Form and Function of the Waihao-Wainono Barrier, South Canterbury

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Abstract

The mixed sand and gravel barrier beaches located on the South Island's East Coast are formed predominantly of Greywacke, eroded from the mountains, and transported via the major river systems. These barriers act as the interface between the South Pacific Ocean and the surrounding hinterland. In times of high energy coastal events, breaching is common.

This thesis examines the form and function of the Waihao-Wainono barrier, a section of the coastline situated north of the Waitaki River. Breaches along this part of the barrier are frequent and several have rendered the surrounding farmland unusable for several years due to the effects of saltwater inundation. There is some concern among the local community as to exactly why the barrier breaches at certain locations and not others, making land planning and management a difficult task for farmers. Several of the local landowners believe that since the construction of the Waitaki Dam in 1935, a significant decrease in sediment size along the barrier has occurred. It is also thought that the barrier form has experienced substantial change.

Through the use of physical techniques used in the field of coastal science, 17 sites along the Waihao-Wainono barrier were studied. Excavations were carried out, surface and substrate profiles recorded and sediment samples collected from the surface, sub- surface and substrate of the barrier.

Analysis of the barrier form and barrier volume concluded that the past breach sites consisted of steeper lower foreshore slopes than the non-breach sites, and at two sites, the substrate was not reached. Breach areas display the greatest barrier volume of all the study sites, which is contrary to belief.

In relation to the surface sediments, the majority of barrier profiles displayed the distinct mean grain size cross shore zonation, characteristic of mixed sand and gravel beaches. The best and most consistent surface sorting was also identified as being a characteristic of the breach sites. The sediment size is not shown to have drastically reduced over the thirty year sampling period as was perceived by the local community.

Within the sub- surface of the barrier, the sediments displayed chaotic sizes and generally poorly sorted material. Several of the breach sites contained a distinct change in sediment size between the coarser surface layer and the finer layer located immediately below. This layering of coarse and fine sized sediments leads to differences in permeability within the barrier, which is thought to be a major factor in why these sites have breached.

Resulting from these findings, a group of characteristics of breach sites was formed and several predictions made as to where the barrier may breach in the near future.

Key words: mixed sand and gravel, barrier, volume, sediment, substrate, profile form.

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Chapter One

Introduction

1.1 Background

This thesis addresses the variability in both form and function of the Waihao-Wainono barrier, a mixed sand and gravel (MSG) barrier situated on the South Canterbury coast. Timaru lies to the north and the Waitaki River to the south. Figure 1.1 shows the study area and its surroundings. Hicks et al., (2002) have suggested a maximum barrier height of up to 7m and a barrier width ranging from 40-100m.

Research for this thesis has taken place along the Wainono coast, the study area starting 14km north of the Waitaki River and extending 28km to the Otaio River. The hinterland is extensively farmed and low lying, much of which rests at elevations of only 1-2m above mean sea level (MSL). At several sites the barrier has 'rolled over' onto the farmland and during numerous storms overtopping or breaching, has flooded the land with saltwater and rendering it unusable. Overtopping occurs when the maximum wave height exceeds that of the barrier crest and breaching occurs when a weak area in the barrier collapses, giving way to water passing through the barrier. The four most southern profile sites within the study area do not experience rollover or overtopping as the barrier is backed by eroding sea cliffs, which continue south to the Waitaki River. These cliffs are composed of alluvial sediment formed in the late Pleistocene and provide sediment to the barrier (Gibb and Adams, 1982).

The area contains a significant ecological and cultural site named Wainono Lagoon, a waterbody that has intermittent connections to the sea, classified as a 'waituna' by Kirk and Lauder (1994).

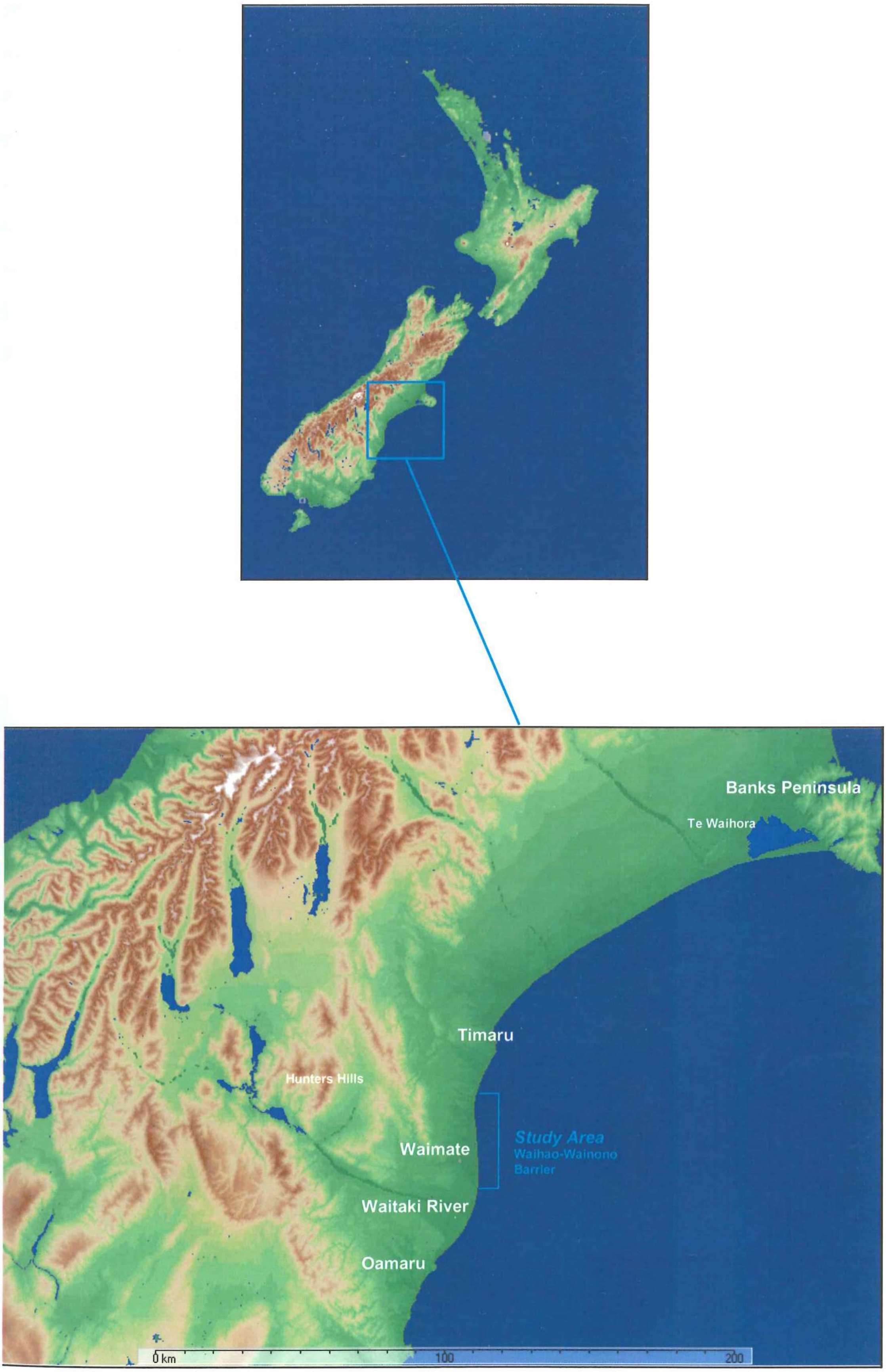


Figure 1.1: Location of the study area.

The study area has been the focus of much recent debate on the effects of reducing sediment supply from the Waitaki River under the proposed Project Aqua scheme, and from existing dams on the River. Project Aqua is a hydro power generation scheme that was proposed by Meridian Energy Ltd. in the hope of reducing power crises that the country experiences on an almost yearly basis. The proposed scheme involved diverting part of the flow of the Waitaki River through a 60km long canal system on the south bank of the river. Figure 1.2 displays the general layout of what was put forward. In addition to the canals a series of six power stations were to be located along the canal system with outfalls back to the river at both Black Point and Steward Road.

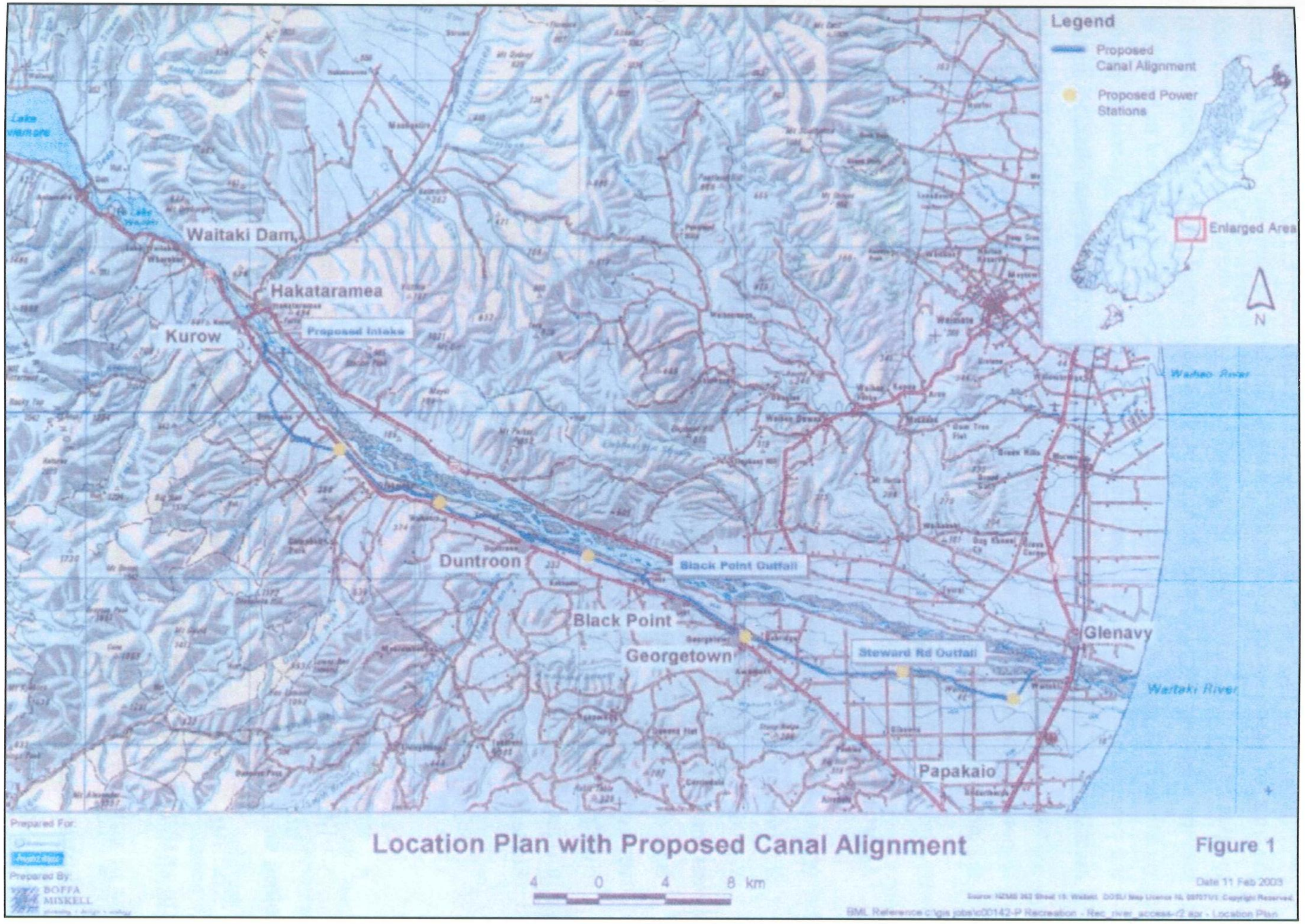


Figure 1.2: Location plan of the proposed canal alignment for Project Aqua (Source: Hicks et al., 2002:3)

This scheme was annulled in March 2004, but many locals are still concerned about the effects the existing dams have on the barrier. These perceived effects of damming include a lowering of the barrier height, a decrease in the barrier width and sediment size, and an increased frequency of overtopping or breach events (Bruce 2003, pers.com.). Figure 1.3 provides an image of one section of the barrier.

Figure 1.3: Photo of the Waihao-Wainono barrier at the Lows Road site.

It is well known that the South Canterbury coast has been steadily eroding for a number of years. The effects of farming and irrigation are thought to have an effect on erosion, but this is not proven. A reduction in sediment supply from the south is a contributing factor to erosion of the Waihao-Wainono barrier. Again it is unknown as to whether this reduction has stemmed from the construction of dams in the Waitaki River dating back to the first dam in 1935, or if it is due to the natural decrease in sediment supply (Kirk, 1980; Shulmeister and Kirk, 1983; Hicks at al., 2002).

As well as erosion being closely linked to barrier breaching, the sediment volume of the barrier and the magnitude of storm events are equally as important in identifying the underlying causes of breaching (Single and Hemmingsen, 2001). During the

April/ May storm series in 1985, the barrier was significantly weakened as the waves removed 29% of the upper beach volume (Todd, 1991). The barrier was breached again in July 1985 during a severe storm event when 500 ha of farmland became inundated with saltwater. The land was unable to be used for agricultural purposes for over three years.

Breaching and overtopping events of different scales are frequent along the Wainono coast and many stopbanks and drains have been constructed to stem the effects of breaching on the surrounding hinterland (Single and Hemmingsen, 2001). Environment Canterbury (ECan) provides annual monitoring through profiling numerous sites along the 30km barrier. This monitoring provides information on the changing form of the barrier.

1.2 Previous Studies on the Waihao-Wainono Barrier

Mixed sand and gravel beaches like those along the East Coast of New Zealand are termed to be rare on a global scale (Kirk, 1980). New Zealand coastal scientists are however gaining an understanding of how mixed sand and gravel beaches function. Members of the Canterbury University Coastal Group have studied these beaches since the mid 1960's, and the South Canterbury coast in particular since the mid 1970's (Kirk, 1980; Single, 1992).

In 1977, Hewson studied the erosion and beach dynamics of the Oamaru-Timaru Coast, describing the processes operating on it and the rates of erosion. The most rapid rates were found south of the Waitaki River. Hewson also constructed a sediment budget model and described the variation of across-shore sediment sizes. General observations of the lowland coast and surrounding areas were made, linking geological information with historical sea level fluctuations.

Neale (1987) studied changes in the average volume of the barrier north of the Waitaki River and believed that 'sediment slugs' were responsible for the variability of sediment volume along the barrier, with above average sediment volumes being termed the crest and below average volume, at a particular site, being termed the trough. According to Neale, the 'slugs' of sediment are sourced from particular events such as flooding of the Waitaki River or severe storm events. These cause erosion of the cliffs, which introduce new sediment to the beach. Neale indicated that the slugs moved northward, and that breaching or overtopping of the barrier would occur in areas of sediment troughs.

Single (1992) found that the beach response on the Waihao-Wainono barrier was strongly connected to the volume of sediment in the foreshore. He concluded that areas with large berms, wider foreshores and high volumes are less likely to breach. Single provided guidelines of beach volume limits based on the actual beach state as a way of predicting whether a site will breach in high-energy events.

Further north, Benn (1987) carried out research on the erosion issue along the Washdyke-Seadown coast north of Timaru. He paid particular attention to the morphological characteristics, the volume and sediments of the beach system, the characteristics of the sediments comprising the beach's hinterland and the erosion trends of the beach. In order to gain volume data Benn excavated several pits along the beach to substrate depth. To date no research of this kind has been carried out along the Waihao-Wainono coast.

In 1999, Hart completed research, which involved an examination of hapua; coarse barriers formed in front of river mouths subsequently causing offset outlets to the sea. She examined the dynamics of hapua type river mouth lagoons, the lagoon hydraulics and morphological variation on hapua behaviour and integration with marine processes. Although her research was not focussed on the Wainono Lowland area, Hart added some new insights into mixed sand and gravel barriers and how they function, especially at or near river mouths.

1.3 Purpose of the Investigation

From previous research along the South Canterbury coast it is clear that our understanding and knowledge of mixed sand and gravel beaches is increasing. However only certain aspects of the barrier have been studied and all have focussed on erosion dominated objectives.

From consideration of the background of the Waihao-Wainono barrier and the previous studies identified in section 1.2, this thesis plans to examine the relationship between barrier variability in both time and space, and sea flooding into the surrounding farmland and hinterland.

Past research on the Waihao-Wainono barrier has been directed at gaining information on the surface profile form and sediment characteristics both cross shore and along shore. Barrier volume has in the past been calculated based on estimations of substrate form and location. The advantage of this study is that in addition to taking account of barrier surface characteristics, sub surface sediments and substrate form is also examined. Volume calculations at each site will be carried out and it is hoped that conclusions will be reached with regard to the depth of the substrate and the role it plays in the determination of breach sites. Planning and management of the area will then be more effective and able to be directed at certain areas of the barrier.

1.3.1 Hypotheses

There are four main hypotheses as to why the barrier breaches at certain sites and not others. Within the context of the development of the barrier, the first three hypotheses are included in the scope of this study.

1) A trough in sediment supply determined by less volume, height and width of the barrier at particular sites.
2) Differences in sediment size, type, distribution and its variability within and between profiles.
3) Differences in substrate elevation and composition.
4) Differences in offshore bathymetry and wave conditions.

1.3.2 Objectives

The objectives of this study are aimed at answering the hypotheses set.

1) To accurately estimate beach volume. This can be used as a baseline for future changes in profile volume.
2) Determine spatial sediment volume variability along and across the barrier.
3) Determine barrier profile form both spatially and temporally over the last thirty years.
4) Determine sediment size distribution spatially both cross-shore, along shore and with depth.
5) To determine whether any temporal trends in changes in sediment size are evident.

1.4 Investigative Framework

When carrying out research a conceptual framework is essential on which to base the study. Within the coastal literature many frameworks are used such as the sediment budget model (Miller and Ziegler, 1958), the morphodynamic model (Wright and Short 1984) and more recently the descriptive model proposed by Hart (1999) to represent the dynamics of hapua. Two conceptual frameworks are used in this study. The first is the Process-response Model (Krumbein, 1963). The process-response model, shown in Figure 1.4 displays the interaction of all parts of a beach system, resulting in the continual environmental adjustment to attain equilibrium.

The model shows that the process elements (energy factors, material factors and shore geometry) affect the response elements of beach geometry and beach materials of the beach system. The feedback loop displays that the response elements can also affect the process elements.

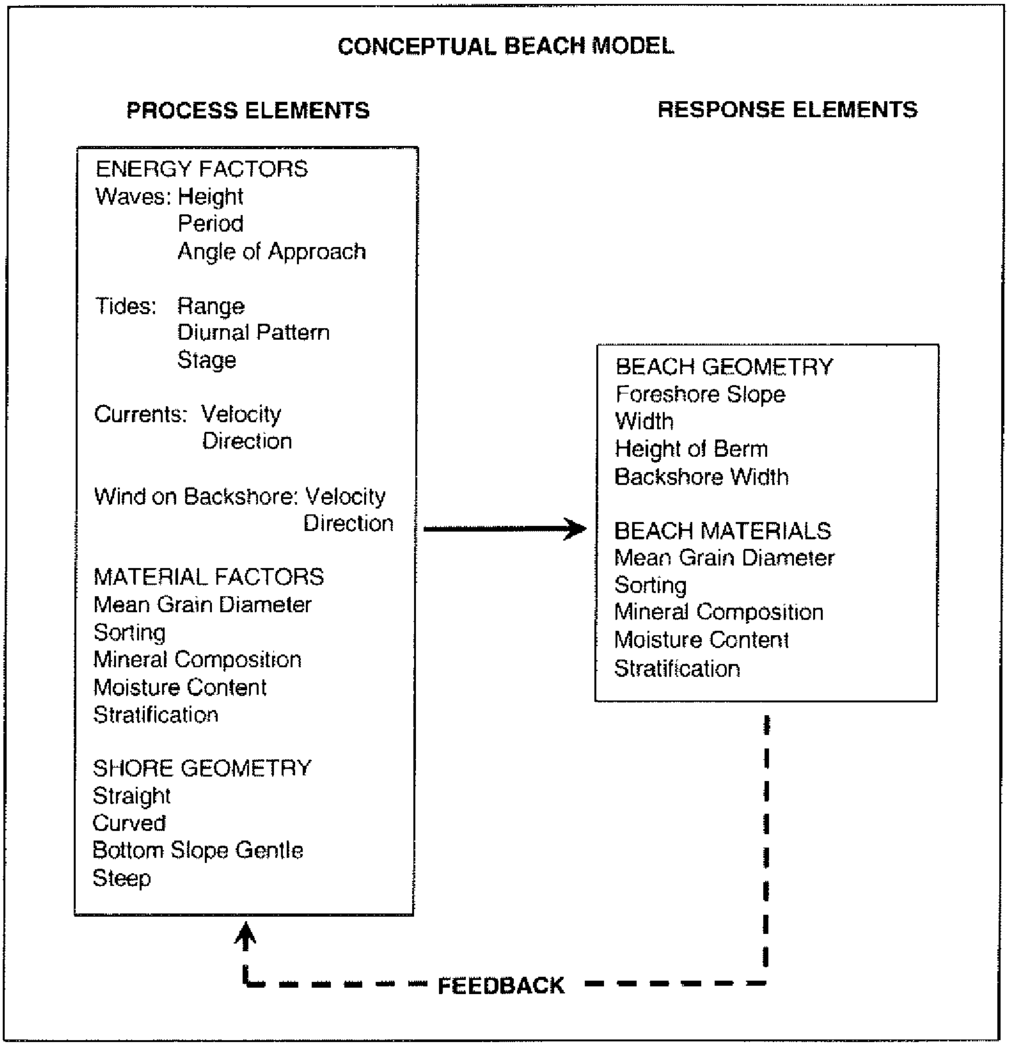


Figure 1.4: The process-response model. Process elements (initial properties) are on the left side and the response elements (resultant properties) are on the right side. From Krumbein (1963).

The ordered control model as termed by Lauder (1987) is the second conceptual framework used in this study and investigates how the variables that influence beach morphology interact (Figure 1.5). The model distinguishes between first order (source area) and second order (hydraulic factors) controls, the two independent variables which provide an initial control beach materials and sediment characteristics.

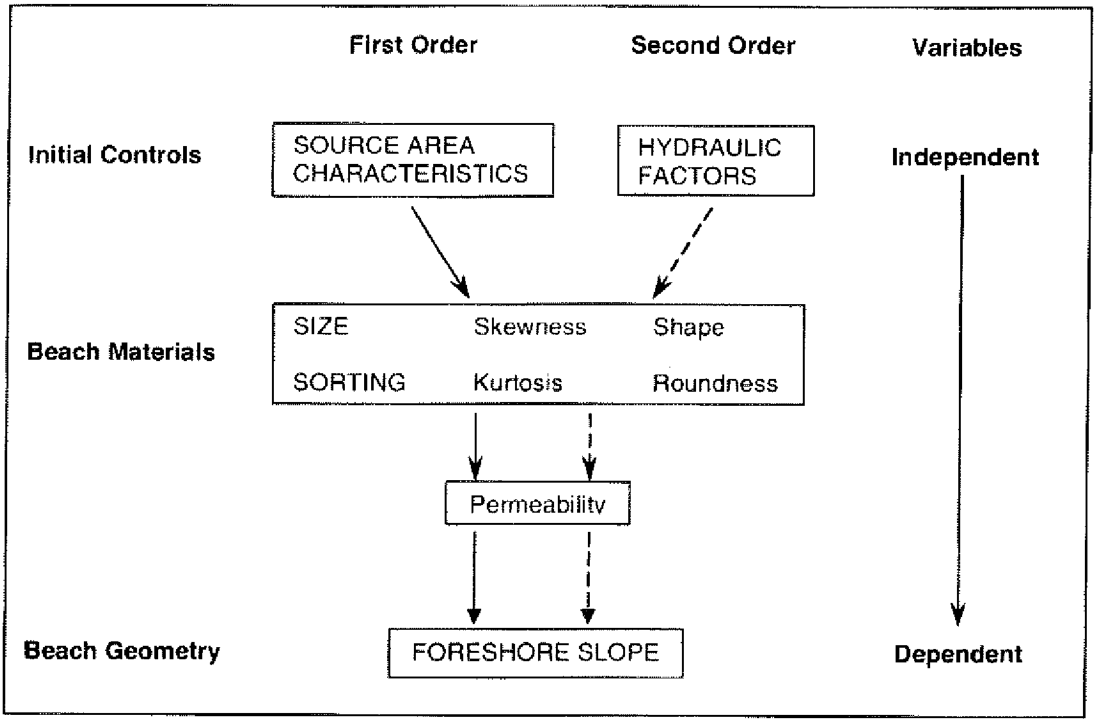


Figure 1.5: The ordered control model relating initial controls, beach materials and beach geometry. The level of dependency decreases from top to bottom. First order controls are indicated by solid arrows, second order by dashed arrows. From Mclean and Kirk (1969).

It is the source area characteristics that have a first order control on the beach materials. For example, if the main source area for a beach is a gravel river, the beach material will be different to a beach that has a dominant source of sandstone cliffs. Hydraulic factors (wave environment, wind environment, currents, tidal influences) are named as the second order variable and influence the material supplied to the beach from the source area. Foreshore slope is seen as the ultimate response element of the beach dependent on all other variables. By using this model the barrier materials and barrier geometry will be investigated.

The ordered control model provides the underlying concept for this research. The main sediment sources of the Waitaki River and the coastal cliffs are known. The barrier characteristics such as sediment size and sorting and the foreshore slopes of both the surface and substrate profiles will be investigated.

1.5 Thesis Approach

In researching the variability of the Waihao-Wainono barrier three main approaches were used. Historical data such as profiles from the 1970's through to 2003 were analysed and organised so that the 2004 profile data could be added to them. Newspaper articles and reports were gathered to find information on historical breaches and storm events. Knowledge of past changes of the barrier is essential to build an understanding of the processes at work on the barrier now, and the processes that have ultimately led to the present form and function of the barrier. Historical data provides a baseline to which present and future data can be added.

The second approach consisted of fieldwork data collection, observations and laboratory analysis. This contributed to the understanding of the present day form of the barrier. The fieldwork required profile surveying of 17 ECan sites along the barrier, all of which can be linked to historical profile data. Excavations along the profile sites were also carried out and sediment samples were collected at varying positions along each profile. Laboratory work was in the form of sediment analysis. The results were then utilised to infer the composition of the barrier and its behaviour in storm events.

The third approach was to combine all of the data to determine the barrier volume and composition and to provide detail as to how and why sites breach.

1.6 Thesis Format

This thesis consists of eight chapters. The purpose of this section is to outline the ideas introduced and discussed in the following chapters. Chapter One has introduced the reader to the background of the immediate study area and stated the hypotheses and objectives of the thesis.

Chapter Two is a review of the mixed sand and gravel beach literature. It describes the morphology of mixed sand and gravel beaches and barriers and provides a global and local context for which the thesis can be placed.

Chapter Three is essentially a description of the research environment, describing the main geomorphic and geologic features of the study area. This chapter provides the reader with a clear understanding of the different components that influence the barrier including physical and anthropogenic systems.

Chapter Four is the methodology section. It outlines data collection methods and analysis techniques. The objective of this chapter is to place this study into a broader academic context through reviewing theoretical concepts related to this research. An insight into the Resource Management Act (1991) is provided in terms of carrying out research within the binding legislation.

Chapter Five presents the results and discussion of the surface and substrate profiles, providing in depth spatial and temporal analysis of the barrier form. Volume calculations are also presented in this chapter.

Chapter Six is the second of the results chapters and is focused on the presentation and discussion of the sediment characteristics (mean grain size and sorting) of the Waihao-Wainono barrier.

The previous two chapters are linked together in Chapter Seven which discusses the main characteristics prevalent at the past breach sites. This chapter makes inferences as to possible future breach sites.

Chapter Eight provides the main conclusions drawn from this study. Hypotheses and objectives outlined in Chapter One are revisited and future research possibilities are discussed.

Chapter Two

Mixed Sand and Gravel Barrier Coasts

2.1 Introduction

The main aims of this chapter are to build on Chapter One by providing an overall understanding of the morphology of mixed sand and gravel beaches. A brief review of the general literature pertaining to this beach type will be provided. The chapter will then focus on barrier beaches, bringing together both local and global understandings of barrier evolution, their distinct features, and the methods used to study them.

2.2 Mixed Sand and Gravel Beaches

Coarse clastic beaches comprising of shingle, gravel, pebbles and boulders are located in the mid to high latitudes where glacial deposits have been reworked and formed into shorelines (Pontee et al. 2004). In New Zealand these beaches are more distinct, displaying neither pure gravel nor pure sand. They are termed mixed sand and gravel beaches and are somewhat more complex than either sand or gravel beaches (Zenkovich, 1967; Kirk, 1980). Zenkovich (1967) has suggested that they are more complicated due to the different ways in which the separate sediment components are displaced.

Kirk (1967) credits the development of studies of gravel dominated coastal systems to Palmer (1834) due to the need for coastal protection and engineering works on these types of beaches in the British Isles. World War II was another era in which studies of gravel beaches increased as soldiers often launched attacks from the sea and there was a need to be aware of the physical surroundings (Kirk, 1967). Since then, studies have focussed on management strategies and process studies. In New Zealand knowledge of gravel beaches has accumulated by way of necessity. This is because of increasing hazard awareness as the human population spreads to once secluded coastal areas.

2.2.1 General Characteristics of Mixed Sand and Gravel Beaches

McLean (1970:142) stated that in New Zealand, all the larger of these mixed sand and gravel beaches embody certain common features:

(1) they contain a wide range of sediment sizes (sand to boulders);

(2) they are derived from the same dominant rock type (greywacke);

(3) they are backed by Pleistocene and Holocene alluvial plains and fans often covered by major rivers; and

(4) they are exposed to the high energy waves of an East coast swell environment.

A typical mixed sand and gravel beach is 100-200m wide but in areas of chronic erosion may be a lot narrower. Beaches may reach 14m high but generally sit at elevations of 4-6m above mean sea level. In profile form, mixed sand and gravel beaches are steep, typically 5-12° and convex in shape (Kirk, 1980).

Kirk (1980) identified four major zones of mixed sand and gravel beaches; the backshore, foreshore, break point step and the nearshore. Figure 2.1 shows this typical morphology. The internal structure is unknown and discovering this 'unknown' is one of the aims of this research.

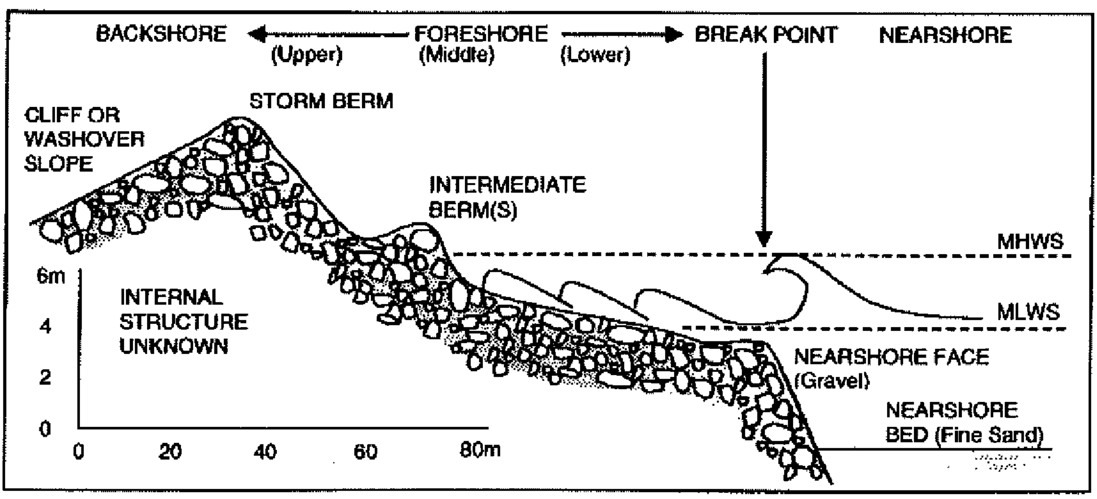


Figure 2.1: Typical morphology of a mixed sand and gravel beach profile. Updated From Kirk (1980:193).

The backshore is landward of the highest limit of the storm swash. The backshore may consist of washover lobes containing the largest sediment on the beach and a high proportion of disc and blade shaped pebbles (Single, 1992). When a cliff backs the beach, a storm berm is usually absent and the foreshore profile is reduced. Mixed sand and gravel beaches rarely have dunes, but if they do, they are usually only weakly developed. This is due to several factors: the occurrence of strong offshore winds, the lack of sand for aeolian transport, and that many mixed sand and gravel coastlines are eroding (Kirk, 1980:193).

Figure 2.1 shows that the foreshore extends from the upper most berm or cliff base to the break point. It is this zone that Kirk (1980) described as the 'engine room' because it is where most of the morphological changes on mixed sand and gravel beaches occur. Swash and backwash processes dominate this zone and it can contain several swash berms that represent the upper limit of low energy events. These berms may be modified or removed from this zone in times of high energy wave events (Single and Hemmingsen, 2001). A major feature of the lower foreshore is a distinct break-point step. This zone is very turbulent as waves breaking at all stages of the tidal cycle are confined to this narrow area. Due to this turbulence any fine material is thrown into suspension and transported offshore, thus the lower foreshore is often characterised by coarse sediment (Kirk, 1980; Dawe, 1997).

Immediately seaward of the break-point step is a narrow steep nearshore face consisting of coarse sediments at or near their angle of repose. At the base, the face gives way to a gently sloping shelf composed of sands too fine to remain in the foreshore. For most other beach types Kirk (1980:194) states that it is often difficult to determine the seaward limit of the nearshore, where deepwater processes give way to shallow water processes. On mixed sand and gravel beaches this boundary is clearly defined.

Neale (1987) showed the mixed sand and gravel shore as containing six zones (subsystems). As shown in Table 2.1, Neale (1987) added two zones to the four zone mixed sand and gravel model of Kirk (1980). He distinguished the swash berm and the storm berm as having distinct process characteristics, effectively adding two sub zones. According to Neale these sub zones are event dependent in their horizontal position on the beach. The sub zones are determined and linked by input from and/or changes in the environmental processes. Changes between sub zones are initiated by process changes. An example is shown in that higher waves will relocate the swash berm higher up the profile and erosional or accretional episodes will alter the geometry of both the nearshore and foreshore faces, which in turn may affect the whole beach profile. From this Neale (1987) believes that all subs zones are interlinked but can be distinguished by differing geometry, sediment composition and process regimes.

Table 2.1: Process-response subsystems of a mixed sand and gravel foreshore (after Neale 1987).

Subzone	Geometry	Materials	Energy Flux
Nearshore Face (breaker zone)	steep	coarse gravels, high settling velocity, low mobility	high, very turbulent, mostly shore-normal dissipation and reflection
Foreshore Face (swash zone)	moderately steep (5°-12°), concave, changeable	gravels and coarse sand, high mobility, well sorted	high, turbulent, increasingly shore-parallel, highly bi-directional
Swash Berm (upper swash)	convex, variable size, shape, and position	coarse gravels, high entrainment velocity, low settling velocity, low mobility	sharp drop in swash velocity, low potential, mostly shore-parallel, some vertical
Storm Face (storm swash)	less steep (5°-7°)	coarse gravels, moderately sorted	intermittently high, moderate obliqueness, some vertical
Storm Berm Washover Slope (upper storm swash or overwash)	near horizontal, reverse slope	coarse gravels, poorly sorted	intermittently moderate, mostly shore-normal and vertical

Short (1979) presented a morphodynamic model that described the recirculation of sediments between the nearshore and the foreshore zones. His model stated that beaches are in dynamic equilibrium between two different profiles, an accretionary sequence (reflective) and an erosional sequence (dissipative). Short's (1979) model predicts that during winter and in times of increasing wave energy, sediment is eroded from the foreshore and transported to the nearshore where it is deposited as sand bars. This flat profile then increases sediment deposition in the nearshore.

The recirculation of sediment between the foreshore and the nearshore, while found on a sandy beach, does not occur on mixed sand and gravel beaches. Jennings and Shulmeister (2002) have developed a morphodynamic model for gravel beach types based on results from the New Zealand setting and one that is intended for micro-meso tidal gravel beaches like those found on the South Island of New Zealand. Jennings and Shulmeister (2002) proposed a three condition model for gravel beaches: (1) pure gravel beach; (2) mixed sand and gravel beach; (3) composite beach. The model uses the morphodynamic concept to link the visual morphology with the hydrodynamic regime. This model was developed from their own research and through reviews of the current literature. Table 2.2 displays the major characteristics of each beach type and Figure 2.2a, b and c illustrate a pure gravel beach, mixed sand and gravel beach and a composite gravel beach respectively.

Table 2.2: Table identifying the major characteristics of pure gravel beaches, mixed sand and gravel beaches and Composite gravel beaches. Adapted from Jennings and Shulmeister (2002:223-224).

Characteristics	Pure gravel beach	Mixed sand and gravel beach	Composite gravel beach
Sediment	Gravel dominated	MSG dominated (Kirk, 1980).	Sand (lower foreshore) and gravel(upper foreshore) zones (Carter and Orford, 1993).
Sediment sorting	Well developed (Bluck, 1967).	Mixed	Gravel area strong sorting
Waves	Surging and collapsing. Irrabaren Number of 1.6-4. Surf zone processes absent.	Plunging and collapsing. Irrabaren Number of 0.7-1.95. Swash processes control. Little or no surf zone processes.	Spilling waves seaward and plunging when reach gavel berm. Irrabaren number of 0.5-1.8. Dissipative surf zone.
Beach widths	Narrow 18-50m	Narrow 30-80m	Narrow <20m to >60m.
Steepness of beach face	$Tan\beta$= 0.1-0.25	$Tan\beta$= 0.04-0.12	$Tan\beta$= 0.03-0.1 (sand) $Tan\beta$= 0.5-1.8 (gravel)
Other characteristics	Highly reflective at all stages of the tidal cycle. During storms the beach face is flattened (Sherman, 1991).	Well-formed break point step and sediment zonation. Sediment transported up the beach during storms to form a berm (Bird, 1976).	Longshore bar/trough system may develop. Cuspate morphology can develop. Reflective state dominates at high tide (Mason et al., 1997).

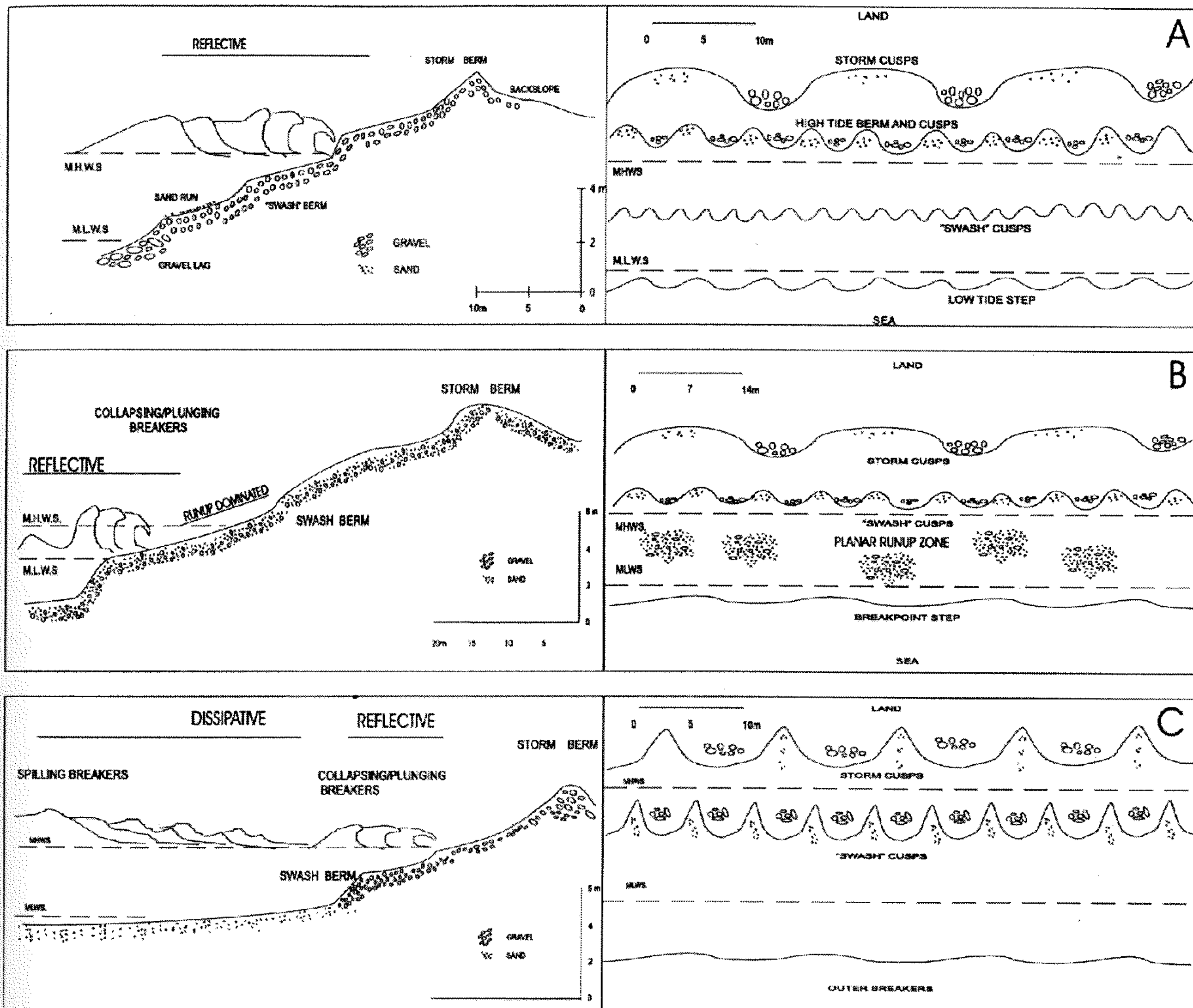


Figure 2.2: Schematic representation of the three gravel beach types, in cross section and plan view A) pure gravel beach B) Mixed sand and gravel beach C) Composite gravel beach. The scale for each beach is different (Jennings and Shulmeister, 2002:224).

2.2.2 Cross-Shore Sediment Zonation

Temporal and spatial differences in sediment size and type vary due to two main reasons (1) sediment source area (2) hydraulic factors such as wave run-up limit (McLean and Kirk, 1969).

New Zealand mixed sand and gravel beaches are derived predominately from greywacke, the basic rock type of the mountain ranges. This rock is eroded by glaciation, weathering processes and during transport by rivers. Because of this harsh abrasion, greywacke has a large range of sediment sizes that are not evenly distributed across the beach profile by wave processes.

The varying shapes and sizes of sediments available to a mixed sand and gravel beach tend to be distributed within different zones. Large sediments with lower sphericities move easily up the beach face in the swash of high-energy waves. The sediment is then unable to be entrained due to lower backwash velocities and the flat shape of the particles. The smaller and often more rounded sediments are more easily moved by the backwash so they are rolled back down to the lower foreshore area (Kirk, 1967).

Shape sorting is often visible across a profile and in 1967, Bluck recognised up to four different sediment zones for gravel beaches. Discs tend to occupy the upper beach and spheres dominate the lower. Imbrication often occurs in heterogeneous sediment in which the smaller particles are trapped between the larger ones. Figure 2.3 displays the zones of clast shape-size as given by Bluck (1999).

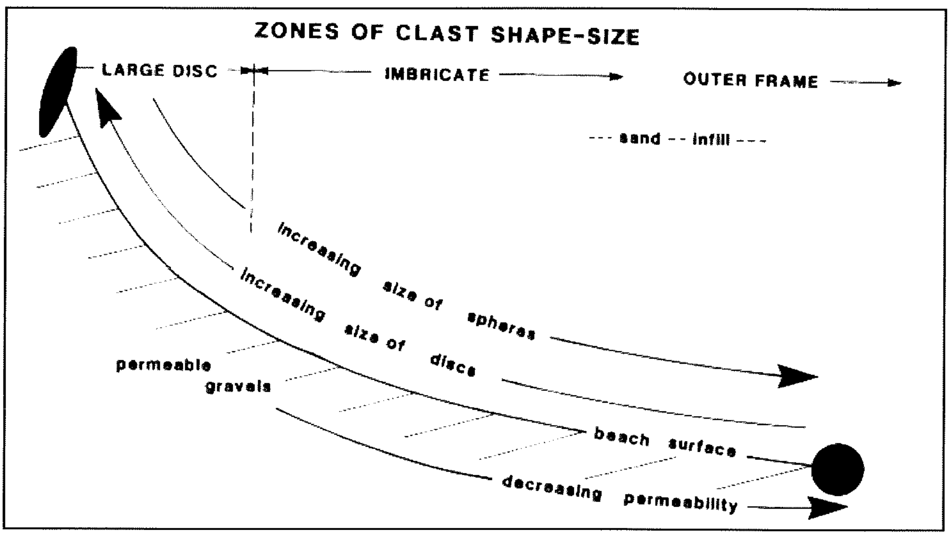


Figure 2.3: Diagram of gravel beach profile with clast shape sorting and zonation (Bluck, 1999:292).

Greywacke tends to erode into disc and blade shaped particles, which results in the upper beach face being very distinctive and the spherical dominated infill and outer frame zones not so easily identifiable. Shulmeister and Rouse (2003) considered that mixed sand and gravel beaches are gravel beaches that lack the imbricate and the outer frame zones in Bluck's (1967,1999) descriptions. This zonation has to be accounted for when collecting sediment samples especially so that temporal comparisons can be made with past and future collections.

A general pattern of across shore sediment zonation in New Zealand mixed sand and gravel beaches is apparent. Single (1992) introduced six sediment zones, as outlined below. In this classification he used the shape descriptions from Sneed and Folk (1958), which are given in Figure 2.4. Each of the zones do not have definite limits but are progressive, displaying a gradual change along the profile:

Backshore Large discs (mean size 70mm) dominate this zone with the disc Shape being very platy or bladed. The surface layer is two or three particles in depth and sand sized material is dispersed amongst the larger clasts.

Barrier Crest Very bladed and bladed dominate over platy shaped particles although there is a complete range of shapes present. Imbrication of the particles on the seaward facing slope is well defined. The mean particle size is 45mm.

Upper Foreshore The complete range of shapes is present but dominated by Bladed and platy shapes and is a result of a combination of events of different magnitudes. This also leads to a mixture of sediment sizes with the mean size being 30mm.

Interberm Nadir The dominant shapes are bladed and platy although there is an even spread of the rest of the shape range. This zone is also active in a range of process magnitudes and can be covered in a lag deposit of sand sized particles. The mean size is slightly less than 30mm.

Intermediate Berm There is a narrower selection of shape particles in this zone, similar in shape to the backshore but with a smaller mean size (40mm) and few particles are smaller than 20mm.

Lower Foreshore This zone is bimodal in size range with a mixture of sand to granule sized particles (mean size 3-5mm) and pebble to cobble sized particles (mean size 18mm). The dominant shape of the larger clasts is bladed but tends towards the platy end of the blade range of axis ratios.

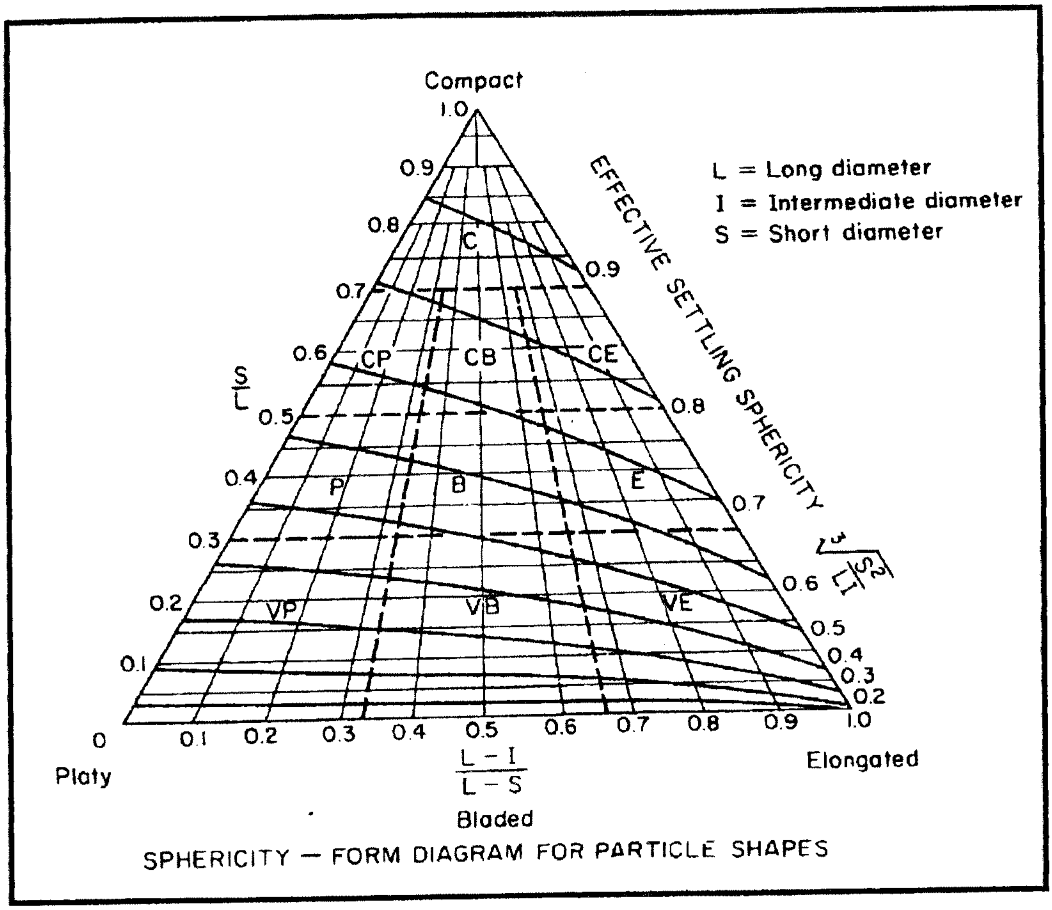


Figure 2.4: Classification of shapes of pebbles (Sneed and Folk 1958).

In section 2.2.1 it was stated that the swash zone is the engine room of mixed sand and gravel beaches as this is where the most change occurs and where the process-response system of the beach is at it's most dynamic. Swash and backwash therefore play a major role in the sediment zonation of the whole beach profile. As waves enter shallow water, wavelength shortens and height increases. Wave energy can be defined as (Komar, 1998):

$$E = 1/8\rho g H^2$$

Where, E=wave energy, ρ = the density of water, H= wave height.

From this equation it can be seen that available wave energy increases up a beach face as water depth becomes shallow at the break point. The wave orbit motion moves sediment landward as water depth shallows, and wave height increases towards the shore due to shoaling. The wave energy in the formula is the energy in the unbroken wave. Larger waves generally have a larger swash, hence have a greater ability to transport larger sediment. If swash occurred on its own, beaches would not be very well sorted, as all of the material would be moved to the same point. The reason why there is such strong foreshore sorting is due to the alternating swash and backwash process as shown in Figure 2.5. Swash energy is released instantaneously when the wave breaks compared to the backwash, which may occur over a number of seconds. The low peak but long period of the backwash means that it is unable to move the coarsest particles but can easily move fine material and because the movement period is longer fine material can be transported offshore with each wave (Shulmeister and Rouse, 2003). Bladed shaped sediments are difficult to entrain so are more likely to be shifted during the swash motion. Motion of spherical particles is more easily initiated. They move a longer distance in backwash, as they are more likely to roll down the beach assisted by gravity.

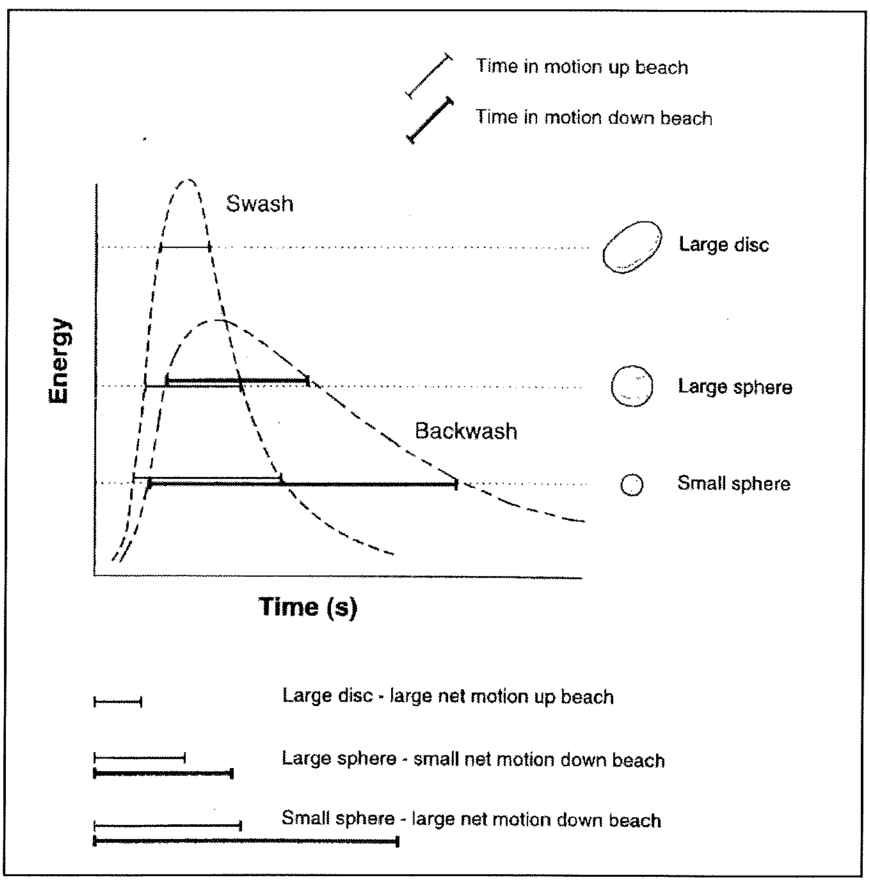


Figure 2.5: An idealised energy profile for swash and backwash. Note the high peak but short duration of lower peak for the backwash, Shulmeister and Rouse, 2003:151)

2.2.3 Longshore Sediment Transport

The movement of beach material alongshore has been a subject of interest in the field of coastal geomorphology since the early nineteenth century. Early studies on longshore transport were carried out by scientists such as Palmer, (1834) and Johnson (1919) and included observations and general descriptions of particle movement.

As knowledge grew and the tools for carrying out quantitative analysis evolved the study of longshore transport has become the most widely studied process that contributes to morphological variation in beaches (e.g. Zenkovich, 1967; Komar, 1976,1975; Komar and Inman, 1970). The large-scale beach changes that result from longshore transport especially draw the attention of those concerned with coastal management. Zenkovich reinforced this in 1967 by stating that:

> *"Study of the processes that alter the appearance of the coastline begins with the displacement of beach material along the shore" (p. 317).*

The majority of longshore transport studies have concentrated on either pure sand or pure gravel beach systems. Sediment transport processes on mixed sand and gravel beaches are poorly understood. Healy and Kirk (1992) believe that the transport of fine and coarse sediments occurs as two separate units, with the distinct break point step in the profile thought to act as a barrier to cross-shore sediment exchange. Once fine sediment is transported off the beach from the swash zone it will not be returned to the system.

