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**River Mouth Processes and  
Morphodynamics on a  
Mixed Sand–Gravel Beach**

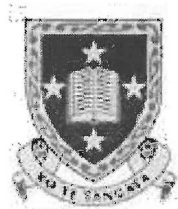
A thesis submitted in partial fulfilment  
of the requirements for the degree of

**Master of Science in Earth Sciences**

By

**Adam Karl Paterson**

at the



**University of Waikato**

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Frontispiece:

The Ashburton hapua drained by the channel at the centre of the picture, as taken by the Cam-Era video camera.

## Abstract

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Where the Ashburton river meets the sea it is impounded by a mixed sand-gravel barrier, formed through littoral transport of sediment, causing a lagoon to form, locally referred to as *hapua*. From the hapua, discharge to the sea is maintained through small, ephemeral channels, which are unstable and are subject to morphological change in response to fluctuations in longshore transport of gravel and variations in river flow rate. There are few descriptions of the morphodynamics of these highly changeable features, particularly changes that occur over short time scales of hours to weeks.

To investigate the patterns and processes involved in the migration of drainage channels, several new instruments were trialed. A methodology of was developed to provide estimates of longshore transport on a gravel beach using a Gravel Transport Sensor. Video camera technology was the primary tool used to study river mouth morphodynamics. The camera provided hourly images of the environment, enabling qualitative assessment using movies of the images to observe morphologic changes, and quantitative measurement of the migration of the channel. Measurements of river flow, wave climate and lagoon water levels were also gathered to investigate the relationships between the morphological response and the forcing factors.

Results of the study showed that the ends of the channel behave differently, with the lagoon end remaining more stable than the seaward end. The seaward end is more exposed to the high wave energy prevalent along this coast. The wave climate, especially wave period and direction, were found to be predictors for the migration rate. The location of the seaward end is more variable due to the fluctuations in wave climate, differing from the lagoon end which is influenced predominantly by river flow rates. It has been found that the migration of the lagoon end occurs in 'steps', which are separated by raised gravel banks, the single persistent feature throughout the study. This stepping migration is driven primarily through episodic events such as high river flow or large wave events.

A recurring pattern of channel migration was observed. An offset of the seaward end of the channel results as longshore transport moves sediment into the channel. Once the offset is sufficiently large, an extreme event may cause the migration of the lagoon end of the channel. A new shorter channel is formed and the migration pattern of the channel recommences.

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# Chapter 1 - Study Design and Purpose

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## 1.1 Introduction

Several large rivers drain the Canterbury Plains, flowing eastwards to the Pacific Ocean. Here their discharge to the sea is constrained by the mixed sand–gravel barriers along the coast. In the shelter of these barriers coastal lagoon features referred to as *hapua* (Kirk and Lauder, 1994) are formed. The hapua discharge to the sea through unstable channels. These discharge points may be ephemeral and transient, which raises several scientific questions and management issues relating to their behavior.

In the river catchments upstream of the hapua there is intensive sheep farming, cropping and other agricultural use. Due to the porous soils and low rainfall, water is an important commodity. Consequently water is abstracted from the rivers and aquifers of the region. The effect of decreased flow rates due to water abstraction influences the size and processes at the hapua. For example, the maintenance of a connection between the hapua and the sea becomes more difficult with decreasing river discharge. Persistent low flows through the hapua–ocean channel may result in channel closure as the river no longer has the capacity to clear sand and gravel moved alongshore in the littoral drift. Closure may have environmental consequences for the town of Ashburton, located approximately 26 km upstream, which discharges sewage into the Ashburton River. If the connection between the Ashburton River hapua and the sea is severed, water that remains in the hapua becomes eutrophic and polluted such that regional guidelines on water quality may regularly be exceeded (Canterbury Regional Council, 1995). The closure also affects aquatic life, preventing migration of salmon and whitebait to and from the sea. Flooding of the area surrounding the hapua can also pose a problem when the river is unable to discharge to the sea. Further problems can arise when waves propagating through the discharge channel attack coastal cliffs backing the lagoon which are built of weakly consolidated outwash gravels.

It is important to understand the dynamics of the channel when setting minimum flow rates for water abstraction. Without an appreciation of the interaction between wave climate and river flow rates, thresholds that determine whether the discharge channel maintains a connection to the sea cannot accurately be defined.

## **1.2 The Cam-Era Project**

Computer controlled video cameras provide an exciting new opportunity to monitor highly ephemeral coastal morphology such as hapua, in a relatively inexpensive and quantitative manner. The Cam-Era project provides computer controlled cameras sited at remote locations, collecting images on an hourly schedule using custom designed software. After on-site processing the images are automatically transmitted to a central archiving computer. Cam-Era is a 3 year project that started in July 1997, with financial support from the Sustainable Management Fund of the Ministry of the Environment, along with backing from the National Institute of Water and Atmospheric Research (NIWA), universities, regional councils and port companies (Hume, *et. al.*, 1999).

To date cameras have been installed at eight sites, which include: Ashburton River mouth, Tairua Beach, Port of Gisborne, Mokau River mouth, Fitzroy and Ocean Beaches, Ohope Beach and the Waimakiriri River (See Figure 1.1).

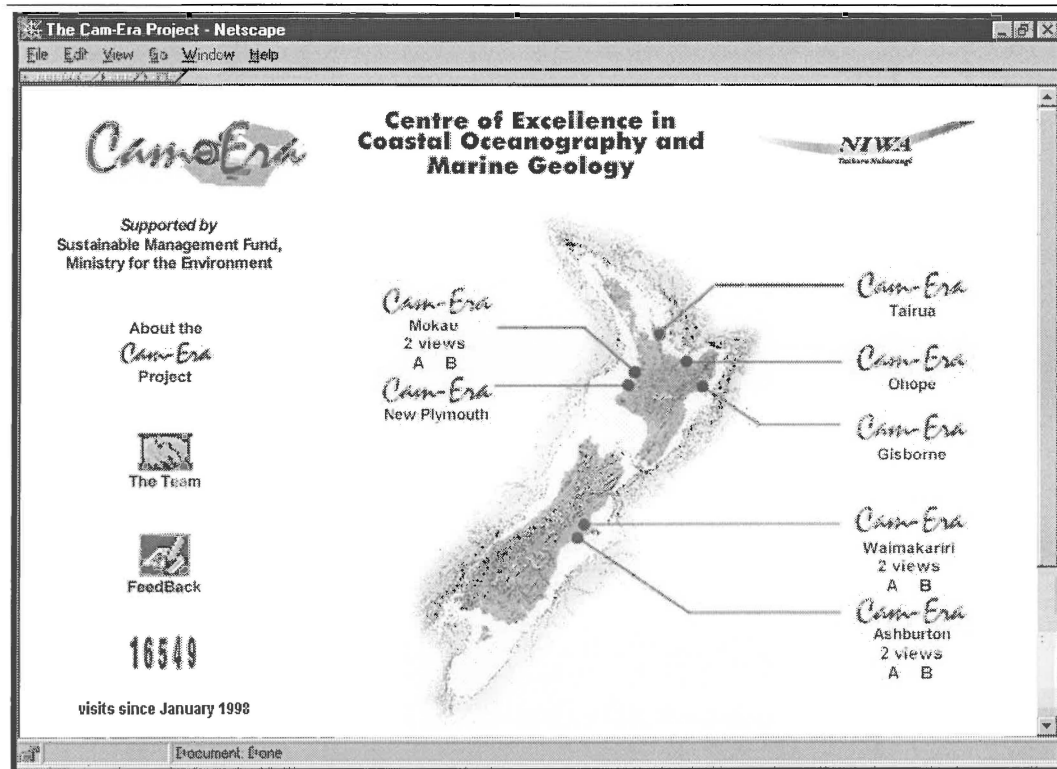


Figure 1.1 — The Cam-Era website at <http://yorick.eco.cri.nz/cam-era/index.htm>, showing the location of the eight Cam-Era sites around New Zealand.

### 1.2.1 Study Location

The Ashburton River mouth is located on the east coast of the South Island of New Zealand. It lies approximately 87 kilometres south of Christchurch, midway along the Canterbury Bight (See Figure 1.2). This is a rapidly eroding coastline, stretching 136 kilometres from Banks Peninsula to Timaru in the south, made up of alluvial gravel plains that have eroded to form coastal cliffs reaching as high as 24 m around the Ashburton River mouth (Kirk, *et. al.*, 1977). Immediately fronting these cliffs are mixed sand-gravel barrier beaches.



Figure 1.2 — The field site of this study – the Ashburton River mouth.

Source: <http://www.expediamaps.com>

The Ashburton River is a small river in comparison to other Canterbury rivers (See Table 1.1). It experiences dramatic flow variations between summer and winter months, making the Ashburton hapua one of the more dynamic on the Canterbury Bight (Kirk, 1991).

Catchment	Area (km <sup>2</sup> )	Mean rainfall (m.yr <sup>-1</sup> )	Mean discharge (m <sup>3</sup> .s <sup>-1</sup> )	10-year flood discharge (m <sup>3</sup> .s <sup>-1</sup> )	Specific sediment yield (t.km <sup>-2</sup> .yr <sup>-1</sup> )
Waiiau	1980	2.00	90.0	1868	1300
Hurunui	2680	-	-	-	1000
Waipara	741	-	-	-	621
Waimakariri	3210	1.90	120.0	2708	1669
Rakaia	2640	3.00	200.0	3764	1641
Ashburton	540	1.40	8.0	170	574
Rangitata	1775	-	-	-	946
Opihi	2372	-	-	-	1000
Waitaki	12118	-	-	-	144
Clutha	21078	-	-	-	94

Table 1.1 — Details of major Canterbury rivers.

Source: Kirk (1991) after Griffiths (1981) and Griffiths and Glasby (1985)

### **1.3 Objectives**

Because the Ashburton hapua exhibits irregular and rapid change at the mouth, it was selected to study as a type example. Accordingly the objectives of this thesis are to:

- Quantify the geomorphic change at the Ashburton River mouth and develop a model of drainage channel migration patterns.
- Investigate the relationships between the wave climate, lagoon water levels and river discharge and the geomorphic response of the Ashburton River mouth.

These objectives will be addressed using the following structural outline:

Chapter 2 reviews coastal processes on gravel and mixed sand–gravel beaches, inlet stability on gravel beaches, measurement of longshore transport, and the use of video image analysis as a tool in modern coastal investigations.

Chapter 3 presents the various data sources available for this study. The techniques used and the tools that have been employed to measure the forcing processes and the response of the system are presented. Database development is discussed as a tool to aid in the data analysis.

Chapter 4 explores the use of a new instrument, the Gravel Transport Sensor (GTS), to measure gravel transport in the littoral zone. Longshore transport of gravel is an important process in channel migration that is poorly understood, thus it was intended that measurements would aid in determining more precise estimates for this component.

Chapter 5 provides a qualitative description of the morphological behaviour of the hapua. Video images provide descriptive information on behavioral patterns, which are supplemented with data gathered using video techniques.

Chapter 6 investigates the relationships between the data sources describing the environmental forcing presented in chapter three and the subsequent morphological response. This will provide a statistical quantification of the relationships between the wave climate, river flow and lagoon water level and the behaviour of the channel.

Chapter 7 provides a concise summary and draws the main conclusions of the study.

## **1.4 Summary**

The Ashburton hapua is a site where breaking ocean swell waves, varying river discharge, tides and other strong forces combine to produce rapid and substantial coastal landform changes. The study of these hapua has in the past been limited to qualitative descriptions of the changes that occur (Kirk, 1983). This study quantifies the changes over a range of time and space scales using a video

imaging technology provided by the Cam-Era project. Findings will provide further understanding of drainage channel migration patterns and rates, which will assist in the future management of the hapua.

# Chapter 2 - Literature Review

---

## 2.1 Mixed Sand–Gravel Coastlines

Coarse clastic beaches are generally found on coasts that are wave dominated and consist of glacial deposits being reworked (Carter and Orford, 1984). Although coarse clastic beaches are relatively common at mid to high latitudes the literature relating to them is rare. The reason for this specified by Carter and Orford (1993) is primarily because of the difficulties involved in measurement in the high-energy environment of the nearshore zone of these beaches. The shorelines are steep and narrow and the waves are, typically, large and plunging.

At high latitudes gravel beaches may also consist of finer sandy components. These mixed sand-gravel beaches are relatively rare on the global scale (Zenkovich, 1967) occurring above 50°N and below 50°S (Carter, *et. al.*, 1984).

Kirk (1980) states that mixed sand-gravel beaches are rare on a world scale and because they occur in relatively unpopulated areas they are of lesser concern and have been studied little. Another reason for the neglect of these beaches may be the difficulty associated with studies of this intricate environment. The complexity of the environment, due to the wide range of sediment sizes, lead Zenkovich (1967) to describe mixed beach dynamics as the most complicated to study and understand.

A further distinction of mixed sand-gravel beaches, further influencing the behaviour of the beach, is made by Mason, *et. al.*, (1997) who describes a composite-type mixed beach where a wide, sandy, inter-tidal terrace is flanked by a shingle ridge. Such a situation differs from the Canterbury Bight mixed sand-gravel coast, which contains a broadly homogeneous mixture of the elements.

## **2.2 Inlet Stability**

Port engineering and development requirements have led to the production of a large collection of work relating to inlet stability. While the Ashburton River mouth can hardly be considered a classical tidal inlet, inlet concepts discussed in the literature may provide some understanding of the behavior of these systems. Most inlet research has been focussed on fine clastic beaches with large tidal prisms and variable tidal ranges. The Ashburton River mouth exits through a mixed sand-gravel barrier and has had a tendency to maintain a positive head gradient between the lagoon and the sea during the study period. While conscious of these differences, as Bruun (1978, Pg. 1.) states:

*“The great variety of parameters involved and the fact that we are dealing with a dynamic situation which adjusts itself to the actual tide, current, wave and sediment situation makes generalisation difficult. Each case must be considered in accordance with its own physical data. Certain basic principles on understanding and handling of the problem, however, have been developed.”*

Thus we can apply some of the knowledge from this field to contribute to a better understanding of the channel stability at the Ashburton River mouth.

Bruun (1990) presents the principles of inlet stability. The stability of an inlet can be considered a balance of the interaction between forces acting to close the inlet, such as littoral drift, and those acting to maintain the connection with the sea, such as tidal prism. This seems applicable to the Ashburton River mouth situation with the river flow, rather than tidal prism, being the primary factor acting to preserve the open channel.

Bruun (1990) identifies the two types of stability of an inlet; locational stability and cross-sectional stability. The present study could not address questions regarding cross-sectional stability because it was not possible to measure this parameter on a regular basis. However, locational stability could be measured during daylight from Cam-Era hourly images of the channel.

Inlets on littoral drift shores migrate in the direction of the prevailing littoral drift. As a result of deposits on the updrift side, the inlet channel is usually forced to move in a downdrift direction (Bruun, 1990). This is also a factor addressed in Komar (1998) where it is stated that the process of offsetting of an inlet gives an indication of the direction of predominant longshore transport (See Figure 2.1).

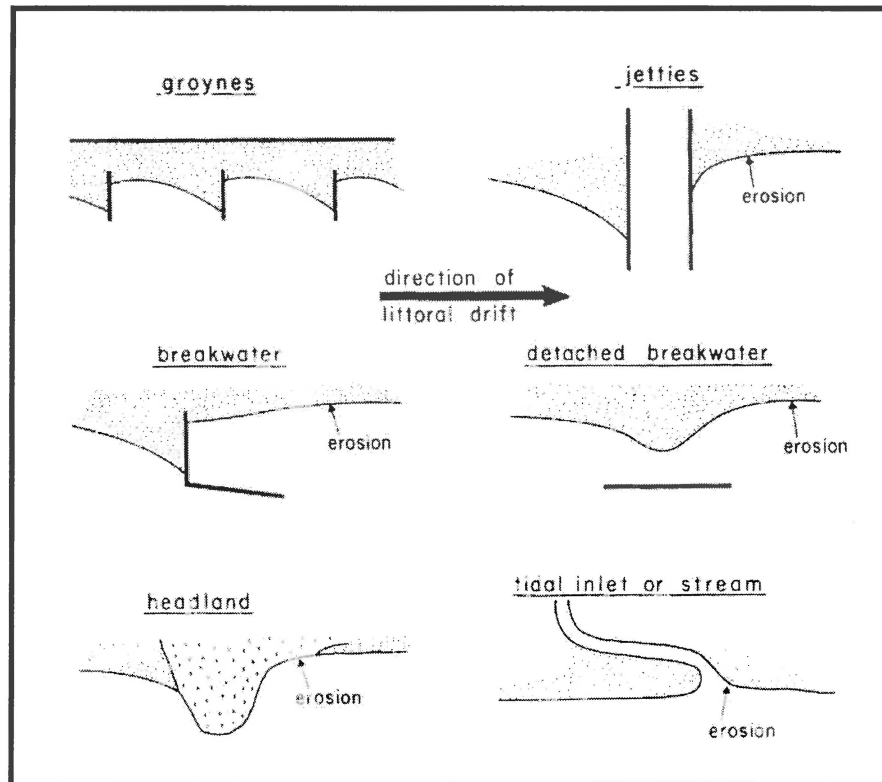


Figure 2.1 — Indicators of the direction of the prevailing littoral drift along the beach.

Source: Komar (1998).

Continued extension of the channel by deposits on the updrift side increases head losses, and the inlet may finally close. This closure is often associated with the breakthrough of a new inlet through the barrier making a shorter connection with the ocean. This brings about a more “hydrodynamically efficient” situation with respect to the draining of the lagoon. In many cases this breakthrough is associated with a flooding of the lagoon which could not be drained through the long channel (Bruun, 1990). Ashburton breakthrough events are considered to be a result of a fresh in the Ashburton river which results in a flooding of the lagoon (Todd, 1992).

### 2.2.1 Inlets on Mixed Sand-Gravel Coasts

Carr (1965) provides one of the few international references regarding river mouth dynamics on a shingle coast. The paper gives a description of changes to a spit and river mouth system on the River Ore, Suffolk, but only on coarse time scales over a long period of time (seven years). The findings illustrate the dynamic nature of changes that occur at the river mouth. The work is limited in application to the study site because that system is much larger than the Ashburton hapua. The dynamics of the channel are different in that the UK situation is more stable due to consistently higher river flows. The beach is also not noted as a mixed sand-gravel beach.

Kelk (1974) describes the stages of development of the lagoon at Ashburton over 14-15 months (See Figure 2.2). The pattern he observed suggested an overall northward migration, categorised by some reversals of this migration when the channel moved back to a point corresponding to the end of the river channel. This suggested that the migration pattern was cyclic, a northward migration truncated by the channel returning to the southern extreme by high river flows.

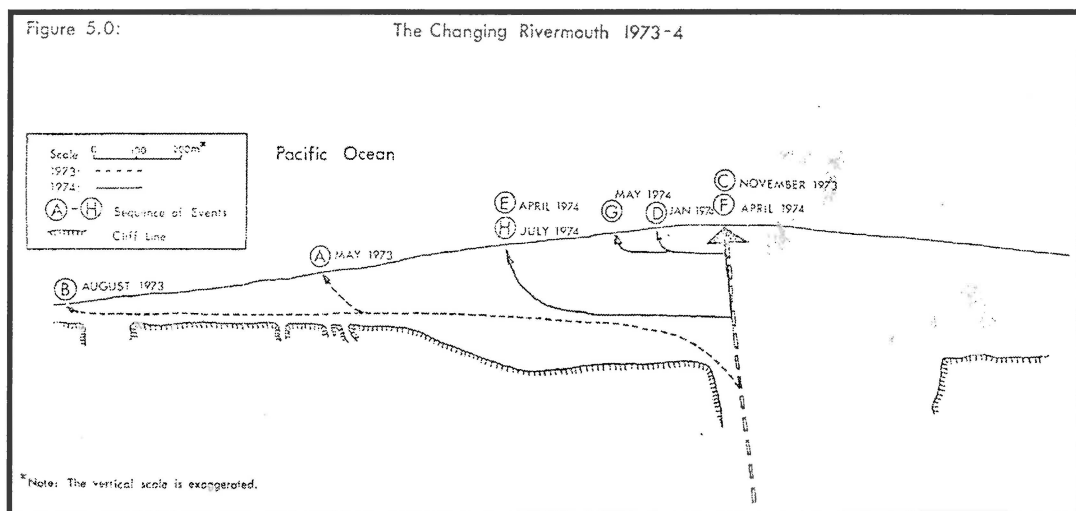


Figure 2.2 — Migration of the Ashburton River mouth during Kelk's (1974) investigation over 14-15 months.

This pattern is also described in Figure 2.3 where the stages of lagoon development are considered as phases categorised by the influence of tides on the lagoon

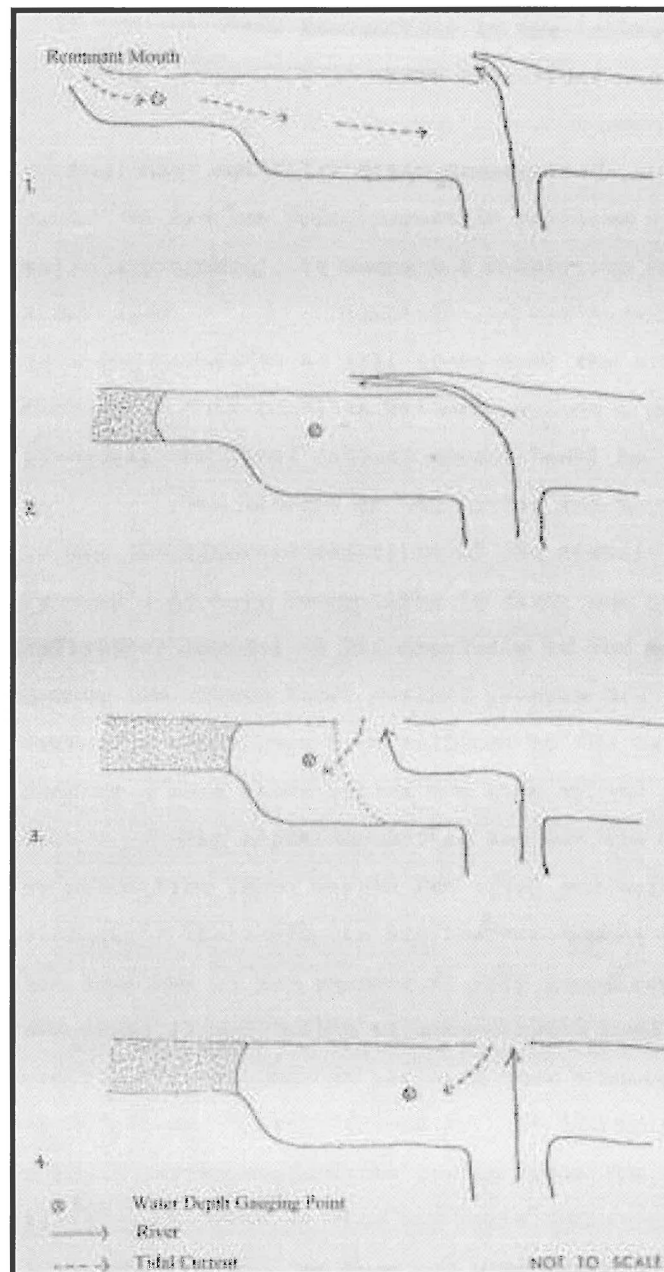


Figure 2.3 — Stages of development of the Ashburton lagoon based on tidal influence from Kelk (1974).

Comparing the behaviour of the Ashburton hapua to other hapua led Kelk to suggest that Ashburton was atypical. He considered the rapid transformations related to the high-energy wave climate, were also partly the result of the dearth of

stabilizing vegetation, the narrow beach and the cyclic river pattern facilitating the accessibility of the wave environment.

Young and Jowett (1982) investigated the dynamics of the Waitaki River mouth and estuary. Data sources included aerial photographs and water levels within the estuary, however other data on waves and beach profiling originally anticipated were abandoned due to various logistical problems and hazardous conditions.

They identified several factors that affect the migration of the river mouth including; river discharge, wave climate and morphological influences, such as topographic elevation. Northerly movement of the channel was attributed to the northerly longshore transport and moderate river flows. The migration of the channel was truncated when, as the lower river backs up due to the decreasing river grade, the river overtops the lengthened spit at a low point and scours a new channel. The old channel then closes as diminishing flows prove incapable of maintaining the connection to the sea. This process is regarded as a cyclic phenomenon.

It was also suggested by Young and Jowett (1982) that material is deposited on the inside bend of the channel as the river turns out to the sea. This complements the littoral drift accumulation on the same bank which accelerates the migration of the channel.

