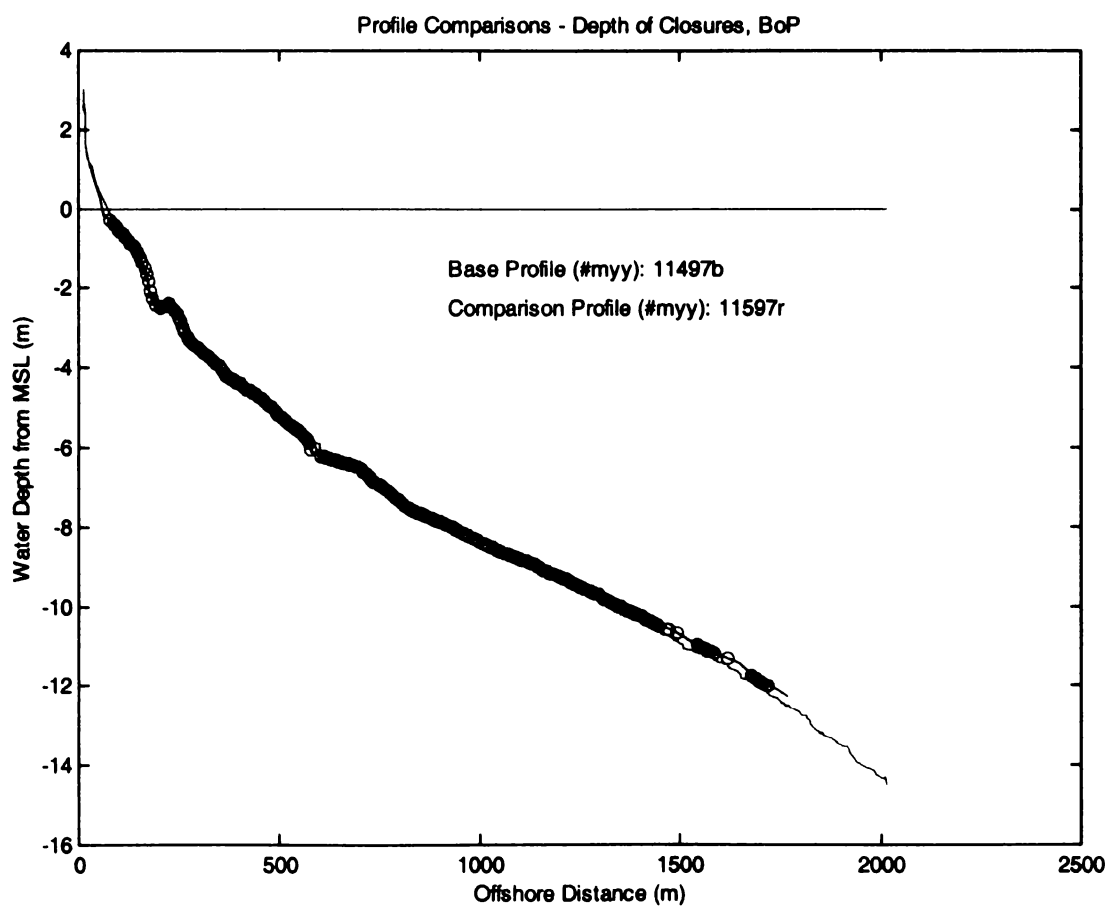
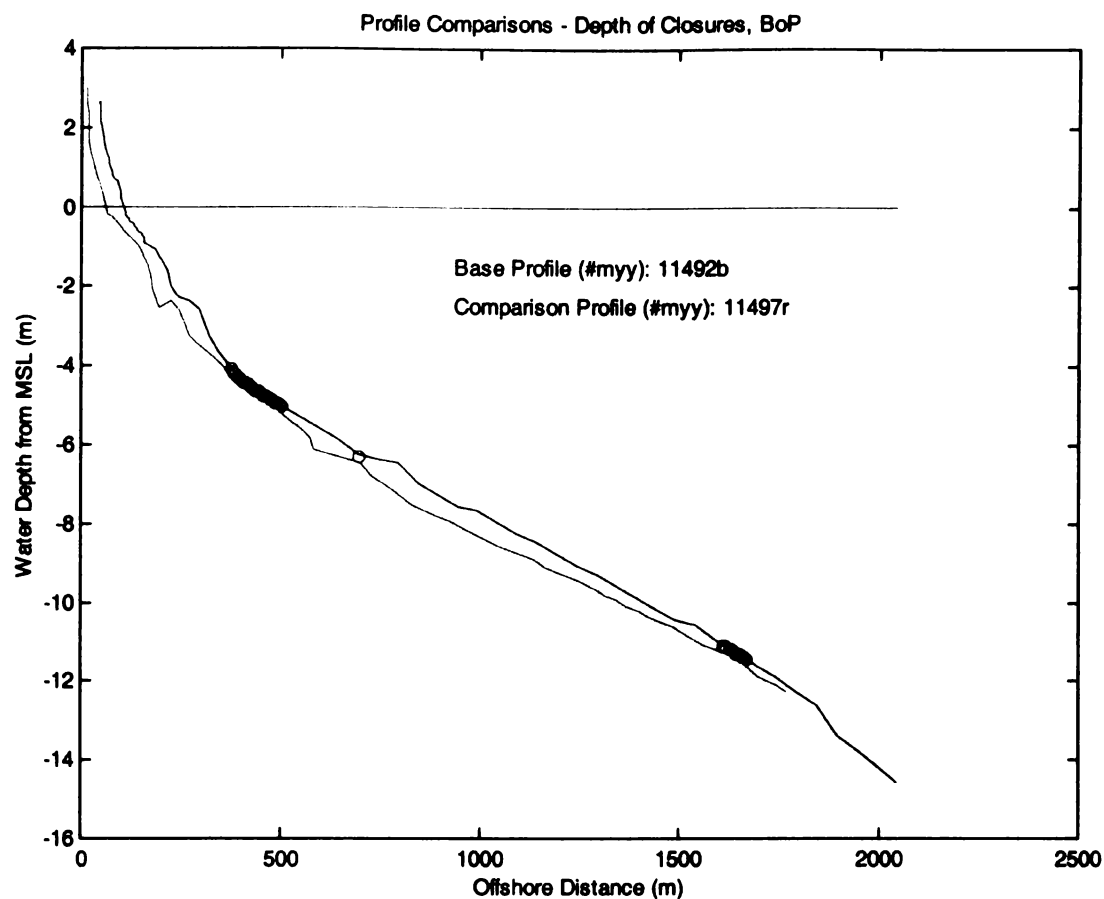


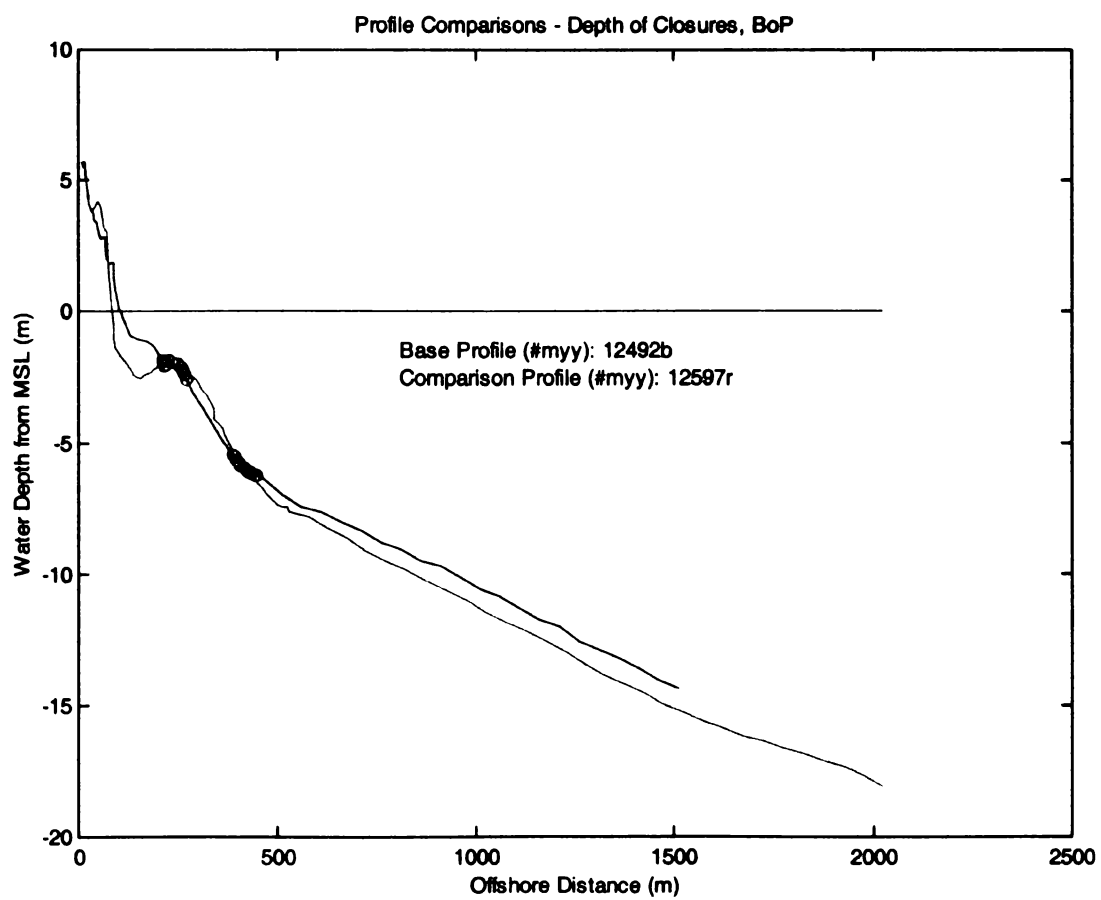
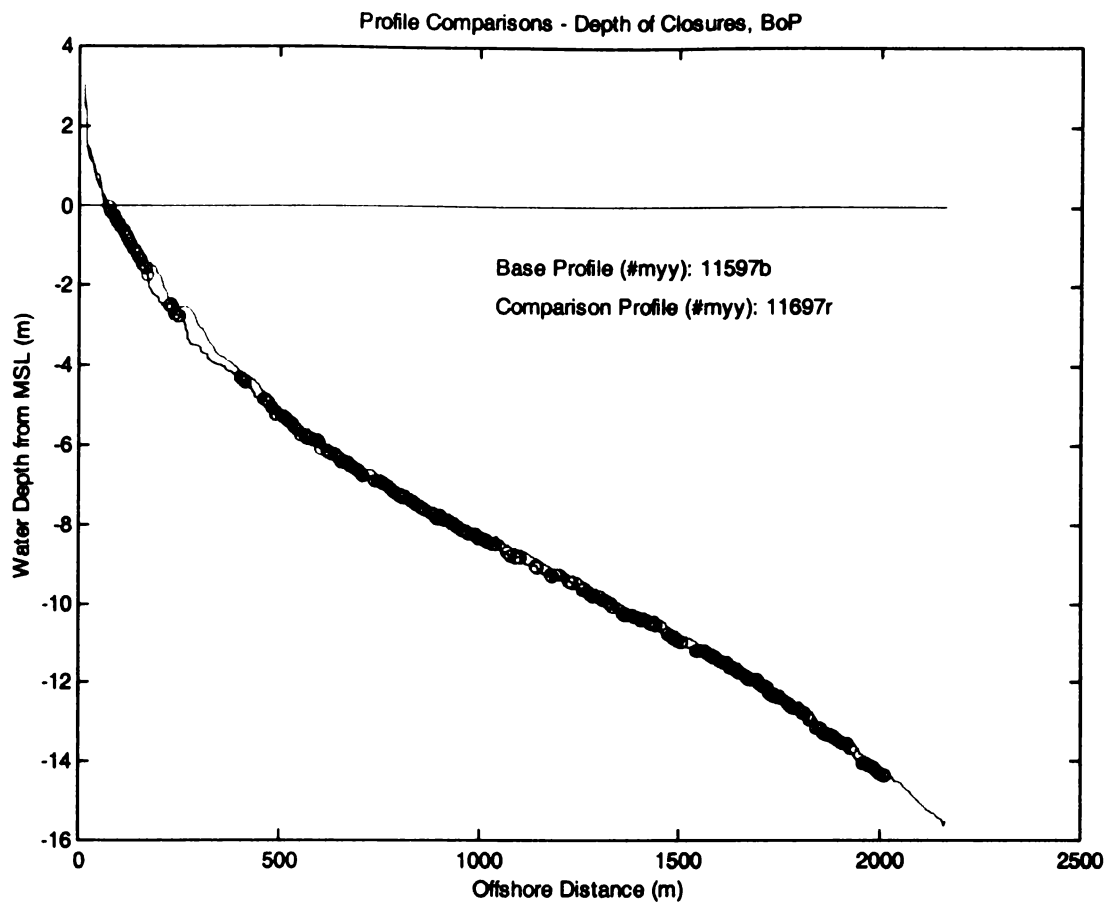


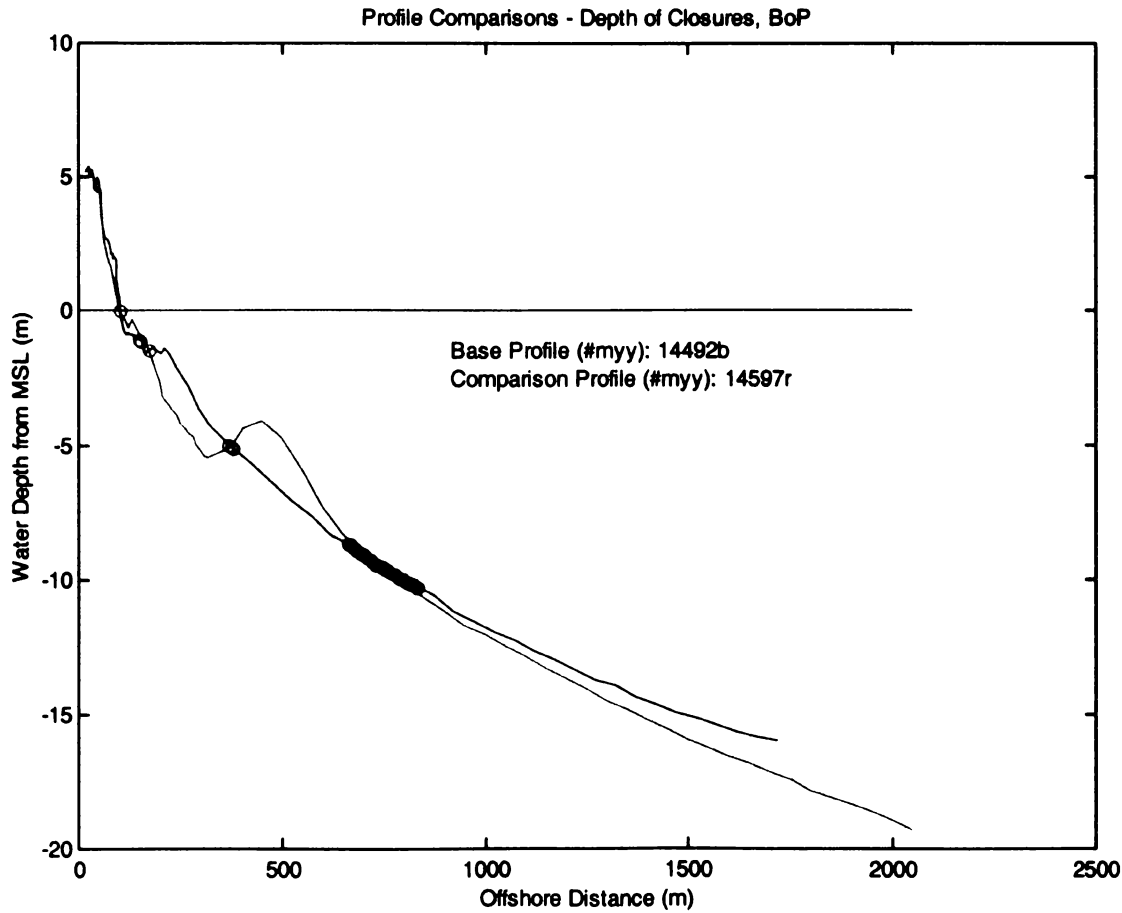
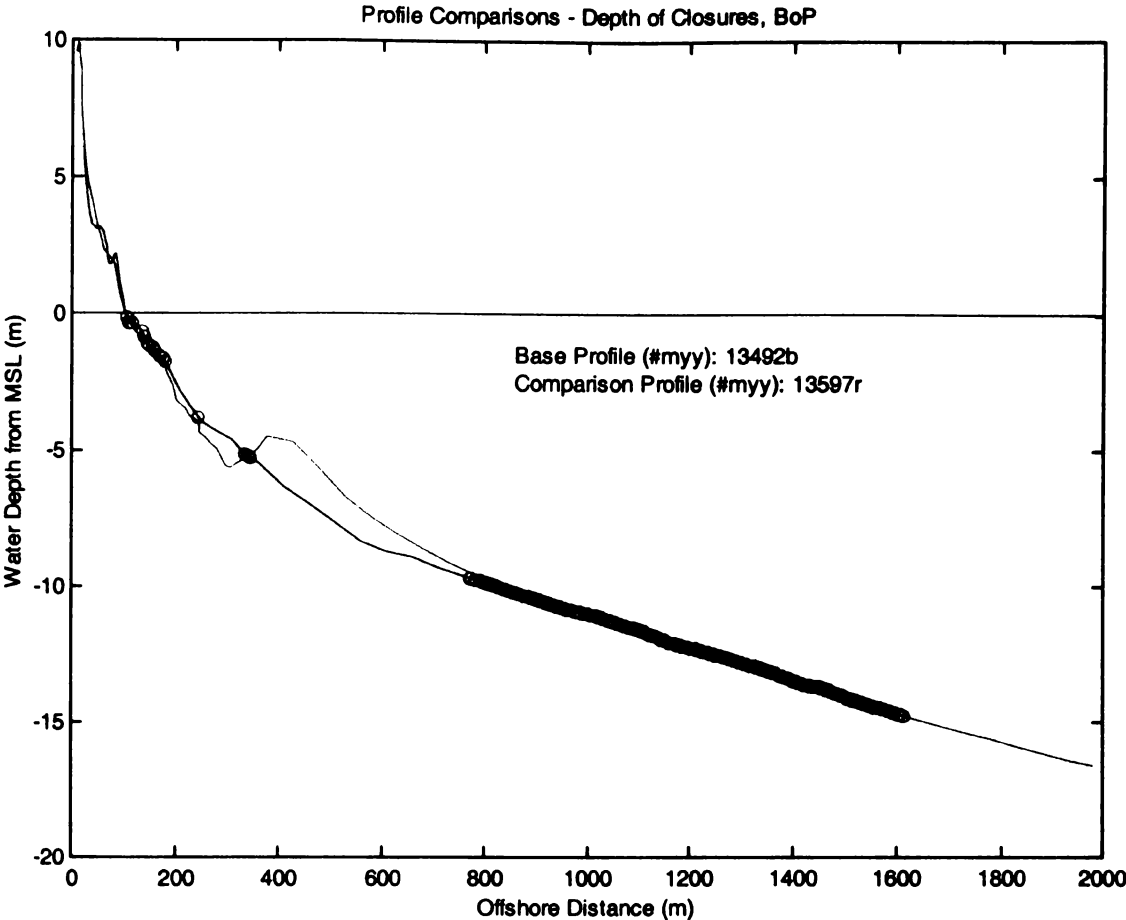


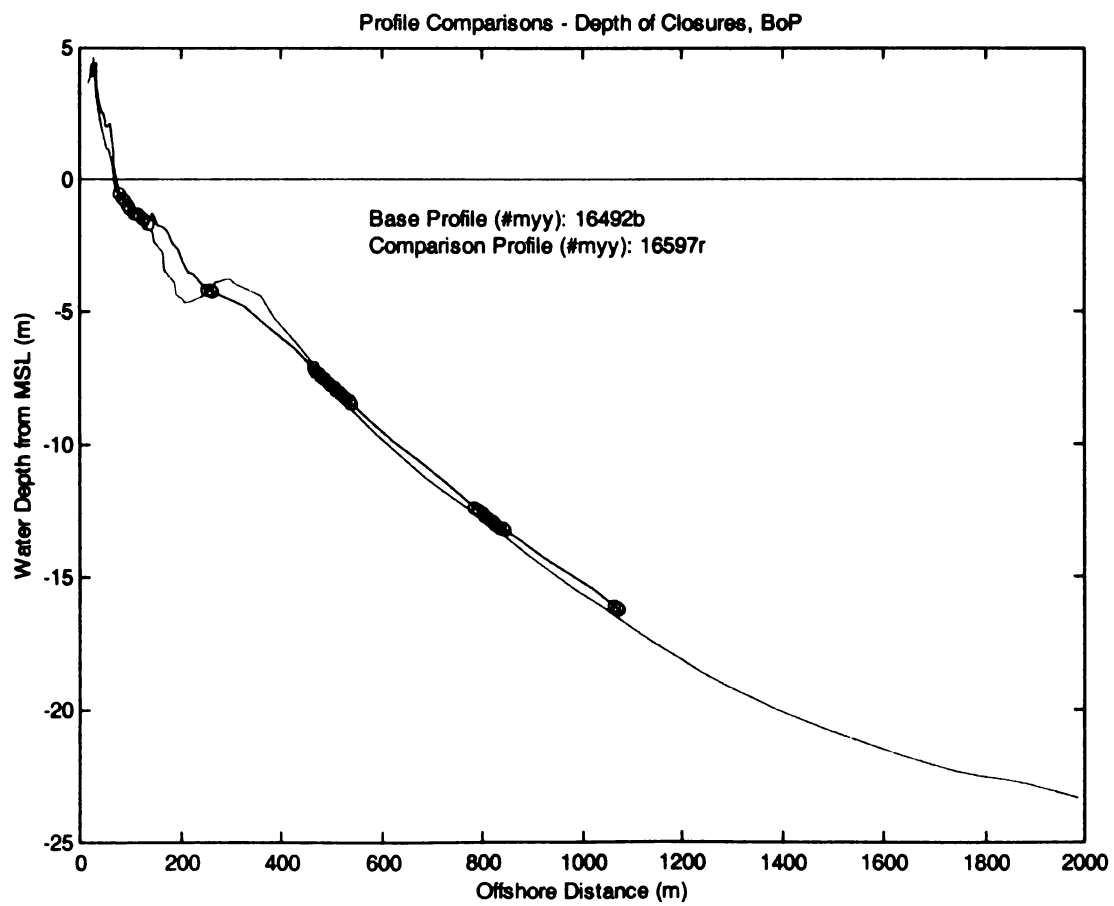
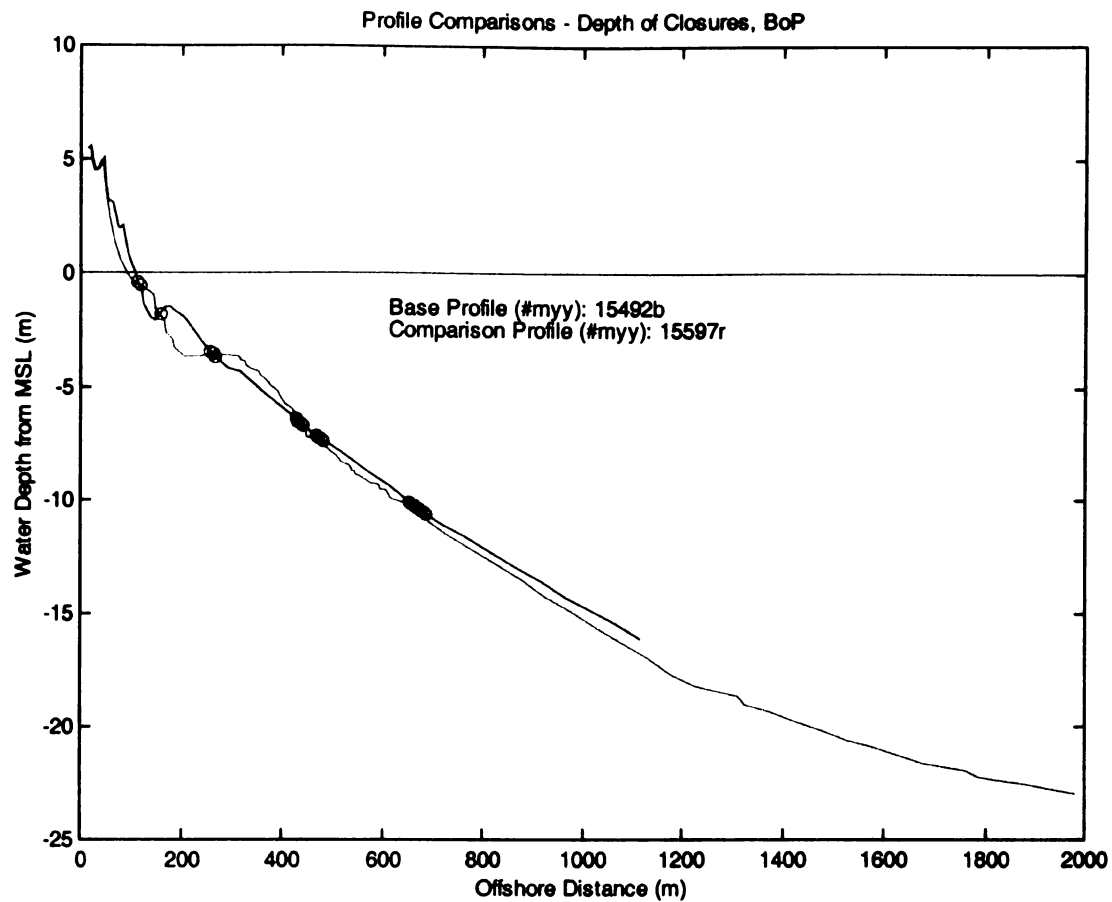


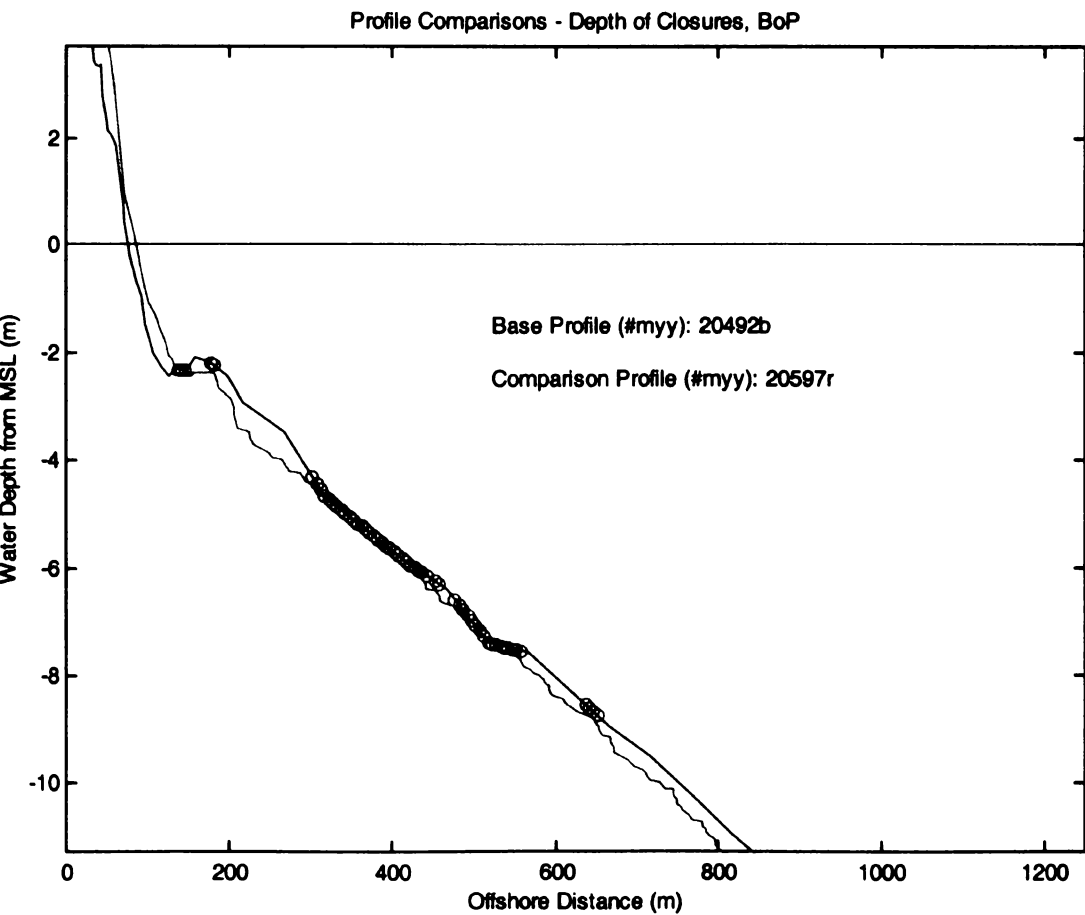
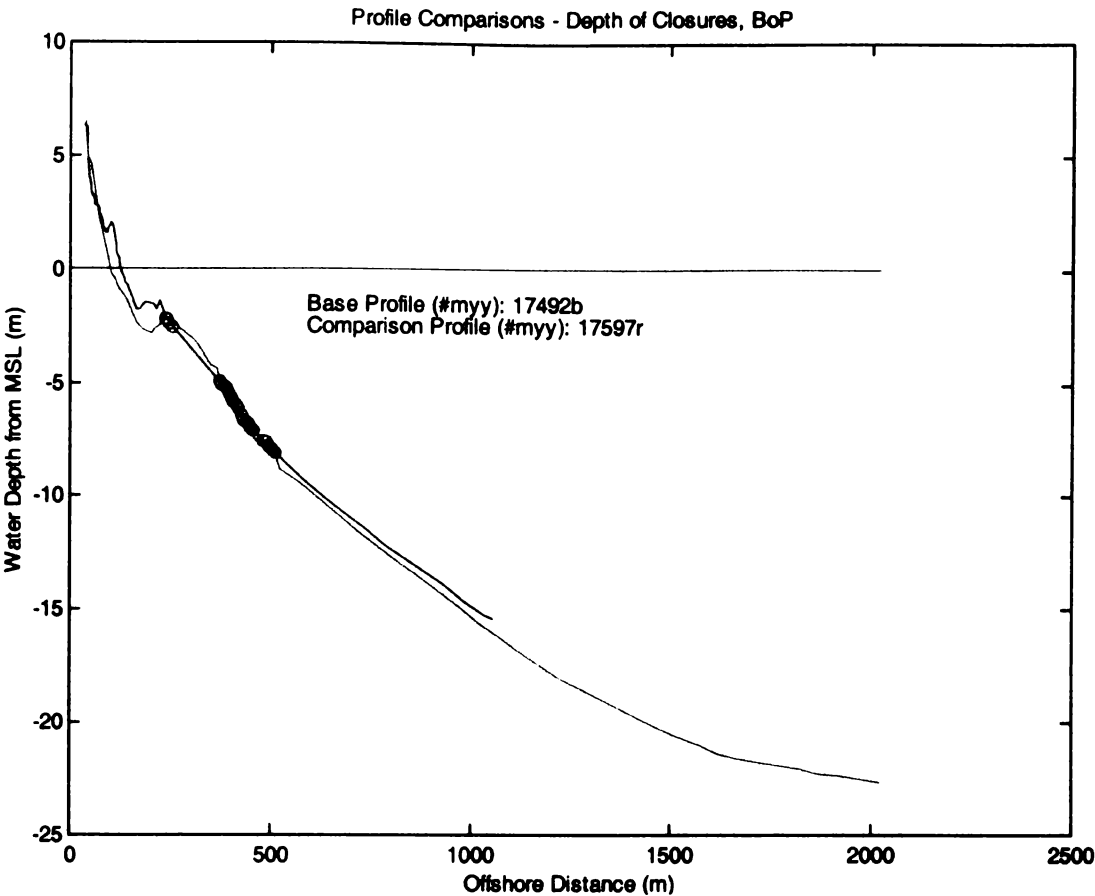


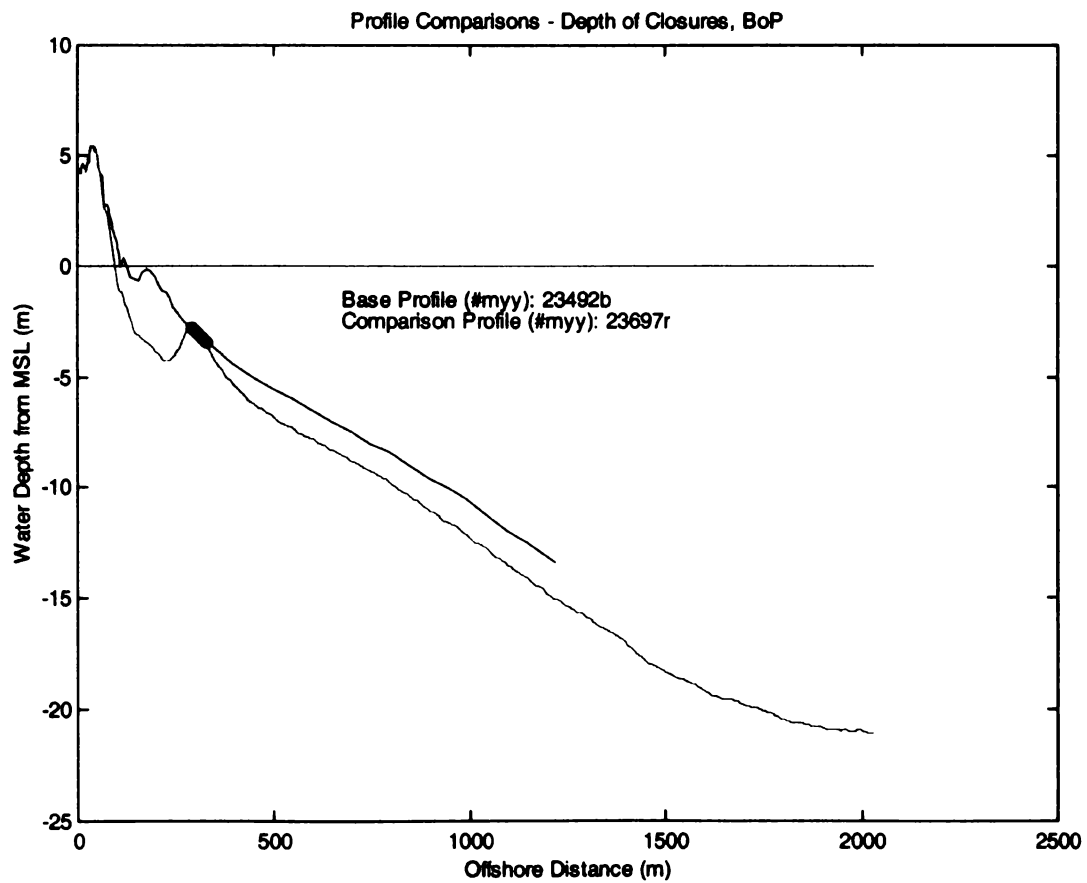
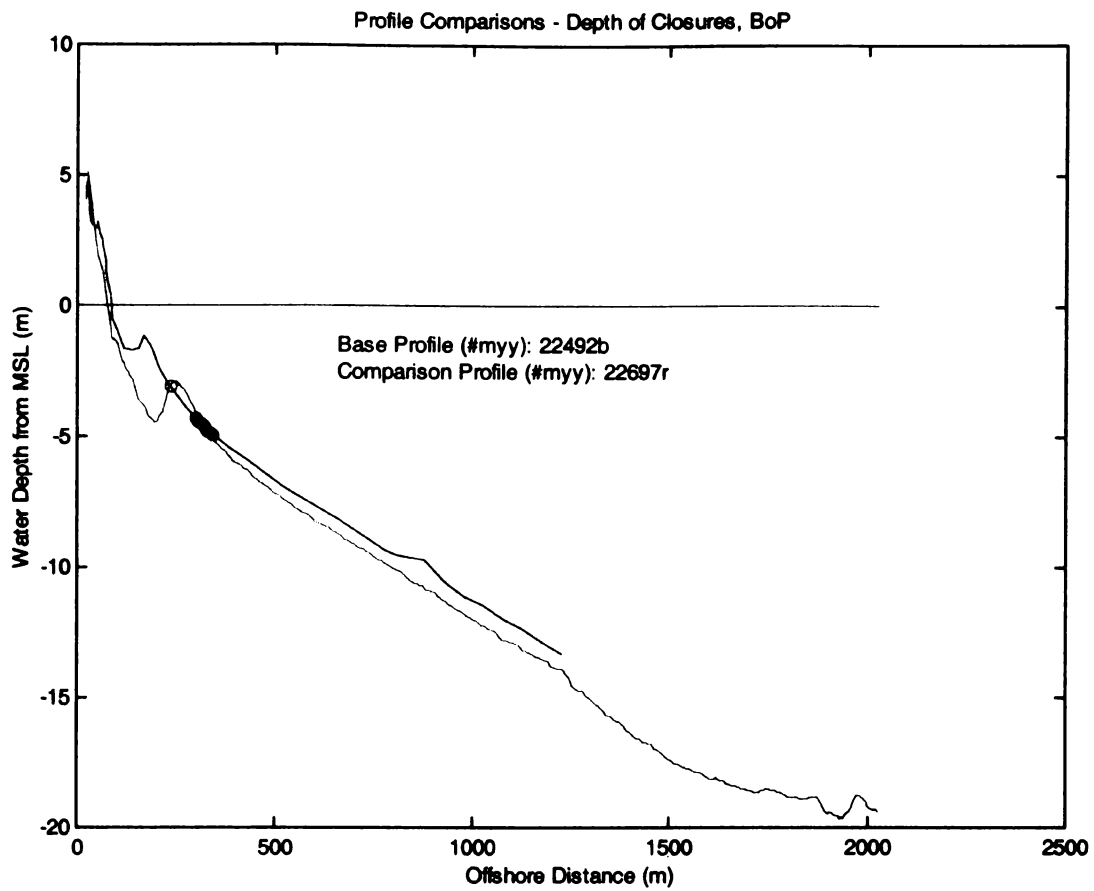


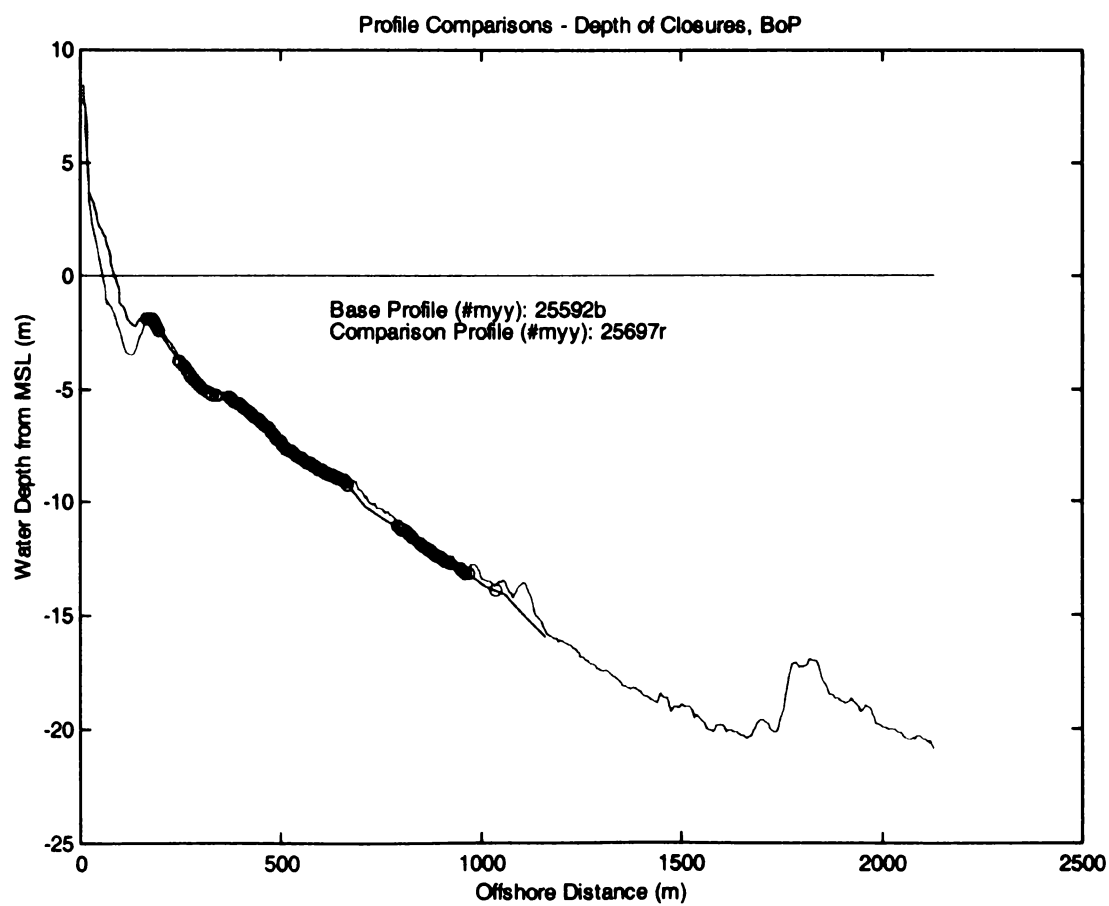
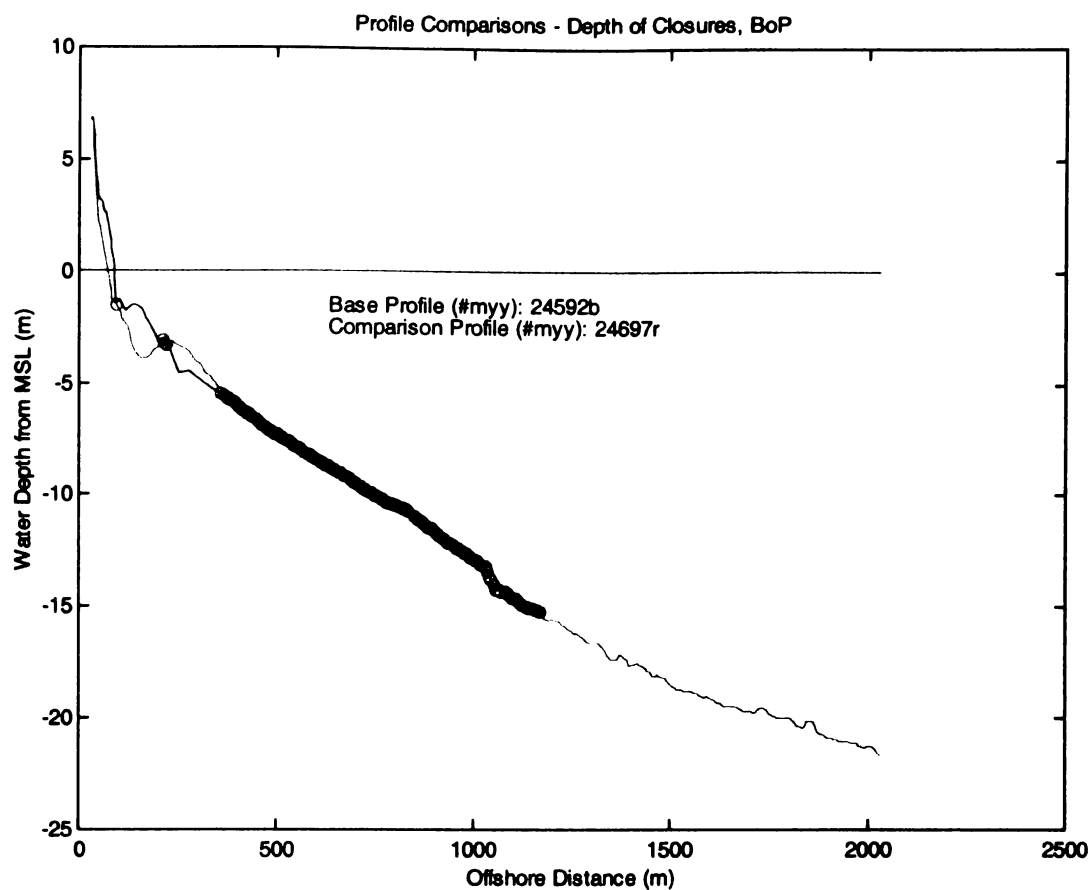


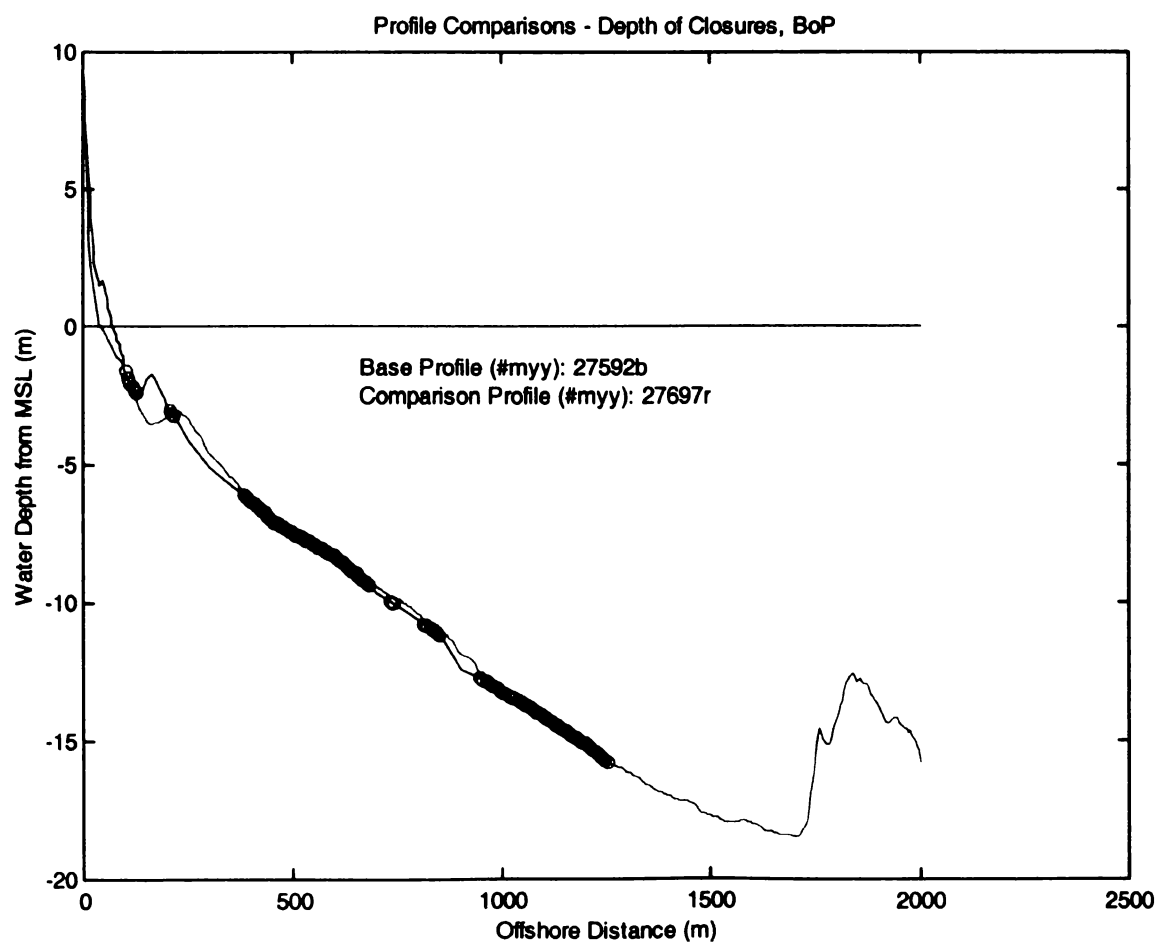
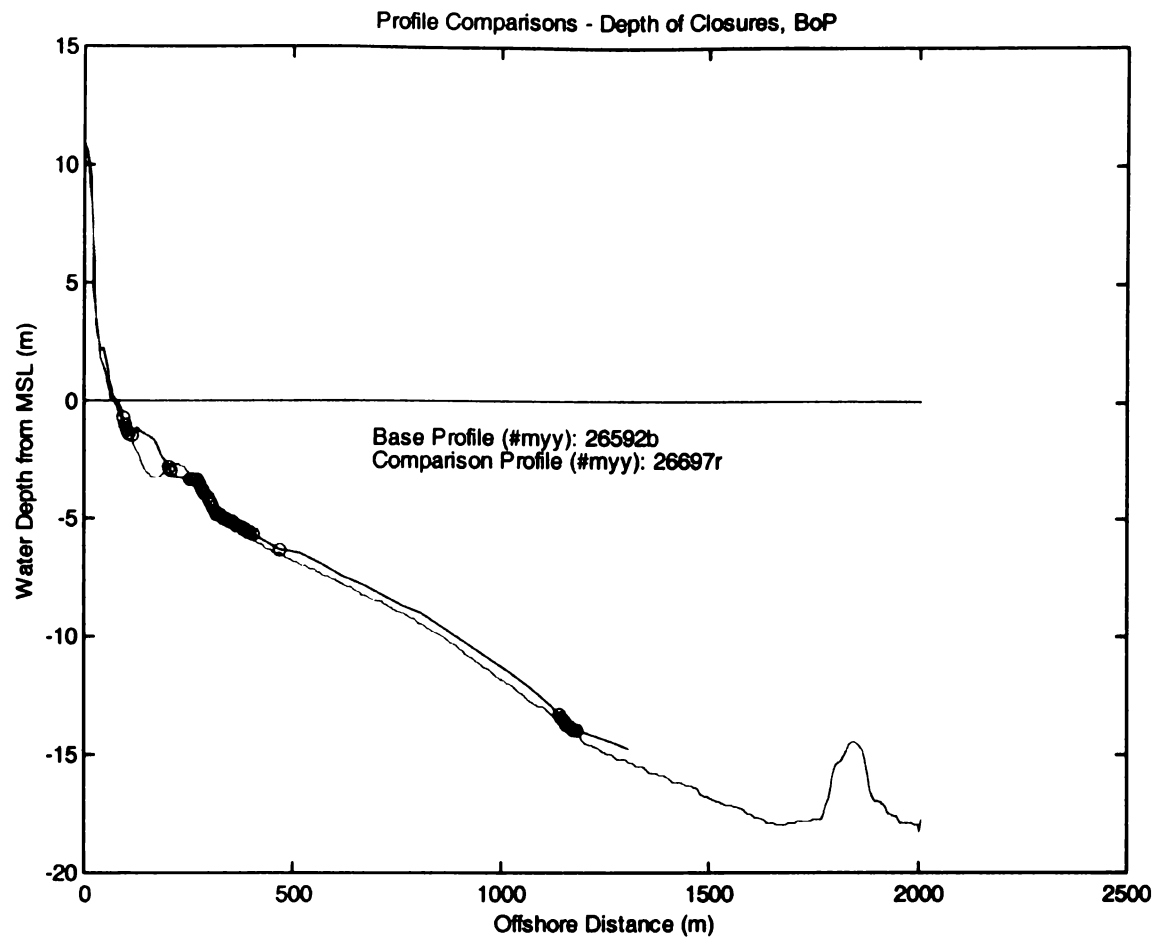