On mixed sand and gravel beaches longshore transport occurs by wave drift in the swash zone. These beaches have a single line of surf so longshore transport is primarily related to the wave approach angle and wave power (Kirk, 1980). This process is visible at the coast. A wave approaching the beach at an angle transforms into a plunging breaker as it crosses the break point step. To the eye this is seen as a peeling back of the wave in the direction of the longshore transport (Single, 1992). Neale (1987) examined the processes and patterns of longshore sediment transport of the mixed sand and gravel beaches south of Timaru. Neale thought that 'sediment slugs', as referred to in Chapter One, developed from an event that produced a large amount of sediment for the coast to rework. The idea of sediment slugs is that longshore transport processes move pulses of sediment along the beach in a consistent manner hence ending up with some sections of the beach containing a greater sediment volume than others. The sediment slugs concept in relation to volume will be discussed more thoroughly in section 2.4.

Longshore sediment transport is common on mixed sand and gravel beaches, especially on those to which rivers contribute the bulk of the sediment supply. The sediments on mixed sand and gravel beaches include a wide range of particles and it is expected that they would be dispersed in some type of regularity. Pettijohn and Ridge (1932) described this as a variation series. The most common linear series is when a bulk supply of gravel occurs at one section of the beach due to a river source or an eroding cliff series. When there is a source point such as this, the grain size gradually diminishes away from the source, as a result of attrition or transport processes. Marshall (1929) described a variation series along a mixed sand and gravel beach north of the Mohaka River, Hawke's Bay. He found that sorting improved away from the river and also that the sediment size became smaller.

Kirk (1967) while studying mixed sand and gravel beaches of the Canterbury Bight, South Island, found no obvious longshore size versus distance relationships. Single (1992) also noted that sediment variation is greater across the beach profile than along the shore during his study of the Waihao-Wainono barrier beach. Hicks and Todd (2003) did find a variation in sediment size, with a northward fining of particle size.

2.2.4 Sediment Abrasion

Marshall (1928) was the first to focus his studies on the processes involved in the breakdown of gravels on New Zealand beaches. He identified three processes of gravel breakdown: abrasion, impact and grinding. From the tumbler experiment's carried out by Marshall, grinding was found to have the greatest erosional force. Grinding occurs when small grains are crushed by contact and pressure of larger sized sediment. The major finding was that 24 hours of tumbler action would cause a weight reduction of about 66% in greywacke sediments.

Adams (1978) proposed that there are even higher abrasion rates on a natural beach environment. He believed that in nature, abrasion would be three to four times greater than that produced by an abrasion mill.

Later, Gibb and Adams (1982) carried out a study focusing on determining a sediment budget between Oamaru and Banks Peninsula on the South Island's east coast. They stated that abrasion rates for greywacke could reach 93%. Gibb and Adams (1982) used the abrasion value given by Adams (1978). However, Hemmingsen (2001) considered that the single sample used by Adams (1978) was too small for an abrasion rate assumption to be made.

Matthews (1983) researched a swash-dominated section of Palliser Bay, Wairarapa and estimated an attrition rate of 40% per year or a gravel life expectancy in the swash zone of around 2.5 years. This research did not take into account the upper beach face which has short periods with swash processes acting on it so therefore would have a lower rate (Shulmeister and Rouse, 2003).

More recent work by Hemmingsen (2001, 2004, *in review, in press*) along the Canterbury Bight has considerably advanced the understanding of abrasion on mixed sand gravel beaches. Hemmingsen (2001) produced a major finding in that the sediments from Washdyke near Timaru abraded more than those from Ashburton further north along the Bight. Results from this study also show that no single value can represent the abrasional behaviour of greywacke on mixed sand and gravel beaches. She proposed several reasons as to why differences in abrasion rates between sites occur, the source and hydraulic selection of sediments and the possible effects of wave energy and the wave environment.

Hemmingsen (2004, *in review*) found that abrasion processes are not just dependent on grain size but significant differences in abrasion rates were found to occur due to differences in the sediment textural mixture of beaches. It was also found that it is no longer just sufficient to look at physical processes associated with abrasion, but that there is a distinct chemical weathering component as well (Eikaas and Hemmingsen, *in press*). Weathering rinds developed when the stones were stationary, and abrasion was still caused by movement. The reason why the backshore sediments abrade quicker than expected for their size, is that the stones are stationary for longer in this area of the beach, hence have more developed rinds. Eikaas and Hemmingsen (*in press*) found there are temporary effects of oxidation of greywacke sediments where there is a reciprocal relationship between Fe_3 and Fe_2 due to the salinity of water in which the sediment particles are being transported.

2.3 Mixed Sand and Gravel Barriers

2.3.1 Barrier Beaches

Hesp and Short (1999:307) define a barrier as a shore parallel, sub-aerial and sub-aqueous accumulation of detrital sediment (sand/boulders) formed by waves, tides and aeolian processes. Essentially a barrier is a coastal landform which acts as a 'barrier' between the sea and older coastal landforms or mainland bedrock. Forbes et al. (1995) believe that barriers can also be distinguished from beaches in that they have washover slopes. The Waihao-Wainono coast fits both the stated criteria.

The first writings on the origin of barriers dates to De Beaumont (1845) who believed barrier emergence occurred through the upward movement of sand bars. Gilbert (1885) proposed that barriers evolved from longshore drift. Apart from this early work, little progress was made in understanding barriers until the 1960's and most of this work was with reference to sandy barriers (Hesp and Short, 1999).

The literature pertaining to gravel barrier beaches is somewhat limited. The majority of research has focussed on the Paraglacial gravel barriers of eastern Canada, Ireland and England. Most barriers at these locations tend to have a limited supply of sediment and it can be said that they make up sediment-starved coasts (Hesp and Short, 1999). The mixed sand and gravel barriers on the east coast of the South Island, New Zealand are termed quasi-paraglacial coasts dominated by fluvial deposits and incorporating glacial outwash (Armon, 1974; Gibb and Adams, 1982). The barriers along the east coast, South Island have formed under different conditions, as the sediment supply from the rivers and fans is abundant, although many of the barriers are in an erosional state (Soons et al., 1997).

2.3.2 Barrier Type and Evolution

Barriers range considerably in all aspects such as size, type, composition, position compared to the mainland, and stability. There are five main controls proposed by Carter et al., (1989) that contribute to the form and behavioural characteristics of a barrier:

1) Sea-level control
2) Basement control
3) Sediment supply control
4) Tidal and wave regimes
5) Textural control imposed by barrier materials

A sixth control can be added from research carried out by Orford et al., (2002):

6) Sediment volume and rate of output

Researchers believe different factors to have varying degrees of importance, but it is generally agreed that sea level control and sediment supply control are the two of greatest importance to barrier formation and stability (e.g.Orford et al., 1995, 1996, 2002; Carter et al., 1989). Different regimes have at least one dominant control and as the barrier changes so too does the dominant control.

Sea level as previously stated is often regarded as being the driving force of barrier formation and change. In areas where sea level is rising, transgressing barriers and eroding cliffs dominate. Carter et al., (1989) researched barrier evolution under differing sea level regimes using Ireland and Nova Scotia as the main study sites. Both the Irish and Canadian sites were mesotidal paraglacial coastlines and were exposed to high energy dominant wave conditions. The difference between the two sites was in the rate of sea level rise. The Irish coast was experiencing a 1.5mm/yr compared to the Canadian coast, which had double the rate of 2-3mm/yr sea level rise. They concluded that in areas of slow relative sea level change, the sediment supply gradually declines and the barrier then turns to other sources to remain stable. In areas where a lagoon was enclosed by a barrier, the hydraulic pressure asserted by the lagoon is a major control as water seeps through the barriers and causes channelling, which is then controlled by the Basement structure. The waves can then change the morphology of the barrier and how it functions. In contrast to this, during rapid sea level rise, the sediment supply is extremely dynamic in that it may switch from an abundant sediment supply to a scarce supply because as the sea level rises, waves have new areas to erode.

Sediment supply is directly related to sea level rise, especially in the Irish and Canadian examples. When there is an excess supply of sediment often an aggradation of ridges forms, appearing as a staircase type feature towards the sea. Where sediment supply is less abundant, the barriers respond by morphological change to stabilise against wave action and sea level rise. Some barriers respond by a change in barrier geometry such as changes in slope, width and height and in others cannibalisation occurs, which involves the reworking of areas of the barrier that have greater sediment volumes to supplement a weaker area in another section of the barrier. These processes may cause barrier stretching and ultimately points in the barrier, which will eventually breach. The most common force of barrier destruction is through the remobilisation of sediments, especially in locations where the barrier may have already breached (Carter et al., 1989; Hesp and Short, 1999)

The many different controlling factors of barrier evolution determine the ultimate form of a barrier. A morphodynamic model has been developed by Canadian and British researchers. Forbes et al., (1990) developed a scheme for the classification of barriers which was later refined by Orford et al., (1991). Barriers are separated into two types: drift aligned and swash aligned. These two barrier types are based upon the shoreline configuration of the barrier in reaction to longshore sediment surplus or scarcity (Orford et al., 1995). Where downdrift sediment supply is sufficient for longshore transport, accretional morphologies will result terming the barrier to be drift aligned. Swash aligned barriers occur where downdrift sediment supply is insufficient for the available longshore power such that sediment already deposited on the barrier is remobilised by the excess energy. The sediment already in the barrier is then liable to erosion (Orford et al., 1996). Figure 2.6 is used to explain the evolutionary typology of gravel barriers on a paraglacial coast undergoing transgression.

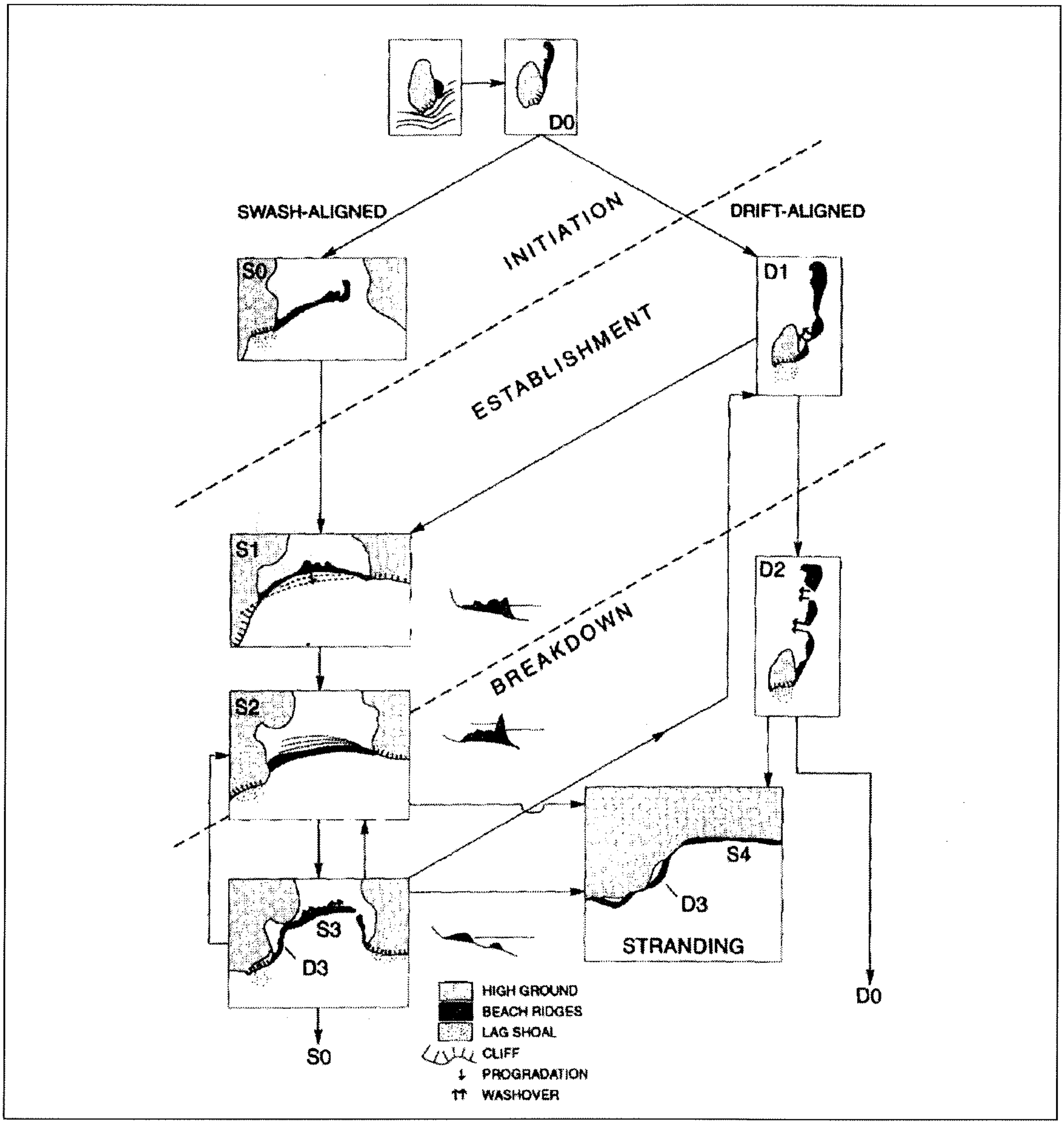


Figure 2.6: Evolutionary typology for gravel barriers on a paraglacial coast undergoing transgression (Forbes et al., 1995:68).

In the conceptual model, barrier structures go through a three stage evolution: (1) Initiation of a spit downdrift of the point source in either a swash or drift alignment (2) development of a mature shore-parallel spit or shore normal barrier (3) breakdown of the barrier through storm overtopping or sediment starvation (Forbes et al., 1995).

Orford et al., (1996) developed a different model in that they believe there are four major distinctive domains: growth, consolidation, breakdown and reformation (Figure 2.7). The domains reflect the importance of the controls stated above and is a variation of that described by Forbes et al., (1995).

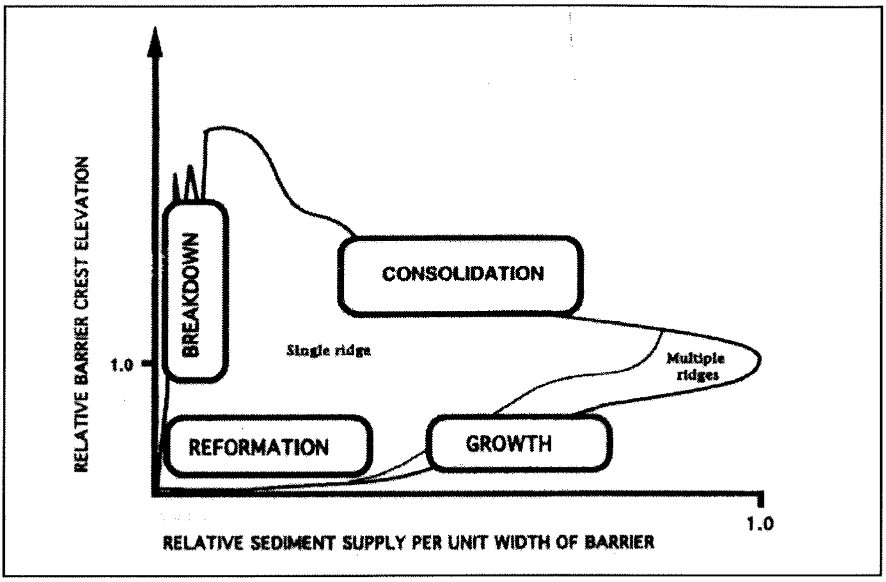


Figure 2.7: The four main barrier domains as defined in terms of response between relative sediment supply and relative barrier crest height. (Orford et al., 1996:601).

The *growth* domain is dependent on increasing sediment supply and ridges are formed with low crests. The sediment supply reaches a peak and then moves into the consolidation domain as the sediment supply rate is reduced but consistent, and a barrier moves into a drift aligned or swash aligned phase. The crest of the barrier increases even though there has been a reduction in the sediment supply due to the increasing shoreline realignment. The *breakdown* domain contains three phases; slow rollover, fast rollover and dissolution. Slow rollover is a sign of barrier transgression and is an indication of washover processes occurring. During *consolidation*, rollover is viewed as stable as the barrier is simply gaining its spatial position. In this state the barrier can respond to the effects of sea level rise and may also increase in height. Slow rollover generally occurs on barrier's where the sediment sizes are ordered in a regular distribution across shore. Fast rollover is a phase in which the barrier is less stable. The diminishing sediment supply along with the reduction in sediment volume will cause spatial instability. Because the barrier transgresses at a fast rate the textural variation is quite random and does not tend to display across shore zonation of most mixed sand and gravel beaches. These two phases highlight the importance of textural variation within a barrier. The final phase of the breakdown domain is dissolution where the unstable barrier can lead to weakened zones within the barrier ultimately causing breaching. During this phase, the basement geometry determines the potential for barrier reformation, the final domain. The sediment eroded from a weakened area of the barrier is then transported and used to construct a new barrier form. This domain process has occurred in the high latitude regions but it is not known whether this is the case for mid-latitude regions such as New Zealand. According to this classification, the Waihao-Wainono barrier is between the breakdown and consolidation domains. Orford et al., (1996) realise there is no set control on the evolution of barriers but the domains they have presented simply imply that there is a set of controls through which environmental interactions create and destruct barriers.

2.3.3 Barrier Breaching

Barrier breaching has been discussed in the literature in relation to barrier evolution and as a phase within it. Breaching occurs as a result of barrier instability, which is defined by the antecedent conditions of the barrier and the processes operating on it. Barriers often enclose lagoons and other important ecological environments. The human population has also spread to previously uninhabited coastal areas and now barriers not only enclose lagoons but also act as protection against the sea for farmland and urban areas. Barrier breaching in many areas has become a hazard to many with financial and ecological assets near the coast.

Barrier breaching has been studied with relation to sea level rise, sediment supply, tidal and wave conditions but only recently have studies been carried out that offer a view on the internal structure and sedimentary stratigraphy of barriers (Bluck, 1999; Orford, 1984). Antecedent morphology of the barrier and the ability for a barrier to self organise is critical. How well a barrier can do this is often dependent on the basement structure, which in essence provides the room for sediment accumulation. The volume of sediment, its characteristics and the morphological structure is critical in defence against storm waves and breaching.

The antecedent morphology, also termed the basement structure, defines a number of attributes of gravel barriers. The form of the basement structure provides a base for the barrier to build upon. In terms of basement geometry, barriers are classified as either 'fringing' or 'free-standing'. Fringing barriers occur when a barrier is formed against a cliff face and free-standing barriers are exactly that and are able to migrate landward (Carter and Orford, 1993). As sea level rises, a fringing barrier is susceptible to being drowned and barrier reformation is dependent upon cliff supply. The basement defines the width of the initial barrier development and also the gradient to which the barrier will develop. The base of a barrier is also the point that is most resistant to wave energy and provides hinge points for sediment to accumulate (Orford et al., 2002).

Sediments then start to distribute across the basement, eventually forming the highest point of the barrier termed the crest. The morphological form of the barrier is defined by the supply of sediment and the forcing involved to move it. The beach crest will be highest if it is formed by high energy storm waves compared to a flatter beach crest formed by lower energy swell waves. The height of the crest is defined by sediment characteristics such as size, shape and sorting. The larger the sediment size, the higher the beach face gradient and the resulting permeability as there is more space between each sediment particle for water to move through. Because of the swash and backwash processes on a mixed sand and gravel beach, most of the sediment is removed from the lower part of the swash zone than from the upper part as discussed in section 2.2 (Masselink and Li, 2001; Caldwell and Williams, 1985). Ultimately a steepened beach gradient then leads to the barrier becoming weakened and vulnerable to breaching during storms (Todd, 1991).

2.3.4 Internal Barrier Structure

Internal stratigraphic studies of mixed sand and gravel beaches are limited firstly because sand beach studies have been the dominant focus and secondly, studying the internal structure is a difficult process to carry out, as it often involves large scale excavation, trenching and coring. Bluck (1967) and Carr (1969) were among the first to research size grading along gravel beaches. Carr collected surface sediment samples along a number of profiles on Chesil beach, England. Samples were also collected from boreholes from the beach ridge, the backslope and a raised beach. The surface samples showed the coarsest gravels to be situated on the crest and the overwash fans, with the smaller pebbles to be found on the lower foreshore. The borehole samples highlighted a general decrease in size and an increase in pebble angularity with distance below the surface. The major benefit of investigating the internal structure of mixed sand and gravel beaches is that it provides insight into their long term dynamics to complement studies of short term barrier process and form (Neal et al., 2002).

Bluck (1999) in a study of gravel beach sequences in Wales and Namibia used both natural and man-made sections to provide an example of the internal structure of barrier beaches. From his study he identified three lithosomic sheets all composed of different clast assemblages- the degree to which clasts show uniformity in size and shape. The first type of gravel lithosome identified is that of regressive barrier bars that form as a result to uneven sediment distribution, forming a bar seaward of the beach. This occurs when sediment supply is high compared to the wave energy or when the sea level is falling. The second type of gravel lithosome sheet contained continuous sheets of gravel due to a continuous supply of sediment to the beach, therefore allowing it to build seaward. The final type of lithosomic sheet identified is of transgressive nature. Bluck (1999) found a truncated stack of lower foreshore deposits produced in response to the transgression of barriers.

Since the first attempts to understand the internal structure of barrier beaches were undertaken, the tools for carrying out this research have advanced and in the last ten years Ground Penetrating Radar (GPR) has helped scientists to form a picture of what lies beneath the surface of barriers. GPR is a non-invasive method of gathering information on the stratigraphic structure of internal deposits and is most efficient when used on low conductive sands and gravels (Leatherman, 1988; Jol et al., 1996; Neal et al., 2002). GPR is the transmission, reflection and reception of electromagnetic waves. Reflections in the stratigraphy occur due to the differing properties of sediments.

Van Heteren et al., (1998) focussed on the interpretations of reflections produced by a GPR system taken from a decade of research along a New England paraglacial coast. This work involved one primary aim; to define and characterise GPR facies and to present the interpretations of them. Van Heteren et al., (1998) were successful and identified interpretations for eight different GPR facies. Figure 2.8 contains the results found. Mixed sand and gravel beaches can best be identified through oblique facies, which were found to be linked to Pleistocene outwash deltas that provide sediment for gravel barriers. Basin-fill facies are those which are likely to occur on barriers backed by a lagoon environment. Van Heteren et al., (1998) believe that GPR as a tool used by itself is not sufficient in determining the internal structure of barriers and that the use of GPR with core sampling and excavation techniques is the most efficient technique.

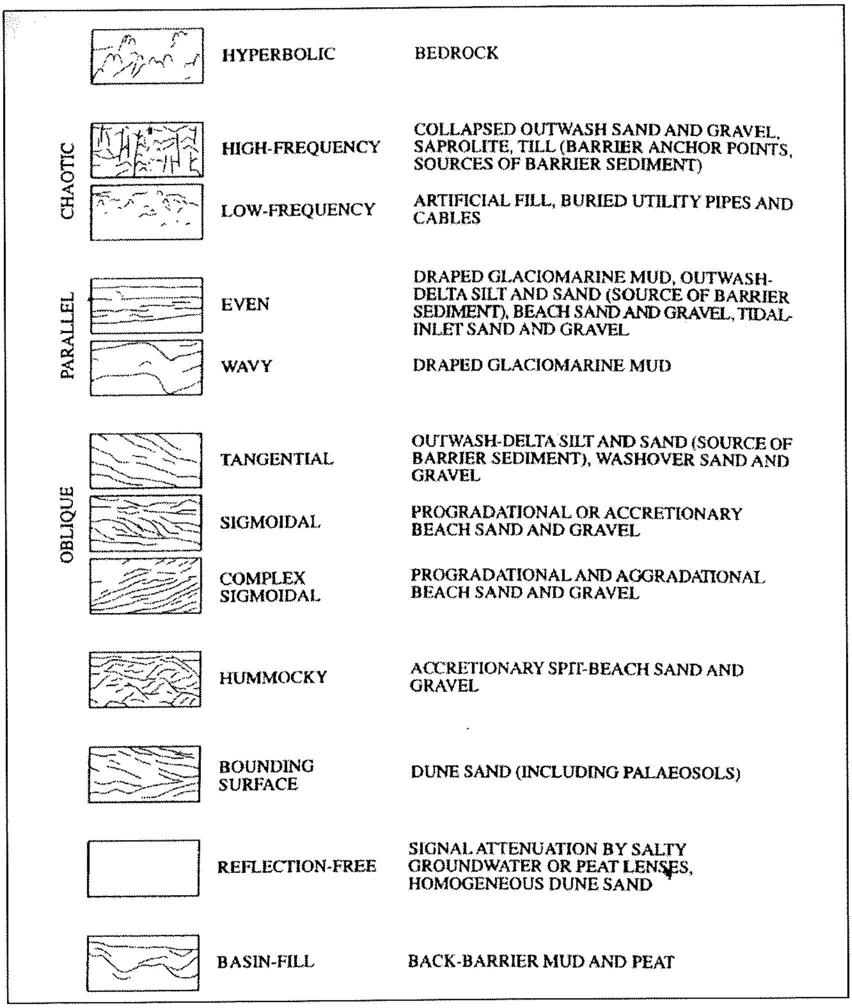


Figure 2.8:GPR facies and their interpretation in a paraglacial coast setting. (Van Heteren et al., 1998:186).

Neal et al., (2002) presented the results of GPR investigations into the internal sedimentary structure of mixed sand and gravel beaches at Suffolk, southeast England. The GPR method was used because beach excavations were unsuccessful as there was little cohesiveness of the gravel and it was impossible to gain relevant data. High frequency GPR surveys were performed along transect lines that were used as part of a two tier monitoring programme in hope of determining a detailed progradational history of the barrier. Neal et al., (2002) found that berm ridges on the backshore display a simple internal structure consisting of one or two seaward dipping beds. This combined with the monitoring data showed that the characteristic formation developed due to specific storm events leading to the landward migration of berm ridges from lower sections on the beach face. Results determine that the beach ridges consist of horizontally and vertically stacked backshore and foreshore deposits that formed during periods of high overtop and overwash of the beach crest. Although the GPR proved successful on some areas of the beach, it proved to be unsuccessful on the present shoreface so shallow excavations were used instead.

During another study carried out on the English coast, Neal et al., (2003) found similar stratigraphies when investigating Cheniers, a special type of beach ridge that are anchored in the upper foreshore and surrounded to landward, seaward and beneath by tidal mudflats. This study was focused on distinguishing the various beach ridge deposits and to identify the processes responsible in their formation. Neal et al., (2003) found similar results to that of the study described above, in that deposits formed through storm induced processes are characterised by gently dipping landward, sub parallel stratification.

The knowledge of GPR as a method for determining the internal stratigraphy of mixed sand and gravel barriers has changed the way research is carried out. It does however seem that this method is most useful for understanding the different geological components of barriers. Through reviewing the gravel barrier literature in relation to breaching and the internal structure it is evident that changes in sediment characteristics such as shape, size and sorting have had little attention. Calculations of the actual barrier volume (the amount of sediment that accommodates the space provided by the basement structure) have been largely ignored in terms of the possible relationship it may have with breach sites.

2.4 Barrier Studies in New Zealand

Coastal barriers are wide spread around New Zealand's extensive coastline (Figure 2.9) and range from barrier islands to strand-plains. Barriers also occur in a range of sediment types consisting of sand in some areas and cobbles in others. Therefore as well as gaining knowledge on mixed sand and gravel barriers, there is also a growing understanding of New Zealand's sandy barriers, although for both types this knowledge is limited.

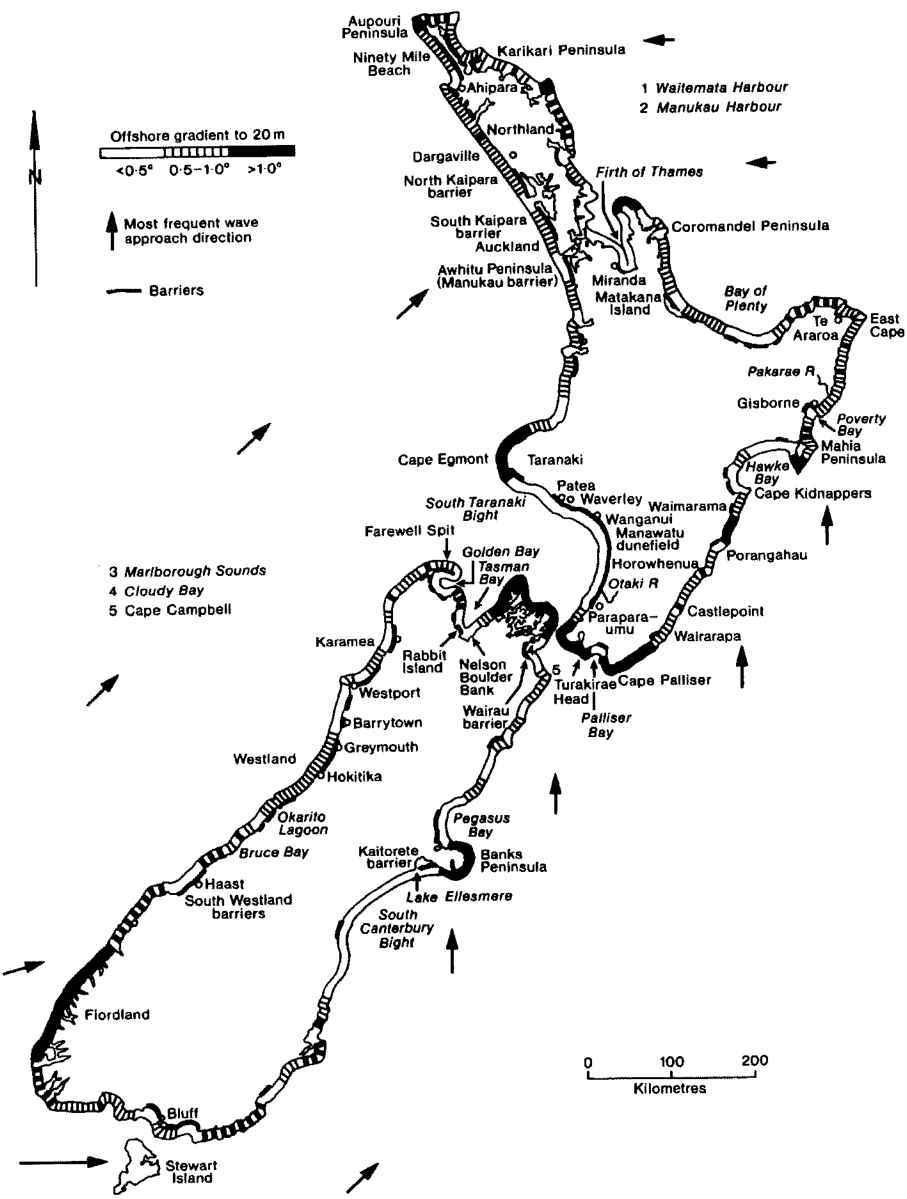


Figure 2.9: Location of barriers in New Zealand (thicker black line around the coastal margin). The arrows display the most frequent deepwater wave approach. (Source: Shepherd and Hesp, 2003:165)

Some barriers are located adjacent to rivers where sediment output is high, such as the barriers along the South Canterbury Coast. The contemporary relationship between sediment input and barrier formation seems to be poor. For many New Zealand barriers, greater significance to barrier formation can be placed on offshore gradients and antecedent morphology rather than on the river sediment inputs. (Shepherd and Hesp, 2003).

Shepherd and Hesp (2003) provide a classification scheme for New Zealand barriers. They state that barriers may be barrier islands (with no attachment to the mainland) or be completely attached to the mainland. In Australia, barriers are termed to be either regressive or transgressive (formed during falling or rising sea levels) or still stand (stable sea-level) (Roy et al., 1994). Shepherd and Hesp (2003) believe New Zealand barriers cannot be classified in such a way due to the varying nature of the environment. For example, New Zealand is a very tectonically active country and relative sea level curves are different at different locations around the coast. In terms of New Zealand sand barriers Shepherd and Hesp have classified them through their morphological parameters (Figure 2.10). It must be noted that these authors did not formulate mixed sand and gravel barrier classifications, although they have incorporated a classification, which accounts for various ridges consisting of gravel or shell material, within a predominantly sandy barrier. The Waihao-Wainono barrier is mixed sand and gravel barrier so does not fit into Shepherd and Hesp's (2003) classification. The use of the sandy barrier classification in this thesis is to highlight the wide range of New Zealand barriers and to show that they occur throughout all sediment types and sizes.

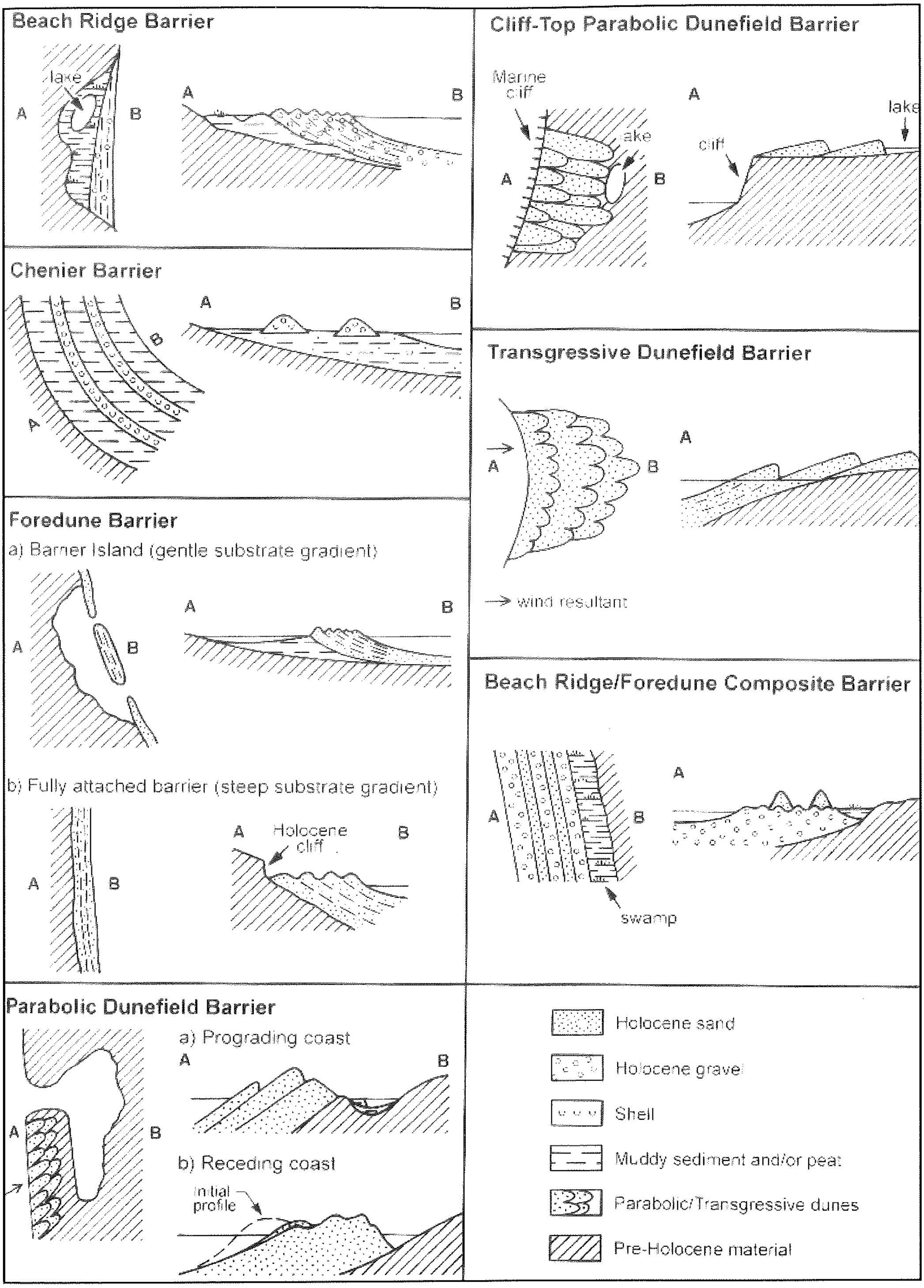


Figure 2.10: Characteristics of New Zealand Barrier Types (Shepherd and Hesp (2003:175).

As mentioned earlier, barriers form in varying environments. The New Zealand coast is scattered with estuarine and lagoonal features, of which several authors have studied. Like barrier classification, a number of classifications on estuaries and lagoons have been provided (e.g. Hume, and Herdendorf, 1998; Pethick, 1984; Owen, 1992; Kjerve, 1994). Kirk and Lauder (1994) concluded that the coastal waterbodies of the east and south coasts of the South Island cannot be characterised as estuaries. Instead, Kirk and Lauder (1994) have described two types of lagoon as being either 'river mouth lagoons' or 'coastal lakes', named hapua and waituna respectively. Table 2.3 is provided below outlining the major characteristics of both hapua and waituna.

Table 2.3: Characteristics of both Hapua and Waituna (After Kirk and Lauder, 1994).

Hapua	Waituna
• Coarse grained MSG • Braided rivers flow into them • Predominantly freshwater • Run parallel along the coast • Impounded by long, narrow spit • Prone to breaching • Distinctive sequence of creation and destruction	• Coarse grained MSG • High energy coasts • Predominantly freshwater • Coasts in long term or chronic erosion • Hinge points or loci of coastal change • Prone to breaching • Occupy low-lying interfan depressions • Positive hydrological balances • Shallow <3deep

Both Hapua and Waituna can be likened to choked lagoons as described by Kjerfve (1994). Kjerfve identified three types of coastal lagoon, choked, restricted and leaky lagoons (Figure 2.11). Choked lagoons are located in high-energy environments where waves are the dominant force and where longshore drift is prevalent, such as at Wainono Lagoon.

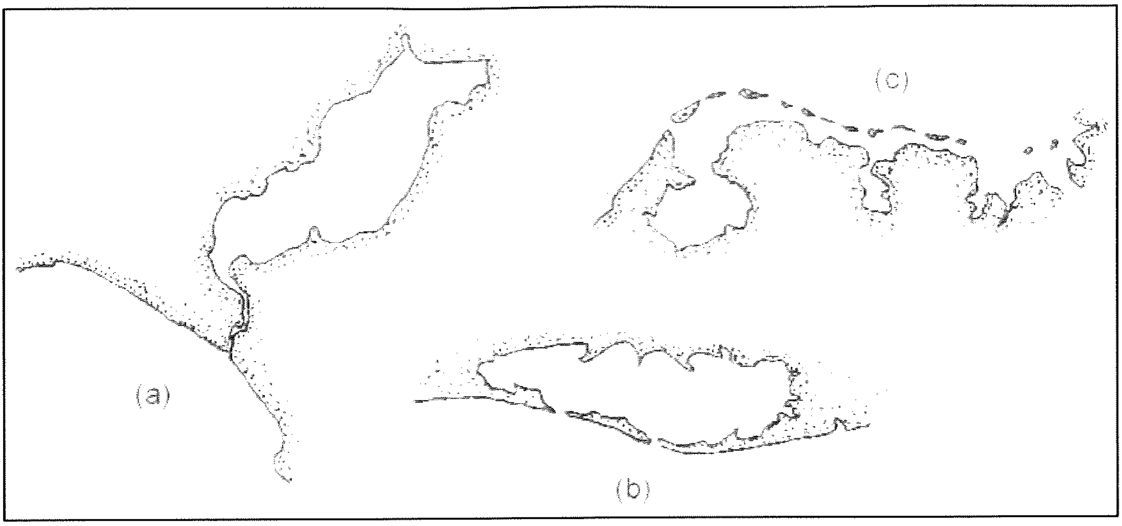


Figure 2.11: Choked (a), restricted (b), and leaky (c) lagoons as defined by Kjerfve (1994)

Waituna have small fluvial inflows, contain finer sediments and have fewer and infrequent openings to the sea. Hapua are river mouth lagoons dominated by large fluvial flows (Kirk and Lauder, 1994). One major difference between hapua and waituna is that many waituna type lagoons over the years have become smaller due to the effects of long term erosion. A good example of this is Waimataitai lagoon near Timaru which was destroyed in the early 1930's. Of importance to this study is that Kirk and Lauder (1994) recognised that both hapua and waituna are prone to breaching. Hapua and waituna differ from lagoons elsewhere in the world such as those described by Carter et al., (1984) and Jennings et al., (1997).

The most recent study of hapua and waituna was carried out by Hart (1999). Hart directed her investigation at the balance between marine and fluvial processes operating on hapua. At both the Ashburton and the Hurunui hapua, it was found that during times of low river flow, waves are the most dominant factor in influencing hapua change. Several new types of hapua behaviour were identified. One of the findings was that flood induced secondary breaches tend to occur some distance from the actual river mouth. Hart examined patterns of permeability within hapua barriers and in doing so stated that it can also be applied to barriers fronting waituna such as Wainono lagoon. It was found that the permeability of the sediments decreased with depth, although this trend was interrupted by intermediate layers of sediments with high and low permeabilities. The different permeability layers within the barrier increases the susceptibility of a barrier to breach due to fluidisation failures. Permeability is explained further in Chapter Seven.

Kaitorete Barrier and Te Waihora south of Banks peninsula have been the focus of several "barrier" studies. From the earliest researchers, Speight (1930) hypothesised that the lake processes of Te Waihora built a series of ridges and that overtopping formed the stratification of sediments.

Armon (1974) carried out a study on the geomorphology of Kaitorete barrier and the surrounding relict ridges. He studied the sediments at the various ridges and of the Kaitorete barrier and found there to be a difference. Armon (1974) found that the sediments of the ridges showed flatter characteristics than those of the Kaitorete barrier, which were more rounded in shape. The sediment of the ridges showed sorting by wave action was limited suggesting that very little sorting had been attributed to wave action. In contrast the rounded sediments of Kaitorete barrier suggested considerable sorting along the coast. He posited that those sediments on the ridges were lake formed rather than marine derived like those on the barrier.

Kirk (1969), through studying the coastal processes in the Canterbury Bight found that sediment arriving from the south was only of a small amount meaning that barrier modification is inevitable. Hemmingsen (1997) found the Kaitorete barrier sediment supply to be in equilibrium, but noted that if in the future there is insufficient sediment availability, then the barrier will scavenge sediment from itself and move inland. Under these conditions Te Waihora, which is now classed as a waituna, may become an open estuary as erosion of the barrier may naturally open it to the sea.
The most recent study of the Kaitorete barrier was by Hemmingsen (1997). Her main findings were that evidence of overtopping has occurred during storms, and in times of high water level in the earliest stages of the barrier's development.

Pickrill (1976) undertook a geomorphological study of the Wairau valley in order to quantify the hypotheses proposed by Cotton (1913) that this coastline had eroded either as a delta or by the infilling of a lagoon. The spit known locally as the 'Boulder Bank' consists of coarse cobbles. However, the cliffs nearby produce finer grained sediment and the Awatere River has no material coarser than fine sand within it for a distance of 10km from the mouth.

Pickrill found the presence of marine blue clays indicating a lagoonal or offshore environment. These lagoonal beds thinned further landward. Combined with the coarsening of the sediments inland, Pickrill (1976) concluded that the characteristics found were due to the shallowing of 'Wairau bay' in its transition to a waituna type lagoon as the barrier formed across the bay. This transition is similar to that of Te Waihora.

2.4.1 Barrier Volume

Neale (1987) developed a concept of longshore sediment transport named sediment slugs, as mentioned earlier. Through the use of this term he identified the movement of slugs of material along the beach as being linked to the supply of sediment into the system from major events such as cliff erosion and river flooding. He identified the pulses of sediment passing through the system as shown in Figure 2.12 and estimated the average rate of slug movement along the Waihao-Wainono coast to be 1.15km/yr. A slug was identified through variations about the mean foreshore volume. An increase in average volume above the mean indicated the presence of a sediment slug at a particular site.

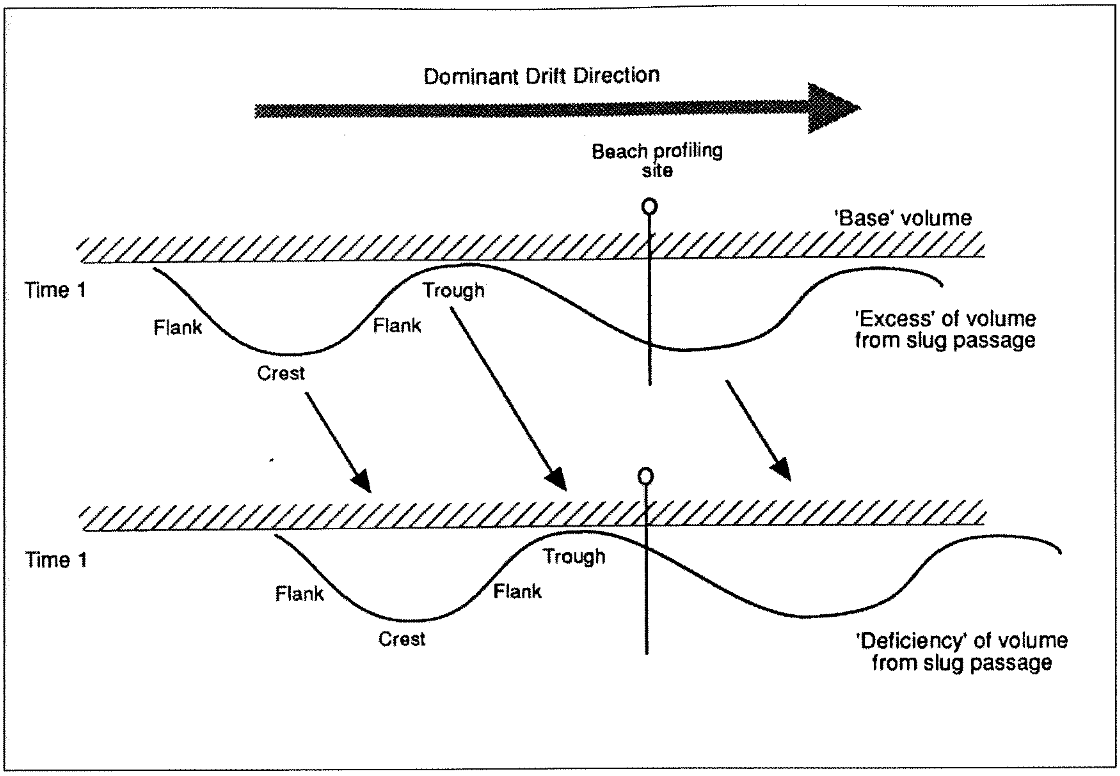


Figure 2.12: The translation of a slug of sediment alongshore (after Neale 1987).

Single (1992) tested Neale's concept of sediment slugs and through his analysis of beach foreshore volumes it is visible that variations in sediment volume exist along the Waihao-Wainono coast. Single found the average difference in sediment volume between the slug crest and the slug trough as being 50.5m^3, very close to the 45m^3 that Neale calculated. Single (1992) believes that sediment slugs play an important role in determining the antecedent morphology available to dissipate wave energy. A slug crest is evidence of a healthy beach as the increased volume provides protection against wave attack. The beach crest is higher and the foreshore is able to absorb and dissipate most of the energy before reaching the crest of the barrier and overtopping by waves is minimised. In contrast the profile containing the sediment trough is more susceptible to overtopping by wave run up as this part of the barrier contains a smaller volume of sediment. This is the area most prone to barrier breaching.

Hicks and Todd (2003) constructed a sediment budget model for the different cells of the Waitaki coast, north of the Waitaki River. They concluded that the barrier volume has remained constant over several thousand years, because if there were a sediment deficit, the barrier would have ceased to exist and if there was a surplus, a series of accretionary ridges would be evident. Net beach volume was used as the determinant of barrier volume rather than gross beach volume as it is more useful in determining the health of a barrier and its response to storm waves (Single, 1992). The net beach volume determines the amount of beach gravel on the barrier without the influence of substrate material.

For their study, Hicks and Todd (2003) determined the volume above an assumed substrate surface; being a horizontal line from the backshore to the beach crest then downward sloping to the mean sea level line as displayed in Figure 2.13. Hicks and Todd (2003) note the discrepancies involved in calculating the net beach volume by assuming a substrate profile line. For cliff-backed profiles, a net beach volume was not estimated, as knowledge of where a cliff substrate may be situated was very limited. Through the use of Environment Canterbury surveys and as discussed by Single (1992), Hicks and Todd believe that storm wave washover is related to beach ridge gravel volume. At the Wainono profile, crest retreat appears to be related to a low net beach volume. The volume appears to be greatest in the ridges in front of the Wainono lagoon. At this site all of the sediment above the mean sea level appears to be barrier gravels.

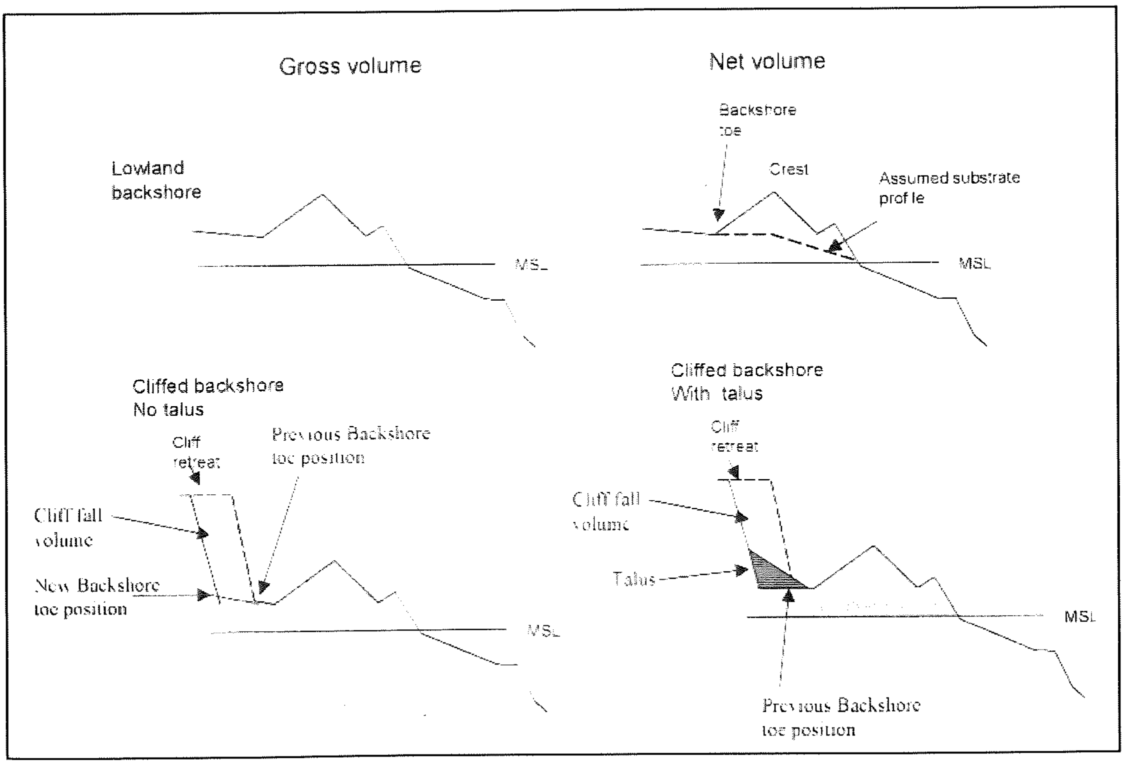


Figure 2.13: Assumed volume calculations used by Hicks and Todd (2003).

In terms of further research on the Waihao-Wainono barrier, Hicks and Todd suggest sampling of beach material across the profile is important, as well as gaining material from within the barrier. Because the use of an assumed substrate was needed to estimate beach volume at different sites, an estimate is just that, and they suggest that profiling of the substrate beneath the barrier will offer more insights into the barriers behaviour in both terms of volume and its relationship to breach events. This study is the basis for the author's research.

2.5 Summary

This chapter has presented a review of mixed sand and gravel beach and barrier literature. The primary aim of this section was to provide a base for the understanding of mixed sand and gravel barrier beaches.

The general characteristics of mixed sand and gravel beaches provided by Kirk (1980) are essential in terms of understanding the way in which mixed sand and gravel beaches function. Jennings and Shulmeister (2002) have provided a condition state model for gravel beaches a) pure gravel beaches b) mixed sand and gravel beaches and c) composite beaches all of which function in slightly different ways.

Barrier beaches were discussed with example from both the global and local context. Within the international context Carter et al., (1989) and Forbes et al., (1991) have provided evolutionary typologies for the formation of barriers in the Canadian setting in which barriers are separated into two types, swash aligned and drift aligned, relating to longshore transport.

With regard to the New Zealand context, studies from Kaitorete barrier highlight the formation and destruction of the barrier and the development of the waituna, Te Waihora. Hemmingsen (1997) studied the geomorphology of the barrier and outlined the phase of its evolution and destruction. Hart (1999) carried out a major study on river mouth dynamics along the South Canterbury coast. Her permeability studies have implications for why the barrier may breach at certain points.

This thesis is based on collecting accurate data on barrier volume. Hicks and Todd (2003) have in the past estimated the volume of the Waihao-Wainono barrier. A greater accuracy is required in order to fully understand how the barrier functions.

Chapter Three

Waihao-Wainono Barrier

3.1 Introduction

This chapter provides a detailed description of the study area. The geologic and geomorphic features of the study area are described in order to understand the major influences that contribute to the form and function of the Waihao-Wainono barrier.

3.2 Location of the Study Area

The Waihao-Wainono barrier is located in the Waimate District an area bounded by the Waitaki River to the south, the Pareora River to the north and the Hakataramea Valley to the west. The Pacific Ocean acts as the eastern boundary. Figure 3.1 outlines the study area and includes place names described in the text.

In 1840, the first descriptions of the coast were made by travellers using the barrier beach as a track between Christchurch and Dunedin. It was not until the 1890's when the influence of the Waitaki River was highlighted and described as the major sediment contributor to the coast (Single, 1992).

The area is dominated by two major features, the Waitaki River and the Hunters Hills. The geomorphology of the area is attributable to the deposition of gravels from the Waitaki River, draining regions of the McKenzie Country, and smaller coastal streams draining the Hunters Hills. The Hunters Hills rise from a flat alluvial plain formed by alluvial outwash fans of the Waitaki River, draining a catchment area of $2400km^2$. The Waihao-Wainono barrier acts as the interface between the Pacific Ocean and the hinterland area and is composed of gravels transported by the rivers from the Southern Alps and from the cliffs of the alluvial fan.

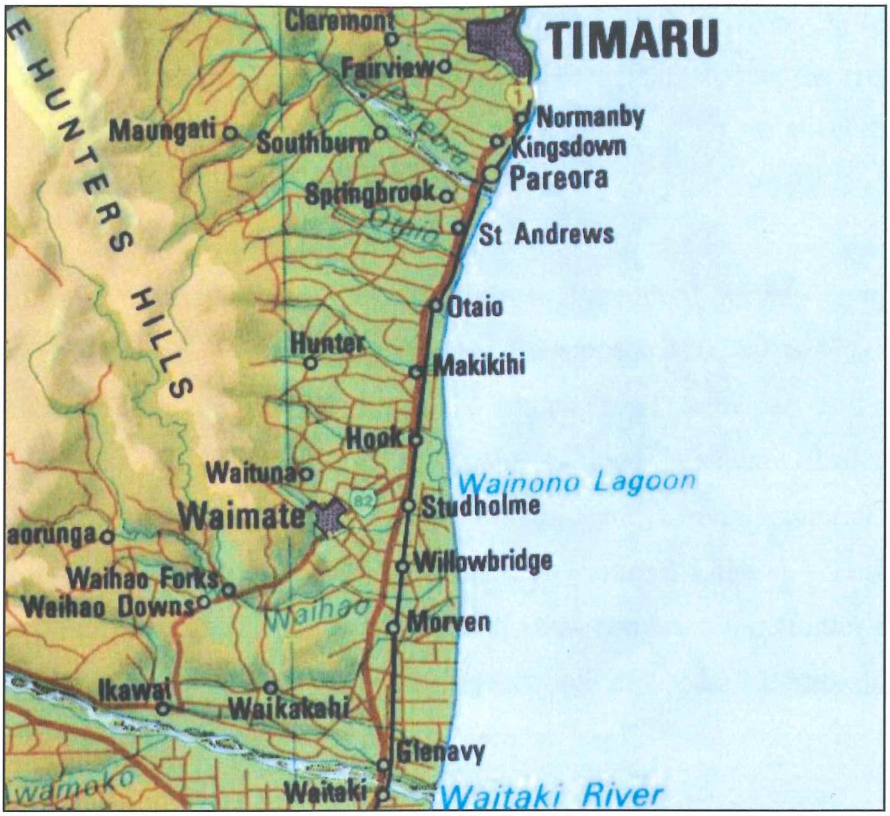


Figure 3.1: Location of the study area including place names mentioned in the text (Scale 1:20,000).