Todd (1983) explores the occurrence of river mouth closure during periods of low flow at the Opihi River mouth. This environment differs from the Ashburton situation in several significant aspects. The component with the most wide-ranging consequences would be the difference in flow rates between the Opihi and Ashburton Rivers. The result of this difference is the regularity with which the Opihi River mouth closes with respect to the Ashburton.

Todd (1983) also identified the existence of longshore currents within the surf zone that were observed to travel in the “wrong theoretical direction” for some wave approaches. He attributed this to the presence of nearshore cell circulations on mixed sand-gravel beaches. This cell circulation may interrupt the typical inlet stability processes that are generally presumed to occur in these situations.

Kirk (1983) reiterated Kelk's (1974) theories of cyclic channel migration. He states the 12-19 month cycle of channel migration is highly variable, representing the interaction between two otherwise independent physical systems. Thus the average value masks the fact that the cycle can be interrupted at any or several times over this period. He further makes an important statement regarding the study of these types of environments (pg. 70):

*"...as researchers, managers, administrators, developers and users, we are concerned with a highly distinctive assemblage of processes and landforms which is scarcely known to international science even though similar systems occur in many countries."*

Todd (1992) recognised the complexity of a river mouth environment on the Canterbury coast and developed a process/response model which, even though simple, still illustrates the complexity of interactions in the environment (See Figure 2.4)

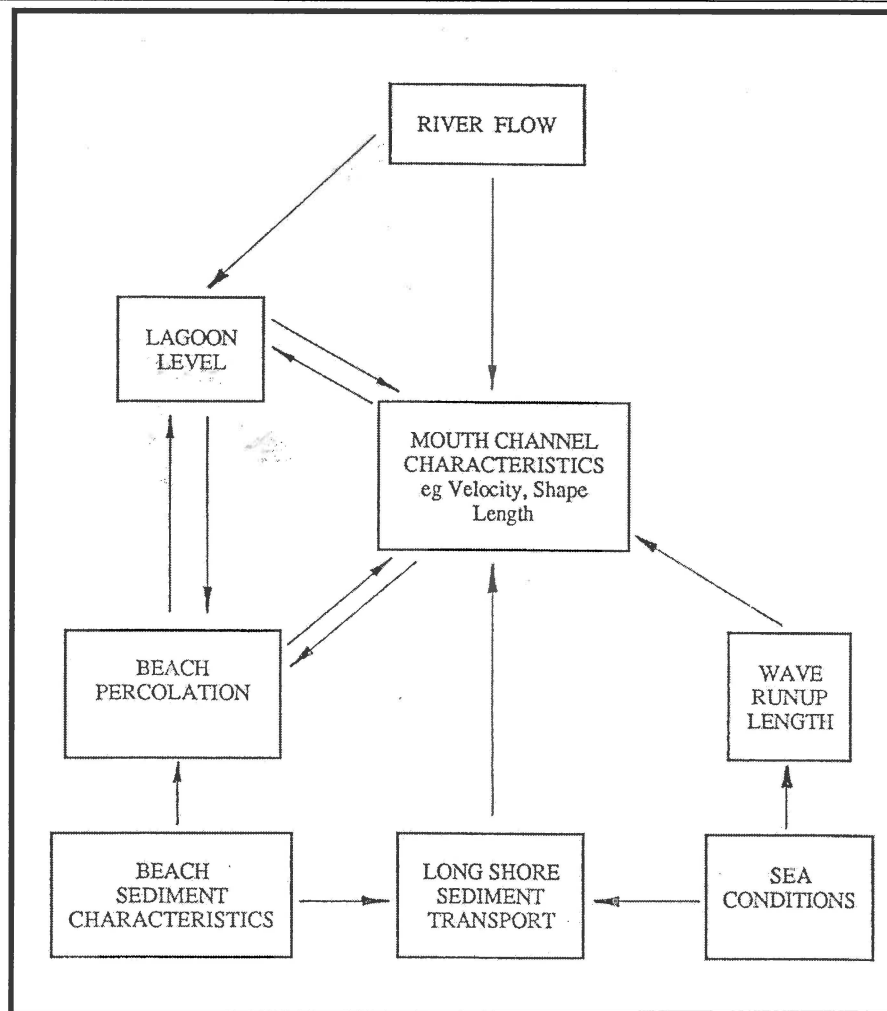


Figure 2.4 — Process/response model of Canterbury Bight River mouth environments.

Source: Todd (1992).

Todd (1992) describes the processes of river mouth migration at the Ashburton River mouth. He outlines how the channel migration follows a common cycle for both the Ashburton and Opihi Rivers (See Figure 2.5):

1. The river discharges to the sea through a shore normal channel opposite the end of the river channel, generally associated with high river flows.
2. The seaward end of the channel migrates alongshore in the direction of the littoral drift resulting in the channel flowing diagonally through the beach. The direction may be to the north or south, with northward migration dominating due to the net longshore transport rates in that direction.
3. Northward migration of the sea opening causes elongation of the channel such that it may run parallel to the coast before entering the sea. The lagoon end of

the channel may also migrate northward to be within the main body of the lagoon.

4. The process is reinitiated by a fresh in the river which breaches the barrier at the original position again. The channel to the north quickly closes and the northern end of the lagoon drains.

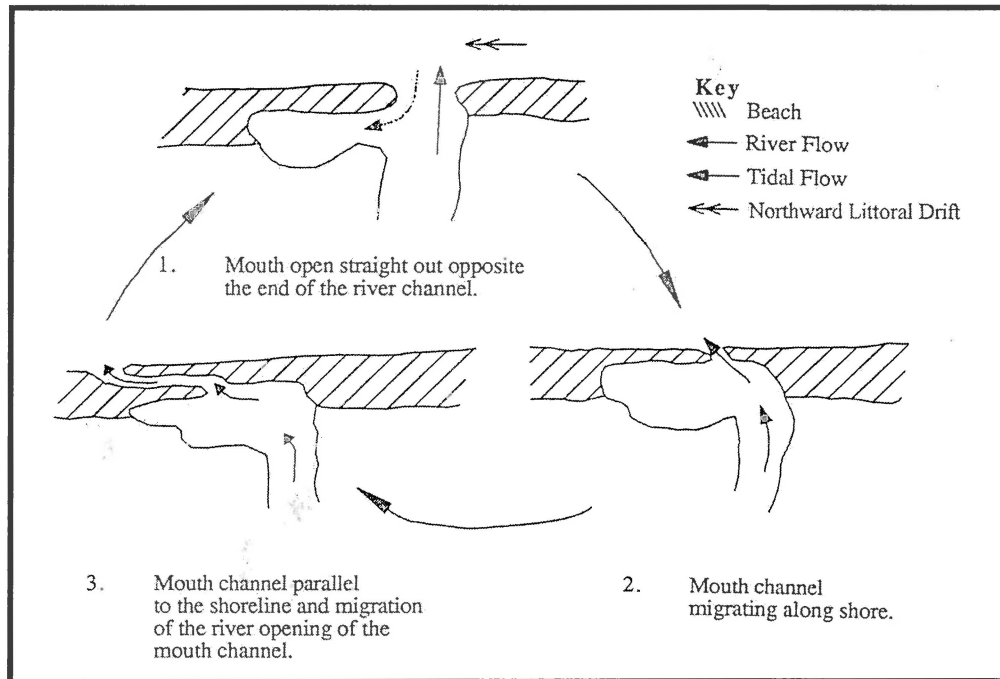


Figure 2.5 — Migrational behavior of river mouth channel described by Todd (1992). Note that Tidal flows are described by a dashed arrow.

Todd (1992) also states that river mouth closure is possible at any stage of this cycle, however it is most common during the third stage. Channel closure is caused by a dominance of alongshore transport over fluvial processes, when the flow to the sea is insufficient to maintain a channel through material deposited at the seaward end of the channel. Events hastening the closure include:

1. Reduction in mouth channel flow due to low river flows, or higher rates of beach percolation (due to greater channel length or higher lagoon levels).
2. High rates of longshore transport of sediment.
3. Increased load of sediment in the mouth channel causing aggradation of the channel bed. This occurs when the wave attack on the channel bank is more concentrated due to either larger waves, spring tides or offshore winds increasing breaker heights.

Aerial photographs have been used on the coast to record changes to the inlet position (For example, Young and Jowett, 1982; Kirk, 1983). This method is limited as migration rates vary on hourly to daily time scales while aerial photography is restricted by costs to being performed at weekly to yearly time scales. Thus measurements are restricted to net distances over long time periods.

On a short time scale field measurements by observers are labour intensive and difficulty is experienced in recruiting observers for long periods of time to undertake these studies (Young and Jowett, 1982). Todd (1992) initiated a five month investigation of the Ashburton River mouth channel with the help of local residents making daily recordings of various channel characteristics, and wind, wave and tidal observations. Findings were to be used to improve understanding of the behaviour of the channel, thus better management of the river mouth could be exercised. From older records including Kelk (1974), aerial photographs and personal communication with long term residents, limits of migration were determined. Estimates ranged up to 2000 m with migration regularly exceeding distances of 800 m from the Hakatere Settlement Road.

Results from the study suggested that on 50% of the days the channel migrated in a northerly direction, 30% of the days experienced southerly migration and on the remaining 20% of days there was no migration. It was an unexpected result in that there was no evidence of significant relationships between alongshore current direction and mouth migration direction or rate. Neither could any relationships be determined between northward migrations and flow rate, wave height, longshore current velocity, or occurrence of overtopping. It was noted that the southerly migrations except one were associated with swell heights of greater than 2 metres and wave overtopping of the beach. The channel remained stationary for long periods associated with river flows over 10 m<sup>3</sup>/s.

### **2.3 Longshore Transport of Gravel**

At the Ashburton River mouth littoral drift is one of the primary controls on channel location and form. Longshore transport, or littoral drift as it is sometimes referred, is induced by a combination of waves and nearshore currents. A long-standing challenge has been to try to quantify the rate at which material is moved

along the shore. While the majority of studies of longshore transport have been made on sandy beaches, recently some measurements have been made of gravel transport rates (Komar, 1998).

In the Canterbury Bight measurements are important for the development of sediment budgets, used to assess rates of coastal erosion and the effects of various developments in the region. Typically measurements have been made to try to determine an empirical relationship with the forcing factors (i.e., waves and nearshore currents).

### **2.3.1 Techniques for Measurement of Longshore Transport of Gravel**

Carter and Orford (1991) state that there have been virtually no attempts to quantify sediment transport on coarse clastic beaches, other than some empirical studies with fine gravel. The few longshore transport estimates for coarse clastic environments that have been made have been mainly restricted to using variations of the CERC formula from the US Army Corps of Engineers (USCERC, 1984) combined with laboratory studies (Van Wellen, *et al.*, 1997).

Direct field measurements of longshore transport on gravel beaches are sparse. The majority of work of this nature involves the use of tracer or trapping of material behind coastal structures and regular profile measurement.

A shortcoming of tracer techniques appears to relate to the ability to recover the tracer. A number of studies have involved the labeling of sediment and tracking its location (Kidson, 1966). Bujalesky and González-Bororino (1991) attempted to measure gravel transport by painting surficial clasts over 1 m<sup>2</sup> areas at several distances from the beach crest, then recording their position after two tidal cycles. However, meager recovery rates in the order of 5% throws doubt on the validity of this experiment.

Aluminium pebbles have been used on shingle beaches, whereby the pebbles are released and, when recovery is required, metal detectors are employed, enabling location to a depth of around 0.4 metres. This was tested at Poole Bay, Dorset

where results were favorable (Wright, *et. al.*, 1978). This method was again used in Bray's (1997) experiments on Chesil Beach, Dorset. Nicholls and Wright (1991) also used aluminium pebbles again in Dorset on Hengistbury Long Beach, near Bournemouth.

These tracer techniques however are relatively expensive and require substantial inputs of time and labour. Measurements of longshore transport are also net, not gross values, unless further inputs of time and labour are provided to enable continuous sampling.

### **2.3.2 Rates of Longshore Transport of Gravel along the Canterbury Coast**

Methods for estimating longshore transport are varied and results notoriously poor such that it is suggested that several methods be employed in each situation to get a more representative 'feel' for the volumes of material being transported. For the Canterbury Bight this has not been the case (Neale, 1987). There have been few field measurements of longshore transport on the Canterbury Bight coastline and those few that have been made must be regarded as inexact due to the imprecise nature of any longshore transport measurement.

In the past, estimates have been based on empirical equations determined by Neale (1987) and added to by Flatman (1997) using a modified version of the CERC formula for longshore transport. The data was provided from Neale's investigation of the profile changes at a breakwater at the Port of Timaru. The results from Neale suggested a modification to the CERC formula to give a 'potential' longshore transport rate. This value has, however, been assumed to be valid for Canterbury Bight beaches, which is questionable given the distance separating the location of the study and where the results have been extrapolated. Another problem is that the results are based on net fluxes as opposed to instantaneous measurements, thus their value for short-term studies is questionable.

Hicks (1998) reviews some of the estimates for longshore transport rates along the Canterbury Bight coastline. Most estimates are only for sections of the coast

excluding Gibb and Adams (1982) who compute a sediment budget for the whole system. The problem with this approach is the accuracy on small sections of the coast may suffer using this technique. Reinen-Hamill (1995) used numerical modelling to study the evolution of the shore between the Orari River and the Rakaia River, however Hicks (1998) raises some important issues regarding the accuracy of these results. The modification of the wave climate to achieve model calibration and some model assumptions introduce doubt into the results. Kirk, Owens and Kelk (1977) compute an estimate of the sediment budget for a section of shore around the Ashburton River mouth using measured profile changes from Kelk (1974). The derivation of some values are questioned by Hicks, who states that the some of their results must be considered highly uncertain.

Kirk (1983) also suggests a net northward transfer of  $100\,000\text{ m}^3\text{yr}^{-1}$  of gravel for the Rakaia River mouth based on estimates from Kirk and Hewson (1979) and Tierney (1977). It is unclear, however how this estimate is produced from the two investigations which returned net northward movements of  $10^4\text{--}10^5\text{ m}^3\text{yr}^{-1}$  and  $60\,000\text{ m}^3\text{yr}^{-1}$  respectively.

Based on these reviews it must be considered that the estimates for longshore transport for this coastline are inadequate, or should at least be treated with great caution, and that further estimates and techniques should be employed to improve accuracy.

## **2.4 Image Analysis**

Photography and its application as a research tool to understand coastal processes is finding a greater use in recent times. Photography in the form of aerial photographs has been used as early as the 1940's (Lippmann and Holman, 1989). In the 1970's sequences of images were compared in order to discriminate time-dependent features (Nichols, 1972). An example of this approach is Berg and Hawley's (1972) use of time interval photography to estimate wave statistics, shoreline responses and functional effects of a littoral barrier in retaining materials. Nichols (1972) similarly used series of aerial and satellite photographs to examine changes in coastal waters. With the introduction of more accessible video technology and digital processing systems, there is now a greater

opportunity to make measurements over large temporal and spatial scales using video image processing routines.

### **2.4.1 International Examples**

Recently major advances have been made using video technology, particularly by US scientists from Oregon State University, the Scripps Institute of Oceanography and the Naval Research Laboratory. The need to study swash zone processes brought about the first concerted effort to develop image analysis techniques. Holman and Guza (1984) investigated the relationship between measurements made by resistance-wires and time lapse photography. The results were encouraging, showing good agreement with differences being explainable and consistent, but required a large input of labour to digitise the data. The measurements made using the photographic techniques were further utilised in Holman and Sallenger (1985) in their investigation of swash processes and setup phenomena.

The techniques for data capture did not incorporate a high level of objectivity due to the reliance on manual processing and input of the data. The publication of papers by Aagard and Holm (1989) and Lippmann and Holman (1989) represented major advances in the field of video camera technology.

Aagard and Holm (1989) discuss an improved method by which records were transferred into computer format. The images were gathered from a sandy beach in Staengehus, Northern Zealand, Denmark. Images were converted from a video record into digital format using a Frame Grabber board and then, using a mouse, the position of the swash front was tracked. However, the resolution of the video image was lower than that experienced in photographs and the procedure was also considered to be more time consuming than the technique employed by Holman and Guza (1984)

Lippmann and Holman (1989) also demonstrated procedures that would prove to be invaluable to video image data collection in the future. Their experiments, carried out as part of the SUPERDUCK experiment, investigated the form of offshore, submerged bars. Their study employed a method, known as rectification,

whereby an oblique image could be transformed into an aerial, or plan, view enabling clarification of the cross- and long-shore dimensions (See Figure 2.6).

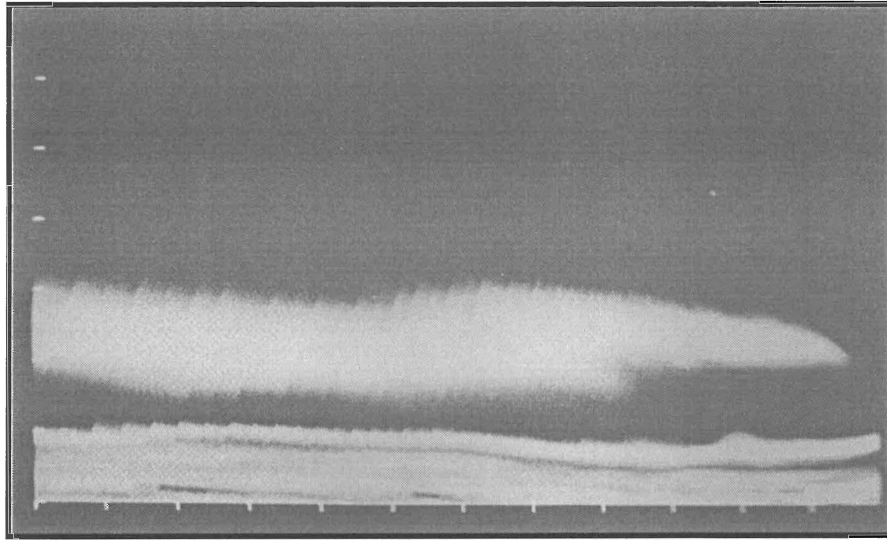


Figure 2.6 — Rectified time exposure image from SUPERDUCK. Tick marks are spaced 50 m apart in both cross and long shore dimensions.

*Source: Lippmann and Holman (1989)*

The method by which this transformation is performed differs to the technique used in this study. Transformation is performed using conventional photogrammetry equations. The transformation equations use camera attributes, such as focal length ( $f_c$ ), optic centre of camera (O), distance of camera above ground plane ( $Z_c$ ) and camera tilt ( $\tau$ ), to determine the real world co-ordinates of a point from their image co-ordinates (See Figure 2.7).

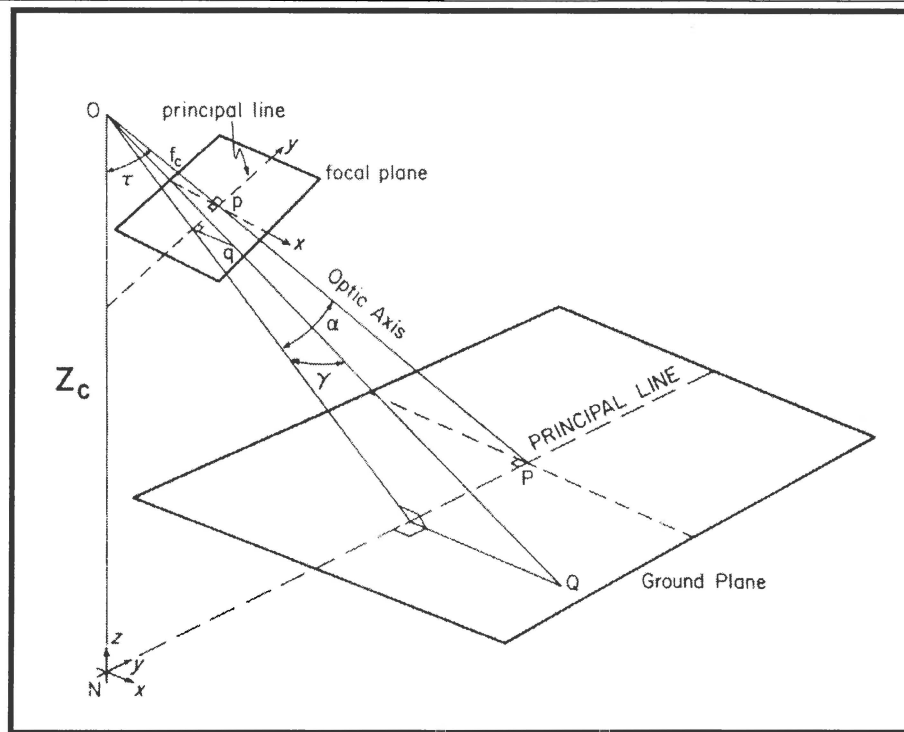


Figure 2.7 — Photogrammetry labeling conventions used by Lippmann and Holman (1989). The location of the point on the ground, Q, is calculated from its point q in the image and measured characteristics of the camera location and viewing angle.

Lippmann and Holman (1989) also have developed a remote sensing technique that allows the visualisation and subsequent quantification of nearshore morphology based on the patterns of incident wave breaking. The premise for this work was that more waves break over shallow bathymetry than the surrounding areas. With the snapshot images, it is not possible to define the spatial limits of the breaking waves, as an instantaneous picture will only show where a wave is breaking at a point, not across an area.

To overcome this shortfall a long time exposure is employed which will average out fluctuations due to the individual waves advancing over shallow areas and will give a statistically stable image (See Figure 2.7). The breaking wave pattern in the top frame suggests the presence of a sand bar but the poor spatial coverage provided by breaking crests and statistical uncertainty associated with natural modulations in wave height render the details of the bar morphology uncertain. The lower plate shows a 10 min time exposure of the breaking waves and provides a much clearer image of the full extent of the bar. Spatial coverage is

both extensive and of high resolution and non-stationary problems are avoided as bar migration occurs on much longer time scales than the sampling interval. Further results from the same experiment were then published in Lippmann and Holman (1990) which compared the various bar forms identified using these video images to those suggested by Wright and Short (1984).



Figure 2.8 — Snapshot and time exposure images. Snapshot image taken during the SUPERDUCK experiment (above) and a 10 minute time exposure from the same experiment at the same date and time (below) showing the shore and bar breaking waves.

Source: Lippmann and Holman (1989)

Holman, *et al.* (1993) and Holland, *et al.* (1997) review the techniques developed to date associated with image analysis and how this style of research may be employed for research in the coastal zone. Both produce some results from work in the past and demonstrate some applications that can also be made using video technology. Holland *et al.* (1997) explore the technicalities regarding image transformation further and broach the issue of lens calibration and the errors inherent in lenses.

The largest group involved in video monitoring of coastal environments, the Argus group, whose members include Rob Holman, Todd Holland, and Nathaniel Plant, have 11 sites accessible via the World Wide Web located internationally (<http://cil-www.oce.orst.edu:8080/>).

### **2.4.2 New Zealand Examples**

The Cam-Era team has pioneered the use of video cameras for environmental monitoring in New Zealand (See <http://yorick.eco.cri.nz/cam-era/index.htm>). The project is a joint venture between NIWA, the Ministry for the Environment, Waikato and Massey University, a number of regional councils and port companies. There are presently ten cameras operational in New Zealand as part of this project, with more planned.

The way the images are used, while not differing from the Argus project in end product, vary in techniques with which they achieved the outcome. The use of averaging is exactly the same as the technique discussed above by Lippmann and Holman (1989). The length of exposure does vary depending on the operator's requirements or preferences. Bailey and Shand (1993) have used averaged images in their investigation of large-scale sand bar evolution with an exposure length of only 3 minutes.

The method by which Bailey and Shand (1993) rectify the images differs in some notable ways from that used by Lippmann and Holman (1989). Bailey and Shand use a series of ground control points, surveyed in to a ground co-ordinate system, to determine relationships between real world and image plane locations. A limitation of this technique is that in the absence of a detailed model, this

correction only applies to a plane. To overcome this short falling of the method the plane that is used is generally approximated to the sea level, thus all measurements made at this level will be accurate. The ground control points are projected from wherever they are taken to the rectification plane (i.e. sea surface) where the resulting point is used to determine the mapping of the image to the rectification plane.

A point in the image is projected to the rectification plane using a least squares fit to determine the co-efficients of equations 2.1 and 2.2.

$$X = \frac{a_0x + a_1y + a_2}{a_6x + a_7y + a_8} \quad \text{Equation 2.1}$$

$$Y = \frac{a_3x + a_4y + a_5}{a_6x + a_7y + a_8} \quad \text{Equation 2.2}$$

To obtain an accurate rectification the ground control points should be distributed across the area of interest and should be determined as accurately as possible. Errors in sea level will cause an offset in the sea surface features. Points above sea level will appear further away than actual and points below sea level will appear closer. Resolution of the image is also strongly dependent on range. The higher the vantage point, the better the resolution of features further from the camera.