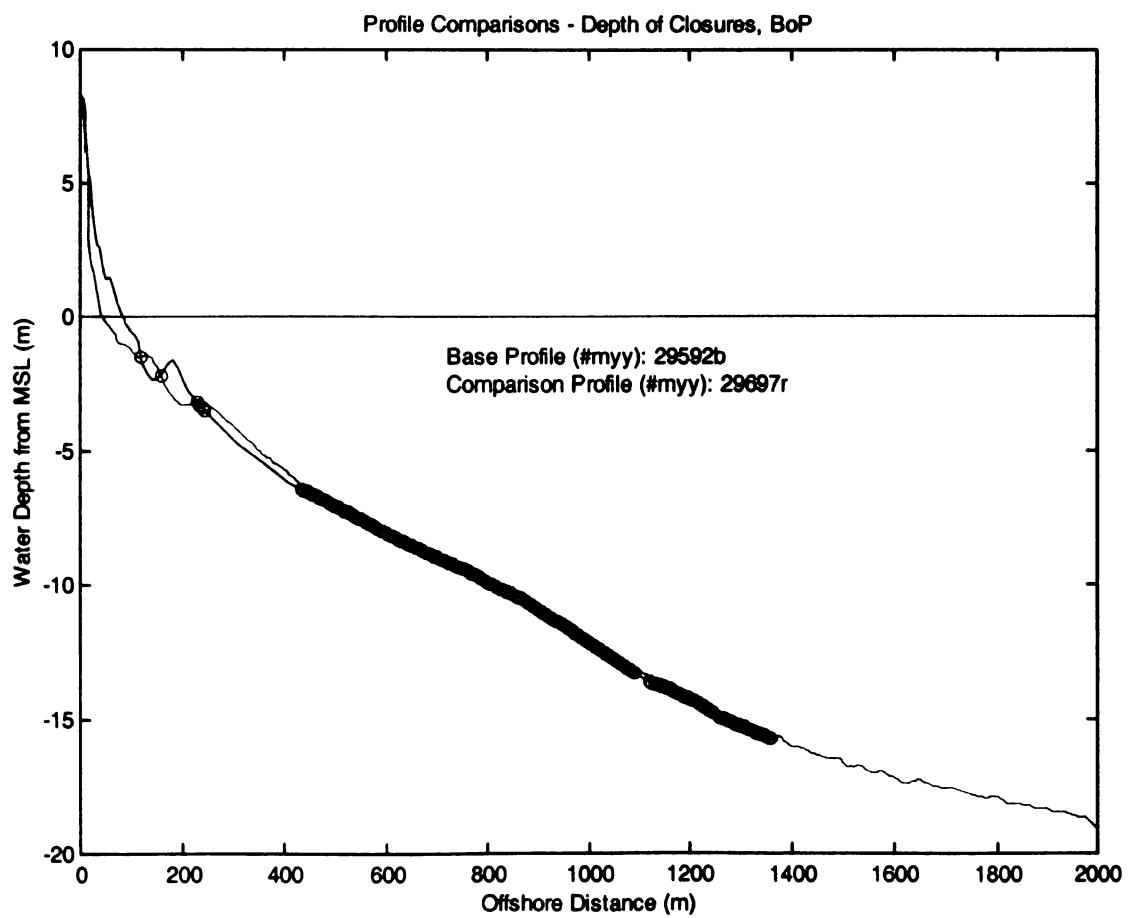
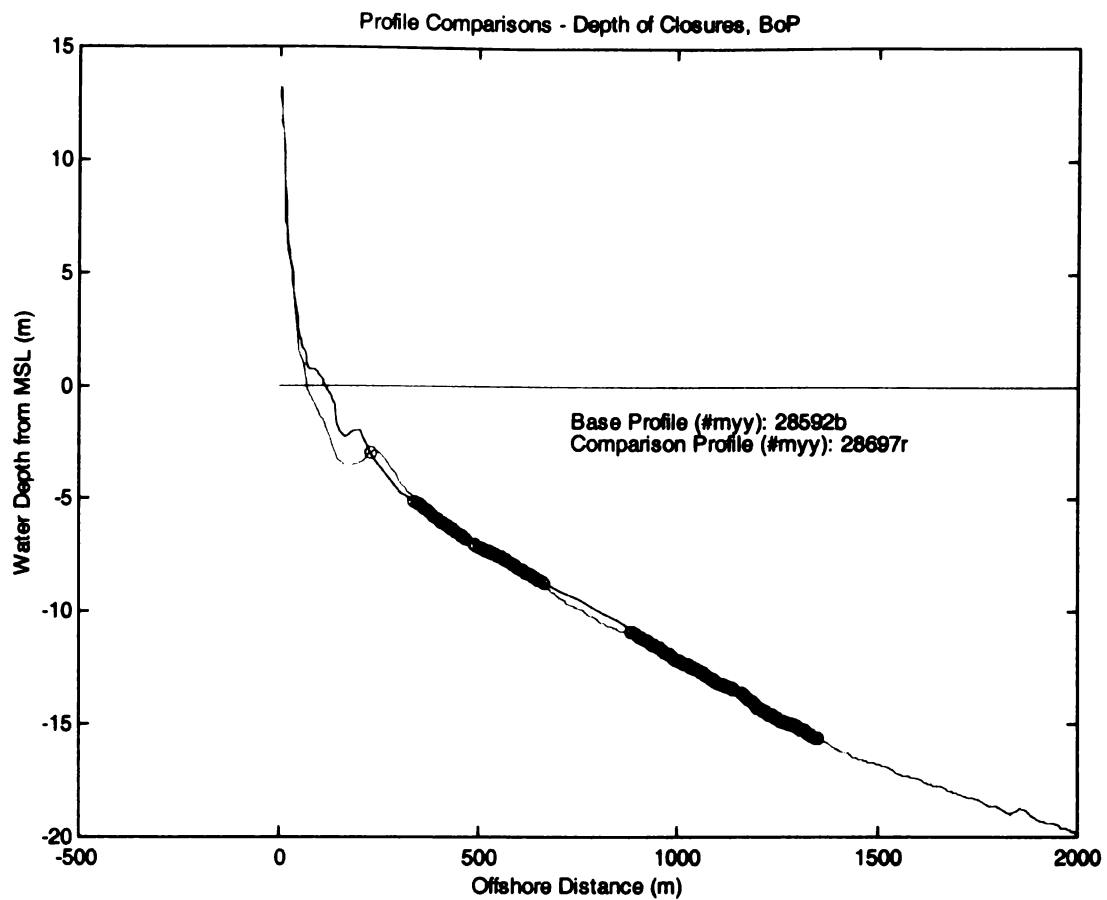


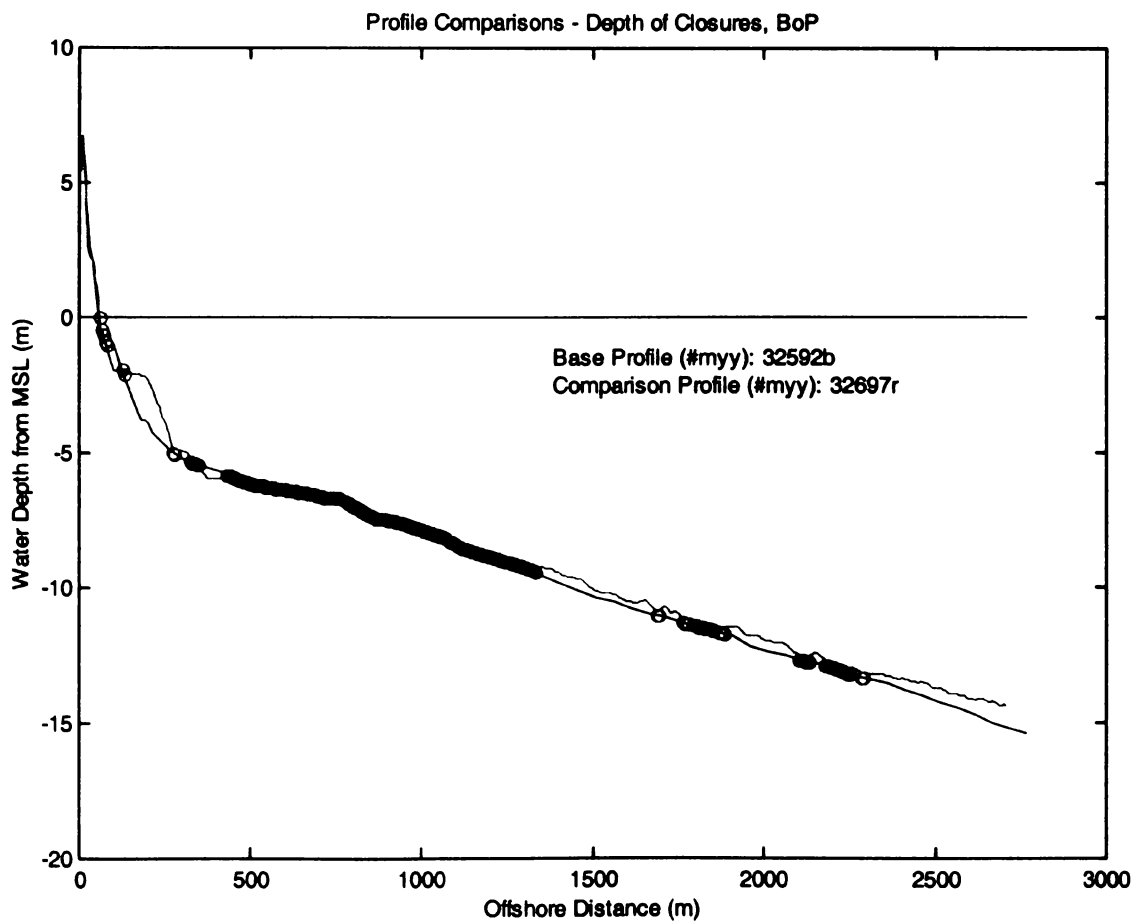
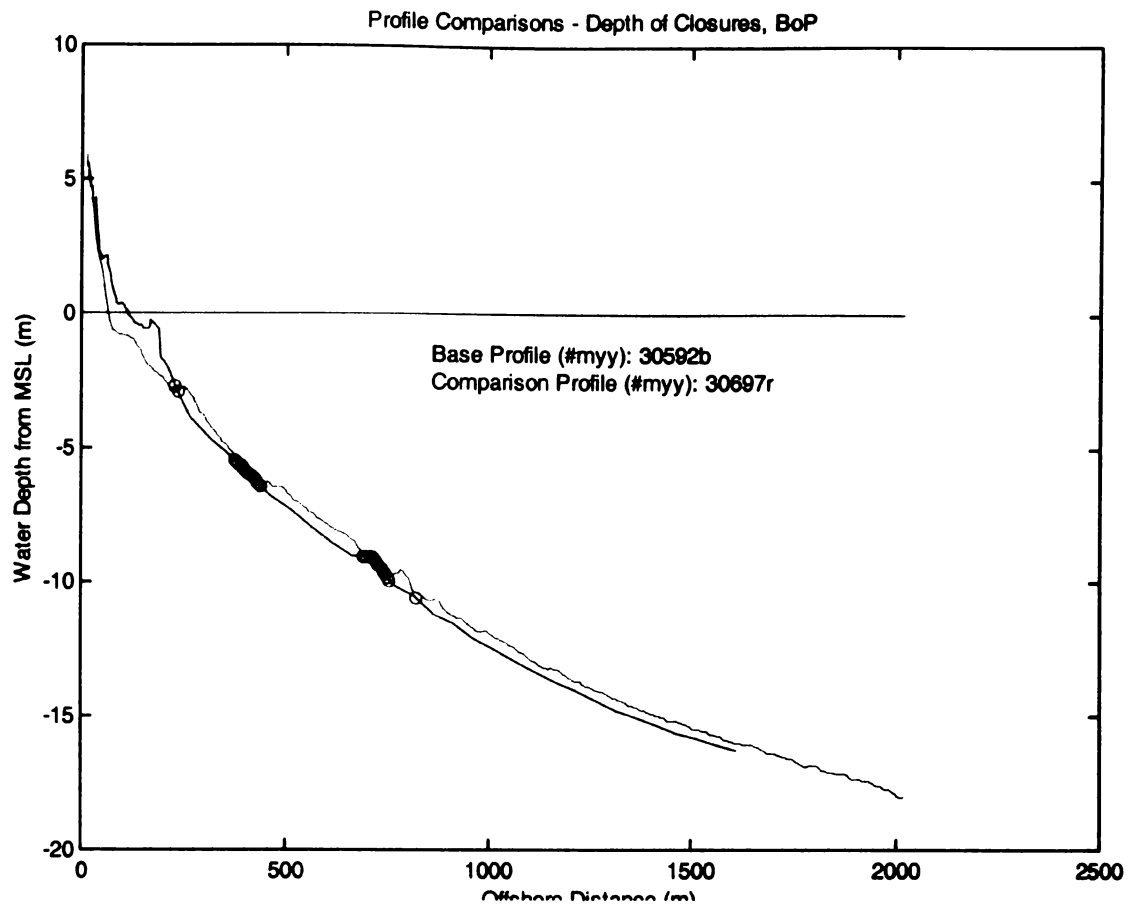


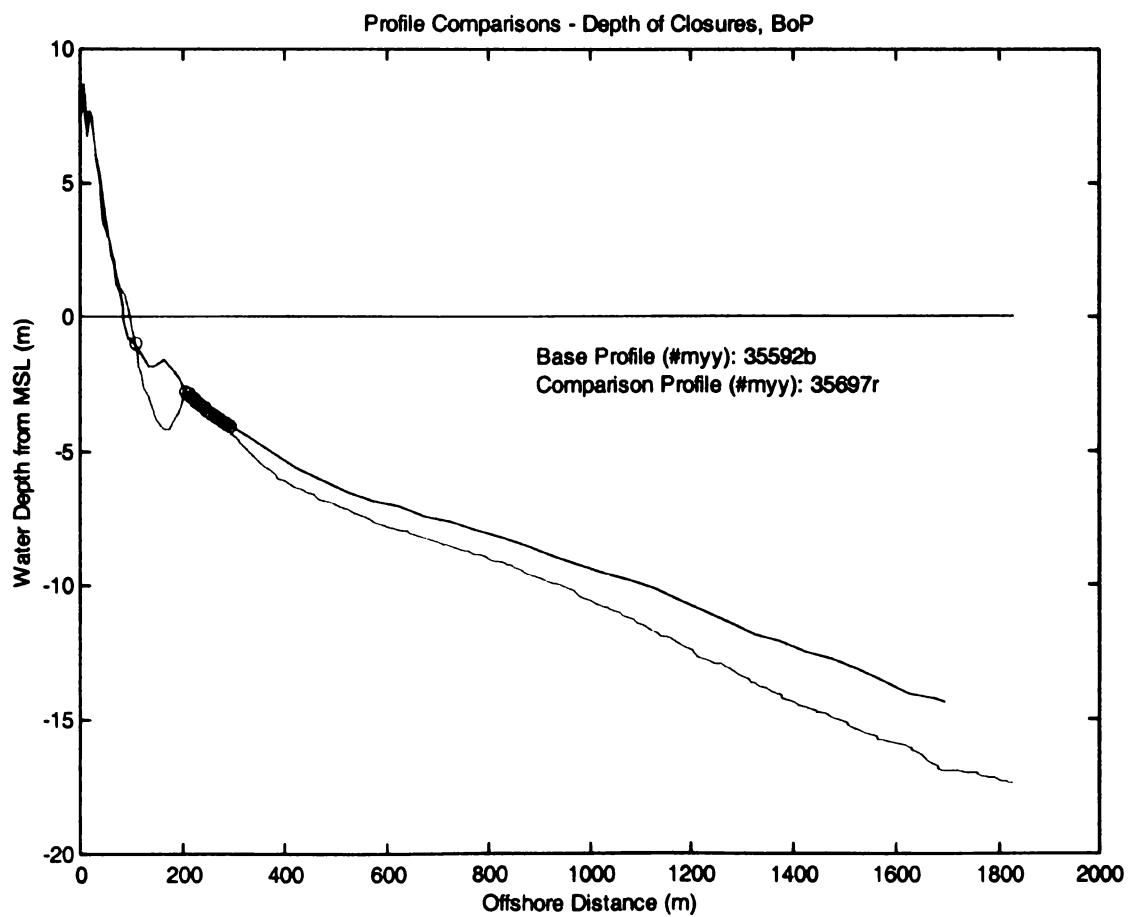
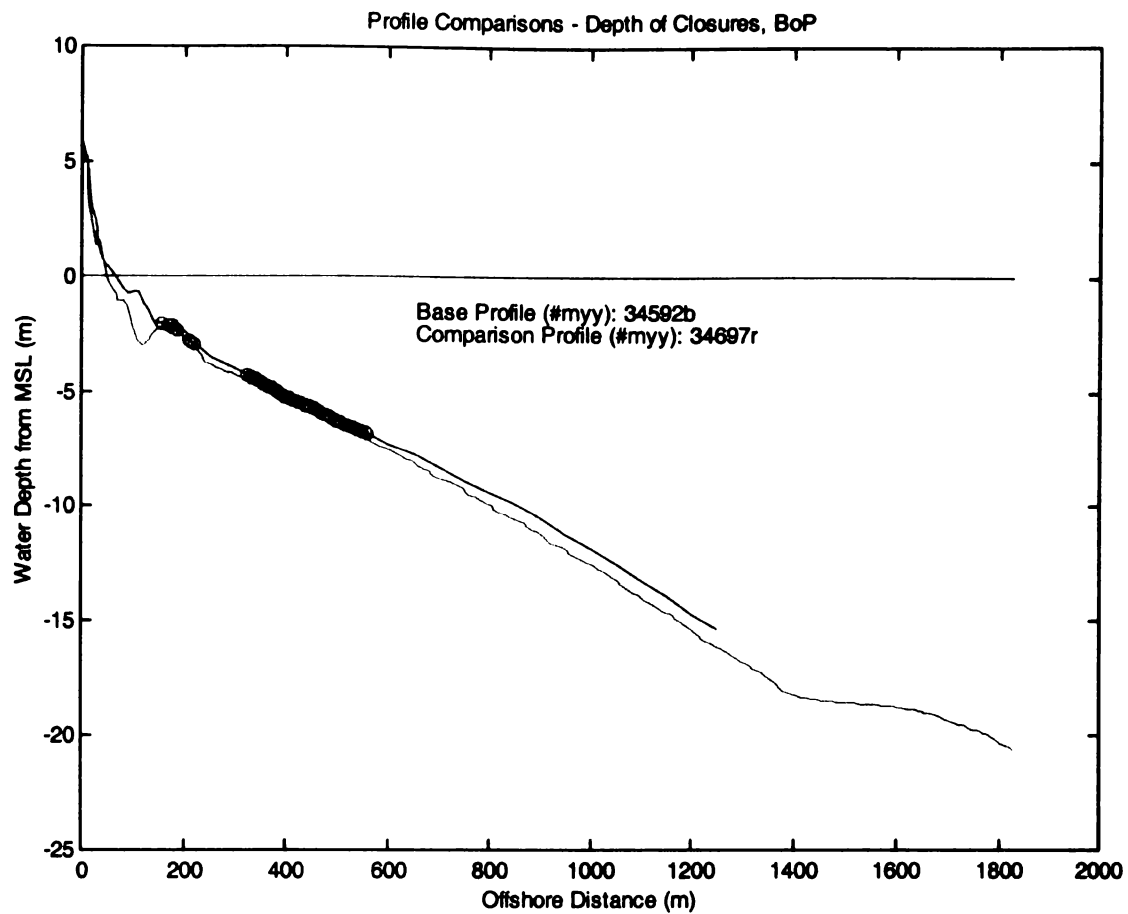


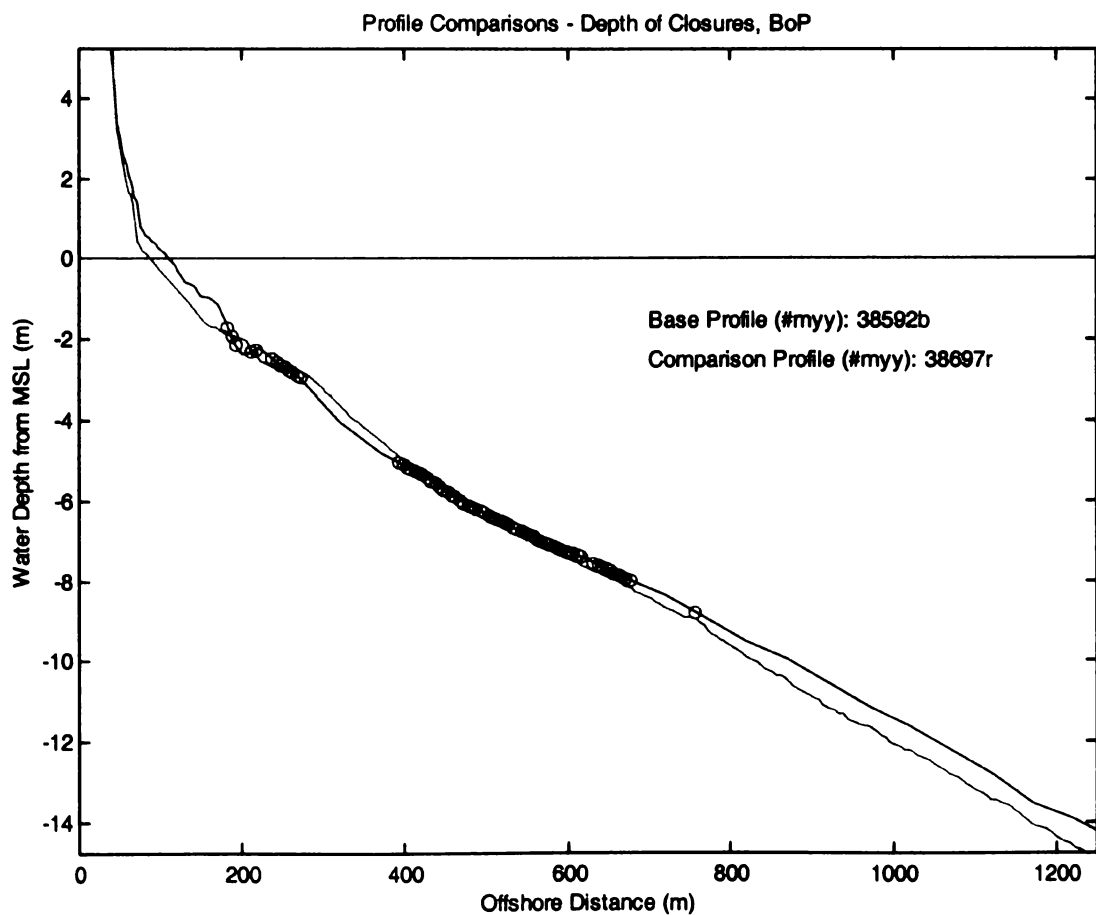
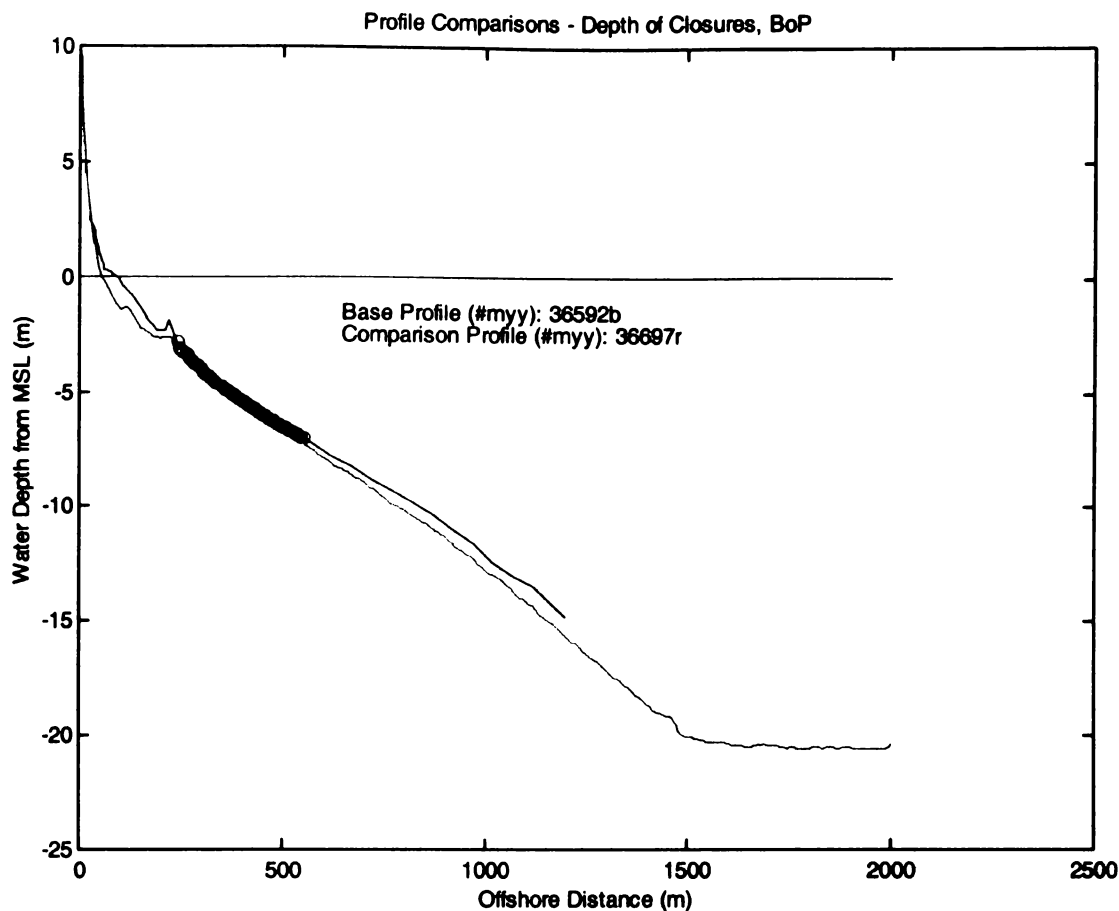


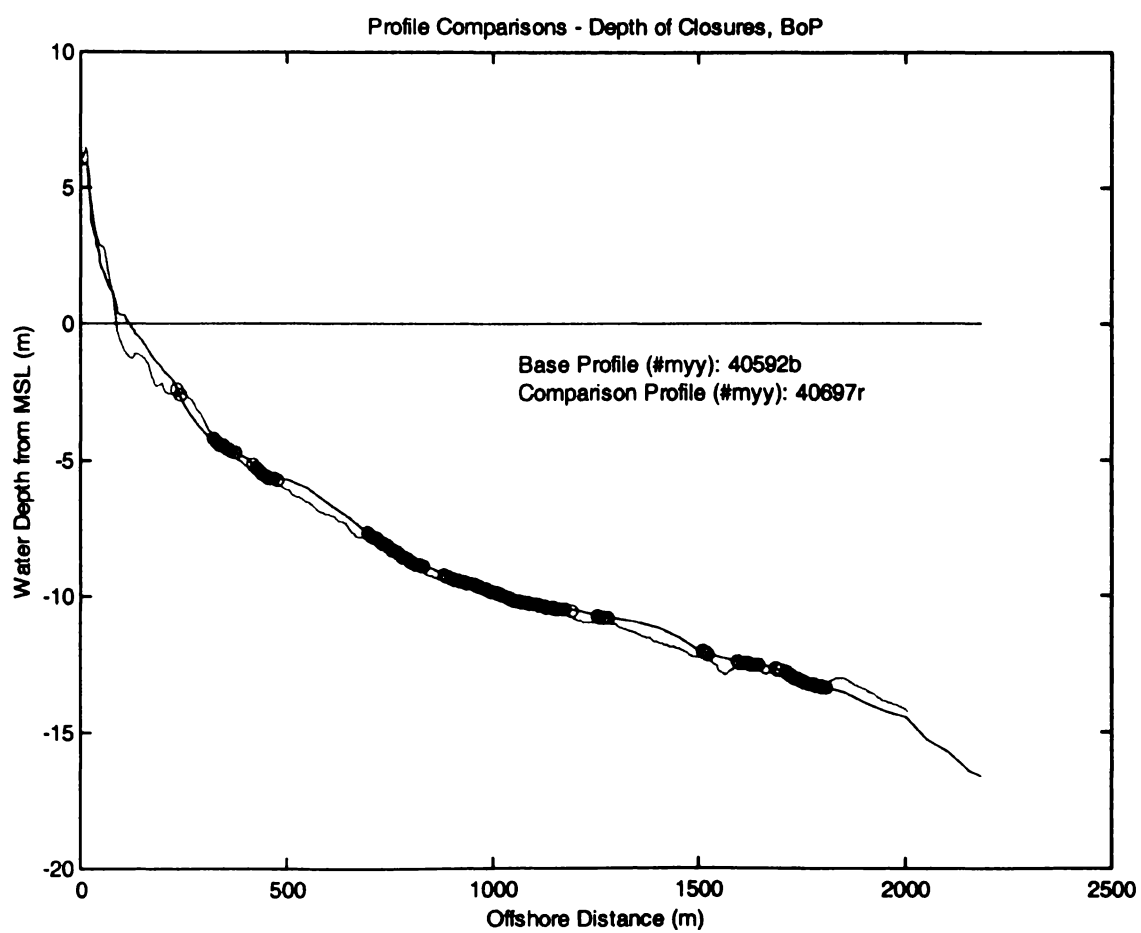
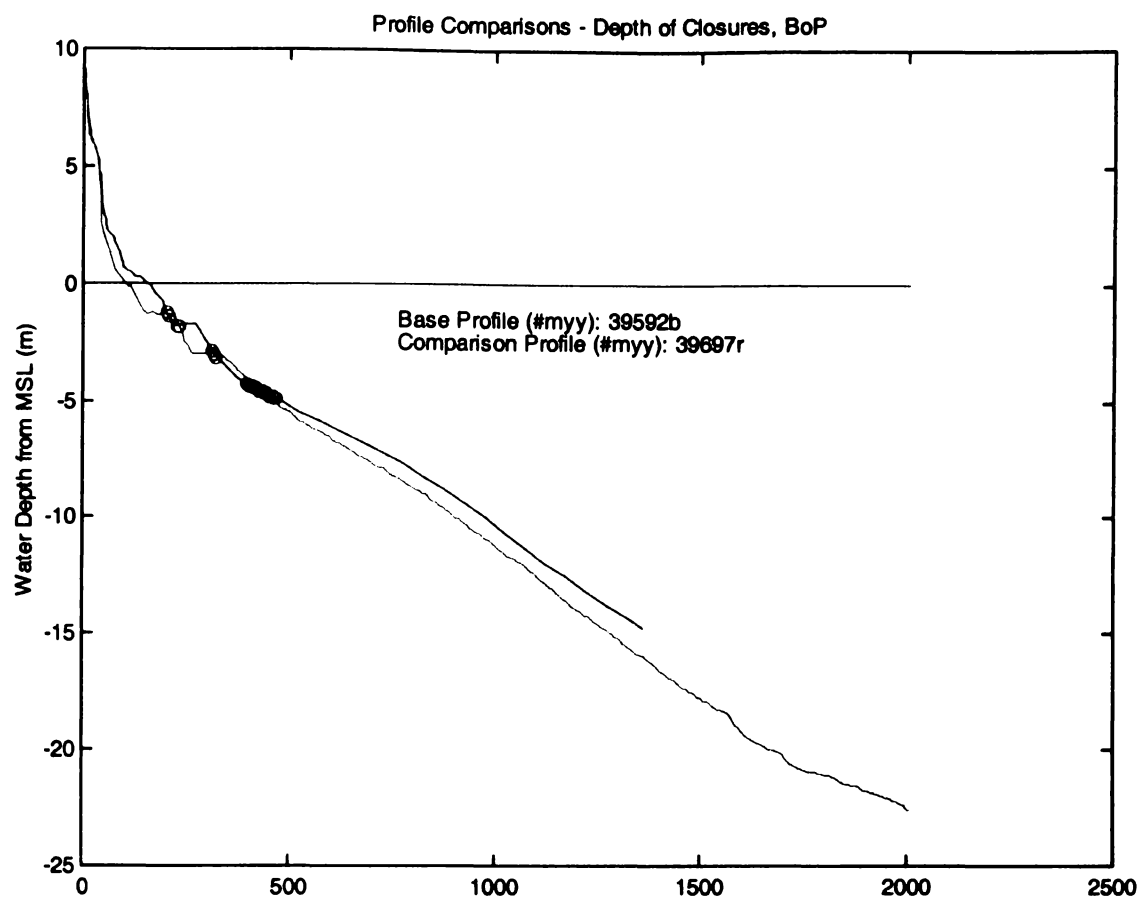


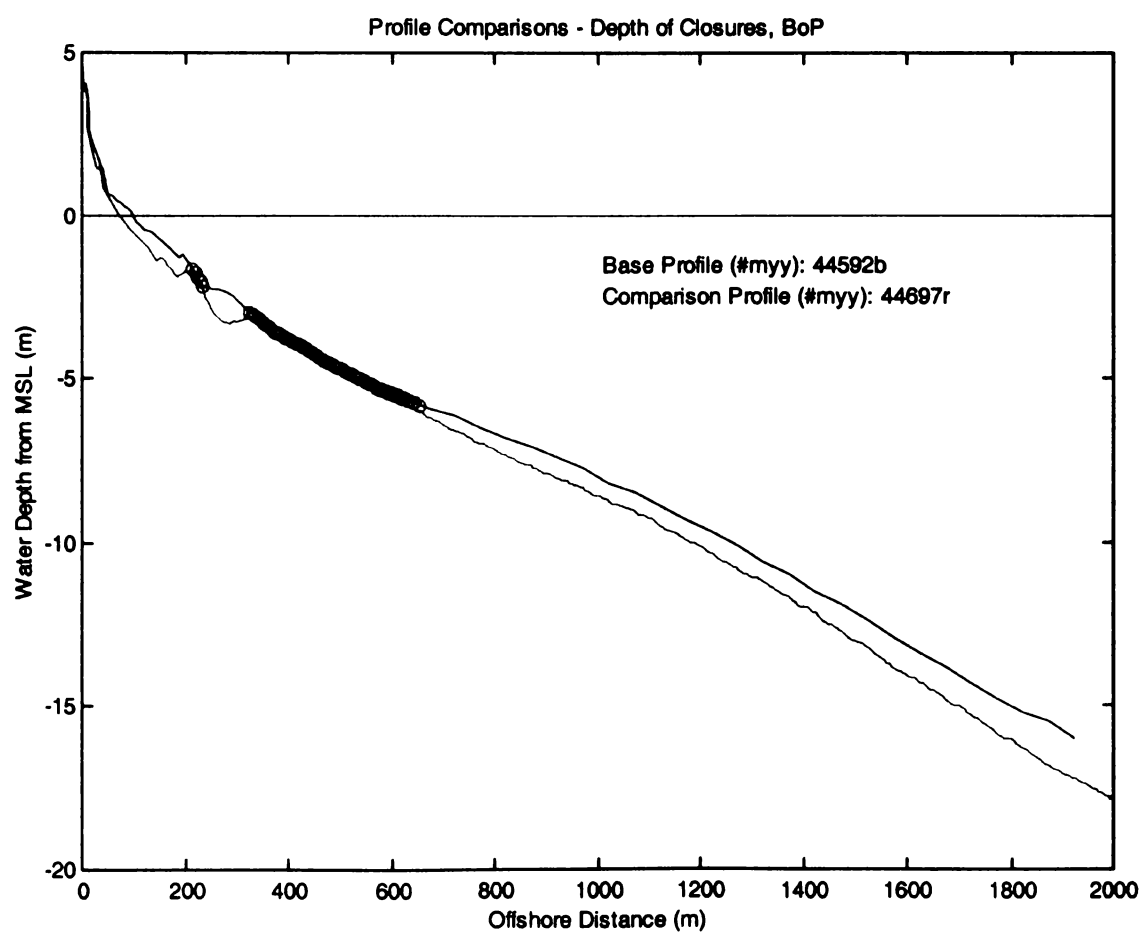
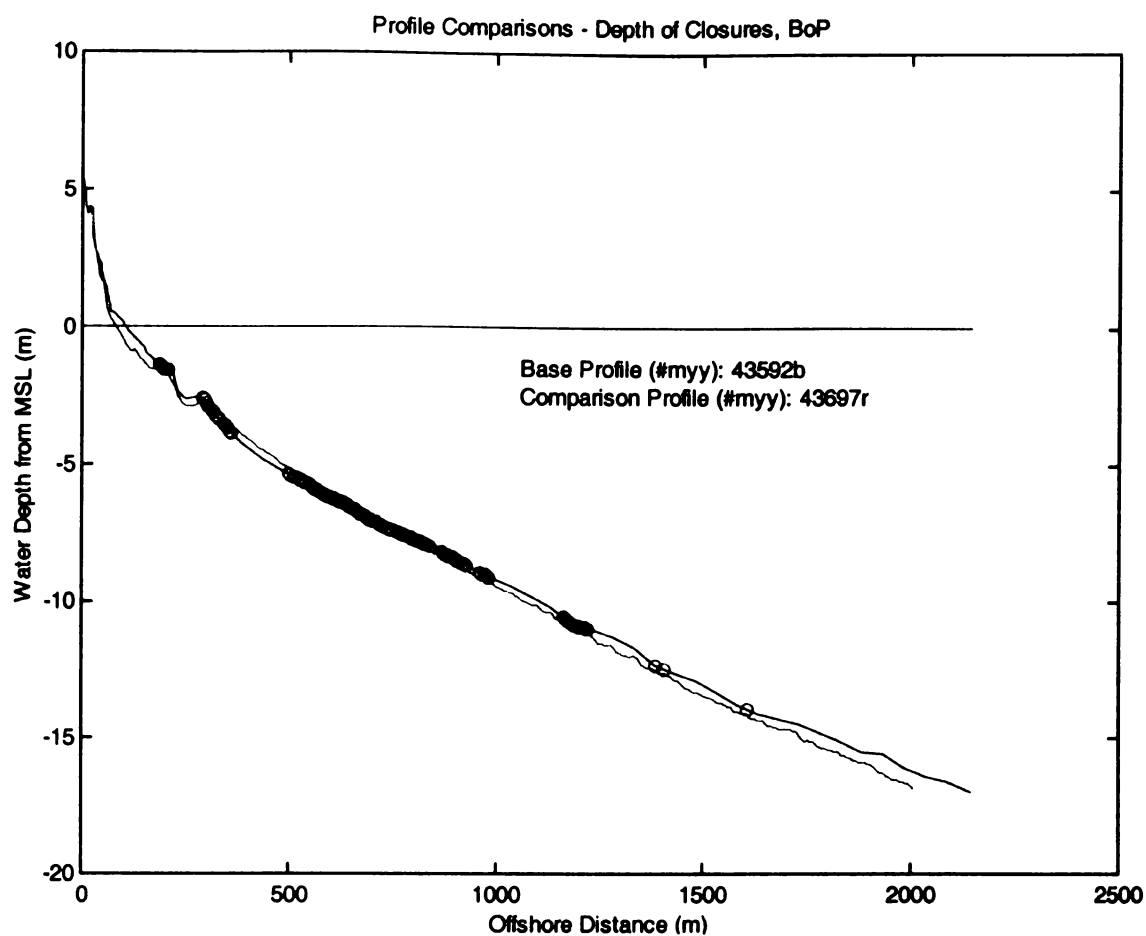


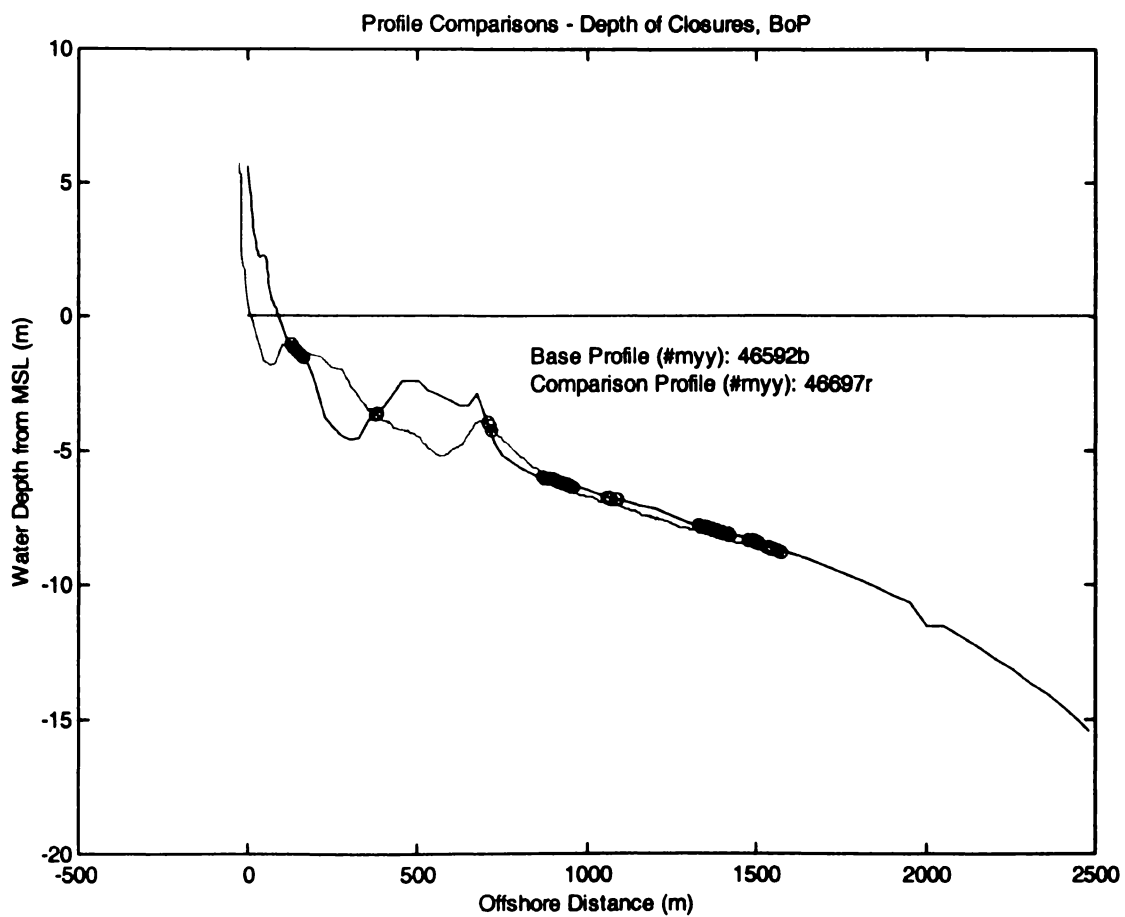
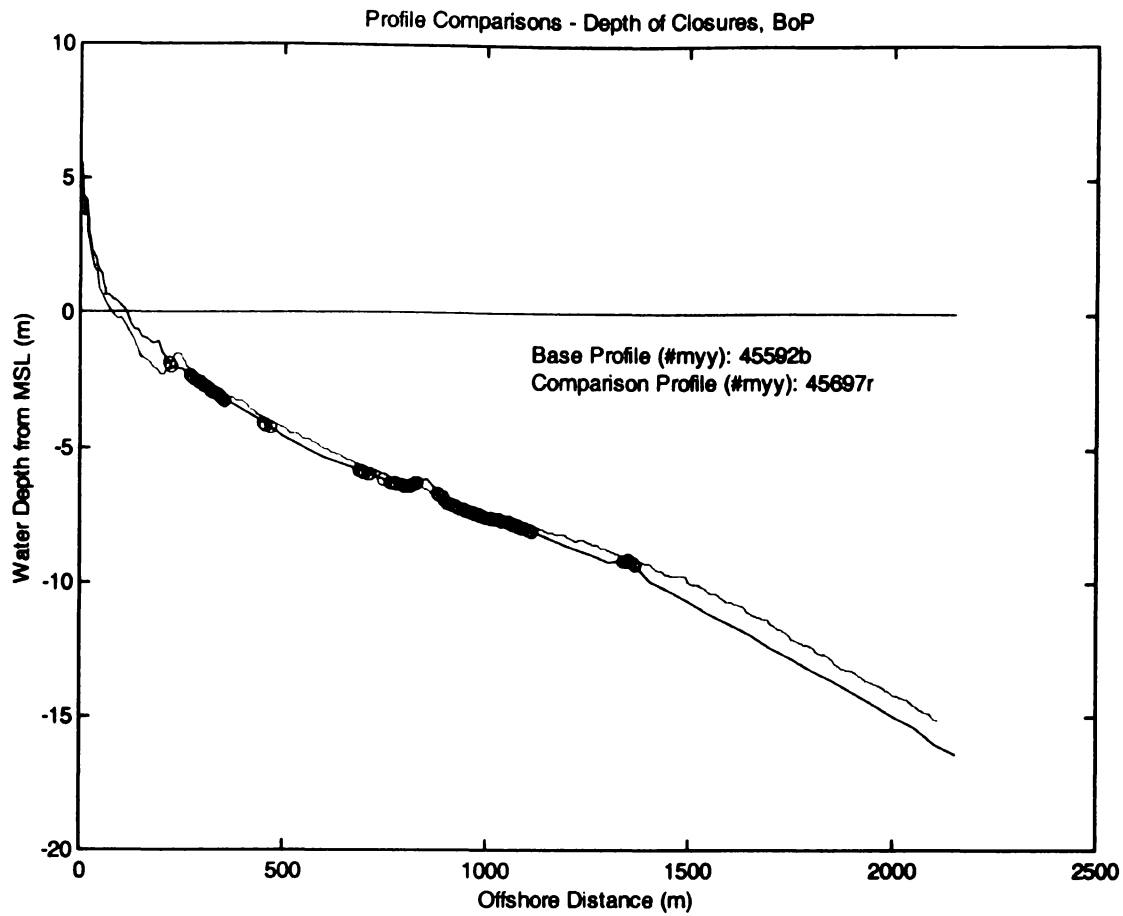


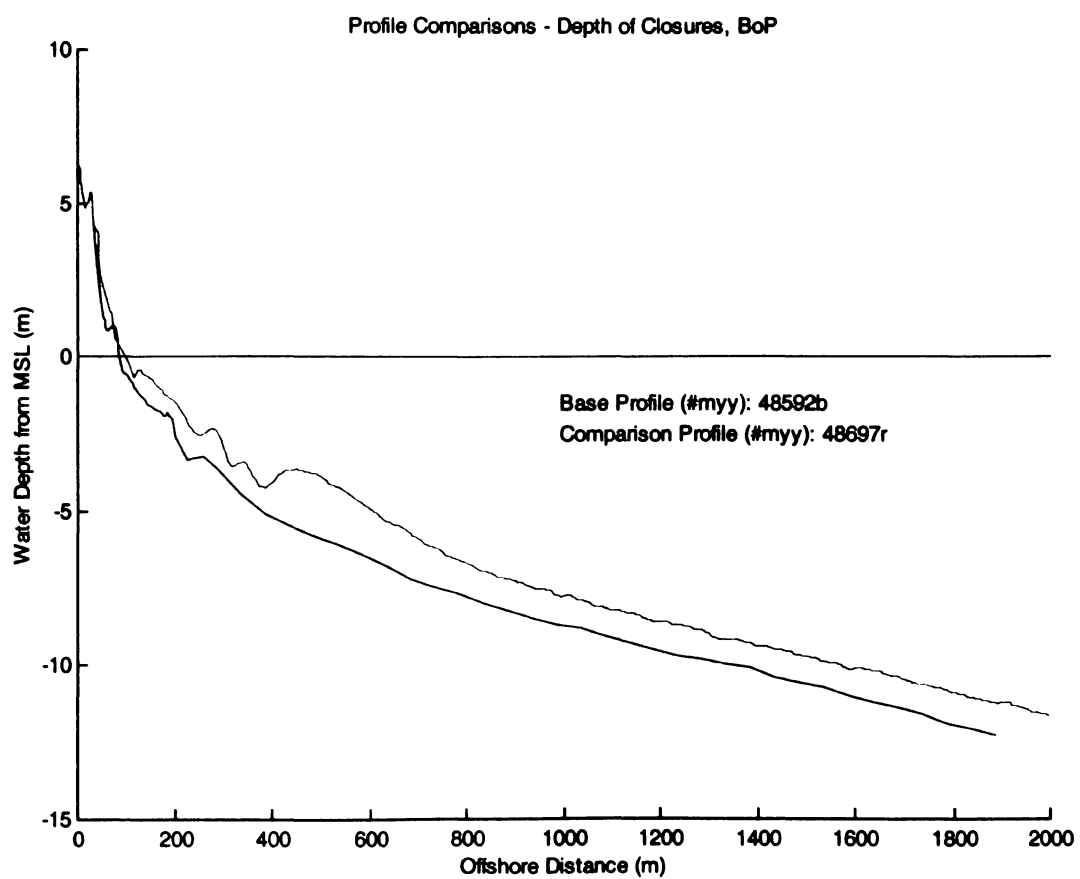
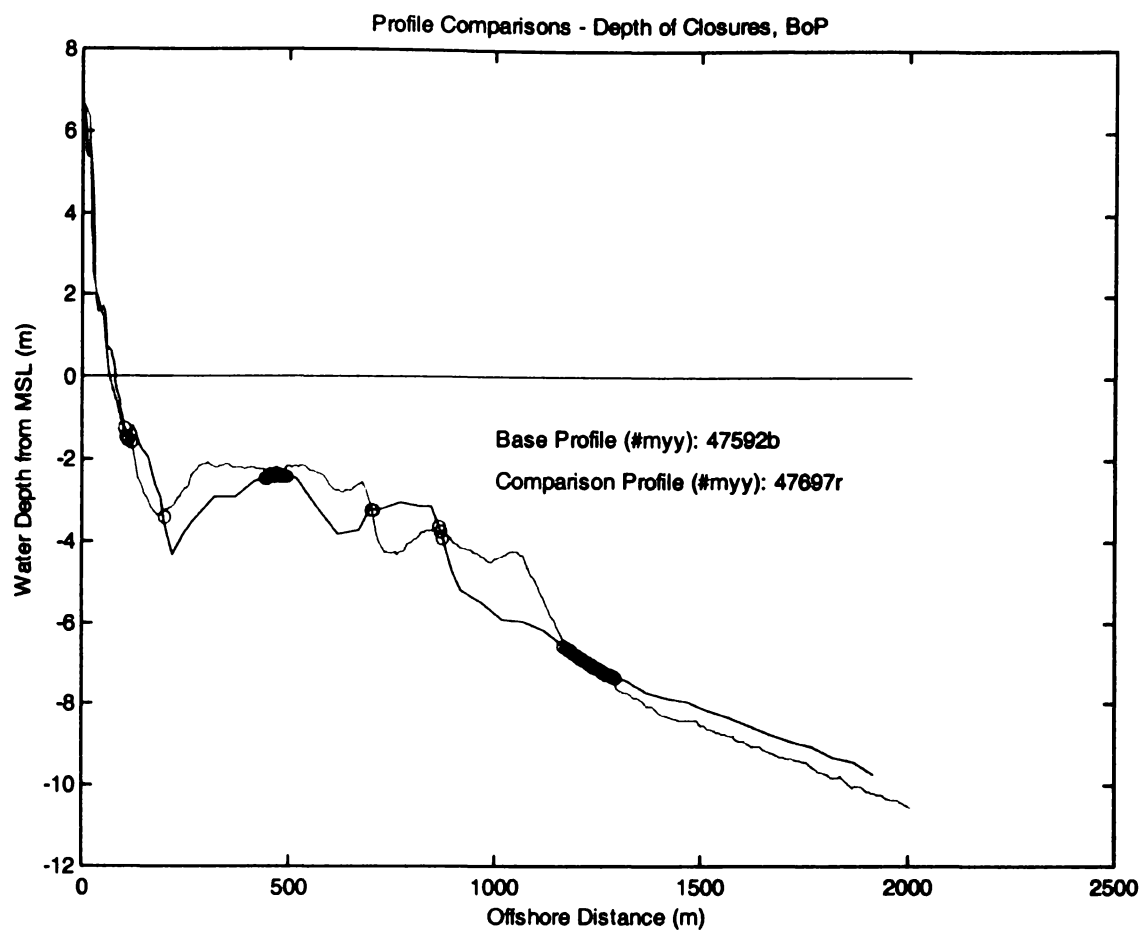