3.3 Description of the Waihao-Wainono Barrier

3.3.1 Geology

An understanding of the geology of the study area is important as the coastline and surrounding hinterland develop according to the basement structure of the sediments, as well as in response to the different processes acting upon it.

The geology of the study area is shown in Figure 3.2 and illustrates the geologic units of the area. The Quaternary geology of the area is derived from Pleistocene glacial activity and to a much lesser extent, tectonic activity. A geological time scale is provided in Appendix 1. The Waitaki River, in the past experienced long phases of alluvial fan building in which the river carrying large supplies of sediment aggraded, which ultimately led to the construction of a broad alluvial fan (Hewson, 1977).

While the glaciers advanced, the sea level lowered and the coastline shifted east by considerable distances. When the climate became warmer, the sea level rose and has continued to do so until its present position. Erosion of the coastline has led to the truncation of this alluvial fan and the shortening of the Waitaki River. Wave action, the contemporary context, has caused the shoreline to retreat, forcing the river mouth to arrive at the coast, at a uniform grade. Erosion of the coastline has also left areas of cliffs (Hicks et al., 2002; Hewson, 1977).

The back barrier area from the Waitaki River to Pareora is largely composed of greywacke gravels laid down during the late Pleistocene (20,000 to 70,000 years before present). These gravels are assumed by Mutch (1963) to be part of the Morven formation (60,000-70,000 years B.P) or of the younger Waikaura formation that occurred 40,000-50,000 years B.P. Areas of Holocene alluvial material are also present near riverbeds and form the base of the Wainono Lagoon. This type of sediment is younger than the greywacke gravels that comprise the Hunter Hills and the hinterland and was laid down 20,000 years ago towards the end of the last glaciation.

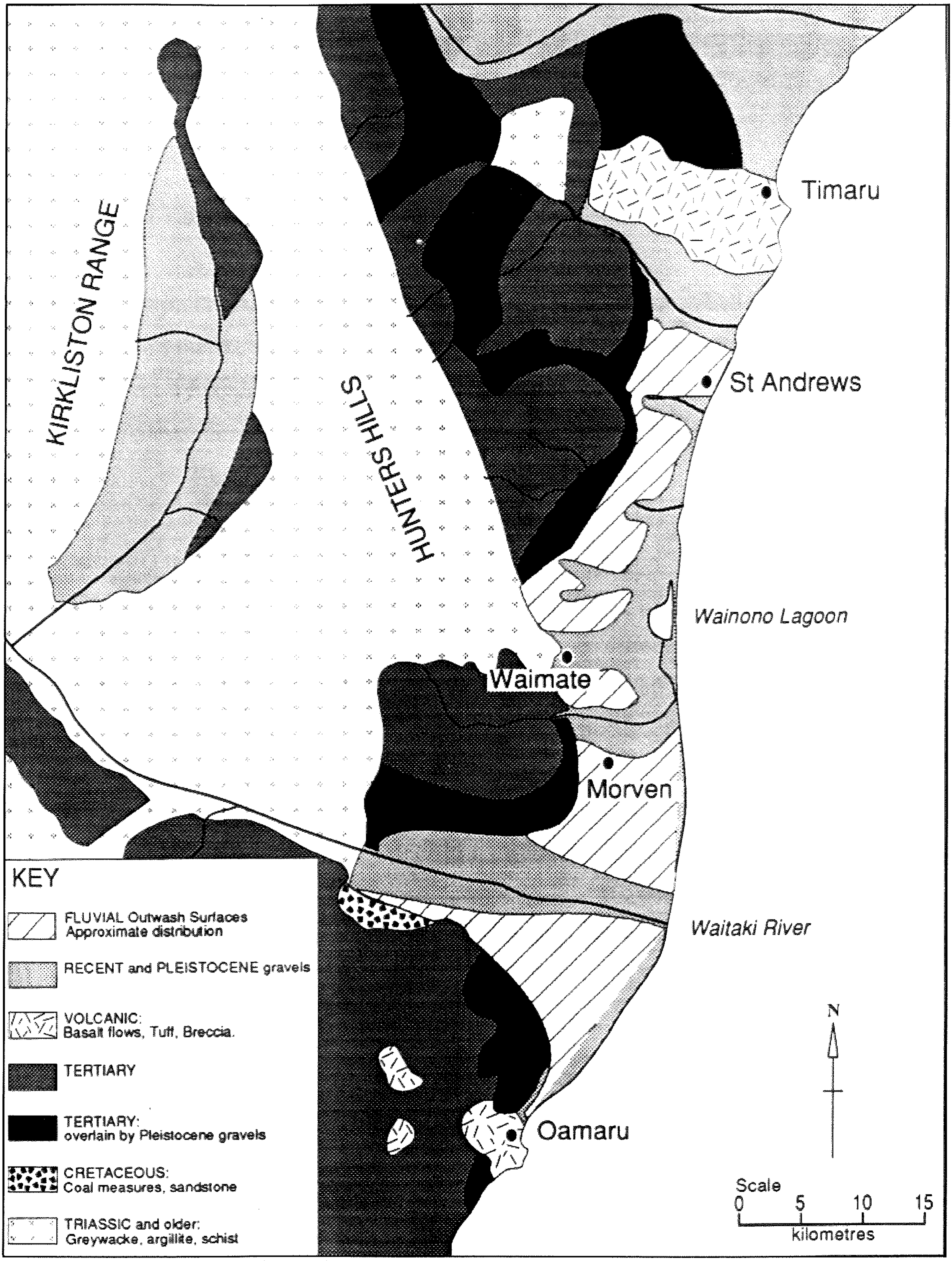


Figure 3.2: Geological map of the North Otago, South Canterbury region (After Hewson, 1977).

3.3.2 Geomorphology

The present topography was shaped during the later stages of the Pleistocene, denuding the area of its tertiary and cretaceous features. Greywacke is the dominant sediment type of the area along with much lesser amounts of schist and argillite (Oborn, 1978). These are the sediments of which the Waihao-Wainono barrier is composed.

The Waitaki to Timaru Coast can be morphologically divided into four sections:

- The coast from Oamaru to 15km north of the Waitaki River
- North of the Waitaki fan to the Makikihi River (Waihao-Wainono Lowlands)
- The coast from Makikihi to St Andrew's
- The coast from St Andrew's to Timaru

The southern section entails the coast from Oamaru to the start of the study area, 15km north of the Waitaki River. Within this section, the shoreline is backed by cliffs where the sea has eroded the alluvial fan over the past 7,000 years. Waihao-Wainono barrier lies in front of the cliffs and contains sediment derived from both the cliffs and the Waitaki River. The river itself lies within the Waitaki valley and is also fronted by a barrier beach in which it maintains an ever-changing opening to the sea (Hicks et al., 2002; Hicks and Todd, 2003; Hewson, 1977).

Along the second section, north of the Waitaki fan to the Makikihi River, the barrier is backed by a lowland area termed by many (eg. Single, 1992; Hicks et al., 2002; Hicks and Todd, 2003) as the Waihao-Wainono lowlands. There are a number of small rivers and streams that drain to the lowland coast. Sinclair's Creek is located on the south side of the Waihao River and drains a small catchment of 11km^2. The creek is often dry and any water that is present is discharged by seepage through beach gravels. Waimate Creek drains into the Dead Arm, with the water eventually ending up in the Waihao River. The Makikihi River drains the area to the north of the Wainono Lagoon. The mouth of this river is closed for the majority of time and opens only in times of high river flow which is able to force the mouth open.

The barrier beach reaches maximum heights of 6.5m above mean sea level and experiences a northward reduction in height. The barrier grows wider to the north and in combination with the reduced height, creates a flatter, more stable foreshore. Figure 3.3 shows a profile of the barrier at the Ryan's Road site at the southern end and the Hook Swamp Road site at the northern end of the barrier. The multi berm morphology outlined by Kirk (1980) and Single (1992) is also evident on these profiles.

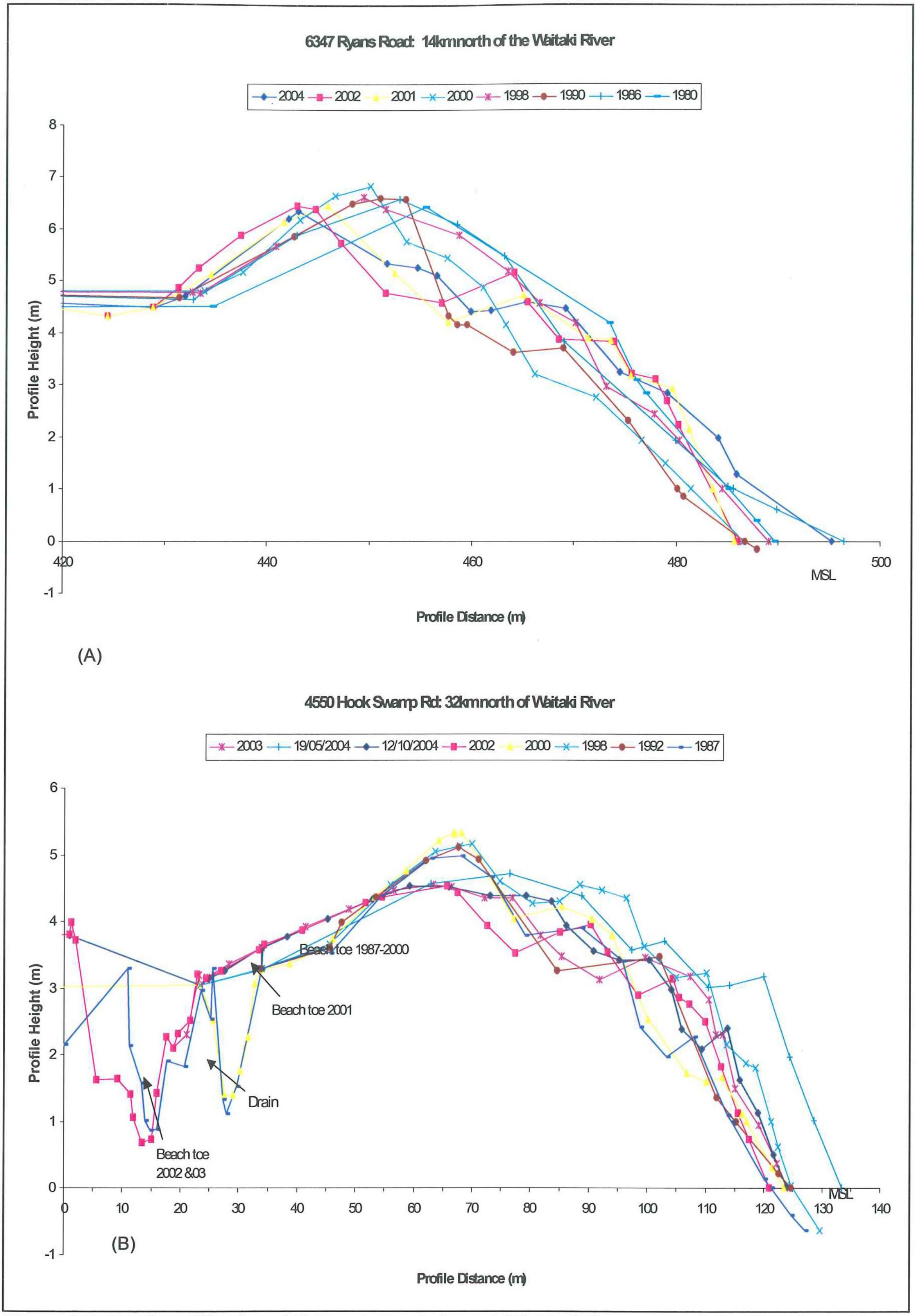


Figure 3.3: Beach profiles from (A) Ryan's Road site and (B) Hook Swamp Road site. Ryan's road is steeper and Hook Swamp Road is flatter.

The hinterland area lies at low elevations behind the barrier, typically 2-3m above mean sea level. The lowest area encountered is the Wainono Lagoon, which occupies a depression behind the barrier. In this section of the coast the barrier is 'rolled over' onto land by storm waves that are high enough to overtop the barrier. The rate of this rollover depends on the frequency and magnitude of storms (Hicks and Todd, 2003). Rollover and inundation events along the South Canterbury coast are discussed in more detail in section 3.4.

The planform of the coastline is concave to Makikihi and then forms a convex shape between Makikihi and Timaru (Hicks and Todd, 2003). Sediment supply to this section of the coast is from the Waihao River, Waimate Creek and Makikihi River. These local rivers are small so most of the sediment on this part of the coast has been transported north from the Waitaki coastal cliffs and the Waitaki River (Pieters, 1996).

The area from St Andrew's to Timaru is again morphologically different to that of the more southerly regions of the coastline. Loess cliffs are the major feature of this area and they provide little sediment to the fronting barrier. The area north to Timaru is an embayment type coast and is composed of sediment from the Pareora River and the remaining sediment drifting from the south. Basalt bedrock forms the coast 3-4km south of Timaru and is especially visible at Tuhawaiki Point.

3.3.3 Wainono Lagoon and the Waihao Box

An area that is particularly vulnerable to overtopping and breaching is Wainono Lagoon. The lagoon occupies a shallow depression behind the barrier and is the lowest area of hinterland; sitting at an elevation only just above mean sea level, in its normal state water levels reach 1m above MSL. The Wainono Lagoon extends 2.5km along the coast and in total is 325 hectares (Pemberton, 1980). Salt marsh and wetlands surround the lagoon, adding a further 140 hectares. The catchment area, which the lagoon acts as a storage area for, is 252km^2. The lagoon does not have a direct opening to the sea; instead it drains via the Waihao "Dead Arm". This Dead Arm meanders from the south east corner of the lagoon in a south westerly direction for 3.4km and then runs behind the barrier for a further 4km until reaching the mouth of the Waihao River. Figure 3.4 shows the lowland area.

The Waihao River also does not have a natural opening to the sea. To combat the lack of a permanent opening, the Waihao Box structure was built in 1897 with the intent to provide an outlet for the river. The current box measures 60m long, 4.6m wide, and 1.2m high, with the top reaching a height of 2.3m above mean sea level (Figure 3.5). Mechanical assistance is often required to clear the sediment that has built up in front of the structure so that the water can be released. The box is closed for around 75% of the time after initially being designed to provide an open mouth in times of normal flow and as a river flood structure during times of high flow (Hicks and Todd, 2003).

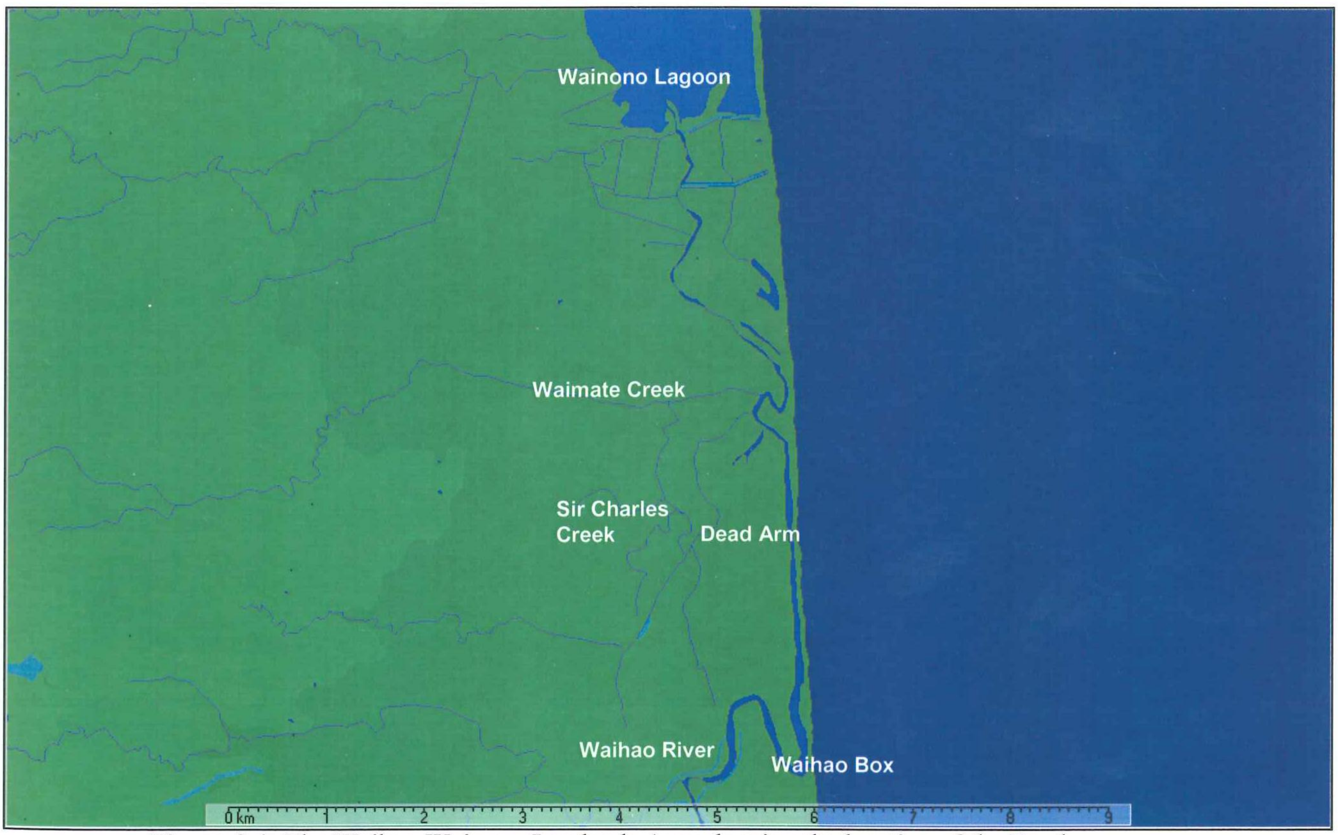


Figure 3.4: The Waihao-Wainono Lowlands Area showing the location of the Dead Arm and the Waihao Box.

Figure 3.5: Photo of the Waihao Box Outlet. The sea is to the left and the Waihao River is to the right of the barrier.

3.3.4 Ecological Significance

The Wainono Lagoon is an area of national importance and is the largest coastal wetland for 250km. The lagoon is a major breeding ground and stop over area for migratory birds and the total population of birds over the summer months has been calculated at up to 9,000 derived from 32 different species (Pearce, 1980). The water ways between the Wainono Lagoon and the Waihao River provide a habitat that supports 14 species of native fish, two of which are restricted and endangered species. Five species of estuarine fish and six species of introduced fish also live there (Ward, 1986).

The waterways around the area and the lagoon itself have a high recreational value to users. Activities include such things as eeling, shooting, white baiting and boating. In the early 1990's the Fish and Game Council purchased 80 hectares of land adjoining the southern side of the lagoon and converted it into a wetland to increase the area for recreational use as almost 200 game-bird hunters use Wainono Lagoon with popularity continuing to increase (Ward, 1986).

3.3.5 Significance to Tangata Whenua

Te Runanga Waihao is the local iwi of the area and they place great importance on the Wainono Lagoon and the surrounding areas. The Waihao River and the lagoon are major Mahinga Kai areas for fishing as they carry traditional foods such as eels, flounder and whitebait. There are three Maori Reserves set aside in the area; Waikawa, an area south of the Waihao River mouth, Te Houiri, a small lagoon between the Waihao River mouth and the Wainono Lagoon, and Puhakatai, a small area north of the lagoon (Hicks and Todd, 2003).

3.3.6 Bathymetry

The offshore morphology is largely unknown as few studies have been undertaken because of the danger and difficulty involved in fieldwork. The geological events that helped to produce the features on land have also created the offshore submarine features. Bathymetric information taken from Hewson (1977) is focussed on the Timaru area and may provide insight into the conditions further down the coast. Figure 3.6 displays the bathymetric information of the area, but unfortunately no bathymetric data has been collected immediately offshore of the study area.

A mix of alluvial gravels, sand and silt are present for quite a distance into the offshore zone near Oamaru, while at Timaru, the seabed consists of fine compact sand. In the Timaru area, the continental shelf is of a gentle slope even though the beaches of the area tend to be steep in profile. It is noted that the seabed flattens towards Timaru so it is envisioned that the nearshore and inner continental shelf is of a steeper slope. Hewson states that although there have been significant changes in the foreshore, the changes are not mirrored in the nearshore.

The bathymetry of the coast plays an important role in terms of the features of the shore, acting as a major control on the waves and currents that ultimately disperse the sediment both across and along the coast.

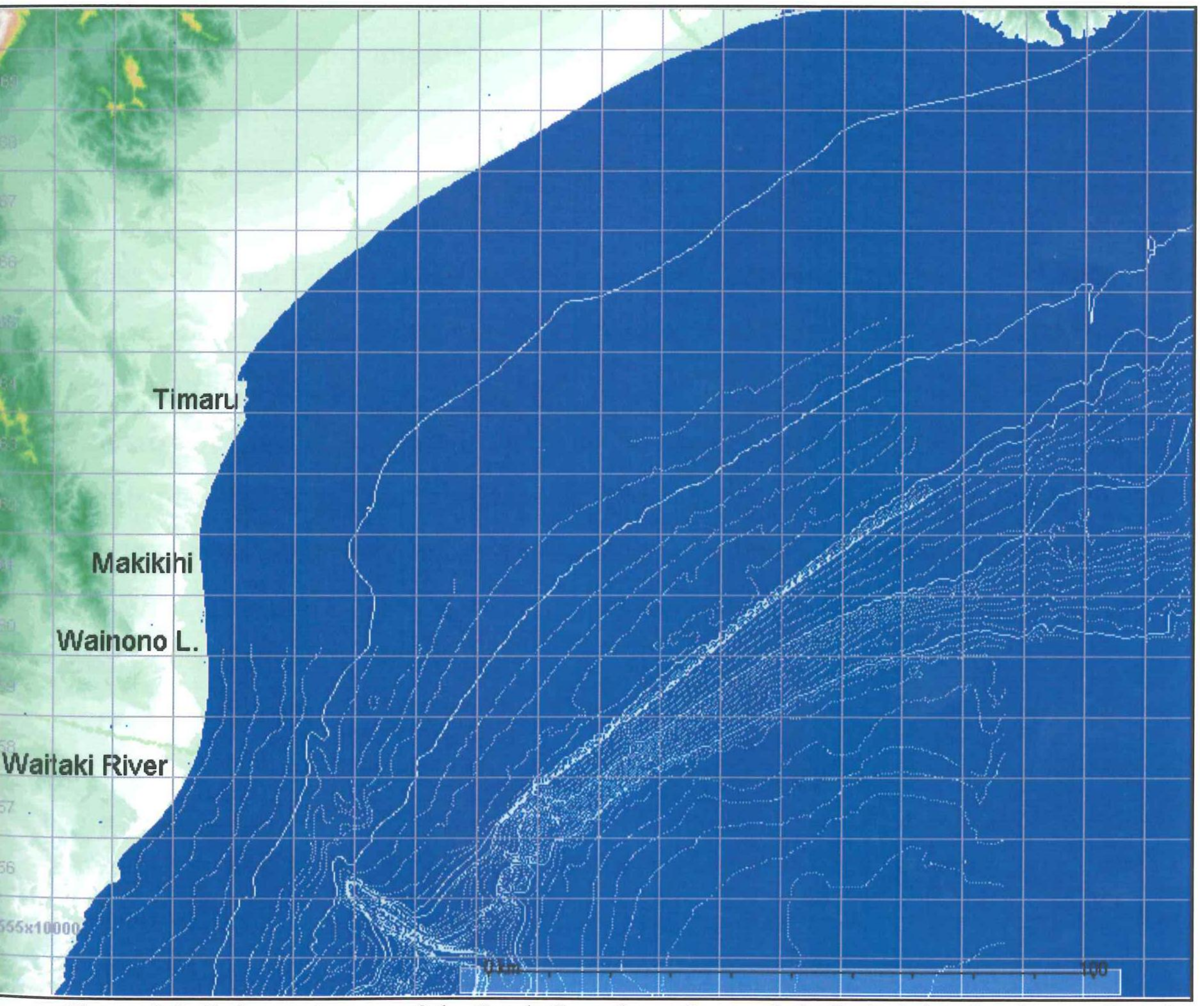


Figure 3.6: Bathymetric map of the South Canterbury Coast. Only limited data has been collected within the offshore zone of the study area.

3.3.7 Sediment Size

Sediment size has a major impact on the morphology and characteristics of gravel barriers as outlined in Chapter Two. Sediment analysis has been carried out from sediment collections along the South Canterbury coast with all studies having focussed on samples taken from the surface of the barrier.

Hewson (1977) found that the composition of samples averaged 70% gravel and 30% sand. A full range of sediment sizes were visible and mean grain sizes ranged from coarse sand (0.9mm) to pebbles and cobbles (32mm). On occasion sediment sizes of 256mm were measured but in general this size is a rarity. Across-shore trends in sediment size were also evident from Hewson's analysis. The mean sediment sizes were largest at the backshore of the barrier and decreased in size to the upper foreshore. The mean size then increased slightly towards the recent storm berm and then decreased sharply towards the nearshore zone. Single (1992) identified a similar trend to that of Hewson. Both authors believed there to be a greater trend in sediment size across shore than any trends found along the coast.

Hicks and Todd (2003) examined and compared grainsize data from 1977 and 1994 surface samples. The samples could be compared as the collections were taken at the same morphologic points along each profile for both years. The 1984 samples gathered by Kirk (1984) were unable to be used as they were gathered at different points making comparisons impossible. Through examining the 1977 and 1994 data, an alongshore trend was identified in that a general fining of sediment northwards was prevalent, although there was a certain amount of scatter between sites. Contrary to many local resident's beliefs there is no sign of any reduction in size between the years of 1977-1994.

3.3.8 Erosion

Studies on erosion of the Waitaki Fan have been a subject of great interest for a number of years. The first research carried out in the area was in fact on erosion. Mc Intyre (1958) compared the shoreline positions to that of the 1877 survey plans at St. Andrews and the 1899 plans north of the Waitaki River. From this he was primarily able to identify that long-term erosion had occurred at both locations. Several authors have provided insight into erosion along the coast and extended Mc Intyre's first observations (Gibb, 1978; Gibb and Adams, 1982; Hewson, 1977; Kirk et al., 1977; Kirk, 1987; Neale, 1987; Todd, 1988; Benn, 1988).

Hewson (1977) concluded that the erosion rate decreased the further north from the Waitaki River. His main hypothesis was because the planform of the shoreline is most convex near the Waitaki River and therefore most vulnerable to wave energy. He also described the proximity of sediment sources to be of great importance along with the possible influences of the Waitaki Dam, which was built in 1935. Hewson concluded through measurements that the erosion rate of the South Canterbury coast was around 0.5m/yr.

Gibb (1978) and Todd (1988) focussed their erosion studies on the cliffed areas of the coast. Gibb reported that 6m of erosion had occurred during one storm in 1974. Further ECan surveys showed a cliff retreat rate of 11.8m over one and a half years during late 1980s. Todd (1988) believed cliff erosion to stem from heavy rainfall events, leading to saturation of the cliff causing areas of the face to collapse. Storm waves then remove the material from the cliff base and the cliff is exposed to further erosion.

Kirk (1987) identified four geomorphic sections of the Waitaki coast, each having different erosion patterns due to the varying processes acting upon them. The first section is that of the alluvial cliffs from Oamaru to north of the Waitaki River, the second, from Waihao River to Makikihi (encompassing the low lying lagoon area). The third section comprises loess cliffs near St. Andrews of which cliff retreat is in the order of 0.3m/yr, and a fourth area south of Timaru, which includes mixed sand and gravel embayments between basaltic outcrops and in contrast to the other sections is accretionary. He focussed on the alluvial outwash cliffs in which he believed there to be 0.45-0.75m/yr of erosion. Erosion of the whole coast but especially that of the cliffs is termed to be episodic, highly dependent on rainfall events and storms producing high energy waves.

3.4 Hydrodynamics

3.4.1 Tides

Tides are the most easily recognisable change in sea level, occurring at least once a day. Tides can vary by several metres each day, altering the level at which waves attack the shore. Tides are therefore an important determinant in the morphology of a coastal zone in terms of erosion and accretion and cross-shore sediment zonation. Tides produce currents and are one of the major processes involved in keeping inlets and entrances to bays and lagoons open (Komar, 1998). There are three main tidal types that are outlined in table 3.1, (1) Microtidal (2) Mesotidal (3) Macrotidal. All of these are based on the spring tidal ranges as they contain the greatest variance.

Table 3.1: Classification of tidal ranges developed by Davies, (1964) in Komar, (1998).

Classification	Tidal Range
Microtidal	Range less than 2m
Mesotidal	Range of 2-4m
Macrotidal	Range greater than 4m

The coastal environment along the Waitaki/Waimate coastline is microtidal because the spring tidal range is small, generally less than 2.0m. The tides are semi-diurnal, with high and low tides occurring twice a day at a 12 hour 20 minute cycle.

The plunging waves and steep foreshore of the beach profile mean that there is little tidal translation of the breaker zone across the beach. Tides reach the coast at different times due to the forces of the moon and rotate around different locations called amphidromic points. These points occur due to the coriolis force which cause currents to flow clockwise in the southern hemisphere and anti-clockwise in the northern hemisphere. Due to the current flowing in a certain direction, the sea then builds up at certain areas around the amphidromic points. These amphidromic points are the reason tides vary both globally and locally (Komar, 1998). Along the Canterbury coastline, Oamaru receives high tide about 40 minutes earlier than Timaru and Timaru receives it 1 hour and 13 minutes earlier than Lyttelton.

Tides have a major impact on the South Canterbury coast as it is during high tide that most inundation events occur. The combination of high-energy events coinciding with high tides can cause waves to reach areas not normally affected during low tide.

3.4.2 Storm Surge

Goring (2004) carried out a study to estimate extreme sea levels on the South Canterbury coast with particular emphasis placed on storm surge at the mouth of the Waitaki River and the Wainono Lagoon.

Green Island and Wainono Lagoon have similar oceanographic characteristics so data from Green Island was used in calculations for Wainono Lagoon. Through analysis of the tide, storm surge and mean sea level, green Island (and hence Wainono Lagoon) has displayed a 2% annual exceedence probability (AEP), or a 1 in 50 year return period, of 1.74m above MSL as shown in Table 3.2.

Table 3.2: 2% AEP (50 y return period) sea levels reduced to MSL. Rising sea level assumed to be 50 years @1.8mm/yr. (MLOS= mean level of the sea). (Source: Goring, 2004:7).

Item	**Green Island**	**Timaru**
Tide + Storm Surge	1.57	1.51
Monthly MLOS fluctuation	0.08	0.08
Present MLOS	0.00	0.03
Rising Sea Level*	0.09	0.09
TOTAL m above MSL	**1.74**	**1.71**

3.4.3 Sea States

Waves are the major contributor to morphological changes on a beach as they expend the greatest amount of energy onto the beach system. Waves operate within a tidal range and they are forced by both winds and currents. The wave environment is the greatest controlling factor in both short-term fluctuations of beach morphology and the long-term evolution of a coast.

Davies (1972) classified the South Canterbury wave environment as an 'east coast swell' type. The waves arriving from the southeast quadrat can be described as having an unlimited fetch, producing waves from varying directions and power. The bulk of the wave energy dispersed on the coast is derived from the southern ocean where most storms are generated (Hicks et al., 2002). Figure 3.7 displays the regional wave hindcast directional frequency data for 1979-1998 at the Wainono Lagoon site on the Waihao-Wainono barrier. This site was chosen as an example as it is in the centre of the study area and it is also representative of the other sites. The wave data shows that the dominant wave direction is from the southeast for at least 80% of the time.

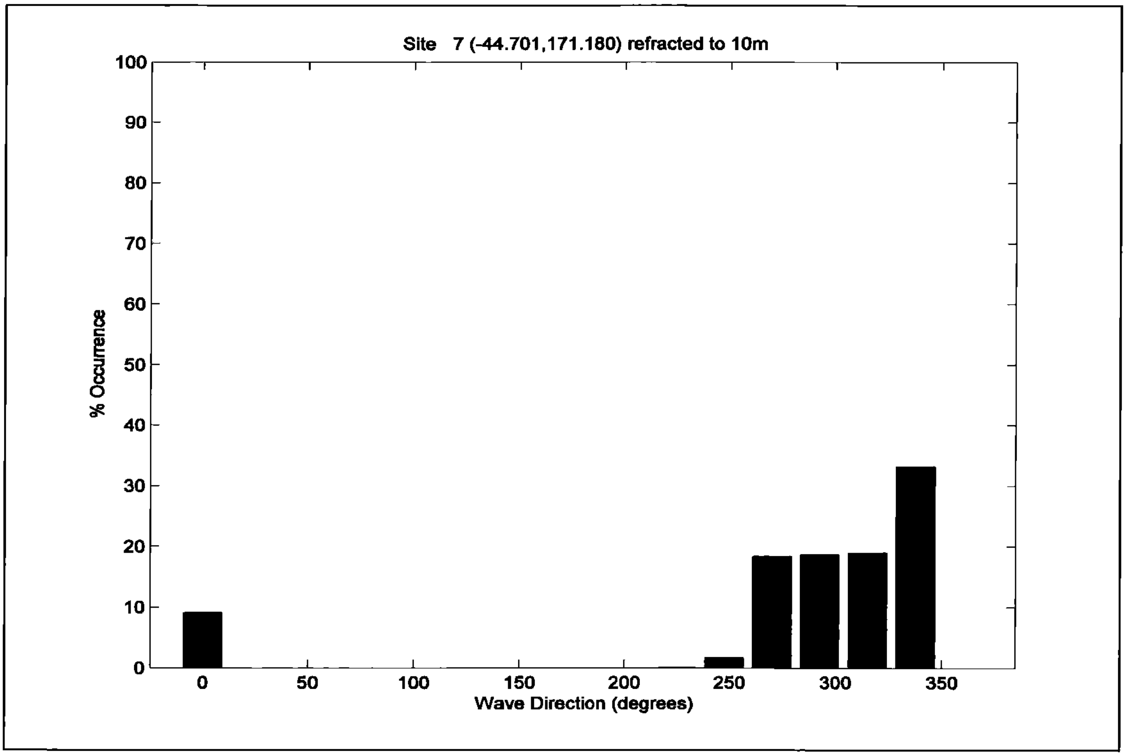


Figure 3.7: Percentage occurrence of wave direction at the Wainono Lagoon site from 1979-1998. Waves arriving from the southeast quadrat are the most common. Note the wave direction is "direction to" at 10m depth (Source: NIWA wave hindcast data).

Wave Refraction does take place along the South Canterbury coast, but because of the large approach angle of high energy events (e.g. 45-90 degrees), refraction is often not complete by the time the waves reach the shore resulting in an oblique wave approach and break at the shore. This results in the waves arriving at the beach at oblique angles and ultimately creates the longshore transport of sediment in a south to north direction. Occasionally, waves generated to the northeast may drive sediment transport in the reverse direction but overall the net transport occurs in a northward direction (Gibb and Adams, 1982).

The significant wave height (Hsig) is calculated as 1/3 of the wave height (H). The significant wave height mean tends to range from 1-1.5m over all of the wave hindcast sites and generally occur about 10% of the time. Figure 3.8 shows an example of the occurrence of significant wave heights at the Wainono Lagoon site.

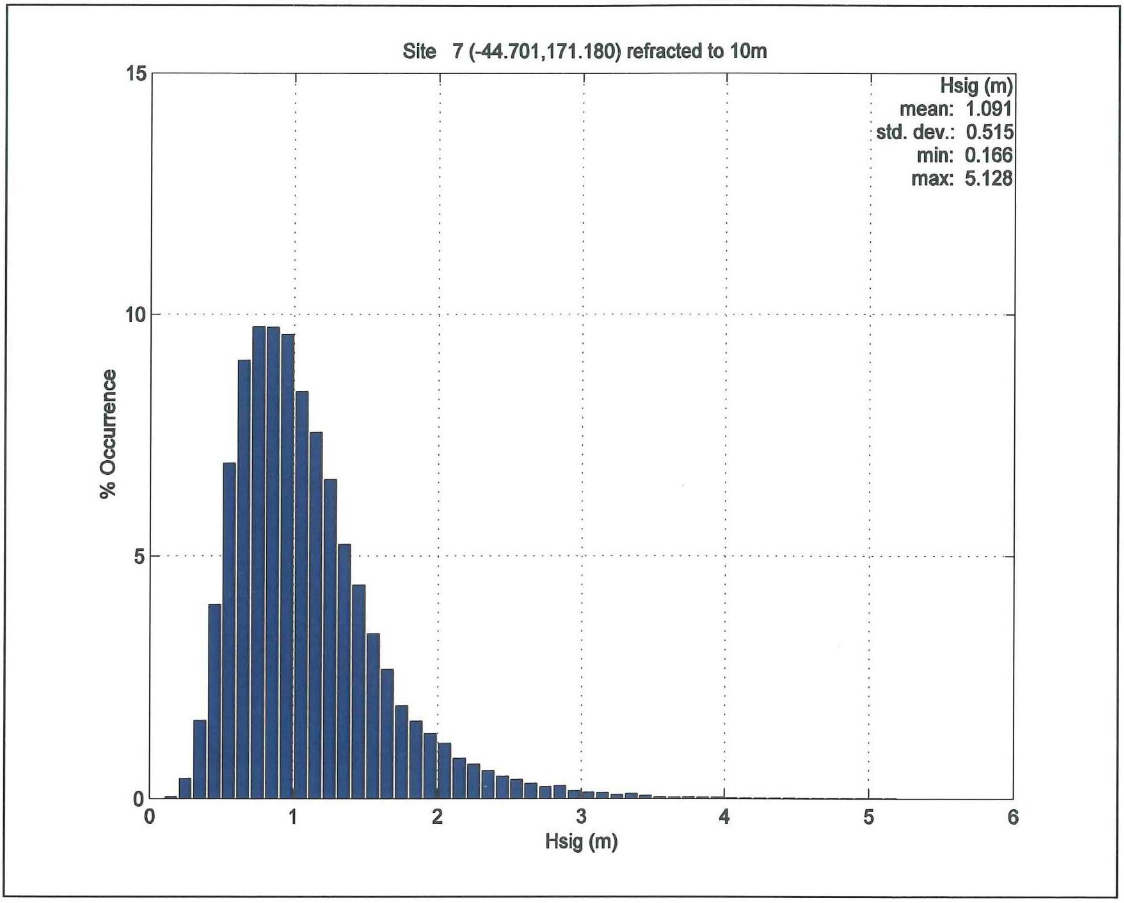


Figure 3.8: Percentage occurrence of significant wave heights (Hsig) at Wainono Lagoon 1979-1998 at 10m depth. (Source: NIWA wave hindcast data).

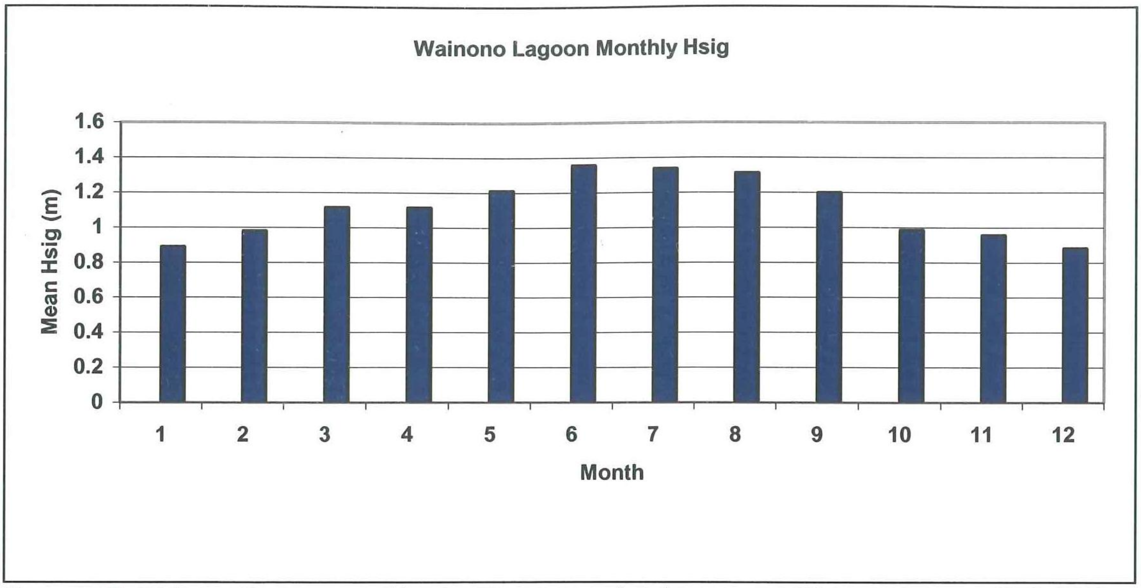


Figure 3.9: Wainono Lagoon monthly significant wave height means at Wainono Lagoon 1979-1998. At 10m depth. Note 1=January 12= December. (Source: NIWA wave hindcast data).

In addition to identifying mean wave figures throughout several years, it is important to identify monthly means within that time. Coastlines and beaches are dynamic features that are in essence moulded by the processes acting upon them. It is of special importance in terms of this research because barrier breaches and flooding events are most likely to occur in times of high wave energy, that is, during the winter months. Figure 3.9 shows that the months in which the highest significant wave heights occur are June to August.

The final graph brings together both the significant wave height and mean direction of the waves. It is clear from Figure 3.10 that the greatest significant wave heights (2-4m) occur when wave direction is from the south-southeast. The Wainono Lagoon site is representative of most other sites apart from the Morris Road site that displays a more southerly direction.

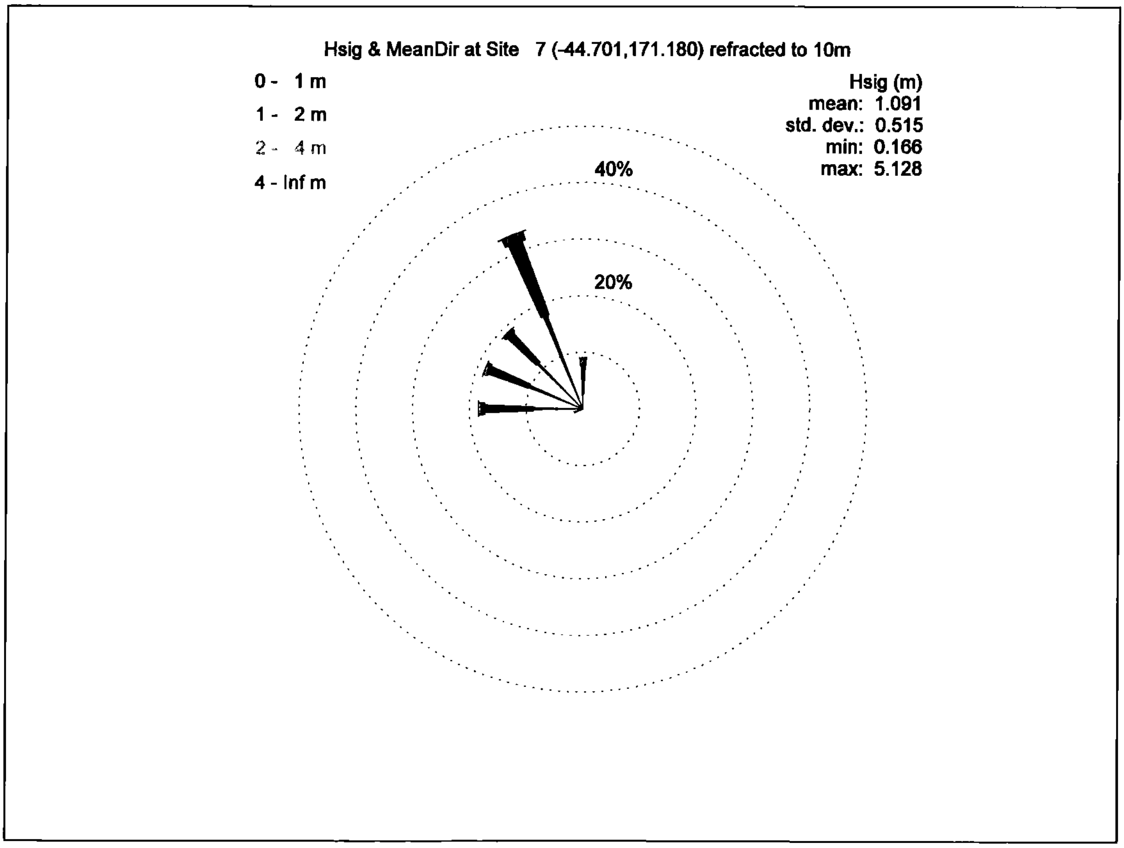


Figure 3.10: Wave Rose of significant wave height (Hsig) and mean direction of waves at the Wainono Lagoon site from 1979-1998. At 10m depth (Source: NIWA wave hindcast data).

3.5 Coastal Inundation

There have been a number of coastal inundation events recorded along the South Canterbury Coast since 1962. The following history of inundation events has been summarised from Todd (1988), Cope and Young (2001), and ECan records, which is taken from Hicks and Todd (2003).

Table 3.3: Summary of inundation events along the Wainono Lowlands, 1962-2002. After Todd and Hicks (2003:74-75).

Date	Area Affected	Inundation Location
April 1962	400 hectares	Flooded south of Timaru. Although no specific locations are given, it is assumed that some of this would have been along the Waihao-Wainono lowland as damage was reported to the Waihao Box.
April 1968	-	Areas along lowland coast shown in Benn (1988) as being flooded by the 'Wahine' storm.
April 1969	350 hectares	The Waihao dead arm blocked by four breaches in the coastal ridge, resulting in flooding. Possibly up to 150 hectares, excluding Wainono Lagoon flooded from Makikihi to Morven, and another 200 hectares in Makikihi to Otaio area.
June 1974	2200 hectares	500 hectares south of Otaio River flooded, and some 1700 hectares experienced interference with drainage due to coastal drains being infilled with sediments
April/July 1977	-	Likely to have been some overtopping along lowland coast.
May 1985	-	Some small-scale breaching at Wainono Lagoon and Waihao Box.
July 1985	505 hectares	Total of 505 hectares flooded along the lowland coast. Breaches of the barrier ridge occurred at Sinclair's Creek, at Waimate Creek on the waihao Dead arm, and Wainono Lagoon.
June 1992	10 hectares	Barrier ridge overtopped, but stopbanks prevented flooding of farmland at all locations except 10 hectares at Kohika stream.
July 2001	1148 hectares	Total of 1148 hectares flooded along the lowland coast. Breaches of the barrier ridge occurred at Wainono Lagoon, Waihao dead arm, and at the Waihao Box.
April 2002	625 hectares	Total of 625 hectares flooded along the lowland coast. The location and scale of the inundated areas being similar to the July 1985 event.

Inundation events occur along the South Canterbury coast through two different processes: beach overtopping and beach failure or breaching. Beach overtopping occurs when wave run-up is greater then the height of the barrier ridge. The swash, instead of returning to the sea as backwash, runs over the top of the ridge and down the backshore slope. This overtopping results in the barrier being 'rolled over' in the landward direction. There are four known conditions that Hicks and Todd (2003) describe as contributing to overtopping and these are displayed in Table 3.3. From observations during storm events this type of process takes place over three to four hours during high tide and occurs fro a maximum of two to three tidal cycles. Flooding from this type of event has been quite extensive especially along the Makikihi to Otaio section as the area behind the barrier is at such low elevations. Once the event is over the barrier height may rebuild but only once the sea conditions a favourable for sediment deposition.

The inundation events along the Waitaki Coast have occurred due to the low barrier ridge and the low-lying nature of the hinterland. Past responses to this hazard have been to construct stopbanks with the hope of preventing salt water inundation of the farmland. The stopbanks have been constructed parallel to the coast and have proven to be unsuccessful in many cases. Bank failure occurs when large volumes of water become trapped between the stopbank and the barrier. Once this water is trapped, drainage of floodwater is difficult. Coastal erosion has a part to play in bank failure with sea flood storage areas being reduced in size as the coast retreats landwards towards the banks and ultimately the banks are overwhelmed by erosion. Coastal stopbanks do not allow this water to escape to the coast, hence increase the area, level and duration of inundation. A list of the stopbanks constructed is provided below and sourced from Hicks and Todd (2003:66-67).

- In the late 1940's and 1950's stopbanks were constructed around the upper Dead Arm from Wainono Lagoon to Waimate Creek, to exclude the lagoon from the farmland on its southern and western sides.

- In 1968 following the 'Wahine' Storm, stopbanks were constructed south of the Makikihi River (750m long) and north of Sinclair's Creek (750m long).

- Following sea flooding from two severe coastal storms in 1974, stopbanks were constructed at Hook Swamp (2.5km long) and south of the Waihao River (1km long).

- Following two storms that caused sea flooding in 1977, a further 3.6km of stopbank were constructed on the landward side of the Dead Arm from Sir Charles Creek to the Waihao River, a 700m section of stopbank to the north of Waimate Creek was realigned as a result of coastal retreat, and banks were constructed on the west side of the lagoon.

- In 1984, as part of the Sinclair's Creek Control Scheme upgrade, the coastal stopbanks were extended south of the creek for 750m to aid the discharge of water through the beach.

- Following coastal storms in 1992, stopbanks were constructed in the Kohika Stream-Otaio area.

In contrast, barrier breaching occurs under different conditions to those that produce overtopping. These conditions are displayed below in Table 3.4. Breaching occurs when the backshore collapses due to part of the beach becoming too narrow to prevent run up flowing through the beach to the backshore. The backshore then collapses and the barrier height rapidly decreases. Water is then able to inundate the hinterland through the now lowered section of the barrier. At all previous breach sites, the barrier ridge was narrow. Breaching generally has a greater effect on the surrounding lowland area, as the volume of water that passes through the breach site is greater than in an overtopping event (Hicks and Todd, 2003).

Table 3.4: Known conditions for both Overtopping and Breaching events to occur (After Hicks and Todd, 2003).

Inundation Processes Along the South Canterbury Coast	
Conditions for *Overtopping*	**Conditions for *Breaching***
High sea level (e.g. High tide) and large storm wave height	High sea level (e.g high tide) and large storm wave height
Flat foreshore	Steep foreshore and narrow upper beach
Poorly sorted sediment distribution so that percolation into the beach is restricted	Well sorted coarse gravel layer on upper beach on top of a base of finer poorly sorted material
Long-duration event so that the width of the beach foreshore becomes saturated and limits percolation	Steep backshore slope

The long-term retreat rates of the Waihao-Wainono barrier are likely to occur at an average retreat rate of 0.25-0.5m/yr as is visible from historical data. Ultimately the rate is dependent on the frequency and magnitude of storm events and on the combination of height and volume of the gravel barrier. The greater the volume, the less likely the storm waves are of overtopping the barrier and vice versa for small volumes (Single, 1992). In the past it is evident that the retreat of the barrier has occurred in unison with the erosion of the cliffs to both the north and south of the lowland coast, otherwise the barrier would be stranded or would follow and embayed coastline.

3.6 Summary

This chapter has provided a detailed description of the study area with the geomorphic and geologic feature identified in order to understand the major influences that contribute to the present form and function of the Waihao-Wainono barrier.

The barrier is an important feature as it acts as the interface between the Pacific Ocean and the hinterland. The Quaternary geology of the area is similar along the coast, composed of alluvial and glacial sediment with a dominance of greywacke.

The South Canterbury Coast can be divided into four morphologic areas, with cliffs backing the coast at some sites, and the Wainono Lagoon and low lying hinterland at others. Most sections of the coast are eroding apart from the area nearest to Timaru where it is accretionary.

The South Canterbury coast is classified as an East coast swell wave environment, with storm waves initiated in the Southern Ocean. The dominant wave direction thus arrives from the south-southeast and the waves are at their most powerful during the winter months when storms are frequent.

Several inundation events caused by overtopping or breaching have taken place along the coast resulting in salt-water inundation of farmland and the surrounding hinterland. Overtopping results in the barrier being rolled back onto land leading to coastal retreat. Several areas along the coast of the Wainono Lagoon have breached and the barrier ridge has significantly decreased in height. The protection of this area is important, as it is an area of national importance in terms of ecology, recreation and culture.

An understanding of the study area is important in terms of identifying the underlying processes that affect the area and to understand the environment in which the Waihao-Wainono barrier has formed. The next Chapter will outline the methods used in researching this area.

Chapter Four

Research and Analysis Techniques

4.1 Introduction

The main objective of this chapter is to outline the research and analysis techniques employed during the study. This chapter essentially has two sections incorporating the main research methods, barrier volume analysis and sediment collection and analysis. In each section a description of the field and laboratory procedures will be outlined along with descriptions of the analysis techniques that have been widely used in sedimentological studies.

4.2 Barrier Volume Determination

Komar (1976) discussed beaches in a way that described them as a protective entity by stating that:

"The beach profile is important in that it can be viewed as an effective natural mechanism which causes waves to break and dissipate their energy. The beach serves as a buffer, protecting sea cliffs and coastal property from the intense wave action" (Komar, 1976:288).

This very statement highlights the importance of the morphological aspects of a beach in that every characteristic of a beach determines how it will respond to the processes acting upon it. The actual volume of the barrier is simply the amount of sediment of which it is constructed, and is one of the major determinants of the protection that the barrier can provide. A small barrier volume means that the 'buffer zone' between the ocean and the hinterland is weak, compared to a larger volume that creates a larger buffer zone, ultimately offering greater protection from the coastal processes. To gain and display volume data effectively, barrier profiles and mechanical excavations were deemed the most appropriate methods.

4.2.1 Barrier Profiles

The profile sites used for this study were first surveyed in 1977 by the South Canterbury Catchment Board, now incorporated into the Canterbury Regional Council (ECan). The profile sites were established in response to the need for continual monitoring of the South Canterbury Coast. Benchmarks were surveyed into position and are identified as metal pins set in concrete blocks at the base of the warratahs or railway irons inserted into the backshore or farmland landward of the barrier. (Single, 1992).

The study area for this research incorporated 17 profile sites including 4 cliff sites, 4 lagoon sites, and 9 sites with various backshore features such as stopbanks, farmland and the Waihao Dead Arm. The sites are shown in Figure 4.1. These sites were chosen, as the author believed that the different backshore characteristics maybe translated into spatial morphological differences within the barrier. Surveying was carried out using a Sokkia 4B Total Station (Figure 4.2) and the staff height was placed at either 2m or 3m depending on the characteristics of the site. The survey of each site took into account the major features of the beach. The survey staff was placed at breaks in slope, berms, tidemarks, storm marks and in areas where a change in sediment characteristics was visible. Sediment sample sites were also surveyed into the line of profile.