## **2.5 Summary**

While literature relating specifically to channels on mixed sand-gravel beaches is rare on an international scale, there is knowledge from associated fields which may be applicable to this study. The basic principles of inlet stability have been incorporated into existing theories on the migration and stability of the channel connecting the Ashburton hapua to the sea. It must be clearly identified however, that inlet stability is a separate field as most work relates to fine clastic

environments with characteristics that significantly differ from those in Ashburton.

Todd has provided the majority of the work specifically related to the drainage channels of hapua on the Canterbury Bight. Theories that have been put forward have suggested a process which, as addressed in inlet stability literature, is a conflict between river flow, acting to maintain an open channel, and longshore transport, attempting to close the channel.

Longshore transport of material along the Canterbury Bight has not been definitively assessed in the past. This situation is mirrored by a global sparsity in longshore transport measurements on gravel coastlines. One of the most significant factors controlling the channel behavior is not well understood on a process level, nor are good quantitative measurements available.

Past studies of these environments have relied on field measurements and aerial photographs of the channel. These measurements would be considered coarse at best as the rates of channel migration can vary significantly between measurements. Incorporation of video camera technology into a study on this environment could be valuable given the extent to which measurement of spatial features can be made, both regularly and for an extended length of time, while requiring only a small outlay of labour and money.

# Chapter 3 - Field Measurements and Data Analysis

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## 3.1 Introduction

What makes this study different to previous attempts at quantitatively defining the behaviour of the Ashburton hapua is the volume of data that is now being collected on the environment. A wide variety of data was assembled during this study to help understand the hapua behaviour and quantify the relationships between the forces which cause morphological change. This dataset certainly comprised of the largest dataset ever assembled for the Ashburton coast.

Data sources included:

- Atmospheric pressure from the NIWA Research station at the Christchurch Airport.
- Video images of the river mouth, lagoon and waves from a camera installed as part of the Cam-Era project by the Canterbury Regional Council and NIWA.
- River flow data from the gauging network operated by the Canterbury Regional Council.
- Wave data from the offshore wave buoy operated in partnership by the Canterbury Regional Council, NIWA and the Christchurch City Council.
- Lagoon water levels from the University of Canterbury water level recorder installed in the lagoon.

NIWA also supplied open coast water levels through a tidal prediction model.

Much of the data required editing and processing from raw formats to a form suitable for use in a database prior to its use in this study. Analysis of the video images in particular required substantial technique development of methods to extract the data and what data to extract. The issues and problems associated with these procedures are detailed in the following text.

A Microsoft Access database was used for handling the data, providing an effective means of data assimilation, data selection and sorting, and exporting of data for analysis.

### **3.2 Data Sources**

The data records span different periods during the study because some instruments were installed during the study period while other records are provided as part of other ongoing studies (See Figure 3.1)

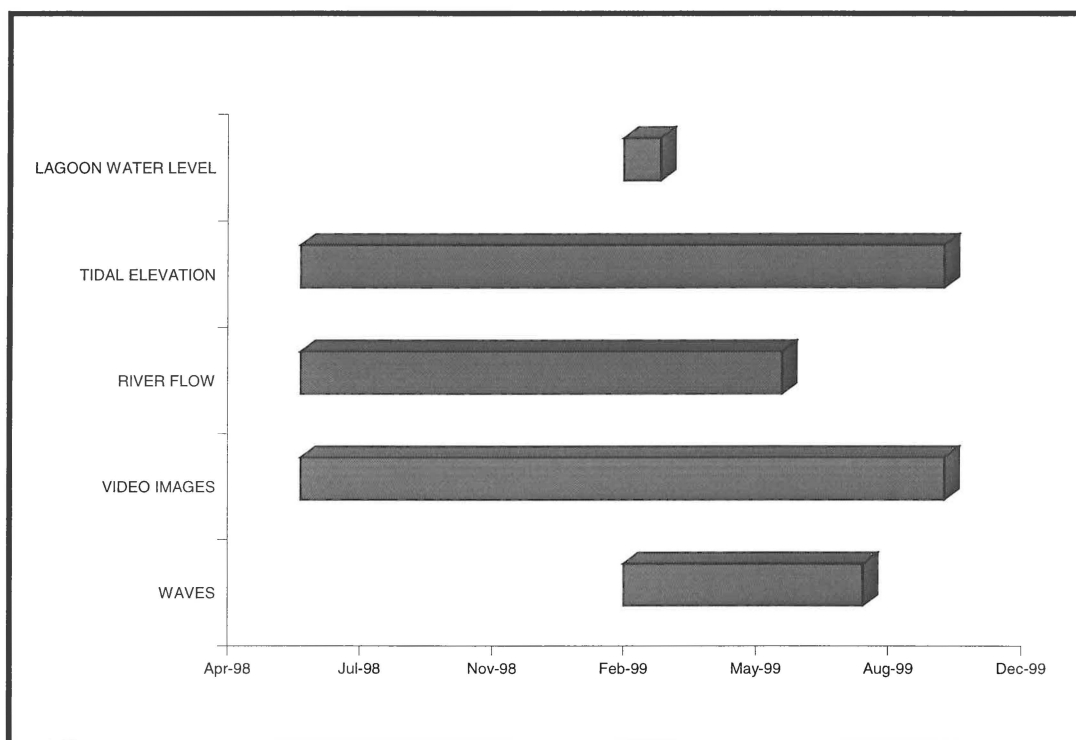


Figure 3.1 — Data collection over the study period.

#### **3.2.1 Open Coast Water Levels (Tidal Fluctuation)**

The tidal record was hindcast using a numerical model supplied by NIWA. The model uses a finite element grid of the region from 163° to 190°E and from -55° to -33°N with depths greater than 200 m obtained from the GEBCO database and a uniform shoaling assumed from 200 m depth shoreward to the coast (Goring *et al.*, 1997).

Limitations imposed by the use of a tidal model included an inability to adapt to atmospheric conditions which can cause variations in water level. At the coast these factors become important as they can generate storm surge. The important components contributing to storm surge are:

1. Change in atmospheric pressure; and
2. Movement of water on/offshore in response to wind stress.

The record was then modified to incorporate the sea level response due to changes in atmospheric pressure. Kathy Walter (NIWA - Christchurch) supplied the atmospheric pressure record from the Christchurch Airport. Using the inverse barometric equation defined by Gill (1982) it is possible to simulate the change in sea level ( $\Delta\eta$ ) as a function of change in atmospheric pressure ( $\Delta p$ ), density of sea-water ( $\rho$ ) and gravitational acceleration ( $g$ ) (See Equation 3.1).

$$\Delta\eta = -\frac{\Delta p}{g\rho} \quad \text{Equation 3.1}$$

For New Zealand a modified version of this equation may be used given that the average atmospheric pressure in New Zealand is assumed as 1014 hPa (deLange, 1997). The modified equation is presented below (See Equation 3.2). Using this equation in conjunction with the tidal model provided a more accurate definition of the open coast water level.

$$\eta_{\Delta P} = 0.010(1014 - p) \quad \text{Equation 3.2}$$

### **3.2.2 Video Data**

#### **3.2.2.1 The Set-Up**

The Cam-Era remote station consists of a Ikegami 1/3 inch colour CCD video camera with a fixed focal length lens of 12 mm and a Pentium 200 MHz computer

with a 2 GB hard drive running Windows NT4. The computer contains an Integral Technologies Flashpoint 128 frame grabber and a 2x Dynalink 33.6 K modem, and is hardwired, in this case, to the local power and phone lines (Hume, et. al., 1999). The camera is mounted on a pole approximately 8 metres high and is angled towards the north-west (See Figure 3.2). The camera sends a video image to the computer hourly. The frame grabber board processes the analog video signal to provide a digital file that is used by software installed on the computer to rectify, stack, average and transmit the data.

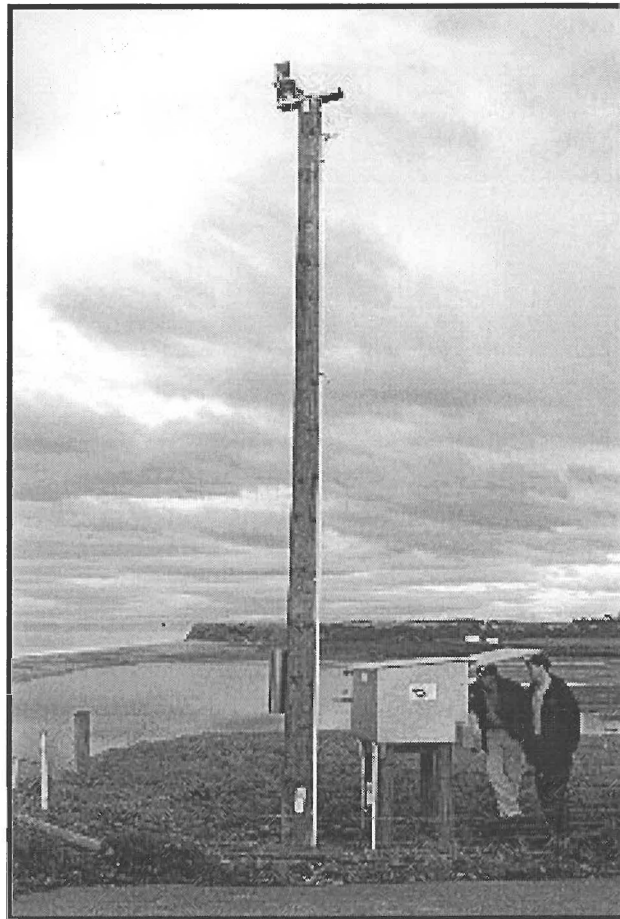


Figure 3.2 — Cam-Era setup. Video camera is mounted on top of the pole and linked to the processing computer in the box mounted alongside the pole.

Source: *Cam-Era Website* (<http://yorick.eco.cri.nz/cam-era/about-ashburton.htm>)

The system is driven by a time scheduling program which enables fully independent data capture and system maintenance. The scheduling program captures the images hourly and runs averaging and time stacking programs which provide one oblique snapshot, one oblique average image and three time stacks.

The scheduling program then connects the modem to the NIWA Hamilton server and transmits all five images, which are archived. The oblique snapshot is posted on the World-Wide-Web.

Oblique video images of the river mouth and hapua have been collected hourly since the installation of the Cam-Era site in June 1998 until the present. However the site has undergone several changes to the approximate location and orientation of the camera (See Table 3.1). Originally the site was configured for one camera (camera A) only. After numerous minor corrections to the camera angle the camera remained stable for approximately five months before a second camera (camera B) was installed which required another camera angle change to camera A.

DATE	CAMERA ANGLE <sup>1</sup>	CAMERA A OBLIQUE IMAGES	GROUND CONTROL POINTS <sup>2</sup>	CAMERA B OBLIQUE IMAGES
22/06/98 –	1	Yes	No	No
23/06/98 –	2	Yes	No	No
23/06/98 –	3	Yes	No	No
23/06/98 –	4	Yes	No	No
7/08/98 –	5	Yes	Yes	No
8/03/99 –	6	Yes	No	No
11/03/99 –	7	Yes	Yes	Yes
present				

Table 3.1 — Data records from the Cam-Era site.

1. Camera angle changes include either physical change to the camera position or changes to image dimensions or resolution.
2. The ground control points are required for images to be rectified

Data provided fell into two categories; that which could be used for qualitative analysis and that used for quantitative analysis.

### 3.2.2.2 Oblique ‘Snapshot’ Images

Oblique ‘snapshot’ images are the raw images that are taken hourly of the site and simultaneously posted on the World Wide Web (See Figure 3.3).

The qualitative dataset encompassing the entire set of oblique images provides a long record of the variation in the morphology of the site. Such data aids in creation of system behavior models. The most efficient technique to view long periods of video data is to create movies of the images (\*.avi files) using a program entitled Avi Constructor. This program enabled incorporation of a series of \*.jpg images into a movie where the speed of frame advance could be set to a predefined rate. Using this technique approximately 5600 images were condensed into 14 \*.avi files each lasting approximately 6.5 minutes.

While it was identified that averaged images would be more useful than snapshots, the advantages of using oblique images over rectified images include:

- Better resolution in the oblique image because the transformation process required for rectification causes a reduction in image clarity and definition of features.
- Less error when viewing the raw image than in the modified image where errors may be introduced as part of the rectification procedure.
- Provides a better understanding of the processes that are operating in each image (i.e. the effect of waves can be clearly identified).
- The oblique snapshot record is the largest dataset.

Problems with the use of snapshot images are often a result of adverse atmospheric conditions. Rain or fog can decrease visibility which affects the quality of the image recorded (See Figure 3.4).

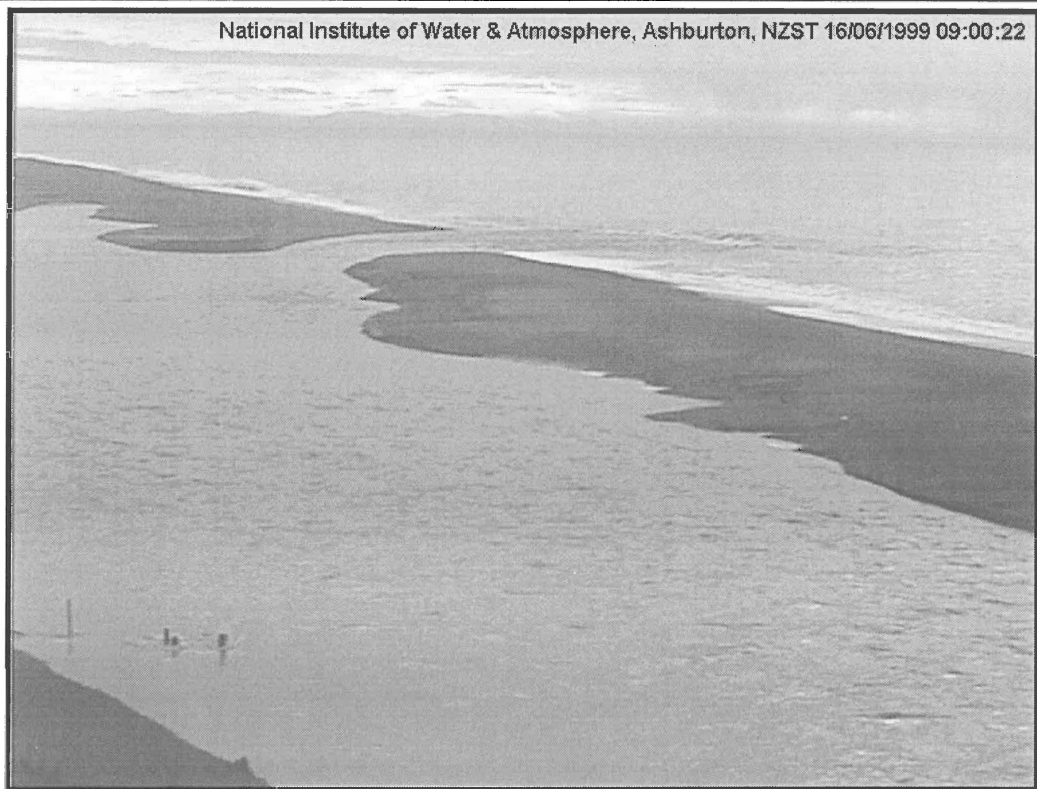


Figure 3.3 — Oblique 'Snapshot' Image as shown on the World Wide Web.

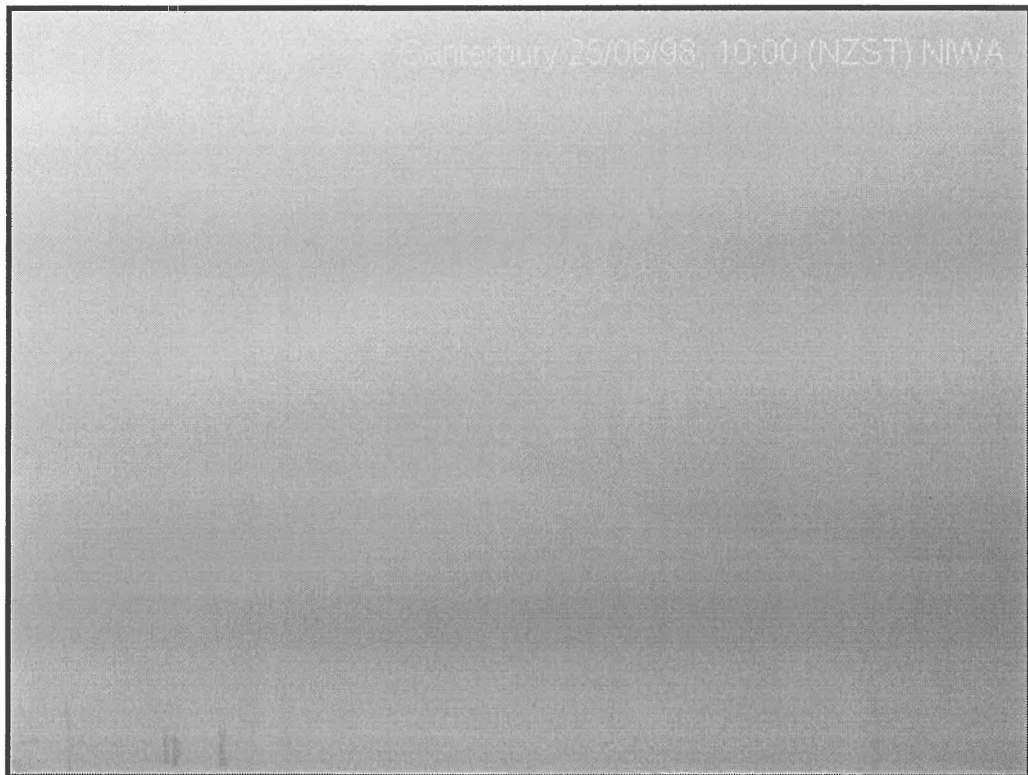


Figure 3.4 — Oblique 'Snapshot' Image showing the effect of adverse atmospheric conditions (fog).

There are also missing images during the hours of darkness. The system is designed to go into a 'sleep' mode during the night where the camera does not attempt to collect any images, as nothing is visible. This results in bursts of data during the day interspersed with gaps during the night. During early mornings, where the sun angle is low, the image quality can be affected by glare and direct sunlight obscuring the features of interest.

Equipment failure contributes to problems, where a distorted or no image is recorded (See Figure 3.5). Another problem is the accumulation of salt and dirt on the camera lens which causes blurring of the images. However this problem is presently being rectified with the installation of remote cleaning devices.

### **3.2.2.3 Oblique Averaged Images**

Averaged images are used to investigate short-term features that are not always evident in 'snapshots'. Don Bailey (Massey University) has developed tools for use within the Cam-Era Project to replicate the averaging technique first described in Lippmann and Holman (1989). The oblique averaged image is made up of 600 images taken at one second intervals for ten minutes. The process of averaging is the same as Lippmann and Holman (1989) whereby each pixel's red, blue and green colour levels are recorded in each image and the average of those levels over the recording period is returned (See Figure 3.6).

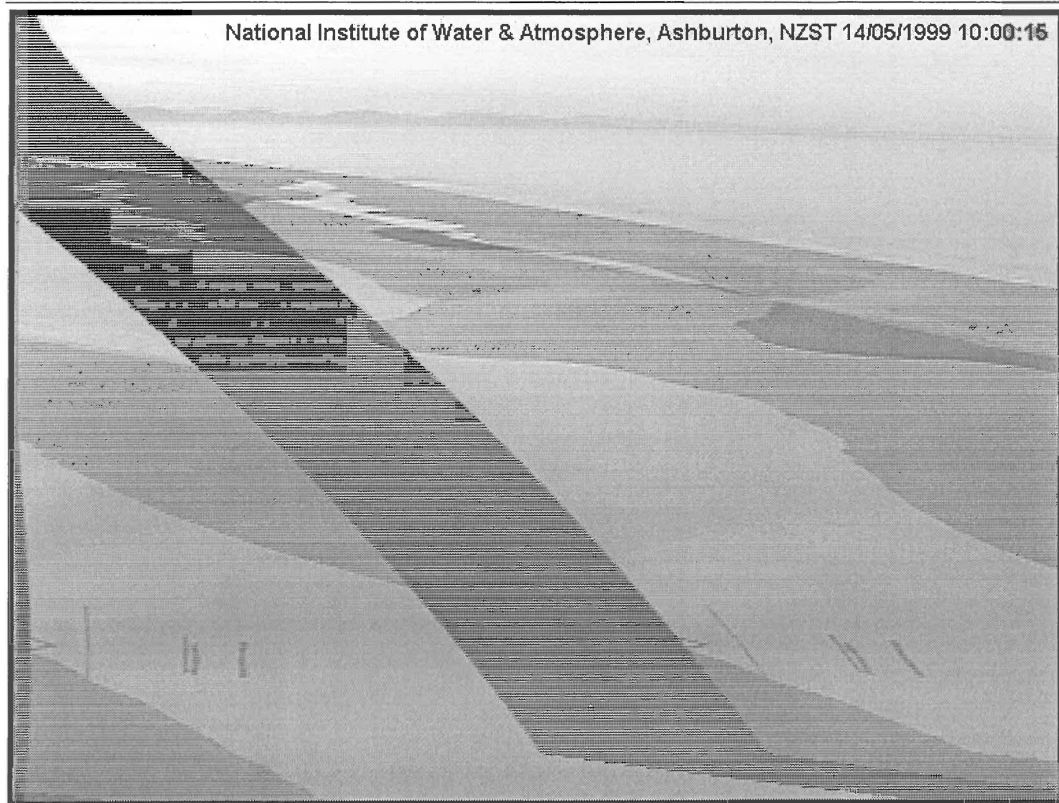


Figure 3.5 — Distorted image due to frame grabbing software.

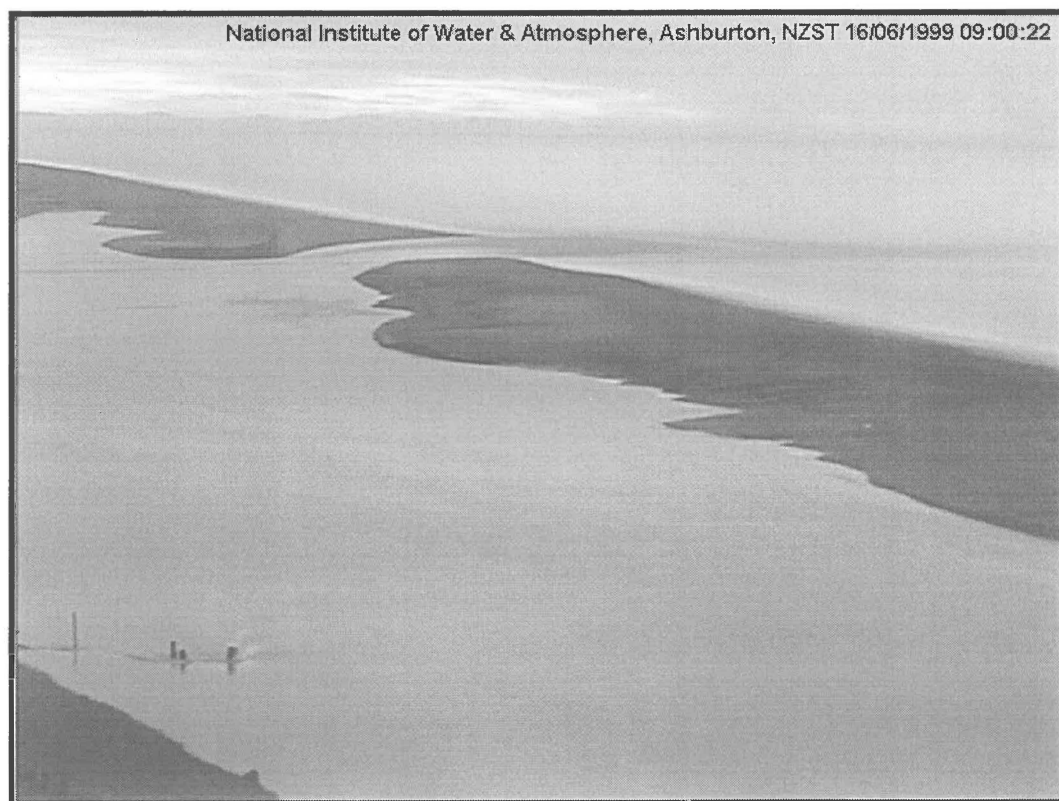


Figure 3.6 — Ten minute average image from the Cam-Era site.

Averaged images were used for the creation of \*.avi files from 11/3/99 onwards. These were adjudged to be more useful than ‘snapshots’ because the images showed features such as the seaward end of the channel with more clarity. Some features temporarily obscured in a snapshot by a large breaking wave or overtopping of the barrier become obvious in the 10 minute average image.