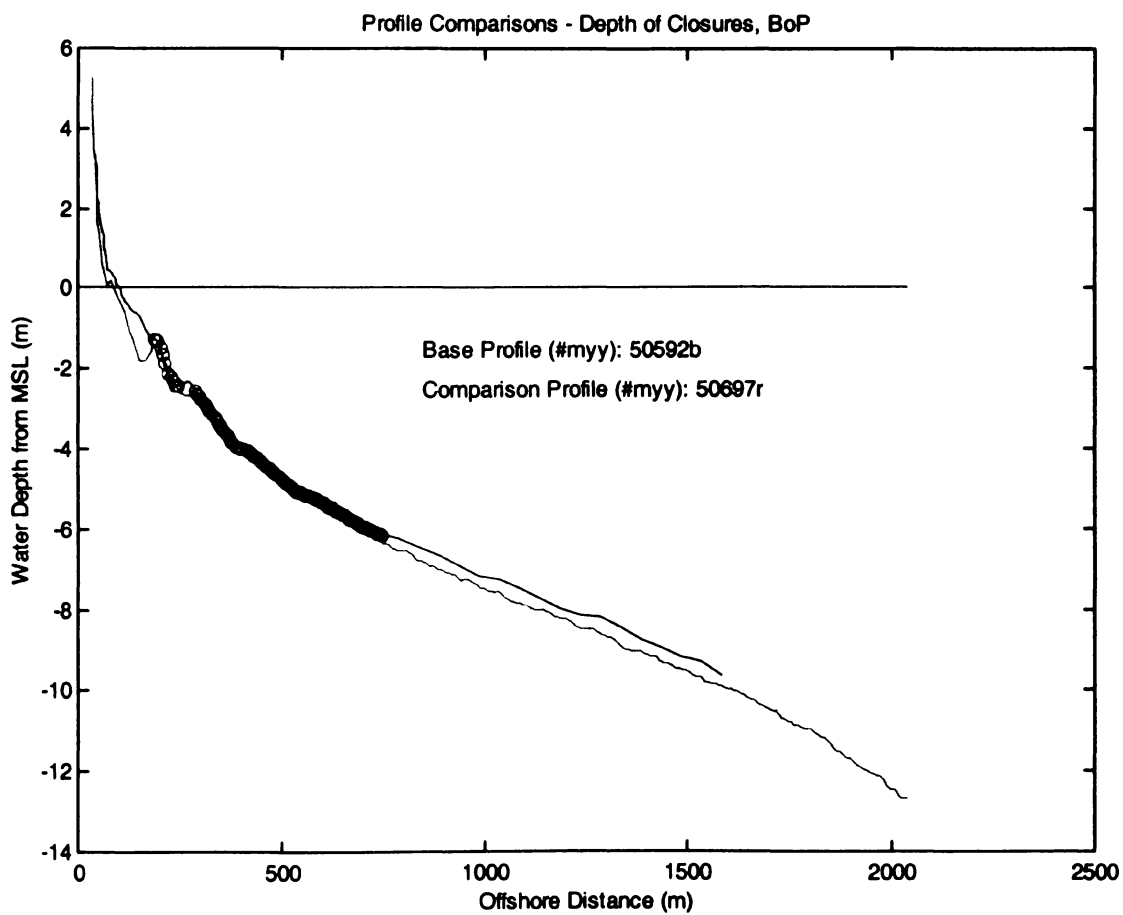
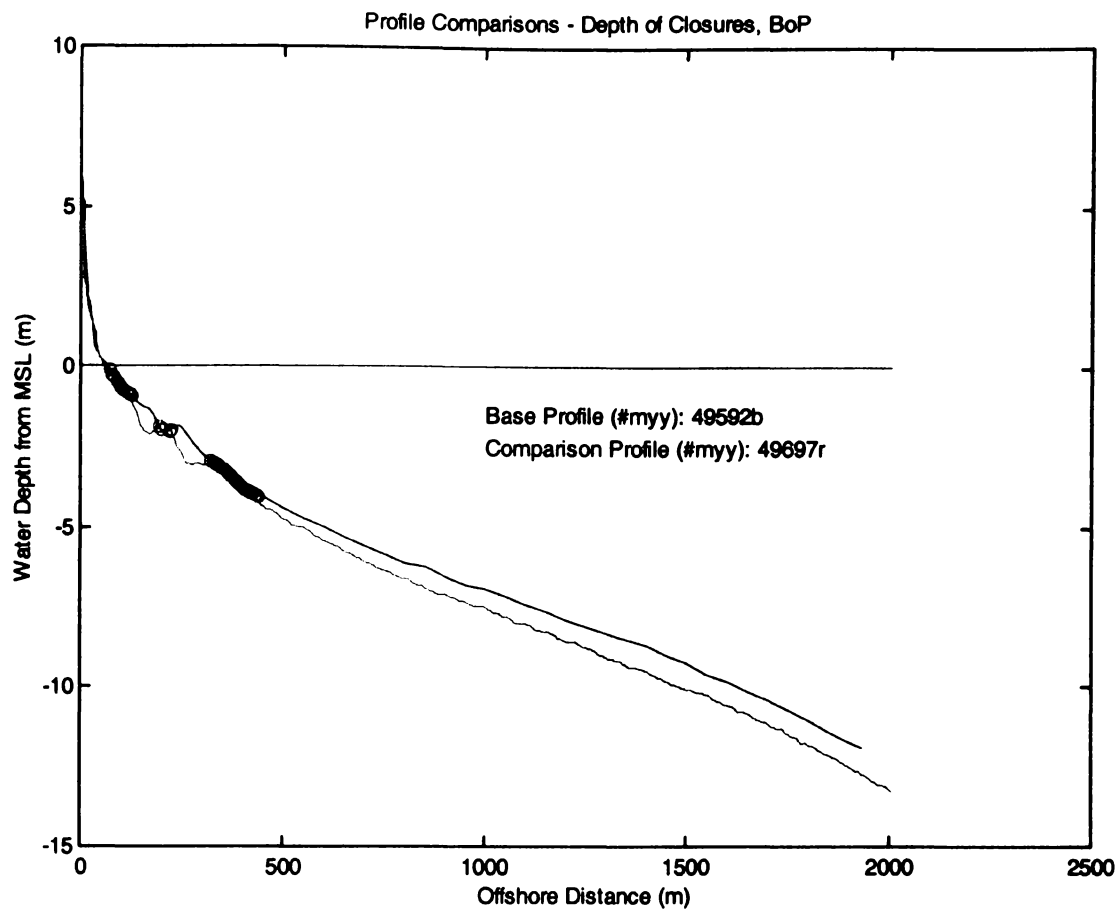


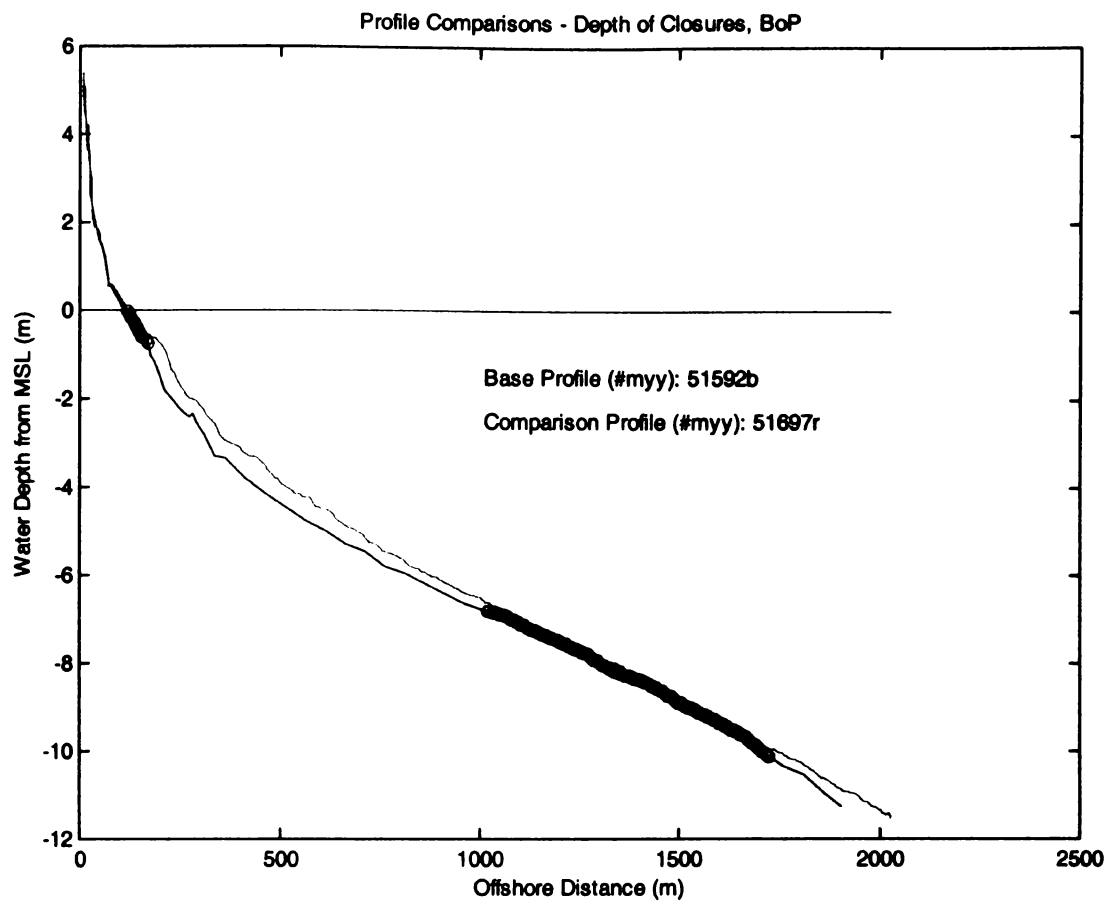












Appendix 4

Least Squares Regression Analysis results for Dean
Equilibrium Profile curve fitting, and

Samples of Least Squares Regression plots and program
output s from TABLECURVE 2D for
BoP Profiles

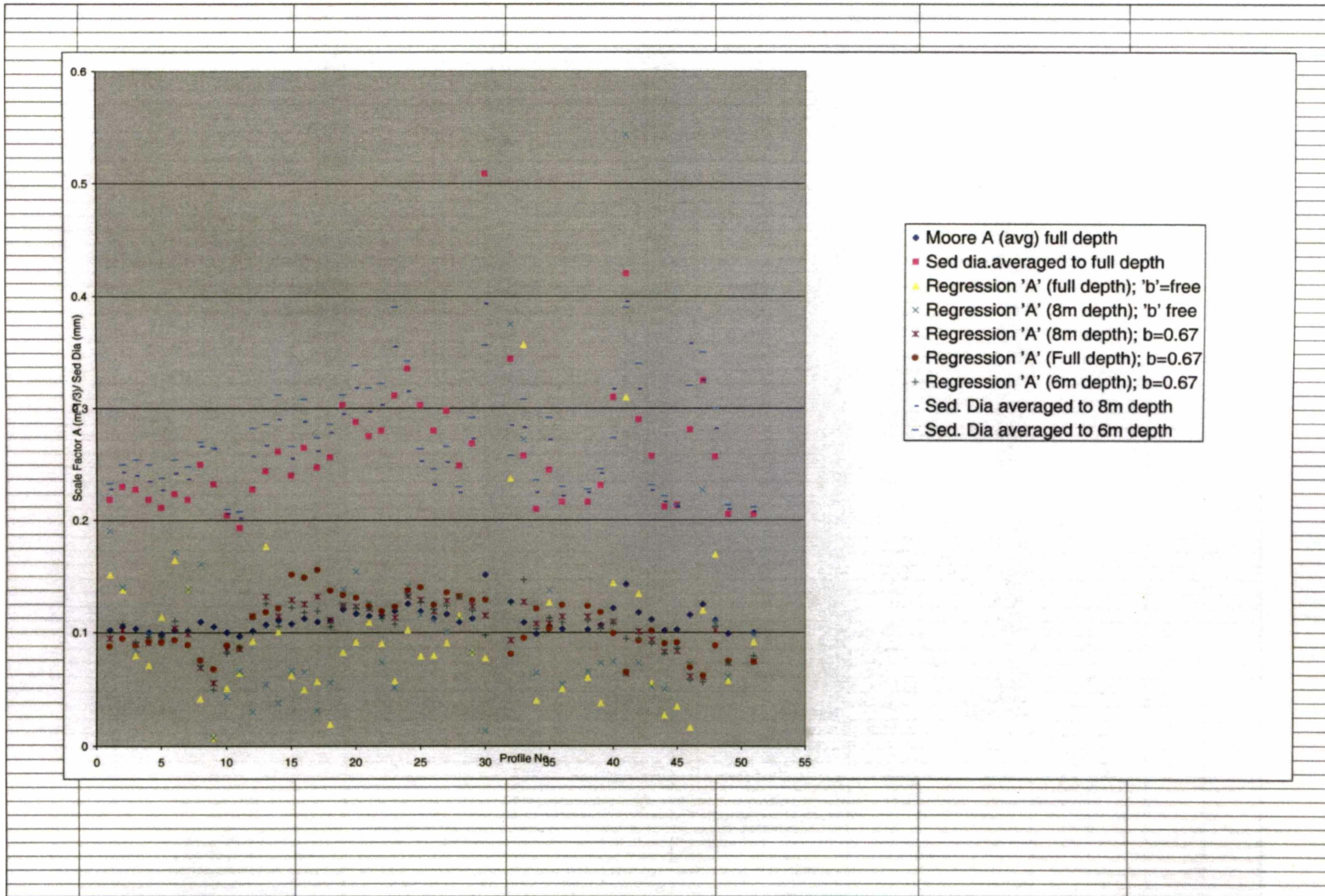
Appendix 4 – Notes

This appendix contains the following:

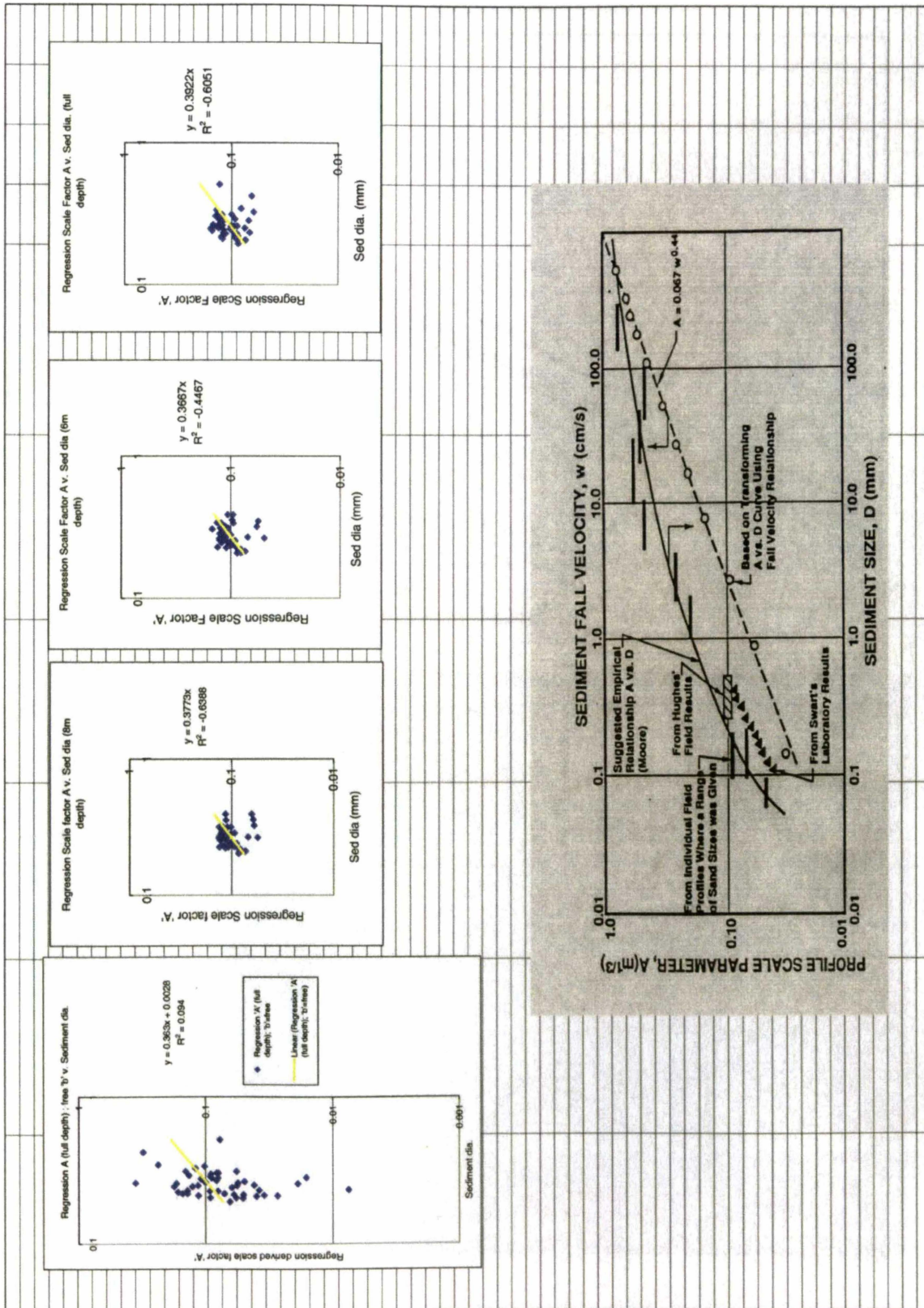
1. Spreadsheet information summarising the regression results for both blindfold fitting of the power curve and Dean's (1977) equation (see equations 1 and 2 below) to the BoP profile dataset. The spreadsheet results also contain tabular and graphical plots of regression and sediment derived scale factors for the various profiles.
2. Examples are provided of the Least Squares Regression analysis output for different closure depths (6,7 and 8 m) using JANDEL's TABLE2DCURVE. Examples of curve plots showing the least squares regression curve with 95 % C.I. are provided for Profiles 10 and 51. A full electronic dataset is available covering all profiles. The two curves fitted to the profile data are as follows:
 1. $y = ax^b$; and
 2. $y = ax^{\frac{2}{3}}$.

Equation 2 is shown on the printouts as $y = \text{Dean Eq}(a)$.

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Sed dia. averaged to full depth	Sed. Dia averaged to 8m depth	Sed. Dia averaged to 6m depth	Moore A (avg) full depth	Moore A (avg) 8m depth	Moore A (avg) 6m depth
0.21875	0.228	0.233	0.102	0.104	0.1064
0.23	0.243	0.25	0.105	0.108	0.1092
0.2275	0.24	0.254	0.1035	0.106	0.1096
0.21875	0.235	0.25	0.1	0.104	0.108
0.21125	0.227	0.238	0.09875	0.103	0.106
0.22375	0.242	0.254	0.102	0.1067	0.1096
0.21875	0.237	0.248	0.10125	0.1063	0.1092
0.25	0.266	0.27	0.10925	0.114	0.1148
0.2325	0.264	0.265	0.105	0.1128	0.113
0.204444	0.206	0.21	0.1	0.1003	0.1003
0.193333	0.202	0.208	0.096444	0.0993	0.1016
0.2275	0.257	0.282	0.10105	0.1092	0.1164
0.24375	0.267	0.286	0.10675	0.1123	0.1172
0.26125	0.29	0.312	0.1105	0.1173	0.1224
0.24	0.255	0.266	0.1075	0.111	0.1132
0.265	0.288	0.308	0.11225	0.1173	0.1216
0.2475	0.262	0.274	0.10925	0.1123	0.1148
0.25625	0.278	0.286	0.11075	0.1157	0.1172
0.3025	0.295	0.312	0.1205	0.119	0.1124
0.2875	0.318	0.338	0.116888	0.1229	0.1267
0.275	0.297	0.318	0.11425	0.1183	0.1228
0.28	0.303	0.322	0.11525	0.1197	0.1232
0.31125	0.355	0.39	0.119125	0.1282	0.1354
0.335	0.315	0.342	0.12555	0.1222	0.1282
0.3025	0.253	0.264	0.118625	0.1107	0.1128
0.28	0.232	0.246	0.112413	0.1043	0.1084
0.2975	0.252	0.266	0.116313	0.1087	0.112
0.24875	0.225	0.23	0.10925	0.1047	0.1056
0.26875	0.273	0.292	0.11225	0.114	0.1184
0.50875	0.393	0.356	0.151188	0.1348	0.1278
0.34375	0.285	0.258	0.127375	0.1157	0.11
0.2575	0.283	0.308	0.10875	0.1143	0.1204
0.21	0.225	0.236	0.09875	0.103	0.106
0.245	0.272	0.292	0.1055	0.112	0.1168
0.21625	0.222	0.23	0.10275	0.1037	0.103
0.21625	0.225	0.228	0.1025	0.1047	0.1052
0.23125	0.242	0.246	0.10625	0.1083	0.1092
0.31	0.317	0.274	0.121725	0.1223	0.1148
0.42	0.395	0.39	0.143257	0.139	0.138
0.29	0.317	0.34	0.11775	0.123	0.1276
0.2575	0.227	0.232	0.1115	0.1053	0.1064
0.2125	0.217	0.222	0.10175	0.1023	0.1036
0.21375	0.212	0.214	0.1025	0.102	0.1024
0.281111	0.358	0.32	0.115556	0.106	0.124
0.325	0.325	0.35	0.125	0.125	0.13
0.257143	0.282	0.3	0.111143	0.113	0.12
0.205714	0.21	0.214	0.099143	0.1003	0.1012
0.205714	0.208	0.212	0.1	0.1007	0.1016
0.261796021	0.267083333	0.27576	0.110705104	0.111825	0.114256333
0.057687108	0.047295735	0.047203273	0.011025431	0.009092421	0.009411329

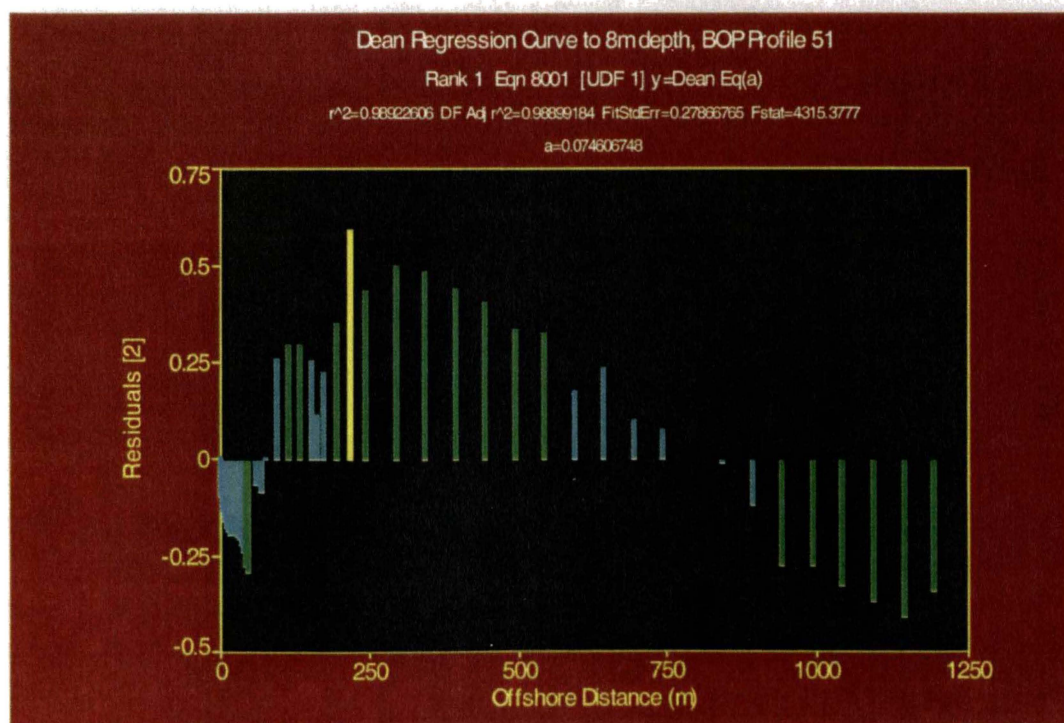
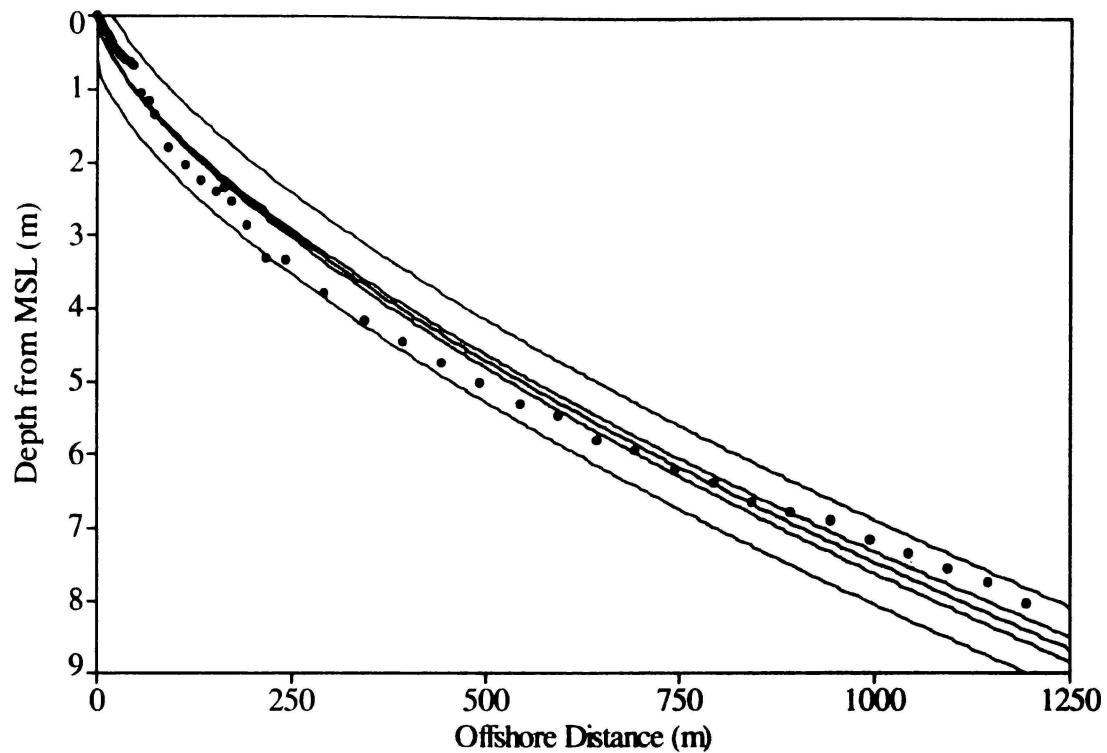


Dean Regression Curve to 8m depth, BOP Profile 51

Rank 1 Eqn 8001 [UDF 1] $y = \text{Dean Eq}(a)$

$r^2 = 0.98922606$ DF Adj $r^2 = 0.98899184$ FitStdErr = 0.27866765 Fstat = 4315.3777

$a = 0.074606748$



Appendix 4 - Least Squares Regression Results

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Rank 1 Eqn 8001 [UDF 1] y=Dean Eq(a)

r^2	Coef Det	DF	Adj r^2	Fit Std Err	F-val
0.9892260591	0.9889918430	0.2786676548	4315.3777335		

Parm	Value	Std Error	t-value	95% Confidence Limits
a	0.074606748	0.000738233	101.0612009	0.073121870 0.076091626

Area Xmin-Xmax		Area Precision	
6015.0955556	1.369816e-08		
Function min	X-Value	Function max	X-Value
1.975293e-08	1.363871e-10	8.3978553754	1193.8000000
1st Deriv min	X-Value	1st Deriv max	X-Value
0.0046899398	1193.8000000	5170748.9665	0.0011937995
2nd Deriv min	X-Value	2nd Deriv max	X-Value
-2.16567e+09	0.0023875990	-1.30813e-06	1193.7655421

Procedure	Error Type	Iterations		
LevMarqdt	Gaussian	7		
r^2	Coef Det	DF	Adj r^2	Fit Std E
0.9892260591	0.9889918430	0.2786676548		
Source	Sum of Squares	DF	Mean Square	F
Regr	335.11351	1	335.11351	4315.38
Error	3.6498161	47	0.077655662	
Total	338.76333	48		

Description: Dean Regression Curve to 8m depth, BOP Profile 51

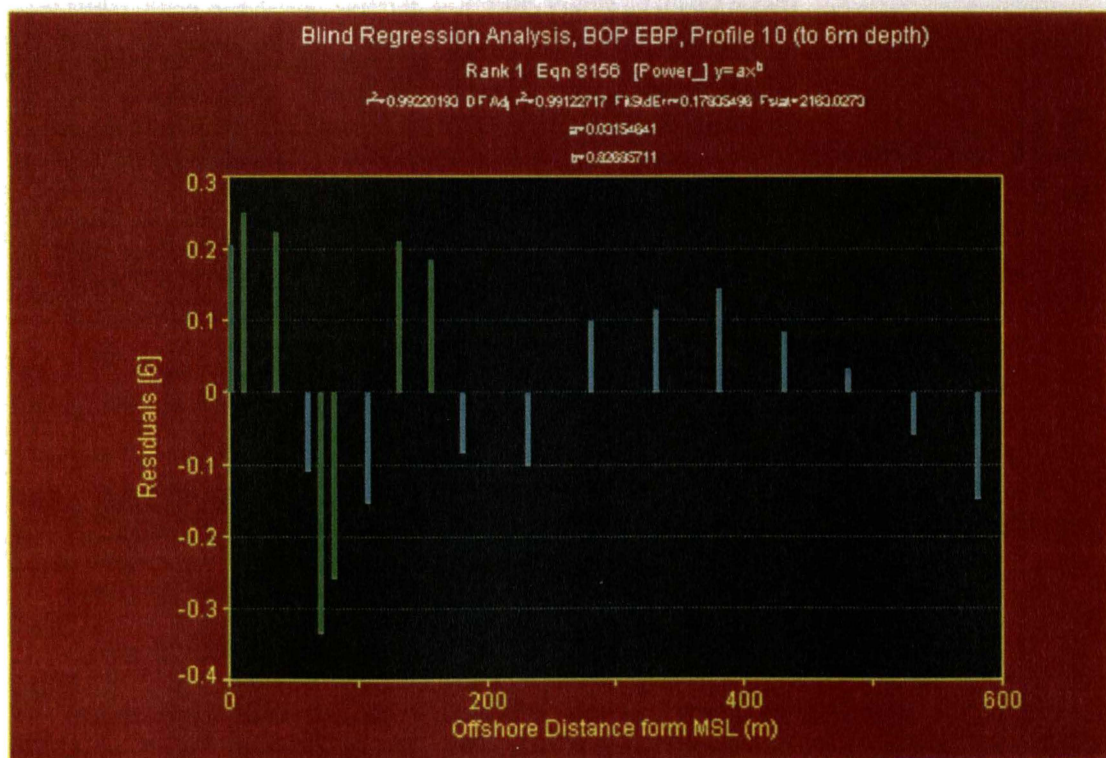
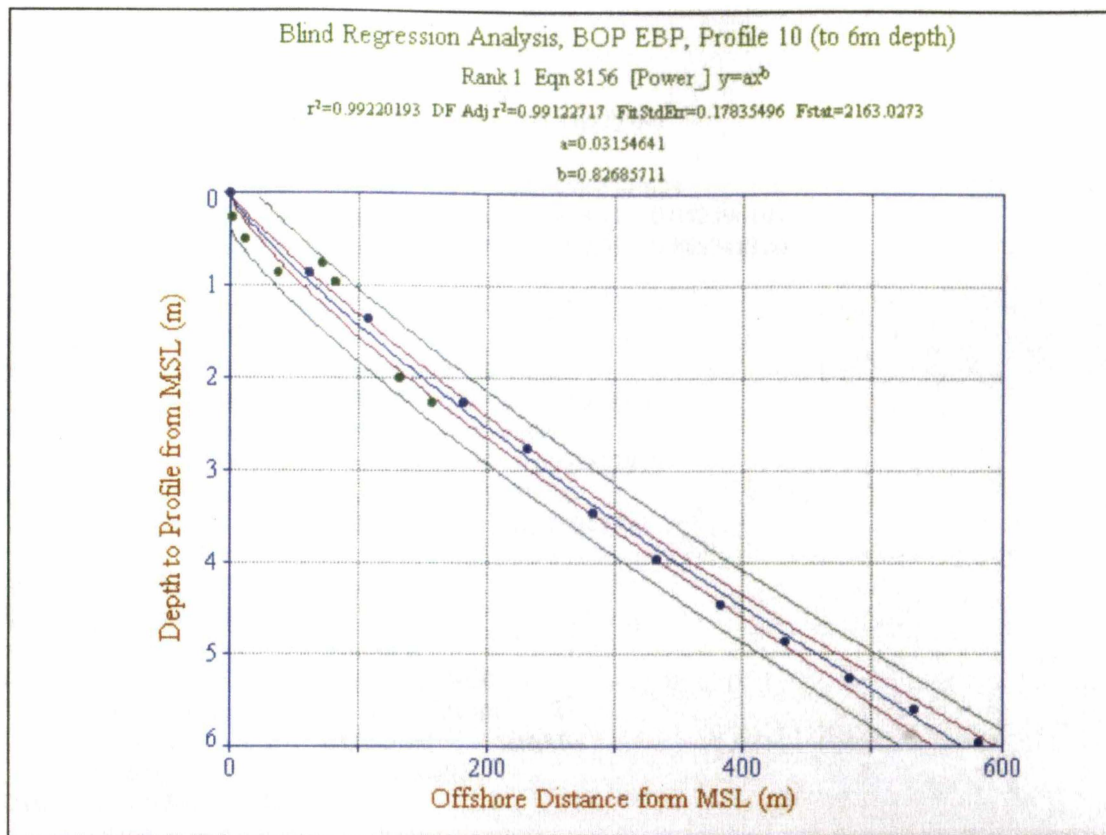
X Variable: Offshore Distance (m)

Xmin: 0.000000000	Xmax: 1193.8000000	Xrange: 1193.8000000
Xmean: 338.17520833	Xstd: 378.67963450	Xmedian: 158.80000000
X@Ymin: 0.000000000	X@Ymax: 1193.8000000	X@Yrange: 1193.8000000

Y Variable: Depth from MSL (m)

Ymin: 0.000000000	Ymax: 8.044000000	Yrange: 8.044000000
Ymean: 3.089000000	Ystd: 2.6847216663	Ymedian: 2.369000000
Y@Xmin: 0.000000000	Y@Xmax: 8.044000000	Y@Xrange: 8.044000000

Date	Time	File Source
Jun 27, 2001	2:51:37 PM	c:\beaches\bop\dean_reg\profil51\bop(8)\profil51.xls



Rank 1 Eqn 8156 [Power_] $y=ax^b$

r^2 Coef Det DF Adj r^2 Fit Std Err F-val
0.9922019324 0.9912271739 0.1783549620 2163.0272569

Parm	Value	Std Error	t-value	95% Confidence Limits
a	0.031546410	0.005230668	6.031047812	0.020496711 0.042596109
b	0.826857109	0.027685436	29.86614047	0.768372092 0.885342126

Area Xmin-Xmax Area Precision

1944.3454873 6.673863e-09
Function min X-Value Function max X-Value
2.846519e-10 1.865636e-10 6.1000195246 582.30000000
1st Deriv min X-Value 1st Deriv max X-Value
0.0086619346 582.30000000 0.1016062779 0.0005822999
2nd Deriv min X-Value 2nd Deriv max X-Value
-19.73340158 0.0011645987 -2.57557e-06 582.29941770

Procedure Error Type Iterations

LevMarqdt Gaussian 8

r^2 Coef Det DF Adj r^2 Fit Std E
0.9922019324 0.9912271739 0.1783549620

Source	Sum of Squares	DF	Mean Square	F
Regr	68.806962	1	68.806962	2163.03
Error	0.54077837	17	0.031810492	
Total	69.347741	18		

Description: Blind Regression Analysis, BOP EBP, Profile 10 (to 6m depth)

X Variable: Offshore Distance form MSL (m)

Xmin: 0.0000000000 Xmax: 582.30000000 Xrange: 582.30000000
Xmean: 216.09000000 Xstd: 189.93619516 Xmedian: 157.30000000
X@Ymin: 0.0000000000 X@Ymax: 582.30000000 X@Yrange: 582.30000000

Y Variable: Depth to Profile from MSL (m)

Ymin: 0.0000000000 Ymax: 5.9480000000 Yrange: 5.9480000000
Ymean: 2.5375789474 Ystd: 1.9628174284 Ymedian: 2.2480000000
Y@Xmin: 0.0000000000 Y@Xmax: 5.9480000000 Y@Xrange: 5.9480000000

Date Time File Source

Jan 25, 1998 3:43:33 PM c:\beaches\bop\dean_reg\profil10\bop(6)\profil10.xls

Rank 1 Eqn 8156 [Power_] $y=ax^b$

XY	* X Value	Y Value	Y Predict	Residual	Residual%	95% Confidence Limits	95% Prediction Limits
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	-7.42e-12 7.415e-12	-0.376772 0.3767719
2	1.6100000	0.2480000	0.0467698	0.2012302	81.141215	0.0316862 0.0618534	-0.330304 0.4238434
3	12.3000000	0.4980000	0.2512729	0.2467271	49.543585	0.1999483 0.3025976	-0.128979 0.6315245

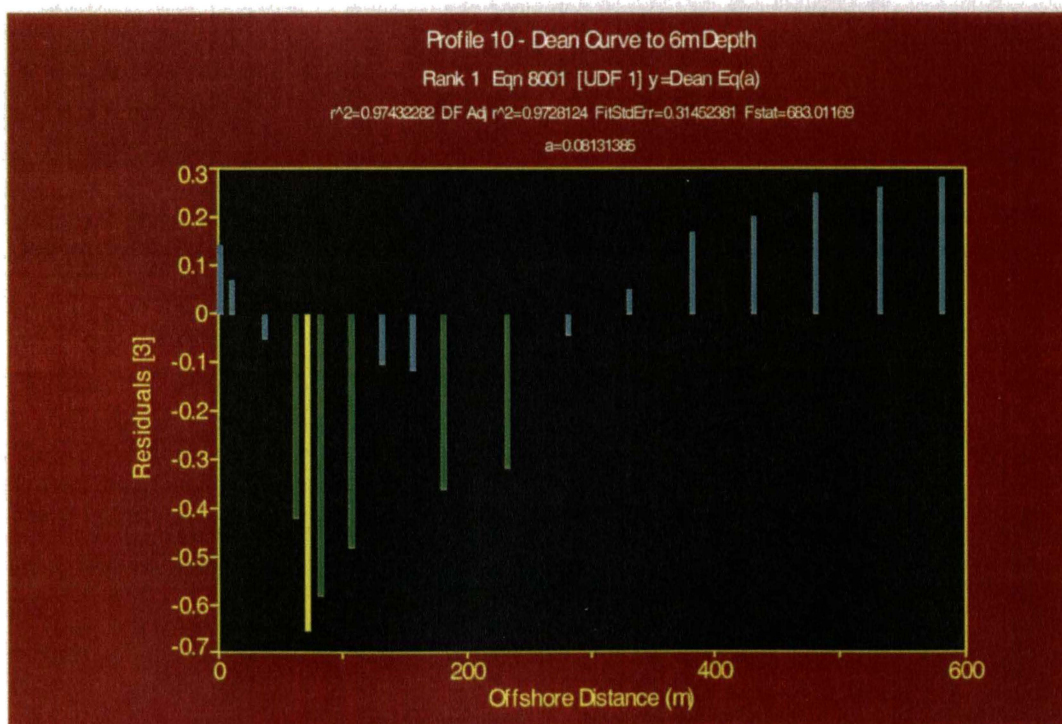
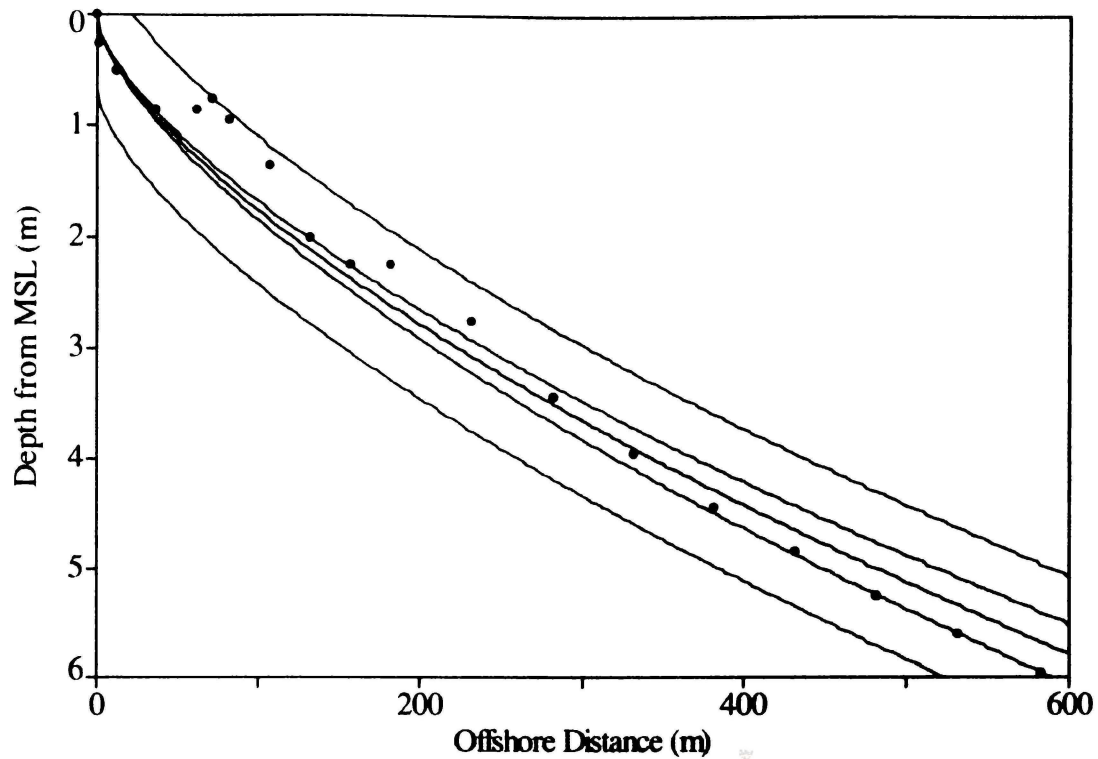
4	37.300000	0.8480000	0.6288232	0.2191768	25.846319	0.5406478	0.7169987	0.2418711
	1.0157753	1						
5	62.300000	0.8480000	0.9610260	-0.113026	-13.32854	0.8544027	1.0676493	0.5694579
	1.3525941	1						
6	72.300000	0.7480000	1.0869052	-0.338905	-45.30818	0.9754647	1.1983457	0.6939981
	1.4798123	1						
7	82.300000	0.9480000	1.2097954	-0.261795	-27.61554	1.0945656	1.3250252	0.8157967
	1.6037940	1						
8	107.30000	1.3480000	1.5064883	-0.158488	-11.75729	1.3852088	1.6277677	1.1106781
	1.9022985	1						
9	132.30000	1.9980000	1.7913349	0.2066651	10.343599	1.6675481	1.9151217	1.3947492
	2.1879206	1						
10	157.30000	2.2480000	2.0669535	0.1810465	8.0536702	1.9430731	2.1908339	1.6703386
	2.4635684	1						
11	182.30000	2.2480000	2.3350569	-0.087057	-3.872639	2.2127054	2.4574085	1.9389169
	2.7311970	1						
12	232.30000	2.7480000	2.8532154	-0.105215	-3.828798	2.7363498	2.9700809	2.4587352
	3.2476955	1						
13	282.30000	3.4480000	3.3522597	0.0957403	2.7766909	3.2405538	3.4639656	2.9592772
	3.7452422	1						
14	332.30000	3.9480000	3.8361469	0.1118531	2.8331579	3.7252588	3.9470350	3.4433961
	4.2288977	1						
15	382.30000	4.4480000	4.3075398	0.1404602	3.1578288	4.1899895	4.4250901	3.9128562
	4.7022233	1						
16	432.30000	4.8480000	4.7683454	0.0796546	1.6430410	4.6355444	4.9011463	4.3688543
	5.1678365	1						
17	482.30000	5.2480000	5.2199927	0.0280073	0.5336752	5.0642489	5.3757365	4.8123002
	5.6276852	1						
18	532.30000	5.5980000	5.6635899	-0.065590	-1.171667	5.4788818	5.8482980	5.2439780
	6.0832018	1						
19	582.30000	5.9480000	6.1000195	-0.152020	-2.555809	5.8818348	6.3182042	5.6646328
	6.5354062	1						

Profile 10 - Dean Curve to 6m Depth

Rank 1 Eqn 8001 [UDF 1] $y = \text{Dean Eq}(a)$

$r^2 = 0.97432282$ DF Adj $r^2 = 0.9728124$ FitStdErr = 0.31452381 Fstat = 683.01169

$a = 0.08131385$



Rank 1 Eqn 8001 [UDF 1] y=Dean Eq(a)

r^2 Coef Det DF Adj r^2 Fit Std Err F-val
0.9743228246 0.9728124025 0.3145238112 683.01168510

Parm Value Std Error t-value 95% Confidence Limits
a 0.081313850 0.001855836 43.81520694 0.077411190 0.085216510

Area Xmin-Xmax Area Precision

1981.4231974 1.369816e-08
Function min X-Value Function max X-Value
2.652925e-08 1.865636e-10 5.6713687756 582.30000000
1st Deriv min X-Value 1st Deriv max X-Value
0.0064933910 582.30000000 1.060079e+07 0.0005822991
2nd Deriv min X-Value 2nd Deriv max X-Value
-9.10252e+09 0.0011645995 -3.7137e-06 582.17618925

Procedure Error Type Iterations

LevMarqdt Gaussian 7
r^2 Coef Det DF Adj r^2 Fit Std E
0.9743228246 0.9728124025 0.3145238112
Source Sum of Squares DF Mean Square F
Regr 67.567087 1 67.567087 683.012
Error 1.7806541 18 0.098925228
Total 69.347741 19

Description: Profile 10 - Dean Curve to 6m Depth

X Variable: Offshore Distance (m)

Xmin: 0.000000000 Xmax: 582.3000000 Xrange: 582.3000000
Xmean: 216.0900000 Xstd: 189.93619516 Xmedian: 157.3000000
X@Ymin: 0.000000000 X@Ymax: 582.3000000 X@Yrange: 582.3000000

Y Variable: Depth from MSL (m)

Ymin: 0.000000000 Ymax: 5.948000000 Yrange: 5.948000000
Ymean: 2.5375789474 Ystd: 1.9628174284 Ymedian: 2.248000000
Y@Xmin: 0.000000000 Y@Xmax: 5.948000000 Y@Xrange: 5.948000000

Date Time File Source

Apr 29, 1980 2:50:32 PM c:\beaches\bop\dean_reg\profil10\bop(6)\profil10.xls

Rank 1 Eqn 8001 [UDF 1] y=Dean Eq(a)

r^2 Coef Det DF Adj r^2 Fit Std Err F-val
0.9878643138 0.9873586602 0.3037673530 2035.0400846

Parm Value Std Error t-value 95% Confidence Limits
a 0.084684945 0.001078118 78.54885248 0.082464175 0.086905714

Area Xmin-Xmax Area Precision

4521.7571318 1.369816e-08
Function min X-Value Function max X-Value
2.743557e-08 1.84607e-10 8.0836775718 932.30000000
1st Deriv min X-Value 1st Deriv max X-Value
0.0057807442 932.30000000 6621087.7307 0.0009322986
2nd Deriv min X-Value 2nd Deriv max X-Value
-3.55094e+09 0.0018645992 -2.06517e-06 932.18553720

Procedure Error Type Iterations

LevMarqdt Gaussian 7
r^2 Coef Det DF Adj r^2 Fit Std E
0.9878643138 0.9873586602 0.3037673530
Source Sum of Squares DF Mean Square F
Regr 187.78252 1 187.78252 2035.04
Error 2.3068651 25 0.092274605
Total 190.08938 26

Description: Dean Regression Curve to 8m depth, BOP Profile 10

X Variable: Depth from MSL (m)

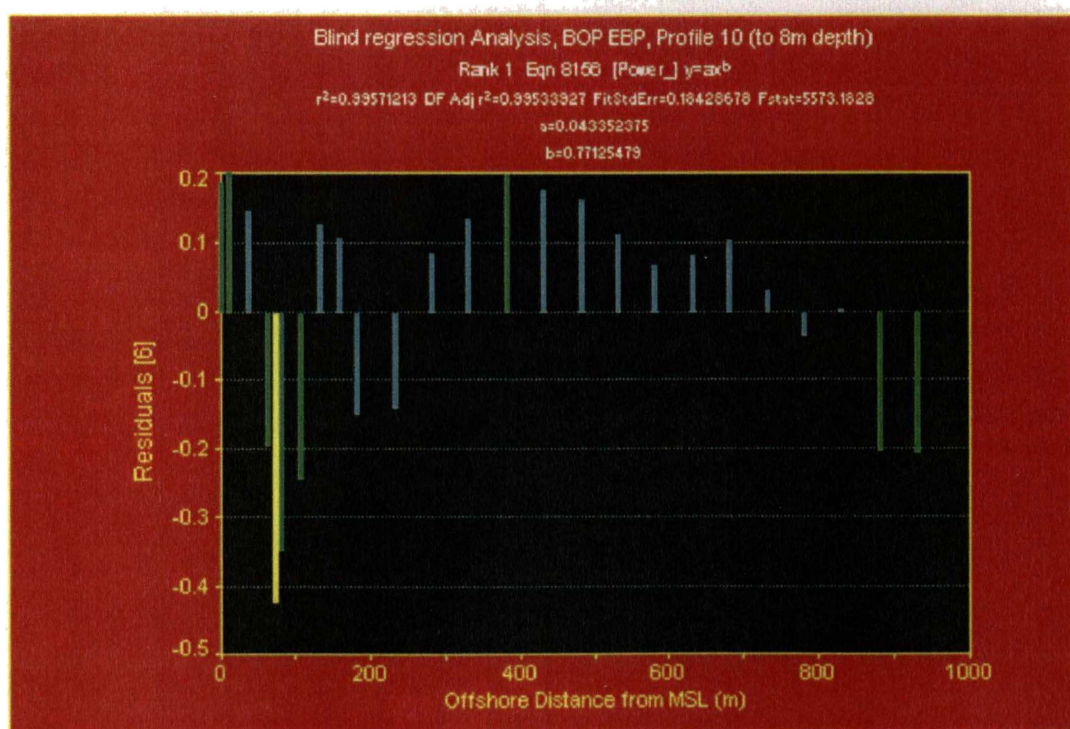
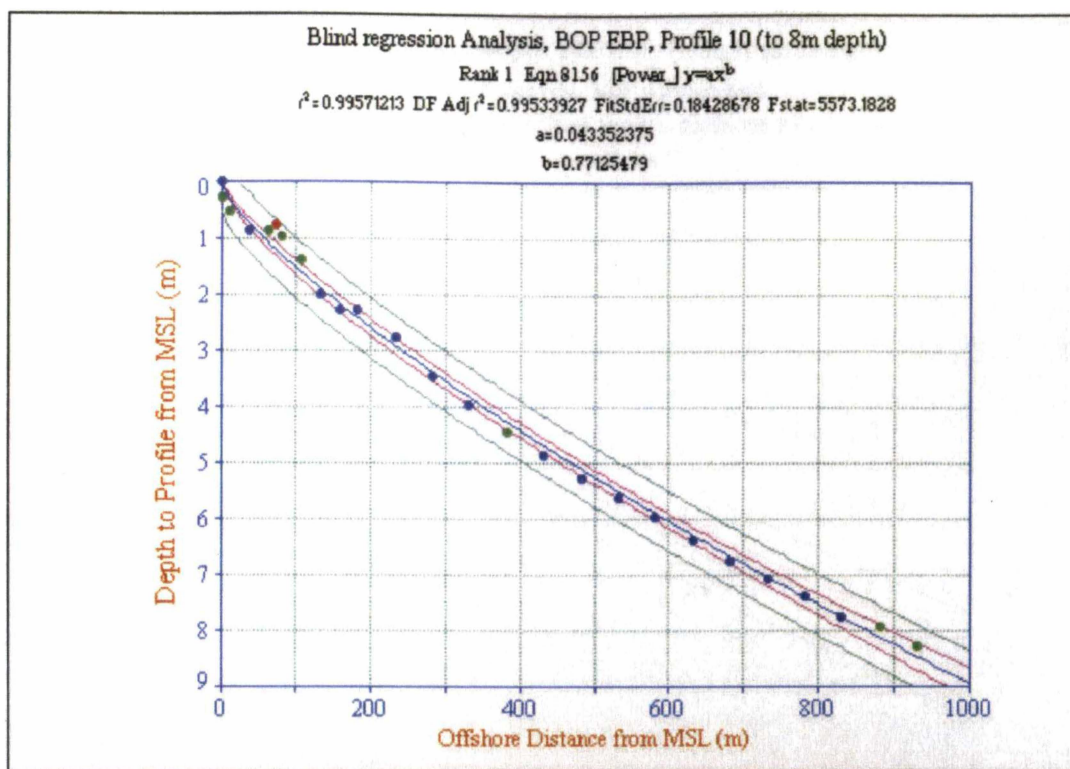
Xmin: 0.0000000000 Xmax: 932.30000000 Xrange: 932.30000000
Xmean: 368.53115385 Xstd: 307.20182661 Xmedian: 307.30000000
X@Ymin: 0.0000000000 X@Ymax: 932.30000000 X@Yrange: 932.30000000