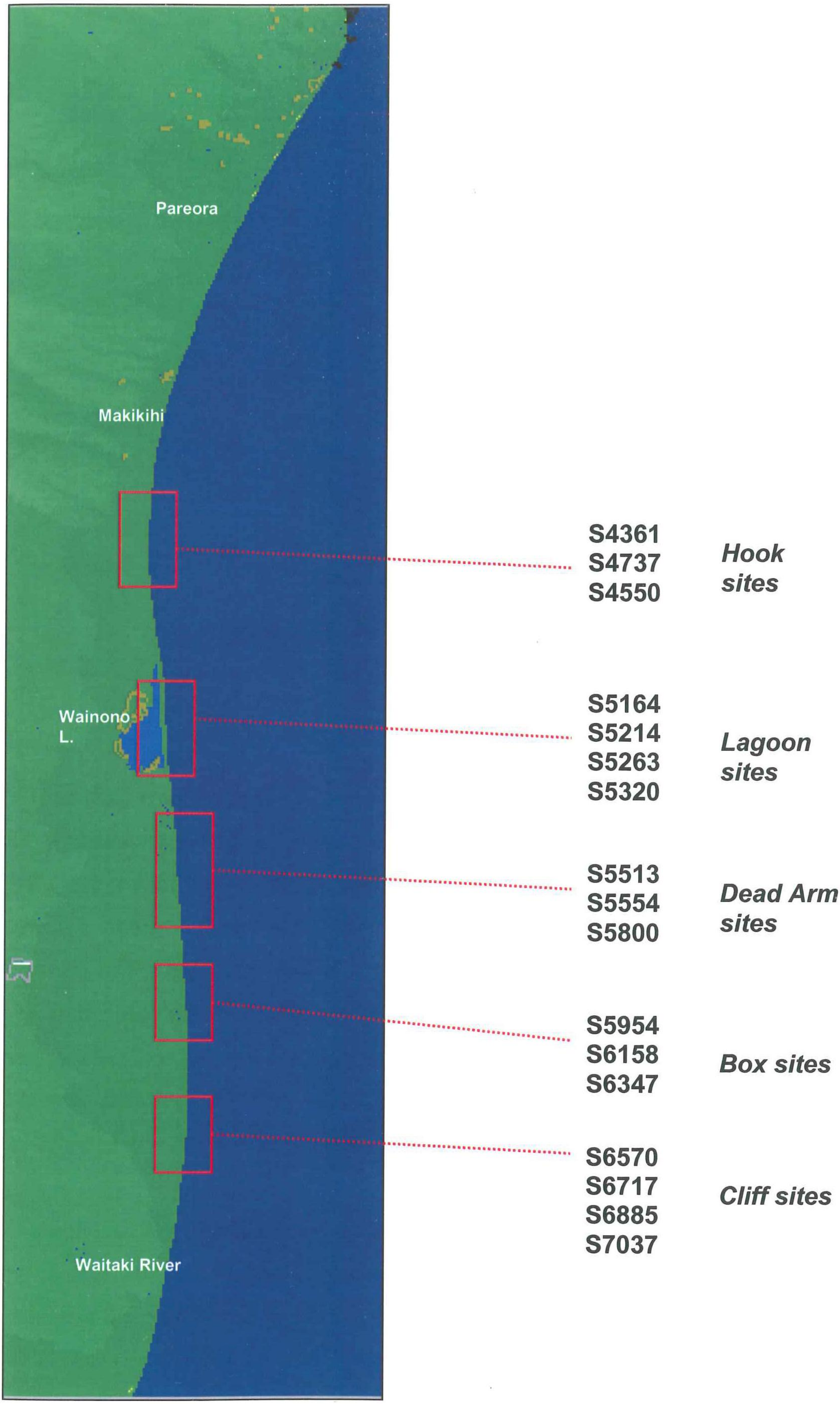


Figure 4.1: Location of study sites along the Waihao-Wainono Barrier. The red boxes correspond to the site numbers and sections to the right.

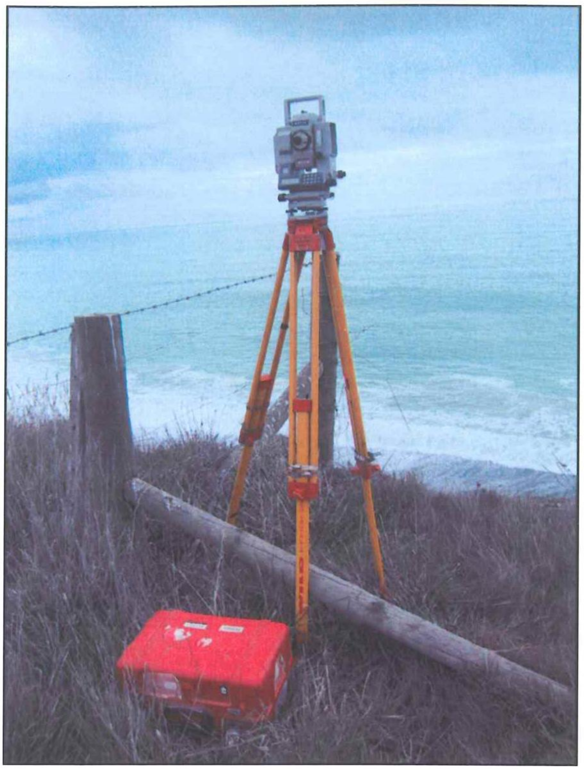


Figure 4.2: Photo of the Sokkia 4B Total Station used in surveying.

The profiles were perpendicular to the shoreline, except for those that ECan survey at an oblique angle to the coast, in which case the author also surveyed with an angle. All surveys were carried out as close to low tide as was possible in order to cover the greatest amount of barrier as was possible. Because of the dangers in surveying seaward of the breaking wave, the sea conditions and the steepness of the foreshore, the staff holder decided at which point the profile would end. The area within the swash zone was the greatest seaward extent of all profiles and constantly changed between sites with the tidal cycle. Subsurface profiles were also carried out in the trenches of the cliff sites and will be described in a later section.

Once the survey data had been collected it was plotted in an excel spreadsheet with horizontal data turned into a (x) coordinate and vertical data a (y) coordinate. The data was then calculated to comply with the ECan data set so each year from 1977 to 2004 could be displayed on the same graph and comparisons easily made.

The labelling of the sites follows a system that was put in place by the then South Canterbury Catchment Board. An example of one of the profile site numbers is SCS5513, where 'SC' means the site is on the South Coast, 'S' is the distance south of the Opihi River and '5513' is that distance in metres. From the information given it is obvious that the site is situated on the South Canterbury Coast 55.13km south of the Opihi River. When referring to the sites in text the number only will be used, for example 'S5513'.

4.2.2 Mechanical Excavation

In order to calculate the volume of the Waihao-Wainono barrier beach, the depth from the surface sediment to the substrate must be identified. The substrate of the barrier is the transition between the basement of the barrier (mud, silt, clays) and the mixed sand and gravel sediments that sit above the basement. The only method of identifying exactly where this point lies was to excavate areas along each profile by way of mechanical digger. This method has been used in many previous studies carried out overseas such as Bluck (1999), Neal et al. (2003). To date the primary aims of excavation have been to identify the different sediment characteristics and to provide baseline subsurface data for Ground Penetrating Radar (GPR) research. Very few inferences have been made with regard to using this information in sediment volume calculations for both sand and mixed sand and gravel beaches. Benn (1987) used the excavation method when he conducted research on the Washdyke-Seadown Lowland Coast. Part of his research was to create a sediment budget for the area in which he included sediment volume calculations.

4.2.3 Resource Consent

For the research to be carried out, the first process was to gain resource consent. Section 12 of the Resource Management Act (RMA) 1991, requires that a resource consent is needed for activities that may have an adverse effect on hazard risk, such as disturbance of the beach profile. Because excavations of the foreshore were planned, Rule 9.2 of the Canterbury Regional Coastal Environment Plan had to be followed. This rule considers the excavation of areas of the barrier to be a discretionary activity. It was deemed by the researcher that effects arising from the excavations would be not more than minor. However, to satisfy the test for non-notification under section 94 of the RMA, landowners, the Waihao Runanga, the Department of Conservation and

Fish and Game New Zealand were notified in writing of the proposed research, and what it entailed. These letters were sent out on the 16th March 2004. A copy of the letter is included in Appendix 2 along with a list of people it was sent to.

Both the landowners of the area and the Waihao Runanga responded by wanting to gain more information. The Runanga decided that a Hui was required in order for all parties to completely understand the objectives of the research process and how it would be carried out. The Hui was attended by the researcher, the Waihao Runanga, representatives of the local landowners and the Meridian Energy iwi liaison group. It was held at the Waihao Runanga Marae on the 23rd of March 2004. The Hui resulted in several conditions being placed on the consent with regard to accidental discovery of cultural artefacts and site choice. The details of this are also provided in the appendices. The Land Use consent to carry out works in the coastal hazard zone from the Morven-Glenavy cliffs to Makikihi coastline for a period of two years was granted on the 21st of April 2004 pursuant to Section 104 of the RMA. A copy of the Resource Consent is included in Appendix 2.

Thoughts on The RMA (1991) Consent Process

My experience of the Resource Management Act has proven to be both positive and negative. The Resource Management Act is an effective legislation in terms of its power as an overall authority to protect the physical and natural environment. The RMA does provide a very effective tool for negotiation. It was great in terms of being able to meet the locals and gain their perceptions of the barrier and to understand the importance it holds for the local community. Most of the local landowners were more than willing to assist with the research by helping identify the weakest areas of the barrier, allowing me access to the barrier from their farms, and also lending me a four-wheel bike.

The negative side of the RMA is that the consent process can be a very long and drawn out one. There seems to be too much room for consultation, and this can be negative for the applicant. In terms of my research it has had several direct affects on the exact methods used and the quality of data obtained:

- The Hui caused delays and affected the timing of the research. The fieldwork was delayed for over one month and optimum conditions were missed for gaining the most concise data. The tidal cycle was a controlling factor in the fieldwork. The optimum time to gain a full day's fieldwork was if low tide occurred around 11am to 12pm. The month missed would have provided the most complete profile data because the tidal range was greatest at that time allowing the maximum beach width to be surveyed

- The initial idea was that trenches be made at all profile sites. Instead through discussions it was decided that pits would be a more stable method for all non-cliff sites. If trenches were allowed, the substrate data would have been very concise and would have left no assumptions. Through excavating pits, only points of the substrate were known and assumptions had to be made on substrate form between the pits.

- The Waihao Runanga was unhappy with the excavations taking place at several of the sites backing the Wainono lagoon. Several planned sites were thus unable to be incorporated into the research. The Runanga were however happy to advise me of the sites that were suitable. Purely in terms of the research, more sites at the Wainono lagoon would have been ideal. The Lagoon is an area of particular interest as several breaches have occurred in the past. Obviously the more data obtained from this area, the more beneficial the research in terms of breach mitigation and coastal planning.

4.2.4 Actual Excavation Method

The mechanical excavations for this research are now described in detail. The reason that a digger (Figure 4.3) was used is because there was no other option at the time. Excavation was the only method that could be used to gain information on both the sediments within the barrier and the depth of the substrate.

Figure 4.3: Photo of the Digger (Rooney Earthmoving) used to excavate the pits and trenches on the Waihao-Wainono Barrier.

Excavations were carried out along the survey profile lines described in section 4.3.1. The pits and trenches were excavated as near to low tide as possible to gain data from the greatest barrier width available. Initially, it was assumed that three to four pits would be sufficient at each profile site, encompassing the backshore, foreshore and swash zones. The number of pits actually excavated at each site varied depending on such things as the width of the barrier, the tide line, and on what was found within the first two pits. For example at three sites, only two pits were excavated as both pits displayed no clear boundary between between beach gravels and the substrate, which was not reached. This lack of boundary meant there was then no need to disturb the beach by excavating a third.

Once the substrate was met, the depths from the surface to the substrate were measured with a tape measure and sediments were collected at various heights and layers. At the sites where substrate was not reached, the height was still recorded as it was deemed to be just as important to know the minimum depth at which beach material was reached.

At the cliff sites it was agreed that trenches would be excavated as landowners believed the barrier to be stable enough in this area to allow trenches. The trenches are a more comprehensive method than pits as the substrate can be exposed the whole way across shore rather than in certain points, as was the case with the pits. By excavating trenches, a complete substrate profile could be surveyed, making it easier to compare and line up with the surface profile. Through the use of a digger, not only was the substrate able to be identified but valuable sub surface sediment information was also gained.

4.2.5 Barrier Volume Analysis

Barrier volume was calculated for all study sites. The net volume was calculated as the area between the surface profile and the substrate profile at each site. All calculation were taken down to mean sea level (MSL), as the barrier was not surveyed beyond this point. At the sites where the substrate boundary was not reached, the volume was calculated from the assumed substrate profile of MSL. All volume figures are displayed as m^3/m.

4.3 Barrier Sediment Characteristics

Understanding beach sediments is a prerequisite for gaining essential information on the nature of the beach and the way in which it responds to different coastal processes. Once this is understood, substantial changes in coastal management, planning and development can be made (Kirk et al. 1987). One of the primary objectives of this research is to gain spatial and temporal information on the distribution of sediment sizes across and along the barrier. Surface samples were collected at each site, along with subsurface collections made possible through the use of a mechanical digger.

4.3.1 Sediment Sampling

Surface samples were gathered according to a purposive system rather than a random one. Hewson (1977), Benn (1987), Dawe (1997), Hart (1999) and Vessey (2003) all used this system of sediment collection on various South Island mixed sand and gravel beaches. The topographical features of the beach, or areas with obvious changes in sediment size were thought to be locations in which the best data would be gained. This allowed for a representative sedimentological range of the morphological divisions of the beach. Because of this, the number of sediment samples varied between sites, although each profile had at least four points of surface collection. The swash zone, the middle berm, top ridge and backshore area were all sampled, so that once analysed, the information could be compared with previous sediment data from 1977 and 1994 and with the conclusions made by Hicks and Todd (2003). The sample sizes varied according to sediment size but generally one to two spades of gravel (3-5kg) were placed into bags, sealed and labelled for easy identification in the laboratory.

Subsurface samples were possible through the use of the mechanical digger. For the non-cliff sites where pits were excavated, sediment samples were taken at various depths within each pit. Samples were chosen by sight and were collected from areas that contained clearly different sediment characteristics or an abundance of one size or type. The depth of each sample was measured with a tape measure, recorded, bagged and labelled ready to be analysed in the laboratory. At the cliff sites where trenches were excavated, subsurface samples were collected again from sight and corresponded to the topographical points of the surface samples.

4.3.2 Graphical Determination of Grain Size Statistics

One of the fundamental aims of sedimentary research is to analyse the textural properties of the sediments. It has long been recognised that size plays an important role in the overall morphology and characteristics of the beach. The grain size system was first proposed by Udden (1898) and is the most popular system in use today. It is a geometrical millimetre grade scale based on the $\log_2$ scale. The boundaries between each grain size are fixed so that each grain size category is twice the preceding size. For example, a very small pebble (4mm) is twice the size of a granule (2mm), which is again twice the size of very coarse sand (1mm) and so on. This scale was revised by Wentworth (1922) and is known to many as the Udden-Wentworth scale (Appendix 3). Krumbein (1934) developed the phi (ø) scale due to the complexities involved in the calculations dealing with numbers that were up to 10 000th of a millimetre. The following is the formula used:

$$\varnothing = -\log_2 d$$

where: ø= phi size

d= sediment particle diameter in millimetres

The scale was inverted, as the most commonly sized particles studied at the time were sands and silts. The introduction of the phi scale meant that fractions were eliminated and particles greater than 1mm are negative values.

The Udden-Wentworth grain size scale is relatively simple; measuring it is not so simple. Folk and Ward (1957) suggested six different methods to express grain size. All have associated limitations and uncertainties. One of the most popular methods of grain size analysis is mass measurement of a sediment sample through the use of the sieving technique.

The sieving procedure involves arranging a series of sieves in an ordered stack, each sieve being ¼ of a phi unit smaller than the one above. It provides a measure of the smallest cross-sectional diameter termed the intermediate axis length (Lewis and McConchie, 1994a). The sieve with the largest phi size is placed on top and the smallest on the bottom of the stack. Sediment sample preparation usually involves drying and weighing the sample. Overall 136 samples were sieved in the Geomorphology Laboratory, Department of Geography, University of Canterbury. For this research, material of size -4ø is placed in the top of the largest sieve and manually shaken until all the sediment that can pass through has done so. This manual process is carried out until the remaining sediment size reaches 1ø. At this stage the sediment is placed in smaller sieves that can fit the mechanical shaker, the sieves are then shaken for a minimum of 10 minutes and a maximum of 20 minutes. During the entire process, sediment grains collect on the variously sized mesh screens of the sieves.

Each sieve fraction is weighed and then converted into a percentage of the total sample weight. There is no upper or lower limit to the size of sediment that can be sieved, but for practical reasons it is normally restricted to sediments from fine gravels (-4ø) to very fine sand (+4ø). For samples above -4ø, manual callipers or a gravelometer are used. A gravelometer is a template that has larger sized phi holes cut into it and through which the larger gravels that do not fit the sieves have to be passed. Material finer than +4Ø was not analysed as this size fraction is considered insignificant in MSG beaches (Folk, 1966). The samples that contained a greater amount of sand and sediment with dried mud attached were washed, the mud wet sieved and the whole sample dried in the oven at a temperature of 70°C and sieved using the process outlined above.

Although sieving only measures one dimension of the particle, it is a useful method when dealing with a range of sediment sizes from very fine sand to coarse gravel. The main limitation of sieving is that it does not take into account the shape or sphericity of the grains. Kennedy et al. (1985) proposed that irregular shaped particles take longer to pass through a sieve than smaller particles. The paper concluded that sieving results are dependent on size and shape instead of solely on size. However in essence, sieving allows standardisation to be applied to grain size measurement which when used to study mixed sand and a gravel beach seems to be the most effective technique. Hence it is the method used in this study.

Once the raw data has been collected it has to be analysed to find patterns and aid interpretation. From the weight retained in each sieve, percentages of the total sample were entered into the Excel workbook used by Dawe (1997). This programme calculated summary statistical parameters including the mean, median, mode, standard deviation (or sorting), skewness and kurtosis. The mean grain size refers to the average grain phi (ø) size of a sample. The Udden-Wentworth mean grain scale (Appendix 3) was used to classify the different classes of phi scale ranging from boulders to silt. The median is the phi size at the fifty percent by weight percentile, i.e. half the particles are finer than the median and half are coarser. The mode is the most common grain size within the sample. Several modes may exist within one sample, especially in samples on mixed sand and gravel beaches where bimodal and polymodal samples are common. The standard deviation is how much the sample varies from the mean. This variance is a measure of the sorting of a sample. Samples containing a wide range of sediment sizes have a large standard deviation and are poorly sorted. Samples with a small grain size range have a small standard deviation, hence are well sorted. Sorting and the mean grain size were the two sediment characteristics analysed in this research. For mean grain size (mm) was used so temporal comparisons could be made and for sorting, both phi and millimetres are used.

A popular belief suggested by several researchers is the idea that sorting is strongly a function of grain size (e.g. Folk and Ward, 1957; Griffiths, 1951). It is thought that the best sorting should always occur amongst fine sand (2-3∅). The sediment sizes between fine sand and gravel are the most poorly sorted. The sorting improves once again as the larger gravel range is reached.(-3--5∅) and the fine clay range +10∅. This suggested relationship produces a sine curve with two distorted cycles (Figure 4.4).

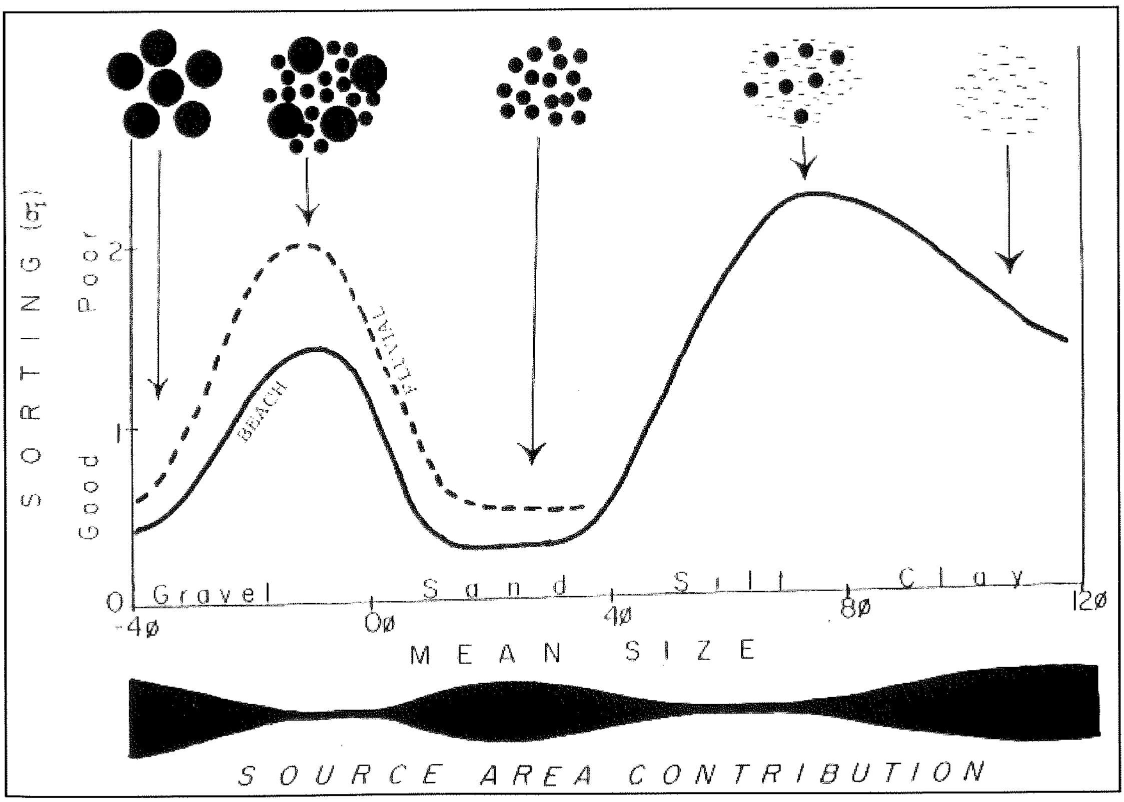


Figure 4.4: The universal size versus sorting relationship presented by Folk (1965:6).

This shape occurs because the weathering processes produce three basic sediment groups:

- Larger sediment produced by blocky breakage of rocks along join or bedding planes.
- A sand-coarse silt group produced by weathering of granular rocks.
- Clay type sediments produced through chemical reactions.

Any material that fits between these three sediment populations shows granules-coarse sand and fine silt are scarce. Folk (1965) developed a source area hypothesis stating that sediments in these two size ranges must be composed of either sand with pebbles, or be of sand or coarse silt with clay. This explains the sinusoidal size-sorting relationship.

A sample can also be referred to in terms of skewness and kurtosis. Skewness is a measure of the degree of symmetry in the distribution curve. A symmetrical curve has a normal distribution. A negatively skewed sample contains an excess of coarse material so is often referred to as coarse skewed. In contrast, a positively skewed sample contains an excess of fine material and is referred to as finely skewed. Kurtosis is the peakedness of a distribution curve and is the ratio between the sorting of the tails and the sorting of the central portion of the sample. A sample is termed leptokurtic if the central portion is better sorted than the tails, making the curve excessively peaked. If the tails are well sorted compared to the central portion of the curve it is termed platykurtic where the curve is deficiently peaked. Platykurtic curves are often bimodal, with one mode more dominant than the other. Examples of skewness and kurtosis are shown in Figure 4.5 (Vessey 2003:62).

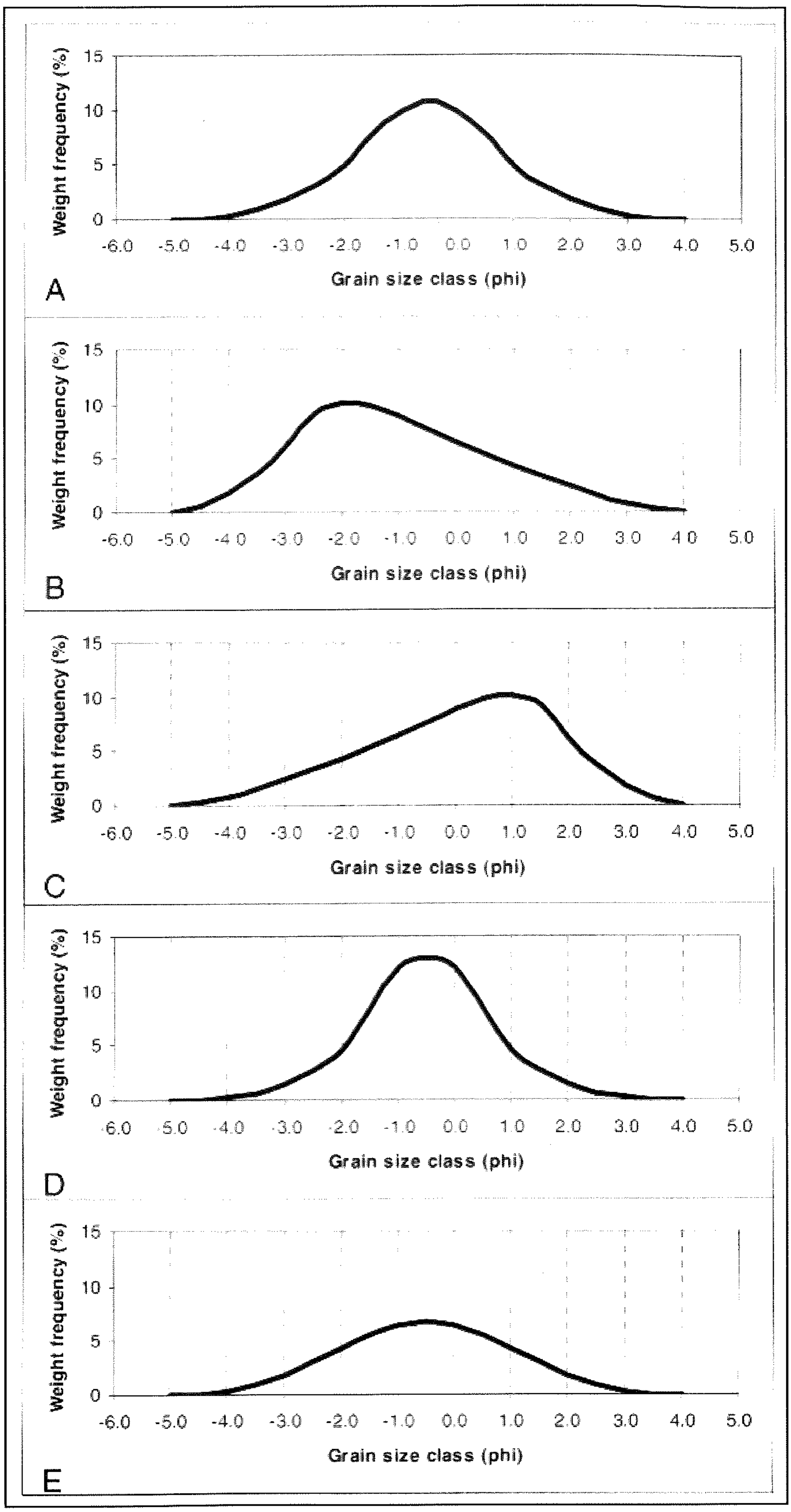


Figure 4. 5: Distribution curves for (A) a "normal" sample, (B) a positively skewed sample, (C) a negatively skewed sample, (D) a leptokurtic sample, and (E) a platykurtic sample (Vessey, 2003:62).

The statistical parameters outlined above can be calculated by graphical methods as found in Folk and Ward (1957) or by the method of moments (e.g. Folk, 1966). The graphical method involves graphing the raw data as a grain size distribution curve. The graph most commonly used is the logarithmic cumulative frequency curve, which presents the phi scale on the x-axis and the cumulative weight percent of each phi on the y-axis. The method of moments is calculated from several different equations. It is agreed by many (Inman, 1952; Lewis and McConchie, 1994a; Folk, 1966) that either method is appropriate and that the same geologic conclusions would be met no matter which method is used. Balsillie (2002) does not agree and believes that the results differ between the graphical method and the method of moments equations. Balsillie et al. (2002) based their study on 211 sediment samples and concluded that the graphical method underestimated the moment mean by 0.6∅.

The graphical equations used in this study are those developed by Folk and Ward (1957) and are the same equations as those used by Dawe (1997). Folk and Ward's parameters:

Graphic mean $(M_z\varnothing) = \dfrac{\varnothing 16 + \varnothing 50 + \varnothing 84}{3}$

Inclusive Graphic standard deviation (sorting) $= \dfrac{\varnothing 84 - \varnothing 16}{4} + \dfrac{\varnothing 95 - \varnothing 5}{6.6}$

Inclusive Graphic skewness $(SK_I) = \dfrac{\varnothing 16 + \varnothing 84 - 2\varnothing 50}{2(\varnothing 84 - \varnothing 16)} + \dfrac{\varnothing 5 + \varnothing 95 - 2\varnothing 50}{2(\varnothing 95 - \varnothing 5)}$

Graphic Kurtosis $K_G = \dfrac{\varnothing 95 - \varnothing 5}{2.44\,(\varnothing 75 - \varnothing 25)}$

The ∅ variables are abstracted from the cumulative graph.

It is widely believed that the method of moments is more mathematically accurate than the graphical method for determining the summary statistics of a sieved sediment. The method of moments was proposed for sediment analysis by Van Orstand (1925) and includes the whole frequency distribution rather than a few selected percentiles that the graphical method uses. Two of the equations are given below where D is the midpoint of the phi class of the sample and W is the sample weight:

1st Moment (mean): $$M\varnothing = \frac{\sum DW}{\sum W}$$

2nd Moment (Standard Deviation): $$\delta\varnothing = \sqrt{\frac{\sum [W(M\varnothing - D)^2]}{\sum W}}$$

Folk (1966) has identified several disadvantages of the method of moments:

1. Any faults in the sieving equipment can lead to distortion in the in the third and fourth moments (skewness and kurtosis).

2. The method of moments requires that the whole sample distribution is calculated. However, many sediment distributions are open ended in that they contain a large portion of unanalysed grains. Because the whole distribution is required, assumptions about unanalysed fractions have to be made.

3. In terms of computation there is an assumption that grains within a class interval have a centre of gravity at the halfway mark of the class. This is not necessarily true, as the midpoint has been shown by Folk (1966) to deviate by as much as 0.30∅.

The writer agrees that both the graphical method and the method of moments have their advantages and their limitations. Both are suitable for analysing a large number of samples as long as the weaknesses and strengths are acknowledged. For this study the graphical method has been used.

4.3.3 Modal Analysis Technique

Curray (1960) revived the modal analysis technique that had been limited in use up until the 1960's. Modal analysis is a technique used to complement grain size analysis. In many cases the use of grain size was not solving many issues in the analysis, such as the deviation from normal distribution. Curray (1960) believed this to be attributed to the fact that sediment samples can contain a large range of sizes comprising of more than one sole mode (unimodal). Most clastic beaches and barriers contain at least three different sediment populations, being gravel, sand and clay (polymodal) (Spencer, 1963). For polymodality to be detected the grain size distribution must have more than one population of sedimentary particles and they must be clearly separate from each other.

Due to the difficulty in describing bimodal and polymodal sediment samples, they are commonly described in terms of the relative proportions of gravel, sand and mud. The proportions can be described in many ways but the most common form is that used by Folk, Andrews and Lewis (1970) and are shown in Figure 4.6.

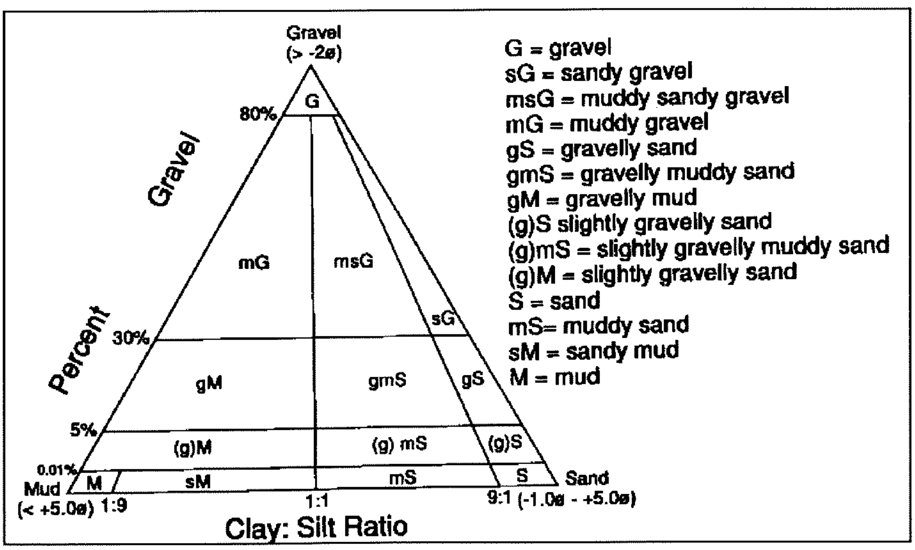


Figure4.6: Textural terminology for gravel bearing sediments. From: (Folk et al., 1970).

The most common type of modal analysis is to construct a frequency curve of the data obtained from the sieving process. Krumbein (1934) outlined a method of deriving a unique frequency curve from the cumulative curve through using graphical differentiation, which involved the use of a tangentometer. The tangentometer is a difficult piece of equipment to acquire so Brotherhood and Griffiths (1947) constructed an involved mathematical method to determine the unique frequency curve. The first, second and third differences of the cumulative curve were compared to obtain an approximate derivative. Curray (1960) used a less precise method based only on the first differences because he felt that the mathematical method was too time consuming. In this study, the frequency distribution curve is formed directly from the raw sieve data. This method is just as efficient as the Brotherhood and Griffiths (1947) method as shown through comparisons determined by Vessey (2003:68) (Figure 4.7) and is a much simpler process.

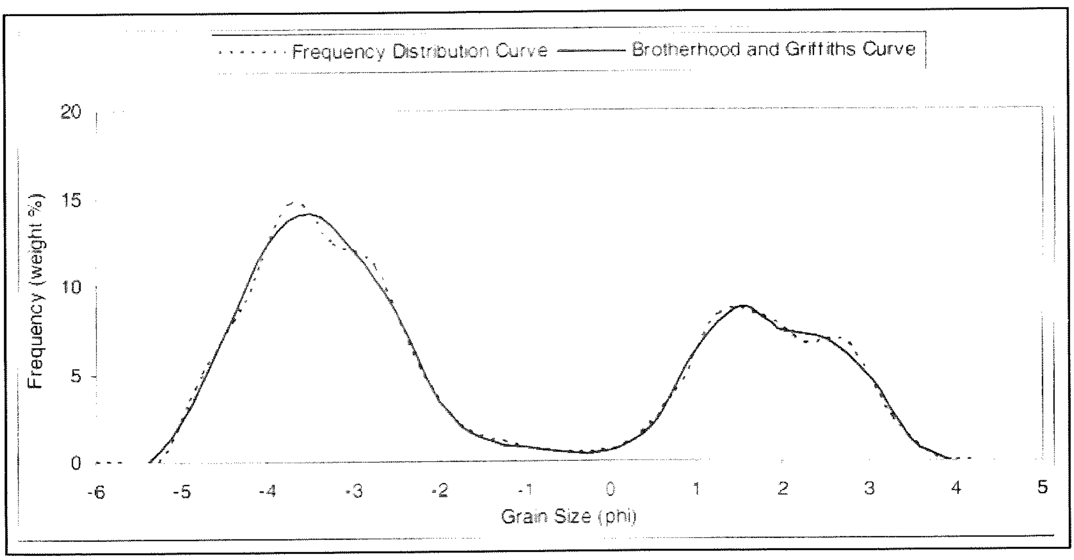


Figure 4. 7: Comparison of mathematically derived unique frequency curve (Brotherhood and Griffiths 1947) with the frequency distribution curve derived directly from raw sieve data. The same modal peaks are detected from either curve; therefore the complex mathematical derivation is unnecessary for modal analysis.

4.4 Summary

A review of the barrier volume and sedimentary analysis techniques used in this study have been provided. To calculate barrier volume at each site, mechanical excavation, requiring a resource consent, was employed to gain data on the substrate profiles. The sediment techniques utilised in this research involve sieving samples to gain mean grain size values. From this, the Graphical approach provided by Folk (1965) was used to calculate sediment sorting values for each sample. The suggestion by Folk (1965) that there is a dominant mean grain size-sorting relationship was also reviewed. Chapter Four has positioned this study into a broader theoretical framework. The following chapter discusses the results obtained from the barrier volume analysis reviewed in this chapter.

Chapter Five

Barrier Profile and Volume Analysis

5.1 Introduction

This chapter presents and discusses the results obtained from surveying both surface and substrate profiles along the Waihao-Wainono barrier. The study is based on the analysis of 17 profile sites. The form of the surface profiles will be presented first, highlighting trends in barrier shape, height, width and slope. This is followed by a discussion on the substrate profiles, again focusing on the characteristics outlined above. An understanding of the surface and substrate barrier form leads to the analysis of barrier volume, the focus of this chapter.

In the past both the substrate form and net barrier volume have been estimated. This chapter hopes to solve the uncertainty and to provide insights into the form and function of the Waihao-Wainono barrier. From this research it is envisioned that new insights into why a barrier breaches at some sites and not others may be identified.

5.2 Surface Profile Morphologies

ECan and the former South Canterbury Catchment Board have carried out surveying of the barrier since 1977. There is now a substantial data set on the surface form and the fluctuations that have occurred over this time period. This information can be used to investigate temporal terms. Although the beach in front of the Morven-Glenavy cliffs and the Waihao-Wainono barrier is a continuous mixed sand and gravel beach system, the beach morphologies vary markedly. For this reason, the profile results are presented in sections, as shown in Table 5.1. The cliff section is presented first, as it consists of the most southern sites, is nearest to the two dominant sediment sources of the Waitaki River and the cliffs themselves, and because transport is away from this area to the other sections further north (Neale, 1987). All surface profile forms are displayed in the set of graphs starting on page 105. Reference is made to them throughout the substrate form section as well.

Table 5.1: Profile site names and numbers and the sections they are grouped.

ECan Profile Site	Name	Distance North of the Waitaki River (Km)	Section
S7037	Archibald's Road	7.2	***Cliffs***
S6885	McLeay's Road	8.8	
S6717	Morris Road	10.3	
S6570	Morven Beach Road	11.0	
S6347	Ryan's Road	14.0	***Box***
S6158	Maori Road	15.7	
S5954	Waihao Box	17.9	
S5800	Lows Road	19.4	***Dead Arm***
S5554	Waimate Creek	21.9	
S5513	Poigndestres Road	22.5	
S5320	Wainono South Bank	24.4	***Lagoon***
S5263	Wainono North Bank	25.0	
S5214	Wainono Lagoon	25.5	
S5164	Wainono Hut	26.0	
S4550	Hook Swamp Road	32.0	***Hook***
S4737	Hook Beach Road	32.1	
S4361	Makikihi	34.0	

5.2.1 Cliff Sites

As shown in Figure 5.3, all four cliff sites display similar surface profiles with the maximum 2004 beach heights ranging from 5.3m to 6m. The profiles are very flat and display gentle slopes from the cliffs to the foreshore. The beach slopes at the cliff sites were surveyed as being 7.4° at S7037 and 9° at both S6685 and S6717. The cliff sites have very narrow beaches, which appear to have widened over the years as the cliffs have eroded supplying the beach with more sediment and a larger area over which to distribute it. The width of the beaches in 2004 range from 37m to 42m (Figure 5.2). Although the cliff line has eroded over time, the beach profiles have not varied dramatically at Archibald's Road (S7037), McLeay's Road (S6885) and Morris Road (S6885). In contrast, Morven Beach Road (S6570) has experienced quite dramatic changes. At this site, human modification has occurred with the dumping and track formation. This site is not included as part of this research as the human modifications are too large and the data gained would be non comparable to the data gained from the other sites within the study area.

5.2.2 Box Sites

Situated to the north of the cliff sites is the section of three 'box' sites, being those that are situated in the vicinity or to the south of the Waihao Box outlet. Figure 5.4 displays that the box sites have similar surface profile shapes. Both Ryans Road (S6347) and Maori Road (S6158) contain three to four berms. The Waihao Box site (S5954)does not display as many berms as the other two in the box section, however from visual examinations of the site, it is clear that it has been altered due to the construction and maintenance of the Waihao Box outlet. Also it is an area that is popular for fishing and there is a clear four-wheel drive path near the site that recreationalists use to gain access to the barrier. Even though there has been some human modification, the site is still considered to be in a comparable state to the other sites.

The maximum 2004 height is 6.33m at S6347 and the smallest maximum height is 5.07m at S6158. The beach widths for the three sites range from 61-69m, almost double the width of the cliff sites. A distinguishing feature of the box profiles is that 'roll over' of the barrier is visible, and is especially clear at S6158 where the crest has moved landward and the barrier ridge has decreased in height (Appendix 4). Washover lobes are also prominent in this area. The foreshore slopes are slightly greater than those of the cliff sites. Ryans Road (S6347) fits the MSG slopes outlined by Kirk (1980) with a foreshore slope of 6.9°, the other two slopes are steeper, at 9.8° at Maori Road and 11.2° at Waihao Box. Waihao Box (S5954) has shown more variability than the other two sites throughout the 30-year surveying period. This is considered to be due to the opening, closing and rebuilding of the Waihao Box outlet, within 50 metres of the profile site.

5.2.3 Dead Arm Sites

The Dead Arm sites are named as such because two (Lows Road S5800, Waimate Creek S5554) of the three sites in this section have the Waihao Dead Arm immediately landward of the backshore of the barrier (Figure 5.1). It is important to note that these two sites have experienced past breach events. The two profiles are both similar in surface shape, have steep (13.8° and 13.7°) foreshore slopes extending to the highest barrier ridge, and very steep backshore slopes to the Waihao Dead Arm (11.2° and 24.3° respectively). The Waimate Creek backshore slope is steep because when this site was breached, the barrier sediment was forced by wave action into the creek. It was necessary for the creek to be cleared to prevent further flooding, so the sediment within it was artificially moved back onto the barrier. The steepness of both the backshore and foreshore slopes may also be a key factor in the breaching of the two sites. The third site, (Poigndestres Road S5513) is located near to where the Dead Arm meanders landward away from the barrier. This site has a flatter foreshore slope compared to the other two sites, displaying a stronger, flatter surface form compared to the other two sites, and has not been breached.

Figure 5.5 shows that at the time of the 2004 survey, the sites have a 10m difference in width. The heights of all Dead Arm sites are similar ranging from 5.1m to 5.5m. The highest site is the most northerly of the section, Poigndestres Road (S5513). With regard to temporal change, the two breach sites have experienced a lot of variability in shape, while the Poigndestres Road has been more stable in form.

Figure 5.1: The Waimate creek site (S5554), displaying the Waihao Dead Arm to the backshore of the barrier.

5.2.4 Lagoon Sites

The lagoon sites are those in front of the Wainono Lagoon. Figure 5.6 exhibits that all four sites in this section show similarities in shape, width and height. All 2004 maximum barrier heights range from 4.9m to 5.8m and the widths range from 74m to 124m, a much greater variation in width than at the Dead Arm sites. This is because the Dead Arm sites, as well as Maori Road, are controlled to some extent by the stop banks and the Dead Arm itself. These stop banks provide an artificial limit to the beach width. In contrast, the lagoon sites do not have stop banks, allowing the barrier to roll in the landward direction, creating greater beach widths than those of the Dead Arm. The widest site is the most northerly of the lagoon section.

The shape of all sites displays distinct crest peaks and berms and the foreshore slopes are relatively steep ranging from 8.2° to 11.9°. Wainono Hut (S5164) and Wainono Lagoon (S5214) breached in 1985 and again in 2001. These sites have a steep foreshore and backshore slope and are similar in shape to the other breach sites of Waimate Creek and Lows Road.

5.2.5 Hook Sites

As shown in Figure 5.7, Hook Swamp Road (S4550) and Hook Beach Road (S4737) profiles are similar in both width and height. A distinct barrier ridge and two major berms occur at both sites. The two sites seem to have experienced little change throughout the 30-year surveying period. In this section, the maximum width of the barrier in 2004 was 110.2m and the height 4.70m (S4550). S4737 is slightly narrower than this and has a higher elevation of 4.67m. The slopes at both sites are steep, especially in the lower foreshore zone where S4550 has a slope of 26.2° and S4737 has a slope of 15.2°.

The Makikihi site (S4361) is the most northern site of the study and is different to both S4550 and S4737 due to the influence of a stopbank, which the beach is now rolling back over. As a result, the Makikihi profile is steep (12.7°) and narrow (60.3m) wide. The beach elevation was 4.9m in 2004, which corresponds to the height of the stopbank.

5.2.6 Comparison of Profile Slopes to Neale (1987)

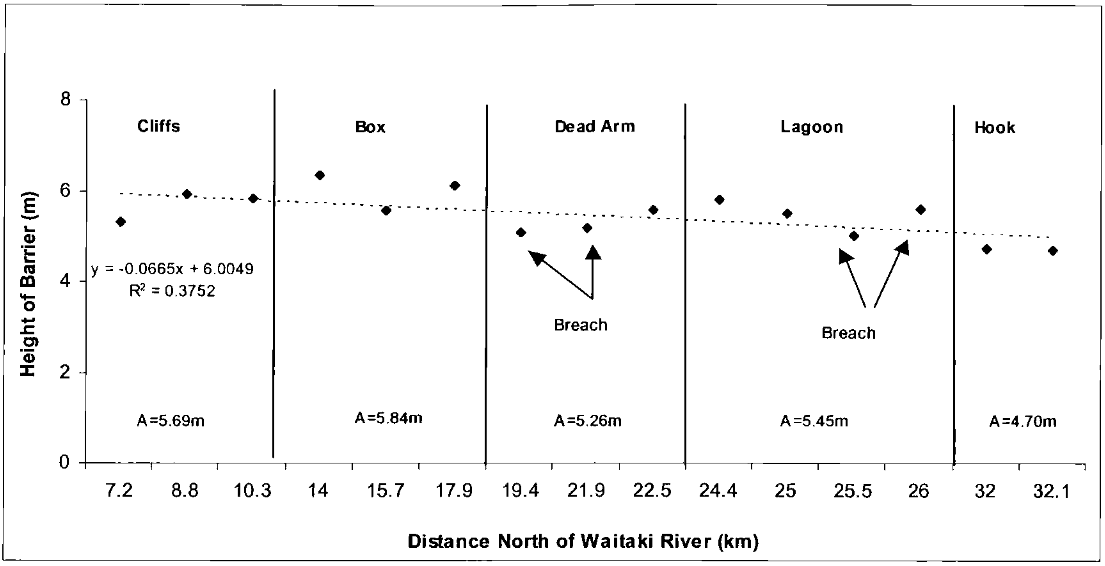
The Hook sites do not fit Neale's (1987) idealised MSG profile zone in terms of the foreshore face. Neale calculated a range of 5°-12° for this zone. This research shows that the foreshore face has in fact a much greater and steeper range than that proposed by Neale (1987). This could be because the surveying for each study was carried out at different times of the year. For this thesis, the research occurred during the autumnal months of April and May. At this time of year, beaches tend to be in a more reflective state, as the winter storm events have not yet greatly modified the barrier forcing a response to a more erosional form. Through identifying all foreshore face slopes, the Waihao-Wainono barrier contains slopes from 11°-26°. However, the foreshore slopes higher up the beach do fit the 5°-12° range suggested by Neale.

5.3 Barrier Surface Profile Longshore Trends

From the above descriptions it can be seen that the Waihao-Wainono barrier surface profiles vary longshore. Each section contains three sites apart from the cliff section that contains four. Within each section, the surface profiles tend to show similarities between two sites. A third site generally has a slightly different form to the other two.

In general the following spatial trends in barrier surface form can be identified:

- Barrier height decreases to the north (Figure 5.2)
- Barrier width increases to the north (Figure 5.2)
- Foreshore slopes become more stable and flatter to the north
- Backshore slopes become flatter to the north
- The breach sites generally have steeper foreshore and backshore surface slopes.
- The lower foreshore slopes at the breach sites are steep (11.3°-13.8°).



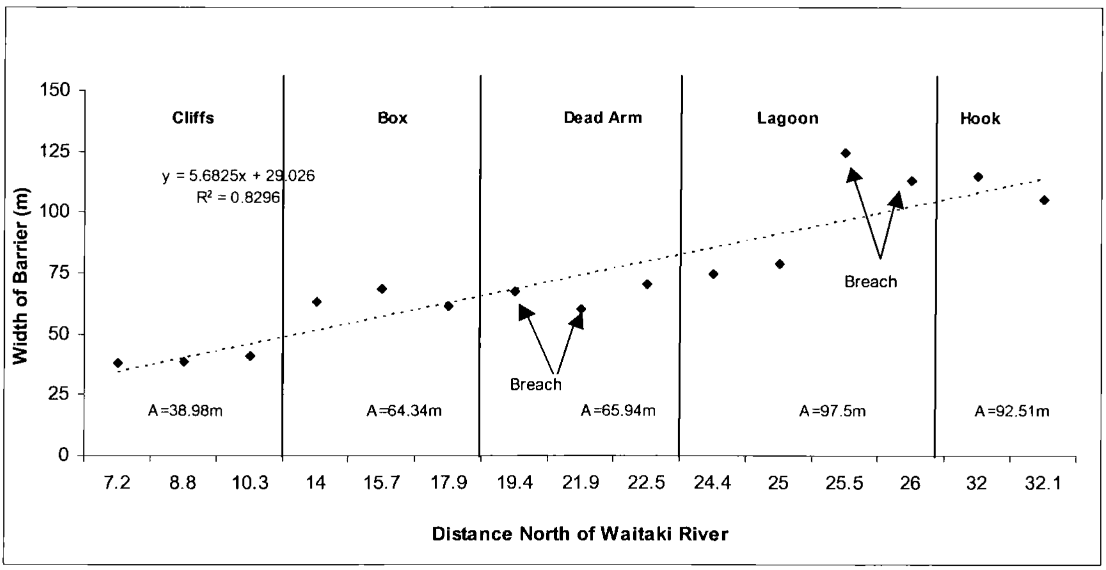


Figure 5.2: Spatial variation in barrier height (top graph) and barrier width (lower graph). A= Average.

5.4 Surface Profile Temporal Changes

The temporal changes in the surface profile of the Waihao-Wainono barrier have already been presented in various theses and reports (eg: Single, 1992, Hicks and Todd, 2003) so a brief outline will be presented here.

Many sites display a large degree of temporal variation in the barrier size and shape. For the majority of time, this temporal variation is the barrier's response to high energy storm events. A prevalent perception held by many locals is that the whole barrier has reduced in size over a time period of 50 years. These perceptions are unable to be tested but temporal trends of the barrier over the last 30 years from 1977-2004 can be investigated, through the examination of ECan beach profiles. Appendix 4 displays all profile sites and the changes throughout the survey period.

Table 5.2 presents the results from Hicks and Todd (2003) on linear regression analysis of temporal trends in barrier width, height, and volume. Although at all sites except for Wainono lagoon, the barrier has become wider over time, the results show that over the total survey period it is difficult to identify a temporal trend in barrier width. For barrier height, Wainono Lagoon and Poigndestres Road are the only areas of significant height decrease. The four other sites used in the study displayed small increases in barrier ridge height over the total survey period. Again, over all sites no constant relationship occurs between ridge height and time.

Table 5.2: Temporal trends in barrier width, height, and net volume by linear regression (LR) (Hicks and Todd, 2003:71).

ECan profile location	Dist from Waitaki River	Barrier Width			Ridge Height			Net Volume		
		Total change (m)	LR Slope (m/yr)	R^2	Total change (m)	LR Slope (m/yr)	R^2	Total change (m^2)	LR Slope (m^2/yr)	R^2
Ryans Rd	14 km	+1.9	-0.41	0.35	+0.04	+0.01	0.25	+0.7	+0.38	0.04
Waihao River	18 km	+12.3	+0.60	0.49	+0.92	+0.02	0.14	+2.4	+1.39	0.30
Poingdestres Rd	24 km	+6.7	+0.34	0.16	-0.72	-0.05	0.83	-4.0	+0.65	0.04
Wainono Lagoon	26 km	-2.1	-0.08	0.01	-1.64	-0.06	0.60	-1.0	+0.02	0.0
Hook Beach Rd	30 km	+6.9	+0.24	0.04	+0.23	+0.01	0.07	+1.6	+0.74	0.03
Hook Swamp Rd	32 km	+9.4	+0.25	0.07	+0.03	+0.01	0.29	+3.4	+2.23	0.48

5.5 Substrate Profile Morphology

Results of the substrate form are presented in this section. Figures 5.3- 5.7 display all of the 2004 surface and substrate profiles. All profile distances are from the origin of the ECan benchmarks. They are grouped together rather than in sections because it is easier to visualise the longshore differences when the graphs are in close proximity to one another. The profiles are described in the same sections as the surface profiles in section 5.2.