Errors in averaged images are exclusively due to hardware malfunctions. At times there was a problem with the frame grabbing software that caused the return of ‘black’ images. When the images are averaged the black images cause a darkening of the average image as the black levels are artificially increased. This can cause a darkened image where features are difficult to distinguish. If the images are not consistent in location of features, as a result of real or apparent camera movement, there can also be a ‘shadowing’ effect that makes objects difficult to discern.

#### **3.2.2.4 Rectified Images**

Rectification is a procedure whereby an oblique image is converted to a equivalent aerial photograph using translation of pixels as defined by a mathematical relationship.

The dataset used for quantitative analysis was smaller than the total video dataset. Analyzing morphological change in a quantifiable sense requires the camera position and image properties to be stable. Further, if accurate ground distances are desired, the images require rectification using ground control points. Thus the size of the dataset is reduced to those that meet the above prerequisites. The images that fulfil those demands provides an image as shown in Figure 3.7.

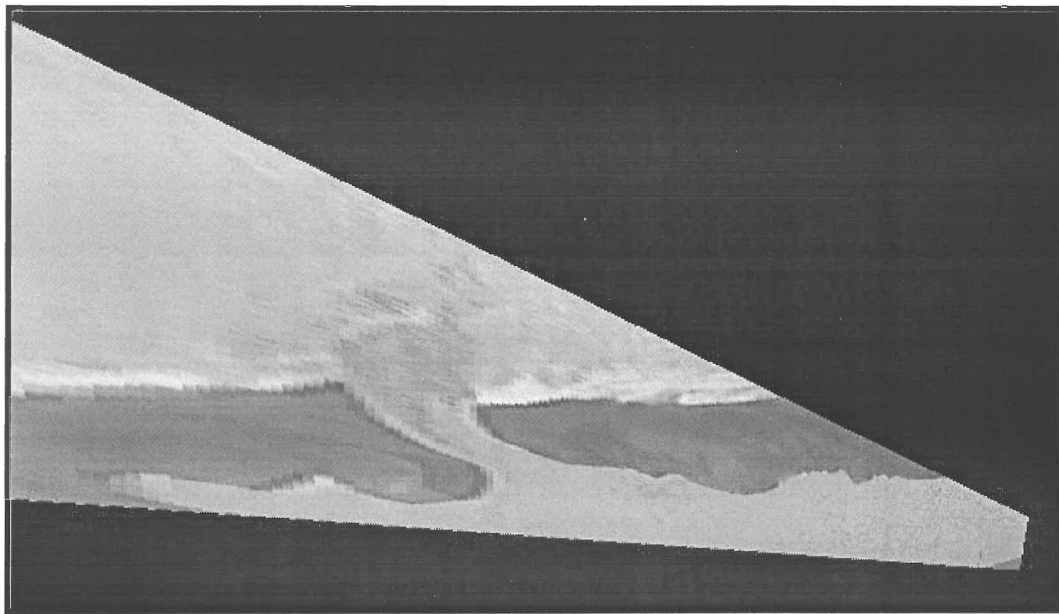


Figure 3.7 — Rectified image of Ashburton hapua. Black area is outside the camera's field-of-view with the left side of the image to the north.

Problems were also encountered regarding stability of the images. The foreground of the images contains several, well established posts that remain as part of a past coastal protection structure. When viewing the images it was evident that the apparent movement of these posts at times, was a result of the movement of the pole and camera setup. To measure the error that would be introduced due to the movement, the location of the right uppermost corner of the post in the images was recorded. The apparent movement of the posts from their location during recording of ground control points would be analogous to the amount of error that the rectified image would contain as a result of the camera movement (See Figure 3.8, Figure 3.9)

The error due to camera movement is considered minor due to the scale of the features that are being investigated along with the relative error that may be attributed to other sources. Those periods where the camera has moved greatest are episodic and are associated with distorted images (See Figure 3.5, Figure 3.10)

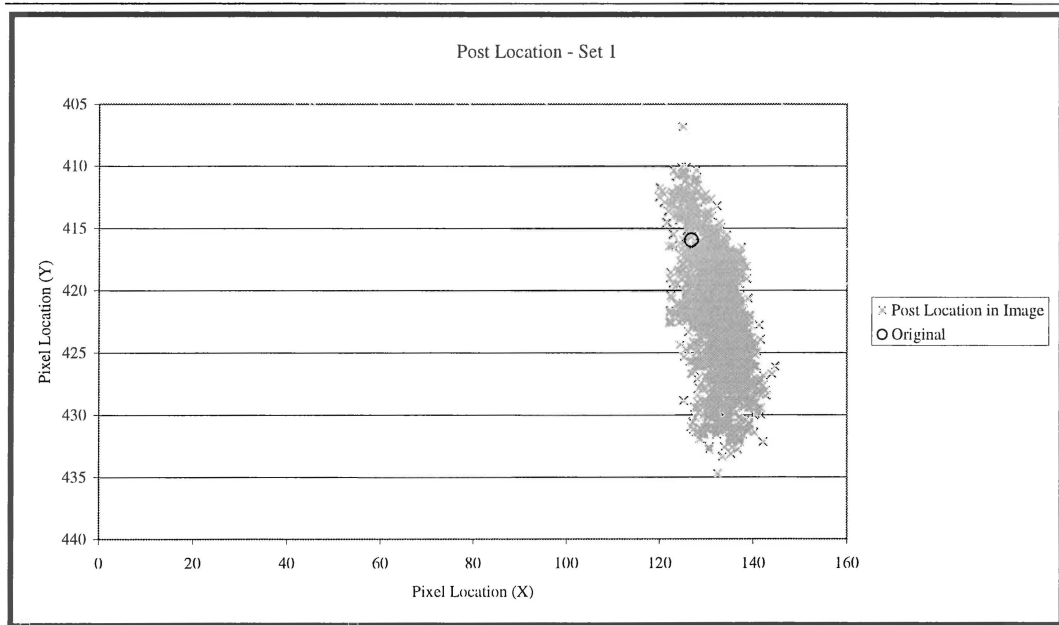


Figure 3.8 — The apparent movement of the post in the first dataset images.

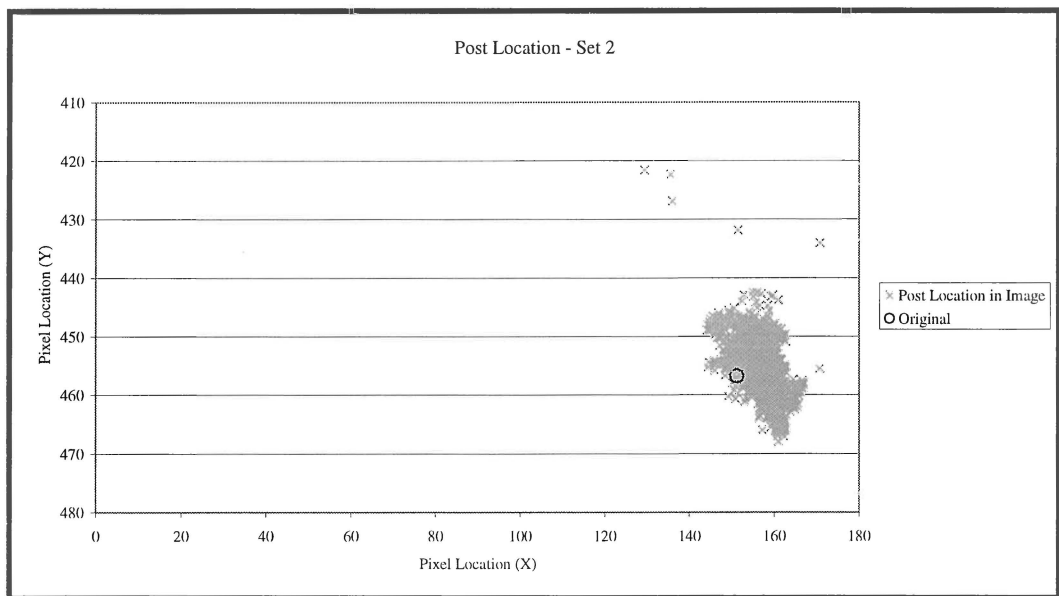


Figure 3.9 — The apparent movement of the post in the second dataset images.

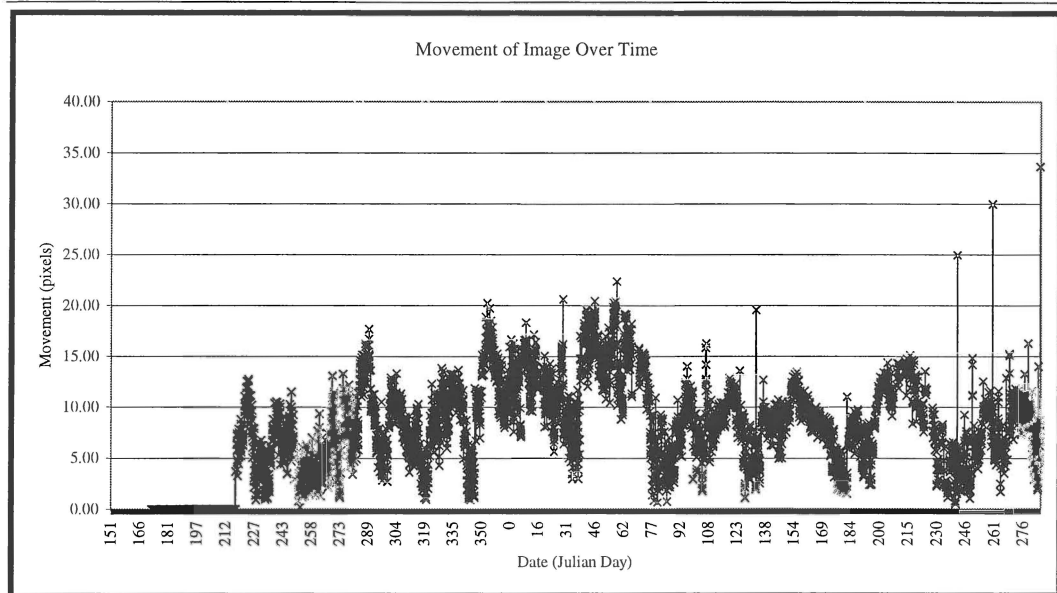


Figure 3.10 — Apparent movement of the images over time.

A rectified image must be supplied with a horizontal level at which to rectify the image to. All surfaces at that specified level will be most accurate with increasing error as the elevation of the surface varies from that level. The level of rectification used was the open coast water level. A shortcoming of the rectification software is that it did not allow for an inclined plane to be rectified. Ideally this would have been attempted because the plane would approximate the water level in the channel returning more accurate transformation of that part of the picture which we are most interested in.

Other errors may be attributed to inaccurate ground control point recording, changes in picture characteristics, and lens error. Errors in recording the location of ground control points can cause large errors as they will affect all images that are rectified using those ground control points. When setting up the configuration file that contains the real world co-ordinates and the image co-ordinates of the ground control points extreme care was taken, including a requirement for replication of results to ensure correct measurements were recorded. Picture characteristics could change as a result of either intentional changes to resolution, or frame grabber problems resulting in movement of the image, both of which render the configuration file incorrect. Lens error for the Tairua Cam-Era site has been measured and found to be greatest on the margins of the image (K. Bryan,

pers. comm.). For the Ashburton case the data is predominantly gathered from the centre of the image, thus such an error will be minimised. Errors at Tairua ranged from +1.4% to -3.6%, which is insignificant in this study relative to the other sources of error.

There is also a degree of error introduced due to the effect of the raised topography around the channel (See Figure 3.11). The height of the banks beside the channel can cause a ‘shadowing’ of the actual bank which suggests a channel width less than the actual width. This error was minimised when viewing the channel ends because of the low relief of the barrier at the seaward and lagoon edges.

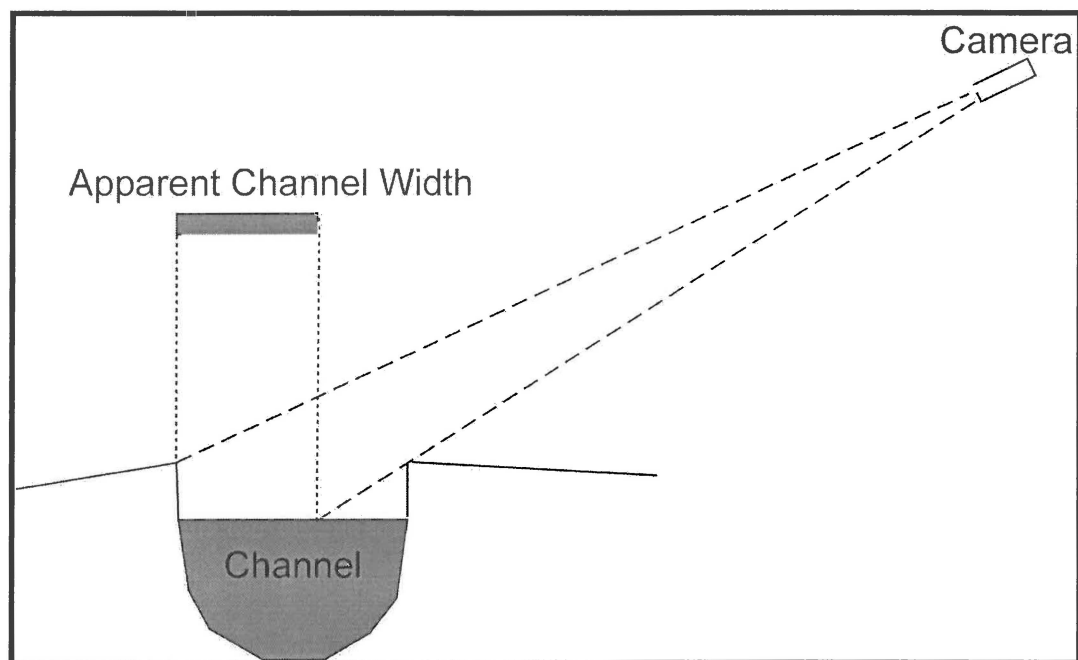


Figure 3.11 — Effect of raised topography around the channel. The shadowing of the channel causes an inaccurate estimate of the channel edge closest to the camera

### 3.2.2.5 Data acquisition

To provide quantitative data on the morphological changes at the hapua a digitisation routine was used in MATLAB. It was hoped that through automation of the process the data could be provided in an objective manner but it became obvious that at times subtle differences in colour and contrast were unable to be

differentiated by a computer program. As a result, we would require subjective analysis, thus defeating the purpose. Manual digitisation was then attempted which enabled a more thorough data collection.

Digitisation required the operator to assess the location of the channel ends and also the wave crests to determine the breaking wave angle (See Figure 3.12). This was often a difficult undertaking. Table 3.2 shows the definitions that were adopted for the procedure.

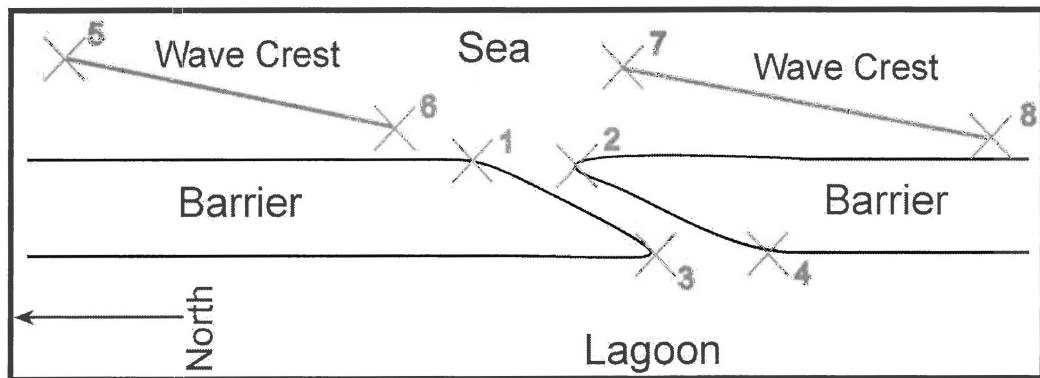


Figure 3.12 — Schematic of digitised points. Numbers refer to points listed in Table 3.2.

Recorded Point	Description
1 Location of the northern bank of the channel at the seaward end.	The point that describes where the northern bank of the channel intersects a straight line that describes the coast.
2 Location of the southern bank of the channel at the seaward end.	The point that describes where the southern bank of the channel intersects a straight line that describes the coast.
3 Location of the northern bank of the channel at the lagoon end.	The point on the northern bank where the width of the channel dramatically increases.
4 Location of the southern bank of the channel at the lagoon end.	The point on the southern bank where the width of the channel dramatically increases.
5 Northern end of Northernmost wave crest.	The wave crest at the northern extreme of the image.
6 Southern end of Northernmost wave crest.	The southern end of the wave crest identified in 6.
7 Northern end of second wave crest.	The northern end of another wave crest not already described in 5.
8 Southern end of second wave crest.	The southern end of the wave crest identified in 7.

Table 3.2 — Description of the points that were digitised. See also Figure 3.12.

To validate the data obtained through the digitisation excel spreadsheets were used to confirm that points were sensible. Excel was also used to obtain the required data through manipulation of the raw data from the digitised points.

### **3.2.3 River Flow Data**

The recording site is approximately 18 km upstream of the river mouth used to provide measurement for water resource management. The flow recorder at the site is a Unidata Starlogger and the stage is measured by a Parascientific pressure sensor which has a resolution of +/- 1 mm.

### **3.2.4 Wave Data**

Wave data was collected for 7 months at a site 17 km East of Le Bons Bay, Banks Peninsula. The buoy was moored at Latitude 43 degrees 45 minutes south, Longitude 173 degrees 15 minutes east in approximately 90 m of water providing a deep-water wave record.

The wave data was provided for approximately 25% of the time with gaps due mainly to transmission errors between the buoy and the shore station. There was also a large gap between 24 March 1999 and 9 April 1999 due to a problem with the buoy's computer.

Results were consistent with past reports (Kelk, 1974, Kirk, 1980; Neale, 1987; Flatman; 1997) indicating the predominant direction of wave transmission and the largest waves being from the south (See Figure 3.13).

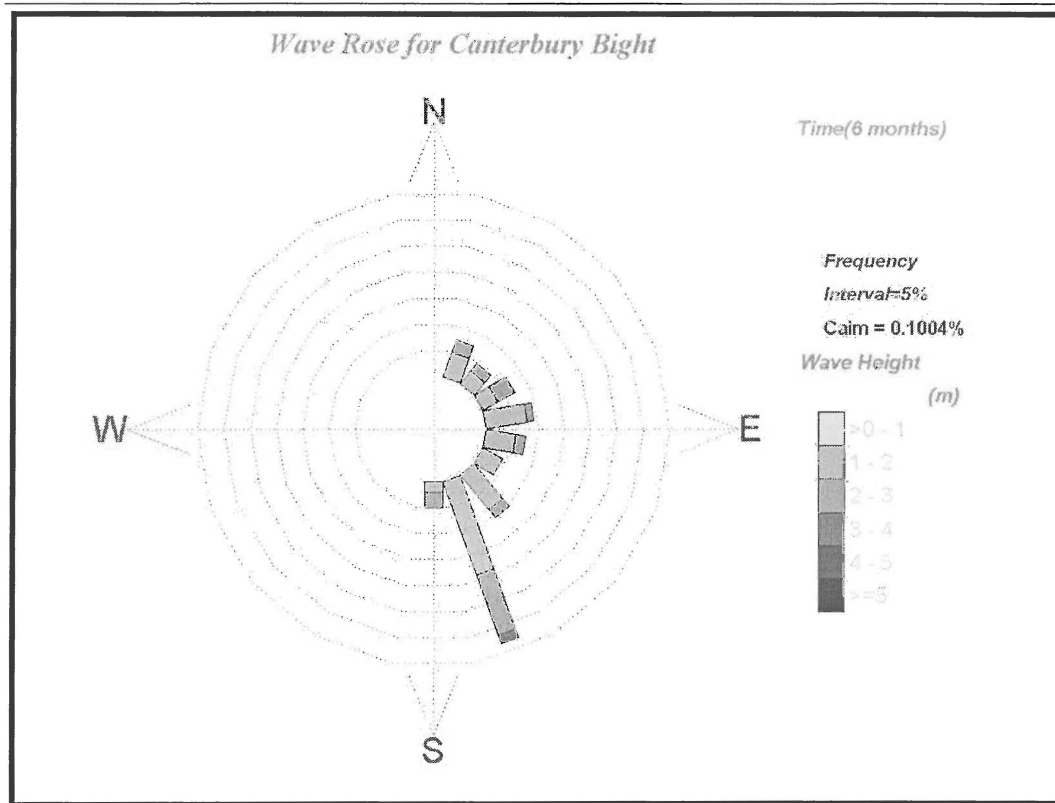


Figure 3.13 — Wave rose based on data from the Canterbury Bight wave buoy from 6/2/99 – 12/8/99.

Source: *MATLAB wave rose program courtesy of Rick Leifting*

### **3.2.5 Lagoon Water Levels**

The lagoon water levels were collected by Deirdre Hart of the Department of Geography, University of Canterbury, from the 13 January 1999 — 4 February 1999 using a pressure transducer. The recorder was located in the vicinity of the camera, mounted on railway irons remaining as part of a coastal protection structure. Depth (in mm) was recorded as the head of water above the pressure transducer. The sensor was 325 mm above M.S.L., however, the depth of water below the instrument does vary according to how much gravel is moving about the lagoon.

As a potential surrogate for the relative lagoon water level, the length of a pole protruding above the water, in the foreground of the image (See Figure 3.3), was recorded. This extended the two month long water level dataset.

The length of the pole was recorded in conjunction with the top corner of the post to identify camera movement (See 3.2.2.4). The length was recorded as the difference in the y dimension of the oblique image between the top of the pole and what was identified as the intersection of the pole with the water level.

In some situations it is impossible to determine the intersection of the water surface on the pole due to shadows or reflections of the pole falling on the water surface. In these cases it is possible to determine the position of the water surface using the pole to the left. It is in approximately the same location as the primary pole thus the intersection of the water surface and the pole is at the same elevation as its neighbor. The second pole is angled which, in cases of shadows being cast, returns an open triangle shape (See Figure 3.14). The apex of this open triangle indicates the location of the water surface on this pole which approximates to the elevation of the water surface on the neighboring pole. The accuracy of this technique is also directly related to the resolution of the image. As the resolution is increased, accuracy of water surface determination is improved.

At times when the lagoon water level is extremely low there may be no water at the post. Conversely when the lagoon water level is extremely high the post may be entirely submerged. Under these circumstances it is not possible to record the water level and -999 is substituted (i.e. No value). Fortunately these occurrences were rare over the study period.

This technique also requires contrasting colours between the post and the background. The exposed lagoon floor or interference due to sunlight reflecting off the water surface can both contribute to this type of error (See Figure 3.15). As the length of exposed pole reaches a minimum it also becomes more difficult to accurately determine the location of the water surface. The neighboring pole's shadow is unavailable when the water level is high as that pole is submerged although the primary pole is still exposed due to its greater length.



Figure 3.14 — Posts in foreground of image. Note the slope of the centre post which aids in determining the length of the right hand side post that is exposed. Also the ripples formed as water passes can suggest where the water surface lies.

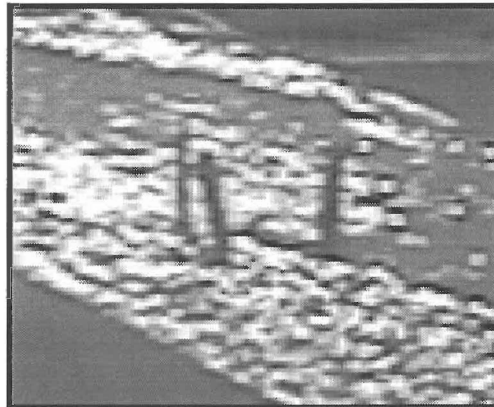


Figure 3.15 — Interference caused by sunlight reflecting off the water surface. The measurement of the length of the post in this image is not possible, thus no value is returned.

Bio fouling can create a problem in reading water levels where debris wraps around the post. Whether the debris floats or not is unknown thus it is incorrect to make any assumption as to whether the material may be used to indicate the water surface. They may float on the water surface, indicating water level as the increased width of pole, or they may not float on the surface leading to incorrect measurements (i.e. solidify and project out at level above water surface).

### **3.3 Database setup**

#### **3.3.1 Aim of Database Creation**

Due to the numerous sources of data involved and the large volume of data provided, a tool was required which would enable quick and easy data recovery. The means by which this was achieved involved the use of a large database. The database program that was chosen was Microsoft Access 97, for a number of reasons:

- The program is included in most Microsoft Office software packages and therefore the use of the database would not require accompanying software.
- The tools available for use in the program are well developed.
- The links with other Microsoft products (i.e. Microsoft Excel) for data analysis are well established.