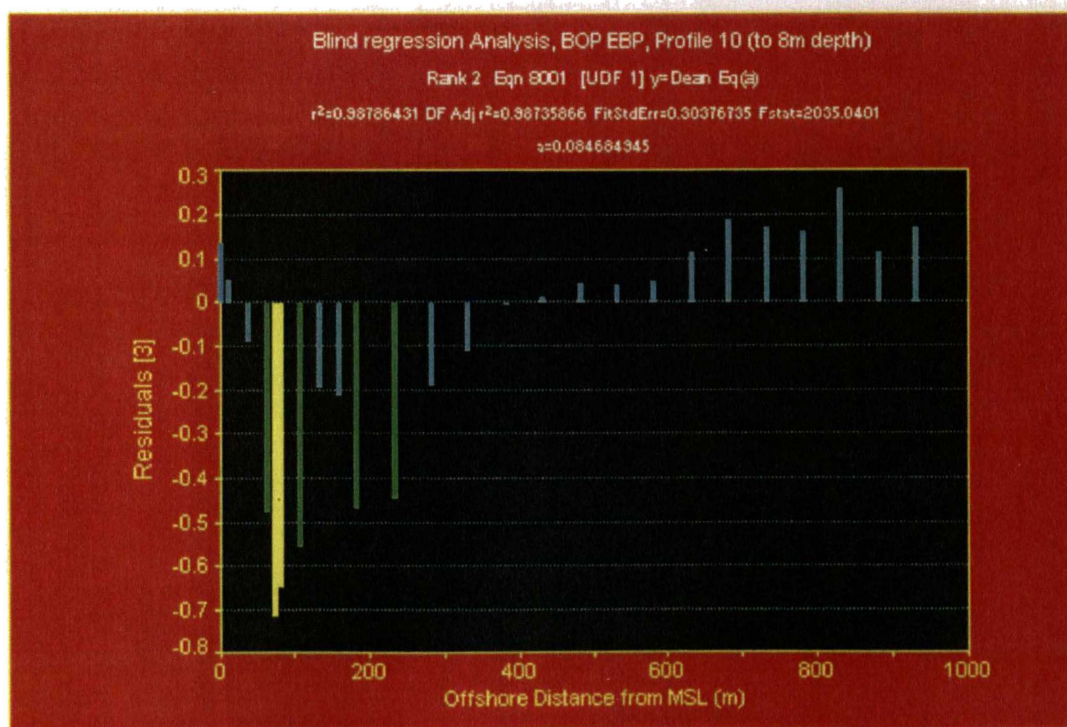
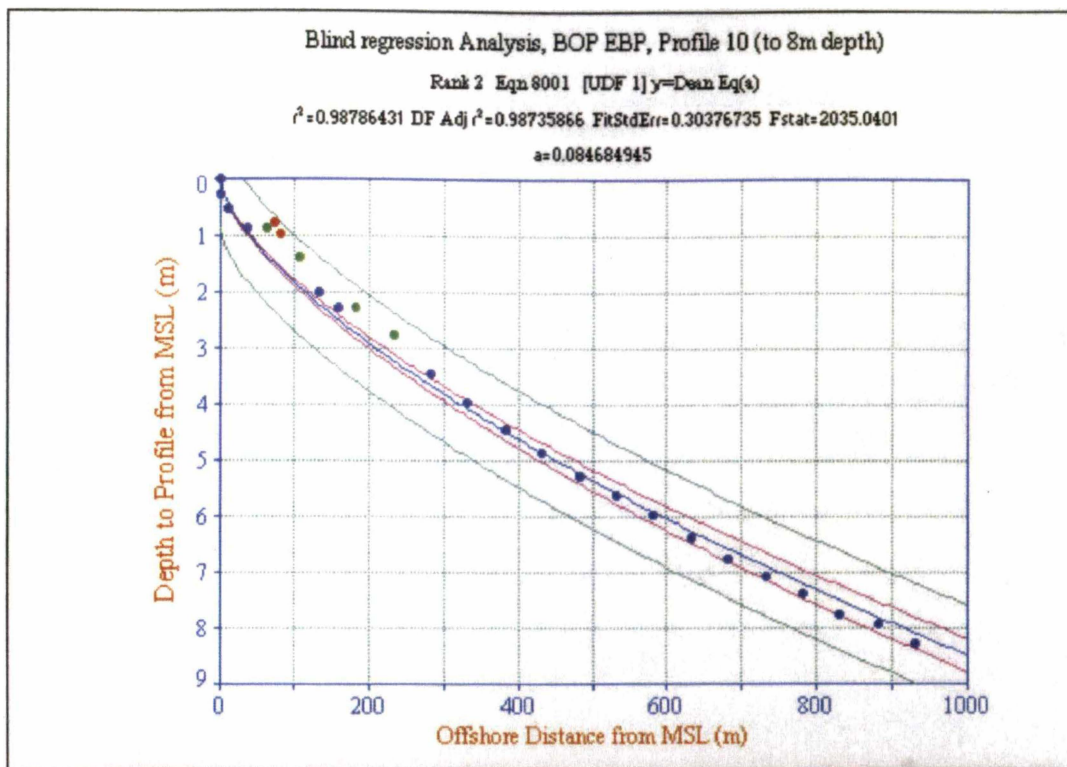
Y Variable: Offshore Distance (m)

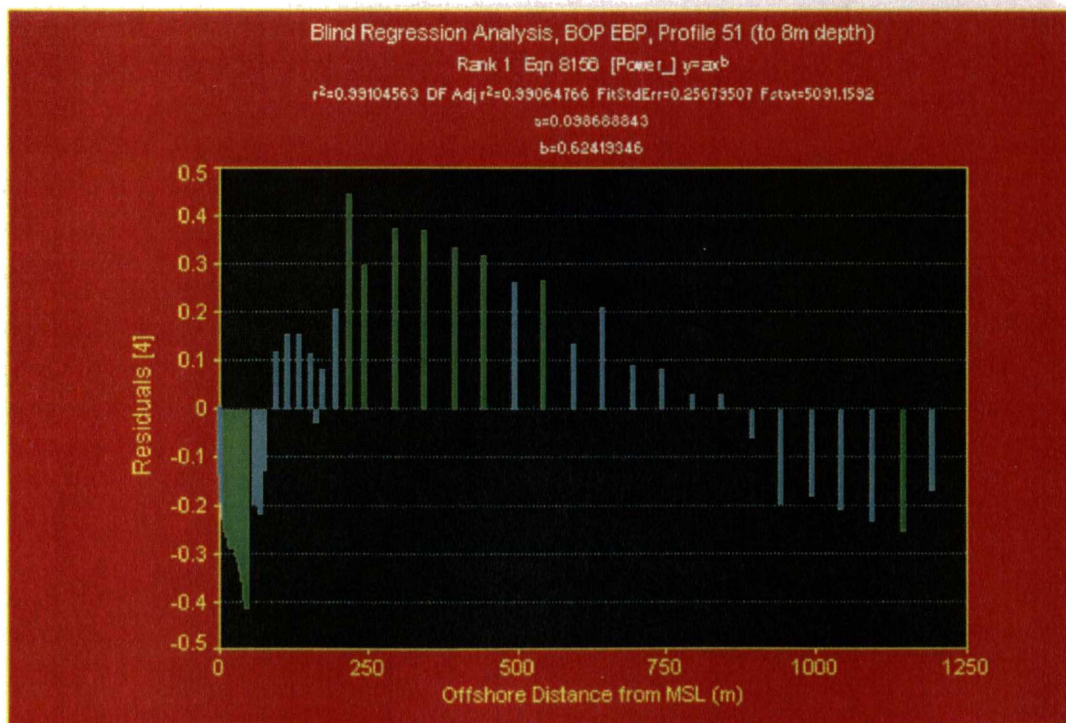
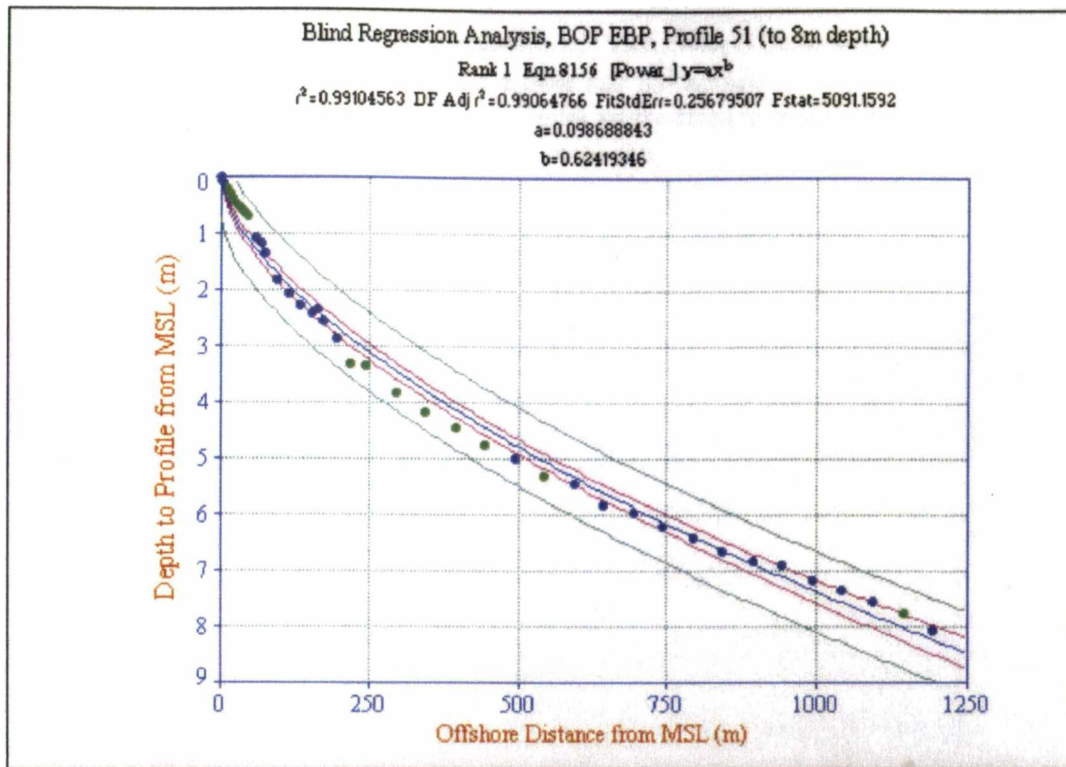
Ymin: 0.0000000000 Ymax: 8.2480000000 Yrange: 8.2480000000
Ymean: 3.8307692308 Ystd: 2.7574581383 Ymedian: 3.6980000000
Y@Xmin: 0.0000000000 Y@Xmax: 8.2480000000 Y@Xrange: 8.2480000000

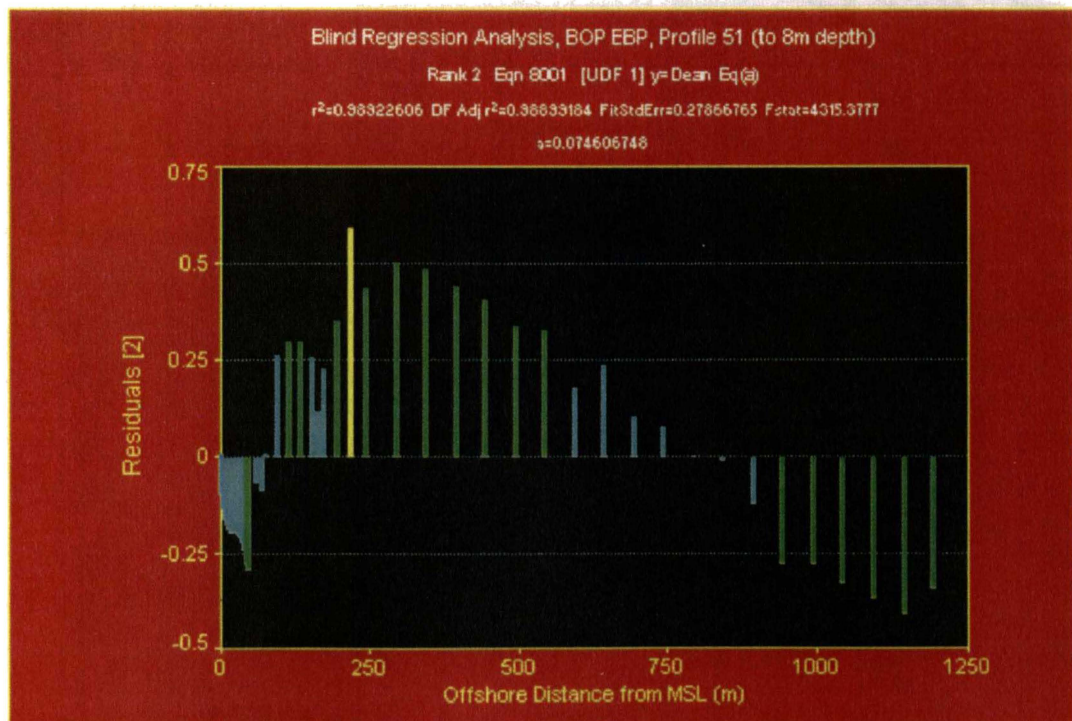
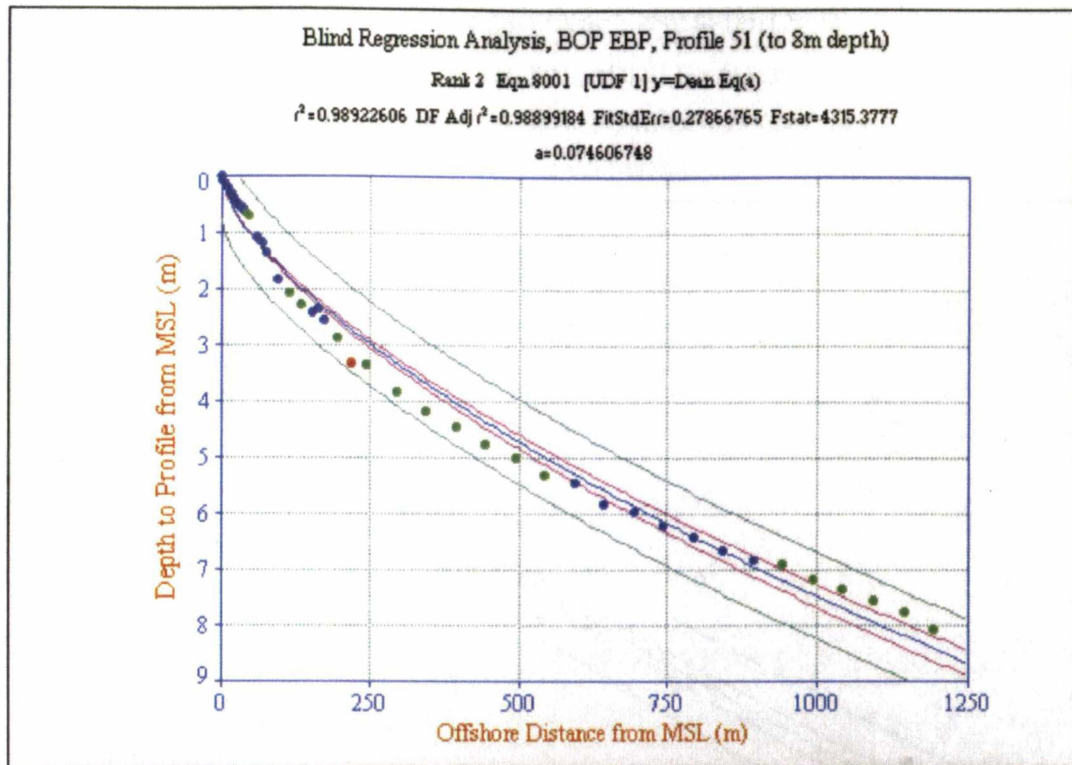
Date Time File Source

Jun 26, 2001 9:10:06 PM c:\beaches\bop\dean_reg\profil10\bop(8)\profil10.xls







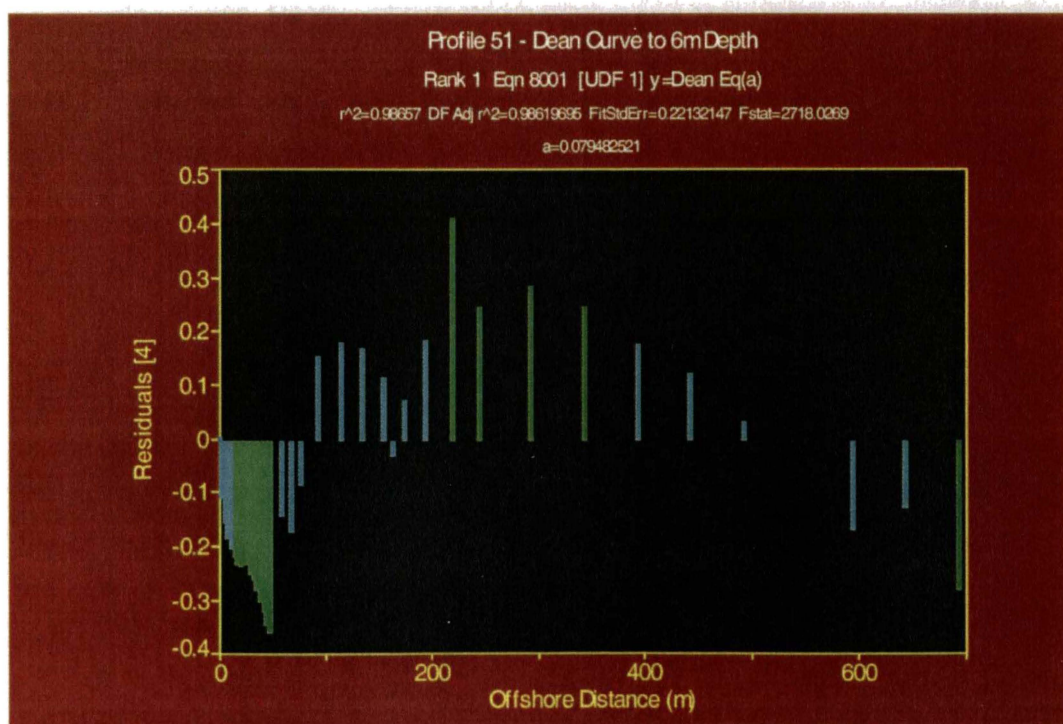
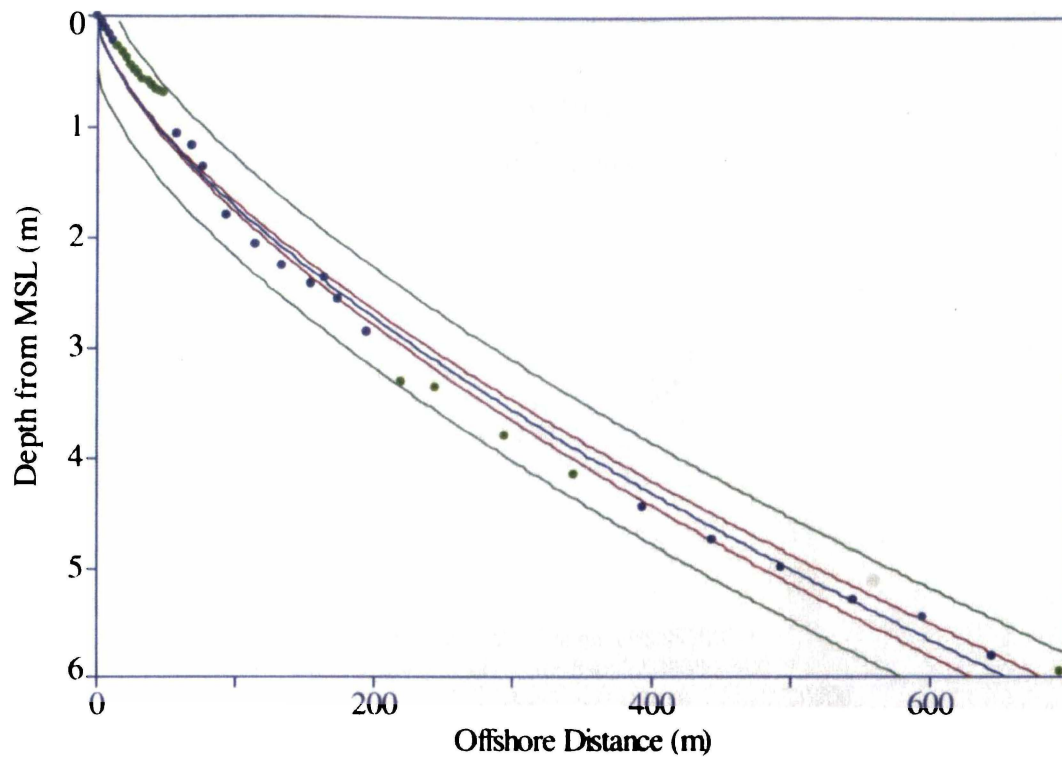


Profile 51 - Dean Curve to 6m Depth

Rank 1 Eqn 8001 [UDF 1] $y = \text{Dean Eq}(a)$

$r^2=0.98657$ DF Adj $r^2=0.98619695$ FitStdErr=0.22132147 Fstat=2718.0269

$a=0.079482521$



Rank 1 Eqn 8001 [UDF 1] y=Dean Eq(a)

r^2 Coef Det DF Adj r^2 Fit Std Err F-val
0.9865700040 0.9861969485 0.2213214708 2718.0268733

Parm Value Std Error t-value 95% Confidence Limits
a 0.079482521 0.001030634 77.12001738 0.077394563 0.081570479

Area Xmin-Xmax Area Precision
2593.5785183 1.369816e-08
Function min X-Value Function max X-Value
1.956717e-08 1.22287e-10 6.2304948253 693.80000000
1st Deriv min X-Value 1st Deriv max X-Value
0.0059871302 693.80000000 8897146.0713 0.0006937990
2nd Deriv min X-Value 2nd Deriv max X-Value
-6.4119e+09 0.0013875994 -2.87244e-06 693.73966765

Procedure Error Type Iterations
LevMarqdt Gaussian 7
r^2 Coef Det DF Adj r^2 Fit Std E
0.9865700040 0.9861969485 0.2213214708
Source Sum of Squares DF Mean Square F
Regr 133.13764 1 133.13764 2718.03
Error 1.8123782 37 0.048983193
Total 134.95001 38

Description: Profile 51 - Dean Curve to 6m Depth

X Variable: Offshore Distance (m)
Xmin: 0.0000000000 Xmax: 693.80000000 Xrange: 693.80000000
Xmean: 172.22131579 Xstd: 202.01992241 Xmedian: 72.480000000
X@Ymin: 0.0000000000 X@Ymax: 693.80000000 X@Yrange: 693.80000000

Y Variable: Depth from MSL (m)
Ymin: 0.0000000000 Ymax: 5.9440000000 Yrange: 5.9440000000
Ymean: 2.0403157895 Ystd: 1.9097899574 Ymedian: 1.2485000000
Y@Xmin: 0.0000000000 Y@Xmax: 5.9440000000 Y@Xrange: 5.9440000000

Date Time File Source
May 2, 2001 3:06:31 PM c:\beaches\bop\dean_reg\profil51\bop(6)\profil51.xls

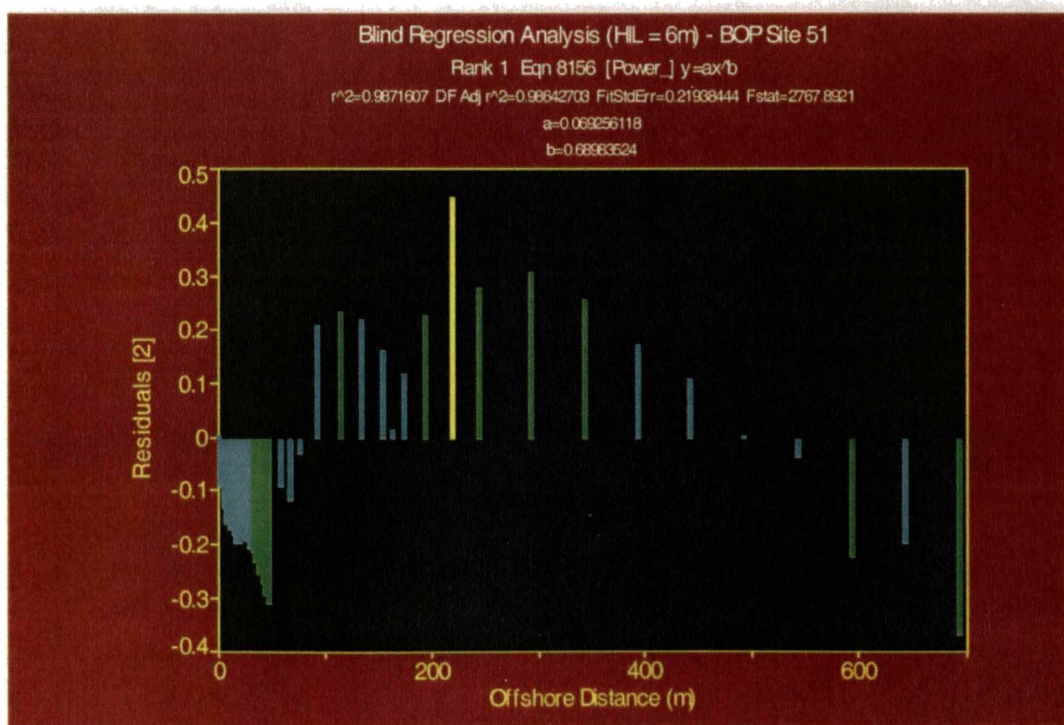
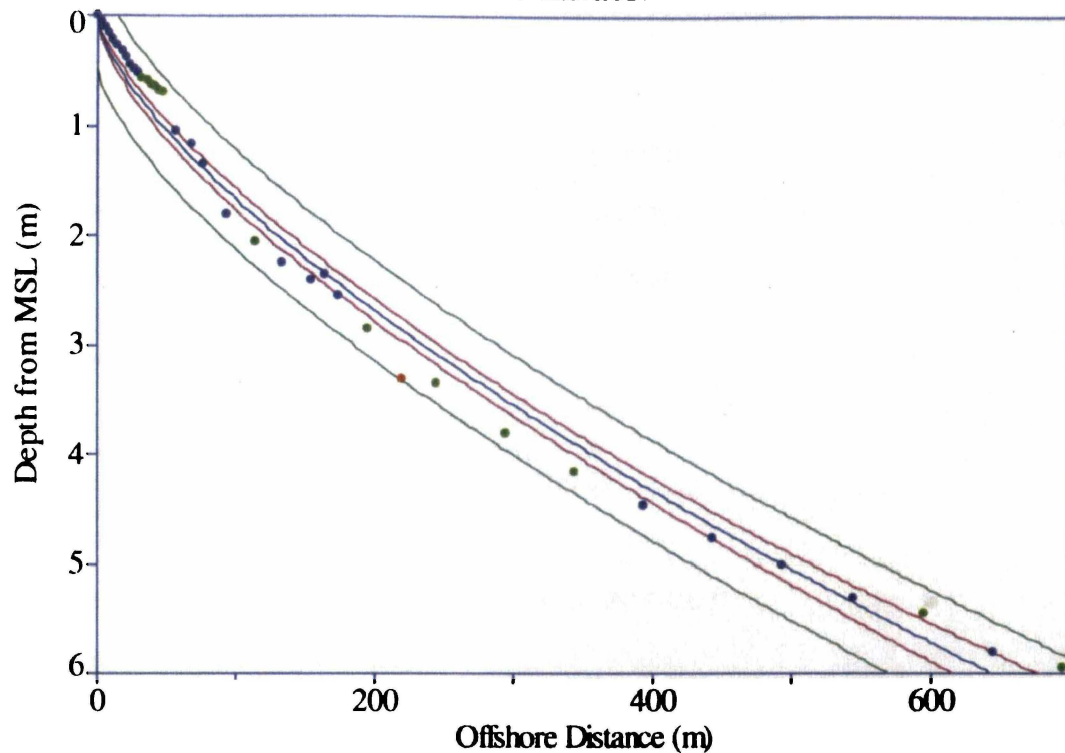
Blind Regression Analysis (HIL = 6m) - BOP Site 51

Rank 1 Eqn 8156 [Power_] $y = ax^b$

$r^2=0.9871607$ DF Adj $r^2=0.98642703$ FitStdErr=0.21938444 Fstat=2767.8921

$a=0.069256118$

$b=0.68983524$



Rank 1 Eqn 8156 [Power_] $y=ax^b$

r^2 Coef Det DF Adj r^2 Fit Std Err F-val
0.9871607040 0.9864270300 0.2193844401 2767.8920597

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.069256118	0.008004563	8.652080298	0.053024344	0.085487892
b	0.689835243	0.019241520	35.85139038	0.650816996	0.728853490

Area Xmin-Xmax Area Precision

2593.1738111 1.052242e-08

Function min X-Value Function max X-Value

1.005504e-08 1.22287e-10 6.3159937914 693.80000000

1st Deriv min X-Value 1st Deriv max X-Value

0.0062799007 693.80000000 0.5331223578 0.0006937993

2nd Deriv min X-Value 2nd Deriv max X-Value

-148.6487734 0.0013875986 -2.80463e-06 693.80000000

Procedure Error Type Iterations

LevMarqdt Gaussian 9

r^2 Coef Det DF Adj r^2 Fit Std E

0.9871607040 0.9864270300 0.2193844401

Source	Sum of Squares	DF	Mean Square	F
Regr	133.21735	1	133.21735	2767.89
Error	1.7326632	36	0.048129533	
Total	134.95001	37		

Description: Blind Regression Analysis (HIL = 6m) - BOP Site 51

X Variable: Offshore Distance (m)

Xmin: 0.0000000000 Xmax: 693.80000000 Xrange: 693.80000000

Xmean: 172.22131579 Xstd: 202.01992241 Xmedian: 72.48000000

X@Ymin: 0.0000000000 X@Ymax: 693.80000000 X@Yrange: 693.80000000

Y Variable: Depth from MSL (m)

Ymin: 0.0000000000 Ymax: 5.9440000000 Yrange: 5.9440000000

Ymean: 2.0403157895 Ystd: 1.9097899574 Ymedian: 1.2485000000

Y@Xmin: 0.0000000000 Y@Xmax: 5.9440000000 Y@Xrange: 5.9440000000

Date Time File Source

May 25, 2001 4:10:35 PM c:\beaches\bop\dean_reg\profil51\bop(6)\profil51.xls

Appendix 5

SYSTAT output for Student t Tests of scale and shape
factor data, and sediment data

Appendix 5 - Notes

This appendix contains results from Student *t* tests applied to the BoP regression and sediment derived Dean (1977) shape (*m*) and scale factor (*A*) data. The first set of results (pages 438-459) summarises the analysis to determine an appropriate shape factor applicable to the BoP profile data, including a one-sample *t* test to determine whether the BoP results are significantly different from data obtained by Dean for the US (Dean, 1977).

The second set of results (pages 461-467) include 2 sample *t* tests comparing the significance of differences obtained between regression and sediment derived scale factors (*A*) for the BoP data with and without outlier profiles removed (i.e. ebb tidal delta profiles). A summary of the regression analysis results for the Dean profile fit to determine scale factor values for all profiles is shown in the table on p 460.

shape

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Table showing Descriptive Statistics for Regression derived Dean's Shape Factor
'm' (exponent)
for the BOP Dataset to Full profile depth, and 8 and 6 m Closure Depths.

	VAR(1)	FULL(1)	V8M(1)	V6M(1)	FULL(2)
N of cases	48	48	48	48	42
Minimum	1.000	0.453	0.356	0.323	0.480
Maximum	51.000	0.981	1.061	1.247	0.981
Range	50.000	0.528	0.706	0.924	0.500
Sum	1208.000	34.093	33.646	35.002	29.788
Median	24.500	0.711	0.695	0.740	0.711
Mean	25.167	0.710	0.701	0.729	0.709
95% CI Upper	29.464	0.742	0.738	0.774	0.740
95% CI Lower	20.869	0.678	0.664	0.684	0.678
Std. Error	2.136	0.016	0.019	0.022	0.015
Standard Dev	14.800	0.111	0.129	0.156	0.099
Variance	219.035	0.012	0.017	0.024	0.010
C.V.	0.588	0.156	0.184	0.213	0.139
Skewness(G1)	0.072	0.057	0.118	0.579	0.088
SE Skewness	0.343	0.343	0.343	0.343	0.365
Kurtosis(G2)	-1.210	0.331	1.325	3.263	0.413
SE Kurtosis	0.674	0.674	0.674	0.674	0.717

	V8M(2)	V6M(2)
N of cases	41	41
Minimum	0.449	0.550
Maximum	0.929	0.893
Range	0.481	0.343
Sum	28.707	30.040
Median	0.695	0.740
Mean	0.700	0.733
95% CI Upper	0.729	0.760
95% CI Lower	0.671	0.706
Std. Error	0.014	0.013
Standard Dev	0.091	0.086
Variance	0.008	0.007
C.V.	0.131	0.117
Skewness(G1)	-0.152	-0.207
SE Skewness	0.369	0.369
Kurtosis(G2)	0.834	-0.294
SE Kurtosis	0.724	0.724

One-sample t test of FULL(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.710	95.00% CI =	0.678 to	0.742
SD =	0.111	t =	2.516	
		DF =	47	Prob =
				0.015

One-sample t test of V8M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.701	95.00% CI =	0.664 to	0.738
SD =	0.129	t =	1.666	
		DF =	47	Prob =
				0.102

One-sample t test of V6M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.729	95.00% CI =	0.684 to	0.774
SD =	0.156	t =	2.635	

		shape			
		DF =	47	Prob =	0.011
One-sample t test of FULL(2) with 42 cases; Ho: Mean = 0.670					
Mean =	0.709	95.00% CI =	0.678 to	0.740	
SD =	0.099		t =	2.572	
		DF =	41	Prob =	0.014
One-sample t test of V8M(2) with 41 cases; Ho: Mean = 0.670					
Mean =	0.700	95.00% CI =	0.671 to	0.729	
SD =	0.091		t =	2.115	
		DF =	40	Prob =	0.041
One-sample t test of V6M(2) with 41 cases; Ho: Mean = 0.670					
Mean =	0.733	95.00% CI =	0.706 to	0.760	
SD =	0.086		t =	4.669	
		DF =	40	Prob =	0.000

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One-sample t test of FULL(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.710	95.00% CI =	0.678 to	0.742
SD =	0.111		t =	2.516
		DF =	47	Prob = 0.015

One-sample t test of V8M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.701	95.00% CI =	0.664 to	0.738
SD =	0.129		t =	1.666
		DF =	47	Prob = 0.102

One-sample t test of V6M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.729	95.00% CI =	0.684 to	0.774
SD =	0.156		t =	2.635
		DF =	47	Prob = 0.011

One-sample t test of FULL(2) with 42 cases; Ho: Mean = 0.670

Mean =	0.709	95.00% CI =	0.678 to	0.740
SD =	0.099		t =	2.572
		DF =	41	Prob = 0.014

One-sample t test of V8M(2) with 41 cases; Ho: Mean = 0.670

Mean =	0.700	95.00% CI =	0.671 to	0.729
SD =	0.091		t =	2.115
		DF =	40	Prob = 0.041

One-sample t test of V6M(2) with 41 cases; Ho: Mean = 0.670

Mean =	0.733	95.00% CI =	0.706 to	0.760
SD =	0.086		t =	4.669
		DF =	40	Prob = 0.000

One-sample t test of FULL(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.710	90.00% CI =	0.683 to	0.737
SD =	0.111		t =	2.516
		DF =	47	Prob = 0.015

One-sample t test of V8M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.701	90.00% CI =	0.670 to	0.732
SD =	0.129		t =	1.666
		DF =	47	Prob = 0.102

One-sample t test of V6M(1) with 48 cases; Ho: Mean = 0.670

Mean =	0.729	90.00% CI =	0.692 to	0.767
SD =	0.156		t =	2.635
		DF =	47	Prob = 0.011

One-sample t test of FULL(2) with 42 cases; Ho: Mean = 0.670

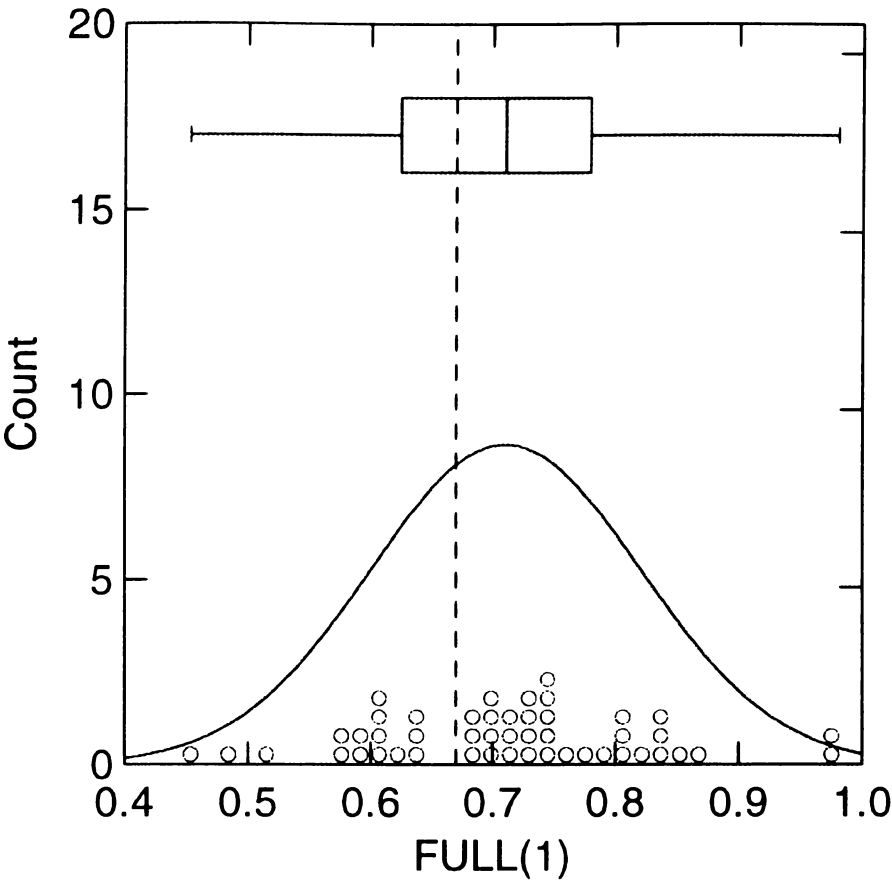
Mean =	0.709	90.00% CI =	0.684 to	0.735
SD =	0.099		t =	2.572
		DF =	41	Prob = 0.014

One-sample t test of V8M(2) with 41 cases; Ho: Mean = 0.670

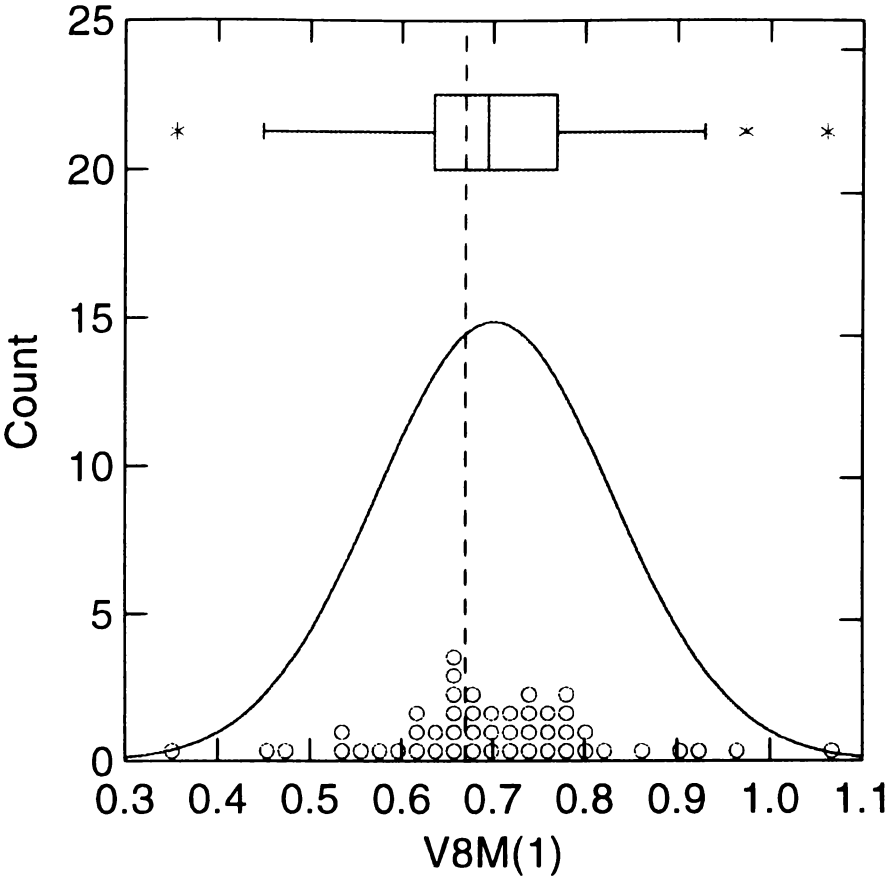
Mean =	0.700	90.00% CI =	0.676 to	0.724
SD =	0.091		t =	2.115

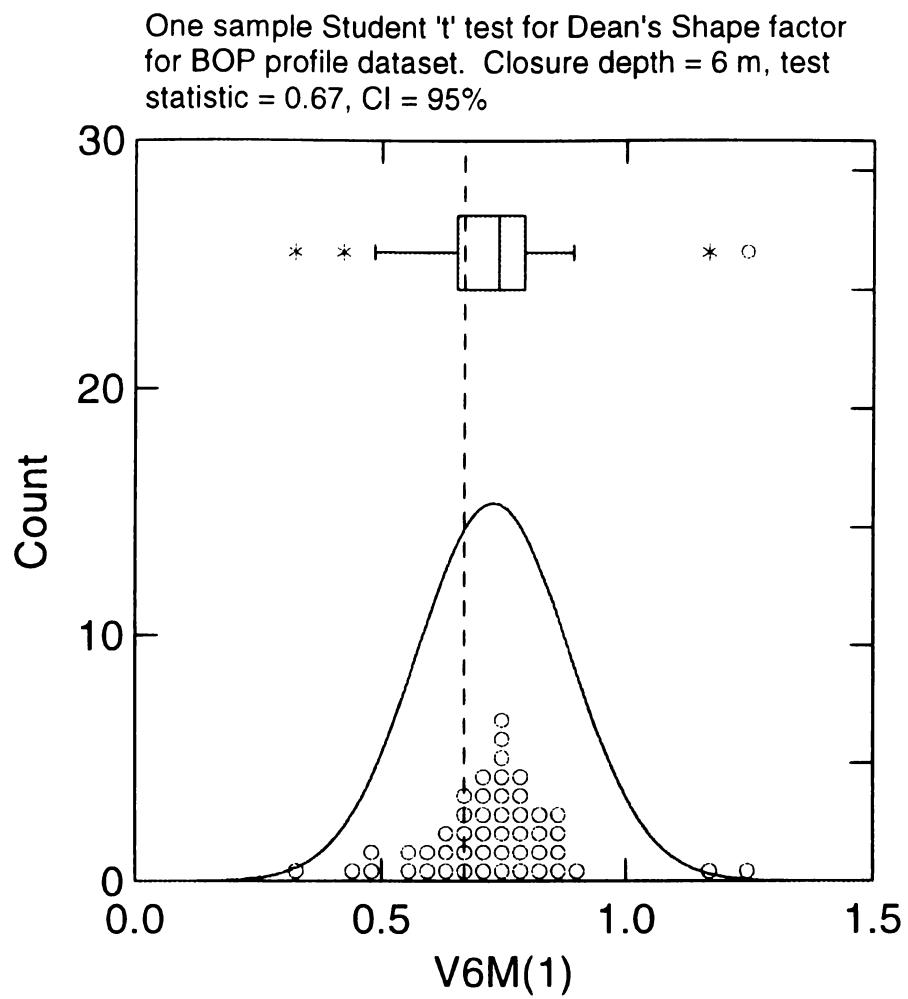
	DF =	40	Prob =	0.041
One-sample t test of V6M(2) with 41 cases; Ho: Mean = 0.670				
Mean =	0.733	90.00% CI =	0.710 to	0.755
SD =	0.086		t =	4.669
	DF =	40	Prob =	0.000
One-sample t test of FULL(1) with 48 cases; Ho: Mean = 0.670				
Mean =	0.710	99.00% CI =	0.667 to	0.753
SD =	0.111		t =	2.516
	DF =	47	Prob =	0.015
One-sample t test of V8M(1) with 48 cases; Ho: Mean = 0.670				
Mean =	0.701	99.00% CI =	0.651 to	0.751
SD =	0.129		t =	1.666
	DF =	47	Prob =	0.102
One-sample t test of V6M(1) with 48 cases; Ho: Mean = 0.670				
Mean =	0.729	99.00% CI =	0.669 to	0.790
SD =	0.156		t =	2.635
	DF =	47	Prob =	0.011
One-sample t test of FULL(2) with 42 cases; Ho: Mean = 0.670				
Mean =	0.709	99.00% CI =	0.668 to	0.750
SD =	0.099		t =	2.572
	DF =	41	Prob =	0.014
One-sample t test of V8M(2) with 41 cases; Ho: Mean = 0.670				
Mean =	0.700	99.00% CI =	0.662 to	0.739
SD =	0.091		t =	2.115
	DF =	40	Prob =	0.041
One-sample t test of V6M(2) with 41 cases; Ho: Mean = 0.670				
Mean =	0.733	99.00% CI =	0.696 to	0.769
SD =	0.086		t =	4.669
	DF =	40	Prob =	0.000

One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = full, test
statistic = 0.67, CI = 95%.

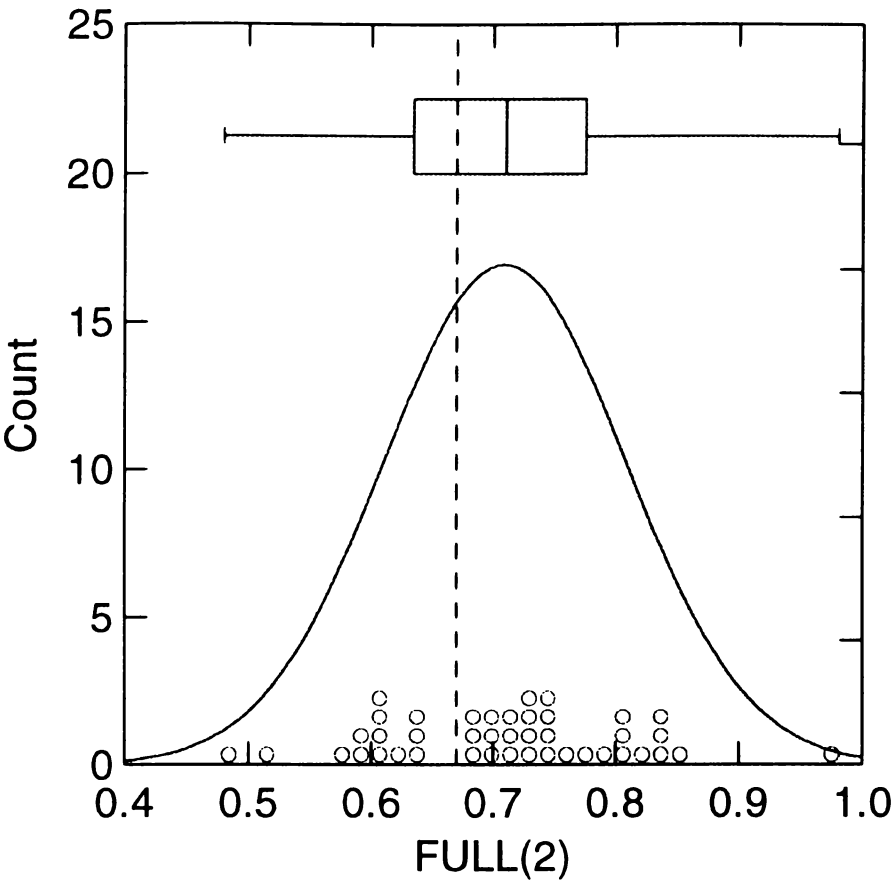


One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure Depth = 8 m, test
statistic = 0.67, CI = 95%

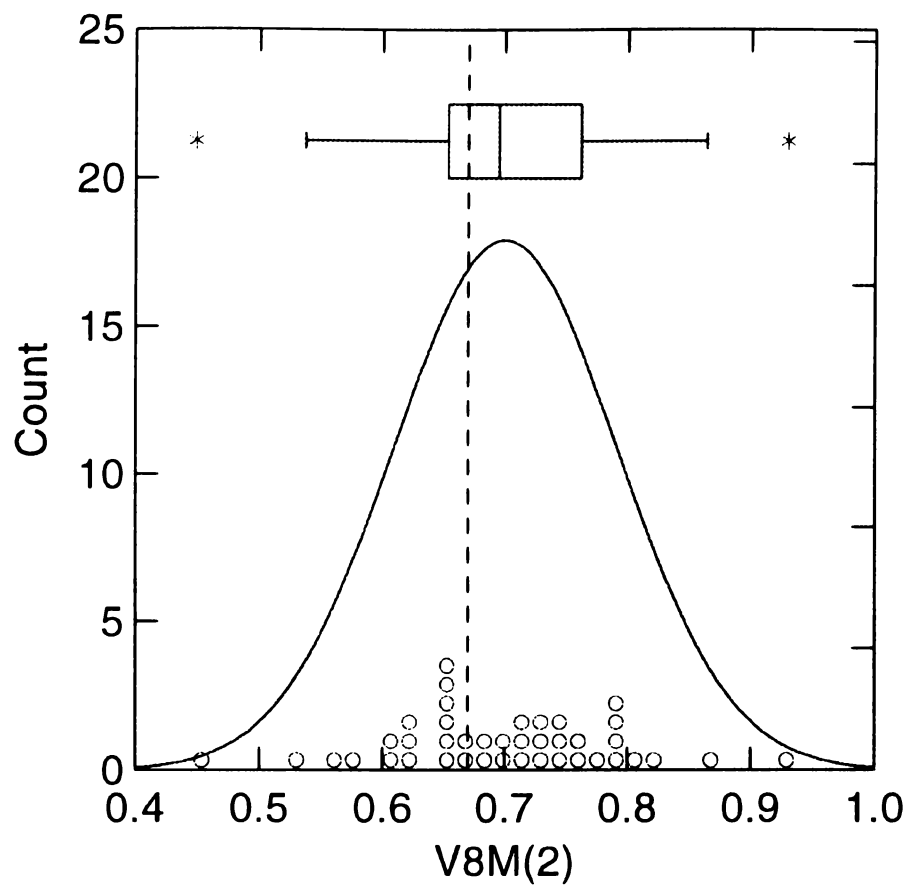




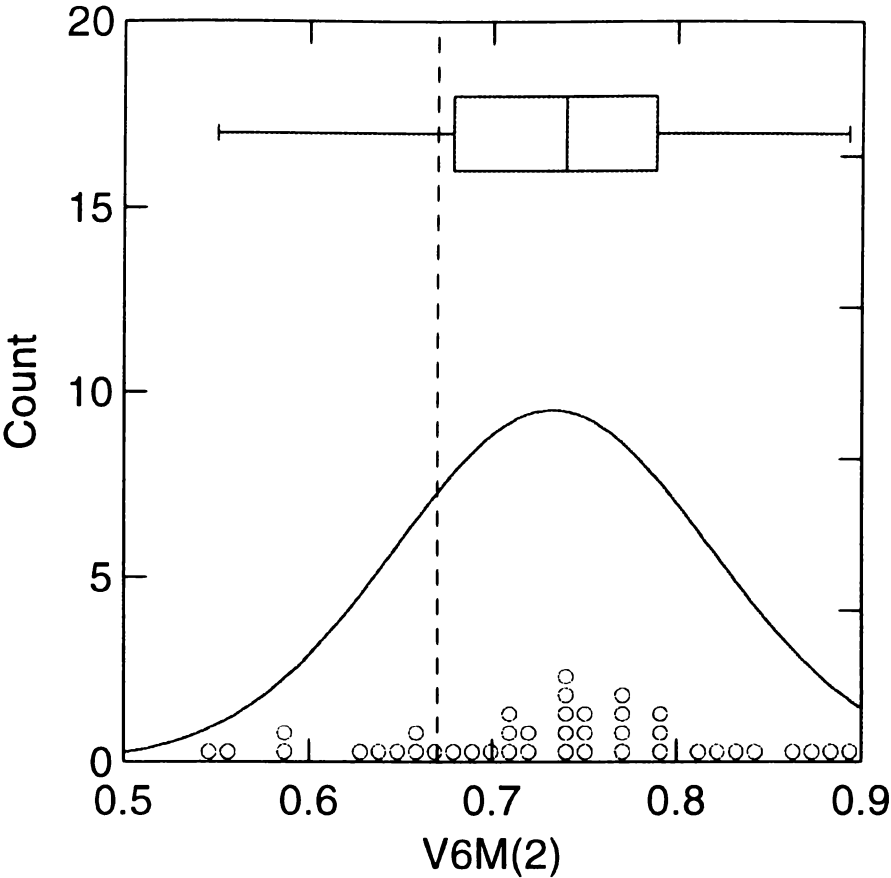
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier profile data removed.
Closure depth = full, test statistic = 0.67, CI = 95%



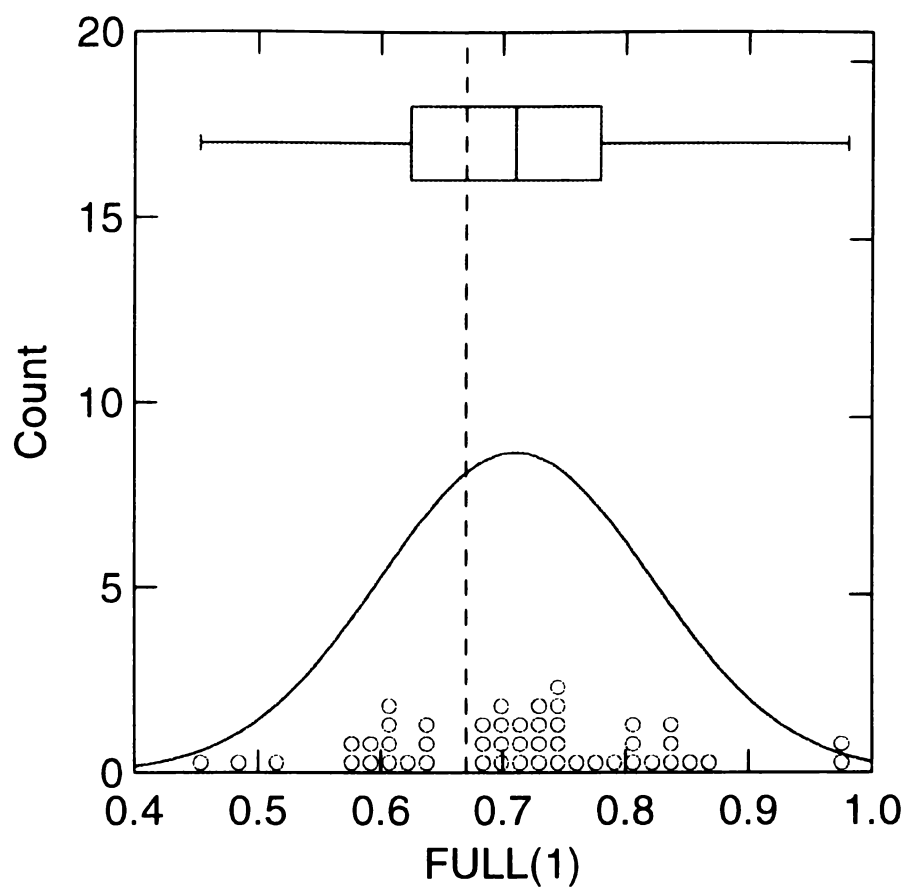
One sample Student 't' test for Dean's Shape factor for
BOP profile dataset with outlier profiles removed.
Closure depth = 8 m, test statistic = 0.67, CI = 95%.