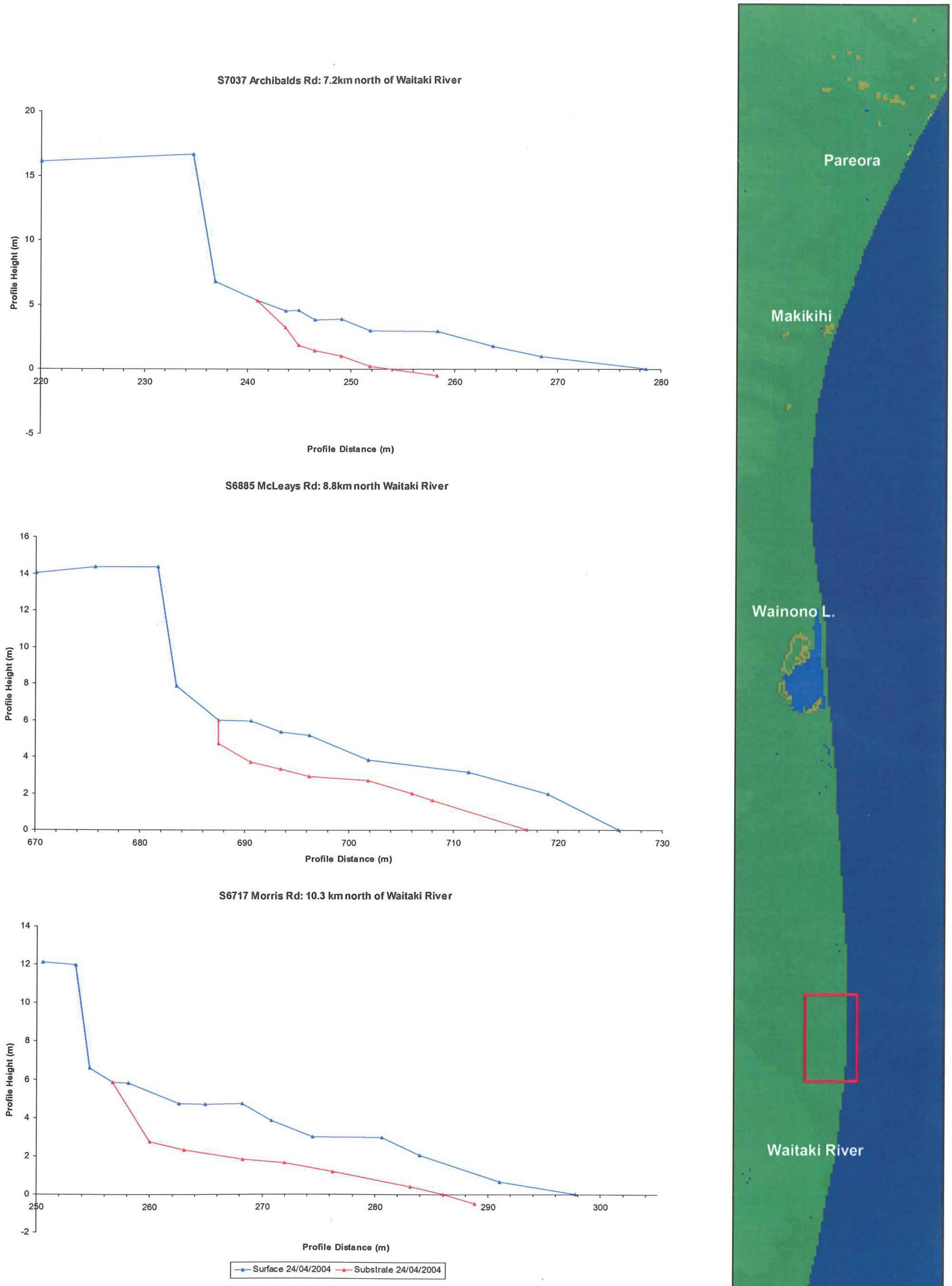
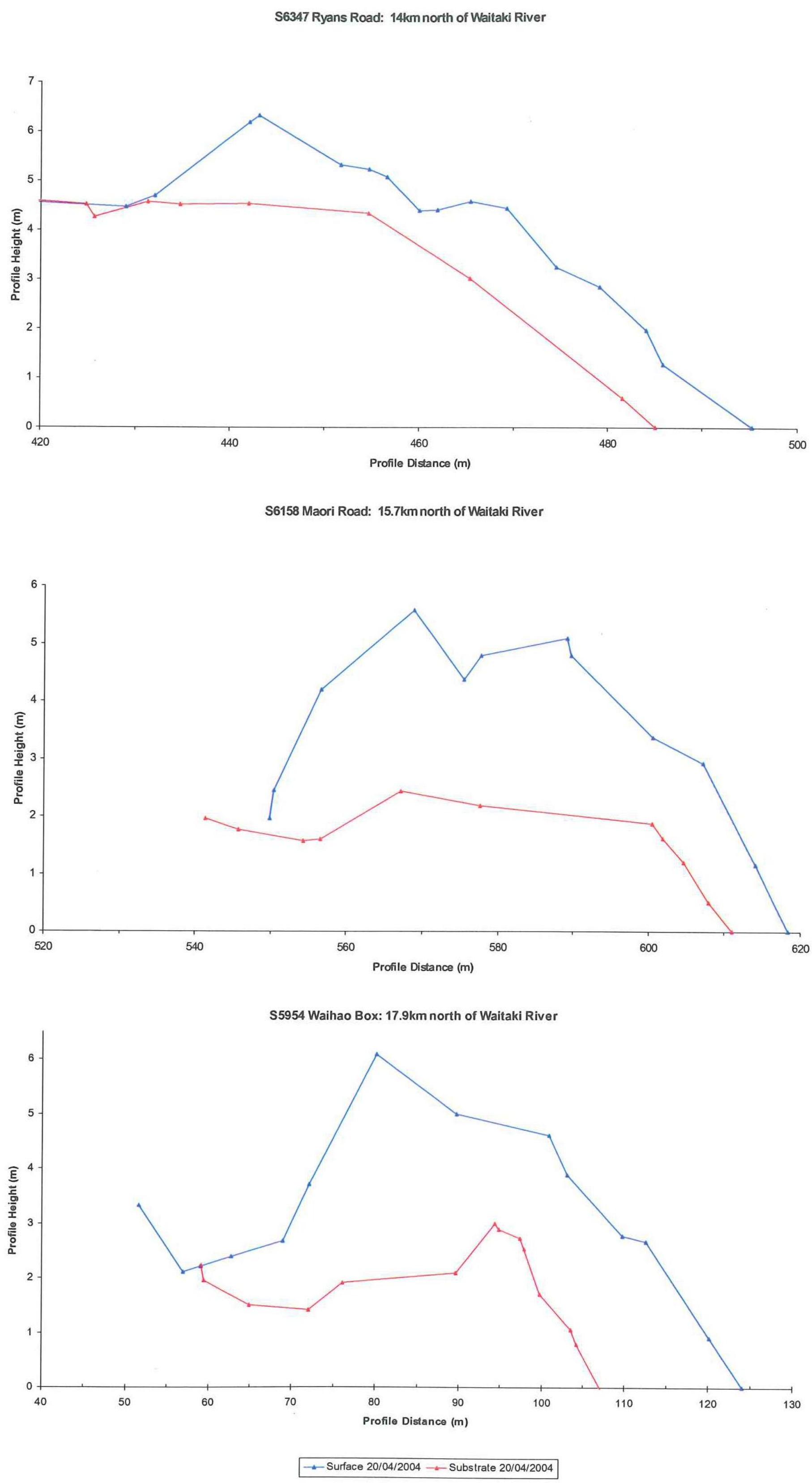


Figure 5.3: The cliff sites dispaying the surface and substrate profiles.



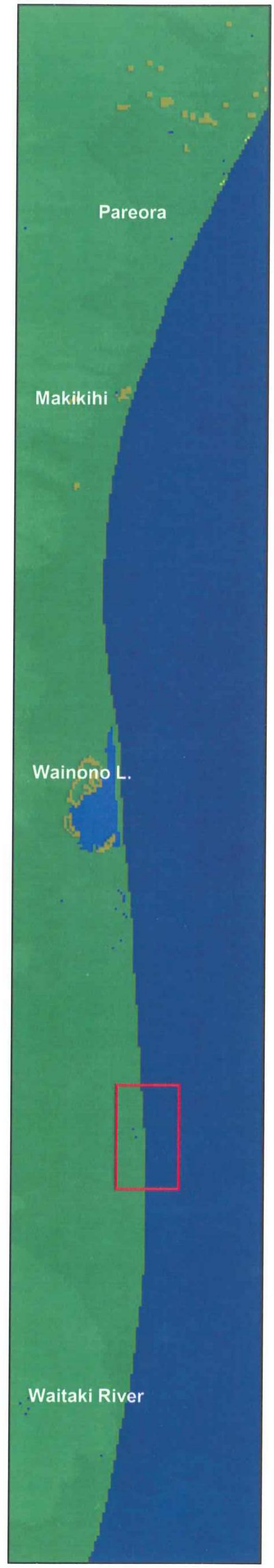
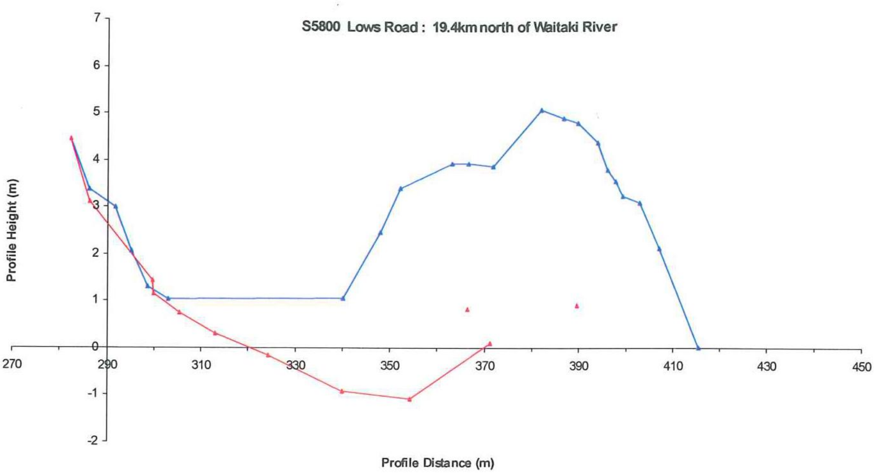
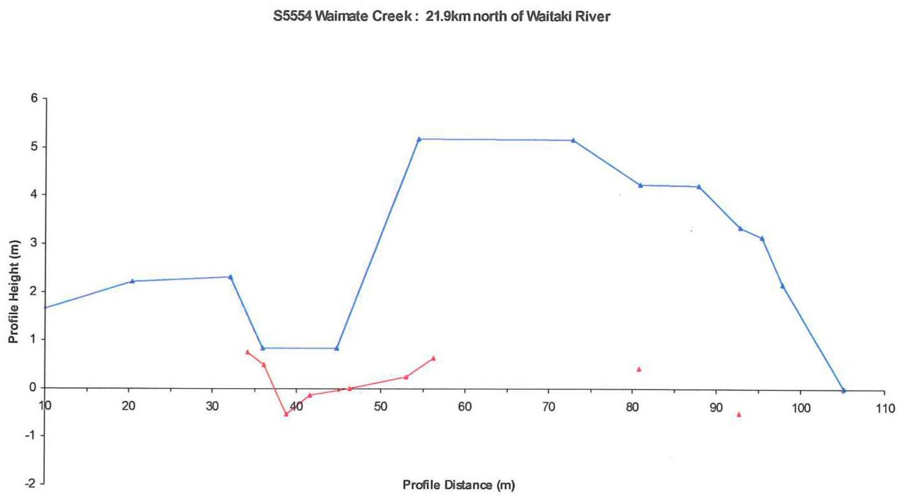
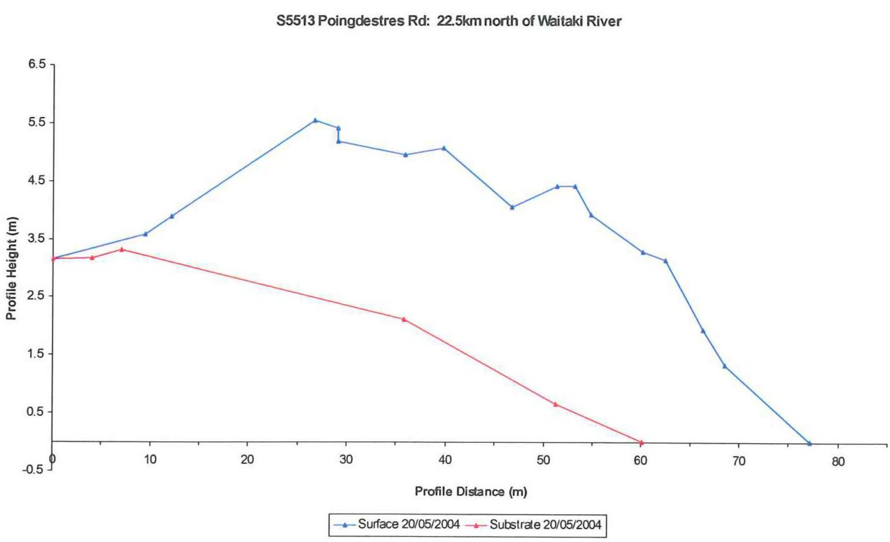


Figure 5.4: The Box sites displaying the surface and substrate profiles.







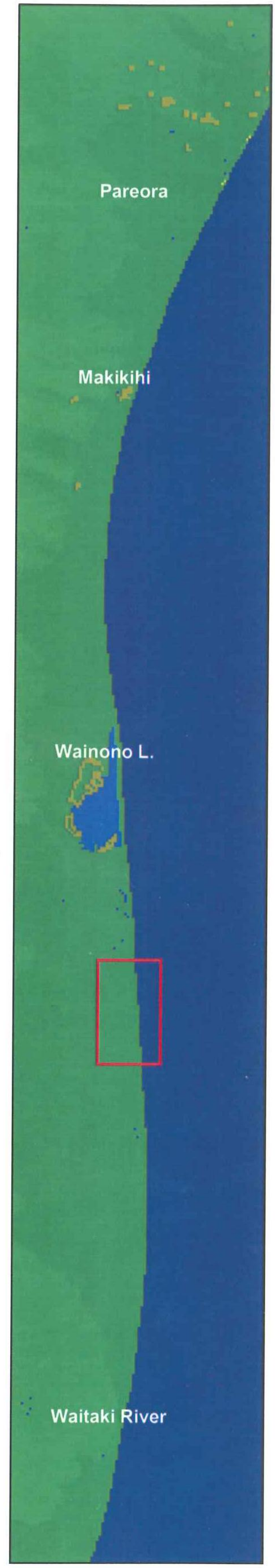
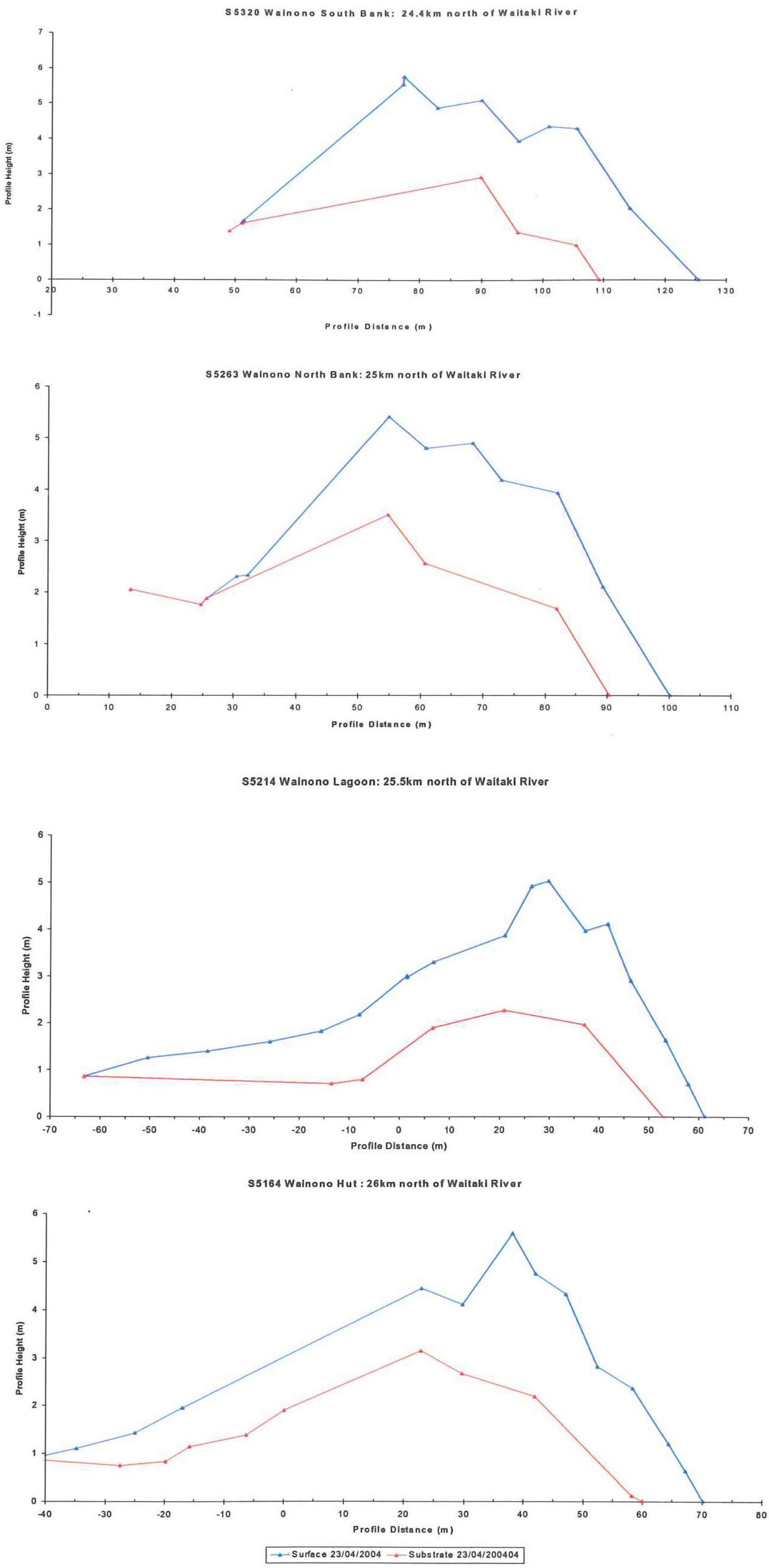


Figure 5.5: The Dead Arm sites displaying the surface and substrate profiles.



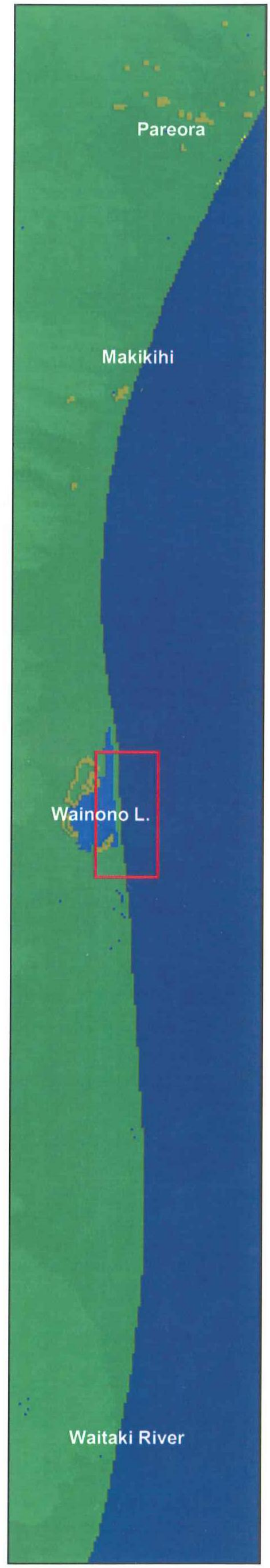
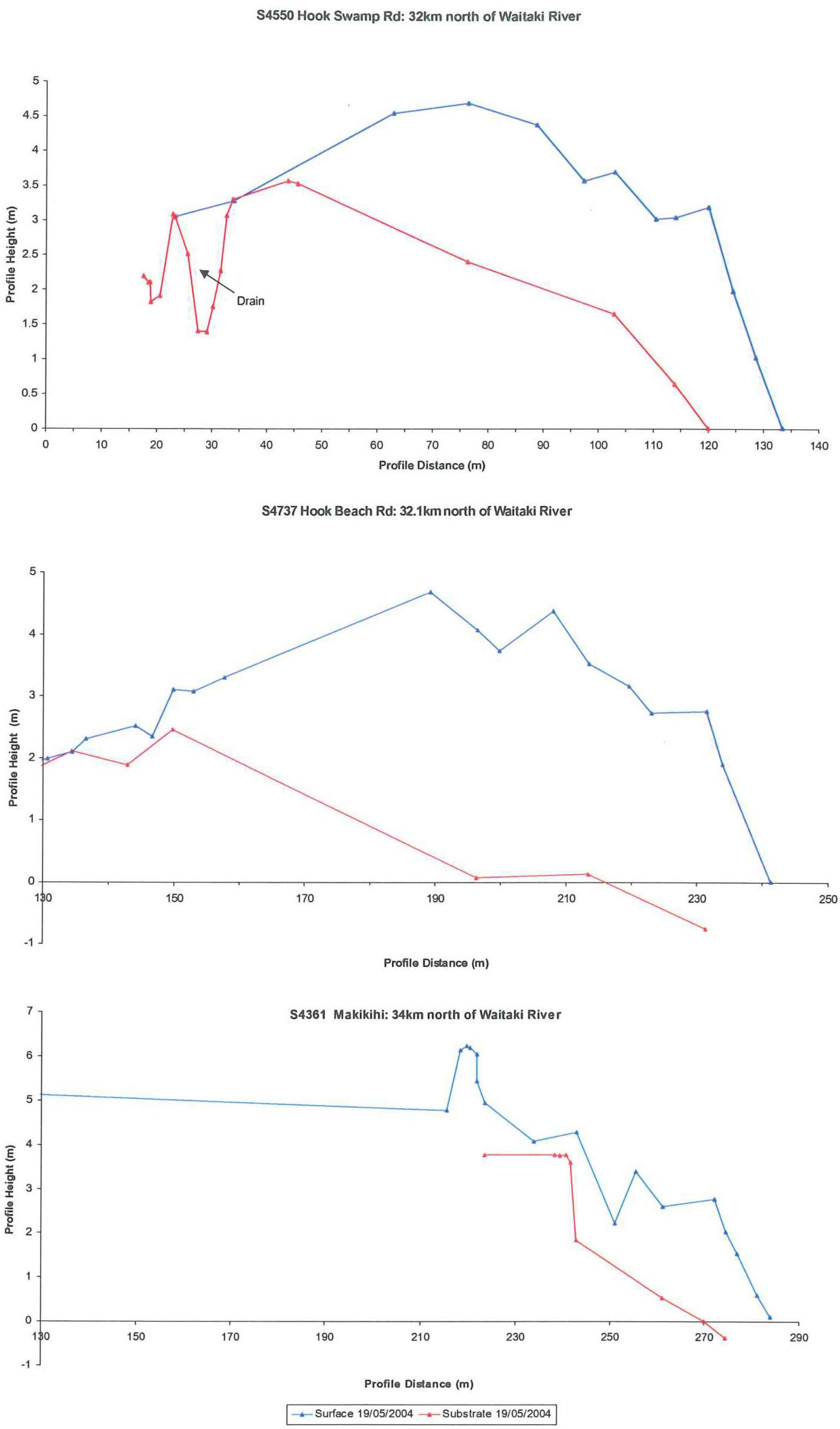
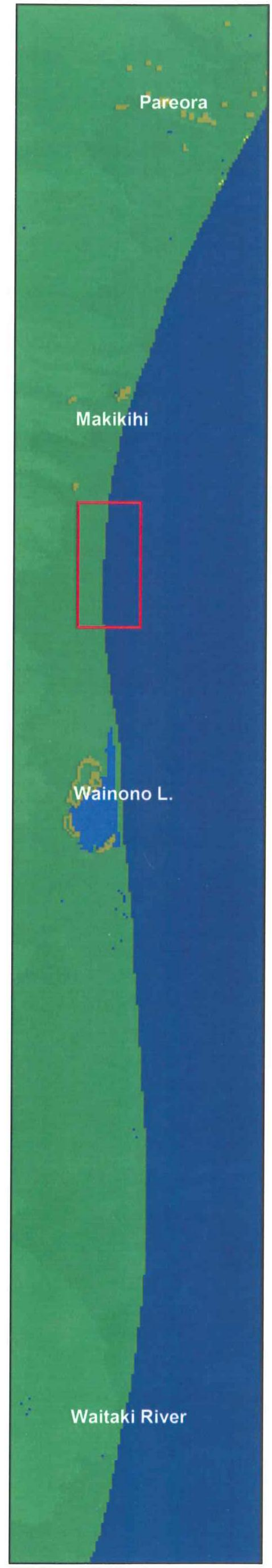


Figure 5.6: The Lagoon sites displaying the surface and substrate profiles.





.**Figure5.7:** The Hook sites displaying the surface and substrate profiles

5.5.1 Cliff Sites

Trenches were excavated at the cliff sites in order to survey the substrate of the four profile sites. Hence, the data gained from this area is very accurate. Figure 5.8 shows an example of one of the cliff trench sites. As shown in Figure 5.3, the substrate at all cliff sites is flat sloping and closely follows the shape of the surface profiles. The substrate tends to be close to the surface, located at shallow depths. At two of the sites, S7037 and S6885, the substrate slope is greater than the surface foreshore slope by a maximum of 2°. The widths of the beach material from the beach toe to where the foreshore slope intersects with Mean Sea Level (MSL) tend to be narrow. During storms, the local landowners stated that large amounts of sediment are eroded from the beach, and at some sites in the past, the substrate has been exposed.

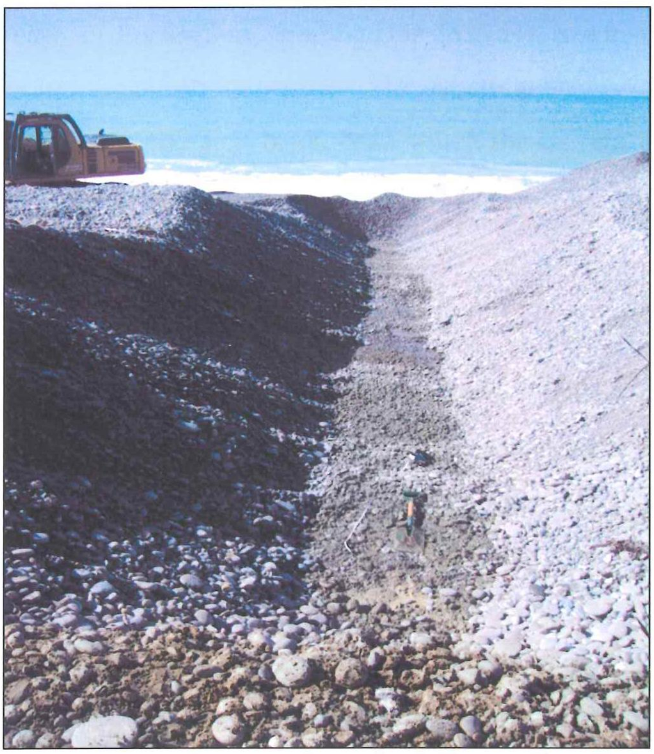


Figure 5.8: Photo of the trench site at McLeays Road (S6885).

5.5.2 Box Sites

The Box sites display quite variable substrate morphologies. At Ryans Road (S6347) the substrate is at a shallow depth and in some locations along the profile, is just 0.5m-1m below the surface profile. The substrate profile also tends to mirror the surface profile. A further 1.7km north, the Maori Road (S6158) substrate is at greater depths compared to the surface form. The hinterland behind this area of the barrier is at a low elevation and the substrate depth within the barrier reflects this height. The slope of the substrate in the foreshore/swash zones follows that of the surface profile. The substrate is slightly steeper than the surface foreshore slope at S6347 (6.9° surface compared to 8.1° substrate). It is slightly flatter at both S6158 by 4° and S5954 by 0.8°.

The most northern site of the section, Waihao Box (S5954), has a very distinct shape in both the surface and the substrate profile. The substrate seems to follow the form of what was a former drain and stop bank, onto which the current barrier has rolled. Although not identified in Figure 5.4, the substrate site was exposed in 1990 at the distance of 95m.

5.5.3 Dead Arm Sites

This section contains two past breach sites, Lows Road (S5800) and Waimate Creek (S5554). Interestingly, the substrate was not reached at theses two sites as the boundary between beach material and substrate was significantly below the depth able to be reached by the digger. Instead of disregarding these sites, the substrate level for calculations of volume was taken from (MSL) to the Beach Toe of the surface profile (Figure 5.5). The results show that if there is any substrate present at all, then it is at quite a depth from the surface. Both sites are backed by the Waihao Dead Arm which may influence the seemingly lack of substrate as the barrier through time has rolled over into the Dead Arm. This lack of substrate is thought to have played a role in the breaches at theses sites.

Poingdestres Road (S5513) substrate shows a different form, following a steady downwards gradient from the backshore to the foreshore. The shape also shows evidence of possible substrate compression, due to the weight of the barrier sediment as it rolls back over the soft hinterland material. Whether this compression is still happening or has only occurred in the past is not known. The substrate slope compared to the surface slope again shows similarities. It must also be noted that S5513 does not have a creek to the backshore, as do the two other sites in this section.

5.5.4 Lagoon Sites

All lagoon substrate profiles are similar and very distinct in shape (Figure 5.6). They are similar to the Waihao Box substrate, displaying one major crest peak within the profile. Compression, shown at Poigndestres Road is not evident at these sites, as was initially though due to the soft nature of lagoonal material. There are three possibilities as to why the substrate takes a peaked form:

- The substrate could be an old barrier which the shoreline, hence the new barrier has rolled onto.

- The shape identified could possibly not be the substrate at all.

- The shape could have formed through the percolation of lagoonal waters seeping through the barrier. The shape identified could possibly be the silt material deposited by the percolation of the water and fine material carried by the wave run up. This suggests that the percolation does not extend right through the barrier. It is a narrow area and becomes narrower as the barrier rolls landward. This area of silt material may be the catalyst for breaching.

If the substrate shape is an old barrier form, as the current barrier rolls over and moves landward, the old barrier underneath would disappear by erosion. This absence of substrate could then lead to more frequent breaching events in the lagoon area.

The four lagoon sites have very similar substrate and surface profile slopes (Appendix 5). Wainono North (S5263) is a site that displays one of the steepest foreshore substrate slopes, especially in the lower foreshore area or foreshore face as described by Neale (1987). S5320 has a steeper substrate foreshore slope than the surface slope with slopes of 14.2° and 12.2° respectively. This substrate slope compared to the surface slope could offer insight into where the barrier may breach.

5.5.5 Hook Sites

The substrate profile at Hook Beach Road (S4737) lies at some depth compared to the surface profile (Figure 5.7). Site S4737 displays a steep yet constant downward gradient from the beach toe to MSL, whereas the S4550 substrate forms more of a convex curve and lies closer to the barrier surface. There is evidence that compression may be occurring or has occurred at S4550. The hinterland is low at this site and the substrate profile displays a slope that suggests compression. The slopes differ between the substrate and the surface profiles.

Makikihi (S4361) is quite different to the other Hook sites in that it truncates due to the stop bank construction directly landward, so is an area that has been modified quite dramatically.

5.6 Barrier Substrate Profile Longshore Trends

The substrate form shows several definite longshore spatial trends:

- The substrate lower foreshore slope is greatest at the lagoon sites (Figure 5.9).
- The depth of the substrate is greater further north. This is due to the lower elevation of the hinterland and could also be because the beaches are slightly higher.
- The lagoon sites (middle) display a distinctive peaked substrate form.

- Two of the three breach sites contain substrates that lie at great depth.

- The breach sites have very steep foreshore substrate slopes (Appendix 5).

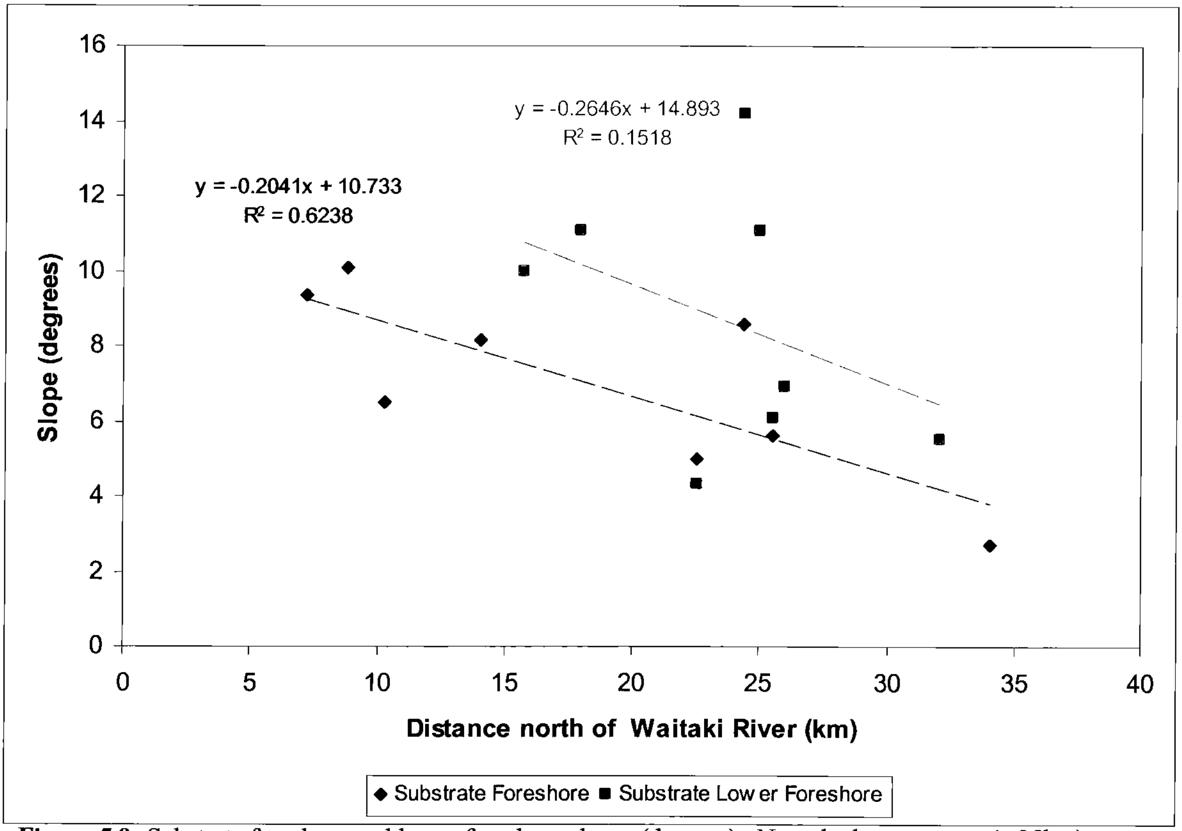


Figure 5.9: Substrate foreshore and lower foreshore slopes (degrees). Note the lagoon areas (c.25km) contain the steepest slopes.

5.7 Barrier Volume Analysis

This section brings together the surface and substrate forms at each site by way of calculating net barrier volume. The net volume is calculated from the 2004 landward beach toe to MSL at each site. It is noted that the barrier profile extends below MSL to the toe of the nearshore face (which occurs at depths between 3 and 6m below MSL in the Waitaki mouth vicinity, as reported by Hicks and Todd, 2003). The substrate will also extend beyond mean sea level, but there is no information on the surface or substrate in this area of the barrier.

The net volume relates to the amount of loose beach gravel and sand on the barrier and does not include any portion of the substrate material (Hicks and Todd, 2003). Essentially, net barrier volume can simply be defined as the amount of sediment between the substrate and the surface of the barrier. It is the volume of available material that determines the 'health' of a beach and its ability to absorb the effects of storm waves without experiencing rollover and crest lowering (Single, 1992). It is therefore of wide belief that barrier volume has a direct link with past breach sites and may provide foresight into possible future breach sites. Barrier volume in the past has been estimated from an assumed substrate. In this research the actual substrate has been identified allowing more accurate barrier volume estimates. In some cases the boundary between the beach material and the substrate was not reached. For these cases a conservative estimate has been calculated based on previous known depth and through using MSL as the boundary. All volume calculations in this chapter have used the 2004 surface and substrate profile data and all of section 5.7 refers to Table 5.3 and Figure 5.10, which present the net barrier volume of all sites along the Waihao-Wainono barrier.

Table 5.3: Profile site volume and the distance north of the Waitaki River (note S6570 and S4361 have been left out of the spatial volume variation due to the influence of human modification). The highlighted areas are breach sites.

Profile Site	Site Volume (m^3/m)	Distance North of the Waitaki River (Km)
S7037	66.5	7.2
S6885	65.6	8.8
S6717	69.2	10.3
S6347	78.6	14.0
S6158	142.1	15.7
S5954	148.0	17.9
S5800	254.7	19.4
S5554	222	21.9
S5513	158.0	22.5
S5320	151.6	24.4
S5263	117.0	25
S5214	161.8	25.5
S5164	151.9	26
S4550	172.2	32
S4737	267.5	34

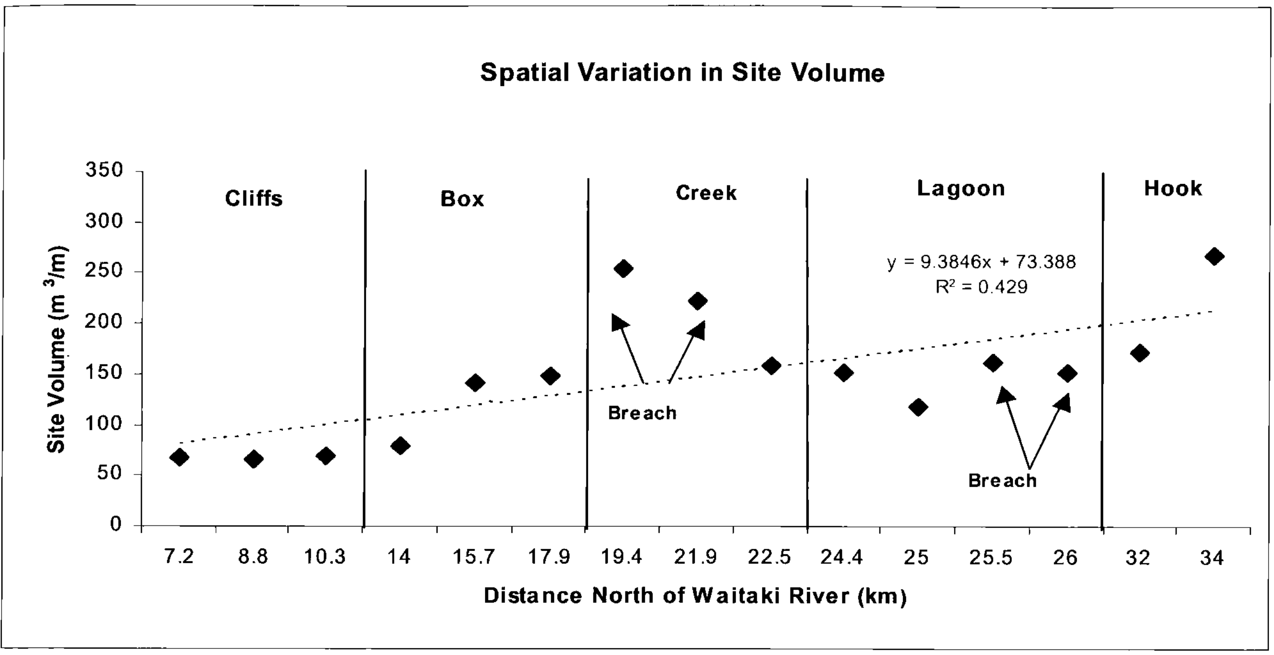


Figure 5.10: Spatial variation in Longshore site volume (note S4361 has been excluded due to the influence of human modification. S6570 is also excluded as per table 5.3).

5.7.1 Cliff Sites

The cliff sites have the lowest volumes of all sections of the barrier, in the order of 65 m^3/m. These low volumes are due to the narrow width (maximum width of 41m) and limited depth of the barrier material. During periods of high energy events, the substrate has become exposed in places and the cliffs backing this section of the barrier have rapidly eroded. This suggests that the barrier volume and width exerts a control over cliff erosion.

5.7.2 Box Sites

Further north, the box sites (Table 5.1) contain a greater volume of mixed sand and gravel material than the cliff sites with a range of $78.59m^3/m$- $148.0m^3/m$. This greater volume is primarily because there is a greater depth of mixed sand and gravel due to a lower substrate elevation. Hence this area is acting as a sink for sediment from the cliffs and river to the south. These sites are backed by low lying swampy hinterland and the Waihao Box site is backed by a carpark area and is very near to where the Waihao Box outlet is located. The maximum width of sites in this area is 68.5m and the maximum barrier height reaches 6.3m, slightly higher than the cliff sites. This section of the barrier has never been recorded as having experienced a breach event. The substrate in this area is located at a greater depth than the substrate at the cliff sites. S6158 and S5954 display very similar volumes, and are double the volume of S6347 located very close to the northern limit of the cliffs.

5.7.3 Dead Arm sites

The Dead Arm sites are the most interesting in terms of barrier volume in relation to breaching. This section contains two past breach sites, Lows Road (S5800) and Waimate Creek (S5554) both of which are backed by the Waihao Dead Arm. These two sites have the two of the greatest volumes of all the sites studied along the Waihao-Wainono barrier with 254.72m^3/m and 221.97m^3/m respectively. These volumes are a minimum, as at these sites, the substrate was unable to be reached by the mechanical digger and was located deeper than the MSL line used for volume calculations. It is unknown whether this deep substrate is due to the site characteristics such as the Dead Arm and the surrounding hinterland, hence influencing breach events, or whether it is due to the breaching actually removing the substrata. It is considered the former, as from observations the breach depth does not appear to extend down to this limit (Todd, pers.com). Because the sites have both experienced breaching, the barrier volume does not seem to be the determinant in where the barrier breaches and a large barrier volume does not necessarily offer the greatest protection against barrier breaching as was stated by Single (1992, 2002).

Poigndestres Road (S5513) has a smaller barrier volume 158.0m^3/m, due to a higher substrata as a result of the site being backed by farmland rather that drainage channel. While this volume is not large compared to the sites within the same section, it is still large when compared to other sections of the barrier. These larger volumes imply that this section of the coast acts as a 'sink' for sediment from further south.

5.7.4 Lagoon Sites

The lagoon sites display several of the widest (at 124.3m max) and highest (at 5.6m max) profile characteristics of the barrier, as was initially assumed. However the barrier volume is not necessarily the greatest in this section and can be attributed to the substrate elevation. The Wainono Lagoon, an ecologically, culturally and recreationally significant area, backs all lagoon sites. Figure 5.11 shows Wainono South with the Department of Conservation sign in the foreground. The volumes in this section are all very similar with three of the sites ranging from 151.64m^3/m- 161.85m^3/m. This area contains two past breach sites, located at the most northern of the lagoon sites and of which the volume is relatively high. These sites do however display very distinct surface and substrate profile shapes. The substrate mirrors the surface profile and contains one distinct peak. The substrate at the breach sites is not extremely shallow or deep, however, the backshore and foreshore surface and substrate slopes for both sites are reasonably steep (Appendix 5). Again, the volume of material at the breach sites, 151.64 and 161.85m^3/m, offers no insight as to why the barrier breached at these two positions along the coastline. Wainono North (S5263) contains about twenty percent less sediment volume than the other breach sites and from Figure 5.3 the width of the sediment between the lower foreshore surface and substrate profiles is narrower then the same area in the other lagoon sites.

Figure 5.11: Photo of the Lagoon area. Site is Wainono South bank (S5320).

5.7.5 Hook Sites

The beach volumes at the Hook sites are large, ranging from 172.24m^3/m – 267.51m^3 /m due to the barrier being wide (max of 110 m), and the low elevation of the substrate. Makikihi (S4361), the most northward site has a significantly lower volume than the other two sites, due to the site being backed by a stop bank that limits the backshore of the barrier, and forces the beach into a narrower form than what would occur in its natural state. For these reasons, this site has not been included in longshore comparisons. However it is deemed essential when presenting the whole section, as even though humans have modified it, it is the form of the barrier at a specific point in time. The whole barrier needs to be managed and knowledge of how sites operate in response to human modification is important.

5.8 Barrier Volume Trends

There are several trends and main conclusions drawn from the barrier volume analysis of the sites along the Waihao-Wainono barrier, these are:

- Barrier volume shows a general increase to the north. Figure 5.5 displays that there is a significant trend (R^2 =0.429).

- The deeper the substrate, the greater the volume. This can also be correlated with the longshore trends in hinterland elevation.

- The greatest barrier volumes are in the Dead Arm section, near the middle of the study area. This is possibly because it is a sediment sink and because the substrate is at the lowest elevations.

- Two of the four past breach sites have the largest volumes of the entire barrier with volumes in excess of $200m^3/m$. Therefore greater volume does not necessarily mean greater protection from breaching as proposed by Single (1992).

5.9 Barrier Shape, Volume and Breaching

This section ties together all results drawn from the shape of the barrier surface and substrate profiles, and from the barrier volume calculations. It is discussed in combination with the breach sites in order to identify the major characteristics that are present at these particular sites. Understanding the barrier characteristics may ultimately aid in identifying potential future breach areas.

From the results presented and discussed in the previous sections of this chapter, several conclusions can be drawn. The main conclusion relates to barrier volume. In the past it has been of wide belief that the greater the volume at a site, the greater the amount of protection offered to the land behind the barrier and the less likely the particular site is to experience a breach or overtopping event (Single, 1992, Neale, 1987). Through volume analysis along the Waihao-Wainono barrier, this hypothesis has proven untrue. The breach sites along the Waihao-Wainono barrier are all sites that comprise the greatest volumes of all 16 sites studied, all four breach sites having a volume in excess of $150m^3$. Volume is not the key as to whether a site is more likely to breach or not. Instead other characteristics such as surface and substrate barrier shape have also been examined in order to identify one or more characteristics specific to these breach areas.

The two major contributors to where a breach site may occur are shown from this research to be due to both foreshore and backshore slopes and/or the depth to the substrate. The width of the permeable layer also seems to have some influence in breaching. At all breach sites, the foreshore and backshore surface slopes are very steep. This steepness may cause a weakness in the barrier and when high energy events occur it does not take long to destablise the already weakened area of barrier. The substrate slopes also seem to play a role in determining where the barrier may breach. At all sites (S5800, S5554, S5214, S5164), the graphs show that the foreshore substrate form tends to mirror the steep surface slopes. Thus the combination of steep substrate slopes and steep surface slopes leads to what is an unstable foreshore face, on which material is easily eroded during storm events as the sediment is already at its greatest angle of repose. Any major wave force can dislodge the sediments and hence weaken the site and make it vulnerable to breaching. A narrow upper barrier allows percolation through the whole width of the barrier. This is evident at the lagoon sites. Percolation results in the slumping and slipping of backshore sediment on the steep slopes that initiated the breaches.

The substrate influences the form of the barriers, as it is the basement structure on which sediments lie. Another major conclusion to be drawn from this research is that at two of the three breach sites, the substrate was not met due to being excessively deep. During the excavation of these sites, the sediment seemed to have a lack of sand mixed in with the gravel. The permeability of sediments at these sites may also be a factor and will be discussed more thoroughly in Chapter Seven. From analysing the barrier, the most stable areas seem to be those where the substrate is close to the surface form, and areas where the substrate slopes are flatter and more stable such as Poigndestres Road (S5513) and Ryans Road (S6347).

At the third breach site at Wainono Lagoon, the substrate displayed a very distinct peaked shape, mirroring that of an old barrier form. As the barrier rolls in the landward direction, this slope will disappear through abrasion from the movement of sediment. When this happens the whole substrate may be lost or simply left behind increasing the possibility of more frequent breach events, especially at the sites that display this substrate form along the lagoon area and at the Waihao Box site. If the outer barrier remains stable for a significant amount of time the process may repeat itself.

One final obvious and important fact about the breach sites is that all breaches occurred where the sites were backed by water. At Lows Road (S5800), the Waihao Dead Arm backs the site, Waimate Creek backs S5554 and at Wainono North (S5263), the lagoon is to the landward direction. The hinterland morphology and elevation is obviously important in terms of the stability of the underlying substrate. At the water backed sites, the through flow may be a major cause of barrier instability.

5.10 Summary

Through analysing the barrier profile at both the surface and the substrate and the volume of sediment at each site, several major findings are prevalent. The most conclusive is that sediment volume is not a contributing factor to where along the barrier a breach may occur. Contrary to wide belief, greater sediment volume does not mean greater protection from breach events.

With regard to barrier form, it has been shown that barrier height decreases to the north as barrier width increases. Foreshore slopes become flatter and more stable to the north and the lower foreshore slopes, particularly at the breach sites, are very steep compared to other non-breach lower foreshore slopes. This same foreshore and lower foreshore slope pattern displayed in the surface profiles is evident when analysing the substrate profiles.

The substrate depth tends to vary according to the hinterland type and elevation to the backshore of the barrier. Within the Dead Arm section of sites, the hinterland is very low accounting for the unsuccessful attempts at reaching the substrate. The substrate form at the lagoon sites is very different to that in other parts of the barrier. The peaked form identified is thought to have formed through the percolation of sediments between the lagoon to one side and the sea to the other. The non-breach sites such as Poigndestres and Ryans Road display very flat stable substrate forms on which the barrier rolled back onto. Both theses sites show evidence of compression of the substrate due to rollover and the increasing weight of the sediments above. The barrier material looks to be weighing down, hence compressing the softer layer of substrate.

These sediment characteristics will be presented in Chapter Six. Through spatial analysis both cross shore, along shore and within the matrix of the barrier it is hoped correlations can be made between the sediments and the breach sites.

Chapter Six

Sediments of the Waihao-Wainono Barrier

6.1 Introduction

The barrier volume, surface profile and substrate profile results were discussed in Chapter Five. Chapter Six effectively builds on the barrier volume discussions by providing results of the sediment characteristics both at the surface and within the barrier.

There is a common perception among the local landowners that the sediment size has dramatically decreased over the past fifty years. Through excavating and gaining sub-surface sediment information it is though that if there was larger sediment in the past, that it should be located within the barrier due to barrier rollover.

The results are divided into three main sections (1) surface sediment characteristics, (2) temporal comparisons of surface sediment data, (3) sub-surface and substrate sediment characteristics.

6.2 Surface Sediments

6.2.1 Cross- Shore Trends

The graphs below display the results attained for all surface cross-shore and long-shore mean grain size and sorting trends. Section 6.2 focuses on these results. One of the main aims of this thesis is to determine the spatial and temporal variations in sediment size and to gain a more in depth understanding of the sediment characteristics at the three past breach sites. From this, it is hoped to determine why exactly these sites have breached and other sites have not. Graphs (Figures 6.1-6.3) have been constructed through the use of the Surfer 8.0 programme.

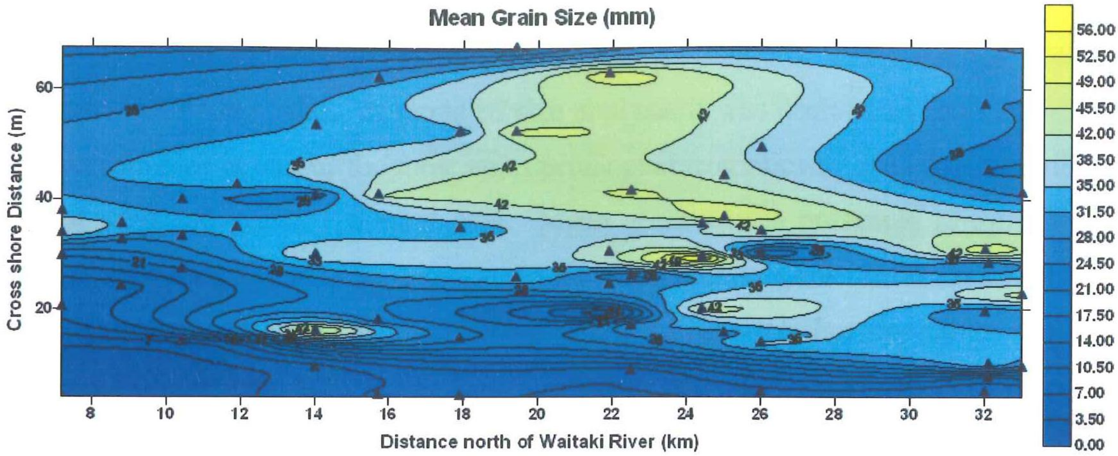


Figure 6.1: Contour map displaying the distribution of mean grain size along the Waihao –Wainono Barrier. Triangles in all the figures denote sample sites along and across the barrier.

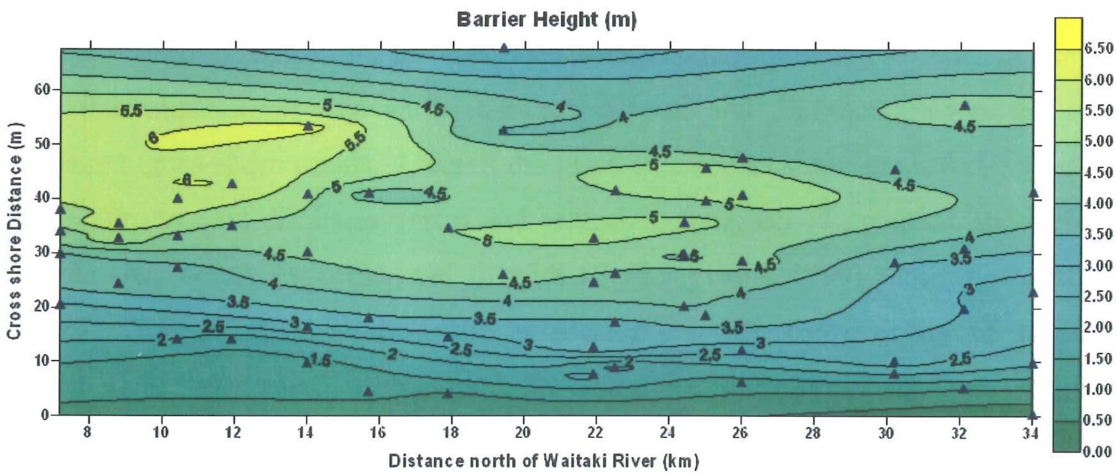


Figure 6.2: Contour map displaying the barrier height along the Waihao –Wainono Barrier.

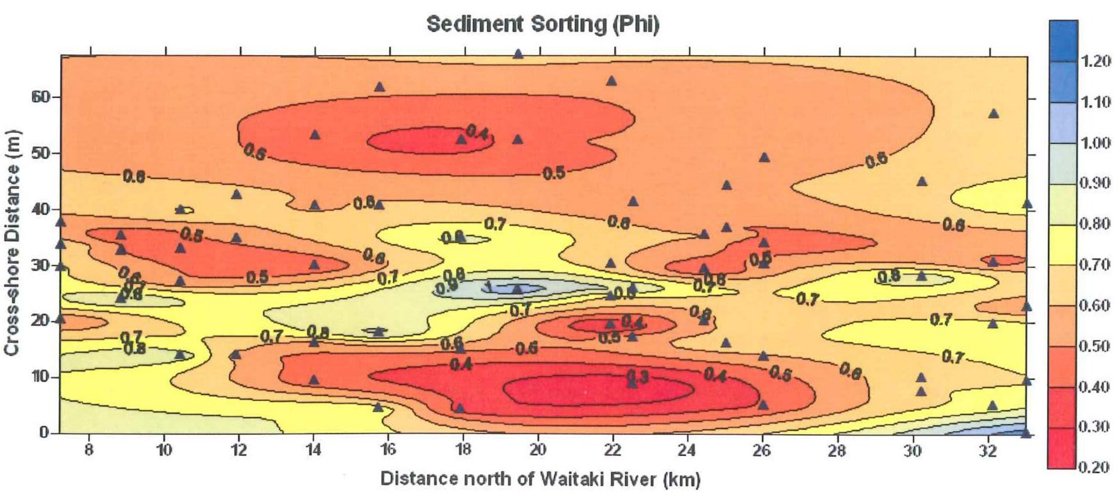


Figure 6.3: Contour map displaying the distribution of sediment sorting along the Waihao –Wainono Barrier.

Mean Grain Size Analysis

Grain size analysis was carried out by way of sieving; the exact method used is outlined in Chapter Four. In terms of size analysis it was decided by the author that mean grain size is one of the most appropriate characteristics to use when describing mixed sand and gravel sediment data. Mean grain size is presented in millimetres (mm) rather than phi units (ϕ) because the temporal comparisons discussed later in the chapter have historically been presented using millimetres. For comparisons to be made, millimetres are used.

Figure 6.1 shows a contour plot of surface mean grain size of the surface sediment samples mapped as a distance north of the Waitaki River on the x axis and as a distance cross-shore on the y axis, landward from mean sea level (MSL). Mean sea level was used to standardise the distances from a common reference point. It can be seen that mean grain size varies between 5.1mm and 58.6mm. There are two dominant cross-shore trends. Overall the grain size across shore tends to be greatest at the 30m to 55m distances, (crest and backshore samples). In general, the surface sample sites are as expected, and fit with Bluck's (1967, 1999) sediment zonation theory. The swash sites show the smallest sizes with the majority of samples classified as very small pebbles and the upper foreshore and backshore samples display the largest mean grain sizes with areas containing mean sizes of 56mm. There is one swash sample located at 14km north of the Waitaki River, which does display a large mean grain size of 52.50mm. Kirk (1980) found this large size to be due to the swash and backwash processes as described in Chapter Two.

The cliff sites, those that lie from 7.2km to 12km north of the Waitaki River, display gradual but noticeable increases in mean grain size across shore. The sediments nearest to the cliff face are the largest. In the middle section of the study area, there tends to be distinct areas of change across shore. Surface sediment samples contain small mean grain sizes at the swash zones. Directly landward of the swash zone the mean grain sizes are slightly larger, displaying a transition to an area of smaller sediments.