#### **3.3.2 Assimilating Data**

Data was provided in a number of forms due to the wide variety of data sources incorporated in this study. All data records were formatted so they were associated to a year, Julian day, and hour. Microsoft Excel was most often used for this transformation and the simple ‘cut and paste’ operations that were used to transfer data into Microsoft Access.

Wave data required interpolation of points as data was recorded at three hourly intervals. This was undertaken using a MATLAB routine which fit a cubic spline interpolation to the time series giving estimates for those points not recorded. This technique should be accurate due to the slow nature of variations in wave parameters that will prevent any wild fluctuations between two data points.

The points where data could not be recorded were returned as -999, which is outside the bounds of any actual data recorded. When analysis was required it was easy to remove these values by running a macro in Microsoft Excel to delete the -999 values.

Each data source was created as a table in Microsoft Access containing 12 000 records corresponding to every hour between Julian day 151, 1998 and Julian day 285, 1999. (See Figure 3.16)

### **3.4 Use of Database**

The power of a database lies in its power to select the data you are interested in and the order in which you want to see it. The database was used to identify the various events of interest and identify the coincidental measurements of forcing processes. If a specific set of morphological conditions were to be examined, for example the location of the channel at the seaward end, it was simple to match the conditions to the other measurements of waves and river flow. It also provided a convenient method to compare records in a manner consistent with each other. Using the exporting tools in the program, all records could be simultaneously transferred into Microsoft Excel.

#### **3.4.1 Query Tool**

The use of a query tool was invaluable for sorting through the voluminous data available to the database. To establish the links between tables, which will enable the recovery of all records meeting a certain set of specifications, it is necessary to establish primary keys. The primary key of a table consists of one or more fields that uniquely identify each record in the table. In this case the primary key was made up of the year, Julian day and hour fields. A table with a primary key has the following advantages:

- Microsoft Access automatically creates an index for the primary key. This index helps speed up queries and other operations.
- When you view records they are displayed in primary key order by default.
- When adding data to a table Microsoft Access does not allow replication of primary keys. Thus you can be sure that each record is unique.

The records in each table are not associated with each other unless a relationship is identified. The records in this database were related using the primary key fields so each record could be recovered for any time period (See Figure 3.17).

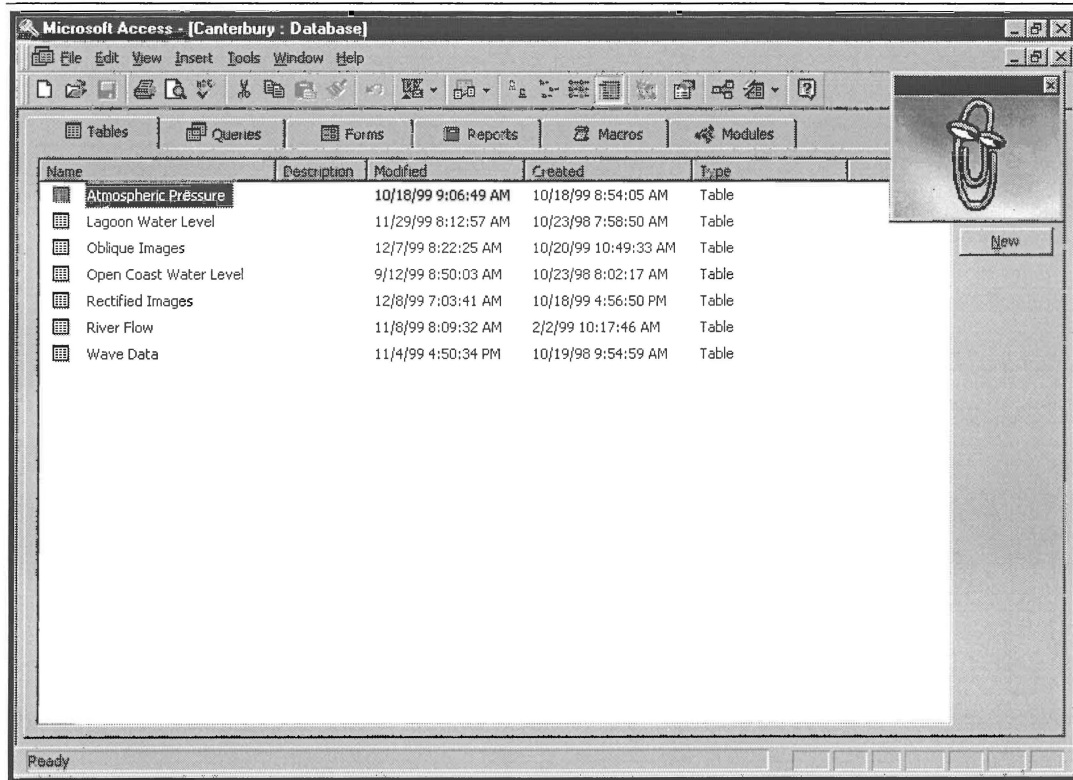


Figure 3.16 — Access Database showing all data sources in table layout

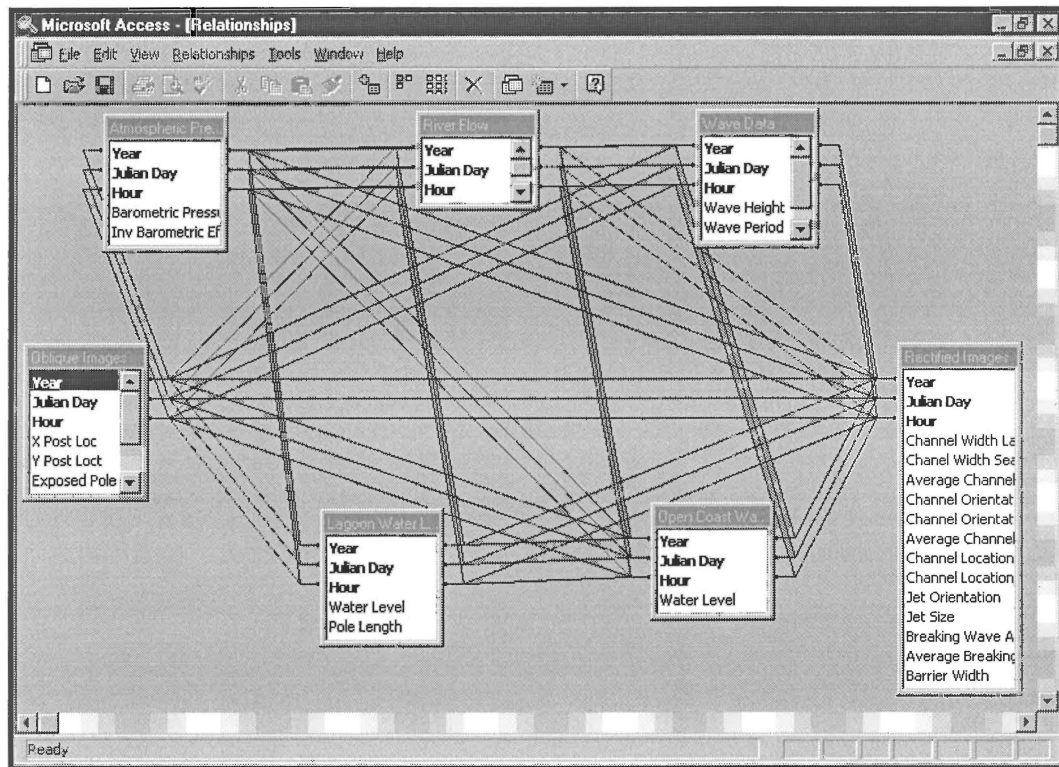


Figure 3.17 — Relationships display in Access illustrating how all tables are interconnected through year, Julian day and hour fields.

With the relationships defined, it is possible now to work with the query tool. Queries give you the power to specify which records are to be returned given that they meet a set of conditions that are applied. In this case we can specify a time period which applies to a certain set of images. For example, the changes to the camera location and angle mean that data gathered from one configuration cannot be compared with data gathered from another. The query tool enables us to recover all of the data that applies to only one configuration.

### **3.4.2 Export data**

One of the primary reasons for creating the database using Microsoft Access was its links to programs such as Microsoft Excel for analysis of data. The ease with which this was done enabled preliminary analysis to be undertaken immediately upon data entry. Once data was provided in Excel format it was available to a number of other analysis tools including MATLAB and Data Desk for more complex statistical analysis.

## **3.5 Summary and Conclusions**

The volume of data collected in this study makes it one of the most extensive datasets collected on the Canterbury coast. The data sources range from numerical modeling of tides to *in situ* recording using a variety of instruments.

While many of the instruments are well established in terms of data capture, the use of video technology to measure morphological change has required substantial effort to develop working methods of data extraction. The camera has a number of substantial problems and errors that must be considered.

The pole, on which the camera was mounted, while necessary in this case, is not ideal unless further measures are undertaken to prevent camera movement. Camera movement will prevent accurate rectification which creates error in the images. It is fortunate that the scale of geomorphic change was large relative to the error so valid data could be presented.

This Cam-Era site provided some unique problems due to the dynamic nature of the environment. It is noted that images require a minimum of one stable point to assess the stability of the images. Without the posts in the foreground of the images it would have been impossible to record the magnitude of the error introduced as a result of pole movement.

Due to a logistical difficulty in deployment and maintenance of a sea level recorder at the Ashburton field site, modeling of the open coast water levels was required. This technique, while acceptable in this study, highlights the need for levels of rectification to be identified early in the study and, if the level varies over time (i.e. water levels) then a method of recording this level is strongly recommended. It should also be noted that, at present, it is only possible to rectify to a horizontal plane. In this study it would have been more accurate to rectify to a plane describing the slope of the water in the channel.

A wide variety of images are available to a camera user. It is important to address the strengths and weaknesses of each type and how these can best meet the needs of the project.

There remain a few problems with the Cam-Era site regarding technical malfunctions as a result of the hardware. Excluding those technical problems the remote camera setup has been very successful, recording 18 months of images during daylight hours without major interruption.

The resolution of images gathered using video becomes important when looking at large scale features, such as the Ashburton hapua. When rectifying the images, the increasing pixel footprint limits the distance from the camera to which accurate measurements can be taken. Increased resolution also provides better accuracy for measurement of features in the images. The technique of measuring the water level would be more accurate with increases in resolution.

The database proved to be an invaluable tool to manage the data gathered. The volume of data and the length of time data was recorded was substantial, requiring an effective tool to keep data sorted and provide data which met specified conditions.

# Chapter 4 - Measuring Gravel Transport Using the Gravel Transport Sensor (GTS)

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## **4.1 Introduction**

Gravel transport plays an important role in the morphological development of the Ashburton River mouth. Movement of material along the shore is an important factor when dealing with issues of inlet stability. An understanding of the magnitude of transport over time will prove helpful in quantifying the relationship between longshore transport and the morphological response of the channel to this driving factor.

Crickmore, *et. al.* (1972) suggest that onshore movement of gravel is very slow from depths between 9–12 metres, and that the majority of gravel movement takes place in the swash zone. Several instruments have been developed to measure gravel transport in the swash zone of gravel beaches all with limited success.

Kirk (1971) developed an instrument to investigate nearshore processes on gravel beaches which he called the dynamometer. The dynamometer was developed to measure energy (velocity) of uprush and backwash. The work of Caldwell, *et. al.* (1982) however indicated that the results obtained by Kirk were inaccurate. They also developed an instrument to measure the force of the swash and backwash but, as noted in Williams and Roberts (1995), it required cables between the instrument and the loggers. Williams and Roberts (1995) state that this is a shortcoming in the gravel beach environment where a remote instrument would be more desirable. Williams and Roberts also developed an instrument, named the ‘Swashometer’, which measures wave forces in the near-shore environment. This instrument, as an added advantage, measured pebble impacts.

This investigation tests the applicability of another instrument, the Gravel Transport Sensor (GTS), to estimate the weight of material moved in the longshore direction. While developed for use in rivers, the GTS appears to have overcome some of the design problems of the other instruments by incorporating the recording devices inside the instrument. It appears to operate in a similar fashion to the ‘Swashometer’ but disregards the wave forces and directly counts pebble impacts on the instrument body to generate data.

The aim in this study was to develop an appropriate methodology and calibration for the GTS in the beach swash zone, then deploy it to measure longshore sediment transport. These estimates would prove useful in understanding the relationship between channel migration and longshore transport at the Ashburton hapua.

## **4.2 Instrument Description**

The GTS is an acoustic device that detects moving sediment particles as they impact a steel pipe. These ‘pings’ are counted and stored at regular intervals, as defined by the user, in the instrument memory. Although developed for use in rivers, it was felt that it could also be applied to studies of nearshore sediment transport on gravel beaches due to its robust design. The instrument design is shown in Figure 4.1.

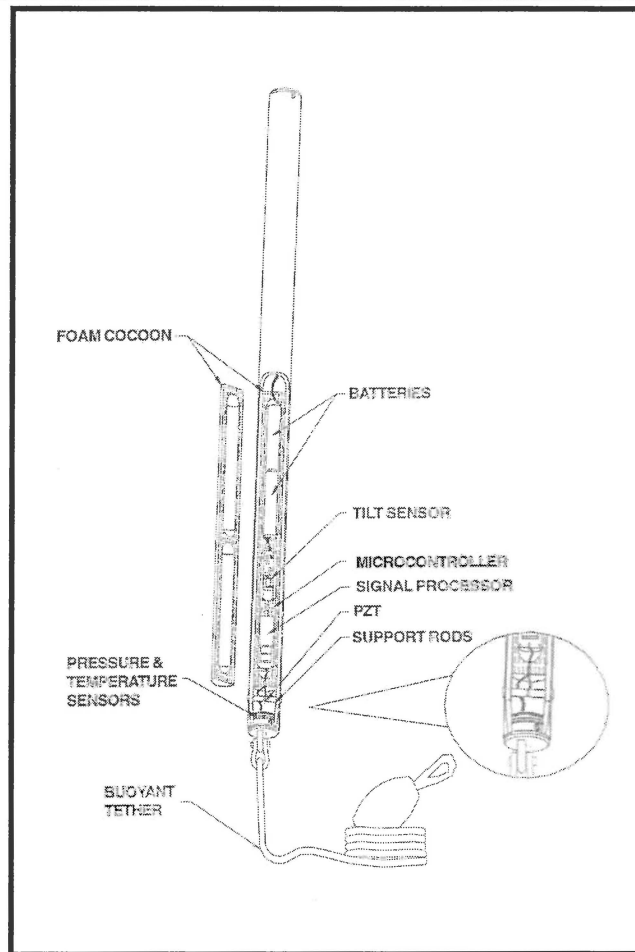


Figure 4.1 — The GTS design schematic, showing internal arrangement of vibration detector, microcontroller, auxiliary sensors, and batteries.

Source: *GTS Instruction Manual – Ver. 1.4, D&A Instrument Company (1999)*

The instrument contains an acoustic detector housed inside a 75 mm stainless steel pipe to make up one structural element. A piezo-electric vibration sensor is clamped between two support rods welded in the pipe wall and auxiliary temperature, pressure, and tilt sensors are sealed in the pipe in a shock-absorbing cocoon. The unit is 123 cm long and weighs 16-kg.

The prototype of this instrument was used in studies by Downing (1981) measuring bed-load transport in both natural and laboratory studies. To the authors knowledge, no studies using this instrument have yet been made in the swash zone of gravel beaches.

### **4.3 Calibration**

The first hurdle in applying the GTS was to calibrate it, or more specifically, determine the relationship between the number of impacts recorded and the corresponding volume of material being transported. This is a site specific and temporally varying relationship, which requires a rapid the calibration procedure to leave a suitable length of time for data capture.

In an attempt to obtain calibration data, it was decided that a sediment trapping experiment would be undertaken concurrently with the GTS deployment. It was planned to deploy the trap in the same approximate location as the GTS and the time of deployment recorded (See Figure 4.2). This would enable a comparison to be made between the mass of sediment transported and the number of impacts recorded by the GTS. Repeated sampling under a range of swash conditions should enable determination of the relationship, which could then be used for further measurement of volumes of gravel transport.



Figure 4.2 — First style of streamer trap in use.

Several assumptions are made using this method. The first is the sediment distribution is considered to remain consistent throughout the measurement period. If the distribution changes the proportion of the distribution measured will change, thus the volume of material moved could remain constant while the

instrument will record a lesser number of impacts. This error will be minimised with repeated sampling provided that distribution does not vary too greatly.

The second assumption is that the proportion of gravel significantly outweighs any fine fraction as the GTS will only record the coarse gravel fraction. The less of the particle distribution that is measured, the less representative the 'ping count' of material transported will be.

The third assumption is that velocity of the gravel moving in separate wave events is uniform. If the same volume of material is moved with a greater velocity a larger proportion will be recorded as impacts by the GTS, thus the trapped volume will remain similar while measured counts will differ.

### **4.3.1 GTS**

Of several problems identified in early trials, the major difficulty was the deployment of the GTS in the surf zone. The instruction manual suggests burial to a depth of around 40 cm. On the gravel beaches studied in this project there is, to a certain extent, armoring by larger stones. This factor caused problems when trying to provide a secure position when the GTS was deployed, as it was not possible to install it as the manual suggested. Due to this problem it was suggested that a frame be built that would provide stability for the instrument without requiring deep burial. The design parameters were:

- it should be easy to transport from site to site,
- deployment and recovery should be relatively easy,
- it should provide maximum stability while minimising disturbance to the flow,
- it is required to be exceptionally robust for high energy steep gravel beach face surf zones, and
- cost would be minimised.

The solution was a simple tripod frame made up of a stainless steel collar that could be detached from the instrument and legs that were also detachable from the collar (See Figure 4.3)



Figure 4.3 — GTS with frame attachment.

### **4.3.2 Streamer Trap**

The sediment trap designed for this project resembles a combination of the streamer trap described by Kraus (1987) and Wang, Kraus and Davis (1998), and the pressure-difference bed-load sampler described by Helley and Smith (1971). Results from Wang, Kraus and Davis (1998) have found a good agreement between measurements made by tracer studies and streamer traps, however it must be noted that this experiment took place on the sand beaches (average grain size = 0.013–2.25 mm) of the Gulf Coast of Florida.

The first trial using the trap was unsuccessful because the trap used was not suitable for the use required (See Figure 4.4). Upon returning from the field the trap was redesigned incorporating the following additional features:

- drag must be minimised,
- nets must be interchangeable,
- transport of the trap should be easy,

- the trap must be able to be emplaced and removed very easily,
- the trap must avoid ‘scooping up’ material that makes up the bed, and
- the trap should capture the gravel moved in an area the same size as the GTS,

The design eventually adopted consisted of a stainless steel frame with a large rectangular aperture of 72 mm by 650 mm (See Figure 4.5). The bottom of the frame was a large rectangular base plate of 300 mm by 200 mm, designed to prevent the accidental ‘scooping’ of the bed material when the trap was emplaced and removed. The handle on top was to aid in the recovery and *in situ* stability of the trap. The net had a mesh size of approximately 1.25 mm by 0.25 mm. This will trap material of a surface area greater than  $0.3125 \text{ mm}^2$  and corresponds to a circular grain size of diameter 0.63 mm or a phi size of  $\sim 1$ , a coarse sand. The net is reversed and fed through the frame then bolted on to the frame using the eyelets. This method was found to be the easiest for recovery of the sediment and the sediment escaping the trap was also minimised.

Limitations to the use of traps are described in Kraus (1987), of which the most notable errors that can occur are: (i) Bed disturbance around the structure of the trap causing unusually high or low values of transport due to scour, and (ii) hydraulic disturbance due to acceleration or deceleration of the flow creating pressure difference which may give higher or lower values of sediment transport. There is also a limitation imposed due to the requirement of an operator to be present when measurements are taken. This limits the use of the trap to breaking wave heights that do not exceed about 2 m (Kraus, 1987).

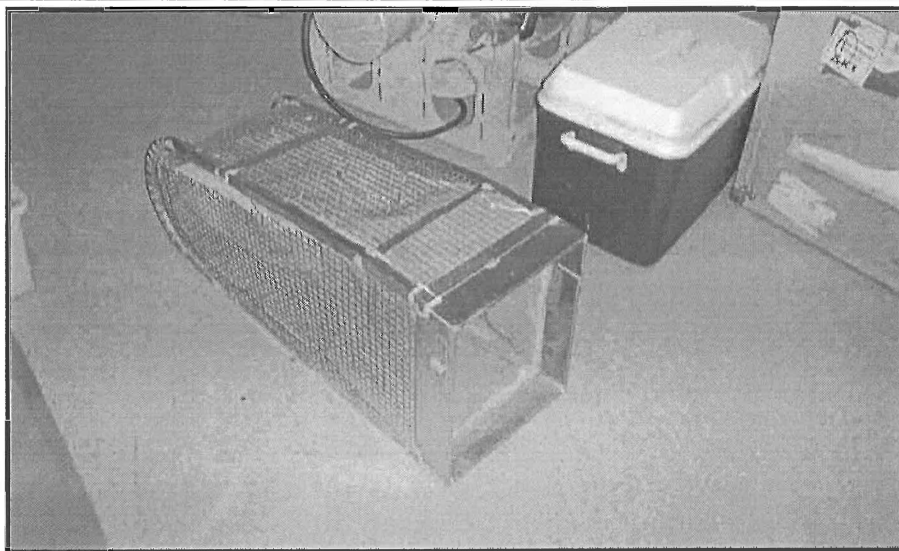


Figure 4.4 — The first streamer trap used. Examination of the flaws enabled an improved instrument to be designed.

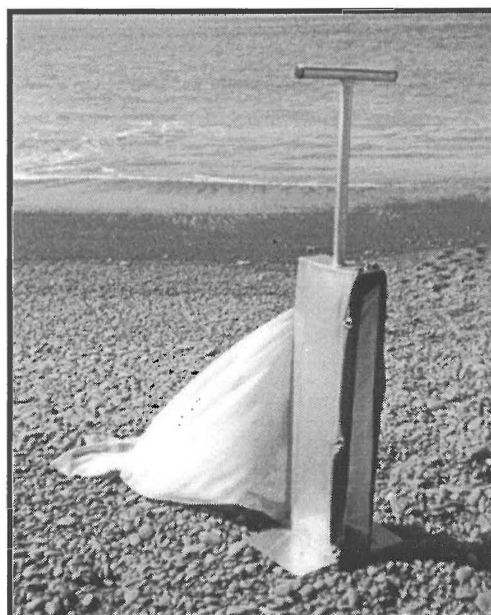


Figure 4.5 — The second type of streamer trap developed.

### **4.3.3 Trial One**

Several field trials were undertaken to adapt the GTS for use in longshore sediment transport studies. The trials were undertaken on a Napier beach in Hawkes Bay due to proximity to Hamilton, and their similarity to the Canterbury

Bight beaches. The Marine Parade beach at Napier exhibited similar behavioral and morphological features as the beach at the Ashburton River mouth.

#### **4.3.3.1 Fieldwork**

##### **Westshore, Napier – 12 March 1999.**

The first trial was made at Westshore due to the storm conditions at the time preventing safe deployment on the more appropriate Marine Parade. The Westshore sediment is made up of mainly sand (See Figure 4.6), but during the fieldwork there was a greater volume of gravel in the surf zone, making it an acceptable site for deployment. The GTS was deployed for approximately 2.5 hours (11:30–14:00) at two sites; 15 m (11:30) and 10 m (12:30) seaward of the flotsam line.

The trial was not successful due mainly to problems with the streamer trap used. The trap used was neither designed for, nor suitable for surf zone use. The problems included an inability to withstand the force of the waves, the size was not small enough for use with only one person and the drag created was too great so that no accurate measurements were made.

Encouraging results were obtained with the instrument however. The data was recorded and downloaded successfully and the frame that supported the GTS appeared to withstand the forces inflicted upon it by the waves. It was noted, however, that the frame should be situated such that one of the legs points away from the direction of wave approach to achieve maximum stability (See Figure 4.7).



Figure 4.6 — Westshore beach as taken on 15/04/99. Note the sediment on the beach has dramatically changed from that experienced during the fieldwork where gravel was much more abundant in the nearshore zone.



Figure 4.7 — GTS installed at Westshore on 12 March 1999. Note the direction of the rear leg of the frame facing away from the direction of wave approach.

To overcome concerns that pebble impacts on the frame could contaminate results by transmitting ‘pings’ through to the instrument (Downing, 1999, *pers. comm.*) a simple rubber collar was inserted between the collar and the instrument.