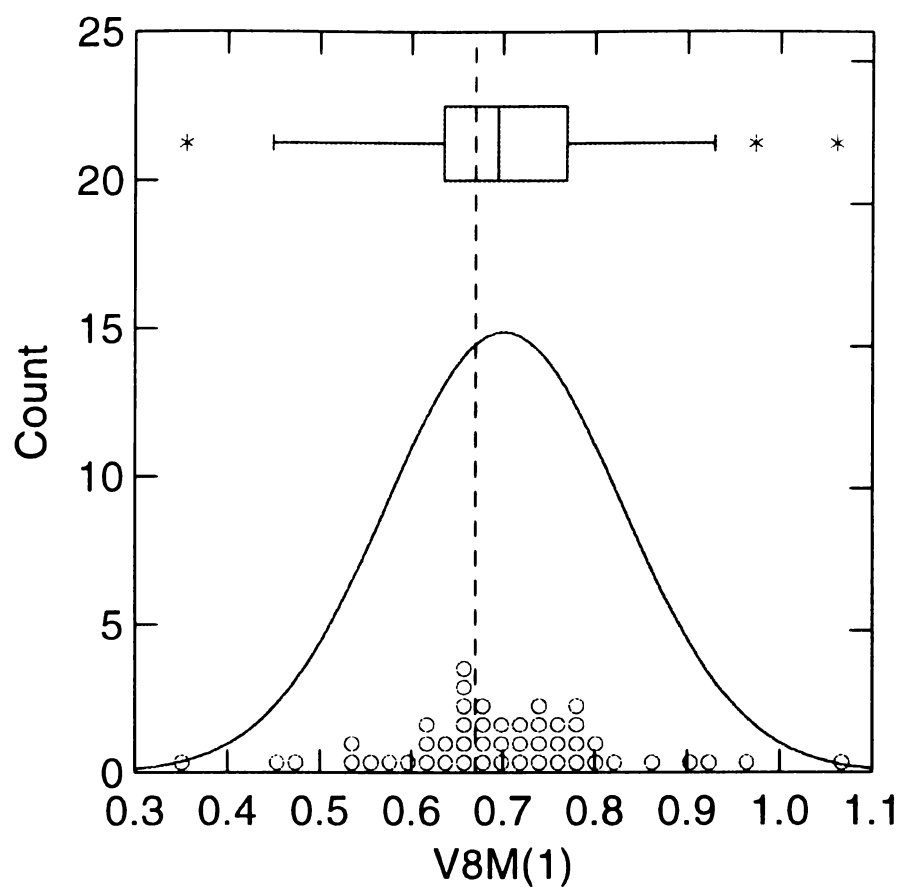
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier data removed.
Closure depth = 6 m, test statistic = 0.67, CI = 95%



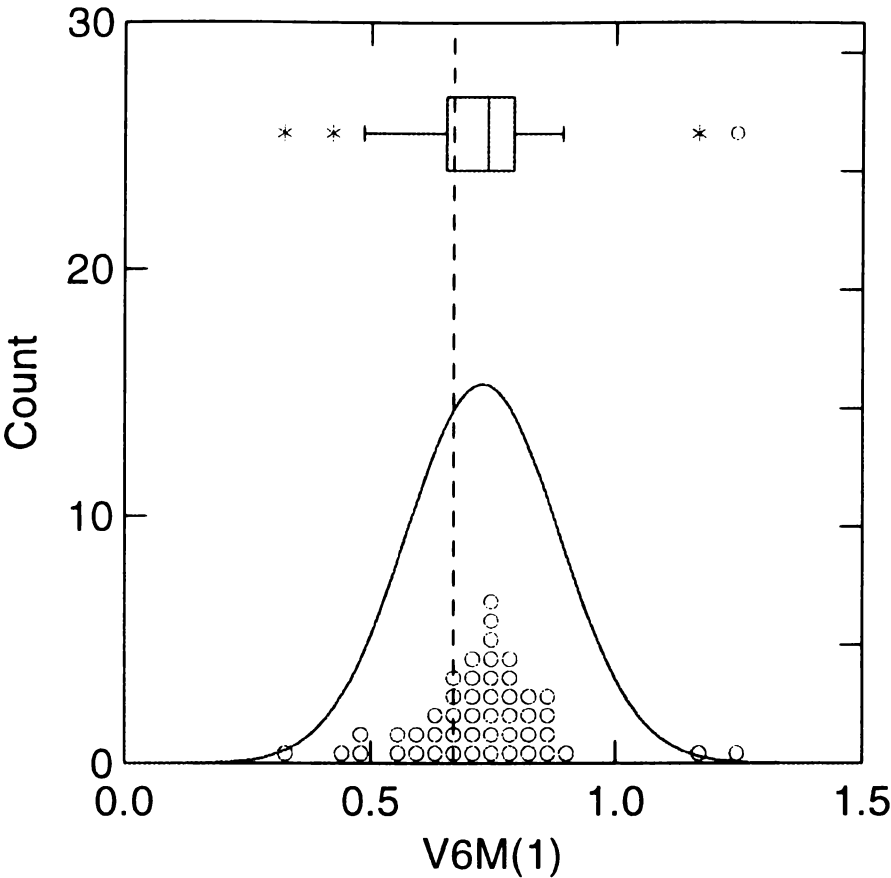
One sample Student 't' test for Dean's Shape factor
BOP profile dataset. Closure depth = full, test
statistic = 0.67, CI = 90%



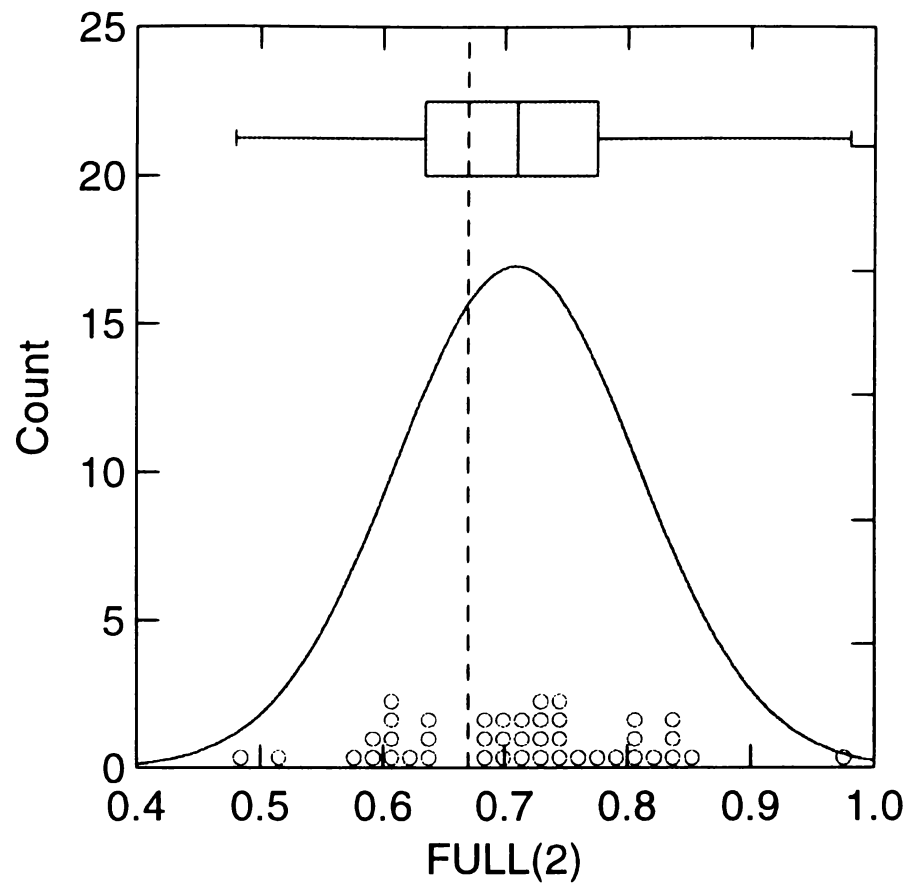
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = 8 m, test
statistic = 0.67, CI = 90%.



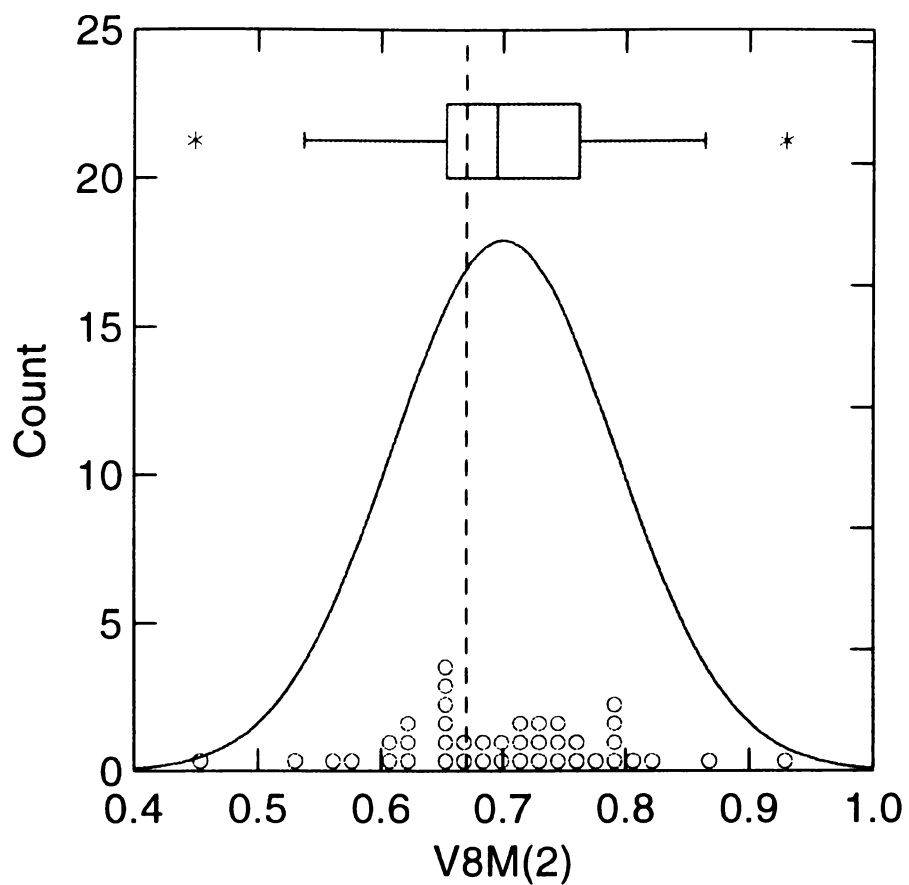
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = 6m, test
statistic = 0.67, CI = 90%.



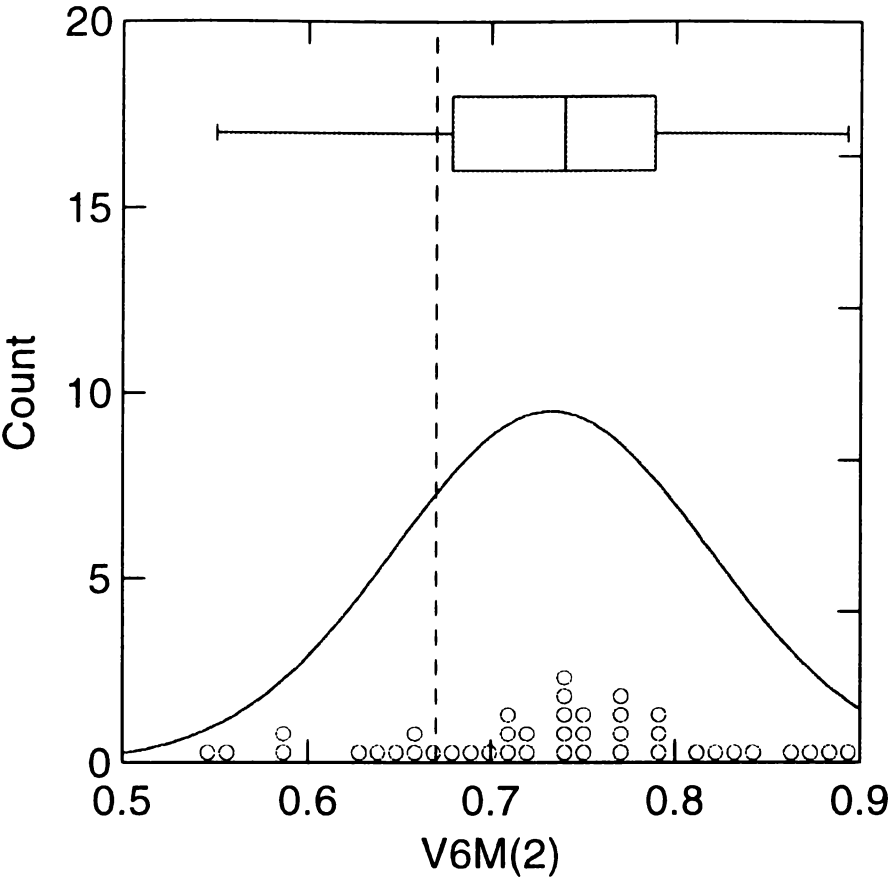
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier profile data removed.
Closure depth = full, test statistic = 0.67, CI = 90%.



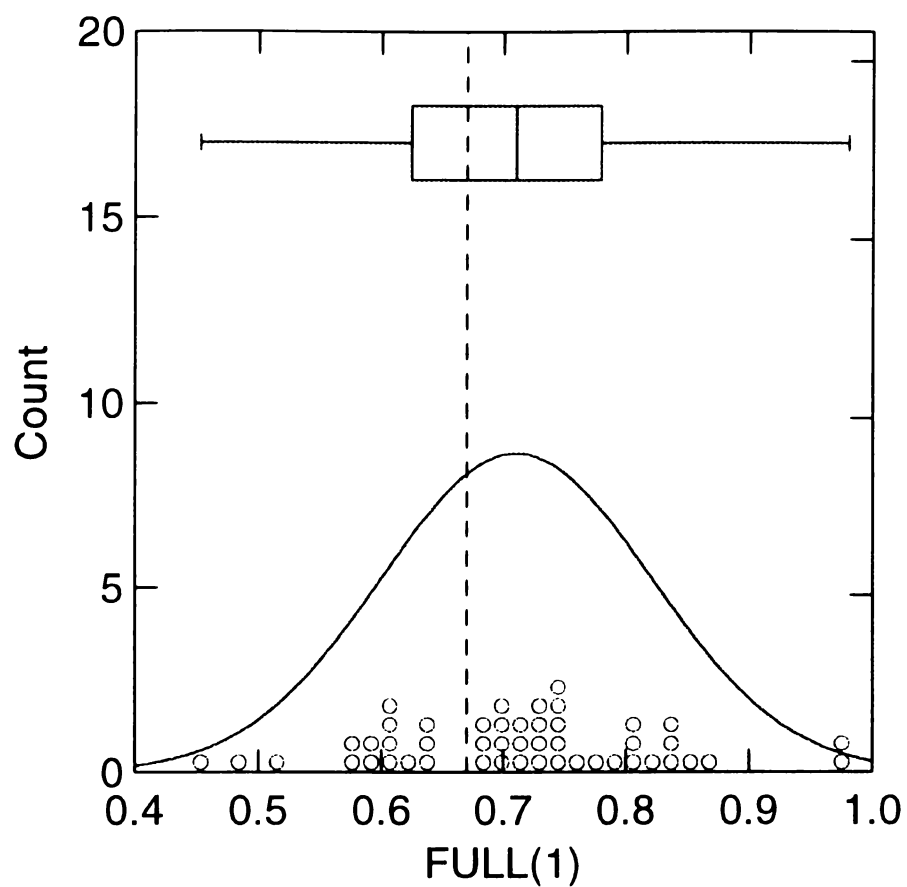
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier data removed.
Closure depth = 8 m, test statistic = 0.67, CI = 90%.



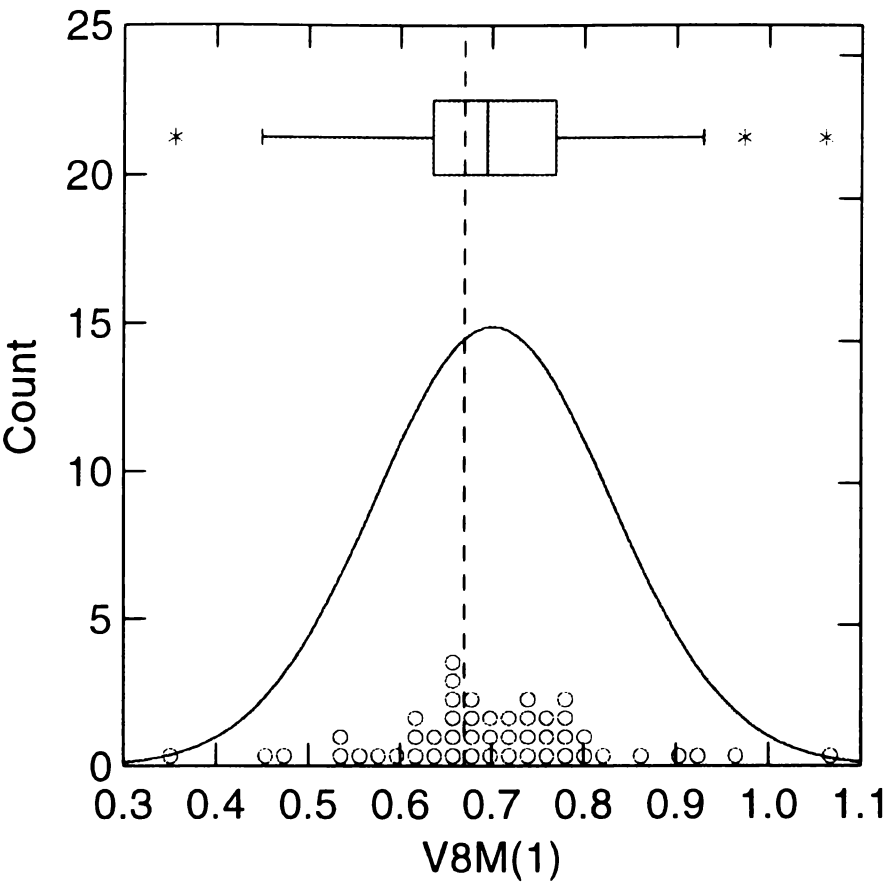
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier data removed.
Closure depth = 6 m, test statistic = 0.67, CI = 90%.



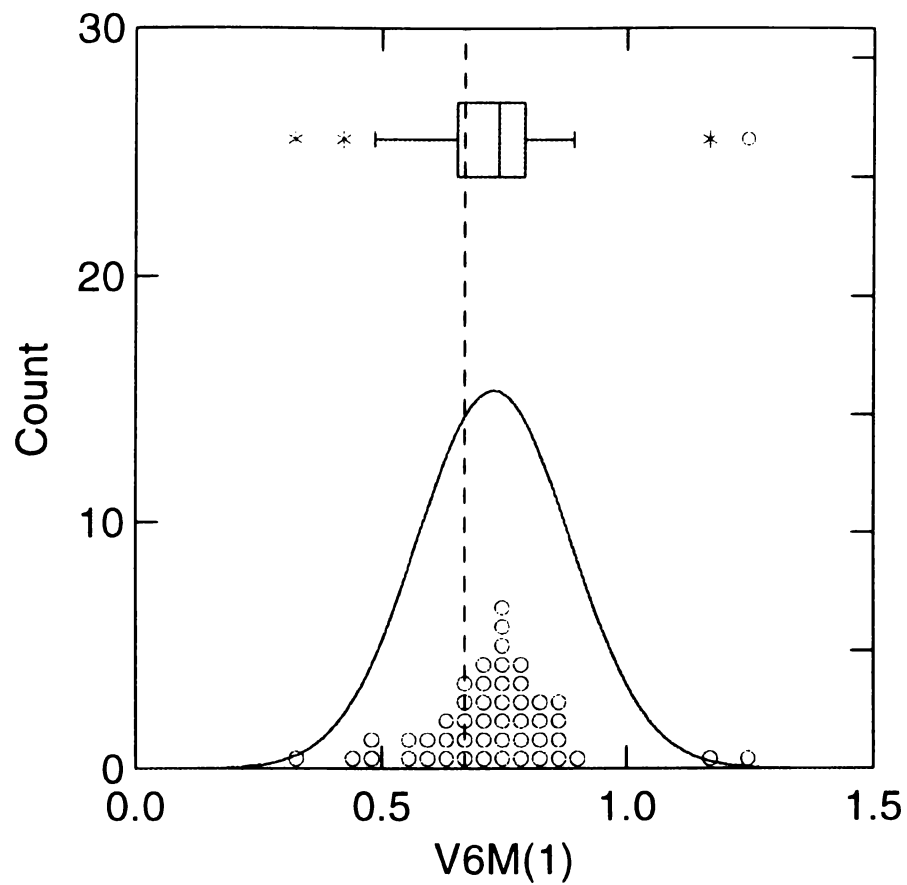
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = full, test
statistic = 0.67, CI = 99%.



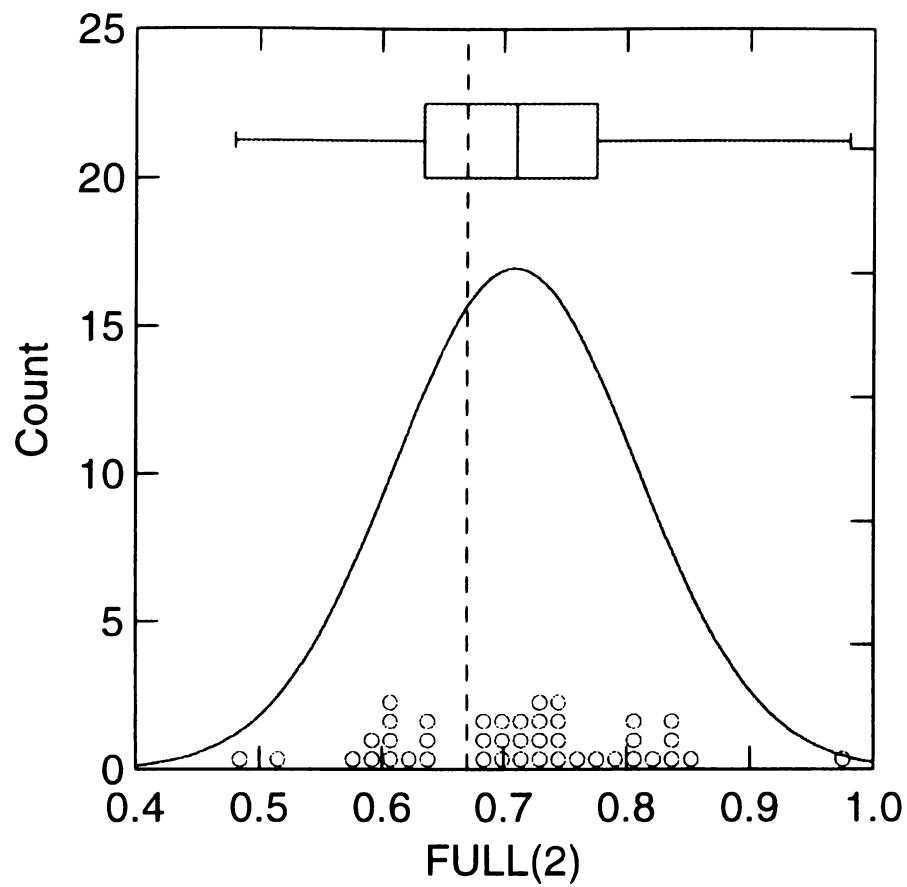
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = 8 m, test
statistic = 0.67, CI = 99%.



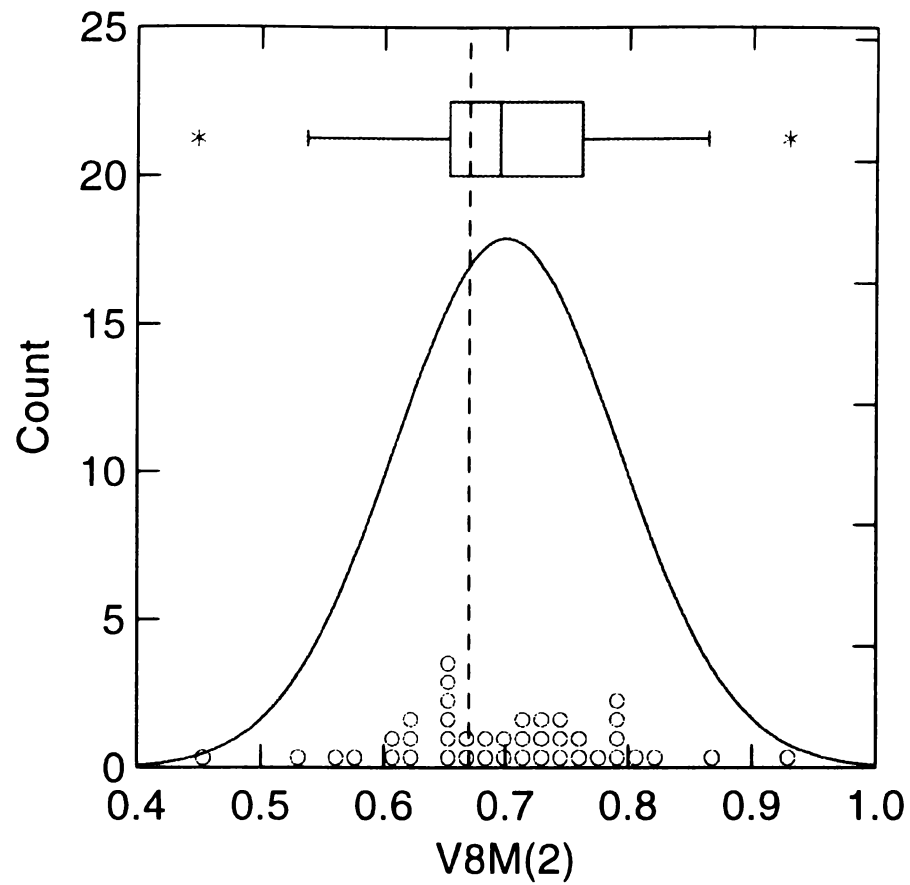
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset. Closure depth = 6 m. Closure
depth = 6 m, test statistic = 0.67, CI = 99%.



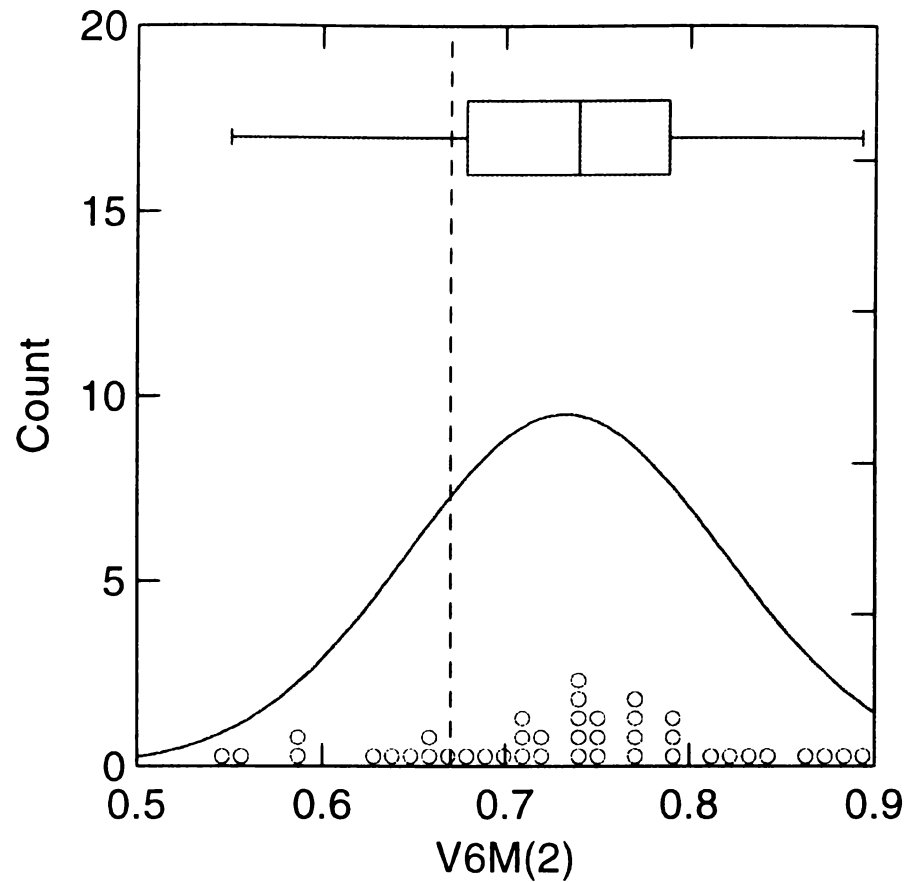
One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier profile data removed.
Closure depth = full, test statistic = 0.67, CI = 99%.



One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier profile data removed.
Closure depth = 8 m, test statistic = 0.67, CI = 99%.



One sample Student 't' test for Dean's Shape factor
for BOP profile dataset with outlier profile data removed.
Closure depth = 6 m, test statistic = 0.67, CI = 99%.



Summary of Regression Analysis for Dean profile fit to full profile dataset										
Site No.	Scale Factor 'A'	R ²	Fit std error (m)	Scale Factor 'A'	R ²	Fit std error (m)	Scale Factor 'A'	R ²	Fit std error (m)	Site No
	6 m Closure Depth m=0.67			8 m Closure Depth m=0.67			Full Depth Closure (approx. HOI), m=0.67			
1	0.1011	0.915	0.497	0.0948	0.9594	0.495	0.0876	0.9907	0.453	1
2	0.1077	0.9763	0.283	0.1021	0.9859	0.318	0.0943	0.9938	0.373	2
3	0.0914	0.975	0.26	0.0896	0.9905	0.251	0.0889	0.9966	0.287	3
4	0.0961	0.9466	0.424	0.091	0.9757	0.416	0.0922	0.9911	0.476	4
5	0.0958	0.961	0.338	0.0949	0.9858	0.31	0.091	0.994	0.31	5
6	0.1102	0.9447	0.374	0.1037	0.977	0.386	0.093	0.9902	0.468	6
7	0.1018	0.9731	0.304	0.0984	0.9866	0.308	0.0887	0.9902	0.441	7
8	0.0705	0.9108	0.6	0.0583	0.9485	0.509	0.0753	0.9758	0.609	8
9	0.0493	0.8624	0.634	0.0555	0.8543	0.789	0.0673	0.94	1.006	9
10	0.0813	0.9743	0.315	0.0847	0.9786	0.304	0.0881	0.9938	0.34	10
11	0.0871	0.9722	0.316	0.0853	0.9871	0.299	0.0861	0.9933	0.374	11
12	0.1003	0.8747	0.593	0.1146	0.9422	0.659	0.1139	0.9891	0.497	12
13	0.1262	0.9494	0.422	0.1319	0.9693	0.436	0.1177	0.9867	0.588	13
14	0.1053	0.9112	0.453	0.1146	0.9435	0.526	0.1214	0.9922	0.501	14
15	0.1223	0.9331	0.431	0.1291	0.9525	0.475	0.1511	0.9838	0.667	15
16	0.11775	0.9612	0.293	0.1252	0.9714	0.365	0.1487	0.9783	0.724	16
17	0.1193	0.9197	0.481	0.1321	0.9322	0.623	0.1557	0.9803	0.751	17
18	0.1051	0.9849	0.221	0.1108	0.9794	0.328	0.1373	0.949	1.025	18
19	0.1244	0.9732	0.301	0.1245	0.9872	0.277	0.1333	0.9917	0.426	19
20	0.1216	0.9234	0.451	0.1232	0.9704	0.417	0.1306	0.9852	0.487	20
21	0.1212	0.9591	0.346	0.1214	0.9841	0.315	0.1235	0.9957	0.283	21
22	0.1122	0.9188	0.479	0.1168	0.9723	0.44	0.1189	0.9922	0.381	22
23	0.107	0.9016	0.493	0.1133	0.9567	0.49	0.1224	0.9838	0.554	23
24	0.1327	0.9252	0.415	0.1323	0.9727	0.38	0.1374	0.9908	0.455	24
25	0.1269	0.9577	0.377	0.1291	0.9765	0.367	0.1402	0.9897	0.5	25
26	0.1203	0.9731	0.286	0.1187	0.9887	0.273	0.1244	0.9908	0.465	26
27	0.1239	0.9291	0.398	0.1281	0.9721	0.386	0.1353	0.993	0.424	27
28	0.1315	0.9551	0.354	0.1318	0.9829	0.329	0.133	0.9965	0.305	28
29	0.1193	0.9391	0.415	0.1229	0.9749	0.396	0.1287	0.9933	0.425	29
30	0.0973	0.7235	0.833	0.1147	0.8438	0.913	0.1288	0.982	0.801	30
32	0.1266	0.9597	0.401	0.093	0.8928	0.886	0.0806	0.9696	0.812	32
33	0.1472	0.9685	0.277	0.1271	0.9437	0.605	0.0948	0.9346	1.051	33
34	0.1029	0.9796	0.236	0.1074	0.9897	0.257	0.121	0.9794	0.678	34
35	0.1128	0.9837	0.218	0.1081	0.9895	0.261	0.103	0.9959	0.298	35
36	0.1088	0.9599	0.368	0.1139	0.9793	0.375	0.1242	0.985	0.563	36
38	0.1104	0.9073	0.307	0.1142	0.986	0.301	0.1234	0.9906	0.467	38
39	0.1035	0.9752	0.305	0.1049	0.9891	0.277	0.1179	0.9799	0.673	39
40	0.1083	0.9664	0.345	0.1091	0.9829	0.328	0.0991	0.9902	0.528	40
41	0.0844	0.8871	1.071	0.0937	0.7043	1.315	0.0647	0.8754	1.22	41
42	0.0949	0.9303	0.388	0.1007	0.9617	0.427	0.0924	0.9918	0.47	42
43	0.0901	0.9706	0.322	0.0934	0.9868	0.313	0.1011	0.9947	0.404	43
44	0.0813	0.9802	0.255	0.0829	0.99	0.248	0.0898	0.9712	0.837	44
45	0.0858	0.995	0.136	0.0837	0.9969	0.15	0.0908	0.9807	0.68	45
46	0.058	0.8105	1.04	0.0615	0.8521	0.921	0.069	0.9288	1.112	46
47	0.059	0.4919	1.039	0.0503	0.7564	1.023	0.0619	0.8643	0.967	47
48	0.1056	0.9805	0.202	0.1022	0.9898	0.22	0.0884	0.9839	0.506	48
49	0.0737	0.9887	0.183	0.0731	0.9954	0.172	0.0744	0.9966	0.219	49
51	0.0795	0.9866	0.221	0.0746	0.9892	0.279	0.0737	0.994	0.278	51
Mean	0.1035	0.9239	0.4115	0.1037	0.9573	0.4404	0.1067	0.9795	0.5658	Mean
Std dev	0.0208	0.0984	0.2129	0.0215	0.0561	0.2380	0.025	0.0262	0.2418	Std dev

Summary of Regression Analysis for Dean profile fit to profile dataset excluding outliers caused by tidal deltas										
Site No.	Scale Factor 'A'	R ²	Fit std error (m)	Scale Factor 'A'	R ²	Fit std error (m)	Scale Factor 'A'	R ²	Fit std error (m)	Site No
	6 m Closure Depth m=0.67			8 m Closure Depth m=0.67			Full Depth Closure (approx. HOI), m=0.67			
1	0.1011	0.915	0.497	0.0948	0.9594	0.495	0.0876	0.9907	0.453	1
2	0.1077	0.9763	0.283	0.1021	0.9859	0.318	0.0943	0.9938	0.373	2
3	0.0914	0.975	0.26	0.0896	0.9905	0.251	0.0889	0.9966	0.287	3
4	0.0961	0.9466	0.424	0.091	0.9757	0.416	0.0922	0.9911	0.476	4
5	0.0958	0.961	0.338	0.0949	0.9858	0.31	0.091	0.994	0.31	5
6	0.1102	0.9447	0.374	0.1037	0.977	0.386	0.093	0.9902	0.468	6
7	0.1018	0.9731	0.304	0.0984	0.9866	0.308	0.0887	0.9902	0.441	7
10	0.0813	0.9743	0.315	0.0847	0.9786	0.304	0.0881	0.9938	0.34	10
11	0.0871	0.9722	0.316	0.0853	0.9871	0.299	0.0861	0.9933	0.374	11
13	0.1262	0.9494	0.422	0.1319	0.9693	0.436	0.1177	0.9867	0.588	13
14	0.1053	0.9112	0.453	0.1146	0.9435	0.526	0.1214	0.9922	0.501	14
15	0.1223	0.9331	0.431	0.1291	0.9525	0.475	0.1511	0.9838	0.667	15
16	0.11775	0.9612	0.293	0.1252	0.9714	0.365	0.1487	0.9783	0.724	16
17	0.1193	0.9197	0.481	0.1321	0.9322	0.623	0.1557	0.9803	0.751	17
18	0.1051	0.9849	0.221	0.1108	0.9794	0.328	0.1373	0.949	1.025	18
19	0.1244	0.9732	0.301	0.1245	0.9872	0.277	0.1333	0.9917	0.426	19
20	0.1216	0.9234	0.451	0.1232	0.9704	0.417	0.1306	0.9852	0.487	20
21	0.1212	0.9591	0.346	0.1214	0.9841	0.315	0.1235	0.9957	0.283	21
22	0.1122	0.9188	0.479	0.1168	0.9723	0.44	0.1189	0.9922	0.381	22
23	0.107	0.9016	0.493	0.1133	0.9567	0.49	0.1224	0.9838	0.554	23
24	0.1327	0.9252	0.415	0.1323	0.9727	0.38	0.1374	0.9908	0.455	24
25	0.1269	0.9577	0.377	0.1291	0.9765	0.367	0.1402	0.9897	0.5	25
26	0.1203	0.9731	0.286	0.1187	0.9887	0.273	0.1244	0.9908	0.465	26
27	0.1239	0.9291	0.398	0.1281	0.9721	0.386	0.1353	0.993	0.424	27
28	0.1315	0.9551	0.354	0.1318	0.9829	0.329	0.133	0.9965	0.305	28
29	0.1193	0.9391	0.415	0.1229	0.9749	0.396	0.1287	0.9933	0.425	29
30	0.0973	0.7235	0.833	0.1147	0.8438	0.913	0.1288	0.982	0.801	30
32	0.1266	0.9597	0.401	0.093	0.8928	0.886	0.0806	0.9696	0.812	32
33	0.1472	0.9685	0.277	0.1271	0.9437	0.605	0.0948	0.9346	1.051	33
34	0.1029	0.9796	0.236	0.1074	0.9897	0.257	0.121	0.9794	0.678	34
35	0.1128	0.9837	0.218	0.1081	0.9895	0.261	0.103	0.9959	0.298	35
36	0.1088	0.9599	0.368	0.1139	0.9793	0.375	0.1242	0.985	0.563	36
38	0.1104	0.9073	0.307	0.1142	0.986	0.301	0.1234	0.9906	0.467	38
39	0.1035	0.9752	0.305	0.1049	0.9891	0.277	0.1179	0.9799	0.673	39
40	0.1083	0.9664	0.345	0.1091	0.9829	0.328	0.0991	0.9902	0.528	40
42	0.0949	0.9303	0.388	0.1007	0.9617	0.427	0.0924	0.9918	0.47	42
43	0.0901	0.9706	0.322	0.0934	0.9868	0.313	0.1011	0.9947	0.404	43
44	0.0813	0.9802	0.255	0.0829	0.99	0.248	0.0898	0.9712	0.837	44
45	0.0858	0.995	0.136	0.0837	0.9969	0.15	0.0908	0.9807	0.68	45
48	0.1056	0.9805	0.202	0.1022	0.9898	0.22	0.0884	0.9839	0.506	48
49	0.0737	0.9887	0.183	0.0731	0.9954	0.172	0.0744	0.9966	0.219	49
51	0.0795	0.9866	0.221	0.0746	0.9892	0.279	0.0737	0.994	0.278	51
Mean	0.1081	0.9502	0.3506	0.1084	0.9719	0.3791	0.1112	0.9864	0.5178	Mean
Std dev	0.0164	0.0439	0.1178	0.0170	0.0282	0.1558	0.025	0.0122	0.1953	Std dev

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IMPORT successfully completed.

Two-sample t test on A grouped by SCALEFACTOR\$ Full Depth

Group	N	Mean	SD
Moore A(avg)	47	0.111	0.011
Regress'A'	48	0.107	0.025

Separate Variance t = 1.058 DF = 64.8 Prob = 0.294
Difference in Means = 0.004 95.00% CI = -0.004 to 0.012

Pooled Variance t = 1.051 DF = 93 Prob = 0.296
Difference in Means = 0.004 95.00% CI = -0.004 to 0.012

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on A grouped by SCALEFACTOR\$ 8 m Closure Depth

Group	N	Mean	SD
Moore A(avg)	48	0.112	0.009
Regress'A'	48	0.104	0.021

Separate Variance t = 2.415 DF = 63.3 Prob = 0.019
Difference in Means = 0.008 95.00% CI = 0.001 to 0.015

Pooled Variance t = 2.415 DF = 94 Prob = 0.018
Difference in Means = 0.008 95.00% CI = 0.001 to 0.015

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on A grouped by SCALEFACTOR\$ 6 m Closure Depth

Group	N	Mean	SD
Moore A(avg)	48	0.114	0.009
Regress'A'	48	0.103	0.021

Separate Variance t = 3.273 DF = 65.4 Prob = 0.002
Difference in Means = 0.011 95.00% CI = 0.004 to 0.017

Pooled Variance t = 3.273 DF = 94 Prob = 0.001
Difference in Means = 0.011 95.00% CI = 0.004 to 0.017

IMPORT successfully completed.

Two-sample t test on A grouped by SCALEFACTOR\$ Full Depth

Group	N	Mean	SD
Moore A(avg)	47	0.111	0.011
Regress'A'	48	0.107	0.025

Separate Variance t = 1.058 DF = 64.8 Prob = 0.294
Difference in Means = 0.004 90.00% CI = -0.002 to 0.011

Pooled Variance t = 1.051 DF = 93 Prob = 0.296
Difference in Means = 0.004 90.00% CI = -0.002 to 0.011

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on A grouped by SCALEFACTOR\$ 8m Closure Depth

Group	N	Mean	SD
-------	---	------	----

Moore A(avg)	48	0.112	0.009
Regress'A'	48	0.104	0.021

Separate Variance t =	2.415	DF = 63.3	Prob = 0.019
Difference in Means =	0.008	90.00% CI =	0.003 to 0.014

Pooled Variance t =	2.415	DF = 94	Prob = 0.018
Difference in Means =	0.008	90.00% CI =	0.003 to 0.014

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR	A	SQRA	LOGA	L10A	EXPA
-------------	---	------	------	------	------

Two-sample t test on A grouped by SCALEFACTOR\$ 6m Closure Depth

Group	N	Mean	SD
Moore A(avg)	48	0.114	0.009
Regress'A'	48	0.103	0.021

Separate Variance t =	3.273	DF = 65.4	Prob = 0.002
Difference in Means =	0.011	90.00% CI =	0.005 to 0.016

Pooled Variance t =	3.273	DF = 94	Prob = 0.001
Difference in Means =	0.011	90.00% CI =	0.005 to 0.016

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR	A	SQRA	LOGA	L10A	EXPA
-------------	---	------	------	------	------

Two-sample t test on SQRA grouped by SCALEFACTOR\$ Full Depth

Group	N	Mean	SD
Moore A(avg)	47	0.333	0.016
Regress'A'	48	0.324	0.039

Separate Variance t =	1.357	DF = 62.8	Prob = 0.180
Difference in Means =	0.008	95.00% CI =	-0.004 to 0.020

Pooled Variance t =	1.347	DF = 93	Prob = 0.181
Difference in Means =	0.008	95.00% CI =	-0.004 to 0.020

Two-sample t test on LOGA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	47	-2.203	0.094
Regress'A'	48	-2.266	0.244

Separate Variance t =	1.652	DF = 60.8	Prob = 0.104
Difference in Means =	0.062	95.00% CI =	-0.013 to 0.138

Pooled Variance t =	1.639	DF = 93	Prob = 0.105
Difference in Means =	0.062	95.00% CI =	-0.013 to 0.138

Two-sample t test on L10A grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	47	-0.957	0.041
Regress'A'	48	-0.984	0.106

Separate Variance t =	1.652	DF = 60.8	Prob = 0.104
Difference in Means =	0.027	95.00% CI =	-0.006 to 0.060

Pooled Variance t =	1.639	DF = 93	Prob = 0.105
Difference in Means =	0.027	95.00% CI =	-0.006 to 0.060

Two-sample t test on EXPA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	47	1.117	0.012
Regress'A'	48	1.113	0.028

Separate Variance t = 0.995 DF = 65.2 Prob = 0.323
Difference in Means = 0.004 95.00% CI = -0.004 to 0.013

Pooled Variance t = 0.988 DF = 93 Prob = 0.326
Difference in Means = 0.004 95.00% CI = -0.004 to 0.013

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on SQRA grouped by SCALEFACTOR\$ 8 m Closure Dpeth

Group	N	Mean	SD
Moore A(avg)	48	0.334	0.013
Regress'A'	48	0.320	0.035

Separate Variance t = 2.590 DF = 60.5 Prob = 0.012
Difference in Means = 0.014 95.00% CI = 0.003 to 0.025

Pooled Variance t = 2.590 DF = 94 Prob = 0.011
Difference in Means = 0.014 95.00% CI = 0.003 to 0.025

Two-sample t test on LOGA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	-2.194	0.079
Regress'A'	48	-2.290	0.230

Separate Variance t = 2.746 DF = 57.9 Prob = 0.008
Difference in Means = 0.096 95.00% CI = 0.026 to 0.167

Pooled Variance t = 2.746 DF = 94 Prob = 0.007
Difference in Means = 0.096 95.00% CI = 0.027 to 0.166

Two-sample t test on L10A grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	-0.953	0.034
Regress'A'	48	-0.995	0.100

Separate Variance t = 2.746 DF = 57.9 Prob = 0.008
Difference in Means = 0.042 95.00% CI = 0.011 to 0.072

Pooled Variance t = 2.746 DF = 94 Prob = 0.007
Difference in Means = 0.042 95.00% CI = 0.012 to 0.072

Two-sample t test on EXPA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	1.118	0.010
Regress'A'	48	1.110	0.024

Separate Variance t = 2.377 DF = 63.9 Prob = 0.020
Difference in Means = 0.009 95.00% CI = 0.001 to 0.016

Pooled Variance t = 2.377 DF = 94 Prob = 0.019
Difference in Means = 0.009 95.00% CI = 0.001 to 0.016

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on SQRA grouped by SCALEFACTOR\$ 6 m Closure Depth

Group	N	Mean	SD
Moore A(avg)	48	0.338	0.014
Regress'A'	48	0.320	0.034

Separate Variance t = 3.364 DF = 62.0 Prob = 0.001
Difference in Means = 0.018 95.00% CI = 0.007 to 0.028

Pooled Variance t = 3.364 DF = 94 Prob = 0.001
Difference in Means = 0.018 95.00% CI = 0.007 to 0.028

Two-sample t test on LOGA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	-2.173	0.081
Regress'A'	48	-2.292	0.228
Separate Variance t = 3.415 DF = 58.7 Prob = 0.001			
Difference in Means = 0.119 95.00% CI = 0.049 to 0.189			
Pooled Variance t = 3.415 DF = 94 Prob = 0.001			
Difference in Means = 0.119 95.00% CI = 0.050 to 0.188			

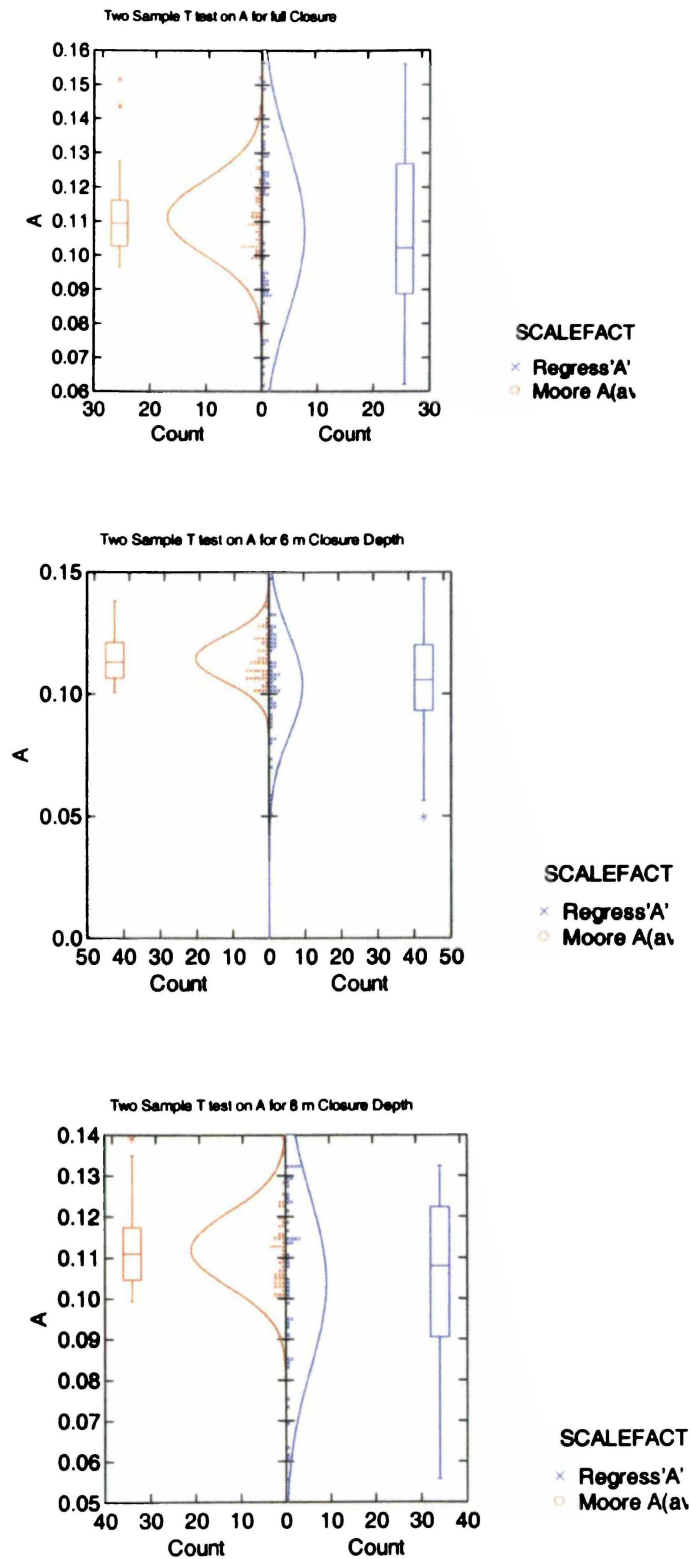
Two-sample t test on L10A grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	-0.944	0.035
Regress'A'	48	-0.995	0.099
Separate Variance t = 3.415 DF = 58.7 Prob = 0.001			
Difference in Means = 0.052 95.00% CI = 0.021 to 0.082			
Pooled Variance t = 3.415 DF = 94 Prob = 0.001			
Difference in Means = 0.052 95.00% CI = 0.022 to 0.082			

Two-sample t test on EXPA grouped by SCALEFACTOR\$

Group	N	Mean	SD
Moore A(avg)	48	1.121	0.011
Regress'A'	48	1.109	0.023
Separate Variance t = 3.248 DF = 66.1 Prob = 0.002			
Difference in Means = 0.012 95.00% CI = 0.005 to 0.019			
Pooled Variance t = 3.248 DF = 94 Prob = 0.002			
Difference in Means = 0.012 95.00% CI = 0.005 to 0.019			

**Plots of results from Two sample T test for Full profile (approx. 15m depth
=HOL) and 8 m closure and 6 m closure depths**



Appendix 5 - Student t tests for Scale and Shape factors

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TUE 7-12-04 2:29:45 PM

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Welcome to SYSTAT!