At Wainono Hut (25km north) and Lows Road (19.4km north) the mean grain size also shows a smooth transition from very small pebbles in the swash zones to large pebbles and cobbles in the backshore zones. At S5164 the medium sized pebbles lie just behind and below the first major crest. This area contains the smaller sediment as it becomes stuck in the backwash as was explained earlier in the section. Waimate Creek (S5554) displays an increase in cross-shore mean grain size at the mid-foreshore/ upper foreshore area. Here the mean grain size increases from 32.3mm to 47.7mm respectively. Lows Road and Waimate Creek are two past breach sites. Each of these profiles contain one of the five largest mean grain size samples of all samples collected (47mm and 46mm).

Two overall trends are obvious. The first has been shown to exist in the above discussion is that there is quite a distinct fining in mean grain size, seaward. In general the backshore areas at most profiles alongshore display the largest sediment size. The map does however show four major areas of difference that are contrary to Bluck's (1999) zones.

The middle section (the Box and Dead Arm sites) displays distinct areas of change across-shore. The Ryans Road site, situated 14km north of the Waitaki River displays a different pattern to that explained above. At this site, sediment size increases with cross-shore distance to 16.1m from MSL where the mean grain size is 49.13mm. It then decreases dramatically over the next 15m to 24.73mm in the foreshore zone and jumps slightly to 31.82mm in the backshore area. This pattern is the same at Wainono South (24.2km north) and at the Hook Swamp and Makikihi sites at the most northern end of the study area. Hewson (1977) found this same pattern. Poingdestres Road displays a slightly different pattern again, in that the sediment size increases (30.75mm) with cross-shore distance from MSL until 26m from MSL where the size becomes smaller (22.53mm). The size then increases to 45.91mm in the backshore zone.

The cross shore mean grain sizes appear to be different to the sizes suggested by Single (1992). As discussed in Chapter two, Single proposed a general pattern of across-shore sediment zonation in New Zealand mixed sand and gravel beaches. At the backshore zones he stated the mean grain size as 70mm (Large cobble). From this research it appears that Single's mean grain sizes are larger than those sampled during this study. Large pebbles are the most common mean grain size of the 2004 backshore samples. The barrier crest contains sizes between large pebbles and cobbles, slightly larger than those analysed by Single (1992). Continuing in the seaward direction the mean grain sizes found in the upper foreshore and interberm nadir are similar to Single's with mean grain sizes of 20-30mm being the most common. Instead of lower foreshore mean grain sizes of between 3-5mm or 18mm as described by Single, this research showed this area to contain sediment with higher mean grain sizes. All samples fitted within the range of 5-12mm, with three sites containing mean grain sizes within 30-43mm. Bimodality of sediments in this zone is not as prominent as described by Single.

When examining cross shore barrier height (Figure 6.2), the barrier elevation is rather uniform, the highest areas are located at the ridge crests and the lowest at the swash and backshore zones of all sites. The highest areas of the barrier tend to be where some of the coarsest sediment is located. Figure 6.1 and 6.2 show that the maximum grain sizes tend to correspond with some of the maximum heights along the Waihao-Wainono barrier. This is evident at the Dead Arm and Lagoon sites (20-26km north). The swash areas are at the lowest elevations and contain the smallest mean grain sizes.

Sorting Analysis

The degree of sorting of a sediment sample is measured by calculating the standard deviation of the sediment distribution. Figure 6.3 shows the sorting variation along the Waihao-Wainono barrier in relation to the cross-shore barrier distance from MSL. Both phi and millimetres are used in the display of sorting figures. For phi, the lower the figure, the better sorted the sample and for millimetres, the higher the figure the better sorted the sample. Figure 6.3 shows the sorting as phi units but figures further in this chapter display sorting as both phi and millimetre values.

Variations in sorting and grain size were found across the surface beach profile, as a response to the hydrodynamic processes and the characteristics of the available material. At the areas where the sediment size is very similar cross shore such as at the lagoon sites, grading does not occur and across beach variation in size and sorting is very minimal. Both Single (1992) and McLean (1970) did not find well developed zones across the beach. They found coarse and fine mean sediment sizes and well sorted and poorly sorted samples at all beach zones from the lower foreshore to the upper backshore.

McLean (1970) stipulated two main reasons for this. Firstly, that shore normal variations are linked to the longshore changes and secondly that the beach is highly turbulent in terms of swash and backwash processes that continually mix the sediments and in response, have a major effect on sorting.

Through examining Figure 6.3 the areas of best sorting along the Waihao-Wainono barrier occur in the swash and backshore zones. The lower foreshore at all sites (15-30m) tends to fall into the moderately sorted category. The barrier then displays quite a well-sorted band 30-35m from MSL throughout all profiles. Waimate Creek, a breach site, has a moderate to very well sorted sediment sample range across shore, while Lows Road (19.4km) shows inconsistent sorting across shore. Further north, the Lagoon sites show very consistent sorting at all surface elevations. All lagoon samples collected are moderately well sorted, apart from two, which are classed as well sorted. The breach site of Wainono Hut (26km) contains one of the well sorted samples and has a very consistent sorting range across shore (0.41, 0.57, 0.55, 0.44,0.53 ø), while Wainono Hut (26km), another breach site, displays the most consistent and best sorting across shore out of all 17-profile sites. From these results it is clear that poor sorting does not necessarily contribute to breaching at the lagoon sites, as the best sorted samples of the whole study area are located at two of the four breach sites. It is in fact thought the well sorted samples may contribute to areas of breach.

The backshore samples, landward of the crest are well sorted because once the waves have deposited the larger material in this zone, there is not enough energy in the wave backwash to transport them back down the barrier. The larger sediments are left and the smaller sediments are entrained and transported back down the beach to the lower foreshore. Often the smaller pebbles will percolate through the pore spaces of the larger sediments and form a layer of smaller sediment below the surface. Ultimately these processes mean that that the backshore/ upper foreshore sediments are generally well sorted due to the limited variation of grain sizes.

The surface of the barrier does display areas of poorly sorted material, which tend to occur randomly. The Lows Road site (S5800), a past breach site is poorly sorted (1.09Ø) on the surface of pit one situated 25.7m from MSL. The upper foreshore and backshore samples collected from the surface of the Lows Road profile are well sorted.

In contrast, Hook Beach Road (32.1km north), part of the Hook sites, contains a backshore surface which contains the most poorly sorted of all surface samples (0.36mm) collected. This is an area that experiences some human modification due to being a popular fishing location. Vehicles travel along the backshore area of this site and may have modified the sediment pattern significantly.

Neale (1987) added two zones to the four zone mixed sand and gravel model of Kirk (1980) as outlined in section 2.2.1. The sorting of the sediments within three of the six subzones was briefly described. The foreshore face (swash zone), storm face (storm swash) and storm berm washover slope (Overwash) sorting descriptions have been refined by this study on the Waihao-Wainono barrier. In the swash zone, sediment samples were classed by Kirk (1980) and Neale (1987) as being well sorted. This research has found sediment samples in this area of the barrier to be well sorted but has also determined that the area at some sites, contains poorly sorted samples. The same is found to be true for the washover slope, where it was determined by Neale (1987) to be an area of poorly sorted samples. It is evident through the 2004 sediment data that this zone is in fact very contrasting either containing poorly sorted samples or well sorted samples. Storm face zones along the barrier tend to display a wide variety of sorting values and cannot simply be classed as moderately sorted as done by Kirk and Neale. This area contains sediments ranging from poor to moderately well sorted material.

There does not appear to be any particular cross shore sorting patterns along the Waihao-Wainono barrier, except that the swash zones, upper foreshore and backshore tend to display the best sorted material, with the exception of the two most northern sites where these areas display the poorest sorting.

6.2.2 Longshore Trends

Mean Grain Size Analysis

The major trends in mean grain size (Figure 6.1)along the Waihao-Wainono barrier are that the mean grain size is finest at the southern cliff sites, where the greatest mean grain size reaches a maximum of 34mm. The mean grain size increases northward to the lagoon sites where the maximum sizes are found and then becomes slightly finer again at the sites north of the lagoon.

Alongshore, most sites show similar values when the mean of the mean grain sizes at each site is calculated (Figure 6.4). Again it is the lagoon sites that show the largest sizes. A very poor positive linear relationship is displayed in terms of greater mean grain sizes to the north. This slight coarsening of mean grain size to the north of the barrier is a different relationship to that proposed by Pettijohn and Ridge (1932) with reference to the variation series, described earlier in Chapter Two. When there is a major source point such as a river, Pettijohn and Ridge (1932) stipulated that the grain size diminishes away from the source. The Waitaki River and the Morven-Glenavy cliffs are the major sediment sources to the Waihao-Wainono barrier and are situated at the southern end of the study site. The mean grain sizes instead of fining with distance, from the sources have shown if anything, an increase in size, especially at the lagoon sites. This finding also contrasts to those found by Marshall (1929) and Dawe (1997).

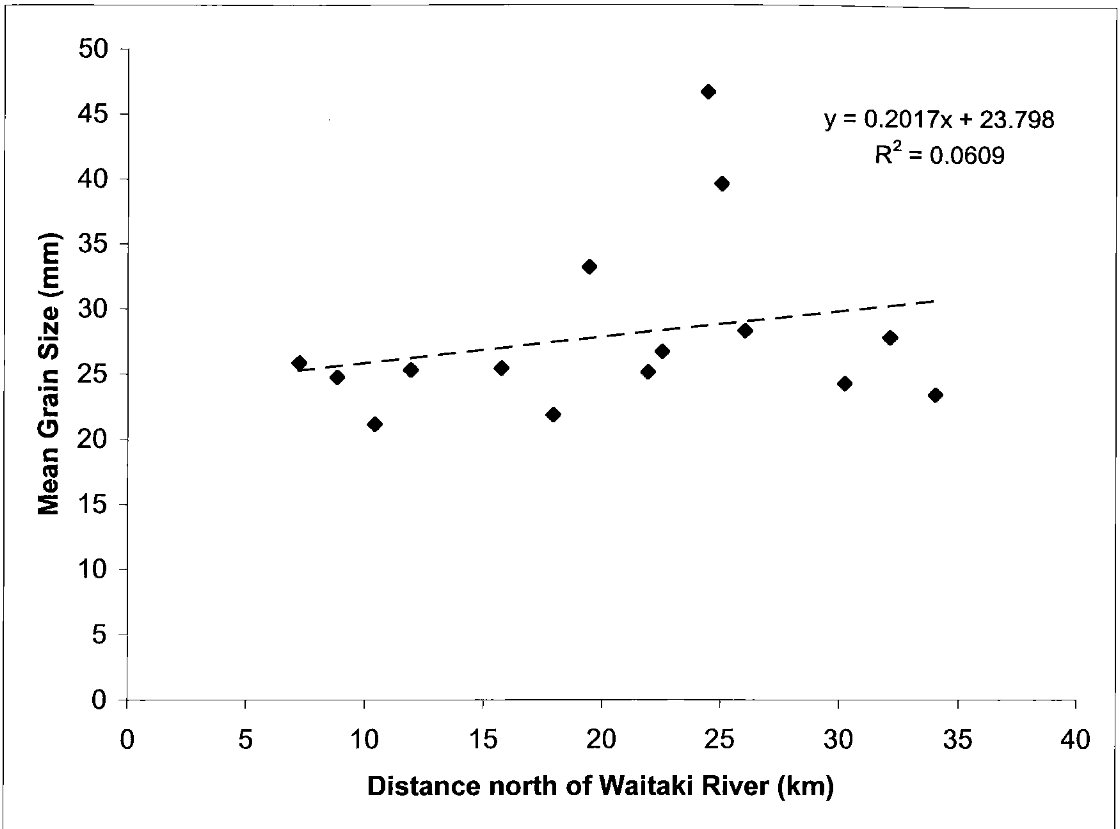


Figure 6.4: Mean of the mean grain sizes from all surface samples at each profile site and distance from the Waitaki River. Note the larger sized sediments in the 20-25km area where Wainono Lagoon is situated.

Kirk (1967) and Single (1992) found no obvious longshore size and distance relationship, instead stating that the across shore relationship is of a greater variation, similar to the findings of this study. If anything, this slight northward coarsening of mean grain size shown in this study contradicts the slight northward fining of sediments proposed by Hicks and Todd (2003).

Several longshore trends can be seen in the fact that Ryans Road (14 km north), Wainono South (24.4 km north), Hook Swamp (32 km north) and Makikihi (34 km north) sites all have similar trends in across shore mean grain size but are all located at different areas of the barrier. The reason for the random cross shore zonation in mean grain size could be because the wave energy is directed at these sites along the barrier in a different way to the other sites that display the typical zonation.

Sorting Analysis

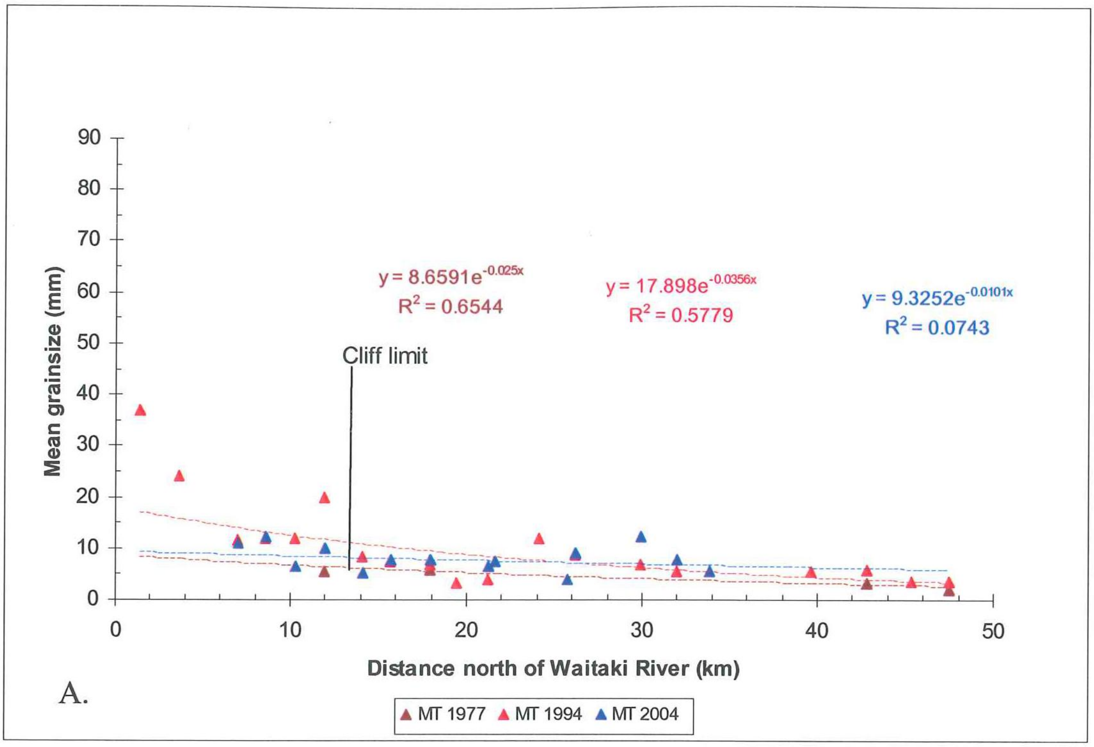
The degree of surface sorting along the barrier ranges from poorly sorted to well sorted. The moderately sorted to well sorted samples tend to dominate. Two general sorting trends have developed along the barrier in regard to the cross shore characteristics. The swash and backshore zones of the barrier are the areas of both the best and most poorly sorted samples.

The most consistently sorted areas in terms of spatial variation are at the cliff sites and at the lagoon sites. All other sections of the barrier show random sorting throughout the different zones, especially within the foreshore areas. Waimate Creek and Wainono Hut, past breach sites, display the most consistent sorting values across shore. Although Waimate Creek displays consistent cross shore sorting, the Dead Arm sites (19.4-22.5km) display the greatest variation in sorting of all the sections of the barrier, with values ranging from poorly sorted to very well sorted. Therefore poor surface sorting is not the main contributor as to whether a site will breach or not.

The most northern section of the study site, the Hook sites range from poorly sorted to well sorted. Hook Beach (30.2km) contains the most poorly sorted of all samples with a sorting value of 1.64 Ø at the backshore zone. This northern section of the beach is the most poorly sorted of the study site. Marshall (1929) in his study concluded that further along shore from the major sediment source, the greater the sorting. The poor sorting values away from the source as found in this particular research contradicts that of Marshall's.

6.2.2.1 Temporal Mean Grain Size Analysis

The beach sediments between the Waitaki River and Timaru has been sampled and analysed through sieve analysis on three previous occasions; 1977 (by Hewson), 1984 (Kirk, 1987), and 1994 (ECan unpublished data). The recent 2004 sediment data from this research can also be added to the previous data to examine for temporal changes. The Waihao-Wainono barrier consists of varying size from the swash zone to the backshore zone (Single, 1992). For temporal comparisons to be made, samples were collected from the same morphological point at each site. The 1977 and 1994 sample were the only samples that had collections at the mid tide zone (swash) and the upper foreshore zone. The 1984 samples were collected at the high tide berm therefore unable to be used for direct comparisons with the other sample dates. This lack of sample site compatibility in 1984 meant that only the 1977 and 1994 data could be used to provide comparisons so the 2004 collection included samples from the swash zone and upper foreshore (Figure 6.5).



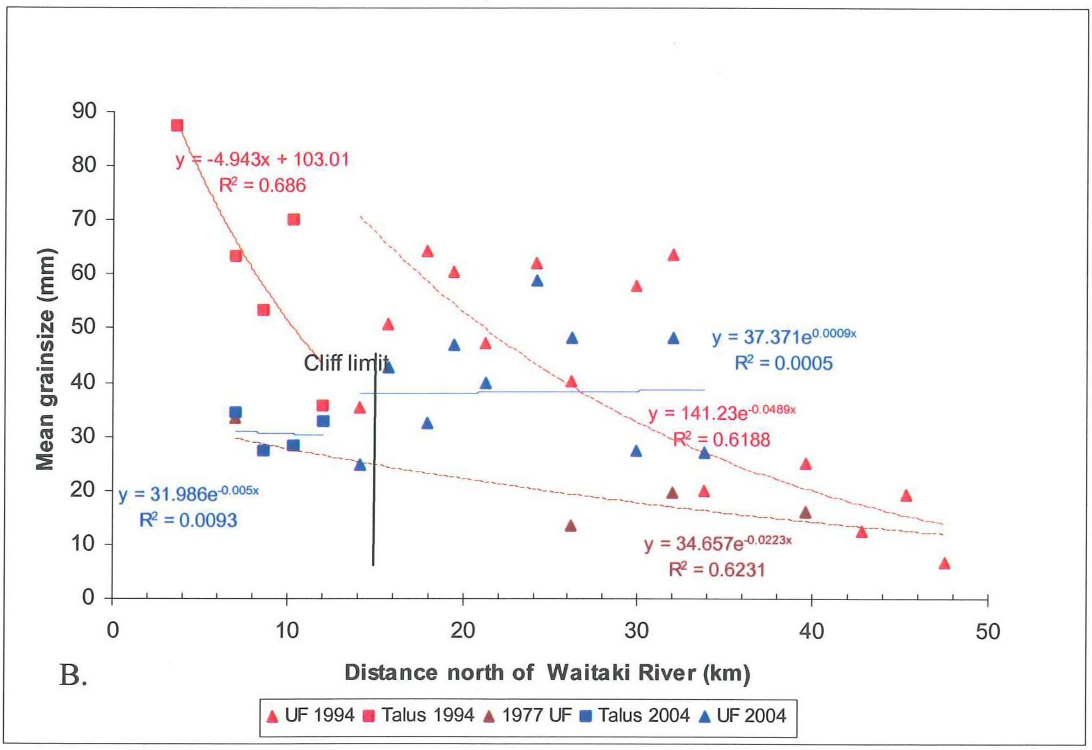


Figure 6:5: Longshore temporal grain size distribution. A. shows the mid tide zones (MT) and B. shows the upper foreshore zones (UF) and Talus (cliff talus).

Swash Zone

Through analysing temporal variations in mean grain size within the mid-tide (swash) zones at different sites along the barrier, no major changes are visible (Figure 6.5 A). Contrary to many local landowners perceptions, the sediments of the swash zone have actually increased in mean grain size from 1977-2004 rather than decreased. This could be because a change in the sediment input and in the coastal processes that transport the sediments. Waves with greater energy are able to move larger sized sediments. This change could also be attributed to slightly different collection points within the swash zones throughout the different profiles and the different sample times.

Throughout all years, a slight fining of mean grain size has occurred with distance north of the Waitaki River. The areas with the greatest mean grain size are located at the Dead Arm and Lagoon sites, both sediment sink areas.

Upper Foreshore Zone

The temporal change from 1977-2004 is clearly displayed. The upper foreshore (Figure 6.5 B) has shown an increase in size between 1977 and 1994. At all sites except for two, the 2004 sediment samples appear to have a smaller mean grain size than the 1994 sediments. The sediment size in 2004 reaches its maximum at the lagoon sites, which lie about 25km north of the Waitaki River. Once this maximum is reached, further northward, the sediment becomes finer. At the cliff sites, the 2004 sediments are a lot smaller than the sediment sizes at the cliff talus in 1994 but are larger than those of 1977.

The area of the barrier where the greatest similarity in sediment size has occurred throughout the 27 years (3 samples) of sampling is the middle section of the barrier, the creek sites and the lagoon sites (19-24km north of the Waitaki River).

6.3 Sub-surface and Substrate Sediment Results

In the previous section, the surface sediment characteristics at both height and across shore were presented. A barrier is a three-dimensional form and how a barrier responds to high-energy events can not be inferred through surface analysis alone. The size and sorting of the sediments within the barrier have just as much bearing on the ultimate form and function of the barrier as do the surface sediments. The sediments within the Waihao-Wainono barrier have never been studied and analysed before so the new knowledge presented in this section can only act to increase our understanding of how the Waihao-Wainono barrier functions. In this section all four breach sites (Lows Road, Waimate Creek, Wainono Hut and Wainono Lagoon) will be analysed. Wainono North, Wainono South and Poigndestres Road will also be analysed due to the large amount of samples collected within the barrier and discussed in relation to the non-breach sites. All depth sediments have been analysed through maximum grain size, mean grain size and sorting. Mean grain size is focussed on more than the maximum size simply because it is a more representative measure of sediment. The reason for including the maximum grain size is to address the perception of local landowners, that the largest material, which was presumably on the surface, is now buried within the subsurface material of the barrier by the process of rollover.

6.3.1 Breach Sites

Lows Road S5800

Sediment Grain Size

Lows Road displays typical sediment size variation (Figure 6.6). At the surface, the largest sediments are those that lie on the highest ridge and the backshore. Within the barrier, the smallest sediments are located at the layer just below the surface. This is the area where very small pebbles are likely to be found as any smaller sediment thrown up amongst the larger sediments percolate down through the pore spaces. This percolation results in armouring, which occurs when larger sediments sit immediately above a fine layer. At a slightly greater depth, the mean grain size increases from the very small pebble classification to a small pebble. The lowest sample site was taken just below 1m from MSL, still part of the sub-surface material, as the substrate could not be reached. Both of the lowest sub-surface samples, the mean grain size were between 16mm and 21mm, classed as medium pebbles.

A general pattern at Lows Road was found. The mean grain size is greatest at the surface and is smallest just below the surface layer. The size then slightly increases, although is still classed as a small pebble. Medium sized pebbles are the mean grain size at the lowest points sampled in both depth pits. This is interesting as it is expected that a greater depth would coincide with smaller sized sediment. Sediments within the barrier at this site did not display any cross-shore change in sediment size and classification. Conclusions made from observations, while excavating the pits, were that the site seemed to have larger sized sediment throughout the pit and that this sediment was more uncohesive (Figure 6.7) than other pits where more abrupt changes in sediment layers occurred. The maximum grain size for all samples is shown in Figure 6.6 and at all levels within the barrier, the maximum sizes were classed as large pebbles and on the surface as cobbles. The sediments do become larger with depth, but the surface samples are still coarser than the subsurface samples and substrate. This is contrary to the local perception.

Mean Sorting

Well sorted material is on the backshore of the surface samples and all other sediment samples collected are either poorly sorted or very poorly sorted. The very poorly sorted samples are those that are located within the sub-surface nearest to the barrier surface and the poorly sorted samples lie at the greatest depths within the barrier. No areas within the sub-surface are classed as having moderately to well sorted sediment. The sorting values reflect the chaotic range of sediment sizes within this area of the barrier.

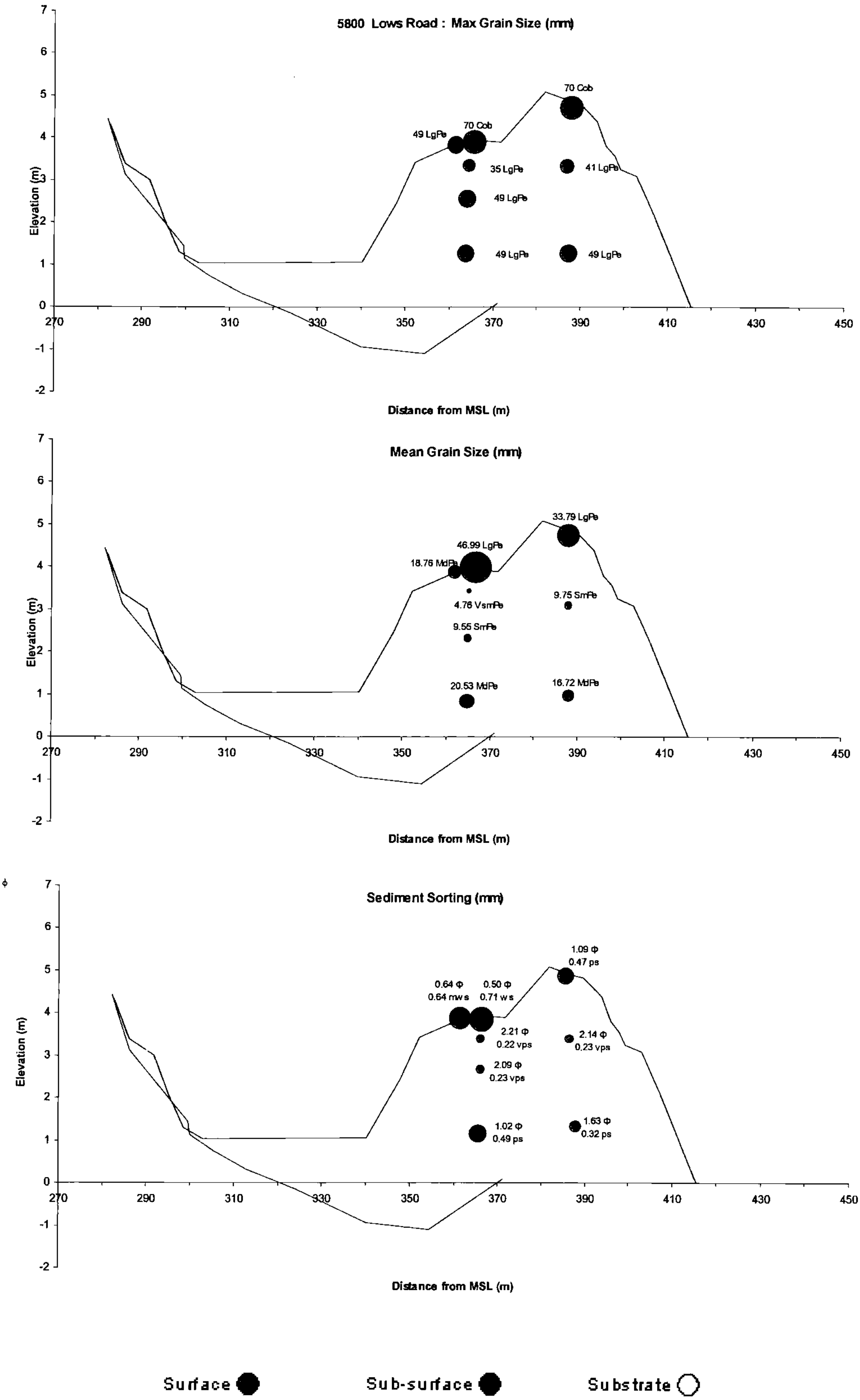


Figure 6.6: Lows Road Sediment Characteristics at the surface, sub-surface and substrate.

Figure 6.7: Photo of Lows Road pit 2. The sediment kept sliding into the pit while excavating, which shows how uncohesive the sediment at this site is.

Waimate Creek S5554

Sediment Grain Size

Waimate Creek is a second breach site at which the substrate was not reached (Figure 6.8). It is only 2km north of the Lows road site, yet contains several differences with regard to mean grain size within the barrier. No samples were taken directly below the surface of Waimate Creek but Figure 6.9 displays the fine layer of sediment just below the surface similar to that shown at Lows Road.

Within the barrier, the samples move from medium sized pebbles to small pebbles and then to granules at the lowest sample points. Distinct layers of sediment size are visible from the surface to the deepest samples but there is no obvious sign of any cross shore mean grain size zonation within the sub-surface samples, as is obvious in the surface sediments. The maximum grain sizes within the barrier are again large with three of the four samples ranging from 42mm to 58mm. The surface maximum grain sizes are larger, the majority being 70mm.

Mean Sorting

The sediment samples show different sorting values than those of Lows Road (S5800). The majority of surface samples are moderately well sorted with the best-sorted sediments in the swash and upper foreshore/backshore zones. Very poorly and poorly sorted sediments dominate the sub-surface indicating the presence of a large range of sediment sizes. Sediment sorting within the barrier shows more of a vertical pattern from the surface to the lower depths, than across shore where no obvious sorting pattern is visible. The vertical sorting and mean grain size patterns show some relationship at this site.

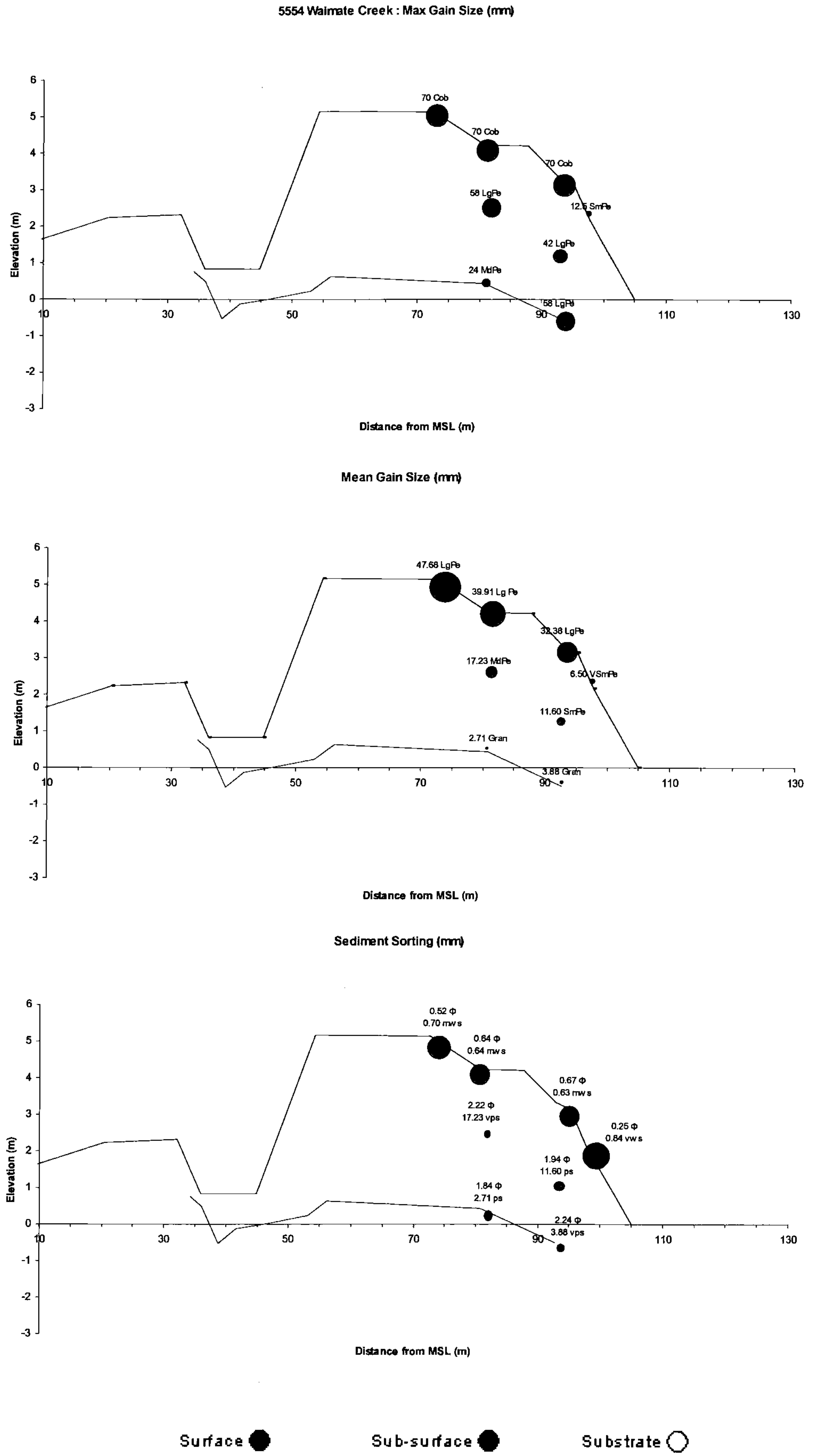


Figure 6.8: Waimate Creek sediment characteristics at the surface, sub-surface and substrate.

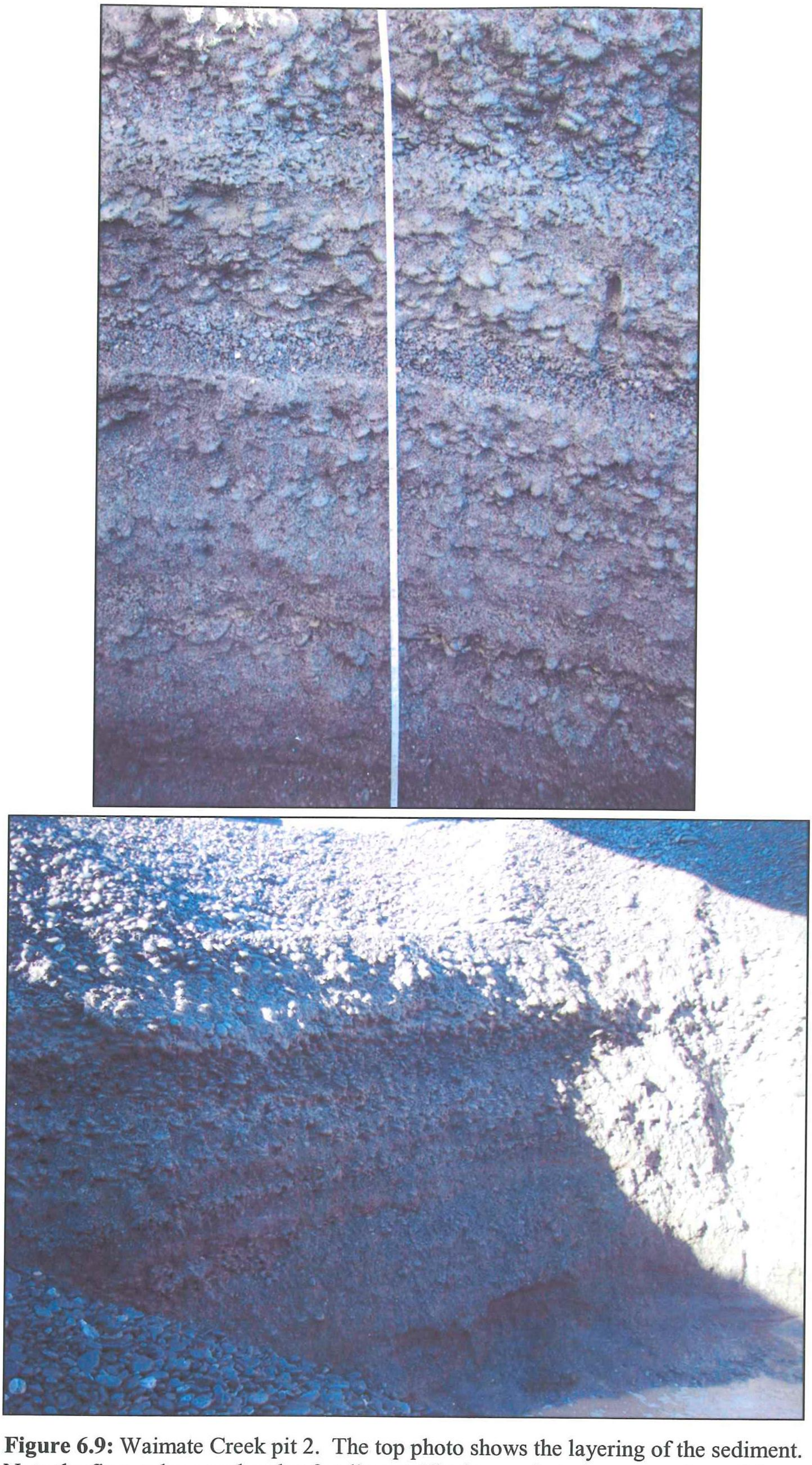


Figure 6.9: Waimate Creek pit 2. The top photo shows the layering of the sediment. Note the fine and coarse bands of sediment. The lower photo is an overview of the pit.

Wainono Lagoon S5214

Sediment Grain Size

The Wainono Lagoon (S5214) breach site has similar mean grain sizes to Waimate Creek. Figure 6.10 and Figure 6.11 displays the sediment characteristics at the surface and within the sub-surface of the barrier. The surface samples across shore consist of a majority of large sized pebbles with the exception of two sample locations, one at the swash which displayed a mean grain size of 4.0mm, classed as a very small pebble and one at the backshore sample which contained a majority of medium sized pebbles.

Wainono Lagoon has a very steep surface and substrate profile. At this site unfortunately only one sub-surface sample was collected. This sample was located just above the substrate and was analysed to have a mean grain size of 8.77mm (small pebble). Several samples were collected at the substrate. The two most seaward substrate samples were classified as very small pebbles. In contrast, the sample collected from the landward side of the substrate has a mean grain size of 45.96mm (large pebbles). It is unknown as to why this sample is much coarser than the other two substrate samples. It could be an old barrier surface as originally thought, over which the modern barrier has rolled. However it can be noted that just below, is a sample with a mean grain size of 9.18mm. One other sample was collected from just below the substrate and falls into the very small sized category. Although limited sub-surface samples were collected, the sediment characteristics are displayed in Figure 6.10. From this figure it is shown that Wainono Lagoon is similar to the other breach sites, consisting of a chaotic mixture of medium mean grain sizes to those that are very small. The maximum grain size ranges from medium pebbles to cobbles, very similar to the surface sizes of large pebbles and cobbles. All of the substrate maximum grain sizes are medium to large except for the most landward sample, which shows the maximum grain size to be a cobble. The sub-surface sample also consists of a maximum grain size of 59mm (very large pebbles).

Mean Sorting

The surface sorting values are not very consistent, ranging from poorly sorted to well sorted material, the most well sorted sediments are located in the backshore sample. The sub-surface contains a very poorly sorted sample. All other substrate and below substrate samples are either very poorly or poorly sorted. At the substrate the sorting values increased slightly in the landward direction.

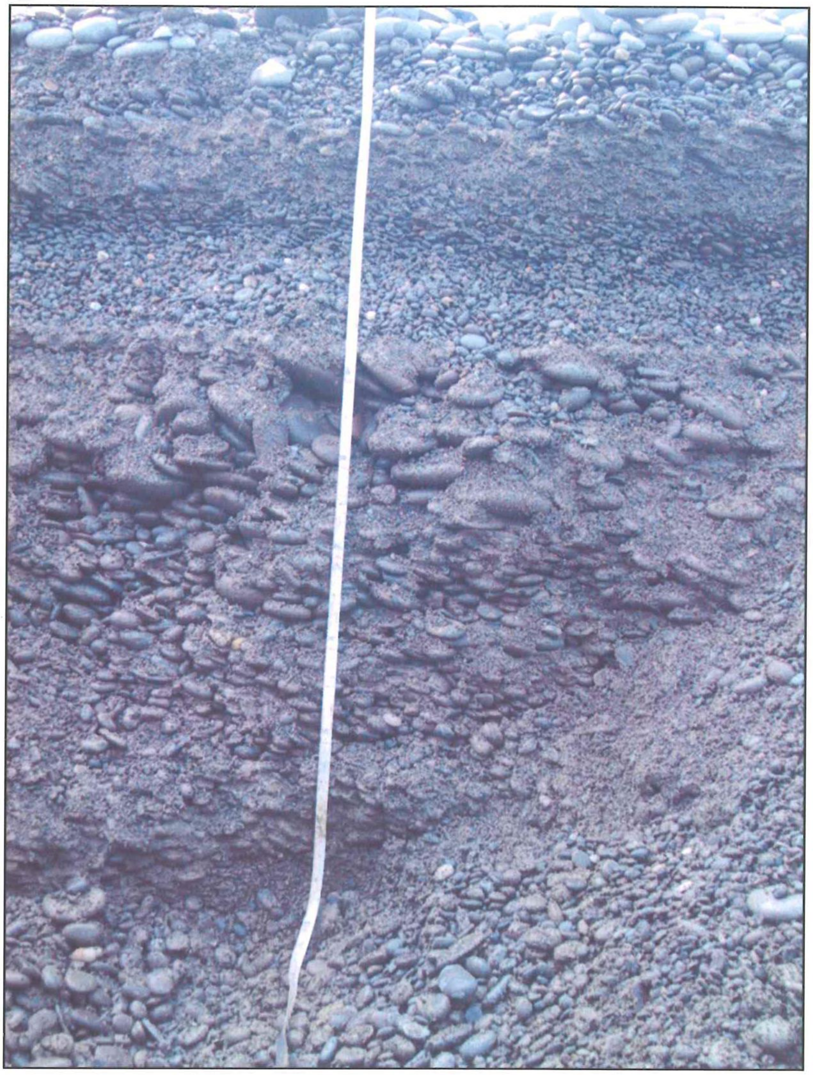


Figure 6.10: Wainono Lagoon site pit 1 (most seaward). Note the distinct layer of fine sediment at the top of the pit and the variation in grain size.

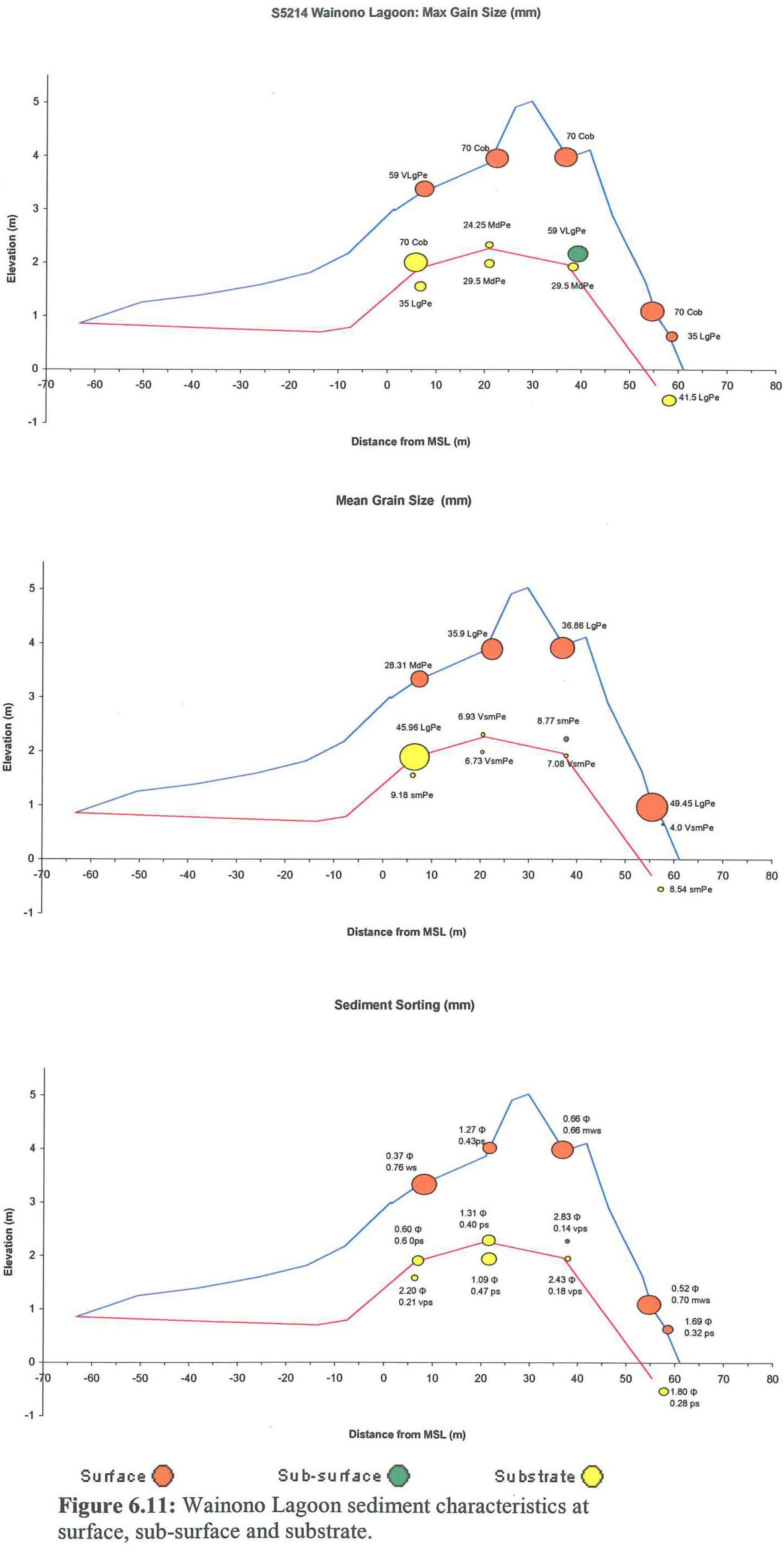


Figure 6.11: Wainono Lagoon sediment characteristics at surface, sub-surface and substrate.

Wainono Hut S5164

Sediment Grain Size

The fourth and most northern breach site is Wainono Hut (S5164), located 500m north of the Wainono Lagoon (S5214) site. This site is the most chaotic of all the breach sites in terms of mean grain size (Figure 6.12).

Wainono Hut, similarly to Wainono Lagoon, displays a very steep surface and substrate profile. The sub-surface does show evidence of the much finer sediment layer that sits below the surface, with the finer consisting of a mean grain size of 5.51mm. In fact all of the samples fall into the very small pebble category with 4.20mm the smallest and 7.57mm the largest of the sub-surface samples. The substrate however, contains a mixture of slightly larger sediment; medium sized at the most landward substrate sample and small at the other two samples. The sediment sizes at Wainono Hut are either large or small, showing areas of distinct layering. Similar to both Wainono lagoon and Waimate Creek. Lows Road is different, showing layering with slightly larger sizes found at greater depth. The maximum grain sizes of all samples are all medium to large. The sub-surface and substrate maximum sizes are slightly smaller than those shown at the previous two sites presented in this section. Again, the sub-surface consists of the smallest sediment, the substrate slightly larger and the surface containing the greatest mean and maximum grain sizes.

Mean Sorting

The sub-surface consists of two very poorly sorted samples (those at the greatest depth) and one poorly sorted sample that sits at a higher elevation. The substrate samples are poorly sorted in the upper foreshore to backshore and very poorly sorted in the foreshore zone. At the substrate, the sorting values increased across shore, similar to the pattern displayed at Wainono Lagoon.

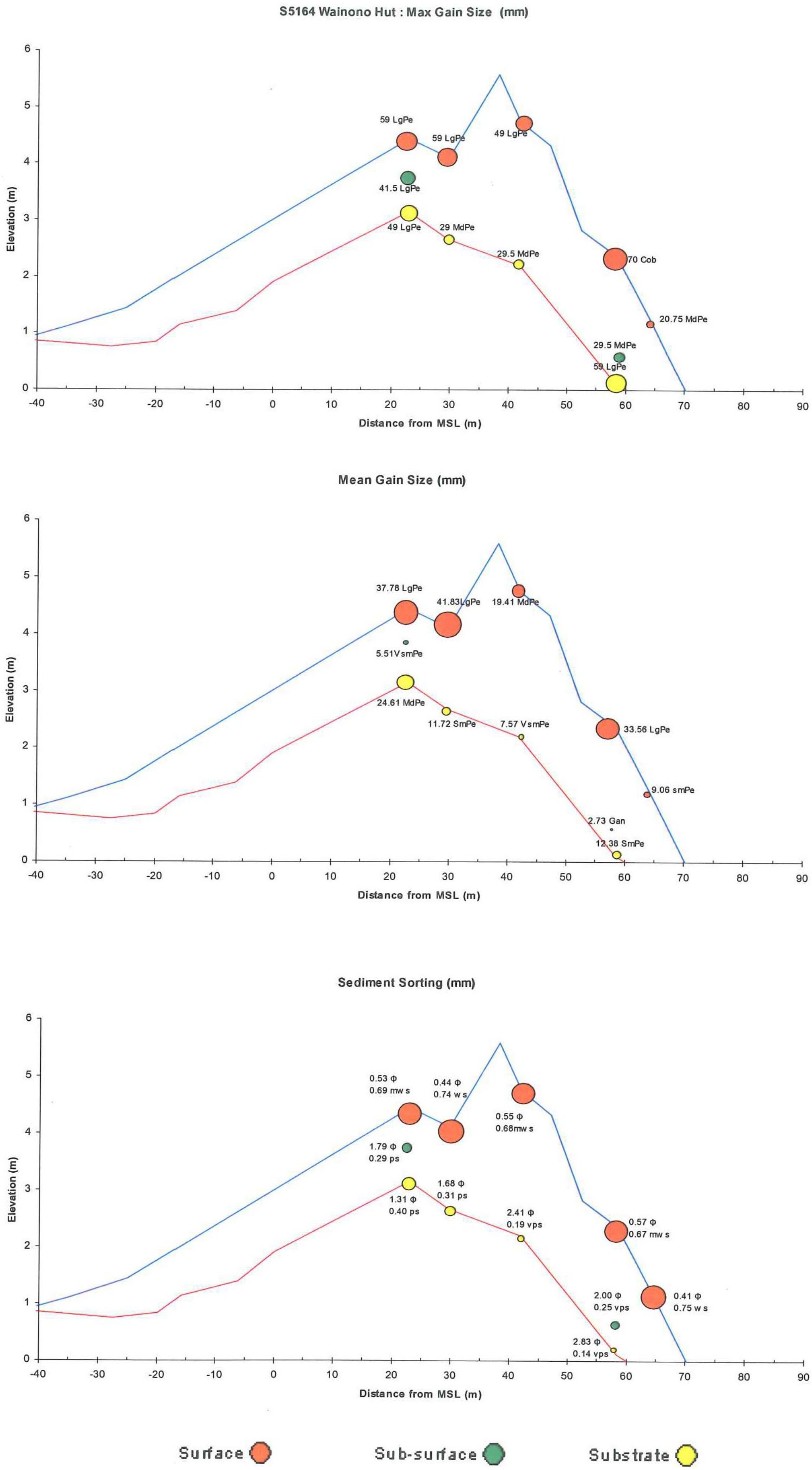


Figure 6.12 Wainono Hut sediment characteristics at surface, sub-surface and substrate.

6.3.2 Non- Breach Sites

Four breach sites have been analysed at depth and presented. Wainono South (Figure 6.13), Wainono North (Figure 6.14) and Poingdestres Road (Figure 6.15) are three non-breach sites located in the same area have also been analysed. The only major difference between the breach sites and the non-breach sites studied is that there seems to be a cross shore mean grain size pattern within the barrier and at the substrate of the non-breach sites.

The Wainono South substrate samples display the smallest mean grain sizes at the most landward pit (2.30mm), increasing seaward to 15.49mm at the bottom of the next pit and then to 47.12mm at the most seaward pit. Figure 6.16 highlights the small sized sediment within the barrier. The opposite pattern occurs at Poingdestres Road (Figure 6.15). Here, the most landward sample in the sub-surface has the greatest mean grain size and decreases in value to the most seaward sample. Figure 6.17 displays an image of the sub-surface at Poigndestres Road. Wainono North bank does not display a cross shore mean grain size pattern but rather a seemingly structured pattern by way of a gradual sediment fining from the surface through to the sub-surface and down to the substrate. Similarly to both Lows Road and Wainono Hut (breach sites), Wainono North displays evidence of the finer sediment layer directly below the surface layer.

Sediment sorting between the breach and non-breach sites in the middle section of the study area does show some differences. The sub-surface samples at Poingdestres Road are made up of very poorly sorted sediments, which is common throughout all sites. However the substrate contains moderately well sorted and very well sorted samples, a contrast especially to Wainono North, where the substrate was reached, and was found to consist of very poorly and poorly sorted samples. Wainono South substrate also contained better-sorted samples ranging from moderately to moderately well sorted values.

It is thought that the depth at which the substrate lies is a major determinant in the stability of the barrier as a whole. The substrate seems to have an effect on the cohesiveness of the sediment layers that sit above. If the substrate is situated too

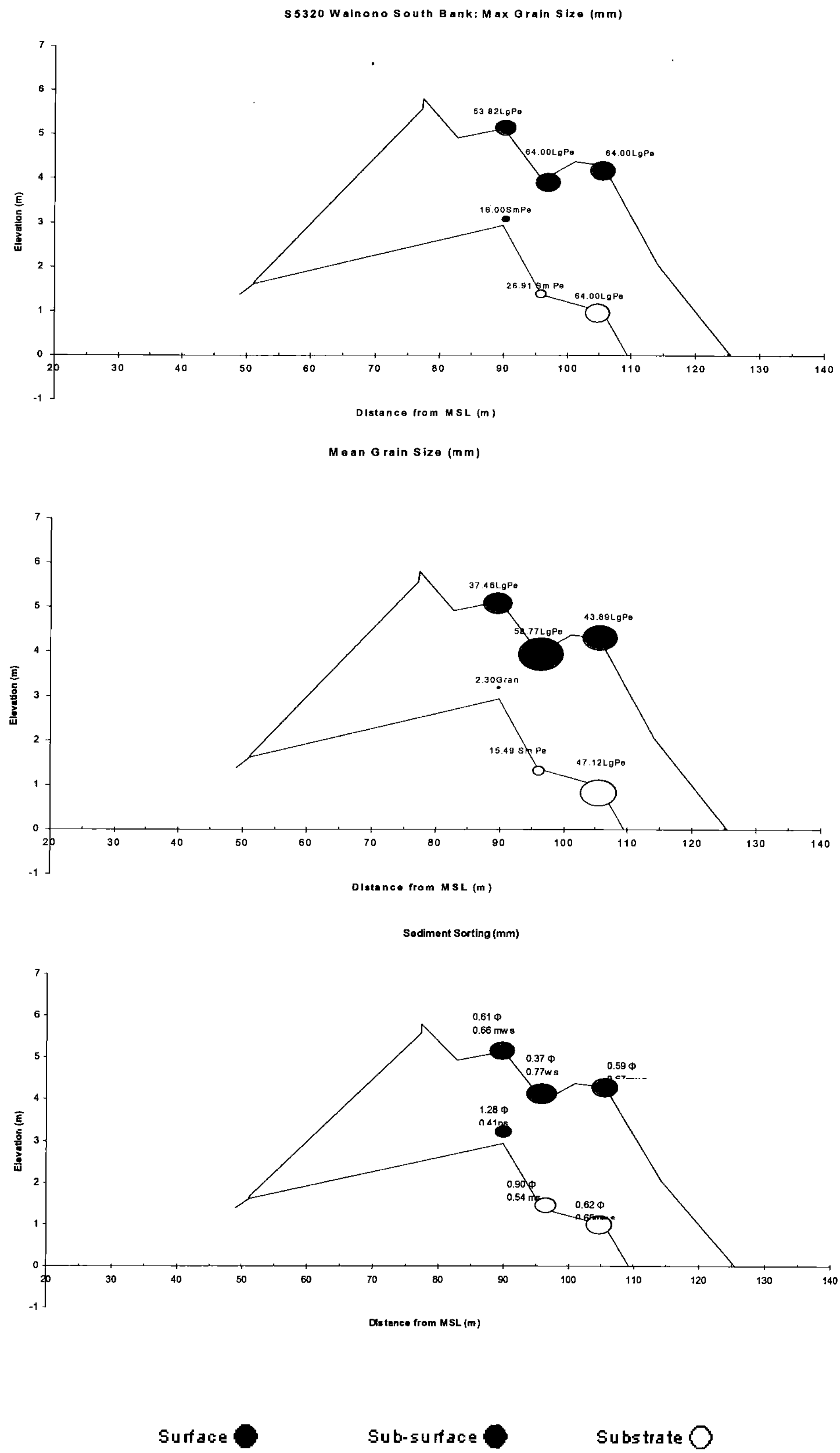


Figure 6.13: Wainono South Sediment characteristics, surface, sub-surface and substrate.