### 4.3.3.2 Results and Discussion

Data collected by the GTS during this deployment seemed reasonable and represented the first data ever collected with the instrument. However there appears to be little correlation between the GTS measurements and the volume of material trapped by the net. Even after some alteration of the timings recorded for sediment samples the correlation improved only slightly (See Figure 4.8).

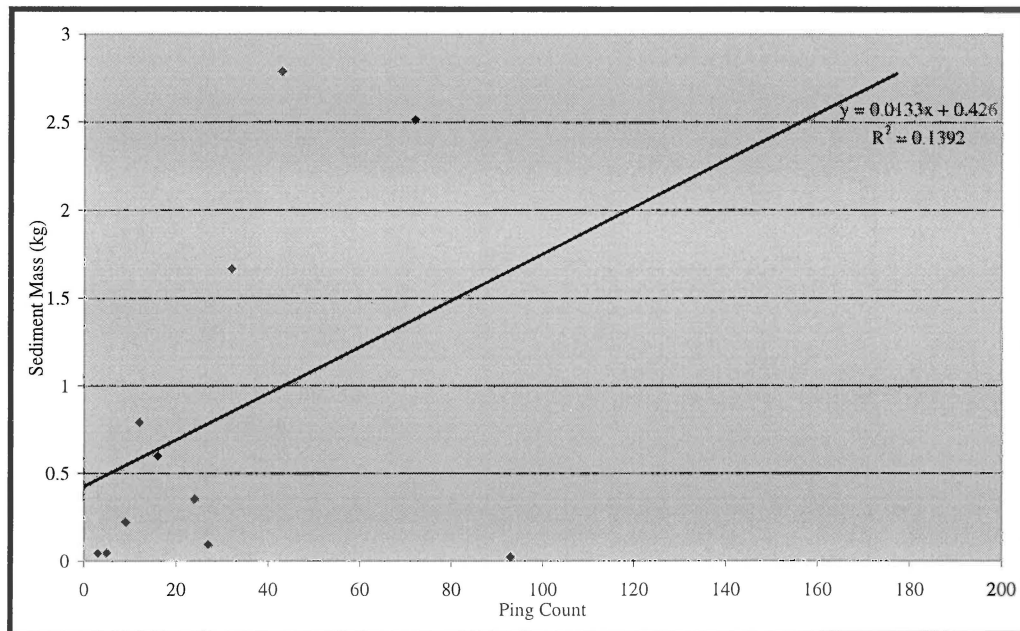


Figure 4.8 — Relationship between trapped sediment and the number of impacts at Westshore on 12 March 1999.

It was identified that a problem existed with the timing of the recording of samples because of the sampling regime used. Upon correspondence with the manufacturers it was found that it was possible to change the timing scheme to one which recorded impacts at 1 Hz. Previously data was only recorded every 5 seconds which was too coarse to accurately identify individual waves. The dataset was manually altered so that the samples corresponded to what was identified as wave events. The correlation was improved from an  $R^2$  value of 0.0552 to 0.1392 but little can be taken from this due to the inaccuracies in the data collection.

## **4.3.4 Trial Two**

### **4.3.4.1 Fieldwork**

#### **Marine Parade, Napier – 3 April 1999.**

The second trial was attempted in low wave conditions (approximately 1 m swell) on Marine Parade in Napier. This beach was very similar in morphology and breaking wave conditions to those encountered at Ashburton, more so than at Westshore (See Figure 4.9).

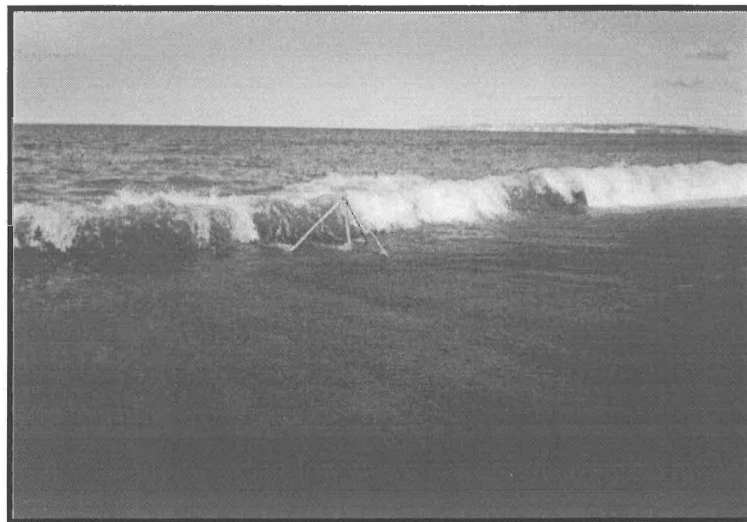


Figure 4.9 — GTS deployed on Marine Parade on 3/04/99

The frame was again successfully deployed. The sampling scheme used was superior to the previous trial due to a more frequent recording interval. This enabled distinction of individual wave events. Data were recorded and downloaded successfully. Questions still remained about the ability of the rubber collar to absorb the impacts transmitted from the frame.

The streamer trap performed better than the previous model, being easier to operate and samples taken were more representative of actual sediment transport events. This observation is based on the ability of the user to maintain a stable trap in the uprush, which will provide a more accurate sample. The trap was more stable in the uprush events thereby trapping a greater proportion of sediment being

transported. The trap was also more robust and there were no concerns about structural failure of the trap.

A total of 40 samples were taken during two deployments over a data collection period of approximately 2.5 hours (10:30–12:00/13:00–14:00).

#### **4.3.4.2 Results and Discussion**

Upon examination of the times series of impacts it was found that the timing of the instrument and sediment samples was not in agreement. This could have been the result of:

- inaccuracies due to the time being taken when the net was set instead of when the wave hit the net,
- the GTS clock unable to keep accurate time, or
- inability to record the length of streamer trap deployment.

Timing is important because it is required to distinguish the uprush and backwash events from the time series. Without the ability to accurately determine which mechanism is in action it is not possible to calibrate the instrument. The sediment trapping scheme only samples uprush events, so a calibration procedure requires only uprush events recorded by the GTS to be examined. Without accurate timing the uprush events could not be distinguished from the backwash with any reliability, which would have impacted heavily on the results.

The timing of sampling was manually altered such that the samples corresponded to wave events, which were easily identifiable from the time series (See Figure 4.10). The failure to record the length of streamer trap deployment was due to the inability of a field assistant to record the time of the deployment and then observe the removal of the trap (of order 2–3 seconds). It was therefore assumed that each deployment was 3 seconds in length.

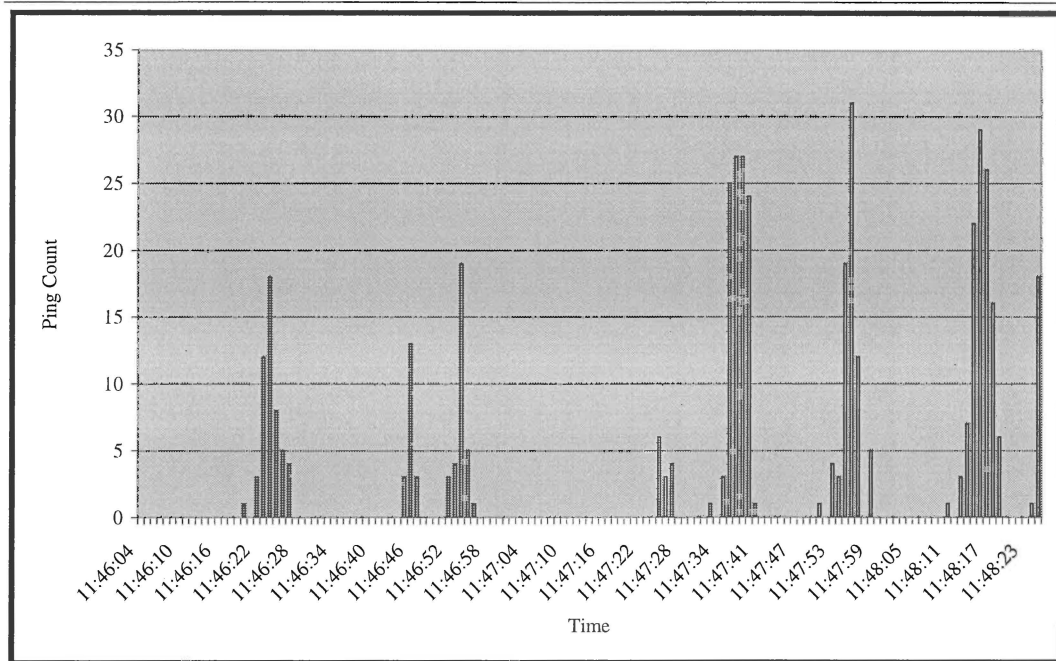


Figure 4.10 — Time series sample from GTS on 3/04/99.

Wave events are clearly distinguishable by the periodic nature of the data record.

Analysis of 10 randomly chosen samples of the 40 collected was undertaken. The samples were dried and sieved at 0.25 phi intervals between  $-3.25$  phi and  $-0.75$  phi. The analysis revealed a consistent distribution of size (See Figure 4.11). This factor is important due to the assumption inherent in this experiment regarding a consistent grain size distribution over the data collection period.

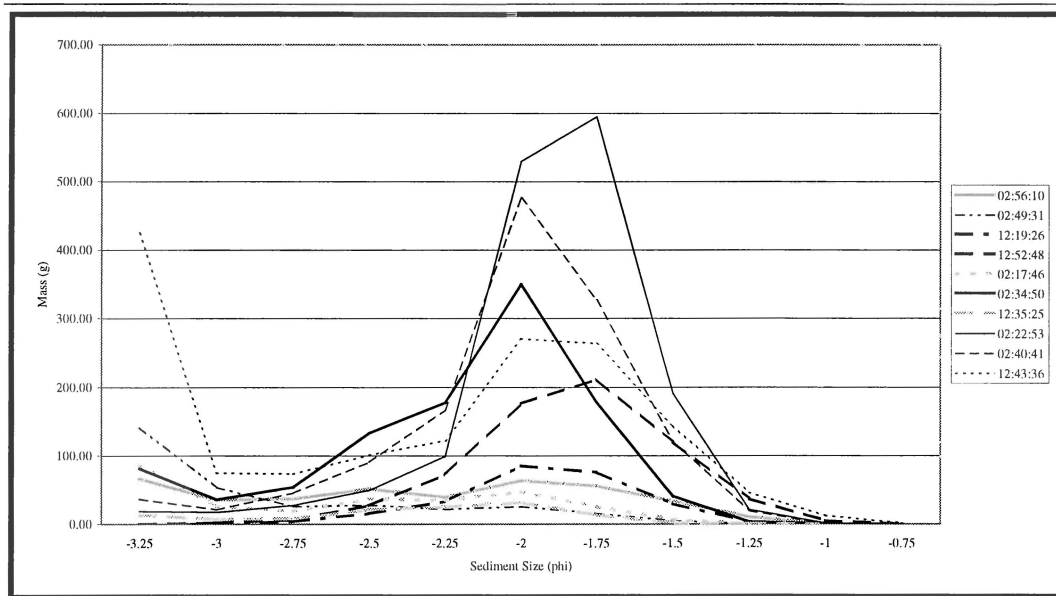


Figure 4.11 — Sediment size distribution of samples taken during trial two on Marine Parade.

The relationship between the trapped sediment and the impact count reflects the cumulation of errors with the  $R^2$  value being only 0.20 (Figure 4.12). The results however show a positive trend and give some idea of the volume of sediment that can be transported in even low wave conditions.

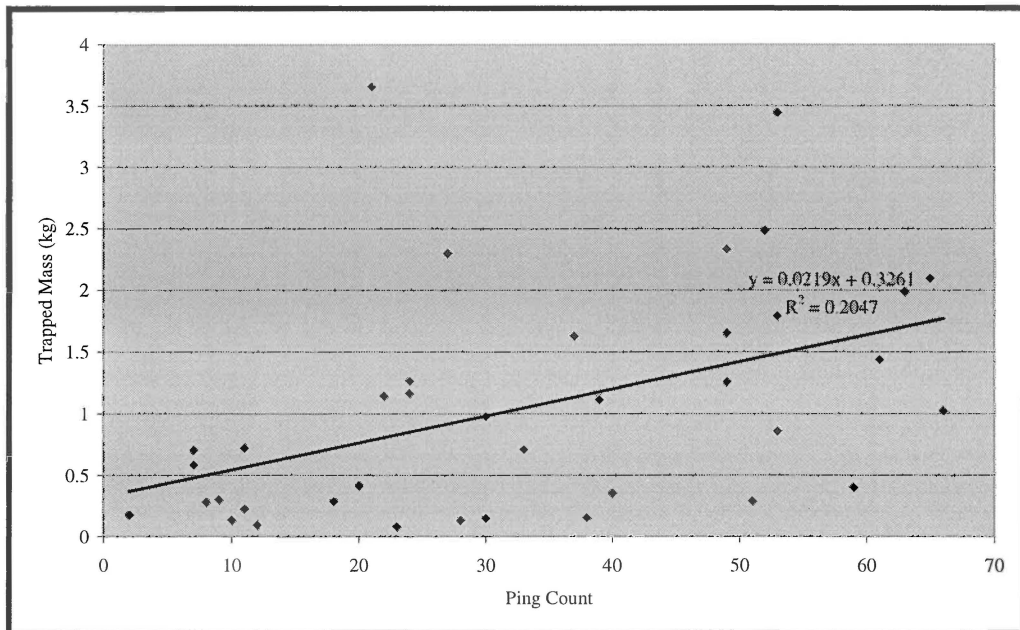


Figure 4.12 — Altered results of trial two showing correlation between trapped sediment mass and GTS measurements

### **4.3.5 Trial Three**

#### **4.3.5.1 Fieldwork**

##### **Marine Parade, Napier – 15 April 1999.**

Again Marine Parade was determined as the ideal site for deployment due to small wave conditions and the similarity exhibited between it and beaches adjacent to the Ashburton River mouth. The wave conditions were locally generated sea waves of about 7 second period from the east and a swell height of approximately 1 m (See Figure 4.13).

The major difference between this trial and the preceding one was the attempt to modify the GTS to give directional results. The idea was to pad the back of the GTS body with foam so that no impacts would be recorded on the backwash. This would negate the requirement for accurate timing by giving an opportunity to collect data only from the uprush events. This was first tested using a 10 cm thick foam cushion to absorb the impacts. It was also protected by a half section of PVC pipe that fitted around the outside of the foam. The entire cushioning unit was attached to the GTS using duct tape.

To test the effectiveness of the cushion, another cushion of the same construction was attached to the front encapsulating the entire instrument (See Figure 4.14). This provided an opportunity to determine whether the instrument was being provided ample cushioning. Under lab conditions it was found that the rubber collar alone did not provide enough of a buffer for frame vibrations. This test would also ascertain the effectiveness of a 10 cm thick foam collar that was added to the rubber collar to prevent frame contamination of the data. The timing of sampling was also improved by recording the wave impact on the instrument as opposed to the impact on the streamer trap.



Figure 4.13 — GTS deployed on Marine Parade with shield affixed on 15/04/99

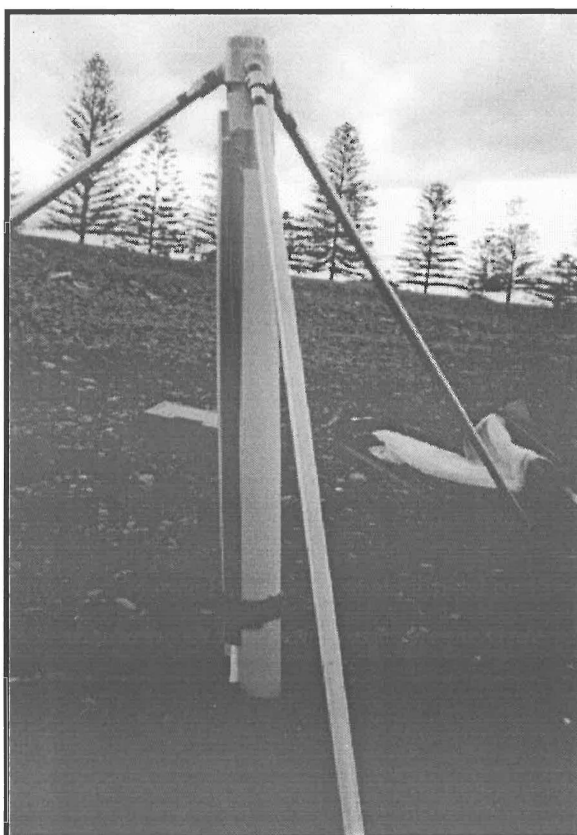


Figure 4.14 — GTS fully encapsulated with foam.

The GTS was deployed for approximately 10 minutes (12:44–12:53) at 39 m seaward of the flotsam line. The instrument appeared to move under large wave

impacts, presumably due to the increased size increasing drag of the instrument during the impacts. Upon recovery of the instrument it was found that the collar was not tightened adequately. This may have allowed movement of the instrument and certainly was the cause of the instrument falling out of the frame as it was transported out of the surf zone. The tightening of the collar is a problematic issue. If over-tightened the transmission of impacts into the GTS is increased, if under-tightened the stability and transportation of the instrument suffers.

Once removed from the surf zone the cushioning was removed from half of the instrument and the GTS was then re-deployed. The GTS was deployed for approximately 20 minutes (13:18–13:40) again at 39 m. The sediment sampling program was then commenced. A problem identified during this deployment was accelerated scour around the GTS presumed to be due to the PVC pipe redirecting flow into the bed. The flow of water past the instrument would be forced upward or downward causing liquefaction of the bed. This caused movement of the GTS upon high wave energy impacts and inaccurate impact counts. For this reason this method of GTS deployment was not continued.

It was then decided to again attempt to investigate the correlation between impacts and trapping using the method from trial two but with more attention paid to timing. The instrument was deployed for 44 minutes (13:58–14:42) at 38.7 m from the flotsam line. The instrument stability was improved and movement of the instrument was not observed. Only six samples were taken because it was a repetition of the previous technique and good quality results were not anticipated.

#### **4.3.5.2 Results and Discussion**

The experiments with padding of the GTS were overall successful. Results showed few impacts were recorded over the deployment period when the instrument was fully cushioned. The few cushioned impacts counted may be attributed to either frame impacts being transmitted through the collar or impacts on either the exposed ends of the instrument. It is highly unlikely that the recordings were due to sediment impacts directly on the GTS.

Sediment size distribution again remained consistent throughout the instrument deployment (See Figure 4.15).

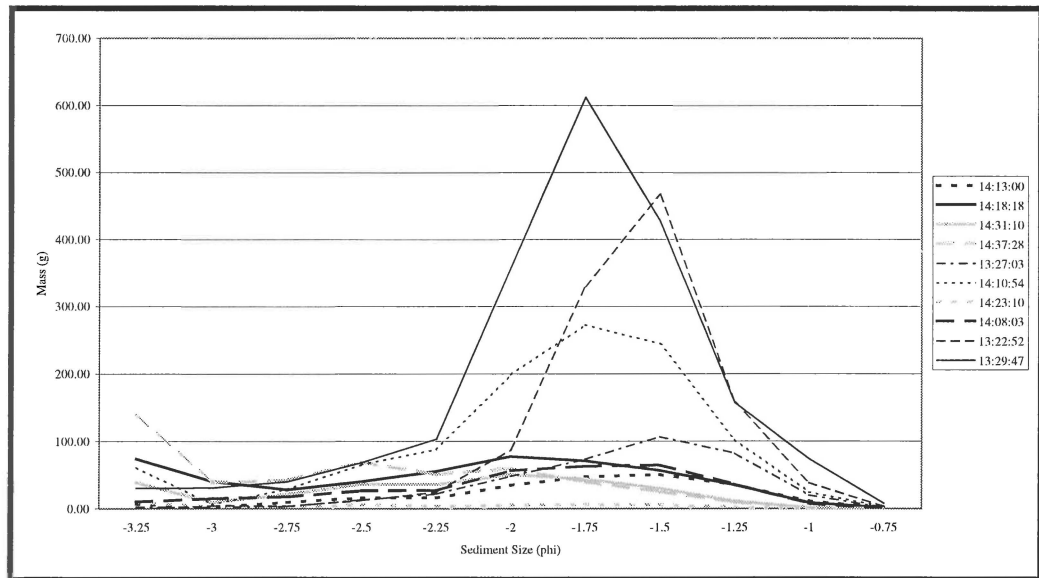


Figure 4.15 — Sediment size distribution of samples from the surf zone - 15/4/99. Samples were gathered from the sediment trap used for GTS calibration.

When the instrument was only half enclosed with foam padding the results were more promising than expected. The correlation was very good even though the number of samples taken was small (See Figure 4.16). This technique shows promise as indicated by the results even though the measurements are influenced by some instrument movement.

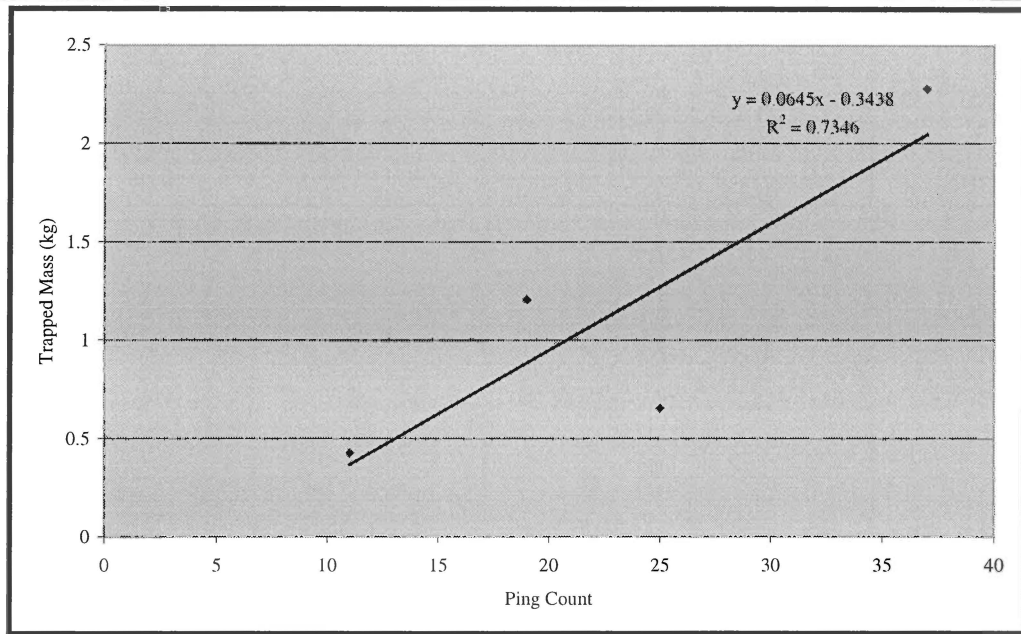


Figure 4.16 — Calibration curve for GTS with instrument partially shielded.

As expected, results from the second part of the study where the earlier method of calibration was used were not improved. The correlation was poor with a large amount of scatter (See Figure 4.17). This reinforces the suggestion that the revised technique is superior to the earlier trial.

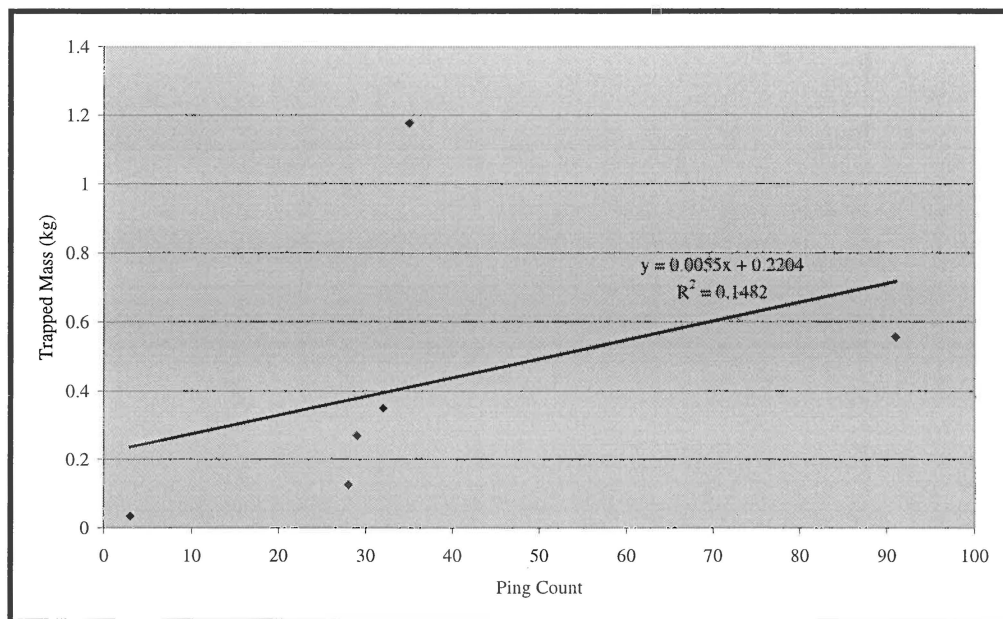


Figure 4.17 — Calibration curve for GTS when instrument is unshielded.