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on A grouped by SCALEFACTOR\$ 8m closure depth with outliers removed

Group	N	Mean	SD
Moore A(avg)	42	0.111	0.008
Regress 'A'	42	0.108	0.017

Separate Variance t = 0.885 DF = 60.0 Prob = 0.380
Difference in Means = 0.003 95.00% CI = -0.003 to 0.008

Pooled Variance t = 0.885 DF = 82 Prob = 0.379
Difference in Means = 0.003 95.00% CI = -0.003 to 0.008

85 cases have been saved into a SYSTAT file

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

Two-sample t test on A grouped by SCALEFACTOR\$ 6m closure depth with outliers removed

Group	N	Mean	SD
Moore A(avg)	42	0.113	0.009
Regress 'A'	42	0.108	0.016

Separate Variance t = 1.740 DF = 62.9 Prob = 0.087
Difference in Means = 0.005 95.00% CI = -0.001 to 0.011

Pooled Variance t = 1.740 DF = 82 Prob = 0.086
Difference in Means = 0.005 95.00% CI = -0.001 to 0.011

84 cases have been saved into a SYSTAT file

Variables in the SYSTAT Rectangular file are:

SCALEFACTOR A SQRA LOGA L10A EXPA

83 cases have been saved into a SYSTAT file

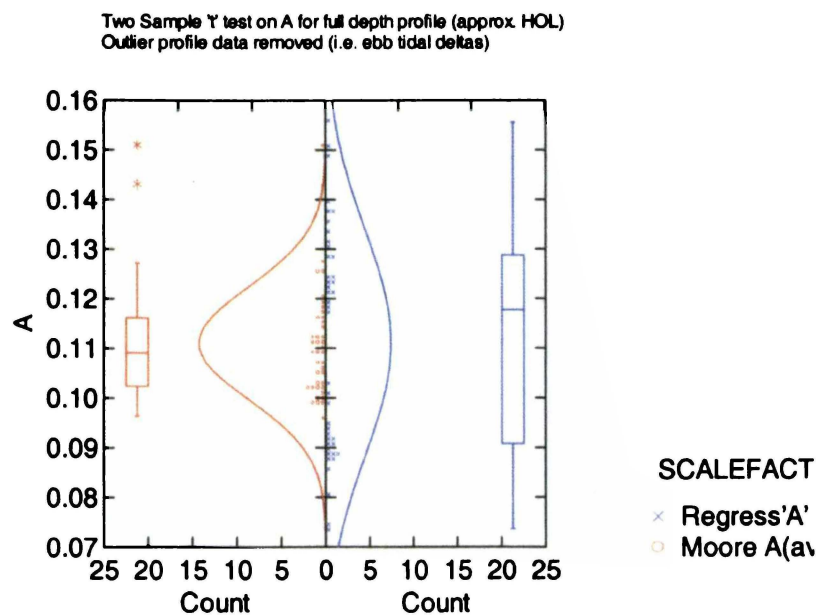
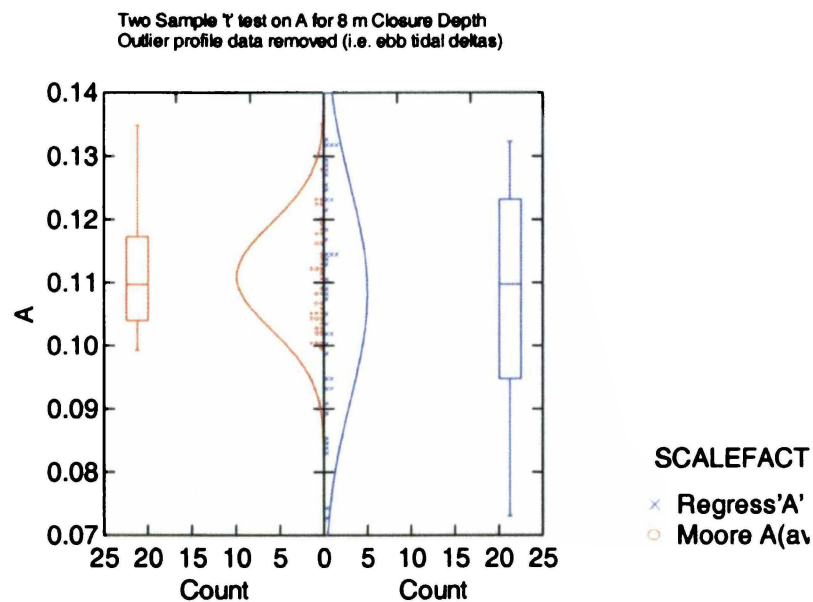
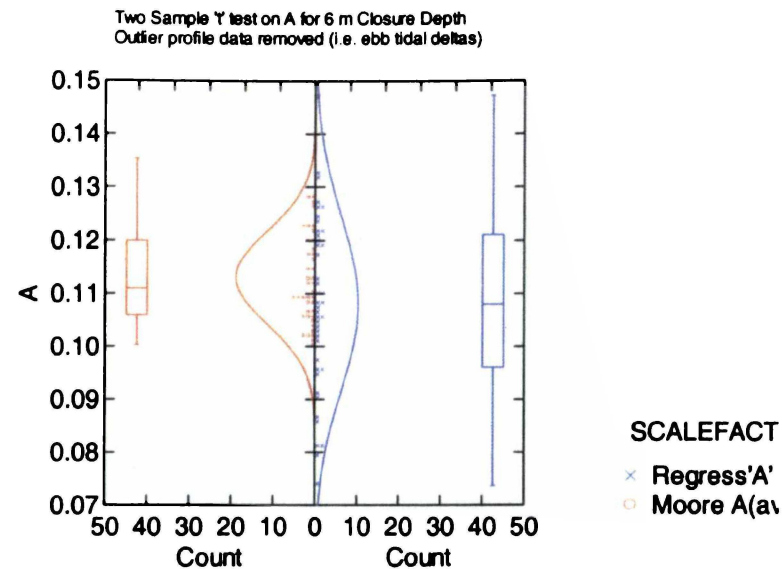
Two-sample t test on A grouped by SCALEFACTOR\$ Full depth with outliers removed

Group	N	Mean	SD
Moore A(avg)	41	0.111	0.011
Regress 'A'	42	0.111	0.023

Separate Variance t = -0.011 DF = 61.1 Prob = 0.991
Difference in Means = -0.000 95.00% CI = -0.008 to 0.008

Pooled Variance t = -0.011 DF = 81 Prob = 0.991
Difference in Means = -0.000 95.00% CI = -0.008 to 0.008

Plots of results from Two sample Student 't' tests for Full profile (approx. 15 m depth = H.O.L.) and 8 and 6 m Closure Depths



Appendix 6

Table summaries of Profile Shift Calculations using Dean
(1977, 1993) models

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet1

Profile Shift Calculations : Dean Equilibrium Beach Profile									
Closure Depth: 6m									
Matlab Routine: Shift1									
Method: Piecewise Variation Dean Model									
Profile #	BOPRC #	Sediment Vol. (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rmsr error	Erosion/Accretion	Profile Shift (m)	Remarks	
1	1	1059	1178	-119	0.3395	E	-19.83		
2	2	987.1	1141	-153.9	0.5114	E	-25.6		
3	3	1248	1101	147	0.4808	A	24.47		
4	4	1146	1228	-82	0.4879	E	-13.73		
5	5	1178	1184	-6	0.5808	E	-0.89		
6	6	980.3	1175	-194.7	0.6861	E	-32.37		
7	7	1094	1034	60	0.4125	A	10.02		
8	8	1718	934	784	0.7831	A	130.7		
9	9	3111	938.5	2172.5	2.299	A	362.1	Ebb Tidal Delta	
10	10	1541	1109	432	0.8358	A	71.98		
11	11	1331	1154	177	0.4072	A	29.53		
12	12	993.5	1394	-400.5	2.157	E	-68.73	Very steep nearshore slope	
13	13	769.9	1093	-323.1	1.87	E	-53.8	Very steep nearshore slope	
14	14	982	969.7	12.3	1.11	A	2.05		
15	15	802	998.4	-196.4	1.352	E	-32.74		
16	16	849.1	978.7	-129.6	1.191	E	-21.6		
17	17	852	1041	-189	1.675	E	-31.48		
18	18	1042	989	53	0.252	A	8.84		
19	19	798.4	1042	-243.6	0.8438	E	-40.53		
20	20	853.8	982.3	-128.5	0.5364	E	-21.42		
21	21	824.4	1087	-262.6	1.084	E	-43.81		
22	22	899.5	1119	-219.5	1.04	E	-38.56		
23	23	938.2	994.1	-55.9	1.171	E	-9.32		
24	24	713.5	1050	-336.5	1.434	E	-56.02		
25	25	777.9	1053	-275.1	1.087	E	-45.91		
26	26	830	1211	-381	1.381	E	-63.55		
27	27	769.6	1176	-406.4	1.616	E	-67.66		
28	28	714.1	1108	-393.9	1.411	E	-65.66		
29	29	828.3	1037	-208.7	1.146	E	-34.71		
30	30	838.4	809.4	29	0.7053	A	4.83		
31	32	744.5	1207	-462.5	1.128	E	-77.01		
32	33	607.5	1319	-711.5	2.042	E	-118.5		
33	34	1052	1237	-185	0.8515	E	-30.85		
34	35	919	1232	-313	1.001	E	-52.16		
35	36	970.4	1120	-149.6	0.8101	E	-24.96		
36	38	955.9	1127	-171.1	0.7348	E	-28.44		
37	39	1061	1037	24	0.3108	A	3.967		
38	40	947.2	958.7	-11.5	0.4132	E	-1.925		
39	41	1186	814.8	371.2	0.9187	A	61.85	Ebb Tidal Delta	
40	42	1251	774.4	476.6	1.228	A	79.47	Ebb Tidal Delta	
41	43	1285	1050	235	0.5331	A	39.12		
42	44	1498	1112	386	0.7272	A	64.32		
43	45	1406	1108	300	0.5611	A	49.99		
44	46	2298	762.3	1535.7	1.176	A	256	Ebb Tidal Delta - Bowentown	
45	47	2521	689.3	1851.7	1.235	A	308.7	Ebb Tidal Delta - Bowentown	
46	48	972.6	912.5	60.1	0.2518	A	10.02		
47	49	1733	1193	540	0.8648	A	90		
48	51	1533	1186	367	0.5724	A	61.11		

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet2

	A	B	C	D	E	F	G	H	I
1	Profile Shift Calculations : Dean Equilibrium Beach Profile								
2	Closure Depth: 6m								
3	Matlab Routine: Shift2								
4	Method: Profile Averaged A Dean Model								
5									
6	Profile #	BOPRC #	Sediment Vol. (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	mer error	Erosion/Accretion	Profile Shift	Remarks
7	1	1	1059	1083	-24	0.3328	E	-3.996	Opape
8	2	2	987.1	1037	-49.9	0.237	E	-8.276	
9	3	3	1248	1059	189	0.435	A	31.5	
10	4	4	1146	1115	31	0.2852	A	5.017	
11	5	5	1178	1137	41	0.2742	A	6.996	
12	6	6	980.3	1083	-102.7	0.3208	E	-17.08	
13	7	7	1094	1095	-1	0.2574	E	-0.087	
14	8	8	1718	976.8	741.2	0.7253	A	123.5	Ebb Tidal Delta
15	9	9	3111	1037	2074	2.487	A	345.8	Ebb Tidal Delta
16	10	10	1541	1115	426	0.823	A	70.95	Ebb Tidal Delta?
17	11	11	1331	1178	153	0.3611	A	25.58	
18	12	12	993.5	1098	-104.5	0.9447	E	-17.43	
19	13	13	769.9	1011	-241.1	1.118	E	-40.23	
20	14	14	982	960.3	21.7	0.555	A	3.618	
21	15	15	802	1001	-199	1.025	E	-33.13	
22	16	16	849.1	937.9	-88.8	0.5268	E	-14.81	
23	17	17	852	978.8	-124.8	1.196	E	-20.81	
24	18	18	1042	957	85	0.2603	A	14.16	
25	19	19	798.4	843.4	-45	0.2263	E	-7.474	
26	20	20	853.3	884.9	-31.6	0.3573	E	-5.185	
27	21	21	824.4	913.4	-89	0.3681	E	-14.83	
28	22	22	899.5	901.5	-2	0.3761	E	-0.34	
29	23	23	938.2	857.9	80.3	0.4252	A	13.39	
30	24	24	713.5	792.8	-79.3	0.3827	E	-13.21	
31	25	25	777.9	863.3	-85.4	0.4088	E	-14.25	
32	26	26	830	936	-106	0.4652	E	-17.66	
33	27	27	769.6	889.2	-119.6	0.605	E	-19.84	
34	28	28	714.1	976.8	-262.7	0.9756	E	-43.79	
35	29	29	828.3	937.9	-109.6	0.5772	E	-18.27	
36	30	30	838.4	600	238.4	0.9808	A	39.73	
37	31	32	744.5	775.9	-31.4	0.3635	E	-5.233	
38	32	33	607.5	983.6	-376.1	1.283	E	-62.67	
39	33	34	1052	1137	-85	0.3843	E	-14.11	
40	34	35	919	1029	-110	0.3561	E	-18.39	
41	35	36	970.4	1071	-100.6	0.5486	E	-18.76	
42	36	38	955.9	1075	-119.1	0.5508	E	-19.82	
43	37	39	1061	1018	43	0.2633	A	7.108	
44	38	40	947.2	830.6	116.6	0.3629	A	19.43	
45	39	41	1186	650.6	535.4	0.6121	A	89.22	Ebb tidal delta
46	40	42	1251	873	378	1.097	A	63.04	Ebb tidal delta
47	41	43	1285	947.4	337.6	0.7632	A	56.28	Matakana Island
48	42	44	1498	1087	411	0.7775	A	68.58	Matakana Island
49	43	45	1406	1075	331	0.6337	A	55.18	Matakana Island
50	44	46	2298	898	1400	1.725	A	234.4	Ebb tidal delta
51	45	47	2521	798.1	1722.9	1.514	A	287.2	Ebb tidal delta
52	46	48	972.6	952	20.6	0.1728	A	3.441	Waihi Beach
53	47	49	1733	1130	603	0.9843	A	100.4	
54	48	51	1533	1115	418	0.8617	A	69.6	North End Waihi Beach

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet3

Profile Shift Calculations : Dean Equilibrium Beach Profile

Closure Depth: 6m

Matlab Routine: Shift 3

Method: Modified Dean Profile with piecewise variation of 'A'

Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rmsr error	Erosion/Accretion	Profile Shift	Remarks
1	1	1059	1206	-147	0.407	E	-24.59	
2	2	987.1	2293	-1305.9	2.303	E	-217.7	
3	3	1248	1639	-391	0.7846	E	-65.14	
4	4	1146	2122	-976	1.61	E	-162.8	
5	5	1178	1921	-743	1.466	E	-123.8	
6	6	980.3	1574	-593.7	1.29	E	-99	
7	7	1094	5726	-4632	5.761	E	-771.9	
8	8	1718	1400	318	0.5287	A	53.06	
9	9	3111	3084	27	0.6329	A	4.473	
10	10	1541	1184	357	0.6775	A	59.46	
11	11	1331	1584	-253	0.5322	E	-42.21	
12	12	993.5	1828	-834.5	2.212	E	-105.7	
13	13	769.9	1076	-306.1	1.447	E	-51.02	
14	14	982	930	52	0.6685	A	8.662	
15	15	802	1138	-336	1.563	E	-55.94	
16	16	849.1	1043	-193.9	0.9824	E	-32.37	
17	17	852	1119	-267	1.909	E	-44.5	
18	18	1042	1196	-154	0.6298	E	-25.72	
19	19	798.4	1178	-377.6	1.178	E	-62.92	
20	20	853.8	1108	-254.2	0.8871	E	-42.42	
21	21	824.4	1002	-177.8	0.7323	E	-29.55	
22	22	899.5	926.3	-26.8	0.6174	E	-4.474	
23	23	938.2	859.1	79.1	0.4698	A	13.2	
24	24	713.5	885.7	-172.2	0.7719	E	-28.7	
25	25	777.9	1471	-693.1	2.174	E	-115.5	
26	26	830	1358	-528	1.508	E	-88.06	
27	27	769.6	1306	-536.4	1.864	E	-89.47	
28	28	714.1	1545	-830.9	2.424	E	-138.4	
29	29	828.3	1374	-545.7	1.77	E	-90.89	
30	30	838.4	1392	-553.6	1.871	E	-92.31	
31	32	744.5	1202	-457.5	1.012	E	-76.25	
32	33	607.5	1160	-552.5	1.697	E	-92.14	
33	34	1052	1661	-609	1.668	E	-101.5	
34	35	919	1040	-121	0.5809	E	-20.17	
35	36	970.4	2245	-1274.6	3.293	E	-212.5	
36	38	955.9	1755	-799.1	2.116	E	-133.2	
37	39	1061	3034	-1973	4.416	E	-328.8	
38	40	947.2	1687	-739.8	1.626	E	-123.3	
39	41	1186	1116	70	1.286	A	11.69	Ebb tidal delta - poor shape
40	42	1251	1063	188	0.6874	A	31.36	Ebb tidal delta - reasonable shape
41	43	1285	2122	-837	1.824	E	-139.6	
42	44	1498	1848	-350	0.6345	E	-58.28	
43	45	1406	1484	-78	0.1614	E	-12.98	Good shape approximation
44	46	2298	1061	1237	1.815	A	206.2	Ebb tidal delta - poor shape
45	47	2521	917.4	1603.6	1.543	A	267.3	Ebb tidal delta - poor shape
46	48	972.6	1105	-132.4	0.4001	E	-22.01	Good shape approximation
47	49	1733	1982	-249	0.3837	E	-41.64	Good shape approximation
48	51	1533	2220	-687	0.9127	E	-114.5	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet4

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 6m								
Matlab Routine: Shift4.m								
Method: Modified Dean Profile with profile averaged 'A' values								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	msr error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	1059	1223	-164	0.4336	E	-27.34	Good shape approximation
2	2	987.1	2234	-1246.9	2.21	E	-207.9	Flat shape prediction - unrealistic?
3	3	1248	1691	-443	0.8366	E	-73.78	Flat shape prediction - unrealistic?
4	4	1146	2094	-948	1.557	E	-158.2	
5	5	1178	1964	-786	1.481	E	-131	
6	6	980.3	1619	-638.7	1.328	E	-106.4	
7	7	1094	5594	-4500	5.547	E	-750	Unrealistic!!!
8	8	1718	1446	272	0.5434	A	45.3	Ebb tidal delta ? - poor prediction
9	9	3111	3195	-84	0.6849	E	-14.01	Ebb tidal delta - poor prediction
10	10	1541	1217	324	0.6103	A	53.94	
11	11	1331	1643	-312	0.623	E	-51.92	
12	12	993.5	1634	-640.5	2.021	E	-106.7	Steep profile - poor prediction
13	13	769.9	1174	-404.1	1.61	E	-67.31	
14	14	982	1109	-127	0.8157	E	-21.24	
15	15	802	1201	-399	1.699	E	-66.43	
16	16	849.1	1102	-252.9	1.064	E	-42.23	
17	17	852	1151	-299	1.843	E	-49.81	
18	18	1042	1234	-192	0.6429	E	-31.98	
19	19	798.4	1094	-295.6	0.8533	E	-49.34	
20	20	853.8	1077	-223.2	0.7232	E	-37.27	
21	21	824.4	1058	-233.6	0.7264	E	-38.94	
22	22	899.5	969.7	-70.2	0.4502	E	-11.69	
23	23	938.2	1015	-76.8	0.4772	E	-12.86	
24	24	713.5	871.7	-158.2	0.5723	E	-26.36	
25	25	777.9	1325	-547.1	1.686	E	-91.18	
26	26	830	1230	-400	1.14	E	-66.72	
27	27	769.6	1197	-427.4	1.42	E	-71.23	
28	28	714.1	1464	-749.9	2.183	E	-124.9	
29	29	828.3	1403	-574.7	1.71	E	-85.84	
30	30	838.4	1233	-394.6	1.51	E	-65.74	
31	32	744.5	966.3	-221.8	0.7196	E	-36.85	
32	33	607.5	1107	-499.5	1.559	E	-83.19	
33	34	1052	1675	-623	1.563	E	-103.9	
34	35	919	1139	-220	0.6072	E	-36.65	
35	36	970.4	2202	-1231.6	3.128	E	-205.2	
36	38	955.9	1740	-784.1	2.05	E	-130.7	
37	39	1061	3007	-1946	4.292	E	-324.3	
38	40	947.2	1599	-651.8	1.474	E	-106.7	
39	41	1186	973.7	212.3	1.145	A	35.38	
40	42	1251	1185	66	0.4775	A	10.97	
41	43	1285	2025	-740	1.434	E	-123.3	
42	44	1498	1855	-357	0.6275	E	-59.46	
43	45	1406	1482	-76	0.159	E	-12.64	Good shape approximation
44	46	2298	1180	1118	1.924	A	186.5	Ebb tidal delta
45	47	2521	1012	1509	1.707	A	251.6	Ebb tidal delta
46	48	972.6	1128	-155.4	0.4101	E	-25.93	
47	49	1733	1971	-238	0.3626	E	-39.67	
48	51	1533	2193	-660	0.8853	E	-110	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 6m			Source: V. Pickett			Profiles Surveyed 1993						
Profile #	BOPRC #	Dean - Piecewise A	Dean - Profile Av. A	Modified Dean - Piecewise	Modified Dean - Profile Av. A	BOP Trend Rates		BOPRC#				
						1990-8	Historic Rates (60-100yrs)					
1	1	E	-19.83	E	-3.996	E	-24.59	E	-27.34	20	-25	1
2	2	E	-25.6	E	-8.276	E	-217.7	E	-207.9	8	0	2
3	3	A	24.47	A	31.5	E	-65.14	E	-73.78	3	-20	3
4	4	E	-13.73	A	5.017	E	-162.8	E	-158.2	-8	-25	4
5	5	E	-0.89	A	6.996	E	-123.8	E	-131	12	30	5
6	6	E	-32.37	E	-17.08	E	-99	E	-106.4	4	20	6
7	7	A	10.02	E	-0.087	E	-771.9	E	-750	2	0	7
8	8	A	130.7	A	123.5	A	53.06	A	45.3	32	-55	8
9	9	A	362.1	A	345.8	A	4.473	E	-14.01	-70	200	9
10	10	A	71.98	A	70.95	A	59.46	A	53.94	-7	65	10
11	11	A	29.53	A	25.56	E	-42.21	E	-51.92	-11	15	11
12	12	E	-66.73	E	-17.43	E	-105.7	E	-106.7	26	25	12
13	13	E	-53.8	E	-40.23	E	-51.02	E	-67.31	3	55	13
14	14	A	2.05	A	3.618	A	8.662	E	-21.24	11		14
15	15	E	-32.74	E	-33.13	E	-55.94	E	-66.43	1		15
16	16	E	-21.6	E	-14.81	E	-32.37	E	-42.23	3	45 to 120	16
17	17	E	-31.48	E	-20.81	E	-44.5	E	-49.81	16	50	17
18	18	A	8.84	A	14.16	E	-25.72	E	-31.98	1		18
19	19	E	-40.53	E	-7.474	E	-62.92	E	-49.34	9	55	19
20	20	E	-21.42	E	-5.185	E	-42.42	E	-37.27	3	0	20
21	21	E	-43.81	E	-14.83	E	-29.55	E	-38.94	1		21
22	22	E	-36.56	E	-0.34	E	-4.474	E	-11.69	6		22
23	23	E	-9.32	A	13.39	A	13.2	E	-12.86	-0.7	-20	23
24	24	E	-56.02	E	-13.21	E	-28.7	E	-26.36	-8	-25	24
25	25	E	-45.91	E	-14.25	E	-115.5	E	-91.18	-8	-15	25
26	26	E	-63.55	E	-17.66	E	-88.06	E	-66.72	-8		26
27	27	E	-67.66	E	-19.94	E	-89.47	E	-71.23	-5		27
28	28	E	-65.66	E	-43.79	E	-138.4	E	-124.9	0	-13	28
29	29	E	-34.71	E	-18.27	E	-90.89	E	-95.84	-4	-8	29
30	30	A	4.83	A	39.73	E	-92.31	E	-65.74		0 to -3	30
31	32	E	-77.01	E	-5.233	E	-76.25	E	-36.95	6	-14	32
32	33	E	-118.5	E	-62.67	E	-92.14	E	-83.19	3		33
33	34	E	-30.85	E	-14.11	E	-101.5	E	-103.9	1		34
34	35	E	-52.16	E	-18.39	E	-20.17	E	-36.65	0	0	35
35	36	E	-24.96	E	-16.76	E	-212.5	E	-205.2	-0.4		36
36	38	E	-28.44	E	-19.82	E	-133.2	E	-130.7	-0.4		38
37	39	A	3.967	A	7.108	E	-328.8	E	-324.3	-1.5	2 to 60	39
38	40	E	-1.925	A	19.43	E	-123.3	E	-108.7	9		40
39	41	A	61.85	A	89.22	A	11.69	A	35.38	-5	100 to 515	41
40	42	A	79.47	A	63.04	A	31.36	A	10.97	-2		42
41	43	A	39.12	A	56.28	E	-139.6	E	-123.3	-7		43
42	44	A	64.32	A	68.58	E	-58.28	E	-59.46	-2	30	44
43	45	A	49.99	A	55.18	E	-12.98	E	-12.64	-9		45
44	46	A	256	A	234.4	A	206.2	A	186.5	-36	55 to 60	46
45	47	A	308.7	A	287.2	A	267.3	A	251.6	-9		47
46	48	A	10.02	A	3.441	E	-22.01	E	-25.93	-2	-35	48
47	49	A	90	A	100.4	E	-41.64	E	-39.67	-1	-8	49
48	51	A	61.11	A	69.6	E	-114.5	E	-110	-5	0	51
Average Erosion/Accretion for BOP			11.49		26.80		-71.39		-71.15	-0.64	10.44	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet6

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 7m								
Metab Routine: Shift 1								
Method: Dean with Piecewise Variation of A								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	mm error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	1629	1772	-143	0.3644	E	-20.51	
2	2	1481	1700	-219	0.4997	E	-31.18	
3	3	1840	1737	103	0.4248	A	14.73	
4	4	1746	1909	-163	0.4886	E	-23.28	
5	5	1722	1845	-123	0.6092	E	-17.59	
6	6	1460	1789	-329	0.6961	E	-47.05	
7	7	1612	1604	8	0.4125	A	1.141	
8	8	2693	1372	1321	1.136	A	188.7	
9	9	4146	1351	2795	3.006	A	399.3	
10	10	2191	1673	518	0.7997	A	73.93	
11	11	1995	1784	211	0.3696	A	30.19	
12	12	1358	2188	-830	2.378	E	-118.6	
13	13	1092	1728	-636	2.145	E	-90.91	
14	14	1358	1563	-205	1.553	E	-29.3	
15	15	1129	1563	-434	2.343	E	-62.05	
16	16	1204	1513	-309	1.682	E	-44.14	
17	17	1154	1545	-391	2.143	E	-55.88	
18	18	1481	1461	20	0.4376	A	2.782	
19	19	1176	1546	-370	0.9751	E	-52.67	
20	20	1245	1487	-242	0.907	E	-34.61	
21	21	1212	1641	-429	1.199	E	-61.34	
22	22	1296	1635	-339	1.061	E	-48.52	
23	23	1342	1588	-246	1.358	E	-35.19	
24	24	1060	1616	-556	1.657	E	-79.51	
25	25	1146	1578	-432	1.373	E	-61.62	
26	26	1215	1869	-654	1.555	E	-93.4	
27	27	1108	1762	-654	1.827	E	-93.34	
28	28	1044	1637	-593	1.537	E	-84.8	
29	29	1193	1643	-450	1.588	E	-64.28	
30	30	1171	1081	90	0.7273	A	12.8	
31	32	1331	1735	-404	1.065	E	-57.76	
32	33	913.9	1975	-1061.1	1.975	E	-161.5	
33	34	1515	1887	-372	1.237	E	-53.15	
34	35	1362	1867	-505	1.03	E	-72.14	
35	36	1383	1704	-321	1.062	E	-45.74	
36	38	1364	1642	-278	0.7925	E	-39.62	
37	39	1549	1539	10	0.2836	A	1.354	
38	40	1418	1330	88	0.4837	A	12.56	
39	41	2374	1156	1218	1.34	A	174	
40	42	1741	1482	259	1.482	A	36.94	
41	43	1845	1557	288	0.511	A	41.1	
42	44	2182	1650	532	0.7606	A	76.02	
43	45	2090	1655	435	0.6046	A	62.1	
44	46	3338	1090	2248	2.066	A	321.2	
45	47	3600	957	2643	2.029	A	377.6	
46	48	1483	1261	222	0.4349	A	31.75	
47	49	2558	1773	783	0.94	A	111.8	
48	51	2360	1714	646	0.7502	A	92.33	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet7

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 7m								
Matlab Routine: Shift2								
Method: Dean with profile averaged A								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	msr error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	1629	1592	37	0.3478	A	5.235	
2	2	1481	1524	-43	0.2138	E	-6.112	
3	3	1840	1557	283	0.4791	A	40.36	
4	4	1746	1640	106	0.3185	A	15.18	
5	5	1722	1671	51	0.2499	A	7.242	
6	6	1480	1592	-132	0.299	E	-18.84	
7	7	1612	1610	2	0.2302	A	0.4028	
8	8	2693	1436	1257	1.1	A	179.5	
9	9	4146	1524	2622	2.8	A	374.5	
10	10	2191	1640	551	0.8533	A	78.74	
11	11	1995	1731	264	0.401	A	37.67	
12	12	1358	1614	-256	1.015	E	-36.66	
13	13	1092	1487	-395	1.327	E	-58.45	
14	14	1358	1412	-54	0.6596	E	-7.695	
15	15	1129	1471	-342	1.401	E	-48.83	
16	16	1204	1379	-175	0.8514	E	-25.06	
17	17	1154	1436	-282	1.681	E	-40.31	
18	18	1481	1407	74	0.2833	A	10.51	
19	19	1176	1240	-64	0.2186	E	-9.158	
20	20	1245	1301	-56	0.379	E	-8.033	
21	21	1212	1343	-131	0.3891	E	-18.66	
22	22	1296	1325	-29	0.3601	E	-4.229	
23	23	1342	1261	81	0.3791	A	11.55	
24	24	1060	1166	-106	0.377	E	-15.1	
25	25	1146	1269	-123	0.487	E	-17.56	
26	26	1215	1378	-161	0.4561	E	-22.89	
27	27	1108	1307	-199	0.67	E	-28.43	
28	28	1044	1436	-392	1.039	E	-56.04	
29	29	1193	1379	-186	0.6247	E	-28.49	
30	30	1171	882.1	288.9	0.9379	A	41.23	
31	32	1331	1141	190	0.4862	A	27.12	
32	33	913.9	1446	-532.1	1.213	E	-76.01	
33	34	1515	1671	-156	0.4696	E	-22.31	
34	35	1362	1513	-151	0.3441	E	-21.58	
35	36	1383	1574	-191	0.6844	E	-27.29	
36	38	1364	1580	-216	0.64	E	-30.83	
37	39	1549	1497	52	0.2388	A	7.339	
38	40	1418	1221	197	0.4566	A	28.15	
39	41	2374	956.5	1417.5	1.189	A	202.5	
40	42	1741	1283	458	1.101	A	65.35	
41	43	1845	1393	452	0.8022	A	64.6	
42	44	2182	1596	584	0.8337	A	83.44	
43	45	2090	1580	510	0.7216	A	72.78	
44	46	3338	1320	2018	2.488	A	286.3	
45	47	3600	1173	2427	2.294	A	346.6	
46	48	1483	1400	83	0.2473	A	11.99	
47	49	2556	1661	895	1.112	A	127.8	
48	51	2362	1640	722	0.8505	A	103.2	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet8

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 7m								
Matlab Routine: Shift3.m								
Method: Modified Dean with piecewise determination of A								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	mm error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	1829	1799	-170	0.3683	E	-24.42	
2	2	1481	3252	-1771	2.348	E	-252.9	
3	3	1840	2409	-569	0.8107	E	-81.31	
4	4	1746	3084	-1338	1.666	E	-191.1	
5	5	1722	2800	-1078	1.563	E	-154	
6	6	1460	2318	-858	1.331	E	-122.5	
7	7			0				No closure depth
8	8	2693	2008	685	0.6822	A	97.87	
9	9	4146	4323	-177	0.8256	E	-25.23	
10	10	2191	1746	445	0.6792	A	63.52	
11	11	1995	2314	-319	0.5007	E	-45.81	
12	12	1358	2459	-1101	2.551	E	-157.4	
13	13	1092	1828	-536	1.781	E	-76.81	
14	14	1358	1416	-58	0.9118	E	-6.349	
15	15	1129	1684	-555	2.178	E	-76.26	
16	16	1201	1558	-357	1.603	E	-50.6	
17	17	1154	1660	-506	2.506	E	-72.26	
18	18	1481	1754	-273	1.22	E	-39.08	
19	19	1178	1741	-563	1.431	E	-60.8	
20	20	1245	1637	-392	1.113	E	-56.05	
21	21	1212	1531	-319	0.9383	E	-45.6	
22	22	1296	1432	-136	0.7425	E	-19.51	
23	23	1342	1334	8	0.5535	A	1.161	
24	24	1060	1367	-307	1.042	E	-43.89	
25	25	1146	2136	-990	2.682	E	-141.4	
26	26	1215	2027	-812	1.728	E	-116	
27	27	1108	1949	-841	2.221	E	-120.1	
28	28	1044	2238	-1194	2.678	E	-170.7	
29	29	1193	2040	-847	2.08	E	-120.9	
30	30	1171	1911	-740	1.92	E	-105.8	
31	32	1331	1796	-465	0.9178	E	-66.5	
32	33	913.9	1780	-866.1	1.655	E	-123.7	
33	34	1515	2441	-926	2.158	E	-132.3	
34	35	1362	1610	-248	0.6128	E	-36.36	
35	36	1383	3191	-1808	3.921	E	-258.2	
36	38	1364	2520	-1156	2.46	E	-165.1	
37	39			0				No closure depth
38	40	1418	2335	-917	1.666	E	-130.9	
39	41	2374	1591	783	0.6236	A	111.8	
40	42	1741	1531	210	1.774	A	30.02	
41	43	1845	3008	-1163	0.6662	E	-166.2	
42	44	2182	2655	-473	0.1523	E	-67.54	
43	45	2090	2156	-66	2.426	E	-9.471	
44	46	3338	1515	1823	2.245	A	260.5	
45	47	3600	1308	2292	0.3931	A	327.5	
46	48	1483	1568	-85	0.3542	E	-12.04	
47	49	2556	2844	-288	0.3542	E	-41.19	
48	51	2362	3148	-786	0.8456	E	-112.3	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet9

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 7m								
Matlab Routine: Shift4.m								
Method: Modified Dean Profile with profile averaged A values								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	mar error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	1629	1784	-155	0.3881	E	-22.27	
2	2	1481	3155	-1674	2.235	E	-239	
3	3	1840	2418	-578	0.8114	E	-82.54	
4	4	1746	2973	-1227	1.534	E	-175.3	
5	5	1722	2798	-1076	1.518	E	-153.7	
6	6	1460	2322	-862	1.319	E	-123.1	
7	7			0				No closure depth
8	8	2693	2076	617	0.8881	A	88.13	
9	9	4146	4462	-316	0.8952	E	-45.2	
10	10	2191	1781	410	0.6237	A	58.52	
11	11	1995	2365	-370	0.5756	E	-52.81	
12	12	1358	2344	-986	2.144	E	-140.9	
13	13	1092	1710	-618	1.783	E	-88.27	
14	14	1358	1616	-258	1.034	E	-36.93	
15	15	1129	1745	-616	2.179	E	-87.97	
16	16	1204	1604	-400	1.507	E	-57.25	
17	17	1154	1674	-520	2.371	E	-74.35	
18	18	1481	1785	-304	1.144	E	-43.47	
19	19	1176	1583	-407	0.9437	E	-58.14	
20	20	1245	1564	-319	0.8472	E	-45.64	
21	21	1212	1541	-329	0.7791	E	-47.04	
22	22	1296	1421	-125	0.4767	E	-17.92	
23	23	1342	1477	-135	0.501	E	-19.27	
24	24	1060	1275	-215	0.6081	E	-30.8	
25	25	1146	1896	-752	1.937	E	-107.4	
26	26	1215	1778	-563	1.171	E	-80.35	
27	27	1108	1727	-619	1.523	E	-88.39	
28	28	1044	2099	-1055	2.351	E	-150.8	
29	29	1193	2013	-820	1.855	E	-117.1	
30	30	1171	1744	-573	1.628	E	-81.86	
31	32	1331	1401	-70	0.6735	E	-10.05	
32	33	913.9	1616	-702.1	1.478	E	-100.2	
33	34	1515	2405	-890	1.878	E	-127.2	
34	35	1362	1665	-303	0.5893	E	-43.21	
35	36	1383	3114	-1731	3.7	E	-247.2	
36	38	1364	2466	-1122	2.347	E	-160.2	
37	39			0				No closure depth
38	40	1418	2268	-850	1.592	E	-121.4	
39	41	2374	1397	977	1.479	A	139.8	
40	42	1741	1710	31	0.4888	A	4.474	
41	43	1845	2860	-1015	1.552	E	-145	
42	44	2182	2644	-462	0.6341	E	-66	
43	45	2090	2135	-45	0.1654	E	-6.456	
44	46	3338	1705	1633	2.423	A	233.4	
45	47	3600	1485	2135	2.249	A	305	
46	48	1483	1641	-158	0.3681	E	-22.47	
47	49	2556	2806	-250	0.3288	E	-35.68	
48	51	2362	3107	-745	0.8167	E	-106.3	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 7m		Source: V. Pickett			Profiles Surveyed 1993							
Profile #	BOPRC #	Dean - Piecewise A		Dean - Profile Av. A		Modified Dean - Piecewise		Modified Dean - Profile Av. A		BOP Trend Rates		BOPRC#
										1990-6	Historic Rates (60-100yrs)	
1	1	E	-20.51	A	5.235	E	-24.42	E	-22.27	20	-25	1
2	2	E	-31.18	E	-6.112	E	-252.9	E	-239	8	0	2
3	3	A	14.73	A	40.36	E	-81.31	E	-82.54	3	-20	3
4	4	E	-23.29	A	15.18	E	-191.1	E	-175.3	-8	-25	4
5	5	E	-17.59	A	7.242	E	-154	E	-153.7	12	30	5
6	6	E	-47.05	E	-18.84	E	-122.5	E	-123.1	4	20	6
7	7	A	1.141	A	0.4028					2	0	7
8	8	A	188.7	A	179.5	A	97.87	A	88.13	32	-55	8
9	9	A	399.3	A	374.5	E	-25.23	E	-45.2	-70	200	9
10	10	A	73.93	A	78.74	A	63.52	A	58.52	-7	65	10
11	11	A	30.19	A	37.67	E	-45.61	E	-52.81	-11	15	11
12	12	E	-118.6	E	-36.66	E	-157.4	E	-140.9	26	25	12
13	13	E	-90.91	E	-56.45	E	-76.61	E	-88.27	3	55	13
14	14	E	-29.3	E	-7.695	E	-8.349	E	-36.93	11		14
15	15	E	-62.05	E	-48.93	E	-76.26	E	-87.97	1		15
16	16	E	-44.14	E	-25.05	E	-50.6	E	-57.25	3	45 to 120	16
17	17	E	-55.88	E	-40.31	E	-72.25	E	-74.35	16	50	17
18	18	A	2.782	A	10.51	E	-39.08	E	-43.47	1		18
19	19	E	-52.87	E	-9.158	E	-80.8	E	-58.14	9	55	19
20	20	E	-34.61	E	-8.033	E	-56.05	E	-45.64	3	0	20
21	21	E	-61.34	E	-18.68	E	-45.6	E	-47.04	1		21
22	22	E	-48.52	E	-4.229	E	-19.51	E	-17.92	6		22
23	23	E	-35.19	A	11.55	A	1.161	E	-19.27	-0.7	-20	23
24	24	E	-79.51	E	-15.1	E	-43.89	E	-30.8	-8	-25	24
25	25	E	-61.62	E	-17.56	E	-141.4	E	-107.4	-8	-15	25
26	26	E	-93.4	E	-22.99	E	-116	E	-80.35	-8		26
27	27	E	-93.34	E	-28.43	E	-120.1	E	-88.39	-5		27
28	28	E	-84.8	E	-56.04	E	-170.7	E	-150.8	0	-13	28
29	29	E	-64.28	E	-26.49	E	-120.9	E	-117.1	-4	-8	29
30	30	A	12.8	A	41.23	E	-105.8	E	-81.86		0 to -3	30
31	32	E	-57.76	A	27.12	E	-66.5	E	-10.05	6	-14	32
32	33	E	-151.5	E	-76.01	E	-123.7	E	-100.2	3		33
33	34	E	-53.15	E	-22.31	E	-132.3	E	-127.2	1		34
34	35	E	-72.14	E	-21.58	E	-35.36	E	-43.21	0	0	35
35	36	E	-45.74	E	-27.29	E	-258.2	E	-247.2	-0.4		36
36	38	E	-39.62	E	-30.83	E	-165.1	E	-160.2	-0.4		38
37	39	A	1.354	A	7.339					-1.5	2 to 60	39
38	40	A	12.56	A	28.15	E	-130.9	E	-121.4	9		40
39	41	A	174	A	202.5	A	111.8	A	139.6	-5	100 to 515	41
40	42	A	36.94	A	65.35	A	30.02	A	4.474	-2		42
41	43	A	41.1	A	64.6	E	-166.2	E	-145	-7		43
42	44	A	76.02	A	83.44	E	-67.54	E	-66	-2	30	44
43	45	A	62.1	A	72.78	E	-9.471	E	-6.456	-9		45
44	46	A	321.2	A	288.3	A	260.5	A	233.4	-36	55 to 60	46
45	47	A	377.6	A	346.6	A	327.5	A	305	-9		47
46	48	A	31.75	A	11.99	E	-12.04	E	-22.47	-2	-35	48
47	49	A	111.8	A	127.8	E	-41.19	E	-35.68	-1	-8	49
48	51	A	92.33	A	103.2	E	-112.3	E	-106.3	-5	0	51
Average Erosion/Accretion for BOP			8.18		32.79		-61.45		-57.17	-0.64	10.44	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet11

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 8m								
Method Routine: Shift 1								
Method: Method: Dean with Piecewise Variation of A								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rmer error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	2370.2802	2508.5423	-138.2621	0.33151	E	-17.28	
2	2	2142.3162	2360.9872	-218.671	0.46386	E	-27.33	
3	3	2630.03	2524.0258	106.0042	0.38513	A	13.25	
4	4	2534.9075	2753.2776	-218.3701	0.45563	E	-27.30	
5	5	2429.3669	2641.1599	-211.793	0.50084	E	-26.47	
6	6	2114.8182	2534.316	-419.4978	0.69008	E	-52.44	
7	7	2299.9489	2328.5619	-28.613	0.37263	E	-3.58	
8	8	3820.2009	1911.9524	1908.2485	1.5815	A	238.53	
9	9	5325.9856	1866.4878	3459.4978	3.2972	A	432.44	
10	10	3000.3072	2398.4534	601.8538	0.74788	A	75.23	
11	11	2836.9829	2570.9937	265.9892	0.35395	A	33.25	
12	12	1836.2194	3157.2587	-1321.0393	2.6205	E	-165.13	
13	13	1487.9735	2515.2672	-1027.2937	2.2972	E	-128.41	
14	14	1818.0466	2299.4806	-481.414	1.8521	E	-60.18	
15	15	1513.1393	2274.19	-761.0507	2.8015	E	-95.13	
16	16	1611.1346	2153.8841	-542.7495	2.2883	E	-67.84	
17	17	1501.6378	2170.8571	-669.2193	2.75	E	-83.65	
18	18	1973.8813	2113.5817	-139.7004	1.9735	E	-17.48	
19	19	1645.4676	2149.4104	-503.9428	1.0974	E	-62.99	
20	20	1707.546	2186.5677	-459.0217	1.4076	E	-57.38	
21	21	1696.7513	2312.2687	-615.5174	1.3151	E	-76.84	
22	22	1799.6783	2273.6095	-473.9312	1.1149	E	-59.24	
23	23	1846.0342	2324.9099	-478.8757	1.5797	E	-59.88	
24	24	1490.9343	2285.8927	-794.9584	1.8179	E	-99.37	
25	25	1575.1887	2227.5259	-652.3372	1.7438	E	-81.54	
26	26	1729.5194	2641.5647	-912.0453	1.6777	E	-114.01	
27	27	1544.8675	2465.8548	-920.9871	2.0257	E	-115.12	
28	28	1474.5676	2304.2192	-829.6516	1.7182	E	-103.71	
29	29	1657.3133	2461.3677	-804.0544	2.0694	E	-100.51	
30	30	1580.8153	1376.9098	203.9057	0.82728	A	25.49	
31	32	2183.5263	2326.6837	-143.1574	1.0648	E	-17.89	
32	33	1402.8502	2761.1914	-1358.3412	1.8648	E	-169.79	
33	34	2071.8821	2721.5804	-649.6983	1.6932	E	-81.21	
34	35	1971.8817	2654.4801	-682.7984	1.0337	E	-85.35	
35	36	1886.3245	2394.3636	-508.0391	1.2309	E	-63.50	
36	38	1881.6733	2301.4476	-419.7743	0.96626	E	-52.47	
37	39	2148.1607	2158.0437	-7.883	0.27813	E	-0.99	
38	40	1982.3879	1750.4734	231.9145	0.66105	A	28.99	
39	41	3882.7893	1554.7144	2328.0749	1.8404	A	291.01	
40	42	2311.7668	1809.7947	501.9721	1.3803	A	62.75	
41	43	2545.5636	2196.3338	349.2298	0.49398	A	43.85	
42	44	3018.7616	2336.0239	682.7377	0.80865	A	85.34	
43	45	2953.3229	2339.4567	613.8662	0.69035	A	76.73	
44	46	4624.9341	1507.1459	3117.7882	3.448	A	389.72	
45	47	4854.8864	1321.307	3533.5794	2.8991	A	441.70	
46	48	2135.9864	1847.9731	288.0133	1.082	A	36.00	
47	49	3617.2568	2480.4694	1136.7874	1.0627	A	142.10	
48	51	3439.7442	2362.6282	1057.116	0.96227	A	132.14	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet12