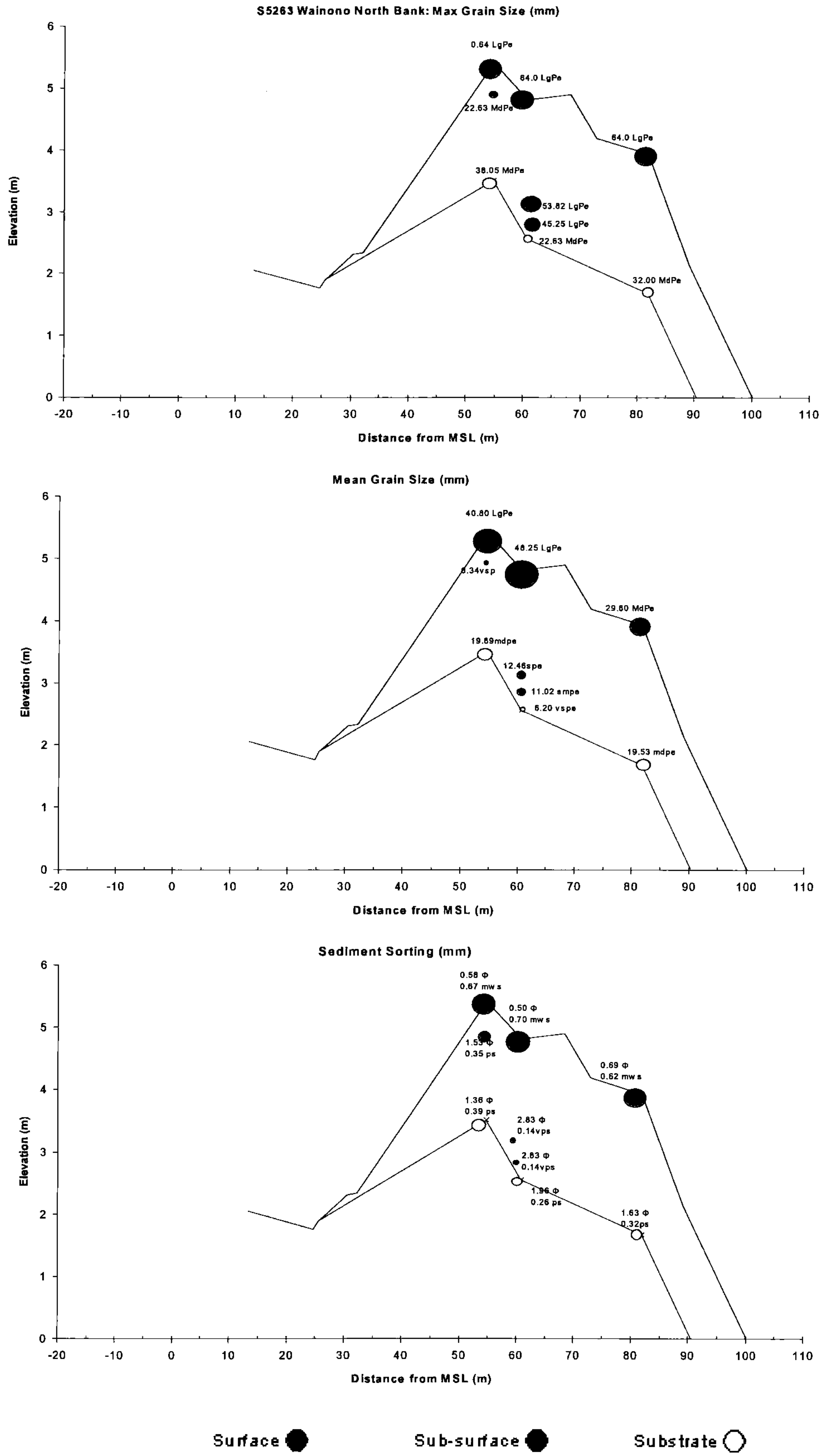


Figure 6.14: Wainono North Sediment characteristics at surface, sub-surface and substrate.

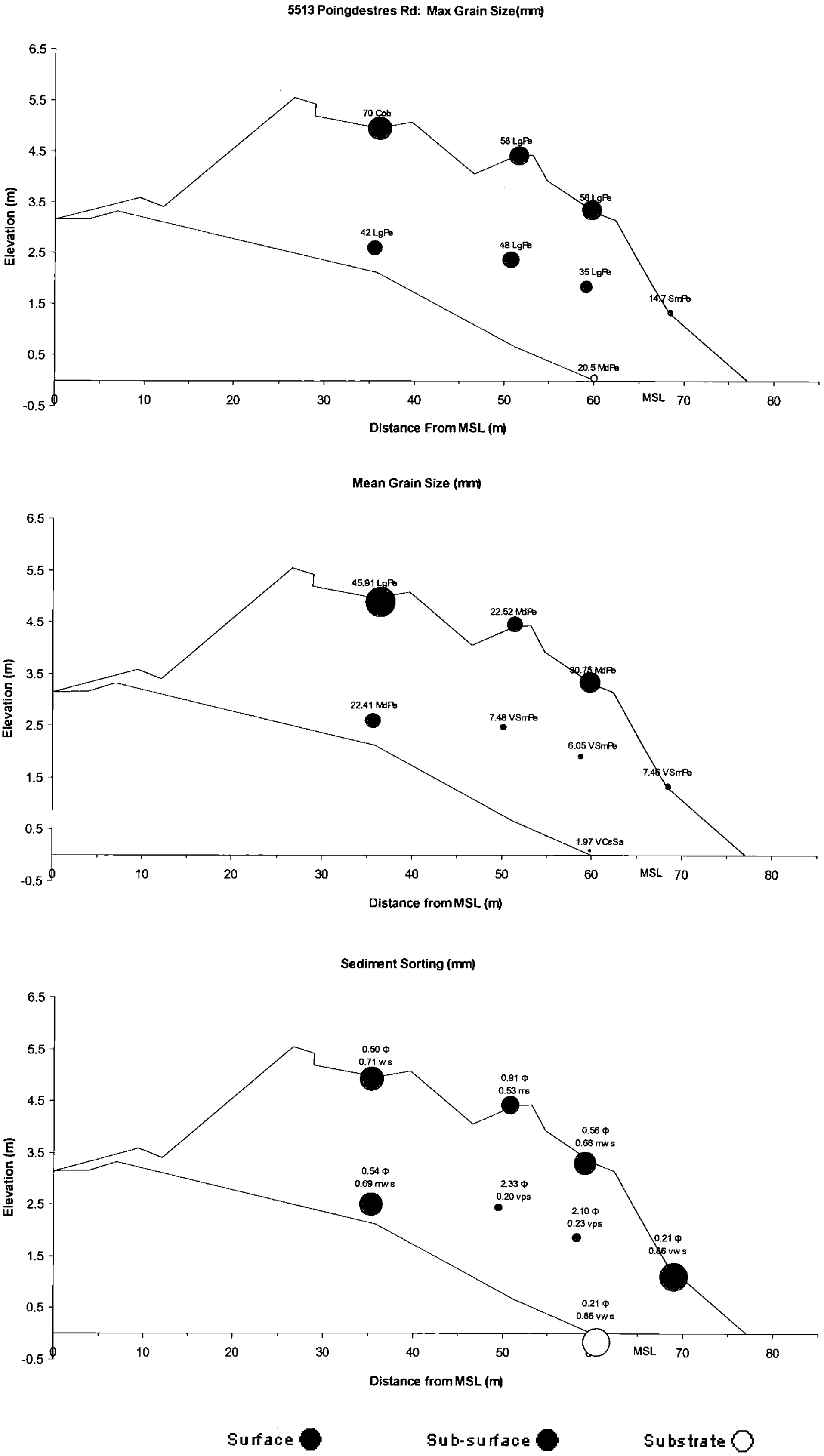


Figure 6.15: Poigndestres Rd Sediment Characteristics at surface, sub-surface and substrate

high, the sediments are influenced too much by the substrate such as at Wainono Hut where the substrate slope and angle leads to disorganised and chaotic sediment

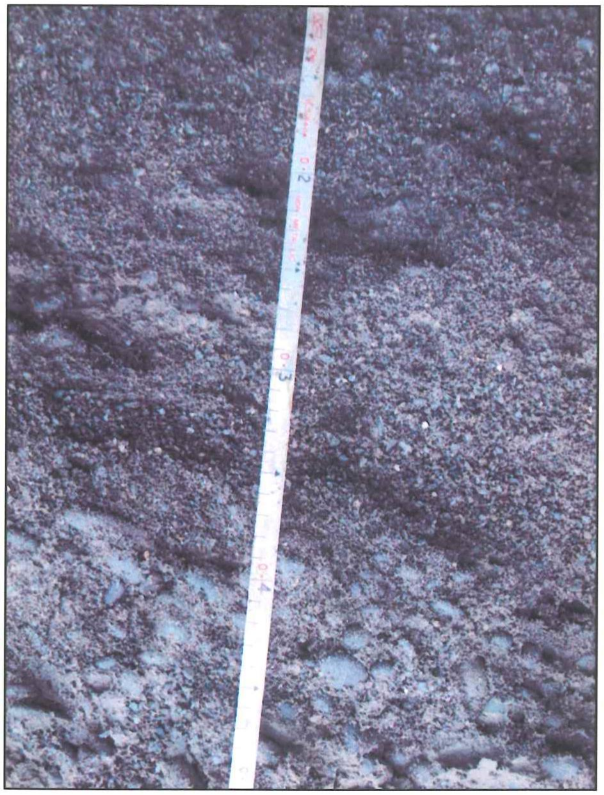


Figure 6.16: Wainono South sub-surface

Figure 6.17: Poigndestres Road sub-surface

arrangement. If the substrate is at considerable depth then there is generally a large volume of sediment sitting on the basement structure. Therefore the cohesive substrate layer influences only a small amount of sediment and the substrate has less of an influence on the rest of the bulk of the sediment such as at Lows Road and Waimate Creek. It must be noted that throughout the study sites, major differences in the substrate type were visible. This too has an effect on the stability and cohesiveness of the sediments above. The differences in substrate reflect the type of hinterland. As stated in Chapter five, the substrate may not have been correctly identified at the lagoon area. It is possible that the silt deposits interpreted as being the substrate are actually a result of the percolation processes from run-up. Figure 6.18 shows two mud/clay substrate types with no sediment visible within the substrate. From viewing this substrate it is clear why the substrate form at Poigndestres Road shows compression due to the weight of the barrier sediment above the soft mud. Figure 6.19 and 6.20 are examples of the substrate material located at Wainono North and Wainono South. This material is thought to be an old barrier form or due to silt percolation from wave run-up processes rather than the actual substrate; hence the pebble sized material within the mud.

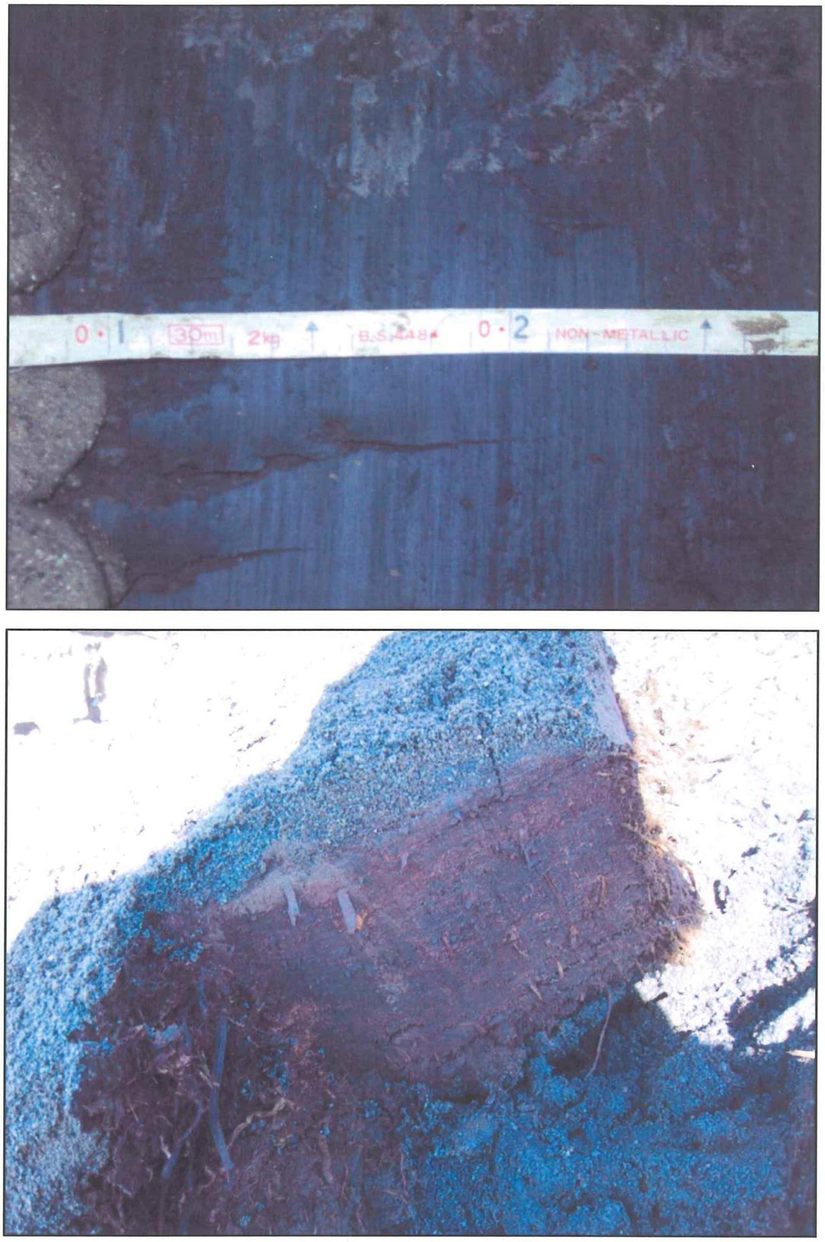


Figure 6.18: Top photo of the mud/clay substrate at Poigndestres Road (S5513) hole 3. Lower photo of Hook Swamp Road (S4550) hole 4 substrate. Note the vegetation in the mud/clay.

Figure 6.19: Wainono North (S5263) substrate and water table

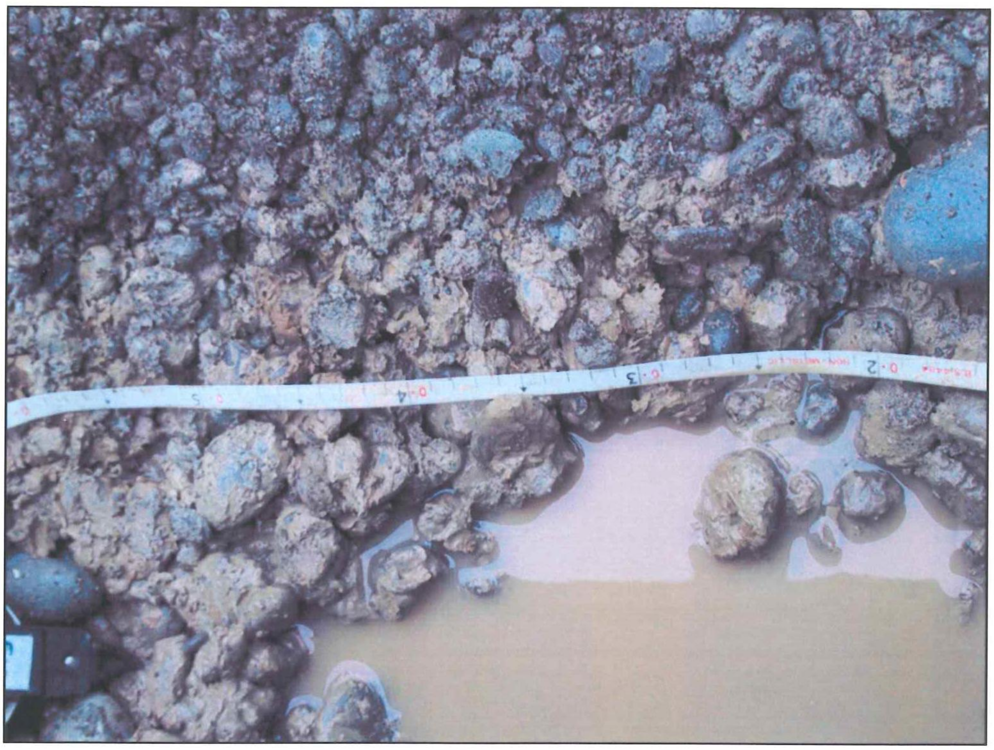


Figure 6.20: Wainono South substrate (S5320)

6.4 Summary

The sediments of the Waihao-Wainono barrier present a wide range of size and sorting values both at the surface and at depth. Through presenting the results, several conclusions can be inferred with regard to why certain areas along the barrier have experienced breach events.

Several patterns exist through examining the surface sediments. The mean grain size is the finest at the southern cliff sites and at its maximum at the Dead Arm and Lagoon sites, where a high frequency of breaching has occurred in the past.

Breach sites and non-breach sites within the same area were analysed at depth with the only major difference between the breach and non-breach sites being that there is a cross shore mean grain size pattern within the sub-surface and substrate at the non-breach sites. Two breach sites and one non-breach site showed evidence of finer sediment beneath the larger sized surface layer.

It is also conclusive that the depth at which the substrate lies is a major determinant in the barrier's stability. All breach sites have either very high or very low substrate elevations, which has a significant influence on the cohesion of sediments.

The sediment analysis added with the volume analysis presented in Chapter Five has created several insights into why the barrier has breached at the four sites. The next chapter will summarise all results and form a list of reasons why the barrier has breached.

Chapter Seven

Controls on Breach Occurrence

7.1 Introduction

A main objective of this thesis is to investigate why certain areas of the Waihao-Wainono barrier have breached.

Chapters One and Three described how breaching and overtopping events along the barrier are frequent occurrences. Both Neale (1987) and Single (1992) concluded beach volume to be strongly connected to the beach response during high energy events. Chapter Three provided a table proposed by Hicks and Todd (2003) outlining the different conditions under which both breaching and overtopping occur. As a result of the findings of this study, additions to the breach conditions can be made. Breach and non-breach sites were examined in terms of the surface and substrate form, volume, and sediment characteristics.

7.2 Breach Site Characteristics

7.2.1 Barrier Form

Surface and substrate forms of each of the 17 sites were examined and several major trends visible at the breach sites are evident. These are:

Surface Form

- Breach sites have steeper foreshore and backshore surface slopes compared to non-breach sites.
- The lower foreshore surface slopes of breach sites are especially prominent with some sites displaying particularly steep profile forms.

- Breach sites as displayed in Figure 5.2 Have slightly lower maximum barrier heights than most other non-breach sites. It is however unknown whether this is a cause of the breach or an effect.

Substrate Form

- Breach sites have steeper foreshore and in some cases backshore slopes than non-breach sites. The substrate form tends to mirror the surface barrier form.
- The two lagoon breach sites (S5164, S5214) display a distinct peaked substrate form which has been assumed as most likely an old barrier or a result of sediment percolation from throughflow and run up processes.
- The Lows Road (S5800) and Waimate Creek (S5554) breach sites have substrate that lie at a great depth compared to any other sites within the study area.

These findings indicate that the slope of both the surface and substrate profiles is important when inferring why a certain site has breached. The slope on which the barrier is formed and which sediment is accumulated determines the stability of the barrier at a particular point. A site that is steep is a lot more unstable than a site, which provides a flatter form.

7.2.2 Barrier Volume

A common thought amongst several researchers (e.g. Neale, 1987; Single, 1992, Single and Hemmingsen, 2001) is that barrier volume is the main contributing factor in the location of a breach. From studies carried out it was posited that the greater the sediment volume at a site, the less likely it was to breach. From this study, the question as to the significance of barrier volume can be answered.

Two of the four past breach sites have the largest volumes of the entire study area containing volumes in excess of $200m^3/m$. The lagoon breach sites also show considerable volumes with $151.88m^3/m$ (S5164) and $161.16m^{3/}m$ (S5214). Barrier volume is thought to be based on the depth at which the substrate lies. The barrier substrate type and elevation is controlled by the hinterland morphology and elevation.

7.2.3 Sediment Characteristics

Sediment characteristics of the Waihao-Wainono barrier have been analysed in the past where studies have focussed on surface sediments rather than the sediments within the barrier. The breach sites contain distinct cross-shore patterns of surface sediment size. Alternating bands of small and large sediments occur until the backshore zone is reached where the sediment reaches its maximum mean grain size. The mean grain size has been most consistent at the breach sites and displays the most consistent surface sorting of all sites sampled. As well as consistency in sorting they also exhibit moderate to high sorting values and are the best sorted areas of the barrier. The temporal variation in mean grain size at the swash and upper foreshore zones shows the lagoon sites, an area with two past breach sites, to have been the most stable area over the past thirty years with mean grain sizes displaying the greatest similarity of all sites over the past thirty years.

The sub-surface at the breach sites is absent of cross-shore mean grain size patterns, which are clear at several of the non-breach sites. Waimate Creek had a poorly sorted sub-surface and contained sediment that while excavating was noted as being very uncohesive. Two breach sites and one non-breach site showed evidence of the finer layer of sediment present beneath the larger sized surface layer. This has a role in the permeability of the barrier sediments. The sediment characteristics and hinterland morphology of the four breach sites seem to have a great influence on why these particular areas have breached.

7.3 Hinterland Morphological Influences on the Breach Sites of the Waihao-Wainono Barrier

All of the breach sites have a hinterland consisting of the Wainono Lagoon, Waimate Creek or the Waihao Dead Arm. This water to the backshore, although sometimes a small amount, creates a hydraulic pressure from the backshore to the ocean. This hydraulic pressure can cause throughflow in coarse clastic barriers and has been identified as an important factor in breaching. It has been suggested that longshore variation in throughflow rates may determine where along a barrier, breaches may occur (Carter et al., 1984).

In terms of the relationship between permeability and sediments, a well sorted deposit is more permeable than a poorly sorted one. Also, coarser sediments have greater permeability than smaller deposits (Krumbein and Monk, 1942 in Shepard, 1963). In relation to the breach sites along the Waihao-Wainono barrier, Waimate Creek and Wainono Hut display consistent sorting values at the surface and are categorised as well to well sorted.

It is thought that layers of low impermeability can increase the likelihood of barrier breaching. At the breach sites, for example Wainono Hut (S5164), the depth analysis displayed layers of large to small mean grain sizes within the barrier, which are effectively layers with high and low levels of permeability. Both Lows Road and Waimate Creek also clearly display this formation. In a letter to the South Canterbury Catchment and Regional Board, Kirk (1985, in Single, 1992) described some of the upper layers of the barrier fronting Wainono Lagoon during a storm in 1985 and proposed a sequence of events leading to the formation of the breach as outlined from Kirk, (1985 in Hart, 1999:136):

1. An effectively impermeable layer of sediments in the barrier allowed high volumes of water to be concentrated within the sediments above.
2. Concurrent with this concentration of water in the upper barrier was an increase in the hydraulic pressure on the barrier, which resulted in high rates of throughflow.
3. These rates of high throughflow caused scouring, erosion and fluidisation of the upper layers of the barrier.
4. Once the barrier crest was lowered, wave run-up flowed directly over the exposed internal sediments, scouring out deeper and wider gaps in the barrier.

From the actual sediment analysis of these breach areas it shown in figure6.6 that the layer of fine, impermeable sediments does exist just below the more permeable surface layer. Hart also found these sequences of layers in the Hurunui and Ashburton barriers in her studies on mixed sand and gravel river mouth lagoons. Kirk (1985, in Single, 1992) found that at high lagoon water levels, these effectively impermeable layers of sediment at Wainono Lagoon allow high volumes of water to be concentrated in the sediments above. The pore water pressure then increases along with throughflow, which in turn increases the shear stress with the sediments eventually leading to the failure of the surface layers and a barrier breach is initiated.

7.4 Possible Future Breach Sites

From this study it is possible to identify areas of the barrier that are most likely to breach (Table 7.1). These are the areas that display some or all of the characteristics identified above.

Table 7.1: Breach Site Characteristics found through studying the Waihao-Wainono barrier.

Factor	Breach Site Characteristic
Barrier Form	
Surface	• Steep foreshore and backshore slopes. • Very steep lower foreshore slopes (11°-14°).
Substrate	• Steep foreshore and lower foreshore slopes (11°-14°). • Substrate located at a great depth. • Substrate displays a distinctive peaked form.
Barrier Volume	• Moderate to large barrier volume (154-254m^3/m).
Sediments	
Mean Grain Size (mm)	• Consistent cross shore mean grain size. • Distinct cross shore pattern of alternating bands of small and large sediment, with a maximum size at the backshore zones. • Absence of any mean grain size cross shore pattern within the matrix. • Layer of fine sediment underneath the layer of larger surface sediments
Sorting (mm)	• Poorly sorted values within the sub-surface • Consistent cross shore surface sorting • Exhibit moderate to high sorting values
Backshore Morphology	• Water to the backshore such as a lagoon or creek. • Low hinterland elevation compared to MSL

Of the non- breach sites, Wainono North S5263, Wainono South S5320 and Maori Road S6158 have the greatest chance of breaching in the near future. Te reason being that the Lagoon, Dead Arm or Waimate Creek (water sites) lies immediately to the backshore of the barrier. This water increases the throughflow and provides an ideal situation for barrier instability. It is recognised that some of these sites do not necessarily contain all the other characteristics mentioned. S5263 has an even greater chance of breaching than the other two water backed sites. The sediment composition is similar to the breach sites in that a fine sediment layer lies just beneath the larger sized layer of surface sediment, increasing the permeability of this site. It has also experienced slight effects from the breaches that have occurred within close proximity.

The four sites that have breached in the past are areas where the barrier may continue to breach in the future.

Chapter Eight

Conclusions

8.1 Thesis Findings and Evaluation

The primary objective of this thesis was to examine the relationship between barrier variability in both time and space and sea flooding into the surrounding farmland and hinterland. This chapter will summarise the main findings of the investigation with respect to the aims and objectives set out in Chapter One.

The first two stated objectives of this research were to accurately estimate beach volume at each profile site and to determine the spatial variability in sediment volume along the barrier.

Through excavations, the substrate was identified at most sites. At some sites the substrate was not reached and instead inferences were made. The lagoon sites displayed substrate with a distinct peaked form, possibly an old barrier or the result of the percolation of silts rather than the actual substrate. Volume calculations were then made. The main school of thought in regard to why certain areas of the barrier breach, has in the past been attributed to barrier volume. Single (1992), Hemmingsen and Single (2001) and Neale (1987) all concluded that breach sites contain the smallest sediment volumes after calculations of an assumed substrate form. Through this thesis and its investigation it can be proven that a small barrier volume does not directly relate to breach events. In fact, two of the four breach sites contain the greatest volumes of all sites studied. Barrier volume displayed a slight increase with distance northward, peaking in the middle section of the study area.

The third objective was to determine barrier form of the surface and substrate profiles both spatially and temporally. Barrier height and width both show an increase northwards. Over the past thirty years since profile data has been collected along the

South Canterbury Coast, little major variation in height and width of the surface of the barrier is evident. The lower foreshore, upper foreshore and backshore slopes are different to those suggested by Neale (1987) with the 2004 data exhibiting steeper slopes than those previously stipulated. In general, the lower foreshore slopes of the beach sites at both the surface and substrate are steeper then the non-breach sites. This steepness in slope is obviously an unstable form for the Waihao-Wainono barrier to display.

The fourth and fifth objectives were to determine any spatial and temporal trends in sediment size and sorting distributions both cross shore and along shore and within the barrier matrix. Distinct cross shore trends are evident and overall the surface sample sites, as expected, generally fit with Bluck's (1967,1999) sediment zonation theory. At most sites, the swash sites display the smallest sized sediment and the backshore zones the largest. However, several locations within the study area do stray from this zonation. A similar pattern to that found by Hewson (1977) is evident at several sites. The mean grain sizes found by Single (1992) are coarser then those collected for this thesis. This is the only finding that is consistent with the local landowners' perceptions of grain size having become smaller over the last fifty years.

Cross shore surface sorting values show the best sorted areas to occur in the swash and backshore zones. Waimate Creek and all of the breach sites show the most consistent and best surface sorting values of the whole barrier. From this it is thought that the well sorted samples may contribute to areas of breach.

Temporal variation in mean grain size within the swash zone has shown an increase in size since 1977-2004. Throughout all of the years a slight fining has occurred with distance north of the Waitaki River. The Lagoon and Dead Arm sites have shown consistency in having the greatest mean grain sizes along this section of the barrier over the thirty year period. This finding is the same for the upper foreshore zone where the greatest mean grain sizes are located at the Dead Arm and Lagoon sites. However, the mean grain sizes in this area are smaller than those sampled in 1994.

The sub-surface sediments within the barrier show differences between the breach and non-breach sites. Several of the breach sites display a finer sediment layer that sits below the coarser surface layer. The sub-surface sediments are somewhat chaotic with often layers of smaller and larger sized sediments visible from the surface through to the substrate. The sub-surface maximum grain size when compared to the surface maximum grain sizes are smaller, therefore disregarding the common perception amongst locals that grain size has decreased over the past fifty years. Other studies (eg. Hart, 1999) have shown that the sediment layering has relevance to the permeability of the barrier, which can ultimately lead to breaching.

Sorting within the barrier sediments is generally very poor at all sites. At both Wainono Lagoon and Wainono Hut, the substrate sorting values showed evidence of a cross shore increase. There is no major sorting pattern within the barrier, although when looking at the figures, in some areas there seems to be a mean grain size/sorting relationship.

This research added to the understanding of the Waihao-Wainono barrier through examining the surface and sub-surface profile form and sediments. A list of characteristics has been formed to help identify areas of the barrier that may breach in the future.

8.2 Suggestions for Further Research

From this thesis, several suggestions for future research have arisen.

Firstly this thesis has provided baseline data on sediment characteristics within the sub-surface of the barrier and on the form of the substrate. From this information, new investigations can be carried out such as trials of Ground Penetrating radar (GPR) along the Waihao-Wainono barrier.

Secondly, it would be of benefit to carry out future sediment characteristic investigations along the Waihao-Wainono barrier, both at the surface and within the barrier. Temporal accumulation of data would provide for an ideal understanding of how the barrier and the sediments within it change over time.

Ideally, data pertaining to the offshore form of the barrier and bathymetry would highlight any differences that may ultimately have an affect the location of breaches.

References

Adams, J., (1978): Data for New Zealand Pebble Abrasion Studies. *New Zealand Journal of Science*. 21:607-610.

Armon, J.W., (1974): Late Quaternary shorelines near Lake Ellesmere, Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics*. 17:63-74.

Balsillie, J.H., (2002): Red flags on the beach: part III. *Journal of Coastal Research*, vol.18, no.4, p.iii.

Balsillie, J.H., Dabous, A.A., Fischer, D.L., (2002): Moment versus graphic measures in granulometry, in Balsillie, J.H. 2002, Red flags on the beach: part III *Journal of Coastal Research*, vol. 18, no. 4, p.iii.

Benn, J.L., (1987): *Erosion of the Washdyke –Seadown Lowland Coast-Past, Prsent and Future*. Unpublished Thesis (M.Sc, Geography), University of Canterbury, Christchurch, New Zealand.

Bird, E.C.F. (1976): *An Introduction to Systematic Geomorphology*. Vol 4 (2nd ed). Australian National University Press, Canberra, 282pp.

Bluck, B.J., (1967): Sedimentation of gravel beaches, examples from South Wales. *Journal of Sedimentary Petrology*. 37:128-156.

Bluck, B.J., (1999): Clast assembling, bed-forms and structure in gravel beaches. *Transactions of the Royal Society of Edinburgh: Earth Sciences*. 89:291-323.

Brotherhood, G., and Griffiths, J., (1947): Mathematical derivation of the unique frequency curve. Journal of Coastal Sedimentary Petrology 2:77-82.

Bruce M (pers.com.) Personal communication December 2003.

Caldwell, N.E. and Williams, A.T., (1985): The roles of beach profile configuration in the discrimination between differing depositional environments affecting coarse clastic beaches. *Journal of Coastal Research* 1, 2:129-139.

Carr, A.P., (1969): Size grading along a pebble beach: Chesil beach, England. *Journal of Sedimentary Petrology*. 39, 1:297-311.

Carter, R.W.G., Forbes, D.L., Jennings, S.C., Orford, J.D., Shaw, J., Taylor, R.B., (1989): Barrier and lagoon coast evolution under differing relative sea-level regimes: examples from Ireland and Nova Scotia. *Marine Geology*. 88:221-242.

Carter, R.W.G. and Orford, J.D. (1993): The morphodynamics of coarse clastic beaches and barriers: A short- and long-term perspective. *Journal of Coastal Research*. Special Issue 15:158-179.

Cope, J., Young, B., (2001): Report on South Canterbury coastal flooding event, 19-22 July 2001. *ECan Technical Report No. U01/101,* 37pp.

Cotton, C.A., (1914): A preliminary note on the uplifted east coast of Marlborough: Transactions of the New Zealand Institute. 46:225-245.

Curray, J.R., (1960): Tracing sediment masses by grain size modes. *In International Geological Congress, Report of the 21st session, Copenhagen, Denmark*, pp119-130.

Davies, J.L., (1964): A morphogenetic approach to world shorelines. Zeitschrift fur Geomorphologie 8:127-142.

Davies, J.L. (1972): *Geographical variation in Coastal Development.* Edinburgh, Oliver and Boyd, 240pp.

Dawe, I.N. (1997): Sediment Patterns on a Mixed Sand and Gravel Beach, Kaikoura, New Zealand. Unpublished Thesis (M.Sc. Geography), University of Canterbury, Christchurch, N.Z.

De Beaumont, L.E. (1845): Septieme lecon. In Bertand, P. *Lecons de Geologie Practique.* Paris 221-252.

Eikaas, H.S. and Hemmingsen, M.A. *(in press)*: A GIS Approach to model Sediment Reduction Susceptibility of Mixed Sand and Gravel Beaches. *Environmental Management.*

Folk, R.L., (1966): A review of grain-size parameters. *Sedimentology*, 6:73-93.

Folk, R.L. (1974): Petrology of Sedimentary Rocks. Hemphill Publishing Company, Austin, Texas.

Folk, R.L., Andrews, P.B, and Lewis, D.W., (1970): Detrital Sediment Rock Classification and Nomenclature for use in New Zealand. *Journal of Geology and Geophysics,* 13, 4:937-968.

Folk, R.L and Ward, W.C., (1957): The Brazos River Bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology, 27,1:3.

Forbes, D.L., Orford, J.D., Carter, R.W.G., Shaw, J. and Jennings, S.C. (1995): Morphodynamic evolution, self-organisation, and instability of coarse-clastic barriers on paraglacial coasts. *Marine Geology.* 126:63-85.

Forbes, D.L., Taylor, R.B., Orford, J.D., Carter, R.W.G. and Shaw, J. (1991): Gravel-barrier migration and overstepping. *Marine Geology*. 97:305-313.

Gibb, R.J., (1978): Rates of coastal erosion and accretion in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 12,4:429-456.

Gibb, R.J., Adams, J., (1982): A Sediment Budget for the East Coast between Oamaru and Banks Peninsula, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*. 25:335-352.

Gilbert, G.K. (1885): The topographic features of lake shores. *US Geological Survey 5th Annual Report*. 69-123.

Goring, D., (2004): *Extreme Sea Levels in South Canterbury*, Unpublished Report for Meridian Energy Limited

Griffiths, J.C. (1951): Size versus sorting in some Caribbean sediments. *Journal of Geology*. 59: 211-243.

Hart, D.E., (1999): *Dynamics of mixed sand and gravel river mouth lagoons: Hapua*. Unpublished Thesis (M.Sc, Geography), University of Canterbury, Christchurch, New Zealand.

Healy, T.R. and Kirk, R.M. (1992): Coasts. In J.M Soons and M.J. Selby (eds), *Landforms of New Zealand* (2nd edn): 161-186. Auckland: Longman Paul.

Hemmingsen, M.A. (1997): *The Coastal Geomorphology of Te Waihora*. Unpublished thesis (M.A, Geography), University of Canterbury, Christchurch, New Zealand.

Hemmingsen, M.A. (2001): The Abrasion of "Greywacke" on a Mixed Sand and Gravel Coast. *Journal of Coastal Research* special issue 34:1-7.

Hemmingsen, M.A. (2004): *Reduction of greywacke sediments on the Canterbury Bight Coast, South Island, New Zealand.* Unpublished Doctoral thesis in Geography, University of Canterbury, Christchurch, New Zealand.

Hemmingsen, M.A. (*in review*): The significance of Textural Mixture to Abrasion of Greywacke Sediments on the Canterbury Bight Coast, South Island, New Zealand. *Journal of Coastal Research.*

Hesp, P.A. and Short, A.D. (1999): Barrier morphodynamics. In A.D Short (Ed.), *Beach and Shoreface Dynamics*, (pp.307-333). Chichester: Wiley.

Hewson, P.A., (1977): *Coastal Erosion and beach Dynamics in South Canterbury-North Otago*. Unpublished Thesis (M.A., Geography) University of Canterbury, Christchurch, New Zealand.

Hicks, D.M. and Todd, D. (2003): *Project Aqua: Coastal and river mouth effects-Supplementary Report.* Unpublished NIWA report for Meridian Energy Ltd.

Hicks, D.M, Wild, M, Todd, D., (2002): *Project Aqua: Coastal and river mouth effects.* Unpublished report to Meridian Energy Ltd.

Hume, T.M. and Herdendorf, C.E. (1988): A Geomorphic classification of estuaries and its application to coastal resource management. A New Zealand example. *Journal of Ocean and Shoreline Management.* 11:249-274.

Inman, D.L., (1952): Measures for describing the size distribution of sediments. *Journal of Sedimentary Petrology*, 22,3:125.

Jennings, R, Orford, J.D, and Carter R.W.G. (1997) Accretion and water levels in enclosed seepage lagoons: Examples from Nova Scotia. *Journal of Coastal Research.* 13:554-563.

Jennings, R. and Shulmeister, J. (2002): A field based classification scheme for gravel beaches. *Marine Geology.* 186:211-228.

Johnson, D.W. (1919): *Shore Processes and Shoreline Development.* Hafner, New York,. 584pp.

Jol, H.M., Smith, D.G. and Meyers, R.A. (1996): Digital Ground Penetrating radar (GPR): A new geophysical tool for coastal barrier research (Examples from the Atlantic, Gulf and pacific Coasts, U.S.A.). *Journal of Coastal Research.*12,4:960-968.

Kennedy, S.K., Meloy, T.P, and Durney, T.E. (1985): Sieve data-size and shape information. *Journal of Sedimentary Petrology*, 55,3:356-360.

Kirk, R.M. (1967): *Beach Morphology and Sediments of the Canterbury Bight.* Unpublished Thesis (M.A. in Geography) University of Canterbury, Christchurch. 173pp.

Kirk, R.M. (1985): Letter to South Canterbury Catchment Board, 10/8/85. *Correspondence held on file by Coastal Investigations Officer,* Canterbury Regional Council.

Kirk, R.M., Owens, I.F., Kelk, J.G. (1977): Coastal Dynamics, East Coast of New Zealand, South Island. *Proceedings of the 3rd Australian Conference in Coastal and Ocean Engineering, Melbourne.*

Kirk, R.M. (1980): Mixed sand and gravel beaches: morphology, processes and sediments. *Progress in Physical Geography.* 4,2:189-210.

Kirk, R.M., (1984): *Enhancement of Coastal Protection by Beach Realignment, South Beach, Timaru.* An unpublished report to Engineers Dept., Timaru Harbour Board. 29pp.

Kirk, R.M., (1987): Coastal Erosion in South Canterbury-North Otago-an overview. A report to the South Canterbury Catchment Board and Regional Water Board. *SCCB Publication No. 52.*

Kirk RM, Lauder G A (1994). *Guidelines for Managing Lagoon-Mouth Closure on Significant Coastal/Wetland Lagoon Systems-Coastal Processes Investigation.* Report to the Department of Conservation, Science and research Division, Wellington

Kirk, R.M, Lumsden, J.L, and Hastie,W.J., (1987): An improved approach to coastal sediment investigations with case studies from New Zealand. *Proceedings of the 2nd Australasian Conference on Coastal and Ocean Engineering,* pp121-131.

Kjerfve, B., (1994): Coastal Lagoons: In B Kjerfve (Ed) *Coastal Lagoon Processes,* Elsevier, Oceanography Series. 60:1-8.

Komar, P.D. (1998): *Beach Processes and Sedimentation (2nd edn).* New Jersey: Prentice Hall.

Komar, P.D. (1975: Nearshore currents: Generation by obliquely incident waves and Longshore variations in breaker height. In Hails, J.R. and Carr, A.P (eds). *Nearshore Sediment Dynamics and Sedimentation.* Wiley, London, 316pp.

Komar, P.D. (1976): *Beach Processes and Sedimentation.* Prentice Hall, Englewood Cliffs.417pp.

Komar, P.D. and Inman, D.L. (1970): Longshore sediment transport on sand beaches. *Journal of Geophysical Research.* 75,30:5914-5927.

Krumbein, W.C., (1934): Size frequency distributions of sediments. *Journal of Sedimentary Petrology*, 4,2:65.

Lewis, D.W and McConchie, D., (1994a): *Analytical Sedimentology*, Chapman and Hall, New York

.

Lewis, D.W and McConchie, D., (1994b): *Practical Sedimentology*, 2nd ed, Chapman and Hall, New York.

Marshall, P. (1928): The wearing of beach gravels. *Transactions of the Royal Society of New Zealand.* 58:507-532.

Marshall, P. (1929): Beach gravels and sand. *Transactions of the New Zealand Institute.* 60:324-365.

Mason, T., Voulgaris, G., Simmonds, D.J. and Collins, M.B. (1997): Hydrodynamics and sediment transport on composite (mixed sand/shingle) beaches: a comparison. *Coastal Dynamics '97* (American Society of Civil Engineers) pp 48-57.

Masselink, G., and Li, L. (2001): The role of swash infiltration in determining the beachface gradient: a numerical study. *Marine Geology*. 176:139-156.

Matthews, E.R. (1983): Measurements of beach pebble attrition in Palliser Bay, Southern North Island, New Zealand. *Sedimentology*. 30:787-799.

McIntyre (1958): Coastal Erosion. South Canterbury up to 1958. Unpublished M.O.W. report held at Timaru Harbour Board

McLean, R.F. (1970): Variations in Grain-size sorting on two Kaikoura Beaches. *Journal of Marine and Freshwater Research* 4,2:141-164..

Mclean, R.F. and Kirk, R.M. (1969): Relationships between grain size, size-sorting and foreshore slope on mixed sand-shingle beaches. *New Zealand Journal of Geology and Geophysics.* 12,1: 138-155.

Mutch, A.R. (1963): Oamaru I:250,000. *New Zealand Geological Map*, sheet 23.

Neale, D.M (1987): *Longshore Sediment Transport in a Mixed Sand and Gravel Foreshore, South Canterbury.* Unpublished Thesis (M.Sc. Geography), University of Canterbury, Christchurch, N.Z. 243pp.

Neal, A., Pontee, N.I., Pye, K. and Richards, J. (2002): Internal structure of mixed-sand-and-gravel beach deposits revealed using ground-penetrating radar. *Sedimentology.* 49:789-804.

Neal, A., Richards, J. and Pye, K. (2003): Sedimentology of coarse-clastic beach-ridge deposits, Essex, southeast England. *Sedimentary Geology.* 162:167-198.

Oborn, L.E., (1978): (cold upper quaternary deposits) Waitaki Catchment, pp608-611. In *Suggate, P.R, Stevens, G.R., Te Punga, M.T. (eds)* The Geology of New Zealand. Govt. Printery Wellington. 2 vols. 820pp.

Orford, J.D. (1975): Discrimination of particle zonation on a pebble beach. *Sedimentology.* 22:441-463.

Orford, J.D. (1977): A proposed mechanism for storm beach sedimentation. *Earth Surface Processes.* 2:381-400.

Orford, J.D and Carter, R.W.G. (1984): Mechanisms to account for the longshore spacing of overwash throats on a coarse clastic barrier in Southeast Ireland. *Marine Geology.* 56:207-226.

Orford, J.D., Carter, R.W.G. and Jennings, S.C. (1991): Coarse clastic barrier environments: evolution and implications for Quaternary sea-level interpretation. *Quaternary International*. 9:87-104.

Orford, J.D., Carter, R.W.G, McKenna, J. and Jennings, S.C. (1995): The relationship between the rate of mesoscale sea- level rise and the retreat rate of swash- aligned, gravel-dominated coastal barriers. *Marine Geology*. 124:177-186.

Orford, J.D., Carter, R.W.G. and Jennings, S.C. (1996): Control domains and morphological phases in gravel-dominated coastal barriers of Nova Scotia. *Journal of Coastal Research*. 12,3:589-605.

Orford, J.D., Forbes, D.L. and Jennings, S.C. (2002): Organisational typologies and time scales of paraglacial gravel-dominated coastal systems. *Geomorphology*. 48:51-85.

Owen, S.J. (1992): The Estuary: Where our rivers meet the sea, Christchurch's Avon-Heathcote Estuary and Brooklands Lagoon. Parks Unit, Christchurch City Council. 137

Palmer, H.R., (1834): Observation on the motions of shingle beaches. Phil. Trans. R. Soc. London, Serial A:567.

Pemberton, A.L. (1980): Future protection of Wainono Lagoon: an investigatory report into the future of Wainono Lagoon. *SCCB Pub. No. 22, 9pp*.

Pethick, J., (1984): *An introduction to Coastal Geomorphology*. Edward Arnold, London, 260pp

Pettijohn, F.J and Ridge, J.D. (1932): A textural variation series of beach sands from Cedar Point, Ohio. *Journal of Sedimentary Petrology*. 2,2:76-88.

Pickerill, R.A. (1976): The Evolution of Coastal Landforms of the Wairau Valley. *New Zealand Geographer.* 32,1:17-29.

Pierce, R.J. (1980): Seasonal and Long-terms changes in bird numbers at Lake Wainono. *Notornis* 27:21-44.

Pieters, (1996): *Coastal Cliff Erosion in South Canterbury.* Unpublished Thesis, (MSc, Geography), University of Canterbury, Christchurch, New Zealand.

Pontee, N.I., Pye, K. and Blott, S.J. (2004): Morphodynamic behaviour and sedimentary variation of mixed sand and gravel beaches, Suffolk, UK. *Journal of Coastal Research.* 20 (1): 256-276.

Reineck, H.E and Singh, I.B., (1973): *Depositional sedimentary environments*, Springer-Verlag, Berlin.

Shepard, M. and Hesp, P., (2003): Sandy Barriers and Coastal Dunes. In G.R. Goff., S.L. Nichol and H.L. Rouse. (Eds), *The New Zealand Coast, Te Tai O Aotearoa*. Dunmore Press, Palmerston North

Sherman, D.J. (1991): Gravel beaches. *National Geographer*. 7:442-452.

Short, A.D. (1979): Three dimensional beach-stage model. *Journal of Geology*. 87: 553-571.

Shulmeister, J. and Rouse, H. (2003): Gravel and mixed sand and gravel beach systems. In G.R. Goff., S.L. Nichol and H.L. Rouse. (Eds), *The New Zealand Coast, Te Tai O Aotearoa*. Dunmore Press, Palmerston North.

Single, M.B., (1992): *High Energy Coastal Processes on Mixed Sand and Gravel Beaches*. Unpublished Thesis (Ph.D Geography), University of Canterbury, Christchurch, New Zealand.

Single, M.B. and Hemmingsen, M., (2001): Mixed sand and gravel barrier beaches of south Canterbury, New Zealand. In J.R. Packham, R.E. Randall, R.S.K.Barnes and Neal, A. (Eds), *Ecology and Geomorphology of Coastal Shingle*. Westbury Academic and Scientific Publishing, West Yorkshire.

Sneed, E.D. and Folk, R.L., (1958): Pebbles in the Lower Colorado River, Texas. A study in particle morphogenesis. *Journal of Geology*. 66:114-150.

Soons, J.M., Shulmeister, J. and Holt, S., (1997): "The Holocene evolution of a well nourished gravelly barrier and lagoon complex, Kaitorete "Spit", Canterbury, New Zealand". *Marine Geology*. 138: 69-90.

Speight, R. (1930): The Lake Ellesmere Spit, with maps, sections and photographs: Transactions 61:147-169.

Spencer, D.W., (1963): The interpretation of grain size distribution curves of clastic sediments. Journal of Sedimentary Petrology, 33,1:180-190.

Roy, P.S., Cowell, D.J, Ferland, M.A. and Thom, B.G., (1994): Wave dominated coasts in RWG later and C.D Woodroffe. (Eds) *Coastal Evolution,* 121-186, Cambridge, Cambridge University Press.

Todd, D.J., (1988): Annotated Coastal Bibliography of South Canterbury. *SCCB Publication No. 57.*

Todd, D.J., (1991): Mixed sand and gravel beach reconstruction experiment, Wainono, South Canterbury, New Zealand. "Coastal Engineering- Climate for Change" 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, 2-6 Dec. 1991.

Todd, D.J., (pers.com.) Personal communication June 2005.

Udden, J.A., (1898): *Mechanical composition of wind deposits*, Augustana Library Publication, no.1

Van Heteren, S., Fitzgerald, D.M., McKinlay, P.A. and Buynevich, I.V., (1998): Radar facies of paraglacial barrier systems: coastal New England, USA. *Sedimentology*. 45: 181-200.

Van Orstand, C.E. (1925): Note on the representation of the distributions of grains in sands: Committee in sedimentation: Research in sedimentation, 1924 – National Research Council. 63-67

Vessey, E.M., (2003): *The Coastal System of Gore Bay, North Canterbury, New Zealand.* Unpublished Thesis (M.Sc. Geography), University of Canterbury, Christchurch, New Zealand.

Waddell, H., (1933): Sphericity and Roundness of rock particles. Journal of Geology, 41:310-331.

Ward, M.F., (1986): *Evidence Given in Joint Planning Hearing of Waimate C.C and SCCB into M.E. Bruce, Waihao Salmon Farm Proposal.* Unpublished. 13pp.

Winkelmolen, A.M., (1969): The Rollability Apparatus. *Sedimentology*. 13:291.

Zenkovich, V.P., (1967): *Processes of Coastal Development.* Oliver and Boyd, London, 783pp.

Zingg, T.H., (1935): Beitrag zur schotteranalyse. *Schweiz. Min.Petr.Mitt*, 15:39-141.

Appendices

Appendix 1
Geological Time Scale

Era	Period	Epoch	Duration
	Quaternary	Holocene	100 000 BP to present
		Pleistocene	2mya - 100 000 BP
	Tertiary	Pliocene	5 - 2 mya (3)
Cenozoic (65)		Miocene	24 - 5 mya (19)
		Oligocene	38 - 24 mya (14)
		Eocene	55 - 38 mya (17)
		Palaeocene	65 - 55 mya (10)
	Cretaceous		144 - 65 mya (38)
Mesozoic (148)	Jurassic		213 - 144 mya (69)
	Triassic		248 - 213 mya (35)
	Permian		286 - 248 mya (38)
	Carboniferous		360 - 286 mya (74)
Palaeozoic (257)	Devonian		408 - 360 mya (48)
	Silurian		438 - 408 mya (30)
	Ordovician		505 - 438 mya (67)
	Cambrian		590 - 505 mya (85)
	PreCambrian		4600 - 590 mya (4010)

Mya = millions of years.

Numbers in brackets refer to duration of the era/period/epoch.

Only a general reference. Durations are often modified from country to country, particularly the Quaternary period, depending on local conditions.

From: Dawe (1997:170).

Appendix 2
Resource Consent

16th March 2004

Mr RTL and Mrs NJ Hayman
174 Haymans Rd
Studholme
Waimate

RESEARCH EXCAVATION PITS ON WAIHAO-WAINONO BARRIER

My name is Joanne Stapleton and I am carrying out research on the Waihao-Wainono coastal barrier for a Masters thesis in Coastal Geography at the University of Canterbury. The objective of my thesis is to determine the relationship between variability in the size of the barrier (eg volume, height, and width) and the occurrence of sea flooding of the surrounding farmland. In past, one of the main limitations to this type of analysis has been that the beach volume has had to be estimated above some assumed datum. In order to overcome this limitation it is proposed to excavate a number of test pits along the barrier to determine the profile of the sub-strata below the beach gravels.

A resource consent from ECan has been applied for to carry out the excavations. A condition on that consent, is the notification of landowners who have property adjoining the barrier about the scale and timing of the work.

In order to tie the sub-strata profile to the beach profiles, the field work will involve excavating test pits across the beach at the location of the 20 ECAN profile sites from Carrolls Rd, Glenavy, to Makikihi. The locations of these profiles are shown on the attached maps. The pits will be excavated by Gary Rooney Contracting, and will be filled in immediately following the extraction of the required data on sediment stratigraphy and gravel depth. In is estimated that this will take approximately one hour per pit.

In order to take advantage of low tides, the field work is proposed to take place in the week starting 22nd of March, and continue in the weeks beginning 5th and 19th April if necessary. All excavations will be finished before May, to avoid duck shooting season.

If you have any concerns or queries please do not hesitate to contact either myself or my thesis supervisor, Derek Todd.

Joanne Stapleton
021-688804
Masters Thesis Student

Derek Todd
027-2787439
Thesis Supervisor

Yours faithfully

Joanne Stapleton

Environment Canterbury
Your regional council

58 Kilmore Street,
PO Box 345,
Christchurch,
Telephone (03) 365-3828,
Fax (03) 365-3194,
Website: www.ecan.govt.nz

21 April, 2004

Meridian Energy Limited
C/- Dtec Consulting
PO Box 11 279
Sockburn
CHRISTCHURCH

Attn: Mr Derek Todd

Dear Mr Todd

RESOURCE MANAGEMENT ACT 1991
NOTICE OF DECISION: RESOURCE CONSENT NO. CRC041904

The decision of Environment Canterbury is to grant your application on the terms and conditions specified in the attached resource consent document. The reasons for the decision are

1) Any adverse effects on the environment as a result of the proposed activity will be minor.

2) There are no persons, who have not provided written approval who are considered to be adversely affected by the granting of this proposal.

For some activities a report is prepared, with officer recommendations, to provide information to the decision makers. If you require a copy of the report please contact our Customer Services section and a copy can be provided.