### **4.3.6 Trial Four**

#### **4.3.6.1 Fieldwork**

##### **Marine Parade, Napier – 22 April 1999.**

The location chosen was again on Marine Parade north of the site used in the two previous trials (See Figure 4.18). Wave conditions were swell waves less than 1 m with periods of around 12 seconds.

There was a clear surf beat present recognised by the regular substantial increase in wave height interspersed with more common smaller wave heights. This presented problems for the deployment of the GTS. If the instrument was deployed too far offshore it was threatened by the larger waves tipping or moving it, not to mention the difficulties for the trap operator (See Figure 4.19). If it was deployed too far inshore there was little sediment transport.

The GTS cushioning was altered to provide more accurate readings. The PVC pipe was removed and the foam cushion was instead wrapped in duct tape and attached to the GTS. This would enable a degree of flex of the cushioning, resulting in less disruption to the flow. To confirm that the cushioning would still provide adequate absorption of the pebble impacts the entire instrument was again enclosed in the foam (See Figure 4.20). The collar cushioning was also altered to minimise frame interference to the instrument. The 10 cm foam cushion was replaced with 6 mm high density, closed cell foam rubber. It was hoped that the collar would now be more secure than the previous method proved to be.



Figure 4.18 — GTS deployed on marine Parade 22/4/99.

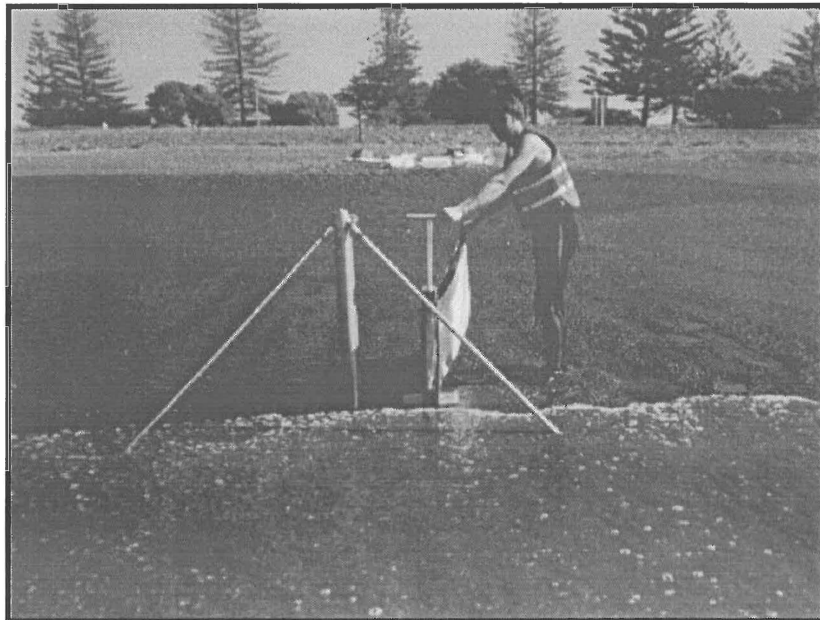


Figure 4.19 — Method of calibration used during fourth trial.



Figure 4.20 — GTS totally shielded on 22/4/99

The instrument was deployed for approximately 3 hours (10:42–12:19/12:28–13:52). During the first deployment the instrument was emplaced 22.5 m from the flotsam line. During this time the first test to determine the effectiveness of the cushioning was completed (10:53–11:18) and then the second phase of the experiment, the calibration procedure, was initiated (11:31–12:19). The instrument was then removed and the data downloaded. The calibration procedure was then continued on the second deployment. It was deployed a further 2.5 m seaward of the site of the first deployment due to the receding tide. At 13:23 the GTS was moved another 2.5 m seaward and again at 13:36. This was due to either a calming of the sea-state or the receding tide reducing the number and intensity of wave events to be measured. Over the period of measurement 30 sediment samples were taken.

#### 4.3.6.2 Results and Discussion

The data obtained were the most convincing data provided to date (See Figure 4.21).

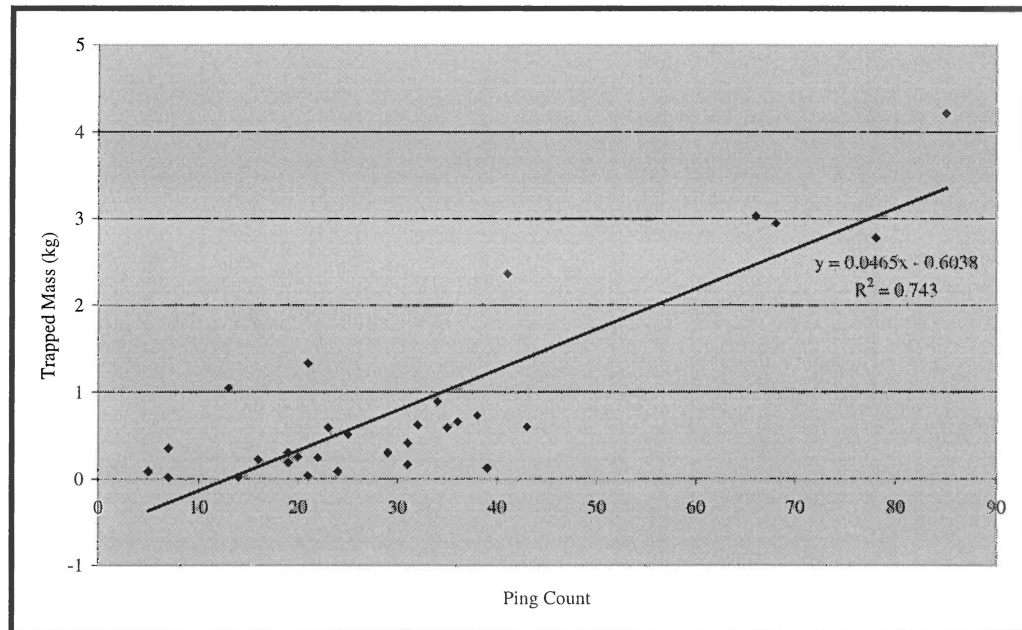


Figure 4.21 — The calibration relationship as defined on 22/4/99

The data has a very high  $R^2$  value showing a good correlation between the number of impacts and the weight of trapped sediment.

There is a large amount of scatter at the low trapped weight end of the scale that may be attributed to an inaccuracy in the use of the streamer trap. It is suspected that the GTS has a much more sensitive response to sediment transport at low wave uprush velocities than the trap. Sediment that is moving within the bed may not have the required energy to move out of the bed and into the trap but the movement of the particles may be recorded as they impact on the GTS.

Sediment size distribution was again uniform for the samples analysed with means of approximately  $-2$  phi (See Figure 4.22).

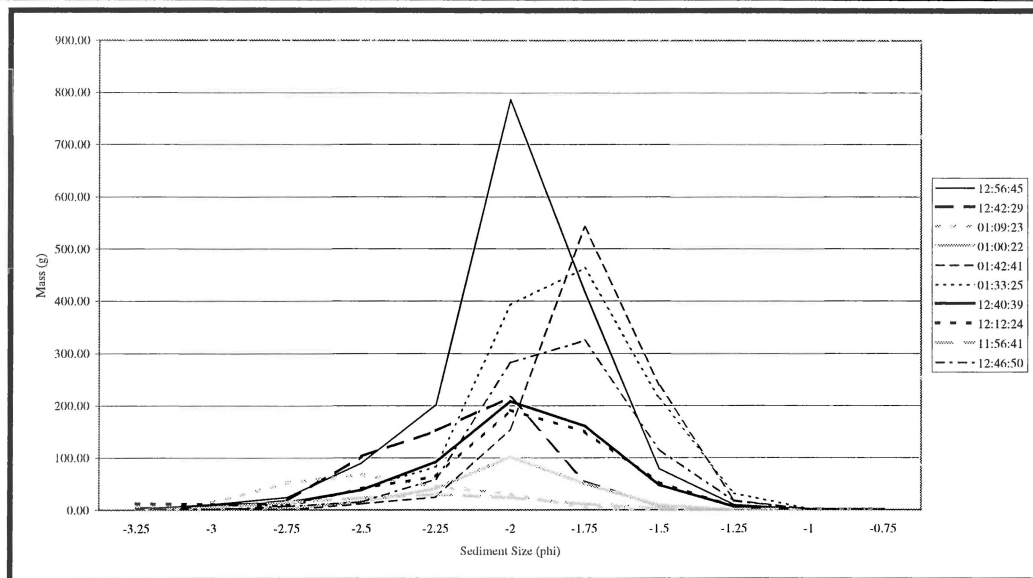


Figure 4.22 — Sediment size distribution of samples from the surf zone – 22/4/99. Samples were gathered from the sediment trap used for GTS calibration

#### **4.4 Application to Mixed Sand–Gravel Beaches**

Using the methods pioneered in Hawkes Bay the GTS was transported to Ashburton with the goal being to make the first field measurements of gravel transport along this stretch of coast. Both locations have been referred to as mixed sand-gravel coastlines so the assumption that the experiment could be replicated on the Canterbury Bight was valid (Kirk, 1980).

It was the intention to compare these measurements against earlier estimates detailed in Hicks (1998).

The fieldwork was carried out during the week 29 April – 6 June at the Ashburton River mouth. The objective was to measure volumes of longshore transport and, using profile change measurements of the inlet, investigate the relationship between volume transport and change.

##### **4.4.1 Methods**

A calibration equation was to be determined using the same method as undertaken in Napier. It would then be possible to examine the amount of sediment being

moved at a discrete location. Moving the GTS to several points along a transect running shore-normal would establish a cross-shore profile of relative sediment transport. The impact flux would be recorded for each point which would then provide data for estimation of total impacts along the transect. This measure of impacts per second per metre was then to be converted to a dry weight mass flux.

To calculate the rate of longshore transport a simple assumption is made. A vector describing the angle of wave approach would be determined using rectified video images from the site. The vector would enable estimation of the proportion of wave energy that will provide for longshore transport and that which would only move material in the cross-shore dimension. This proportion, it is assumed, approximates the proportion of the total volume of transport that is moved longshore.

Surveying of the spit at the Ashburton River mouth provided comparative data on volume change. The survey was undertaken as follows. The level was set up and a grid was initiated from a known location. The grid consisted of a series of points 5 metres apart in a 20 m x 70 m matrix. Heights were measured at each of the grid coordinates which enabled a surface plot of the spit and subsequent volume analysis using SURFER<sup>®</sup> software.

## **4.4.2 Results and Discussion**

### **4.4.2.1 Trial 1 - June 1**

The first trial took place under moderate to small wave conditions however southerly swells infrequently caused a large increase in wave height. The first objective was to deploy the instrument in a number of locations along a cross-shore transect. The GTS was deployed at 3 metre intervals from 21-39 m seaward of the top of the barrier. The instrument remained at each location for 10 minutes to incorporate all variations in wave energy up to a 10 minute period. The step was measured as 47 m seaward of the top of the barrier which defines the outer extreme of sediment transport. However it was not possible to deploy the GTS out to this distance due to the high energy of the plunging waves. The

measurements suggested a series of curves that would fit to the cross-shore profile of sediment transport, the best fit being a power curve (See Figure 4.23). The GTS was then deployed for calibration.

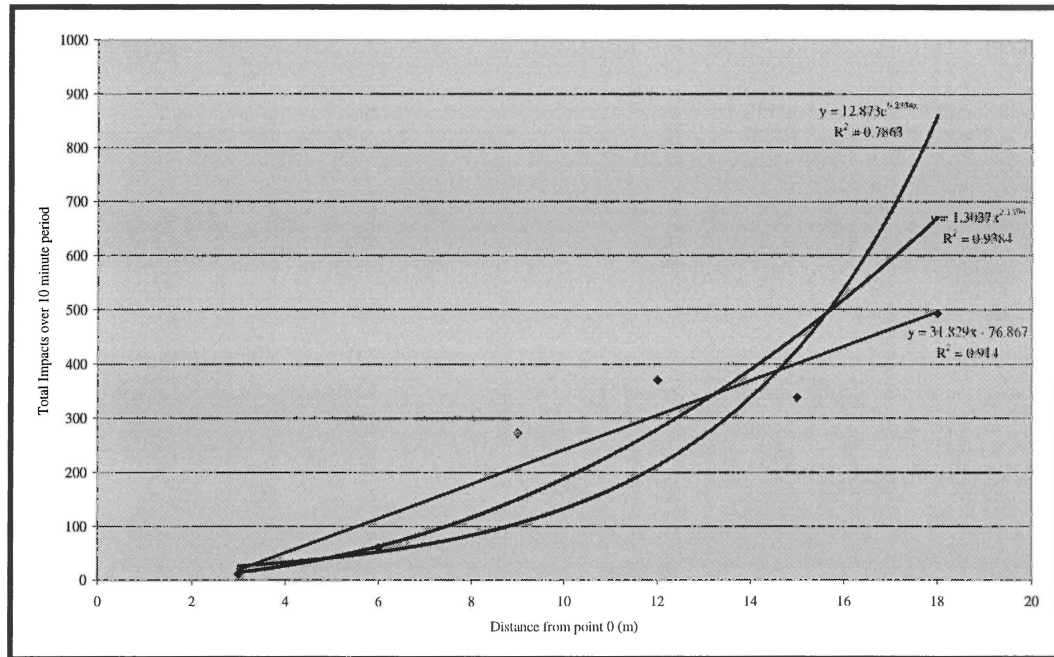


Figure 4.23 — Cross-shore profile of sediment transport as determined on June 1 at the Ashburton River mouth beach.

It was immediately noticeable that the sediment size distribution was remarkably different to that found in Napier. The sediment appeared finer with a far greater proportion of coarse sand than found on the Napier foreshore (See Figure 4.24). As the experiment continued the distribution of the sediment size underwent a large change such that when the experiment concluded approximately one hour later the distribution was reversed (See Figure 4.25).

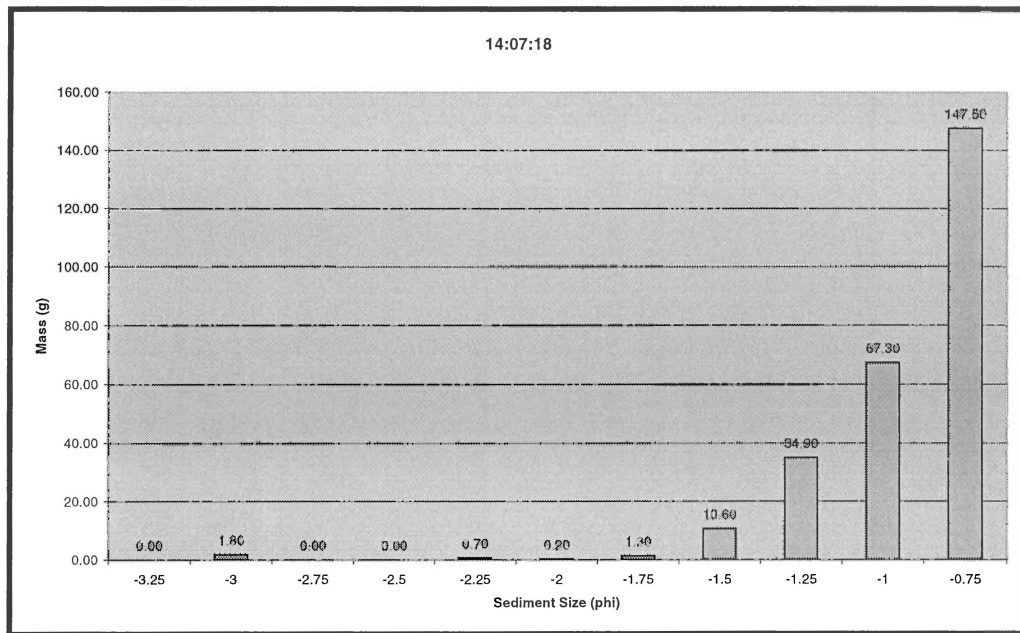


Figure 4.24 — Sediment distribution at 14:07, June 1, Ashburton River mouth beach.

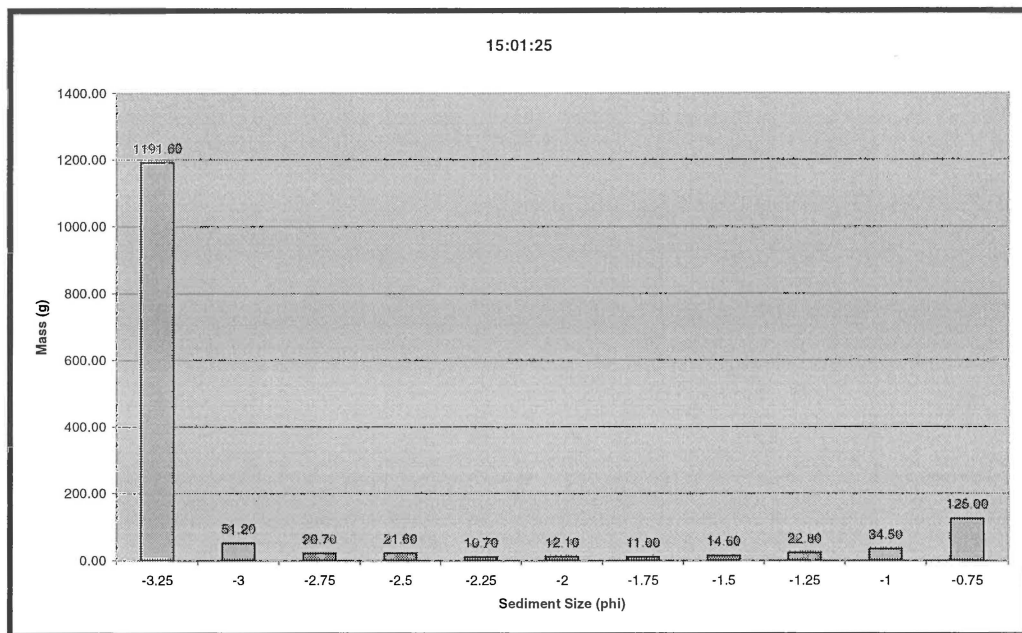


Figure 4.25 — Distribution of sediment size at 15:01, June 1, Ashburton River mouth beach.

The GTS was also buried during this deployment an extra 17 cm deep. This suggests that the larger grains were moved into this region perhaps overlaying the fine sediments that were observed earlier.

The poor relationship between impacts and trapped sediment is due to the error in the two assumptions regarding sediment distribution (See Figure 4.26). Sediment distribution during the experiment was inconsistent with that found in Napier and varied over the length of the experiment (See Figure 4.27). This invalidates two assumptions, that the sediment size distribution remains consistent and that gravel-sized sediment outweighs the finer proportions that are not counted by the GTS.

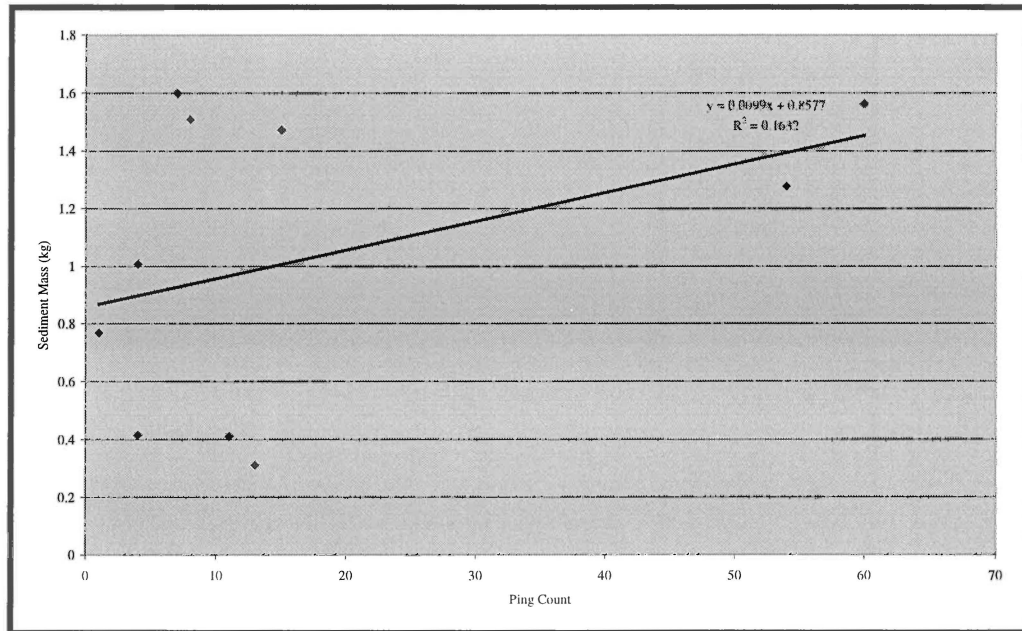


Figure 4.26 — Calibration between impact count and trapped weight as examined on June 1

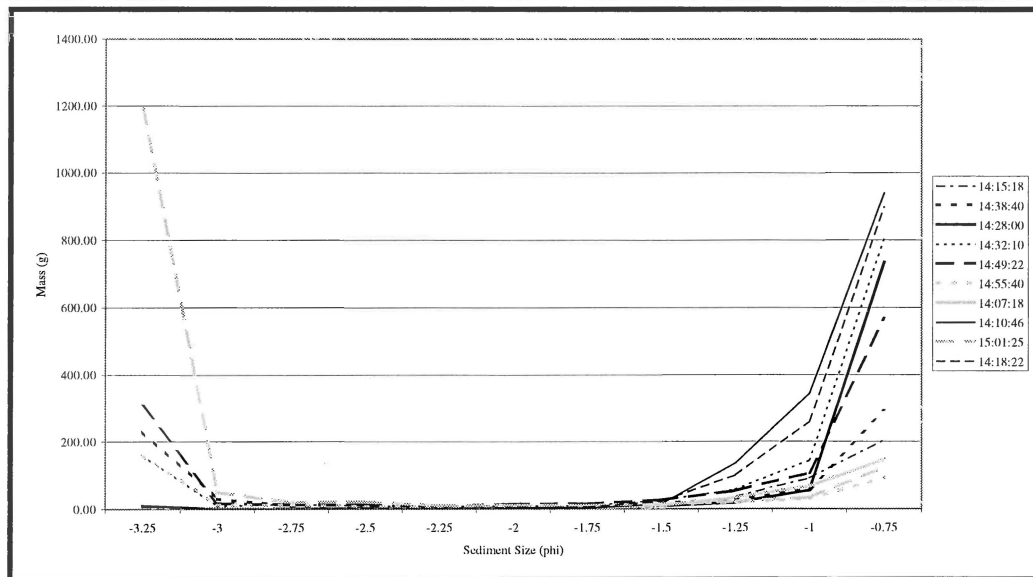


Figure 4.27 — Sediment size distribution of all samples taken on June 1 at the Ashburton River mouth

#### 4.4.2.2 Trial 2 - June 2

The swash zone was profiled at approximately midday followed by another attempt at calibration. The measured cross-shore profile of sediment transport did not agree with the previous results. The results, shown in Figure 4.28 show a profile best described by a linear trend. Again sediment sizes were smaller than those previously experienced at Napier (See Figure 4.29). The calibration equation again suffered as a result of the assumptions not holding true, giving very low  $R^2$  values (See Figure 4.30).