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 8 m								
Mathlab Routine: Shift 2								
Method: Profile averaged A values								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rms error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	2370.2802	2222.7349	147.5453	0.40431	A	18.44	
2	2	2142.3182	2128.1598	14.1586	0.24594	A	1.77	
3	3	2630.03	2174.5908	455.4394	0.5098	A	56.93	
4	4	2534.9075	2289.7485	245.159	0.42593	A	30.84	
5	5	2429.3669	2333.3616	96.0053	0.25457	A	12.00	
6	6	2114.8182	2222.7349	-107.9167	0.27682	E	-13.49	
7	7	2299.9489	2247.4774	52.4715	0.23602	A	6.56	
8	8	3820.2009	2005.1936	1815.0073	1.5534	A	226.88	
9	9	5325.9856	2128.1598	3197.826	2.9999	A	399.73	
10	10	3000.3072	2289.7485	710.5587	0.88584	A	88.82	
11	11	2836.9829	2417.5291	419.4538	0.53687	A	52.43	
12	12	1836.2194	2254.153	-417.9336	1.0315	E	-52.24	
13	13	1487.9735	2076.0435	-588.07	1.397	E	-73.51	
14	14	1818.0466	1971.2657	-153.2191	0.7882	E	-19.15	
15	15	1513.1393	2054.3557	-541.2164	1.8286	E	-67.65	
16	16	1811.1346	1925.3478	-314.2132	1.2522	E	-39.28	
17	17	1501.6378	2005.1936	-503.5558	2.1111	E	-62.84	
18	18	1973.8813	1984.5948	-9.2665	0.63781	A	1.16	
19	19	1645.4676	1731.0471	-85.5795	0.23317	E	-10.70	
20	20	1707.546	1816.5719	-109.0259	0.40787	E	-13.63	
21	21	1896.7513	1875.0143	-178.263	0.40058	E	-22.28	
22	22	1799.8783	1850.884	-50.9857	0.34219	E	-6.37	
23	23	1846.0342	1781.1038	84.9304	0.3433	A	10.62	
24	24	1490.9343	1627.4213	-136.487	0.37646	E	-17.06	
25	25	1575.1887	1772.2498	-197.0611	0.58236	E	-24.83	
26	26	1729.5194	1921.3348	-191.8154	0.42941	E	-23.08	
27	27	1544.8675	1825.364	-280.4965	0.68759	E	-35.06	
28	28	1474.5678	2005.1936	-530.626	1.103	E	-66.33	
29	29	1657.3133	1925.3478	-268.0345	0.66224	E	-33.50	
30	30	1580.8153	1231.7399	349.0754	0.90908	A	43.63	
31	32	2183.5263	1592.8094	590.7169	0.71387	A	73.84	
32	33	1402.8502	2019.0382	-616.188	1.1092	E	-77.02	
33	34	2071.8821	2333.3616	-261.4795	0.63815	E	-32.68	
34	35	1971.6817	2113.0487	-141.367	0.31564	E	-17.67	
35	36	1886.3245	2198.4431	-312.1186	0.79883	E	-39.01	
36	38	1881.6733	2206.491	-324.8177	0.73856	E	-40.60	
37	39	2148.1607	2090.715	57.4457	0.21865	A	7.18	
38	40	1982.3879	1705.1137	277.2742	0.5563	A	34.66	
39	41	3882.7893	1335.5185	2547.2708	1.9248	A	318.41	
40	42	2311.7668	1792.0405	519.7263	1.0379	A	84.97	
41	43	2545.5636	1944.8063	600.7573	0.85419	A	75.09	
42	44	3018.7816	2230.9317	787.8299	0.93656	A	98.48	
43	45	2953.3229	2206.491	746.8319	0.85682	A	93.35	
44	46	4624.9341	1843.3286	2781.6055	3.0536	A	347.70	
45	47	4854.8864	1638.4185	3216.4679	2.8541	A	402.06	
46	48	2135.9864	1954.1878	181.7986	0.35773	A	22.72	
47	49	3617.2568	2319.5084	1297.7504	1.2563	A	162.22	
48	51	3439.7442	2289.7485	1149.9957	1.0696	A	143.75	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet13

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth: 8 m								
Matlab Routine: Shift 3								
Method: Modified Dean Profile with piecewise variation of A								
Profile #	BOPRC #	Sediment Vol. (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rmar error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	2370.2802	2543.0882	-172.808	0.33254	E	-21.60	
2	2	2142.3162	4400.3781	-2258.0619	2.3723	E	-282.26	
3	3	2630.03	3366.0497	-736.0197	0.8182	E	-92.00	
4	4	2534.9075	4255.4891	-1720.5816	1.7507	E	-215.07	
5	5	2429.3669	3879.7826	-1450.4157	1.6318	E	-181.30	
6	6	2114.8182	3234.4645	-1119.6463	1.3354	E	-139.96	
7	7			0				NO closure depth for predicted profile
8	8	3820.2009	2745.3126	1074.8883	1.2534	A	134.36	
9	9	5325.9856	5815.6561	-489.6705	1.0285	E	-61.21	
10	10	3000.3072	2451.9603	548.3469	0.67012	A	68.54	
11	11	2836.9829	3222.3948	-385.4119	0.47426	E	-48.18	
12	12	1836.2194	3508.3425	-1672.1231	2.9184	E	-209.02	
13	13	1487.9735	2341.2576	-853.2841	1.9173	E	-106.66	
14	14	1818.0466	2051.5208	-233.4742	1.2163	E	-29.18	
15	15	1513.1393	2378.5899	-865.4506	2.6374	E	-108.18	
16	16	1611.1346	2207.3355	-596.2009	2.2374	E	-74.53	
17	17	1501.6378	2330.8666	-829.2288	3.0736	E	-103.65	
18	18	1973.8813	2451.2559	-477.3746	2.1984	E	-59.67	
19	19	1645.4676	2436.2624	-790.7948	1.7296	E	-98.65	
20	20	1707.546	2303.9998	-596.4538	1.4788	E	-74.56	
21	21	1696.7513	2200.7481	-503.9968	1.1533	E	-63.00	
22	22	1799.6783	2066.0913	-266.413	0.86748	E	-33.30	
23	23	1846.0342	1980.2966	-114.2624	0.75468	E	-14.28	
24	24	1490.9343	1989.7689	-498.8346	1.3307	E	-62.35	
25	25	1575.1887	2634.7537	-1359.565	3.0285	E	-169.95	
26	26	1729.5194	2662.5464	-1133.027	2.0285	E	-141.63	
27	27	1544.8675	2742.4217	-1197.5542	2.6207	E	-149.69	
28	28	1474.5676	3088.8467	-1614.2791	2.991	E	-201.78	
29	29	1657.3133	2886.6135	-1229.3002	2.5172	E	-153.66	
30	30	1580.8153	2519.1592	-938.3439	1.9128	E	-117.29	
31	32	2183.5263	2505.5381	-322.0118	0.88835	E	-40.25	
32	33	1402.8502	2562.3948	-1159.5446	1.558	E	-144.94	
33	34	2071.8821	3411.544	-1339.6619	2.8336	E	-167.46	
34	35	1971.6617	2338.1756	-366.4939	0.62399	E	-45.81	
35	36			0				NO closure depth for predicted profile
36	38	1881.6733	3454.4682	-1572.7949	2.9002	E	-196.60	
37	39			0				NO closure depth for predicted profile
38	40	1982.3879	3087.7856	-1105.3977	1.6611	E	-136.17	
39	41	3882.7893	2156.0978	1726.6915	1.5189	A	215.84	
40	42	2311.7668	2141.7368	170.03	0.56459	A	21.25	
41	43	2545.5636	4047.5547	-1501.9911	1.9104	E	-187.75	
42	44	3018.7616	3637.4094	-618.6478	0.75143	E	-77.33	
43	45	2953.3229	2981.833	-28.5101	0.16212	E	-3.56	
44	46	4624.9341	2074.74	2550.1941	2.9559	A	318.77	
45	47	4854.8864	1781.6669	3073.2195	2.7584	A	384.15	
46	48	2135.9864	2126.0405	9.9459	0.44451	A	1.24	
47	49	3617.2568	3888.72	-269.4632	0.32563	E	-33.68	
48	51	3439.7442	4264.8213	-825.0771	0.77791	E	-103.13	

Appendix 6 - Table Summaries of Profile Shift calculations

Sheet14

Profile Shift Calculations : Dean Equilibrium Beach Profile								
Closure Depth:								
Matlab Routine: Shift4								
Method: Modified Dean Profile with profile averaged A								
Profile #	BOPRC #	Sediment Vol (m3/m)	Dean Vol. (m3/m)	Diff. m3/m	rmsr error	Erosion/Accretion	Profile Shift (m)	Remarks
1	1	2370.2802	2476.1445	-105.8643	0.37258	E	-13.23	
2	2	2142.3162	4258.1821	-2115.8659	2.2395	E	-264.48	
3	3	2630.03	3298.814	-668.784	0.76605	E	-83.60	
4	4	2534.9075	4031.2018	-1496.2941	1.5171	E	-187.04	
5	5	2429.3669	3805.7493	-1376.3824	1.5249	E	-172.05	
6	6	2114.8182	3176.8819	-1062.0637	1.2781	E	-132.76	
7	7			0				NO closure depth for predicted profile
8	8	3820.2009	2841.275	978.9259	1.2064	A	122.37	
9	9	5325.9856	5966.0267	-640.0411	1.0733	E	-80.01	
10	10	3000.3072	2477.1978	523.1098	0.63684	A	65.39	
11	11	2836.9829	3245.566	-408.5831	0.53158	E	-51.07	
12	12	1836.2194	3208.2504	-1372.031	2.2453	E	-171.50	
13	13	1487.9735	2368.5191	-880.5456	1.8468	E	-110.07	
14	14	1818.0466	2240.1817	-422.1351	1.2148	E	-52.77	
15	15	1513.1393	2412.6056	-899.4663	2.6569	E	-112.43	
16	16	1611.1346	2221.2558	-610.1212	1.9686	E	-78.27	
17	17	1501.6378	2317.8039	-816.1661	2.8534	E	-102.02	
18	18	1973.8813	2459.0114	-485.1301	1.9014	E	-60.64	
19	19	1645.4676	2179.8184	-534.3508	1.0692	E	-66.79	
20	20	1707.546	2161.67	-454.124	1.0038	E	-56.77	
21	21	1696.7513	2135.9762	-439.2249	0.83862	E	-54.90	
22	22	1799.6783	1978.9848	-179.3065	0.48841	E	-22.41	
23	23	1846.0342	2044.3893	-198.3551	0.52917	E	-24.79	
24	24	1490.9343	1773.4877	-282.5534	0.63891	E	-35.32	
25	25	1575.1887	2594.2057	-1019.017	2.2646	E	-127.38	
26	26	1729.5194	2446.6836	-717.1642	1.2031	E	-89.65	
27	27	1544.8675	2374.3734	-829.5059	1.6794	E	-103.69	
28	28	1474.5676	2872.0624	-1397.4948	2.5491	E	-174.69	
29	29	1657.3133	2754.2425	-1096.9292	2.0022	E	-137.12	
30	30	1580.8153	2357.5616	-776.7463	1.6866	E	-97.09	
31	32	2183.5263	1933.7775	249.7488	0.78237	A	31.22	
32	33	1402.8502	2242.465	-839.6148	1.3594	E	-104.95	
33	34	2071.8821	3292.6909	-1220.8088	2.2874	E	-152.60	
34	35	1971.6817	2313.1073	-341.4256	0.54275	E	-42.68	
35	36			0				NO closure depth for predicted profile
36	38	1881.6733	3390.001	-1508.3277	2.7144	E	-168.54	
37	39			0				NO closure depth for predicted profile
38	40	1982.3879	3072.6486	-1090.2607	1.6488	E	-136.28	
39	41	3882.7893	1911.3205	1971.4688				
40	42	2311.7668	2349.3926	-37.6258	0.48468	E	-4.70	
41	43	2545.5636	3861.4511	-1315.8875	1.6963	E	-164.49	
42	44	3018.7616	3597.7275	-578.9659	0.67448	E	-72.37	
43	45	2953.3229	2931.6909	21.632	0.21461	A	2.70	
44	46	4624.9341	2346.2897	2278.6444	2.5715	A	284.83	
45	47	4854.8864	2020.4401	2834.4463	2.5963	A	354.31	
46	48	2135.9864	2270.6784	-134.692	0.34153	E	-16.64	
47	49	3617.2568	3815.0349	-197.7781	0.31508	E	-24.72	
48	51	3439.7442	4208.0016	-768.2574	0.75031	E	-95.78	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 8 m			Source: V. Pickett			Profiles Surveyed 1993						
Profile #	BOPRC #	Dean - Piecewise A	Dean - Profile Av. A	Modified Dean - Piecewise	Modified Dean - Profile Av. A	BOP Trend Rates		BOPRC#				
						1990-6	Historic Rates (60-100yrs)					
1	1	E	-17.28	A	18.44	E	-21.60	E	-13.23	20	-25	1
2	2	E	-27.33	A	1.77	E	-282.26	E	-264.48	8	0	2
3	3	A	13.25	A	56.93	E	-92.00	E	-83.60	3	-20	3
4	4	E	-27.30	A	30.64	E	-215.07	E	-187.04	-8	-25	4
5	5	E	-26.47	A	12.00	E	-181.30	E	-172.05	12	30	5
6	6	E	-52.44	E	-13.49	E	-139.96	E	-132.76	4	20	6
7	7	E	-3.58	A	6.56	NO closure depth for predicted profile		NO closure depth for predicted profile		2	0	7
8	8	A	238.53	A	226.88	A	134.36	A	122.37	32	-55	8
9	9	A	432.44	A	399.73	E	-61.21	E	-80.01	-70	200	9
10	10	A	75.23	A	88.82	A	88.54	A	86.39	-7	65	10
11	11	A	33.25	A	52.43	E	-48.18	E	-51.07	-11	15	11
12	12	E	-165.13	E	-52.24	E	-209.02	E	-171.50	26	25	12
13	13	E	-128.41	E	-73.51	E	-106.66	E	-110.07	3	55	13
14	14	E	-60.18	E	-19.15	E	-29.18	E	-52.77	11		14
15	15	E	-95.13	E	-67.65	E	108.18	E	-112.43	1		15
16	16	E	-67.84	E	-39.28	E	-74.53	E	-76.27	3	45 to 120	16
17	17	E	-83.65	E	-62.94	E	-103.65	E	-102.02	16	50	17
18	18	E	-17.46	A	1.16	E	-59.67	E	-60.64	1		18
19	19	E	-62.99	E	-10.70	E	-98.85	E	-66.79	9	55	19
20	20	E	-57.38	E	-13.63	E	-74.56	E	-56.77	3	0	20
21	21	E	-76.94	E	-22.28	E	-63.00	E	-54.90	1		21
22	22	E	-59.24	E	-6.37	E	-33.30	E	-22.41	6		22
23	23	E	-59.86	A	10.62	E	-14.28	E	-24.79	-0.7	-20	23
24	24	E	-99.37	E	-17.06	E	-62.35	E	-35.32	-8	-25	24
25	25	E	-81.54	E	-24.63	E	-169.95	E	-127.38	-8	-15	25
26	26	E	-114.01	E	-23.98	E	-141.63	E	-89.65	-8		26
27	27	E	-115.12	E	-35.06	E	-149.69	E	-103.69	-5		27
28	28	E	-103.71	E	-66.33	E	-201.78	E	-174.69	0	-13	28
29	29	E	-100.51	E	-33.50	E	-153.66	E	-137.12	-4	-8	29
30	30	A	25.49	A	43.63	E	-117.29	E	-97.09		0 to -3	30
31	32	E	-17.89	A	73.84	E	-40.25	A	31.22	6	-14	32
32	33	E	-169.79	E	-77.02	E	-144.94	E	-104.95	3		33
33	34	E	-81.21	E	-32.68	E	-167.46	E	-152.60	1		34
34	35	E	-85.35	E	-17.67	E	-45.81	E	-42.68	0	0	35
35	36	E	-63.50	E	-39.01	NO closure depth for predicted profile		NO closure depth for predicted profile		-0.4		36
36	38	E	-52.47	E	-40.60	E	-196.60	E	-188.54	-0.4		38
37	39	E	-0.99	A	7.18	NO closure depth for predicted profile		NO closure depth for predicted profile		-1.5	2 to 60	39
38	40	A	28.99	A	34.66	E	-138.17	E	-136.28	9		40
39	41	A	291.01	A	318.41	A	215.84	NO closure depth for predicted profile		-5	100 to 515	41
40	42	A	62.75	A	64.97	A	21.25	E	-4.70	-2		42
41	43	A	43.65	A	75.09	E	-187.75	E	-164.49	-7		43
42	44	A	85.34	A	98.48	E	-77.33	E	-72.37	-2	30	44
43	45	A	76.73	A	93.35	E	-3.56	A	2.70	-9		45
44	46	A	389.72	A	347.70	A	318.77	A	284.83	-36	55 to 60	46
45	47	A	441.70	A	402.06	A	384.15	A	354.31	-9		47
46	48	A	36.00	A	22.72	A	1.24	E	-16.84	-2	-35	48
47	49	A	142.10	A	162.22	E	-33.68	E	-24.72	-1	-8	49
48	51	A	132.14	A	143.75	E	-103.13	E	-95.78	-5	0	51
Average Erosion/Accretion for BOP			7.80		41.78		-66.83		-63.72	-0.64	10.44	

Appendix 6 - Table Summaries of Profile Shift calculations

1	1	0.1905	0.2289	0.2675	0.3061	0.3447	0.3833	0.4219	0.4605	0.4991	0.5377	0.5763	0.6149	0.6535	0.6921	0.7307	0.7693	0.8079	0.8465	0.8851	0.9237	0.9623	1.0009	1.0395	1.0781	1.1167	1.1553	1.1939	1.2325	1.2711	1.3097	1.3483	1.3869	1.4255	1.4641	1.5027	1.5413	1.5799	1.6185	1.6571	1.6957	1.7343	1.7729	1.8115	1.8501	1.8887	1.9273	1.9659	2.0045	2.0431	2.0817	2.1203	2.1589	2.1975	2.2361	2.2747	2.3133	2.3519	2.3905	2.4291	2.4677	2.5063	2.5449	2.5835	2.6221	2.6607	2.6993	2.7379	2.7765	2.8151	2.8537	2.8923	2.9309	2.9695	3.0081	3.0467	3.0853	3.1239	3.1625	3.2011	3.2397	3.2783	3.3169	3.3555	3.3941	3.4327	3.4713	3.5099	3.5485	3.5871	3.6257	3.6643	3.7029	3.7415	3.7801	3.8187	3.8573	3.8959	3.9345	3.9731	4.0117	4.0503	4.0889	4.1275	4.1661	4.2047	4.2433	4.2819	4.3205	4.3591	4.3977	4.4363	4.4749	4.5135	4.5521	4.5907	4.6293	4.6679	4.7065	4.7451	4.7837	4.8223	4.8609	4.8995	4.9381	4.9767	5.0153	5.0539	5.0925	5.1311	5.1697	5.2083	5.2469	5.2855	5.3241	5.3627	5.4013	5.4399	5.4785	5.5171	5.5557	5.5943	5.6329	5.6715	5.7101	5.7487	5.7873	5.8259	5.8645	5.9031	5.9417	5.9803	6.0189	6.0575	6.0961	6.1347	6.1733	6.2119	6.2505	6.2891	6.3277	6.3663	6.4049	6.4435	6.4821	6.5207	6.5593	6.5979	6.6365	6.6751	6.7137	6.7523	6.7909	6.8295	6.8681	6.9067	6.9453	6.9839	7.0225	7.0611	7.0997	7.1383	7.1769	7.2155	7.2541	7.2927	7.3313	7.3699	7.4085	7.4471	7.4857	7.5243	7.5629	7.6015	7.6401	7.6787	7.7173	7.7559	7.7945	7.8331	7.8717	7.9103	7.9489	7.9875	8.0261	8.0647	8.1033	8.1419	8.1805	8.2191	8.2577	8.2963	8.3349	8.3735	8.4121	8.4507	8.4893	8.5279	8.5665	8.6051	8.6437	8.6823	8.7209	8.7595	8.7981	8.8367	8.8753	8.9139	8.9525	8.9911	9.0297	9.0683	9.1069	9.1455	9.1841	9.2227	9.2613	9.2999	9.3385	9.3771	9.4157	9.4543	9.4929	9.5315	9.5701	9.6087	9.6473	9.6859	9.7245	9.7631	9.8017	9.8403	9.8789	9.9175	9.9561	9.9947	10.0333	10.0719	10.1105	10.1491	10.1877	10.2263	10.2649	10.3035	10.3421	10.3807	10.4193	10.4579	10.4965	10.5351	10.5737	10.6123	10.6509	10.6895	10.7281	10.7667	10.8053	10.8439	10.8825	10.9211	10.9597	10.9983	11.0369	11.0755	11.1141	11.1527	11.1913	11.2299	11.2685	11.3071	11.3457	11.3843	11.4229	11.4615	11.5001	11.5387	11.5773	11.6159	11.6545	11.6931	11.7317	11.7703	11.8089	11.8475	11.8861	11.9247	11.9633	12.0019	12.0405	12.0791	12.1177	12.1563	12.1949	12.2335	12.2721	12.3107	12.3493	12.3879	12.4265	12.4651	12.5037	12.5423	12.5809	12.6195	12.6581	12.6967	12.7353	12.7739	12.8125	12.8511	12.8897	12.9283	12.9669	13.0055	13.0441	13.0827	13.1213	13.1599	13.1985	13.2371	13.2757	13.3143	13.3529	13.3915	13.4301	13.4687	13.5073	13.5459	13.5845	13.6231	13.6617	13.7003	13.7389	13.7775	13.8161	13.8547	13.8933	13.9319	13.9705	14.0091	14.0477	14.0863	14.1249	14.1635	14.2021	14.2407	14.2793	14.3179	14.3565	14.3951	14.4337	14.4723	14.5109	14.5495	14.5881	14.6267	14.6653	14.7039	14.7425	14.7811	14.8197	14.8583	14.8969	14.9355	14.9741	15.0127	15.0513	15.0899	15.1285	15.1671	15.2057	15.2443	15.2829	15.3215	15.3601	15.3987	15.4373	15.4759	15.5145	15.5531	15.5917	15.6303	15.6689	15.7075	15.7461	15.7847	15.8233	15.8619	15.9005	15.9391	15.9777	16.0163	16.0549	16.0935	16.1321	16.1707	16.2093	16.2479	16.2865	16.3251	16.3637	16.4023	16.4409	16.4795	16.5181	16.5567	16.5953	16.6339	16.6725	16.7111	16.7497	16.7883	16.8269	16.8655	16.9041	16.9427	16.9813	17.0199	17.0585	17.0971	17.1357	17.1743	17.2129	17.2515	17.2901	17.3287	17.3673	17.4059	17.4445	17.4831	17.5217	17.5603	17.5989	17.6375	17.6761	17.7147	17.7533	17.7919	17.8305	17.8691	17.9077	17.9463	17.9849	18.0235	18.0621	18.1007	18.1393	18.1779	18.2165	18.2551	18.2937	18.3323	18.3709	18.4095	18.4481	18.4867	18.5253	18.5639	18.6025	18.6411	18.6797	18.7183	18.7569	18.7955	18.8341	18.8727	18.9113	18.9499	18.9885	19.0271	19.0657	19.1043	19.1429	19.1815	19.2201	19.2587	19.2973	19.3359	19.3745	19.4131	19.4517	19.4903	19.5289	19.5675	19.6061	19.6447	19.6833	19.7219	19.7605	19.7991	19.8377	19.8763	19.9149	19.9535	19.9921	20.0307	20.0693	20.1079	20.1465	20.1851	20.2237	20.2623	20.3009	20.3395	20.3781	20.4167	20.4553	20.4939	20.5325	20.5711	20.6097	20.6483	20.6869	20.7255	20.7641	20.8027	20.8413	20.8799	20.9185	20.9571	20.9957	21.0343	21.0729	21.1115	21.1501	21.1887	21.2273	21.2659	21.3045	21.3431	21.3817	21.4203	21.4589	21.4975	21.5361	21.5747	21.6133	21.6519	21.6905	21.7291	21.7677	21.8063	21.8449	21.8835	21.9221	21.9607	21.9993	22.0379	22.0765	22.1151	22.1537	22.1923	22.2309	22.2695	22.3081	22.3467	22.3853	22.4239	22.4625	22.5011	22.5397	22.5783	22.6169	22.6555	22.6941	22.7327	22.7713	22.8099	22.8485	22.8871	22.9257	22.9643	23.0029	23.0415	23.0801	23.1187	23.1573	23.1959	23.2345	23.2731	23.3117	23.3503	23.3889	23.4275	23.4661	23.5047	23.5433	23.5819	23.6205	23.6591	23.6977	23.7363	23.7749	23.8135	23.8521	23.8907	23.9293	23.9679	24.0065	24.0451	24.0837	24.1223	24.1609	24.1995	24.2381	24.2767	24.3153	24.3539	24.3925	24.4311	24.4697	24.5083	24.5469	24.5855	24.6241	24.6627	24.7013	24.7399	24.7785	24.8171	24.8557	24.8943	24.9329	24.9715	25.0101	25.0487	25.0873	25.1259	25.1645	25.2031	25.2417	25.2803	25.3189	25.3575	25.3961	25.4347	25.4733	25.5119	25.5505	25.5891	25.6277	25.6663	25.7049	25.7435	25.7821	25.8207	25.8593	25.8979	25.9365	25.9751	26.0137	26.0523	26.0909	26.1295	26.1681	26.2067	26.2453	26.2839	26.3225	26.3611	26.3997	26.4383	26.4769	26.5155	26.5541	26.5927	26.6313	26.6699	26.7085	26.7471	26.7857	26.8243	26.8629	26.9015	26.9401	26.9787	27.0173	27.0559	27.0945	27.1331	27.1717	27.2103	27.2489	27.2875	27.3261	27.3647	27.4033	27.4419	27.4805	27.5191	27.5577	27.5963	27.6349	27.6735	27.7121	27.7507	27.7893	27.8279	27.8665	27.9051	27.9437	27.9823	28.0209	28.0595	28.0981	28.1367	28.1753	28.2139	28.2525	28.2911	28.3297	28.3683	28.4069	28.4455	28.4841	28.5227	28.5613	28.5999	28.6385	28.6771	28.7157	28.7543	28.7929	28.8315	28.8701	28.9087	28.9473	28.9859	29.0245	29.0631	29.1017	29.1403	29.1789	29.2175	29.2561	29.2947	29.3333	29.3719	29.4105	29.4491	29.4877	29.5263	29.5649	29.6035	29.6421	29.6807	29.7193	29.7579	29.7965	29.8351	29.8737	29.9123	29.9509	29.9895	30.0281	30.0667	30.1053	30.1439	30.1825	30.2211	30.2597	30.2983	30.3369	30.3755	30.4141	30.4527	30.4913	30.5299	30.5685	30.6071	30.6457	30.6843	30.7229	30.7615	30.8001	30.8387	30.8773	30.9159	30.9545	30.9931	31.0317	31.0703	31.1089	31.1475	31.1861	31.2247	31.2633	31.3019	31.3405	31.3791	31.4177	31.4563	31.4949	31.5335	31.5721	31.6107	31.6493	31.6879	31.7265	31.7651	31.8037	31.8423	31.8809	31.9195	31.9581	31.9967	32.0353	32.0739	32.1125	32.1511	32.1897	32.2283	32.2669	32.3055	32.3441	32.3827	32.4213	32.4599	32.4985	32.5371	32.5757	32.6143	32.6529	32.6915	32.7301	32.7687	32.8073	32.8459	32.8845	32.9231	32.9617	33.0003	33.0389	33.0775	33.1161	33.1547	33.1933	33.2319	33.2705	33.3091	33.3477	33.3863	33.4249	33.4635	33.5021	33.5407	33.5793	33.6179	33.6565	33.6951	33.7337	33.7723	33.8109	33.8495	33.8881	33.9267	33.9653	34.0039	34.0425	34.0811	34.1197	34.1583	34.1969	34.2355	34.2741	34.3127	34.3513	34.3899	34.4285	34.4671	34.5057	34.5443	34.5829	34.6215	34.6601	34.6987	34.7373	34.7759	34.8145	34.8531	34.8917	34.9303	34.9689	35.0075	35.0461	35.0847	35.1233	35.1619	35.2005	35.2391	35.2777	35.3163	35.3549	35.3935	35.4321	35.4707	35.5093	35.5479	35.5865	35.6251	35.6637	35.7023	35.7409	35.7795	35.8181	35.8567	35.8953	35.9339	35.9725	36.0111	36.0497	36.0883	36.1269	36.1655	36.2041	36.2427	36.2813	36.3199	36.3585	36.3971	36.4357	36.4743	36.5129	36.5515	36.5901	36.6287	36.6673	36.7059	36.7445	36.7831	36.8217	36.8603	36.8989	36.9375	36.9761	37.0147	37.0533	37.0919	37.1305	37.1691	37.2077	37.2463	37.2849	37.3235	37.3621	37.4007	37.4393	37.4779	37.5165	37.5551	37.5937	37.6323	37.6709	37.7095	37.7481	37.7867	37.8253	37.8639	37.9025	37.9411	37.9797	38.0183	38.0569	38.0955	38.1341	38.1727	38.2113	38.2499	38.2885	38.3271	38.3657	38.4043	38.4429	38.4815	38.5201	38.5587	38.5973	38.6359	38.6745	38.7131	38.7517	38.7903	38.8289	38.8675	38.9061	38.9447	38.9833	39.0219	39.0605	39.0991	39.1377	39.1763	39.2149	39.2535	39.2921	39.3307	39.3693	39.4079	39.4465	39.4851	39.5237	39.5623	39.6009	39.6395	39.6781	39.7167	39.7553	39.7939	39.8325	39.8711	39.9097	39.9483	39.9869	40.0255	40.0641	40.1027	40.1413	40.1799	40.2185	40.2571	40.2957	40.3343	40.3729	40.4115	40.4501	40.4887	40.5273	40.5659	40.6045	40.6431	40.6817	40.7203	40.7589
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N.B See pages 484 to 486 for breakdowns of this page

Profile #	BOPRC #	rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A
6m Closure Depth					
1	1	0.3395	0.3328	0.407	0.4336
2	2	0.5114	0.237	2.303	2.21
3	3	0.4608	0.435	0.7846	0.8366
4	4	0.4979	0.2852	1.61	1.557
5	5	0.5808	0.2742	1.466	1.481
6	6	0.6961	0.3206	1.29	1.328
7	7	0.4125	0.2574	5.761	5.547
8	8	0.7831	0.7253	0.5297	0.5434
9	9	2.299	2.487	0.6329	0.6849
10	10	0.8358	0.823	0.6775	0.6103
11	11	0.4072	0.3611	0.5322	0.623
12	12	2.157	0.9447	2.212	2.021
13	13	1.87	1.118	1.447	1.61
14	14	1.11	0.555	0.6695	0.8157
15	15	1.352	1.025	1.563	1.699
16	16	1.191	0.5268	0.9824	1.084
17	17	1.675	1.196	1.909	1.843
18	18	0.252	0.2803	0.6298	0.6429
19	19	0.8438	0.2263	1.178	0.8533
20	20	0.5364	0.3573	0.8871	0.7232
21	21	1.064	0.3681	0.7323	0.7264
22	22	1.04	0.3781	0.6174	0.4502
23	23	1.171	0.4252	0.4698	0.4772
24	24	1.434	0.3827	0.7719	0.5723
25	25	1.087	0.4088	2.174	1.686
26	26	1.381	0.4852	1.508	1.14
27	27	1.616	0.805	1.864	1.42
28	28	1.411	0.9756	2.424	2.183
29	29	1.148	0.5772	1.77	1.71
30	30	0.7053	0.9808	1.871	1.51
31	32	1.128	0.3835	1.012	0.7186
32	33	2.042	1.283	1.697	1.559
33	34	0.8515	0.3643	1.666	1.563
34	35	1.001	0.3561	0.5609	0.6072
35	36	0.8101	0.5486	3.293	3.128
36	38	0.7348	0.5508	2.116	2.05
37	39	0.3106	0.2633	4.416	4.292
38	40	0.4132	0.3829	1.628	1.474
39	41	0.9187	0.6121	1.266	1.145
40	42	1.228	1.097	0.6874	0.4775
41	43	0.5331	0.7632	1.624	1.434
42	44	0.7272	0.7775	0.6345	0.6275
43	45	0.5611	0.6337	0.1614	0.159
44	46	1.176	1.725	1.815	1.924
45	47	1.235	1.514	1.543	1.707
46	48	0.2518	0.1728	0.4001	0.4101
47	49	0.8648	0.9843	0.3837	0.3626
48	51	0.5724	0.6617	0.9127	0.8853
Average rmsr		0.96	0.66	1.41	1.32
st dev		0.50	0.44	1.02	0.98

rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A
7m Closure Depth			
0.3644	0.3478	0.3683	0.3891
0.4997	0.2138	2.348	2.235
0.4246	0.4791	0.8107	0.8114
0.4886	0.3185	1.666	1.534
0.6092	0.2499	1.563	1.518
0.6961	0.299	1.331	1.319
0.4125	0.2302		
1.136	1.1	0.8922	0.8881
3.006	2.8	0.8256	0.8952
0.7997	0.8533	0.6792	0.6237
0.3696	0.401	0.5007	0.5756
2.378	1.015	2.551	2.144
2.145	1.327	1.751	1.783
1.553	0.6568	0.9118	1.034
2.343	1.401	2.178	2.179
1.682	0.8514	1.603	1.507
2.143	1.681	2.508	2.371
0.4378	0.2833	1.22	1.144
0.9751	0.2196	1.431	0.9437
0.907	0.379	1.113	0.8472
1.199	0.3891	0.9383	0.7791
1.061	0.3601	0.7425	0.4767
1.358	0.3791	0.5535	0.501
1.657	0.377	1.042	0.6081
1.373	0.487	2.662	1.937
1.555	0.4561	1.728	1.171
1.827	0.67	2.221	1.523
1.537	1.039	2.678	2.351
1.588	0.6247	2.08	1.855
0.7273	0.9379	1.92	1.628
1.065	0.4862	0.9178	0.6735
1.975	1.213	1.655	1.476
1.237	0.4696	2.158	1.676
1.03	0.3441	0.6128	0.5893
1.082	0.6644	3.921	3.7
0.7925	0.64	2.46	2.347
0.2836	0.2368		
0.4837	0.4566	1.666	1.592
1.34	1.189	0.6236	1.479
1.482	1.101	1.774	0.4888
0.511	0.8022	0.6652	1.552
0.7606	0.8337	0.1523	0.6341
0.6046	0.7216	2.426	0.1654
2.066	2.488	2.245	2.423
2.029	2.294	0.3931	2.249
0.4349	0.2473	0.3542	0.3681
0.94	1.112	0.3542	0.3288
0.7502	0.8505	0.6456	0.8167
1.17	0.77	1.44	1.31
0.65	0.58	0.83	0.75

rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A	BOPRC #
8m Closure Depth				
0.33151	0.40431	0.33254	0.37256	1
0.46386	0.24594	2.3723	2.2395	2
0.38513	0.5698	0.8182	0.76605	3
0.45563	0.42593	1.7507	1.5171	4
0.59084	0.25457	1.6318	1.5249	5
0.69008	0.27682	1.3354	1.2781	6
0.37263	0.23602			7
1.5815	1.5534	1.2534	1.2064	8
3.2972	2.9969	1.0285	1.0733	9
0.74788	0.88584	0.67012	0.63684	10
0.35395	0.53687	0.47428	0.53158	11
2.6205	1.0315	2.9184	2.2453	12
2.2972	1.397	1.9173	1.8468	13
1.8521	0.7882	1.2163	1.2148	14
2.8015	1.8286	2.8374	2.6569	15
2.2883	1.2522	2.2374	1.9686	16
2.75	2.1111	3.0736	2.8534	17
1.9735	0.63781	2.1964	1.9014	18
1.0974	0.23317	1.7296	1.0692	19
1.4078	0.40767	1.4788	1.0038	20
1.3151	0.40058	1.1533	0.83862	21
1.1149	0.34219	0.88748	0.48841	22
1.5797	0.3433	0.75468	0.52917	23
1.8179	0.37646	1.3307	0.63891	24
1.7438	0.59236	3.0285	2.2646	25
1.6777	0.42941	2.0285	1.2031	26
2.0257	0.68759	2.6207	1.6794	27
1.7162	1.103	2.991	2.5491	28
2.0694	0.66224	2.5172	2.0022	29
0.82728	0.90908	1.9128	1.6866	30
1.0846	0.71387	0.88835	0.78237	32
1.8646	1.1092	1.558	1.3594	33
1.6932	0.63815	2.8336	2.2874	34
1.0337	0.31564	0.62399	0.54275	35
1.2309	0.79663			36
0.98626	0.73856	2.9002	2.7144	38
0.27813	0.21865			39
0.68105	0.5563	1.6611	1.6488	40
1.8404	1.9248	1.5189		41
1.3803	1.0379	0.56459	0.48468	42
0.49398	0.85419	1.9104	1.6983	43
0.80665	0.93656	0.75143	0.67448	44
0.69035	0.85682	0.16212	0.21461	45
3.446	3.0538	2.9559	2.5715	46
2.8991	2.8541	2.7584	2.5963	47
1.082	0.35773	0.44451	0.34153	48
1.0827	1.2583	0.32583	0.31508	49
0.96227	1.0896	0.77791	0.75031	51
1.41	0.90	1.62	1.38	
0.81	0.70	0.88	0.77	

Appendix 6 - Table Summaries of
Profile Shift calculations

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N.B See pages 488 to 490 for breakdowns of this page

Profile #	BOPRC #	rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A
6m Closure Depth					
1	1	0.3395	0.3328	0.407	0.4336
2	2	0.5114	0.237	2.303	2.21
3	3	0.4608	0.435	0.7846	0.8366
4	4	0.4979	0.2852	1.61	1.557
5	5	0.5808	0.2742	1.466	1.481
6	6	0.6961	0.3206	1.29	1.328
7	7	0.4125	0.2574	5.761	5.547
8	8				
9	9				
10	10	0.8358	0.823	0.6775	0.6103
11	11	0.4072	0.3611	0.5322	0.623
12	12	2.157	0.9447	2.212	2.021
13	13	1.87	1.118	1.447	1.61
14	14	1.11	0.555	0.6695	0.8157
15	15	1.352	1.025	1.563	1.699
16	16	1.191	0.5268	0.9824	1.064
17	17	1.675	1.196	1.909	1.843
18	18	0.252	0.2603	0.6298	0.6429
19	19	0.8438	0.2263	1.178	0.8533
20	20	0.5364	0.3573	0.6871	0.7232
21	21	1.064	0.3681	0.7323	0.7264
22	22	1.04	0.3761	0.6174	0.4502
23	23	1.171	0.4252	0.4696	0.4772
24	24	1.434	0.3827	0.7719	0.5723
25	25	1.087	0.4088	2.174	1.686
26	26	1.381	0.4652	1.508	1.14
27	27	1.616	0.605	1.864	1.42
28	28	1.411	0.9756	2.424	2.183
29	29	1.146	0.5772	1.77	1.71
30	30	0.7053	0.6808	1.871	1.51
31	32	1.128	0.3635	1.012	0.7196
32	33	2.042	1.283	1.697	1.559
33	34	0.8515	0.3643	1.666	1.563
34	35	1.001	0.3561	0.5609	0.6072
35	36	0.8101	0.5486	3.293	3.128
36	38	0.7348	0.5508	2.116	2.05
37	39	0.3106	0.2633	4.416	4.292
38	40	0.4132	0.3629	1.626	1.474
39	41				
40	42	1.228	1.097	0.6874	0.4775
41	43	0.5331	0.7632	1.624	1.434
42	44	0.7272	0.7775	0.6345	0.6275
43	45	0.5611	0.6337	0.1614	0.159
44	46				
45	47				
46	48	0.2518	0.1728	0.4001	0.4101
47	49	0.8648	0.9843	0.3837	0.3626
48	51	0.5724	0.6617	0.8127	0.8853
Average rmsr		0.93	0.56	1.43	1.34
st dev		0.48	0.30	1.07	1.02

rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A
7m Closure Depth			
0.3644	0.3478	0.3683	0.3891
0.4997	0.2138	2.348	2.235
0.4246	0.4791	0.8107	0.8114
0.4886	0.3185	1.666	1.534
0.8092	0.2499	1.583	1.518
0.6961	0.299	1.331	1.319
0.4125	0.2302		
0.7997	0.8533	0.6792	0.6237
0.3696	0.401	0.5007	0.5756
2.378	1.015	2.551	2.144
2.145	1.327	1.751	1.783
1.553	0.6598	0.9118	1.034
2.343	1.401	2.178	2.179
1.682	0.8514	1.603	1.507
2.143	1.681	2.508	2.371
0.4376	0.2833	1.22	1.144
0.9751	0.2196	1.431	0.9437
0.907	0.379	1.113	0.8472
1.199	0.3891	0.9383	0.7791
1.061	0.3601	0.7425	0.4767
1.358	0.3791	0.5535	0.501
1.657	0.377	1.042	0.6061
1.373	0.487	2.662	1.937
1.555	0.4561	1.726	1.171
1.827	0.67	2.221	1.523
1.537	1.039	2.678	2.351
1.588	0.6247	2.08	1.855
0.7273	0.9379	1.92	1.628
1.065	0.4862	0.9178	0.6735
1.975	1.213	1.655	1.476
1.237	0.4696	2.158	1.876
1.03	0.3441	0.6128	0.5693
1.082	0.6644	3.921	3.7
0.7925	0.64	2.46	2.347
0.2836	0.2388		
0.4837	0.4566	1.666	1.592
1.482	1.101	1.774	0.4888
0.511	0.8022	0.6652	1.552
0.7606	0.8337	0.1523	0.6341
0.6046	0.7216	2.426	0.1654
0.4349	0.2473	0.3542	0.3681
0.94	1.112	0.3542	0.3288
0.7502	0.8505	0.8456	0.8167
1.08	0.63	1.49	1.28
0.59	0.36	0.83	0.75

Appendix 6 - Table Summaries of
Profile Shift calculations

rmsr error - Dean Piecewise A	rmsr error - Dean average A	rmsr error - Mod Dean Piecewise A	rmsr error - Mod Dean Average A	BOPRC #
8m Closure Depth				
0.33151	0.40431	0.33254	0.37256	1
0.46366	0.24564	2.3723	2.2395	2
0.38513	0.5698	0.8182	0.76605	3
0.45563	0.42593	1.7507	1.5171	4
0.59084	0.25457	1.6318	1.5249	5
0.69008	0.27682	1.3354	1.2781	6
0.37263	0.23602			7
				8
				9
0.74786	0.88584	0.67012	0.63684	10
0.35395	0.53687	0.47428	0.53158	11
2.6205	1.0315	2.9184	2.2453	12
2.2972	1.397	1.9173	1.8468	13
1.8521	0.7882	1.2163	1.2148	14
2.8015	1.8286	2.8374	2.6569	15
2.2883	1.2522	2.2374	1.9686	16
2.75	2.1111	3.0736	2.8534	17
1.9735	0.63781	2.1964	1.9014	18
1.0974	0.23317	1.7296	1.0692	19
1.4076	0.40767	1.4788	1.0038	20
1.3151	0.40058	1.1533	0.83882	21
1.1149	0.34219	0.86748	0.48841	22
1.5797	0.3433	0.75468	0.52917	23
1.8179	0.37646	1.3307	0.83891	24
1.7438	0.59236	3.0285	2.2646	25
1.6777	0.42941	2.0285	1.2031	26
2.0257	0.68759	2.6207	1.6794	27
1.7162	1.103	2.991	2.5491	28
2.0694	0.66224	2.5172	2.0022	29
0.82728	0.90908	1.9128	1.6866	30
1.0846	0.71387	0.88835	0.78237	32
1.8646	1.1092	1.558	1.3594	33
1.6932	0.63815	2.8336	2.2874	34
1.0337	0.31564	0.62399	0.54275	35
1.2309	0.79663			36
0.98626	0.73856	2.9002	2.7144	38
0.27813	0.21865			39
0.68105	0.5563	1.6611	1.6488	40
				41
1.3803	1.0379	0.56459	0.48468	42
0.49398	0.85419	1.9104	1.6983	43
0.80665	0.93656	0.75143	0.67448	44
0.69035	0.85682	0.16212	0.21461	45
				46
				47
1.082	0.35773	0.44451	0.34153	48
1.0627	1.2563	0.32563	0.31508	49
0.96227	1.0696	0.77791	0.75031	51
1.27	0.72	1.59	1.33	
0.70	0.42	0.89	0.76	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 6m			Source: V. Pickett			Profiles Surveyed 1993						
Profile #	BOPRC #	Dean - Piecewise A		Dean - Profile Av. A		Modified Dean - Piecewise		Modified Dean - Profile Av. A		BOP Trend Rates		BOPRC#
										1990-6	Historic Rates (60-100yrs)	
1	1	E	-19.83	E	-3.996	E	-24.59	E	-27.34	20	-25	1
2	2	E	-25.6	E	-8.276	E	-217.7	E	-207.9	8	0	2
3	3	A	24.47	A	31.5	E	-65.14	E	-73.78	3	-20	3
4	4	E	-13.73	A	5.017	E	-162.8	E	-158.2	-8	-25	4
5	5	E	-0.89	A	6.996	E	-123.8	E	-131	12	30	5
6	6	E	-32.37	E	-17.08	E	-99	E	-106.4	4	20	6
7	7	A	10.02	E	-0.087	E	-771.9	E	-750	2	0	7
8	8											8
9	9											9
10	10	A	71.98	A	70.95	A	59.46	A	53.94	-7	65	10
11	11	A	29.53	A	25.56	E	-42.21	E	-51.92	-11	15	11
12	12	E	-66.73	E	-17.43	E	-105.7	E	-106.7	26	25	12
13	13	E	-53.8	E	-40.23	E	-51.02	E	-67.31	3	55	13
14	14	A	2.05	A	3.618	A	8.662	E	-21.24	11		14
15	15	E	-32.74	E	-33.13	E	-55.94	E	-66.43	1		15
16	16	E	-21.6	E	-14.81	E	-32.37	E	-42.23	3	45 to 120	16
17	17	E	-31.48	E	-20.81	E	-44.5	E	-49.81	16	50	17
18	18	A	8.84	A	14.16	E	-25.72	E	-31.98	1		18
19	19	E	-40.53	E	-7.474	E	-62.92	E	-49.34	9	55	19
20	20	E	-21.42	E	-5.185	E	-42.42	E	-37.27	3	0	20
21	21	E	-43.81	E	-14.83	E	-29.55	E	-38.94	1		21
22	22	E	-36.56	E	-0.34	E	-4.474	E	-11.69	6		22
23	23	E	-9.32	A	13.39	A	13.2	E	-12.86	-0.7	-20	23
24	24	E	-56.02	E	-13.21	E	-28.7	E	-26.36	-8	-25	24
25	25	E	-45.91	E	-14.25	E	-115.5	E	-91.18	-8	-15	25
26	26	E	-63.55	E	-17.66	E	-88.06	E	-66.72	-8		26
27	27	E	-67.66	E	-19.94	E	-89.47	E	-71.23	-5		27
28	28	E	-65.66	E	-43.79	E	-138.4	E	-124.9	0	-13	28
29	29	E	-34.71	E	-18.27	E	-90.89	E	-95.84	-4	-8	29
30	30	A	4.83	A	39.73	E	-92.31	E	-65.74		0 to -3	30
31	32	E	-77.01	E	-5.233	E	-76.25	E	-36.95	6	-14	32
32	33	E	-118.5	E	-62.67	E	-92.14	E	-83.19	3		33
33	34	E	-30.85	E	-14.11	E	-101.5	E	-103.9	1		34
34	35	E	-52.16	E	-18.39	E	-20.17	E	-36.65	0	0	35
35	36	E	-24.96	E	-16.76	E	-212.5	E	-205.2	-0.4		36
36	38	E	-28.44	E	-19.82	E	-133.2	E	-130.7	-0.4		38
37	39	A	3.967	A	7.108	E	-328.8	E	-324.3	-1.5	2 to 60	39
38	40	E	-1.925	A	19.43	E	-123.3	E	-108.7	9		40
39	41											41
40	42	A	79.47	A	63.04	A	31.36	A	10.97	-2		42
41	43	A	39.12	A	56.28	E	-139.6	E	-123.3	-7		43
42	44	A	64.32	A	68.58	E	-58.28	E	-59.46	-2	30	44
43	45	A	49.99	A	55.18	E	-12.98	E	-12.64	-9		45
44	46											46
45	47											47
46	48	A	10.02	A	3.441	E	-22.01	E	-25.93	-2	-35	48
47	49	A	90	A	100.4	E	-41.64	E	-39.67	-1	-8	49
48	51	A	61.11	A	69.6	E	-114.5	E	-110	-5	0	51
Average Erosion/Accretion for BOP			-13.21		4.80		-92.31		-91.16	1.38	5.48	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 7m			Source: V. Pickett			Profiles Surveyed 1993						
Profile #	BOFRC #	Dean - Piecewise A		Dean - Profile Av. A		Modified Dean - Piecewise		Modified Dean - Profile Av. A		BOP Trend Rates		BOPRC#
										1990-6	Historic Rates (50-100yrs)	
1	1	E	-20.51	A	5.235	E	-24.42	E	-22.27	20	-25	1
2	2	E	-31.18	E	-6.112	E	-252.9	E	-239	8	0	2
3	3	A	14.73	A	40.36	E	-81.31	E	-82.54	3	-20	3
4	4	E	-23.29	A	15.18	E	-191.1	E	-175.3	-8	-25	4
5	5	E	-17.59	A	7.242	E	-154	E	-153.7	12	30	5
6	6	E	-47.05	E	-18.84	E	-122.5	E	-123.1	4	20	6
7	7	A	1.141	A	0.4028	NO closure depth for predicted profile		NO closure depth for predicted profile		2	0	7
8	8											8
9	9											9
10	10	A	73.93	A	78.74	A	63.52	A	58.52	-7	65	10
11	11	A	30.19	A	37.67	E	-45.61	E	-52.81	-11	15	11
12	12	E	-118.6	E	-36.66	E	-157.4	E	-140.9	26	25	12
13	13	E	-90.91	E	-56.45	E	76.61	E	-88.27	3	55	13
14	14	E	-29.3	E	-7.695	E	-8.349	E	-36.93	11		14
15	15	E	-62.05	E	-48.93	E	-76.26	E	-87.97	1		15
16	16	E	-44.14	E	-25.05	E	-50.6	E	-57.25	3	45 to 120	16
17	17	E	-55.88	E	-40.31	E	-72.25	E	-74.35	16	50	17
18	18	A	2.782	A	10.51	E	-39.08	E	-43.47	1		18
19	19	E	-52.87	E	-9.158	E	-80.8	E	-58.14	9	55	19
20	20	E	-34.61	E	-8.033	E	-56.05	E	-45.64	3	0	20
21	21	E	-61.34	E	-18.68	E	-45.6	E	-47.04	1		21
22	22	E	-48.52	E	-4.229	E	-19.51	E	-17.92	6		22
23	23	E	-35.19	A	11.55	A	1.161	E	-19.27	-0.7	-20	23
24	24	E	-79.51	E	-15.1	E	-43.89	E	-30.8	-8	-25	24
25	25	E	-61.62	E	-17.56	E	-141.4	E	-107.4	-8	-15	25
26	26	E	-93.4	E	-22.99	E	-116	E	-80.35	-8		26
27	27	E	-93.34	E	-28.43	E	-120.1	E	-88.39	-5		27
28	28	E	-84.8	E	-56.04	E	-170.7	E	-150.8	0	-13	28
29	29	E	-64.28	E	-26.49	E	-120.9	E	-117.1	-4	-8	29
30	30	A	12.8	A	41.23	E	-105.8	E	-81.86		0 to -3	30
31	32	E	-57.76	A	27.12	E	-66.5	E	-10.05	6	-14	32
32	33	E	-151.5	E	-76.01	E	-123.7	E	-100.2	3		33
33	34	E	-53.15	E	-22.31	E	-132.3	E	-127.2	1		34
34	35	E	-72.14	E	-21.58	E	-35.36	E	-43.21	0	0	35
35	36	E	-45.74	E	-27.29	E	-258.2	E	-247.2	-0.4		36
36	38	E	-39.62	E	-30.83	E	-165.1	E	-160.2	-0.4		38
37	39	A	1.354	A	7.339	NO closure depth for predicted profile		NO closure depth for predicted profile		-1.5	2 to 60	39
38	40	A	12.56	A	28.15	E	-130.9	E	-121.4	9		40
39	41											41
40	42	A	36.94	A	65.35	A	30.02	A	4.474	-2		42
41	43	A	41.1	A	64.6	E	-166.2	E	-145	-7		43
42	44	A	76.02	A	83.44	E	-67.54	E	-66	-2	30	44
43	45	A	62.1	A	72.78	E	-9.471	E	-6.456	-9		45
44	46											46
45	47											47
46	48	A	31.75	A	11.99	E	-12.04	E	-22.47	-2	-35	48
47	49	A	111.8	A	127.8	E	-41.19	E	-35.68	-1	-8	49
48	51	A	92.33	A	103.2	E	-112.3	E	-106.3	-5	0	51
Average Erosion/Accretion for BOP			-24.85		3.57		-87.79		-81.73	1.38	5.48	

Comparison of Equilibrium Predictions by Method - BOP Beach Profiles												
Closure Depth: 8 m			Source: V. Pickett			Profiles Surveyed 1993						
Profile #	BOPRC #	Dean - Piecewise A		Dean - Profile Av. A		Modified Dean - Piecewise		Modified Dean - Profile Av. A		BOP Trend Rates		BOPRC #
										1990-6	1990-6 Tonic Rates (60-100yrs)	
1	1	E	-17.28	A	18.44	E	-21.60	E	-13.23	20	-25	1
2	2	E	-27.33	A	1.77	E	-282.26	E	-264.48	8	0	2
3	3	A	13.25	A	56.93	E	-92.00	E	-83.60	3	-20	3
4	4	E	-27.30	A	30.64	E	-215.07	E	-187.04	-8	-25	4
5	5	E	-26.47	A	12.00	E	-181.30	E	-172.05	12	30	5
6	6	E	-52.44	E	-13.49	E	-139.96	E	-132.76	4	20	6
7	7	E	-3.58	A	6.56	NO closure depth for predicted profile		NO closure depth for predicted profile		2	0	7
8	8											
9	9											
10	10	A	75.23	A	88.82	A	68.54	A	65.39	-7	65	10
11	11	A	33.25	A	52.43	E	-48.18	E	-51.07	-11	15	11
12	12	E	-165.13	E	-52.24	E	-209.02	E	-171.50	26	25	12
13	13	E	-128.41	E	-73.51	E	-106.66	E	-110.07	3	55	13
14	14	E	-60.18	E	-19.15	E	-29.18	E	-52.77	11		14
15	15	E	-95.13	E	-67.65	E	-108.18	E	-112.43	1		15
16	16	E	-67.84	E	-39.28	E	-74.53	E	-76.27	3	45 to 120	16
17	17	E	-83.65	E	-62.94	E	-103.65	E	-102.02	16	50	17
18	18	E	-17.46	A	1.16	E	-59.67	E	-60.64	1		18
19	19	E	-62.99	E	-10.70	E	-98.85	E	-66.79	9	55	19
20	20	E	-57.38	E	-13.63	E	-74.56	E	-56.77	3	0	20
21	21	E	-76.94	E	-22.28	E	-63.00	E	-54.90	1		21
22	22	E	-59.24	E	-6.37	E	-33.30	E	-22.41	6		22
23	23	E	-59.86	A	10.62	E	-14.28	E	-24.79	-0.7	-20	23
24	24	E	-99.37	E	-17.06	E	-62.35	E	-35.32	-8	-25	24
25	25	E	-81.54	E	-24.63	E	-169.95	E	-127.38	-8	-15	25
26	26	E	-114.01	E	-23.98	E	-141.63	E	-89.65	-8		26
27	27	E	-115.12	E	-35.06	E	-149.69	E	-103.69	-5		27
28	28	E	-103.71	E	-66.33	E	-201.78	E	-174.69	0	-13	28
29	29	E	-100.51	E	-33.50	E	-153.66	E	-137.12	-4	-8	29
30	30	A	25.49	A	43.63	E	-117.29	E	-97.09		0 to -3	30
31	32	E	-17.89	A	73.84	E	-40.25	A	31.22	6	-14	32
32	33	E	-169.79	E	-77.02	E	-144.94	E	-104.95	3		33
33	34	E	-81.21	E	-32.68	E	-167.46	E	-152.60	1		34
34	35	E	-85.35	E	-17.67	E	-45.81	E	-42.68	0	0	35
35	36	E	-63.50	E	-39.01	NO closure depth for predicted profile		NO closure depth for predicted profile		-0.4		36
36	38	E	-52.47	E	-40.60	E	-196.60	E	-188.54	-0.4		38
37	39	E	-0.99	A	7.18	NO closure depth for predicted profile		NO closure depth for predicted profile		-1.5	2 to 60	39
38	40	A	28.99	A	34.66	E	-138.17	E	-136.28	9		40
39	41											
40	42	A	62.75	A	64.97	A	21.25	E	-4.70	-2		42
41	43	A	43.65	A	75.09	E	-187.75	E	-164.49	-7		43
42	44	A	85.34	A	98.48	E	-77.33	E	-72.37	-2	30	44
43	45	A	76.73	A	93.35	E	-3.56	A	2.70	-9		45
44	46											46
45	47											47
46	48	A	36.00	A	22.72	A	1.24	E	-16.84	-2	-35	48
47	49	A	142.10	A	162.22	E	-33.68	E	-24.72	-1	-8	49
48	51	A	132.14	A	143.75	E	-103.13	E	-95.78	-5	0	51
			-33.00		7.22		-99.98		-87.13	1.38	5.48	

Appendix 7

Copies of Papers presented to Pacific Ports and Coast
Conference 1997

Coastal Hazard Identification : The Application of the Kriebel (1989) Numerical Model for Predicting the Effects of Cut and Fill Storm Events on Bay of Plenty Beaches

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SUMMARY - This paper describes the preliminary results of applying the EDUNE model (Kriebel 1989) to a dataset of 48 beach profiles in the Bay of Plenty. Parameters required to run the model include: storm duration, wave height, storm surge elevation, average grain size along the profile, wave runup, and beach geometry including the location of sea walls (if any). The model outputs include the time series plots of beach profile changes throughout the storm and provides cut and fill rates occurring on the profile as volume per unit length (m^3m^{-1}) of beach. A storm scenario approximating a design storm equivalent to the Wahine storm was applied and the resulting profiles analysed to determine erosion effects. The application of the model allows (amongst other things) the identification of hazard prone zones for use in coastal management plans under the Resource Management Act 1991.