If you do not agree with the consent authority decision, you may object to the whole or any part of the decision. Notice of any objection must be in writing and lodged with Environment Canterbury within 15 working days of receipt of this decision.

Alternatively you may appeal to the Environment Court, P O Box 2069, Christchurch. The notice of appeal must be lodged with the Court within 15 working days of receipt of this decision, with a copy forwarded to Environment Canterbury within the same period. If you are in any doubt about the correct procedures, you should seek legal advice.

The commencement date for your resource consent is the date of this letter advising you of the decision, unless you lodge an appeal against the decision. The commencement date will then be the date on which the decision on the appeal is determined.

Enclosed is our Customer Satisfaction Survey. Please help us to provide a quality service that meets our customer needs by filling out the survey form and returning it in the postage paid envelope provided. Your feedback is anonymous unless you complete the space provided on the survey form with your name and consent number. If you would like a reply to any matters raised in your survey reply, please tick the box provided on the form.

Also enclosed is a Consent Holder Fact Sheet, which you should read and keep for future reference. This fact sheet contains important information about your consent and answers some commonly asked questions about what will happen next in the life of your resource consent.

Our Ref **CO6C/21549**
Your Ref:
Contact: ***Customer Services***

Charges, set in accordance with section 36 of the Resource Management Act 1991, shall be paid to the Regional Council for the carrying out of its functions in relation to the administration, monitoring and supervision of resource consents and for the carrying out of its functions under section 35 of the Act.

Thank you for helping us make Canterbury a great place to live.

If you have any queries please contact our Customer Services Section by telephoning (03) 365 3828, or 0800 ECINFO (0800 324 636).

Yours sincerely

Tania Harris
TEAM LEADER CONSENTS ADMINISTRATION
on behalf Environment Canterbury
Encl.

CRC041904

RESOURCE CONSENT

Pursuant to Section 104 of the Resource Management Act 1991

The Canterbury Regional Council (known as Environment Canterbury)

GRANTS TO: Meridian Energy Limited

A Land Use Consent: To carry out works in the coastal hazard zone

DATE GRANTED: 20 April 2004 ***EXPIRY DATE:*** 20 April 2006

IN CONNECTION WITH THE FOLLOWING PROPERTY:

LOCATION: Coastline, MORVEN GLENAVY CLIFFS TO MAKIKIHI

LEGAL DESCRIPTION:

SUBJECT TO THE FOLLOWING CONDITIONS:

1) The works to excavate exploratory pits and trenches in the Coastal Hazard Zone:
   (a) Shall only be carried out between map references NZMS 260 J40:6395-1801 and J41:6427-8603; and
   (b) Shall only be carried out at the sites identified on Plan CRC041748 attached to this consent, except that
   (c) Additional sites to those identified on Plan CRC041748 may be excavated provided that Waihao Runanga and any adjacent landowners are notified at least five working days prior to commencement of works.

2) Works shall cease if a New Zealand Meteorological Service coastal storm warning is issued, and shall only resume after consultation with the Canterbury Regional Council's Coastal Resources Section.

3) Excavation shall cease on reaching the substrata of the beach profile.

4) No trenches shall be excavated at sites north of Morven Beach Road at or about map reference NZMS 260 J40:6549-1801.

5) Representatives of the Waihao Runanga and adjacent landowners shall both be notified at least 48 hours prior to the commencement of works at each site, and shall be allowed on site by the consent holder to observe the works.

6) The Department of Conservation, Fish and Game New Zealand and all adjoining landowners to the site of works shall be notified at least 48 hours prior to the commencement of works.

7) The consent holder shall follow the Accidental Discovery Protocol provided by Waihao Runanga, and works shall cease if requested by the representative of Waihao Runanga on site.

8) No works shall be carried out during the first week of May or during any weekend or public holiday of May, June or July. During these months machinery shall not be in operation on the beach prior to 9am during weekdays.

9) Machinery shall only enter and exit the beach via existing tracks, and all practicable measures shall be taken to avoid disturbance of vegetation on the beach.

CRC041904

RESOURCE CONSENT

Pursuant to Section 104 of the Resource Management Act 1991

The Canterbury Regional Council (known as Environment Canterbury)

GRANTS TO: Meridian Energy Limited

A Land Use Consent: To carry out works in the coastal hazard zone

DATE GRANTED: 20 April 2004 ***EXPIRY DATE:*** 20 April 2006

IN CONNECTION WITH THE FOLLOWING PROPERTY:

LOCATION: Coastline, MORVEN GLENAVY CLIFFS TO MAKIKIHI

LEGAL DESCRIPTION:

SUBJECT TO THE FOLLOWING CONDITIONS:

1) The works to excavate exploratory pits and trenches in the Coastal Hazard Zone:
   (a) Shall only be carried out between map references NZMS 260 J40:6395-1801 and J41:6427-8603; and
   (b) Shall only be carried out at the sites identified on Plan CRC041748 attached to this consent, except that
   (c) Additional sites to those identified on Plan CRC041748 may be excavated provided that Waihao Runanga and any adjacent landowners are notified at least five working days prior to commencement of works.

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6) The Department of Conservation, Fish and Game New Zealand and all adjoining landowners to the site of works shall be notified at least 48 hours prior to the commencement of works.

7) The consent holder shall follow the Accidental Discovery Protocol provided by Waihao Runanga, and works shall cease if requested by the representative of Waihao Runanga on site.

8) No works shall be carried out during the first week of May or during any weekend or public holiday of May, June or July. During these months machinery shall not be in operation on the beach prior to 9am during weekdays.

9) Machinery shall only enter and exit the beach via existing tracks, and all practicable measures shall be taken to avoid disturbance of vegetation on the beach.

10) All excavations will be in filled on the same day as they are excavated and any gravel, sand and natural material disturbed by the works shall be reshaped and formed to a state consistent with the surrounding beach profile.

11) (a) (a)The Canterbury Regional Council shall be notified at least 48 hours prior to the commencement of works at each site, and
(b) A plan showing the location of all excavations shall be forwarded to the Canterbury Regional Council within one month of the completion of works.

12) All practicable measures shall be undertaken to minimise effects on amenity values, wildlife, vegetation and ecological values.

13) There shall be no storage of fuel or refuelling of vehicles and machinery anywhere on the foreshore.

14) For the duration of the works, all reasonable measures shall be taken to minimise the restrictions to public access to, or along, the foreshore.

15) Vehicles and machinery shall not be operated in flowing water, and all reasonable measures shall be taken to prevent oil leaking from machinery.

ISSUED AT CHRISTCHURCH ON 21 APRIL 2004

Tania Harris
TEAM LEADER CONSENTS ADMINISTRATION
on behalf of the Canterbury Regional Council

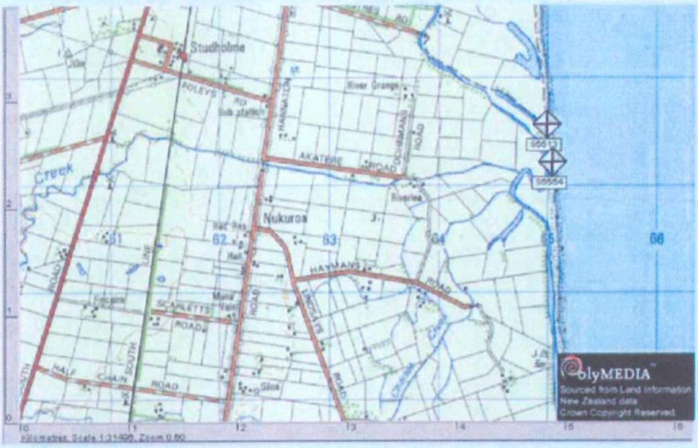
Plan CRC041748

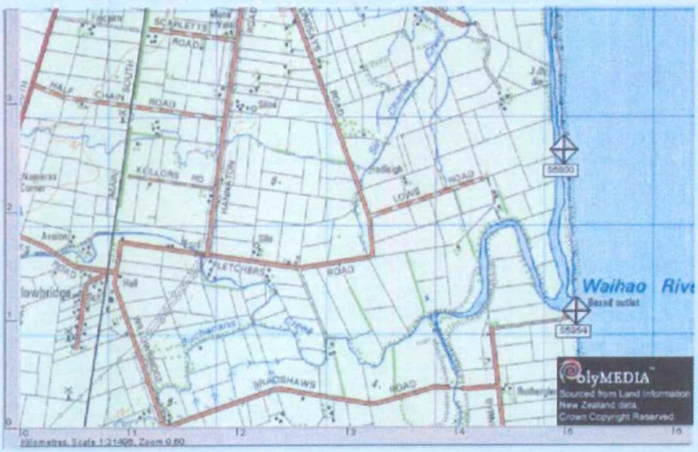
Locations of Beach Excavation Location for Meridian energy Consent Application CRC041748

Note: numbers at locations are ECan profile site numbers)


HOOK STATION RD
KINGSBURYS ROAD
Hook
Wainono Lagoon
olyMEDIA
Sourced from Land Information New Zealand data.
Crown Copyright Reserved.
Kilometres, Scale 1:31496, Zoom 0.60


Wainono Lagoon
Stream
Studholme
olyMEDIA
Sourced from Land Information New Zealand data.
Crown Copyright Reserved.
Kilometres, Scale 1:31496, Zoom 0.60

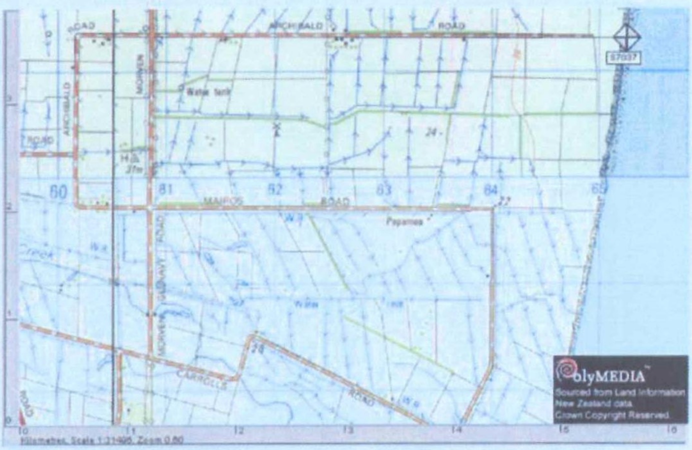

Studholme
FOLEYS RD
HANNATON
River Grange
AKATORE
ROAD
Creek
Nukuroa
SCARLETTS
HALF CHAIN ROAD
SOUTH
olyMEDIA
Sourced from Land Information New Zealand data.
Crown Copyright Reserved.


SCARLETTS
HALF CHAIN ROAD
KELLORS RD
HANNATON
LOWS ROAD
FLETCHERS
ROAD
BRADSHAWS
Waihao River
olyMEDIA
Sourced from Land Information New Zealand data.
Crown Copyright Reserved.


River
Waihao
olyMEDIA
Sourced from Land Information New Zealand data Crown Copyright Reserved.


Morven
olyMEDIA
Sourced from Land Information New Zealand data Crown Copyright Reserved.


Water tank
MORRIS
ROAD
Walton Park
Water tank
McLEAYS
ROAD
GLENAVY
MAIN
SOUTH
ARCHIBALD
ROAD
olyMEDIA
Sourced from Land Information
New Zealand data.
Crown Copyright Reserved.
Kilometres, Scale 1:21495, Zoom 0.60


ARCHIBALD
ROAD
MORVEN
Water tank
MAIRES
ROAD
Papamea
CARROLLS
ROAD
olyMEDIA
Sourced from Land Information
New Zealand data.
Crown Copyright Reserved.
Kilometres, Scale 1:21495, Zoom 0.60


CARROLLS
ROAD
Glenavy
ANDREWS
ROAD
Sub station
Motor camp
ROAD
S7400
S7620
Waitaki Huts
polyMEDIA
Sourced from Land Information New Zealand data
Crown Copyright Reserved
Kilometres, Scale 1:31496, Zoom 0.80

Derek Todd Environmental and Coastal Consulting
Postal Address:
P O Box 11279
Sockburn, Christchurch
36 William Street
Prebbleton, Christchurch
Phone: 03 364 2987 Ext 7908
Mobile: 027 278 7439
Fax: 03 364 2907
Email: dtec@xtra.co.nz
A/H: 03 349 3248
Principal Consultant: Derek Todd

DTec Consulting Ltd

APPLICATION BY MERIDIAN ENERGY TO UNDERTAKE EXCAVATION OF BEACH AND FORESHORE IN THE COASTAL HAZARD ZONE AND COASTAL MARINE AREA.

1. INTRODUCTION

The applicants, Meridian Energy seek consent to excavate a number of pits across and along the Waihao-Wainono coastal barrier from Andrews Road, Glenavy to Makikihi River for the purpose of research. This excavation is part of the Project Aqua investigations, being required to determine volumes of gravel in the barrier. University of Canterbury Geography student, Joanne Stapleton, will undertake the research as part of a post-graduate thesis study.

It is proposed that these excavations will take place over a 2-month period in March and April 2004 as this is the optimum time for tides, and will not effect duck shooting season, beginning in May.

2. DESCRIPTION OF PROPOSED ACTIVITY

The applicant proposes to excavate on the coastal barrier in the Coastal Hazard Zone and the Coastal Marine Area under the following conditions. The applicant needs to excavate in order to find the volume of the gravel barrier, which will contribute to a greater understanding of the barrier.

i. The pits will be excavated along twenty Environment Canterbury (ECAN) profiles between map references from J40: 640-162 to J41: 641-858. The general location is shown in the location map in the application form, and a list of profile locations is attached to this report.

ii. Up to four pits will be dug along each profile from the backshore to the foreshore (figure 1). The most seaward pit may be located below mean high water spring (MHWS), hence may be in the Coastal Marine Area. The other pits are in the Coastal Hazard Zone.

iii. The pits will extend as deep as the substrate of the barrier. This is estimated to be 1-8m below the barrier.

iv. The pits will be immediately filled with the original material once data has been collected. This is estimated to be a maximum of 1 hour. No excavation will remain open over night.

v. A mechanical digger will carry out the excavations

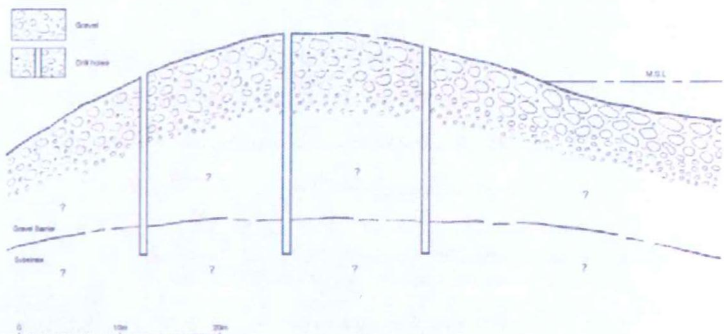


Figure 1 Example of where the pits will be located along the line of profile

vi. Transportation will be along the barrier and will avoid all vegetation. Entry and exit points will be via existing access tracks.

vii. Timing will coincide with low tide at midday to allow maximum time for data collection.

3. LEGAL AND PLANNING MATTERS

3.1 Resource Management Act (RMA) 1991

Section 12 of the RMA sates that:

"The RMA prohibits most activities in the Coastal Marine Area unless they are expressly allowed by a rule in a regional coastal plan, or a resource consent".

Some of the proposed excavation will take place in the Coastal Marine Area, therefore must be authorized by a rule in a regional coastal plan or resource consent.

3.2 New Zealand Coastal Policy Statement

The proposed excavations do not contravene any policies in the New Zealand Coastal Policy Statement.

3.3 Regional Policy Statement and Plans

Canterbury Regional Coastal Environment Plan

The following rules are considered relevant to this application:

Rule 9.2 Discretionary Activities within Coastal Hazard Zones.

> ***(e) The excavation, filling, or disposal of spoil in volumes greater than 5 cubic metres per 100 square metres of land area;***

Because of this rule the excavations are considered a discretionary activity.

3.4 Restriction of Discretion for Rule 9.2

"The Regional Council restricts its discretion to the following matters when considering an application for a resource consent in accordance with rule 9.2 of this plan and in imposing conditions in accordance with section 108 of the Act:

(a) whether the activity is likely to exacerbate coastal erosion; and

(b) whether the activity is lilkey to lead to adverse effects from natural hazards on any other property, (where property has the same meaning as in Section 2 of the Building Act 1991);

(c) provision for the removal of any structure or parts of any structure that are rendered unusable through coastal erosion."

The excavations will not exacerbate coastal erosion or lead to adverse effects from Natural hazards on other property. No structures are involved with this proposal.

4. DESCRIPTION OF THE AFFECTED ENVIRONMENT

7. MITIGATION MEASURES

The applicant considers that the procedure proposed in section 2 is adequate for the mitigation of adverse effects. No other mitigation methods are considered necessary.

8. CONSULTATION

Due to no adverse affects, consultation is not considered necessary. However adjoining landowners, Waihao Runanga and the Department of Conservation will be notified in writing prior to excavation starting.

9. PART II MATTERS

9.1 RMA Section 5 (2): Purpose of the Act

"Promote the sustainable management of natural and physical resources while-

(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and safeguarding the life-supporting capacity of air, water, soil and ecosystems; and

(b) Avoiding, remedying, or mitigating any adverse effects of activitites on the environment"

The research that will take place is seen to promote the purpose of the Act as it is part of the investigations into adverse affects that Project Aqua may have on the surrounding coastal environment.

9.2 RMA Section 6: Matters of National Importance

"Recognise and provide for the following matters of national importance:

(a) The preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins, and the protection of them from inappropriate subdivision, use, and development:

(b) The protection of outstanding natural features and landscapes from inappropriate subdivision, use, and development:

(c) The protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:

(d) The maintenance and enhancement of public access to and along the coastal marine area, lakes, and rivers:

(e) The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga."

The excavation of test pits will not compromise any of the matters of National Importance.

9.3 RMA Section 7: Other Matters

The proposed activity does not contravene any part of section 7

9.4 RMA Section 8: Treaty of Waitangi

The proposed excavation takes account of the Treaty of Waitangi.

10 OTHER RELEVANT MATTERS

10.1 Decisions of the Environment Court

The applicant is unaware of any decision of the Environment court that would preclude the grant of this consent.

10.2 Previous Council Decisions

The Regional Council has approved a similar application for excavating test pits in a Coastal Zone under similar circumstances to those proposed.

11 CONCLUSIONS

11.1 Section 105 Restriction on Granting Consent for Discretionary Activities

Section 105 sets out prerequisites that must be met before consent can be granted for a discretionary activity within the Coastal Hazard Zone and Coastal Marine Area. Given all adverse effects on the environment are minor, this test is met.

11.2 Notification

"In accordance with Section 94 (1A) of the Act, an application for a resource consent for an activity that is sought in accordance with Rule 9.2 of this plan may be considered without the need to obtain the written approval of affected persons, and therefore need not be notified in accordance with section 93 of the Act".

It is considered that this application meets these criteria, and therefore should proceed non-notified.

11.3 Duration

Due to the nature of the research, it may be necessary to excavate further pits at a later date. However this will not be known until the research of the initial excavations is known. I recommend that the Land Use consent and Coastal Permit are granted for a period of 1 year.

11.4 Suggested Conditions

1. The applicant only wishes to excavate along the 20 ECAN profile sites ranging from Map reference J40:640-162 to J41:641-858.

2. The applicant will fill the pits with the original material once all data is logged.

3. No pits will be left open over night.

4. Written notification to adjoining landowners, Waihao Runanga, and the Department of Conservation prior to excavation.

5. The mechanical excavator will only enter and exit the beach via existing access tracks.

6. All transport along the beach will be below vegetated areas.

Thank you for taking the time to read this application and I look forward to your quick response.

Jo Stapleton

For: Derek Todd
DTec Consulting Ltd

FOR OFFICE USE ONLY

Application No:

Charges paid: Receipt No:

Environment Canterbury
Your regional council

Application for a resource consent

To: The Chief Executive, Environment Canterbury:
58 Kilmore Street, PO Box 345, CHRISTCHURCH, ph (03) 365 3828, fax (03) 365 3194
75 Church Street, PO Box 550, TIMARU, ph (03) 688-9069, fax (03) 688 9067
Beach Road, PO Box 59, KAIKOURA, ph (03) 319 5781, fax (03) 319 5809

If you need guidance in filling out this form please contact our Customer Services Section on 365-3828 or toll free 0800 EC INFO (0800 324 636) who will be able to provide some general assistance or provide you with a list of consultants who can help you with your application.

NOTES TO APPLICANTS

1. Section 88 of the Resource Management Act 1991 sets out the information you must provide as part of your application for resource consent. This information is set out in Parts A and B of this form. If your application does not provide all this information, it cannot be receipted and processed by the Council and will be returned to you. You do not need to provide the information requested in Part C of this form but it will assist the Council in processing your application.
2. This application form may be used for all types of resource consents for which Environment Canterbury has responsibility. For many types of activity the Council has prepared inserts which will assist you with the preparation of the assessment of effects on the environment and the inclusion of any other information required under any plan or regulation.
3. Your application must be accompanied with the preliminary fixed charge prescribed in the enclosed "Schedule of Charges". If, when your application has been processed, the actual and reasonable costs incurred by Environment Canterbury exceed the charge, you will be invoiced for the balance. Where the cost of processing an application is less than the preliminary fixed charges paid, the balance will be refunded.
4. All accounts are payable by the 20th day of the month following the date of invoice. If the account is not paid within 30 days after the due date, our debt collection agent may charge you a fee equal to 25% of the unpaid portion of the price, but no less than $25.00. Where the total debt collection costs, legal and other costs arising from the collection of any amount owing exceeds the debt collection fee charged, our debt collection agent is also entitled to recover such additional costs from you. This clause is intended to be for the benefit and enforcement of our debt collection agent under the Contracts (Privacy) Act 1982.

PART A APPLICATION DETAILS

Please complete all questions and sign and date the form

1 Full names and address of applicant(s)

Surname: ____ First Names: ____

Surname: ____ First Names: ____

OR Company name: MERIDIAN ENERGY

Postal address: PO BOX 2050, CHRISTCHURCH

Phone (home) ____ phone (business) 03-357-9795

fax (home) ____ fax (business) 03-3579821

email: selwyn.blackmore@meridianenergy.co.nz

contact person SELWYN BLACKMORE.

2. Consultant/Agents details: (if applicable)

Contact Person: DEREK TODD
Company: DTEC CONSULTING LTD
Postal address: PO BOX 11-279
SOCKBURN, CHRISTCHURCH
email: dtec @xtra.co.nz

Phone (03) 3642981 / 64 7903
Fax (03) 3642907

During the processing of your application who will the contact person be?
- [ ] Applicant
- [x] Consultant/Agent

3. The names and addresses of the owner and occupier of the site to which this application relates:

(You only need to include this information if they are different to the applicant)

Owner: CROWN - COASTAL FORESHORE / BEACH.
Postal address:

Phone ( )
Fax ( )

Occupier:
Postal address:

Phone ( )
Fax ( )

4. The location of the site to which this application relates:

Site address: COASTAL BEACH - MORVEN SHINGLY CLIFFS TO MAKIKIHI.
Locality: WAIMATE.
Legal description:
Map reference (if known):

The legal description can be found on the certificate of title, valuation notice, subdivision plan or rate demand for the site. Please include a copy of any of these with your application.

This application form also includes a full page for a plan of the site. Please complete this plan showing the location of the proposed activity and indicate any relevant identifying features such as buildings, roads, rivers etc. The inserts the Council has prepared to assist you in completing Part B of your application, "Assessment of Effects on the Environment", may also ask for details to be included on this plan.

5. In which District or City Council is this site located?

Kaikoura DC	[ ]	Selwyn DC	[ ]	Waitaki DC	[ ]
Banks Peninsula DC	[ ]	Waimate DC	[x]	Christchurch CC	[ ]
MacKenzie DC	[ ]	Waimakariri DC	[ ]	Timaru DC	[ ]
Hurunui DC	[ ]	Ashburton DC	[ ]		

Have you consulted with the District or City Council to determine whether you require a consent for this activity from them? Yes [x] No [ ]

If yes, what was their response? DO NOT REQUIRE A CONSENT FROM THEM

If a consent is required, have you applied for it? YES [ ] NO [ ]

6. What type(s) of resource consents are you applying for from Environment Canterbury?

Coastal Permit

- ☐ Reclaim or drain foreshore or seabed
- ☐ Place, alter or remove structure
- ☑ Disturb foreshore or seabed
- ☐ Deposit substance
- ☐ Planting foreshore or seabed
- ☐ Occupy coastal marine area
- ☐ Remove natural material (eg sand)
- ☐ Install/Alter bore
- ☐ Take water
- ☐ Dam water
- ☐ Divert water
- ☐ Use water
- ☐ Discharge contaminant to air
- ☐ Discharge contaminant or water to water
- ☐ Discharge contaminant to land
- ☐ Other

Land Use Consent

- ☐ Install/alter bore
- ☐ High country burning
- ☐ Earthworks
- ☐ Vegetation Clearance
- ☐ Contaminant storage
- ☑ Activity in coastal hazards zone
- ☐ Fencing/grazing in waterway
- ☐ Planting in waterway
- ☐ Use, place, alter or remove structure in waterway
- ☐ Disturb bed of waterway (incl excavation of gravel)
- ☐ Deposit substance in waterway
- ☐ Reclaim or drain waterway
- ☐ Place a structure within 8 metres of a waterway

Water Permit

- ☐ Take groundwater
- ☐ Take surface water
- ☐ Dam water
- ☐ Divert water
- ☐ Use water

Discharge Permit

- ☐ Discharge contaminant to air
- ☐ Discharge contaminant or water to water
- ☐ Discharge contaminant to land

7. Description of the activity:

Please describe fully the proposal for which consent(s) are being sought. It is important you fill this out correctly, as the Council cannot grant consent for any activity you do not apply for:

TO DIG THREE TO FOUR PITS ALONG 20 ECAN PROFILE SITES ON THE WAIHAO-WAINONO BARRIER FOR THE PURPOSE OF RESEARCH.

8. Other information required by regional plans or regulations:

Regional Plans or regulations may specify other information that must be provided as part of your application. If additional information is required, this will be set out in the appropriate insert the Council has prepared to assist you in completing Part B of your application, "Assessment of Effects on the Environment".

PART B ASSESSMENT OF EFFECTS ON THE ENVIRONMENT

You must include an assessment of the effects of your activity on the environment as part of your application.

Section 88 of the Resource Management Act 1991 requires that each application include an assessment of the actual and potential effects of the activity on the environment. This assessment must be prepared in accordance with the Fourth Schedule of the Resource Management Act. A copy of this schedule is reprinted in full on the back page of this application form.

The assessment of effects shall be prepared in such detail as corresponds with the scale and significance of the effects that the activity may have on the environment. This assessment will differ for each application depending on the type and scale of the activity. Consultation is one of the best ways of identifying adverse effects. Information on consultation is given on the back page.

To assist you in preparing this assessment, the Council has prepared a number of inserts that provide guidance for completing this part of the application. For minor activities, all that will be required is the completion of these inserts. Where the potential effects of the activity are more significant, we recommend you undertake a full assessment of effects, with professional assistance if necessary.

For further assistance in preparing this assessment, the Council also has a fact sheet available entitled "Preparation of Assessment of Effects on the Environment".

PART C OTHER INFORMATION

You do not need to provide the following details but they will assist with the processing of your application.

1. Previous consents:

Have you held any previous consents at this site for this activity or any related activities? YES ☐ NO ☑

If yes, Consent number(s) ☐

2. If your application is to replace an exisiting consent which has not yet expired, do you agree to your application being processed outside the timeframes set out in the Resource Management Act but before the expiry of your exisiting consent? YES ☐ NO ☐

3. Notification:

If your assessment of effects has shown that adverse effects on the environment are likely to be more than minor and/or there are people who may be adversely affected from whom you are unable to obtain written approval, you may wish to request that your application be publicly advertised in order to avoid possible delays in the processing of your application.

The final decision to advertise an application will still be made by Environment Canterbury.

Please note that an application cannot be advertised unless there is sufficient information for the notice that makes it clear what is being applied for, and how it might affect the environment (including people).

I request that my application is publicly advertised (tick box). ☐

4. Duration requested:

Please specify the duration sought for your consent(s) 1 years ☐ months

N.B. Other than for reclamations and some land use consents the maximum duration allowed under the Act is 35 years.

5. Start date:

Resource consents lapse two years after their commencement date unless the consent has been given effect to or an application is made to the Council to extend this period. However, if the Council is aware during the processing of your application that you may not give effect to the consent within these first two years, provision can be made as part of the consent to extend the period before the consent lapses.

When do you propose to start the activity? 1/03/2004

SIGNATURE AND DATE:

D. Todd | 26/2/04 | Derek Todd

(Signature of applicant or person authorised to sign on behalf of applicant) (Date) (Full name of person signing)

ADDITIONAL NOTES TO APPLICANTS

1. Your application need not be publicly notified if Environment Canterbury is satisfied that the adverse effects on the environment will be minor and written approval has been obtained from every person the Council considers may be adversely affected by the granting of your application (unless the Council considers it unreasonable to require the obtaining of every such approval). Enclosed is a form "Written Approval of Persons Likely to be Adversely Affected" to help you obtain such approvals.

2. Section 128 of the Resource Management Act 1991 sets out the circumstances in which Environment Canterbury may review the conditions of a resource consent. Under Section 128(c) the Council may undertake a review at any time if the application contained any inaccuracies which materially influenced the decision made.

3. The information you provide with your application is official information. It will be used to process your application and, together with other official information, assist in the management of the region's natural and physical resources. Access to information held by Environment Canterbury is administered in accordance with the Local Government Official Information and Meetings Act 1987, and Privacy Act, 1993. Your information may be disclosed in accordance with the terms of these Acts. **It is therefore important you advise the Council if your application includes trade secrets and/or commercially sensitive material.**

CHECKLIST

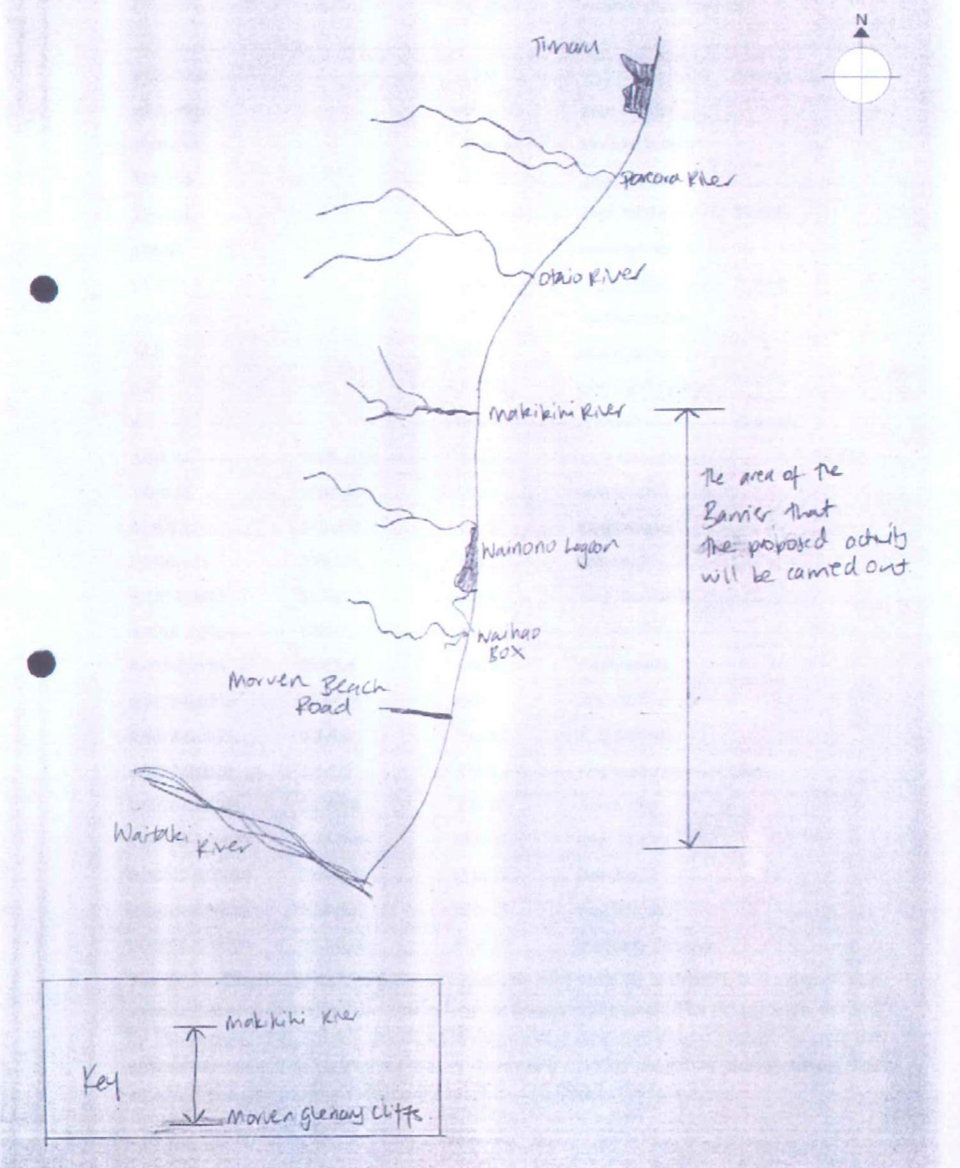
Have you remembered to:

- ☐ Complete all the details set out in Part A of this application form
- ☐ Include an assessment of effects of the activity on the environment, set out in Part B of this application form
- ☐ Include a site plan
- ☐ Include a copy of the certificate of title, rates demand, subdivision plan or valuation notice for the site your application relates to
- ☐ Sign and date the application form
- ☐ Include the appropriate preliminary fixed charge as set out in the "Schedule of Charges"

Location Plan

OFFICE USE - CONSENT NO:

Please complete this plan showing the site with the location of the proposed activity and indicate any relevant identifying features such as buildings, roads, rivers etc. The inserts the Council has prepared to assist you in completing Part B of your application, "Assessment of Effects on the Environment", may also ask for details to be included on this plan.

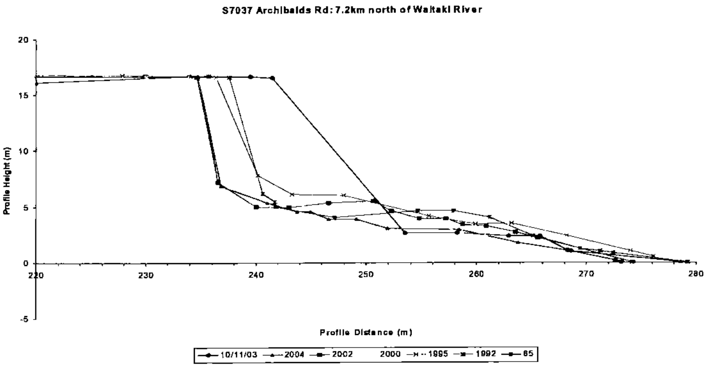


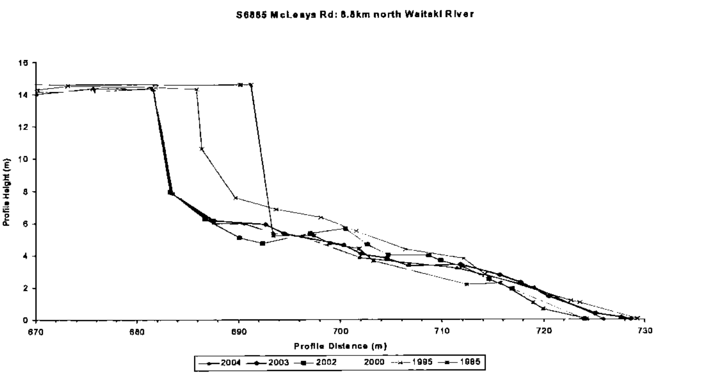
Appendix 3
Udden – Wentworth Scale

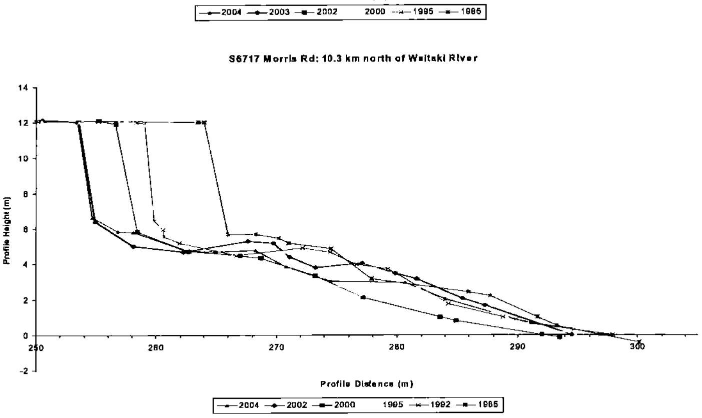
Grain size (mm)	microns	Phi class (ø)	nominal classifications
4096-2048 ----------		-12 to -11 --------	very large boulder -- Boulder - GRAVEL
2048-1024		-11 to -10	large boulder
1024-512		-10 to -9	medium boulder
512-256		-9 to -8	small boulder
256-128		-8 to -7 ----------	large cobble -------- Cobble
128-64		-7 to -6	small cobble
64-32		-6 to -5 ----------	large pebble -------- Pebble
32-16		-5 to -4	medium pebble
16-8		-4 to -3	small pebble
8-4		-3 to -2	very small pebble
4-2		-2 to -1 --------	granules ------------ Granule
2.0-1.0------------------	2000-1000 --------	-1 to 0 ----------	very coarse sand --------------- SAND
1.0-0.50	1000-500	0 to 1	coarse sand
0.50-0.25	500-250	1 to 2	medium sand
0.25-0.125	250-125	2 to 3	fine sand
0.125-0.0625	125-62.5	3 to 4	very fine sand
0.0625-0.031----------	62.5-31-------------	4 to 5 ----------	coarse silt -------------------- MUD
0.031-0.0156	31-15.6	5 to 6	medium silt
0.0156-0.0078	15.6-7.8	6 to 7	fine silt
0.0078-0.0039	7.8-3.9	7 to 8	very fine silt
0.0039-0.0020	3.9-2.0	8 to 9 ----------	very coarse clay ---- Clay
0.0020-0.00098	2.0-0.98	9 to 10	coarse clay
0.00098-0.00049	0.98-0.49	10 to 11	medium clay
0.00049-0.00024	0.49-0.24	11 to 12	fine clay
0.00024-0.00012	0.24-0.12	12 to 13	very fine clay
0.00012-0.00006	0.12-0.06	13 to 14	extremely fine clay

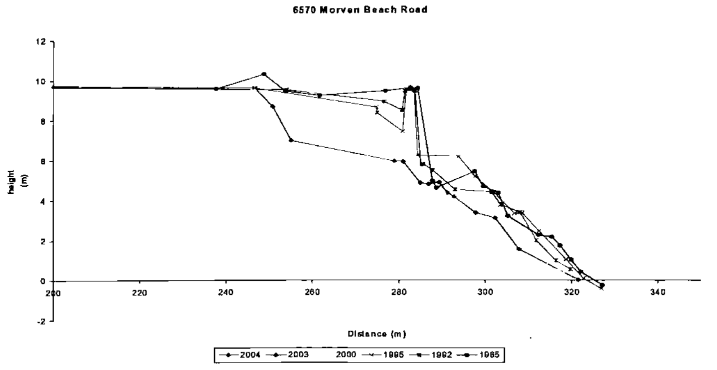
The Udden-Wentworth scale is the most commonly used scale for sediments. It is a logarithmic scale in that each grade limit is twice as large as the preceding grade. The phi (ø) scale, devised by Krumbein (1934), quickly gained wide usage and is now used almost exclusively over the millimetres scale. The highlighted text is Wentworth's (1922) simplified classifications. The other nominal classifications are the authors, based on Uddens (1914) version.

Appendix 4
Barrier profiles

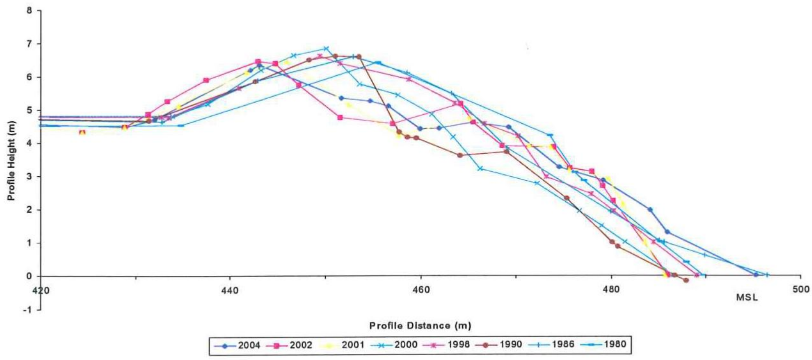




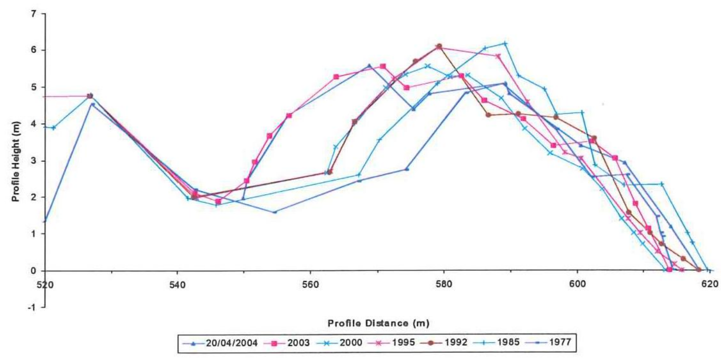




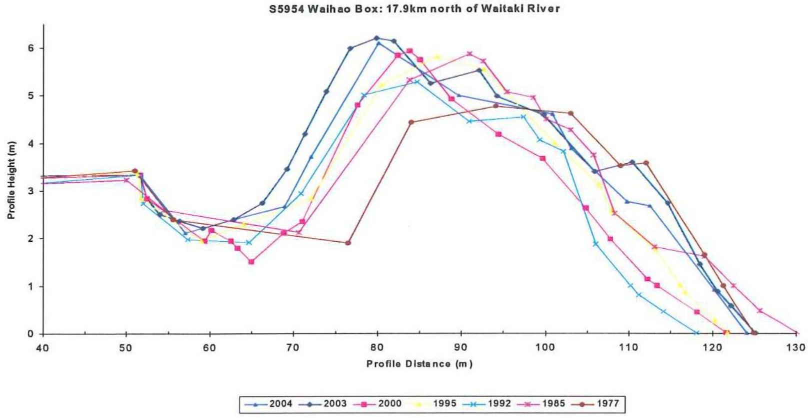
6347 Ryans Road: 14km north of the Waitaki River

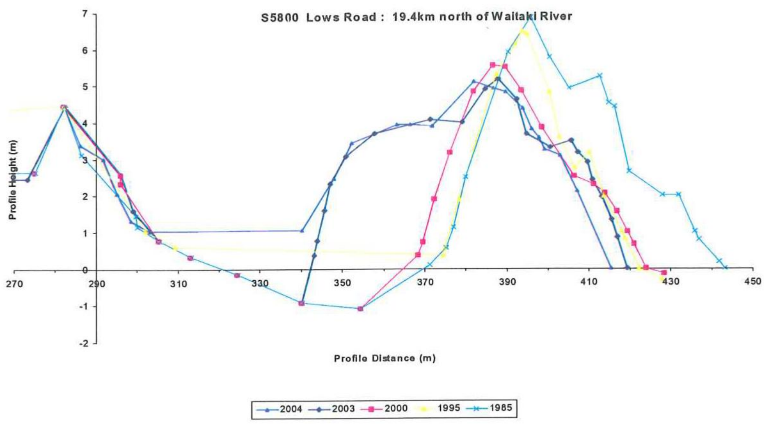


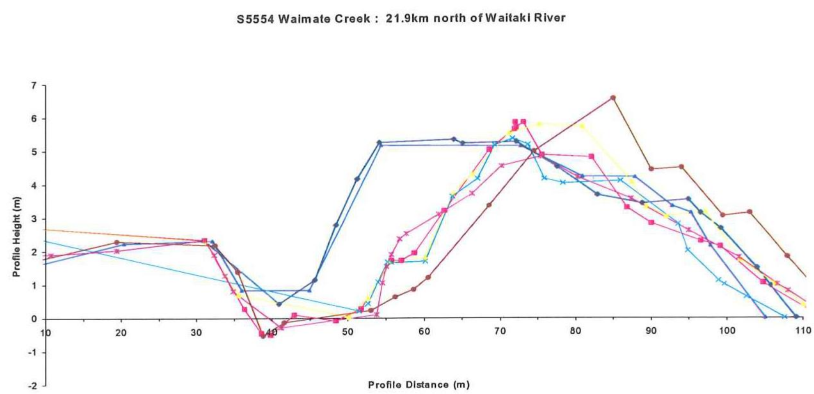
S6158 Maori Road: 15.7km north of Waitaki River

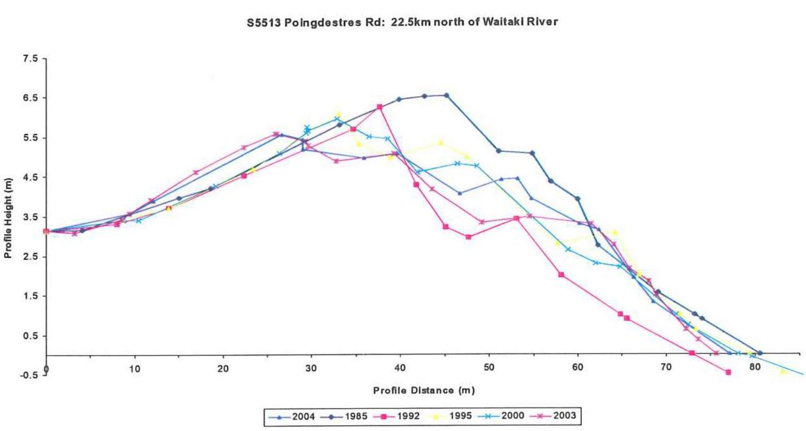


S5954 Waihao Box: 17.9km north of Waitaki River

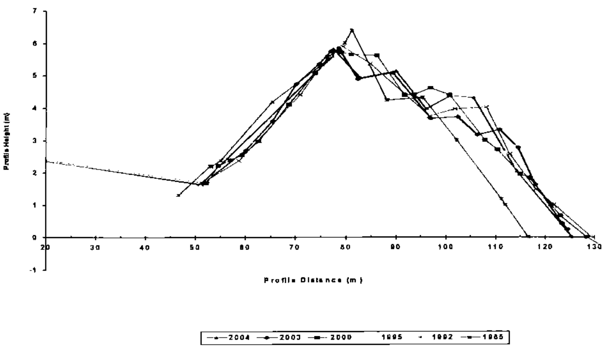



S5800 Lows Road : 19.4km north of Waitaki River
Profile Height (m)
Profile Distance (m)
2004
2003
2000
1995
1985

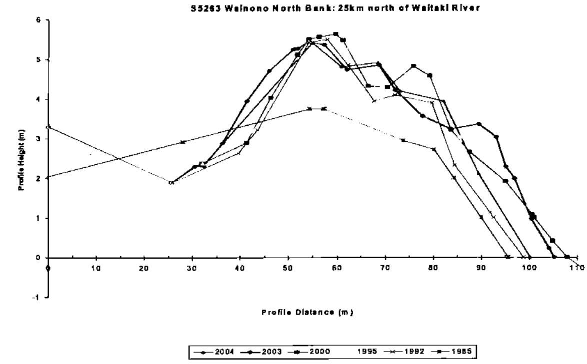

S5554 Waimate Creek : 21.9km north of Waitaki River
Profile Height (m)
Profile Distance (m)


S5513 Poingdestres Rd: 22.5km north of Waitaki River
Profile Height (m)
Profile Distance (m)
2004
1985
1992
1995
2000
2003

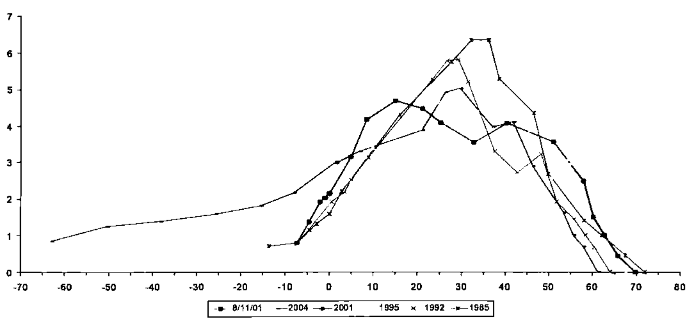
S5320 Wainono South Bank: 24.4km north of Waitaki River



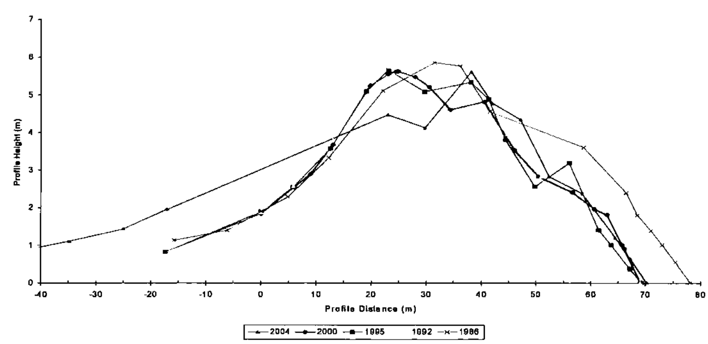
S5263 Wainono North Bank: 25km north of Waitaki River

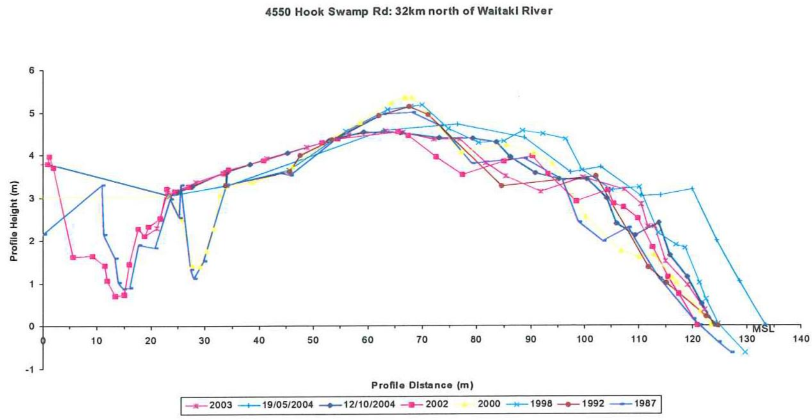


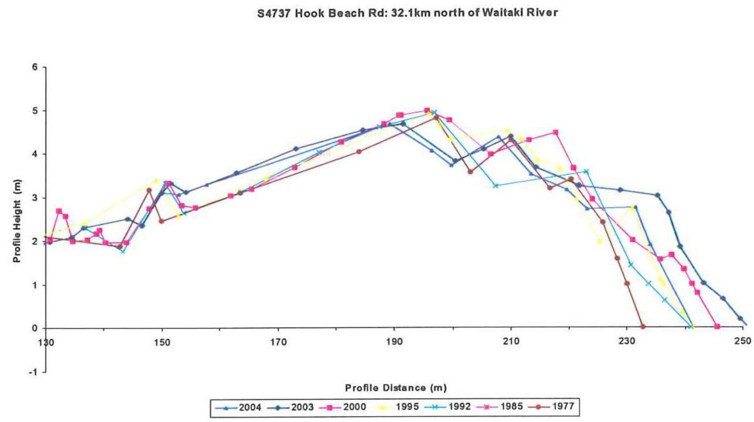
S5214 Wainono lagoon: 25.5km north of Waitaki River

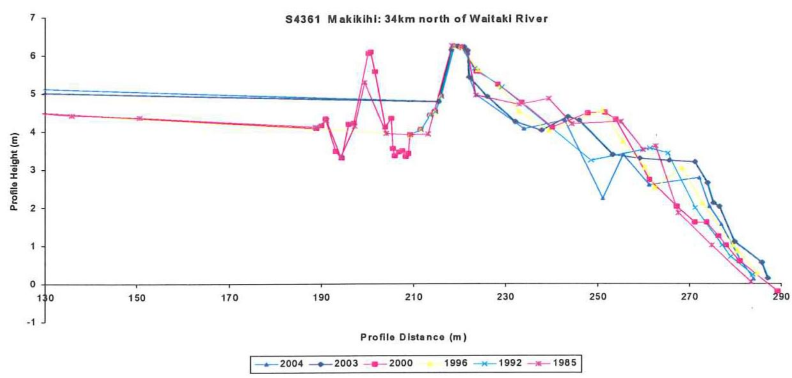


S5164 Wainono Hut : 26km north of Waitaki River




4550 Hook Swamp Rd: 32km north of Waitaki River
Profile Height (m)
Profile Distance (m)
MSL
2003
19/05/2004
12/10/2004
2002
2000
1998
1992
1987


S4737 Hook Beach Rd: 32.1km north of Waitaki River
Profile Height (m)
Profile Distance (m)
2004
2003
2000
1995
1992
1985
1977


S4361 Makikihi: 34km north of Waitaki River
Profile Height (m)
Profile Distance (m)
2004
2003
2000
1996
1992
1985

Appendix 5
Slopes

Site	Barrier Zone	Slope (°)
S7037	Surface foreshore	7.47
	Substrate foreshore	9.36
S6885	Surface foreshore	10.06
	Substrate foreshore	9.07
S6717	Surface foreshore	9.12
	Substrate foreshore	6.49
S6347	Surface foreshore	6.96
	Substrate foreshore	8.14
S6158	Surface foreshore	9.8
	Surface lower foreshore	14.5
	Substrate lower foreshore	10.0
S5954	Surface foreshore	11.20
	Surface lower foreshore	12.86
	Substrate lower foreshore	11.05
S5800	Surface foreshore	8.59
	Surface lower foreshore	13.82
	Surface backshore	5.52
	Surface lower backshore	11.24
S5554	Surface foreshore	9.07
	Surface lower foreshore	13.7
	Surface backshore	24.3
S5513	Surface foreshore	3.27
	Surface lower foreshore	10.9
	Substrate foreshore	5.0
	Substrate lower foreshore	4.32
S5320	Surface foreshore	8.2
	Surface lower foreshore	12.2
	Surface backshore	9.05
	Substrate foreshore	8.56
	Substrate lower foreshore	14.2
	Substrate backshore	2.2
S5263	Surface foreshore	8.7
	Surface lower foreshore	12.2
	Surface backshore	7.8
	Substrate foreshore	5.61
	Substrate lower foreshore	11.06
	Substrate backshore	3.14
S5214	Surface foreshore	11.9
	Surface lower foreshore	11.7
	Surface backshore	4.5
	Substrate lower foreshore	6.1
	Substrate backshore	3.0

Site	Barrier Zone	Slope (°)
S5164	Surface foreshore Surface lower foreshore Surface backshore Substrate lower foreshore Substrate backshore	9.8 11.3 3.5 6.9 2.7
S4550	Surface lower foreshore Substrate lower foreshore	26.2 5.5
S4737	Surface foreshore Surface lower foreshore Surface backshore Substrate foreshore	7.4 15.2 2.6 2.7
S4361	Surface foreshore Surface lower foreshore Substrate lower foreshore	4.5 12.7 4.0

Appendix 6
Sorting Table (Phi)

Under .35 Φ, very well sorted	1.0 □2.0 Φ, poorly sorted
.35 - .50 Φ, well sorted	2.0 □4.0 Φ, very poorly sorted
.50 - .71 Φ, moderately well sorted	Over 4.0 Φ, extremely poorly sorted
.71 □1.0 Φ, moderately sorted	

From: Folk (1965:46).