1. INTRODUCTION

Kriebel (1989) has produced a two dimensional numerical model (EDUNE) to simulate storm surge and beach and dune erosion. This model has been applied to the Florida coast for that state (National Research Council 1990). In this study the application of the EDUNE model has been investigated as a potential tool for coastal hazard identification for the duned coastline of the Bay of Plenty (BOP).

2. THEORETICAL BACKGROUND

The EDUNE model (Kriebel 1989) is based on equilibrium profile theory (Dean 1977). Dean (1977), analysed several mechanisms for equilibrium profile development and concluded that the profile form was determined by the mechanism of uniform dissipation of wave energy per unit volume in the surf zone. Kriebel (1989) points out that based on this assumed forcing mechanism, and the assumption of spilling breaking waves, a power equation (Dean 1977) can be derived to represent the equilibrium beach form:

$$y = Ax^b \quad (1)$$

Where y = is the water depth, x is the distance offshore from the still water shoreline (often assumed to be Mean Sea Level), and A is the scale factor governing the steepness of the profile. Dean (1977) also related the scale factor A to a unique value of energy dissipation across the profile which is equivalent to the energy dissipation per unit volume. This unique variable (D_{eq}) exists when the energy dissipation equates to the profile of equilibrium.

Least squares fit of equation 1 by Dean (1977), and Moore (1982) to over 500 profiles has resulted in the development

of an empirical relationships between "A" (or D) and sediment size and fall velocity.

Kriebel (1986) has suggested that during a severe storm, the elevated water levels permit waves to break closer to shore. This results in greater energy dissipation to occur over all points within the surf zone and creates a situation where the profile will be out of equilibrium with storm wave energy dissipation. The beach profile responds to this disequilibrium by redistributing sand across the profile so that the depth adjusts to a point where the depth is equivalent to the wave energy dissipation per unit volume.

Based on these concepts and using linear wave theory, the sediment transport rate, Q_s , may be determined at each contour level across the profile in the surf zone by:

$$Q_s = K (D - D_{eq}) \quad (2)$$

Where Q_s = offshore sediment flux (i.e. volume of sediment passing through a unit area per unit time), K is a transport rate parameter determined by calibration carried out on data from Saville (1957), D is the incident wave energy dissipation per unit volume and D_{eq} is the equilibrium wave energy.

D_{eq} is solved by resolving the equation (Dean 1977).

$$A = \left[\frac{24}{5} \frac{D_{eq}}{\gamma \kappa^2 g^{\frac{1}{2}}} \right]^{\frac{2}{3}} \quad (3)$$

where κ = ratio of spilling breaker height into depth (approximated by the value 0.78), γ is the specific weight of water, and g is the gravitational constant.

The energy dissipation per unit volume, D , is defined as

$$D = \frac{1}{h} \frac{dF}{dx} \quad (4)$$

Where F is the wave energy flux across the surf zone. Based on the linear assumption of shallow water spilling breaking waves, energy flux may be written as a function of water depth only as:

$$F = \frac{1}{8} \rho g^{\frac{3}{2}} \kappa^2 h^{\frac{5}{2}} = \frac{\partial(EC_t)}{\partial x} \quad (5)$$

Where the values are as before for equation 3 and h is water depth.

In the model the off shore boundary condition is defined by the breaker index times wave height. However the driving forces in the model are the resultant water level increase from storm surge coincident with incident wave height.

Finally the model is two dimensional in that the total sand volume across the profile must be conserved. As a consequence the model is only applicable where the sand exchange is essentially diabathic as expressed in the equation:

$$\frac{dx}{dt} = - \frac{dQ_s}{dh} \quad (6)$$

where x represents distance along the profile, t , the specified time period over which adjustment occurs, and h represents water depth to profile from sea level.

3. MODEL APPLICATION

As described above the model relies on a relatively simple approximation of beach responses to storm surge effects. This simplicity offers some advantages for coastal management in that the level of information required to apply it, compared to say more complex models, is relatively low, so long as measured profiles, sediment data and some tidal and wave climate information is available.

3.1 Scale Factor Data

Bay of Plenty beach profiles have been monitored for a period of thirty years (Healy et al., 1977) so that some historical data exists concerning erosion/accretion trends. This information in general suggests that most beaches in the Bay of Plenty have undergone cyclical phases of erosion and accretion. The beaches therefore exhibit characteristics of being in dynamic equilibrium. In 1993 Dommerholt (unpublished data, University of Waikato, Dean et al., 1993) surveyed 48 of the coastal monitoring sites which

included both ashore and offshore sediment sampling for each profile out to the Hallermeier Outer Limit (approximately 15m depth).

The sediments collected were subject to grain size analysis and the diameters converted to the equivalent Dean scale factor value from the relationships of grain diameter to scale factor as presented by Dean (1991). This relationship was digitised to create a MATLAB file that uses linear interpolation to determine the scale factor for grain diameters between 0.01 and 1000.00 mm (DeLange 1996, unpub data, University of Waikato). The scale factors were derived for all samples and both overall and profile averaged values calculated for the data set.

This analysis indicates an overall average scale factor for the data set of 0.111 while the individual profile averaged values are shown in Table 1 (Pickett et al., 1997).

Site No.	Profile Scale Factors (D)	
	Regression	Sediment
1	0.1511	0.1020
2	0.1380	0.1050
3	0.0794	0.1035
4	0.0708	0.1000
5	0.1135	0.0987
6	0.1640	0.1020
7	0.1387	0.1012
8	0.0414	0.1092
9	0.0075	0.1050
10	0.0507	0.1000
11	0.0640	0.0964
12	0.0923	0.1011
13	0.1765	0.1067
14	0.1004	0.1105
15	0.0617	0.1075
16	0.0494	0.1122
17	0.0564	0.1092
18	0.0188	0.1107
19	0.0821	0.1205
20	0.0911	0.1167
21	0.1088	0.1142
22	0.0898	0.1152
23	0.0570	0.1191
24	0.1020	0.1255
25	0.0789	0.1186
26	0.0794	0.1124
27	0.0906	0.1163
28	0.1147	0.1092
29	0.0822	0.1122
30	0.0772	0.1512
32	0.2375	0.1274
33	0.3564	0.1087
34	0.0398	0.0987
35	0.1270	0.1055
36	0.0503	0.1027
38	0.0598	0.1025
39	0.0379	0.1062
40	0.1440	0.1217
41	0.3097	0.1433
42	0.1346	0.1177
43	0.0554	0.1115
44	0.0270	0.1017
45	0.0347	0.1025
46	0.0162	0.1156
47	0.1195	0.1250
48	0.1693	0.1111

49	0.0573	0.0991
51	0.0913	0.1000

Table 1: Comparison of Regression and Sediment derived Scale Factors for the 48 BOP Profiles (A in $m^{1/3}$)

This information provides one of the required information inputs to the data input files for EDUNE (Kriebel 1989).

3.2 Storm Scenarios - Surge Characteristics

EDUNE allows for data input to cover either individually or collectively the following wave and surge characteristics:

- Wave height - Kriebel (1989) recommends the use of h_{rms} (root mean-square wave height) since it represents a single wave height (m) that contains the same energy density as the complete wave spectrum.
- Runup - vertical distance (m) from still-water flood level to the limit of wave runup.
- Surge Level (Selev) - maximum storm surge level. For the purpose of this study, storm surge components incorporated into this variable included wave set up, barometric set up, wind set up, and tidal surge (spring tide).

The wave height data used for determining input to the model was derived from the extremal significant wave analysis for the Tauranga Harbour Entrance by De Large (1993). Predictions of significant wave height in this report are based on a Weibull distribution with the upper 90% used for a 100 year return period system. This figure has been rounded to the nearest whole metre to provide a h_s value of 8m. Using the formula of Komar and Goughan (1973) from Healy (1977) and Frisby and Goldberg (1981), the h_{rms} was calculated as 5.66m. This again was rounded up to the nearest whole metre following its conversion to breaker height (i.e. 6 m). The formulae used are shown below:

$$H_{rms} = \frac{H_s}{\sqrt{2}} \quad (7)$$

$$H_{br} = \frac{0.563 H_{rms}}{\sqrt[3]{H_{rms}/L_{ms}}} \quad (8)$$

Where $T = 7.6s$ (Frisby and Goldberg, 1981).

The components of storm surge were then calculated as follows:

- Wave set-up,

$$h_b = 0.19 \left[1 - 2.82 \sqrt{\frac{H_b}{gT^2}} \right] H_b; \quad (9)$$

- Wave run-up,

$$h_r = \sqrt{H_b L_{ms}} \tan \beta; \quad (10)$$

where β is the gradient of the offshore bar;

- Barometric setup

$$h_{\Delta p} = 0.010(1014 - P) \quad (11)$$

where P is the storm system minimum pressure in mb;

- Wind setup

$$h_w = \frac{kh_1 u^2 W}{gh_1^2 (1 - h_2/h_1)} \ln \left(\frac{h_1}{h_2} \right) \quad (12)$$

Where $k = \text{constant} = 3 \times 10^{-6}$
 $u = \text{wind speed (m/s)}$
 $w = \text{width of the continental shelf}$
 $h_1 = \text{the depth at shelf break}$
 $h_2 = \text{the depth at the shore or point of interest}$

(Healy 1993)

The detailed results of this analysis yielded the following results for a storm with average winds of 80km/h. (see table 2, h_i

H_{rms}	L_{ms}	H_{br}	h_b	h_r	$h_{\Delta p}$	h_w	h_i
5.5	7.6	5.7	0.75	0.35	0.55	1.14	0.55

Table 2 : storm surge input parameters for modelling

The surge elevation (selev) was then calculated as follows with the figures then rounded up to the nearest metre to increase the conservative output from the model.

$$\begin{aligned} \text{Selev} &= 0.75 + 0.35 + 0.55 + 1.14 \\ &= +2.79\text{m} \\ &\equiv +3.0\text{m} \\ \text{Runup (} h_r \text{)} &= +0.55\text{m} \\ &\equiv +1.0\text{m} \end{aligned}$$

3.3 Modelling Results

These storm scenario characteristics were then applied to the 46 profiles of the Bay of Plenty dataset (see figure 1).

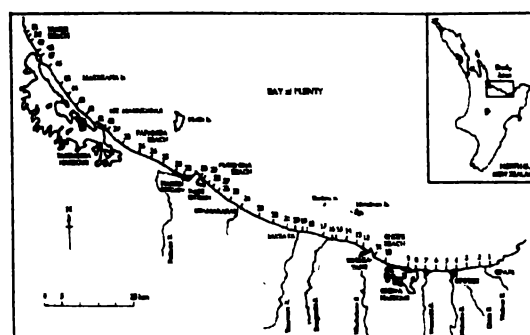


Figure 1: BOP Profile Sites

The summary results of this analysis for a 24 hr storm are shown in table 3 and include the following output variables where:

- VMAX, is the maximum volume eroded above MSL expressed as m^3/m of beach;
- VSWFL, is the maximum volume eroded above the peak flood level;
- DXSWFL, represents the maximum horizontal change in the position of the peak still water flood level of the storm;
- DXDUNE, is the horizontal erosion determined by the modelling for the foredune crest
- TIME, in the table represents the time of maximum erosion over the storm duration period (i.e. 24hr).

Profile No	VMAX m^3/m	VSWFL m^3/m	DXSWFL m	DXDUNE m	TIME hr
1	52.2	7.2	-1.2	-12.2	18.88
2	62.3	30.4	-9.1	-7.7	18.75
3	62.9	41.2	-9.1	0.0	18.13
4	49.3	34.7	-8.1	0.0	18.88
5	59.0	17.2	-14.9	0.0	19.13
6	132.9	0.0	-0.6	0.0	20.0
7	48.9	33.4	-8.4	0.0	17.5
8	42.2	0.1	-5.1	0.0	18.0
9	43.8	35.8	-11.9	0.0	15.25
10	21.9	18.7	-6.1	-4.3	14.88
12	60.0	9.8	-18.6	0.0	18.13
13	83.5	14.1	-24.2	0.0	19.67
14	79.7	30.7	-14.9	0.0	18.25
15	91.5	32.2	-23.9	0.0	19.50
16	89.4	11.7	-15.4	-2.1	19.13
17	77.6	23.7	-9.8	-3.2	19.38
18	87.5	45.2	-23.9	0.0	18.38
19	111.8	17.5	-39.7	-2.4	19.50
20	134.9	66.2	-28.2	-0.2	19.50
21	129.8	58.8	-30.6	-7.0	19.63
22	101.0	24.7	-32.5	-0.9	19.38
23	51.3	27.8	-8.5	0.0	17.13
24	154.9	80.4	-29.5	-2.9	19.88
25	112.5	54.8	-18.3	-2.1	19.63
26	134.8	111.4	-12.0	0.0	18.75
27	119.9	82.8	-13.9	0.0	20.88
28	81.4	46.1	-13.8	0.0	19.63
29	100.7	58.5	-12.3	0.0	19.63
30	46.5	23.7	-6.5	0.0	19.38
32	132.5	72.1	-22.3	-1.9	19.88
33	158.7	92.6	-24.6	-2.7	20.00
34	76.2	52.1	-15.7	-12.2	17.25
35	119.4	70.9	-25.5	0.0	18.88
36	67.9	57.0	-7.5	-1.4	16.88
39	24.7	18.3	-0.3	0.0	16.63
40	72.7	17.9	-7.4	0.0	24
41	0.0	-11.7	18.4	0.0	16.7
42	0.0	-13.7	6.2	0.0	8.6
43	0.0	-14.6	13.1	0.0	16.63
44	0.0	-20.4	21.9	0.0	16.50
45	0.0	-17.8	17.9	0.0	16.50
46	33.3	5.4	-1.5	0.0	17.00
47	93.1	62.6	-14.2	-4.5	18.75
48	75.9	34.8	-21.3	-7.3	19.25
49	60.6	50.5	-10.8	-5.9	16.00
50	47.1	32.1	-14.4	0.0	16.38

Table 3: Outputs from model for 24hr Storm surge for 46 Profiles form the BOP dataset

Table 3 summarises some of the key outputs calculated from the modelling exercise. These have been statistically analysed to provide the following results:

- The mean maximum profile erosion above MSL for all the profiles in the dataset is $73.6 m^3/m$.
- The maximum profile erosion of $158.7 m^3/m$ occurred at Profile 33
- The 95 percentile upper and lower limits for VMAX are 73.6 and $61.0 m^3/m$.
- The mean erosion of the still water flood level for all the profiles (VSWFL) is $33.3 m^3/m$;
- The maximum dune crest erosion is -12.2m (profile (Profile 1) with the mean being -1.8m;
- The 95 percentile upper and lower limits for DXDUNE (dune crest erosion) are -0.8 and -2.7m respectively; and
- The mean time to maximum erosion (VMAX) is 18.27 hrs for the 24hr design storm

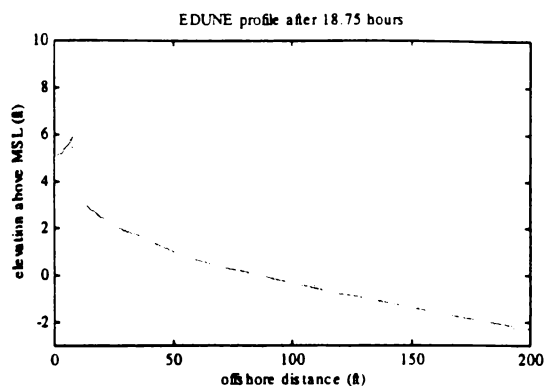
These statistics are contained in the following table

	VMAX	VSWFL	DXSWFL	DXDUNE	TIME
No	46	46	46	46	46
Min.	0.0	-20.40	-39.70	-12.20	8.60
Max.	158.7	111.40	21.90	0.0	24.00
Range	158.7	131.80	61.60	12.20	15.40
Sum	3386.20	1526.90	-539.00	-80.90	840.59
Median	74.3	31.40	-12.15	0.0	18.81
Mean	73.61	33.19	-11.72	-1.76	18.27
U.95%	86.26	42.16	-7.80	-0.83	18.92
L.95%	60.96	24.22	-15.64	-2.68	17.62
Std error	6.28	4.45	1.95	0.46	0.32
Std Dev.	42.60	30.20	13.25	3.12	2.19
Variance	1814.39	912.29	174.38	9.7216	4.80
C.V.	0.5786	0.9099	-1.1270	-1.7729	0.12
Skewness (G1)	0.0305	0.3464	0.5791	-2.1134	-1.705
SE Skew.	0.3501	0.3501	0.3501	0.3501	0.3501
Kurtosis (G2)	-0.5893	-0.0891	0.6894	4.1480	8.0603
SE Kurt	0.6876	0.6876	0.6876	0.6876	0.6876

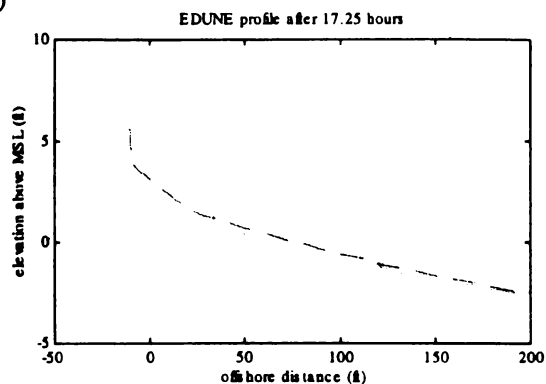
Table 4: Statistical Analysis of Results in Table 3

The EDUNE model also provides data output in a time series form. As part of the study this output was processed through a routine developed in MATLAB to plot the time series data contained in the output file EDUNE.DAT. This routine produces plots spaced at six equal time intervals during the storm cycle with the final profile plot produced representing the profile achieved at the time of maximum erosion. Examples of representative plots produced from BOP data are shown in the following diagrams. The original profile is shown as a solid line while the pecked line represent the profile obtained at the time of maximum erosion.

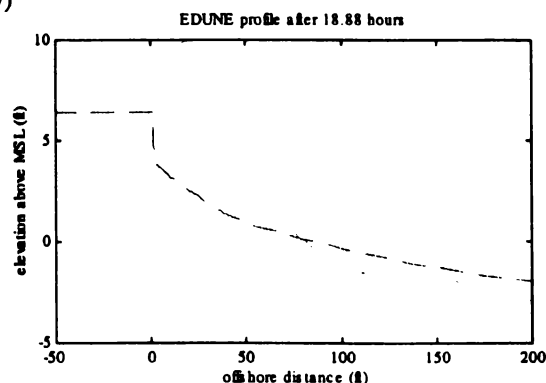
(i)



(ii)



(iv)



(iv)

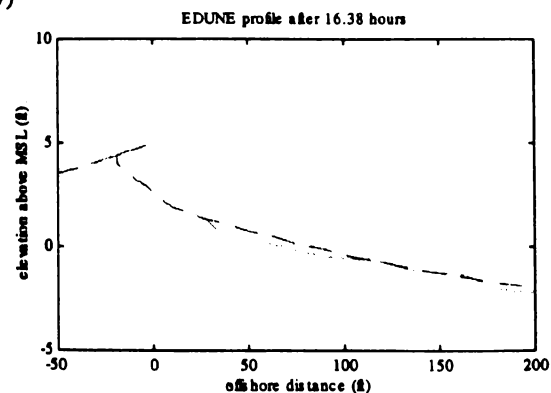


Figure 2: Examples of Plots from EDUNE showing profiles at time of maximum erosion (distances in metres)

(i). Profile 1 (Opape), (ii) Profile 34 (Papamoa), (iii) Profile 40 (Maunganui), (iv) Profile 50 (Waihi)

4 MAJOR FINDINGS

The modelling exercise carried out on the BOP data set has shown the following:

1. That utilising the design storm of 24 hrs duration on profiles depicting BOP beaches, we note that the mean cut out achieved above MSL is $73.6 \text{ m}^3/\text{m}$ of beach with a standard deviation of $42.60 \text{ m}^3/\text{m}$.
2. 19 of the 46 profiles are subject to erosion sufficient to remove the dune crest.
3. The model plots show that there are localised areas that will suffer flooding due to erosion and overtopping of the foredune. Areas at risk appear to be Opape-Hukuwai, Ohope, Piripai-Matata, Papamoa, and Bowentown-Waihi Beach. It is interesting to note that at Pukehina Beach the modelling depicted large erosion cuts but no dune crest erosion.
4. Maximum dune erosion for the conditions simulated in the modelling occurred at the Maketu - Papamoa profiles 32-34.. Although large erosion values were also obtained for Bowentown (profile 47).
5. Maximum dune cut out occurs after about 18 hours.

The above findings are considered consistent with the historical and anecdotal evidence of episodic dune erosion in the BOP. (Harray 1976, Healy 1993).

For technical reasons the model will not accept offshore bars within the simulation routines. For these cases the measured profile required smoothing. This is considered only a minor disadvantage as the major forcing mechanisms in the model in determining the erosion profile are dependent on storm surge and run up elevations.

Future work is planned to calibrate and verify the model. This includes allowing for variations in scale factors (see Table 1) to more accurately reflect individual profile sediments, applying a storm hydrograph derived from real data and to refine wave height inputs to the model to reflect more realistic storm scenarios and related risk.

5. CONCLUSIONS

From the results obtained to date the following conclusions can be made:

1. The EDUNE model appears to predict realistic results for storm wave erosion at frontal dunes in the BOP.
2. Using the design storm the mean volumes of sand eroded to the time of maximum erosion was $73.6 \text{ m}^3/\text{m}$ of beach. The maximum dune crest erosion was 12.1m with

the overall mean being 1.8m when averaged over all 46 profiles. However this increases to 4.3m when averaged over the 19 profiles affected.

3. Further data of specific storm parameters are required to verify the model.

4 The model has the potential for coastal erosion hazard identification and if proven under New Zealand conditions, offers a tool for use in coastal resource management.

Acknowledgements: This paper is a contribution under the FRST funded CHAMP programme.

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Equilibrium Status of Beach Profiles on Bay of Plenty Beaches: Application of the Dean Profile for Coastal Hazard Identification

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SUMMARY This paper describes the application of the Dean Equilibrium Beach Profile (EBP) concept to 48 beach profiles in the Bay of Plenty (BOP) in order to :

- determine appropriate scale, shape and depth of closure factors for use on Bay of Plenty beaches;
- compare the derived scale and shape factors with typical figures found by Bruun (1954), Dean (1977), and Dean (1991) for eastern United States beaches;
- compare the ability of the model (including the Dean (1991) variant) to characterise the sandy beaches of the Bay of Plenty; and
- to assess the predictive potential of the model to determine the equilibrium status of Bay of Plenty Beaches (i.e. whether the beach is potentially erosive or accretional) for use in coastal hazard modeling.

The analysis comprised fitting curves to the profile data by least squares regression from which we determined how well the basic Dean model, $y = Ax^{2/3}$ and its later modification (Kriebel & Dean 1985) characterises BOP beaches. Having obtained appropriate scale and shape factors these values were then used to test the "equilibrium" status of the beaches. Results were found to be influenced by choice of closure depths but generally indicated an erosion potential for most BOP profiles.

1. INTRODUCTION

The 'Dean Equilibrium Profile' (EBP) model (Dean 1977) is considered to have a potential for use in the management of the coastal environment. The model is a two dimensional representation of the equilibrium profile form arising as a result of equal wave energy dissipation in the surf zone in relation to grain size. The model may be used to ascertain the equilibrium status of sandy beaches and by corollary it can be used potentially in a predictive capacity to determine beach responses (erosion/accretion) to changes in sea level.

In this paper the model has been applied to a series of profiles along the Bay of Plenty (BOP) beaches with the aim of :

- calibrating the Dean EBP model in terms of measured Bay of Plenty (BOP) profiles to determine appropriate scale, shape and depth of closure factors for use in the Bay of Plenty;
- comparing the derived scale and shape factors with typical figures found by Bruun (1954), Dean (1977), and Dean (1991);
- comparing the ability of the model (including the Dean (1991) variant) to characterise the sandy beaches of the Bay of Plenty; and
- assessing the predictive potential of the model to determine the equilibrium status of Bay of Plenty Beaches (i.e. whether the beach is potentially erosive or accretional) for use in coastal hazard modeling.

2. THEORETICAL BACKGROUND

It has been suggested by Bruun (1954) and Dean (1977) that a power curve of the general form,

$$y = Ax^b \quad (1)$$

approximates a sandy two dimensional beach profile (where x represents the offshore distance, y the profile depth from sea level, A is the scale factor and b is the shape factor), and that such a profile can be used to represent a beach that is in dynamic equilibrium with the available wave energy and sediment grain sizes. This profile is produced as a result of energy dissipation per unit volume of water in the surf zone (Dean 1977) and the shape is largely dependent on the sediment characteristics of the site. Dean claims that if the exponent is fixed at $2/3$ then the scale factor A varies systematically with sediment texture, and that sediment will be mobilised by energy dissipation with the finer material moved offshore within a defined closure depth. This produces a curved profile in which the coarser sediment is located in the high energy environment of the surf zone close to shore (Dean 1991).

The EBP has been documented as having four basic characteristics. These are:

- they are usually concave upwards
- smaller grain sizes result in lower nearshore gradients
- the beach face is normally planar

- steep waves produces milder slopes and a tendency for bar formation.

Some researchers have suggested several variations to equation (1) in order to improve the representation of beach profiles (Kriebel & Dean 1985, Dean 1991, & Bodge 1992). Much of this work has been based on empirical beach measurements throughout the world and data from wave tank experiments.

One of the variants suggested by Kriebel & Dean (1986), and Dean (1991) and considered further here is described in the following equation

$$x = \frac{y}{m} + \frac{y^{3/2}}{A^{3/2}} \quad (2)$$

where x is the offshore distance, y is the profile depth from sea level, A represents the scale factor, m is the beachface slope, and b is the shape factor as before. This modified profile is an attempt to create a more realistic composite profile to overcome difficulties associated with the infinite slope problem which equation 1 suggests as the profile approaches the origin. This modified Dean profile therefore involves both a linear component representing the beach face and a concave curve typical of the surf and offshore zone. The equation also form the basis for the Kriebel (1989) EDUNE model which can be used to predict short term cut and fill events (Pickett et al., 1997).

3 BEACH ENVIRONMENT OF THE BAY OF PLENTY

The Bay of Plenty (BOP) is situated on the north eastern coast of the North Island of New Zealand (see figure 1). Its general aspect lies towards the north and north east and as such is generally protected from the sequences of anticyclones, low pressure systems and fronts that cross the country from the south and west (Healy et al., 1977). However the beaches of the BOP are susceptible to the affects of intense depressions and tropical cyclones, often associated with La Nina conditions, that can produce strong winds and swells from the north and northeast. These conditions are frequently associated with episodes of beach erosion along the northeastern coast of New Zealand, and in particular the Bay of Plenty Coast.

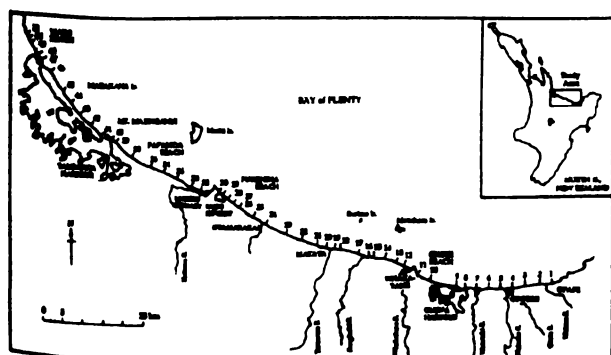


Figure 1: BOP Beach Profile Sites

The Bay of Plenty can be described as a long gently curving sandy barrier coastline (Healy et al., 1977) occasionally broken by sandy inlets, lagoonal estuaries and isolated rocky promotories. The coastline is comprised mainly of Holocene sandy barrier deposits consisting of tombolos, barrier spits and islands and dune ridge sequences. Much of these rhyolitic sands have been derived from erosion of tephra deposits of the nearby volcanic plateau (Healy et al., 1977 after Davies-Colley, 1976)

4. STUDY METHODOLOGY

The data used for this study consists of data surveyed by Dommerholt (unpublished research data, University of Waikato) in 1993 for the Bay of Plenty Regional Council beach monitoring sites (see figure 1). This data consisted of both measured profiles for 48 sites and sand diameter measurements derived from bottom sediment samples taken along the profile at the time of survey. Profiles were measured to the Hallermeier Outer Limit (approximately 15m) as calculated from available wave data statistics.

The methodology employed to meet the aims of this study involved the following:

- applying a 'blindfolded regression analysis' to the BOP data set to fit the $y=Ax^b$ profile to the measured profiles. The 'goodness of fit' of the Dean profile to the measured beach profile was then compared using the least squares coefficient of determination, R^2 . The regression analysis was carried out using routines in MATLAB and the curve fitting software, TABLE 2D CURVE. The output was then used to determine how well the averaged and individual shape and scale factors fitted with Deans exponent of 2/3 (shape factor), and the profile scale factors derived from the conversion of the measured sediment diameters by the methodology of Moore (1982) and Dean (1991) utilising measured fall velocities.

A sensitivity analysis was then carried out to determine whether improvements could be obtained from fitting the power curve (equation 1) to profiles limited to 8m water depth (approximately the Hallermeier Inner Limit).

- applying the Dean EBP ($y = Ax^{2/3}$) by regression analysis to the 48 profiles in the BOP data set to determine both the 'goodness of fit' (R^2) of the measured profile to the EBPs and the agreement between the calculated scale factor A and the measured value determined from averaging the sediment derived values for each profile.
- trial the application of the modified Dean model to predict the equilibrium status (ie erosion/accretion potential) of beaches in the BOP data set.

5. RESULTS

5.1 Blindfold Regression Analysis

The regression analysis was carried out to fit a power equation of the form defined in equation 1. The regression analysis allowed for the power curve to be forced through zero (mean sea level) with both parameters left free to be determined by least squares regression. The results of this investigation are shown in table 1. Statistical analysis of these 48 values including means and 95 percentile confidence intervals for the output data are shown in table 2.

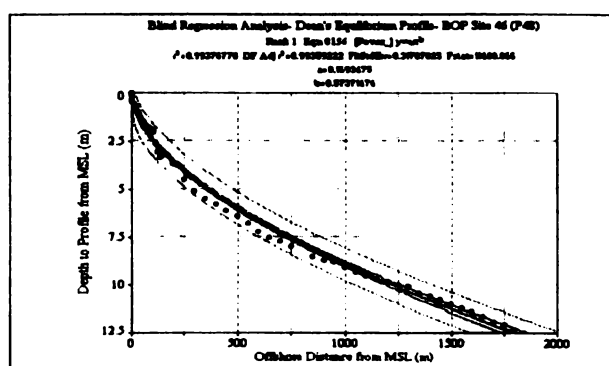
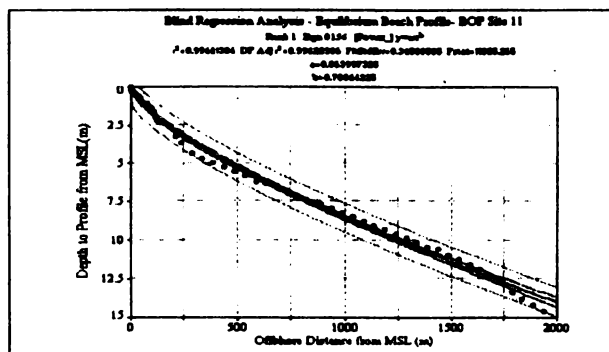
Site No.	parameter A	exponent b	R
1	0.1511	0.5922	0.9960
2	0.1380	0.6134	0.9961
3	0.0794	0.6824	0.9967
4	0.0708	0.7034	0.9920
5	0.1135	0.6347	0.9949
6	0.1640	0.5878	0.9954
7	0.1387	0.6046	0.9938
8	0.0414	0.7489	0.9805
9	0.0075	0.9691	0.9829
10	0.0507	0.7445	0.9981
11	0.0640	0.7084	0.9944
12	0.0923	0.6971	0.9898
13	0.1765	0.6076	0.9899
14	0.1004	0.6942	0.9927
15	0.0617	0.8053	0.9957
16	0.0494	0.8393	0.9972
17	0.0564	0.8251	0.9945
18	0.0188	0.9807	0.9914
19	0.0821	0.7409	0.9952
20	0.0911	0.7235	0.9873
21	0.1088	0.6860	0.9960
22	0.0898	0.7092	0.9936
23	0.0570	0.7837	0.9940
24	0.1020	0.7123	0.9925
25	0.0789	0.7548	0.9948
26	0.0794	0.7339	0.9938
27	0.0906	0.7283	0.9955
28	0.1147	0.6878	0.9968
29	0.0822	0.7337	0.9961
30	0.0772	0.7415	0.9857
32	0.2375	0.5216	0.9903
33	0.3564	0.4803	0.9832
34	0.0398	0.8344	0.9961
35	0.1270	0.6366	0.9966
36	0.0503	0.8050	0.9972
38	0.0598	0.7755	0.9981
39	0.0379	0.8365	0.9949
40	0.1440	0.6147	0.9924
41	0.3097	0.4531	0.9246
42	0.1346	0.6149	0.9941
43	0.0554	0.7505	0.9989
44	0.0270	0.8449	0.9957
45	0.0347	0.8003	0.9906
46	0.0162	0.8636	0.9472
47	0.1195	0.5730	0.8900
48	0.1693	0.5737	0.9938
49	0.0573	0.7037	0.9976
51	0.0913	0.6362	0.9947

Table 1: Results of Blindfolded Regression Analysis profiles measured to H.O.L.

	Scale Factor 'A'	Shape Factor 'B'
No of Cases	48	48
Minimum	0.008	0.453
Maximum	0.772	0.981
Range	0.764	0.528
Sum	5.428	34.058
Median	0.086	0.711
Mean	0.113	0.710
95% CI Upper	0.148	0.742
95% CI Lower	0.078	0.677
Std Error	0.017	0.016
Standard Dev.	0.119	0.112
Variance	0.014	0.012
C.V.	1.054	0.0158
Skewness	3.982	0.045
SE Skewness	0.343	0.343
Kurtosis	20.088	0.274
SE Kurtosis	0.674	0.674

Table 2: Statistical Distribution of Results from Table 1

Two examples of the regression curves produced from this analysis are shown in figure 2.



Figures 2: Regression Curves for sites 11 and 46

To summarise the statistical and the regression analysis the following statements can be made:

- the goodness of fit achieved by fitting a power curve to the 48 individual profiles is extremely good as shown by the coefficient of determination (R^2) for the each of the 48 profiles examined;
- the average of all the exponent 'b' values obtained is 0.710 ± 0.033 (at the 95% CI). This puts Dean's 0.67 value at the extreme lower limit of the confidence

range. However it is possible to argue statistically that the results obtained with the BOP data are not significantly different from the data obtained by Dean from analysing the 502 profiles in the USA (Dean 1977);

The results of the regression derived scale factor values (A) were then compared to those determined from the sediment sampling for each profile. This comparison is shown in Table 3.

Site No.	Profile Scale Factors (A)	
	Regression	Sediment
1	0.1511	0.1020
2	0.1380	0.1050
3	0.0794	0.1035
4	0.0708	0.1000
5	0.1135	0.0987
6	0.1640	0.1020
7	0.1387	0.1012
8	0.0414	0.1092
9	0.0075	0.1050
10	0.0507	0.1000
11	0.0640	0.0964
12	0.0923	0.1011
13	0.1765	0.1067
14	0.1004	0.1105
15	0.0617	0.1075
16	0.0494	0.1122
17	0.0564	0.1092
18	0.0188	0.1107
19	0.0821	0.1205
20	0.0911	0.1167
21	0.1088	0.1142
22	0.0898	0.1152
23	0.0570	0.1191
24	0.1020	0.1255
25	0.0789	0.1186
26	0.0794	0.1124
27	0.0906	0.1163
28	0.1147	0.1092
29	0.0822	0.1122
30	0.0772	0.1512
32	0.2375	0.1274
33	0.3564	0.1087
34	0.0398	0.0987
35	0.1270	0.1055
36	0.0503	0.1027
38	0.0598	0.1025
39	0.0379	0.1062
40	0.1440	0.1217
41	0.3097	0.1433
42	0.1346	0.1177
43	0.0554	0.1115
44	0.0270	0.1017
45	0.0347	0.1025
46	0.0162	0.1156
47	0.1195	0.1250
48	0.1693	0.1111
49	0.0573	0.0991
51	0.0913	0.1000

Table 3: Comparison of Regression and Sediment derived Scale Factors for the 48 BOP Profiles (A in $m^{1/3}$)

The means of both sample sets are 0.098 and 0.111 respectively. While a student t test of the results indicates

that at the 95 % CI there is no significant difference between the means of the two sets, the variance between some of the individual profiles are significant.

5.2 Fitting Dean's Profile (equation 1) to the BOP dataset with a fixed exponent of 2/3

This analysis was carried out to fit the Dean profile (equation 1) to the measured profiles holding the exponent value to 2/3, and to compare the regression derived shape factor to those values obtained from the sediment sampling. The results of this analysis are shown in Table 4.

Site No.	Profile Scale Factors (A)		Ratio Regression Analysis
	Regression	Sediment	
1	0.0876	0.1020	0.9907
2	0.0943	0.1050	0.9938
3	0.0889	0.1035	0.9966
4	0.0922	0.1000	0.9911
5	0.0910	0.0987	0.9940
6	0.0930	0.1020	0.9902
7	0.0887	0.1012	0.9902
8	0.0752	0.1092	0.9758
9	0.0673	0.1050	0.9460
10	0.0881	0.1000	0.9938
11	0.0861	0.0964	0.9933
12	0.1136	0.1011	0.9891
13	0.1177	0.1067	0.9867
14	0.1214	0.1105	0.9922
15	0.1511	0.1075	0.9838
16	0.1487	0.1122	0.9783
17	0.1557	0.1092	0.9803
18	0.1373	0.1107	0.9490
19	0.1333	0.1205	0.9917
20	0.1306	0.1167	0.9852
21	0.1235	0.1142	0.9957
22	0.1189	0.1152	0.9922
23	0.1224	0.1191	0.9839
24	0.1374	0.1255	0.9908
25	0.1402	0.1186	0.9897
26	0.1244	0.1124	0.9908
27	0.1353	0.1163	0.9930
28	0.1320	0.1092	0.9965
29	0.1287	0.1122	0.9933
30	0.1288	0.1512	0.9820
32	0.0806	0.1274	0.9695
33	0.0948	0.1087	0.9346
34	0.1210	0.0987	0.9794
35	0.1030	0.1055	0.9959
36	0.1242	0.1027	0.9850
38	0.1234	0.1025	0.9906
39	0.1179	0.1062	0.9799
40	0.0991	0.1217	0.9902
41	0.0647	0.1433	0.8754
42	0.0924	0.1177	0.9918
43	0.1010	0.1115	0.9947
44	0.0949	0.1017	0.9782
45	0.0908	0.1025	0.9807
46	0.0690	0.1156	0.9268
47	0.0619	0.1250	0.8843
48	0.0844	0.1111	0.9839
49	0.0744	0.0991	0.9966
51	0.0737	0.1000	0.9940

Table 4: Comparison of Regression and Sediment Derived Scale Factors for the Dean Profile

Examination of these results indicates that the least squares regression fit of equation 1 with the exponent held at Deans' derived value of $2/3$ (Dean 1977) still results in a good fit (R^2) being achieved between the field data and the regression curve. Analysis of the sediment derived shape factor also shows that there is good agreement between these and the regression derived values. Examples of the regression plots are shown in figure 3.

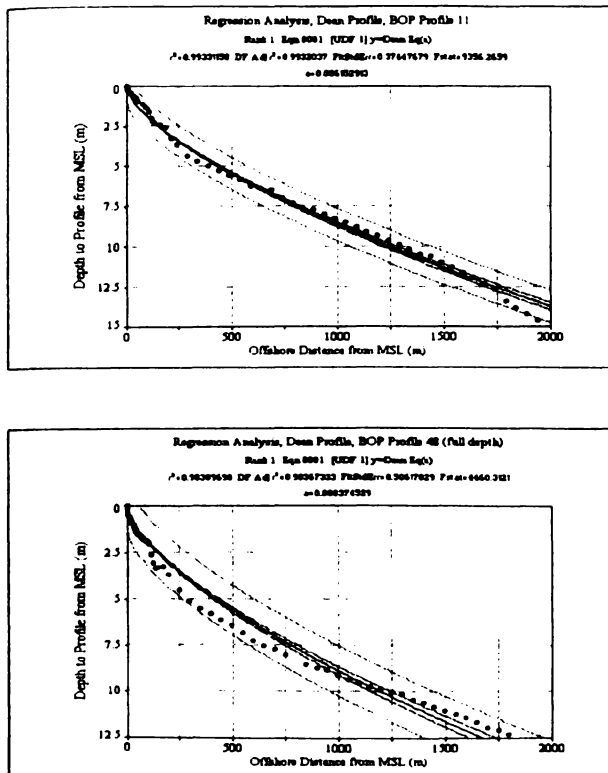


Figure 3: Typical Regression Curves obtained by fitting the Dean Equation to Measured Profiles- Sites 11 and 48, BOP Data set

A sensitivity analysis was also carried out to test the response of the regression values to changes in profile depth by limiting the depth of profile analysed to 8m depth below MSL. The values obtained for R^2 and the root mean square error (ϵ) although not reported here, showed only minor variation to those derived from the full depth profile.

5.3 Shoreline Prediction - Preliminary Application of the Modified Dean Model

Given the good correlation generally obtained between regression derived values for the Dean scale factor and averaged values determined directly from the sediment analysis, together with the confirmation of the shape factor at $2/3$ (i.e. the Dean exponent) as reported above, a preliminary trial was carried out using the modified Dean Profile (equation 2) to predict the equilibrium status (or 'Erosion/Accretion Potential') of the 48 BOP Beach Sites.

As discussed above, the modified Dean model conceptually offers the opportunity for an improved representation of the equilibrium beach profile. This together with a piece wise approach to the derivation of the scale factor from individual sediment samples should, theoretically provide a realistic assessment of the stability of the beaches contained in the BOP dataset. This approach has therefore been used to determine the sediment balance existing between the calculated and surveyed profiles measured to their outer limits (-12 to -16m, approximate Hallermeier outer closure depth). Two typical plot outputs are shown in figure 4 with the results of the equilibrium analysis tabulated in Table 5. This analysis indicates that of the total profiles considered, forty (83%) are susceptible to erosion while only eight contain a surplus of sediment and may therefore accrete.

Site No	Sediment Area under Profile (m ²)	Area under Profile (m ²)	Surplus Deficit of sediment (m ³)	Equilibrium Status
1	13,740	13,240	500	Accretion
2	11,730	16,860	-5,130	Erosion
3	13,540	15,770	-2,230	Erosion
4	14,400	19,140	-4,740	Erosion
5	7,530	10,027	-2,497	Erosion
6	12,630	15,551	-2,921	Erosion
7	12,540	24,200	-11,660	Erosion
8	14,000	10,290	3710	Erosion
9	13,610	15,680	-2,070	Erosion
10	11,230	9,996	1,234	Accretion
11	12,700	13,720	-1,020	Erosion
12	8,112	12,310	-4,198	Erosion
13	7,921	11,110	-3,189	Erosion
14	9,441	12,590	-3,149	Erosion
15	7,176	10,370	-3,194	Erosion
16	7,455	10,240	-2,785	Erosion
17	6,240	9,146	-2,906	Erosion
18	6,600	8,346	-1,746	Erosion
19	6,677	8,949	-2,272	Erosion
20	5,103	6,511	-1,408	Erosion
21	6,310	7,996	-1,686	Erosion
22	6,324	7,468	-1,144	Erosion
23	7,131	8,415	-1,284	Erosion
24	7,195	9,099	-1,904	Erosion
25	7,761	11,190	-3,429	Erosion
26	8,306	11,330	-3,024	Erosion
27	7,957	11,380	-3,423	Erosion
28	8,096	12,190	-4,094	Erosion
29	8,583	12,420	-3,837	Erosion
30	8,958	10,920	-1,962	Erosion
32	15,630	10,092	5,538	Accretion
33	10,330	11,870	-1,540	Erosion
34	8,764	12,080	-3,316	Erosion
35	9,325	10,810	-1,485	Erosion
36	7,695	11,850	-4,155	Erosion
38	7,771	11,280	-3,509	Erosion
39	8,431	13,610	-5,179	Erosion
40	14,230	15,710	-1,480	Erosion
41	9,198	4,518	4,680	Accretion
42	13,310	12,150	1,160	Accretion
43	14,140	18,720	-4,580	Erosion
44	13,980	16,690	-2,710	Erosion
45	16,120	16,550	-430	Erosion
46	18,390	9,789	8,601	Accretion
47	7,680	2,839	4,841	Accretion
48	7,634	6,201	1,433	Accretion

Site No.	Sediment Area under Profile (m ²)	Area under Dean Profile (m ²)	Surplus/ Deficit of sediment (+/-)	Equilibrium Status
49	9,686	9,906	-220	Erosion
51	8,366	9,286	-920	Erosion

Table 5, Determination of Equilibrium status for BOP beaches using the Dean modified EBP with piecewise determination of scale factor for each profile.

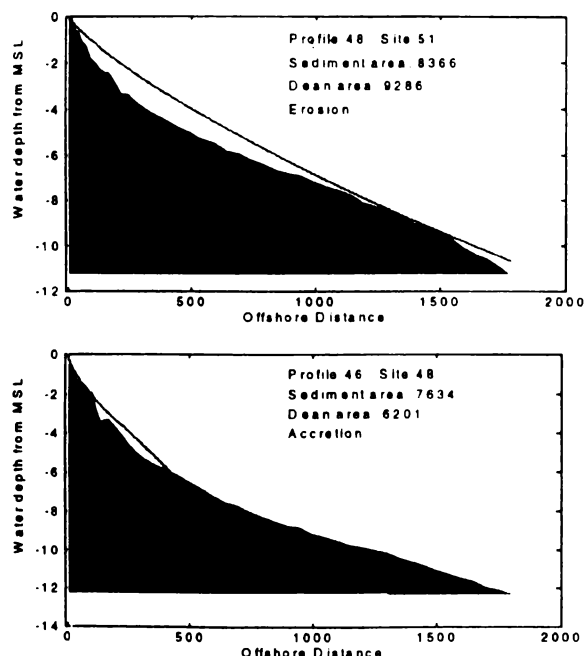


Figure 4: Example of plots for modified Dean EBPs for sites 11 and 48 showing equilibrium status of profile.

6. CONCLUSION

The objective of this exercise was to evaluate the Dean EBP model in terms of representing beach profiles in the Bay of Plenty. As with Dean (1977) and Bruun (1954) it would appear from the results obtained in this examination that a Dean Profile utilising a shape factor 'b' = 2/3 (taken from equation 1) arguably provides a reasonably good approximation of the measured profiles.

The analysis also showed that a reasonable agreement was obtained between the sediment derived scale factors and

those derived from fitting Dean's power curve to the measured profiles. It is suggested from this examination that the Dean model and its variant have a potential for use in identifying coastal stability and consequently coastal hazard in the Bay of Plenty.

However the equilibrium status results described in Table 5 above need to be considered with caution as the scale of erosion predicted seems to be unrealistic. One possible explanation is that the use of the outer Hallermeier Limit to the define closure depth is inappropriate for use in the model and that a more realistic determination might be obtained by limiting closure depths to those approximating an inner limit of closure of around 7 to 8m. This finding is generally consistent with the findings of Dean et al. (1993). Another possibility is that the piecewise derivation of the scale factor is unsuitable and that use of averaged values may provide a more appropriate solution.

Further work is therefore required on these matters before the model can be confirmed for use in hazard assessment.

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