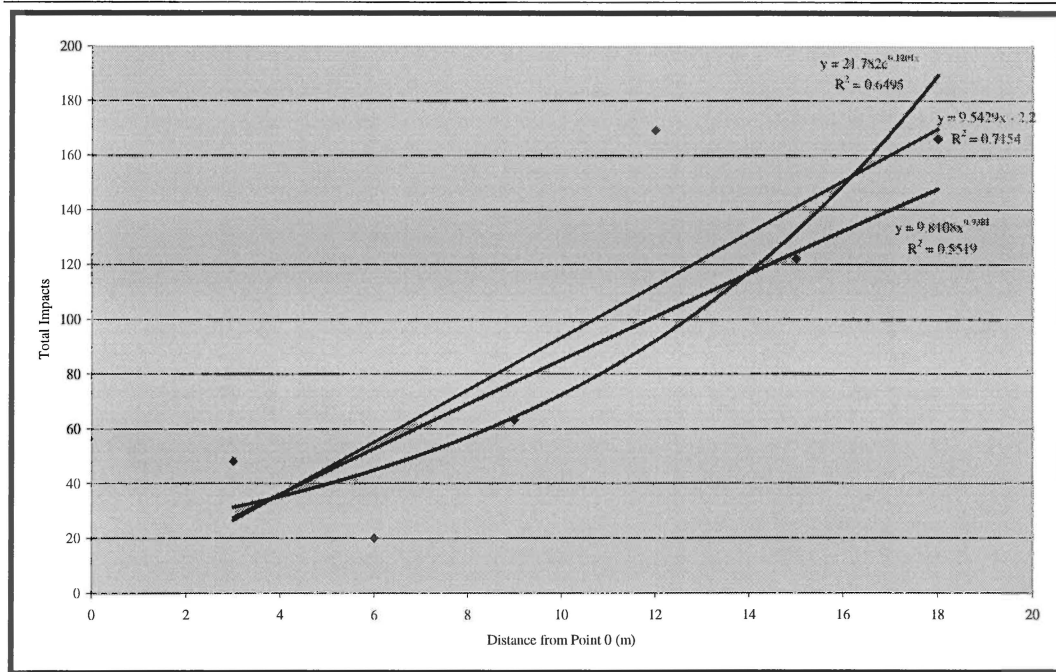


Figure 4.28 — Cross-shore profile as determined on June 2 at the Ashburton River mouth beach

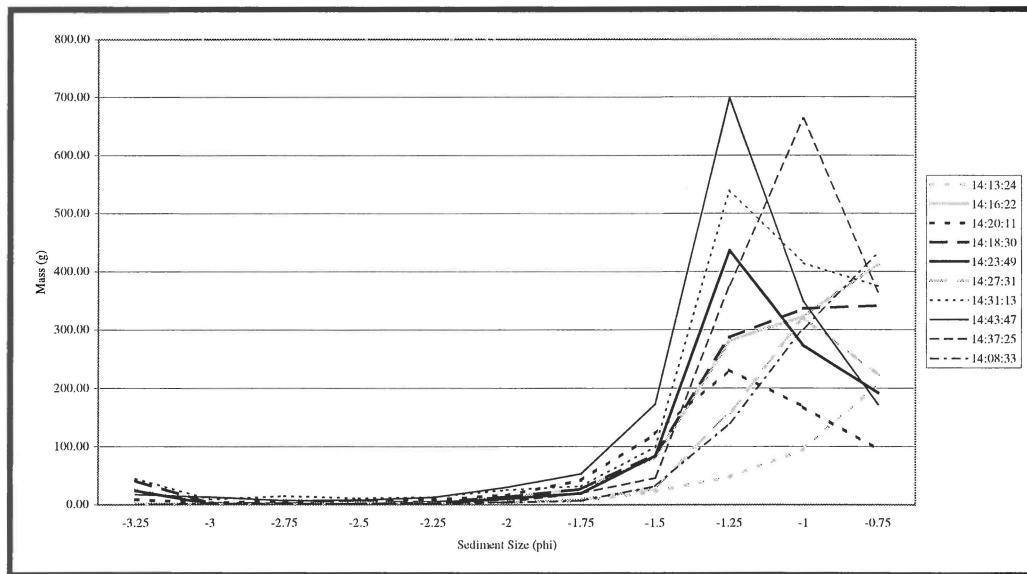


Figure 4.29 — Sediment distribution on June 2 taken from sediment trap samples in the swash zone on the Ashburton River mouth beach.

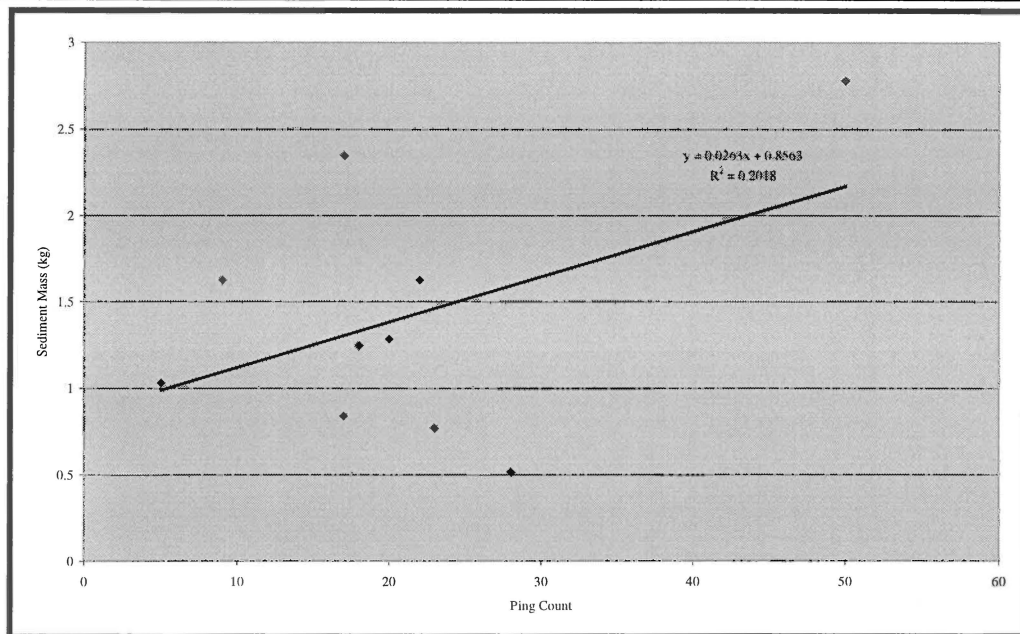


Figure 4.30 — Calibration relationship based on data from the June 2 experiment on the Ashburton River mouth beach.

#### 4.4.2.3 Trial 3 - June 3

Conditions on this trial worsened such that after a shortened period of deployment of the GTS to gather information on the cross-shore profile of sediment transport it was no longer safe to deploy the instrument. Results again suggested a linear trend would best describe the data collected (See Figure 4.31).

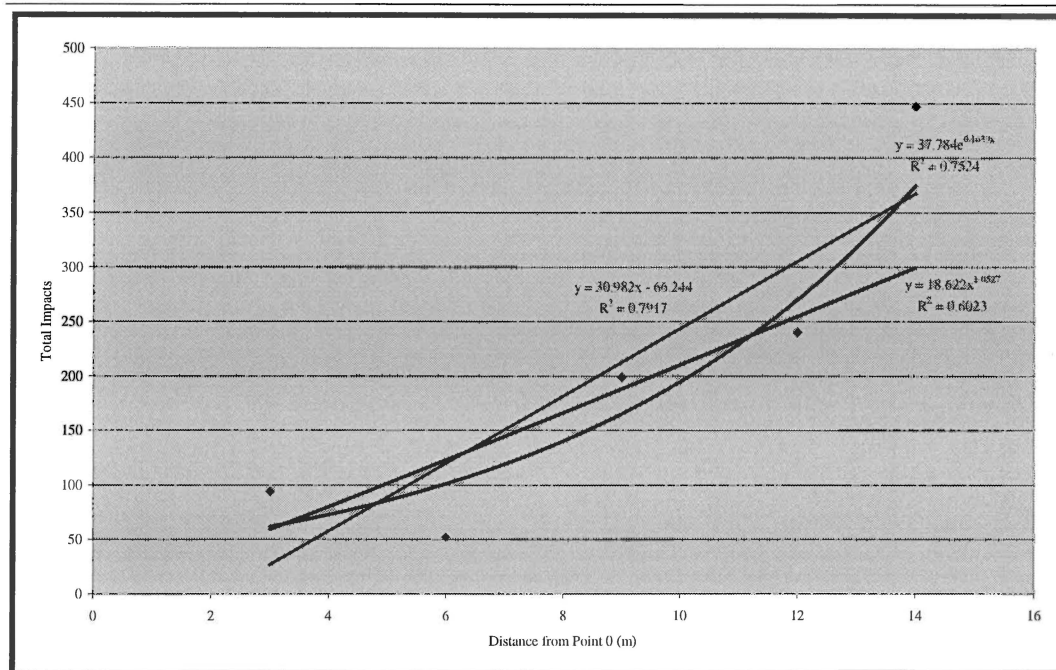


Figure 4.31 — Cross-shore profile as determined on June 3 at the Ashburton River mouth beach.

#### 4.4.2.4 Trial 4 - June 5

The profiling of the cross-shore sediment transport pattern was attempted first which returned results inconsistent with the two previous measurements showing a power trend to best fit the data (See Figure 4.32). Grain sizes appeared more consistent during this experiment but still exhibited a wide variation in distribution over the course of the experiment (See Figure 4.33). This again has caused poor relationships between impact counts and trapped weight of sediments (See Figure 4.34)

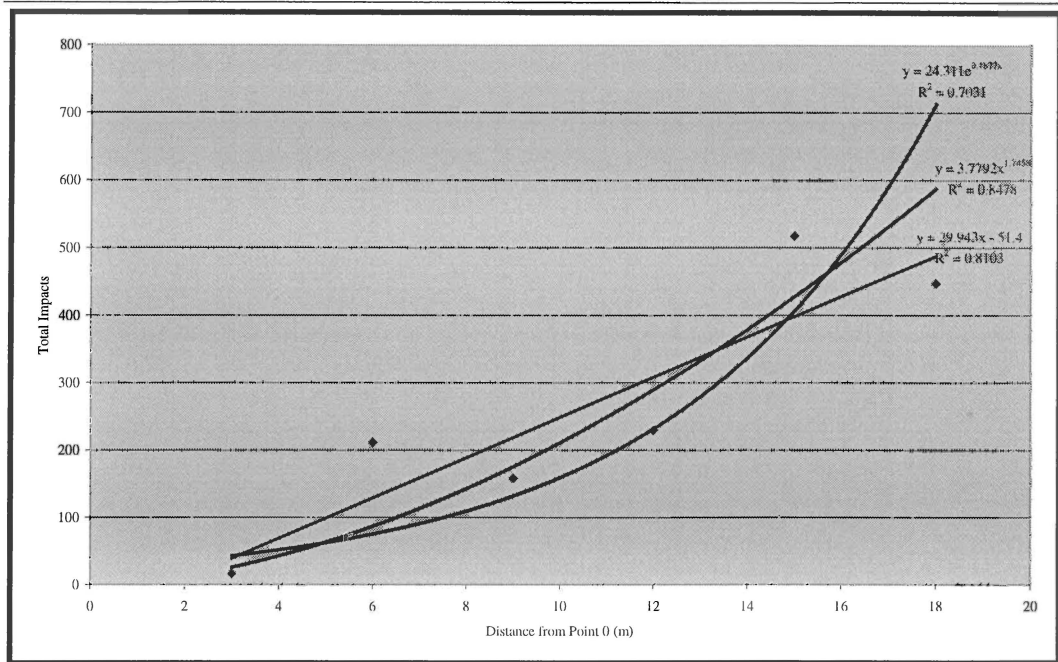


Figure 4.32 — Cross-shore profile as determined on June 5 at the Ashburton River mouth beach.

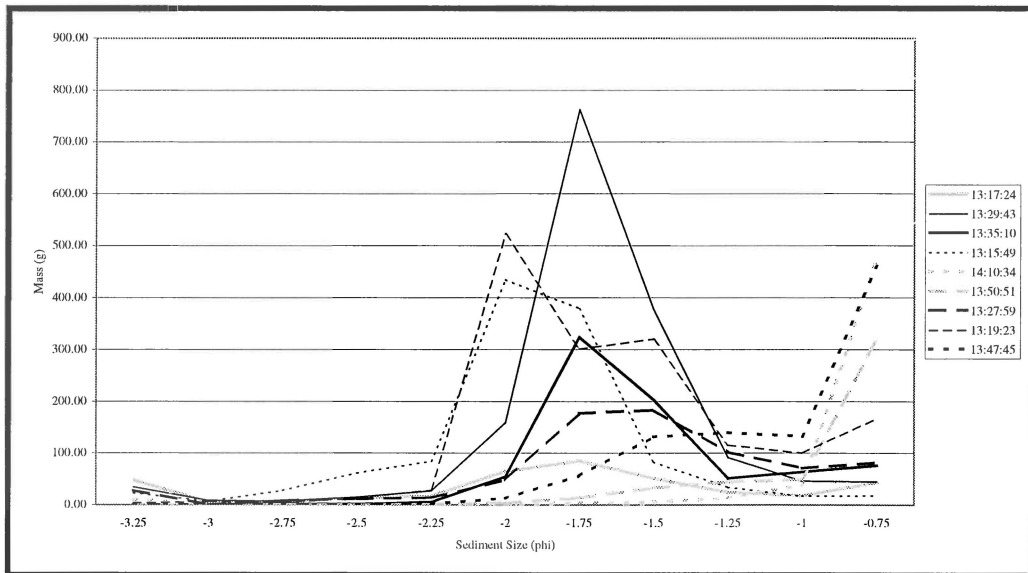


Figure 4.33 — Sediment size distribution on June 5 from samples taken using the sediment trap on the Ashburton River mouth beach.

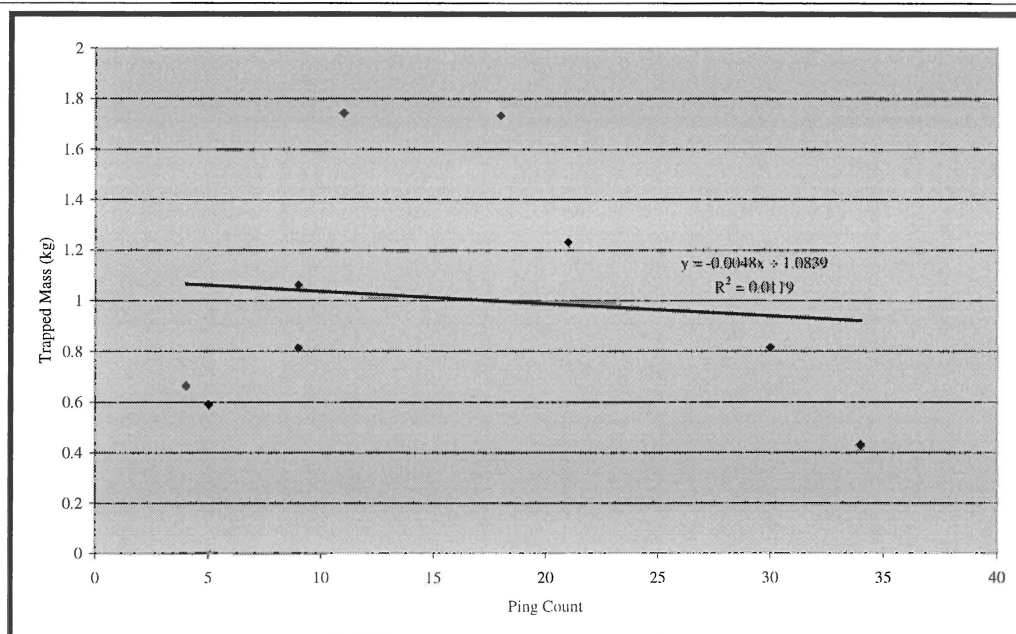


Figure 4.34 — Calibration relationship on trial 4 on the Ashburton River mouth beach

## **4.5 Conclusions**

The GTS was found to be useful in determining a mass of material being transported in the swash zone provided the sediment did not contain high concentrations of fine material. In Napier, where sediment was predominantly gravel, the measurements obtained showed good correlation with the mass of sediment trapped. At the Ashburton River mouth the sediment contained a much higher sand fraction and the results were less convincing.

The frame is not suitable for use at locations close to the break point because of the intense turbulence of this zone. Modifications to the stability of the platform could overcome this shortfall. It is suspected that during high-energy conditions, impacts are transmitted through to the GTS. The method to prevent this most probably lies with improved impact absorption materials that would not require that a trade-off exist between instrument sensitivity and instrument security.

Sediment size distribution is one of the main factors that can bring about error in the use of this instrument on gravel beaches. A major assumption is that the size distribution remains stable. In Napier this assumption tends to hold true, however

at the Ashburton River mouth beach a completely different situation was experienced. The grain size distribution was found to alternate between uni- and bi-modal and the mean grain size varied. The dynamic nature of these changes are poorly understood and this limits application of the GTS in the mixed sand-gravel swash zone. The effect of much higher sand concentrations in the sediment at the Ashburton River mouth is also assumed to cause error because the GTS only measures a proportion of the distribution of sediment sizes.

Laboratory tests on the instrument calibration would be useful to compare with field calibration to further examine suitability of the instrument for field studies.

Profiles of gravel transport across the shore are confused and it appears that a simple profile does not exist. It was decided not to proceed with further investigation into the profile shape because of the lack of success with measurement the volume of material being moved in a cross-shore transect. These results suggest a possible area for further research, the results of which will aid in understanding of the longshore transport patterns on these beaches.

# Chapter 5 - Channel Processes and Morphodynamics

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## **5.1 Introduction**

A better understanding of channel processes and river mouth morphodynamics at the Ashburton hapua is relevant to the maintenance regulation and management of catchment runoff and river flows. Simple theories have been presented to explain river mouth migration on the Canterbury coastline. These theories have been loosely based around tidal inlet stability and migration theories. To date there has been little data to verify these theories, and indeed check if tidal inlet theory is relevant to these situations. Kirk (1980) suggests that mixed sand-gravel beaches are “morphologically distinct from and more complex than either sand or shingle beaches”, thus care must be taken when assuming similar behaviour of features in the two different environments.

Video images from the Ashburton Cam-Era provide for the most comprehensive record of morphodynamic change of a hapua and river channel to date.

## **5.2 Methodology**

The following image analysis procedures were used to analyse morphodynamic changes. The oblique snapshots and averaged images were combined into 14 \*.avi files which provided a quick and dynamic method of observing the morphological changes over a long period of time. An advantage of using oblique images as opposed to rectified images for this purpose was that some features and the interaction of the geomorphology with wave and river processes was more clearly observable. Rectified images can at times obscure features and processes due to the nature of their creation. The alteration of the image decreases clarity of the picture making some objects less easy to observe and identify under poor light conditions.

The first step was to view the \*.avi files to discern any patterns in the migration of the channel. This was purely a qualitative analysis that was designed to clarify possible influential processes on the morphology.

Then, using data parameterised from the rectified images, the patterns of morphological response to various forcings were analysed. The analysis determined that the factors that best described the channel behaviour were:

- Location of the northern bank of the channel at the seaward end.
- Location of the southern bank of the channel at the seaward end.
- Location of the northern bank of the channel at the lagoon end.
- Location of the southern bank of the channel at the lagoon end.

From this data further parameters were quantified including:

- Channel orientation.
- Channel width.
- Barrier width.

Identifying the location of the channel was subjective, requiring manual digitising of the shoreline positions. This was difficult when:

- High wave conditions caused overtopping of the barrier which confused the accurate identification of the channel location. Overwash is also more likely around the channel as this area tends to have a lower elevation due to the recent evolution of that part of the barrier.
- The location of the coast varies in response to wave runup as the coast is defined by the shoreward extent of the sea. Thus the channel margins will appear to move in response to the variation in wave runup that is experienced between two images of unequal runup extent.

At the lagoon end of the channel other problems in identifying an accurate measure of channel location included:

- Recurves in the channel can cause an unrealistic interpretation of where the lagoon end of the channel is measured,
- A ‘delta-like’ formation sometimes exists in the upper channel that essentially gives two channels. The standard solution to this is to record the location of channel bifurcation as the end of the channel,
- At some times the lagoon water level can drop to such an extent that the lagoon is drained of water. When this occurs the channel does not show a lagoon end of the channel in the image, rather the channel flows from outside the image to the sea in one channel.

Inaccuracies also occur when variations in lighting and contrast levels make features ill-defined. These errors are considered minor in comparison to errors arising through other sources listed above.

### **5.3 Results**

It was observed that the channel migrated predominantly in a northerly direction. While for short periods the channel could migrate to the south, the net migration was more consistently to the north (See Figure 5.1, Figure 5.2). This pattern was most evident at the seaward end of the channel but holds true for the lagoon end of the channel. However, the patterns and rates of migration differ between the seaward and landward ends.

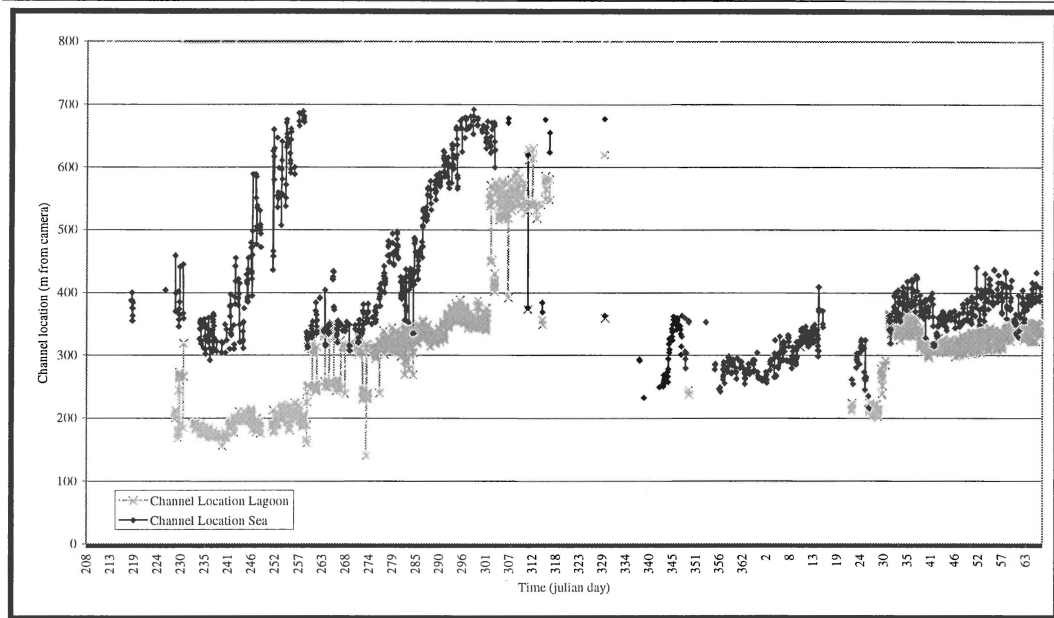


Figure 5.1 — Location of the channel at the lagoon and seaward ends during the first data collection period spanning 28/7/98 – 8/3/99.

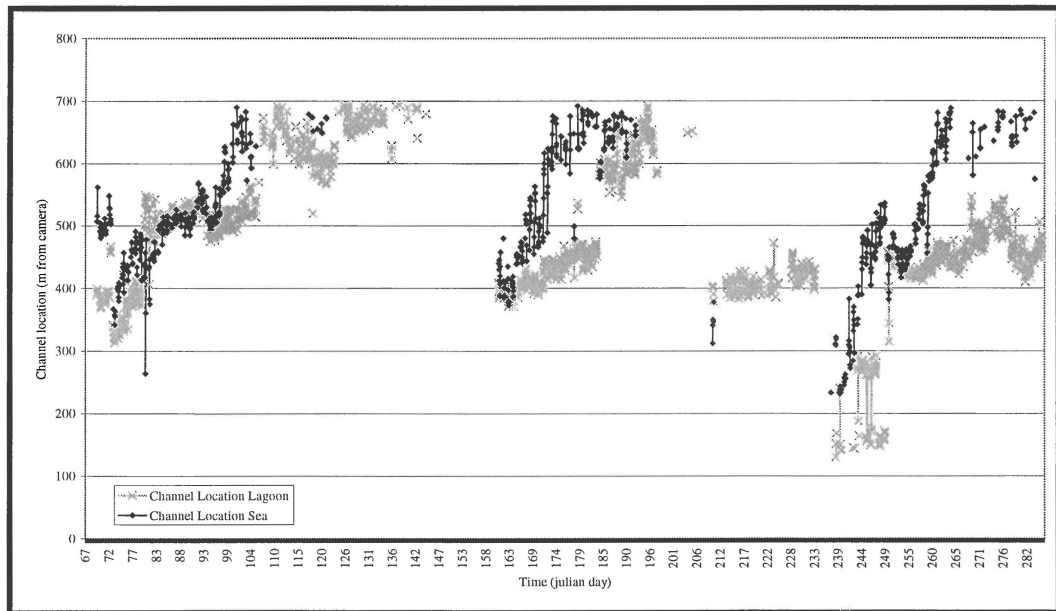


Figure 5.2 — Location of the channel at the lagoon and seaward ends during the second data collection period spanning 11/3/99 – 13/10/99.

The seaward end of the channel moves to the north until it reaches a maximum, at which time the location generally rapidly returns to a position further south in one

episodic barrier breach event. The lagoon end of the channel moves both north and south in a ‘stepping’ fashion that is also driven by discrete migration events.

The channel location was more mobile at its seaward end than at the lagoon end. The location of the seaward end of the channel was more evenly distributed across the field of view (See Figure 5.3) than the location of the lagoon end. The seaward end was most frequently located between 300 – 400 metres from the camera.

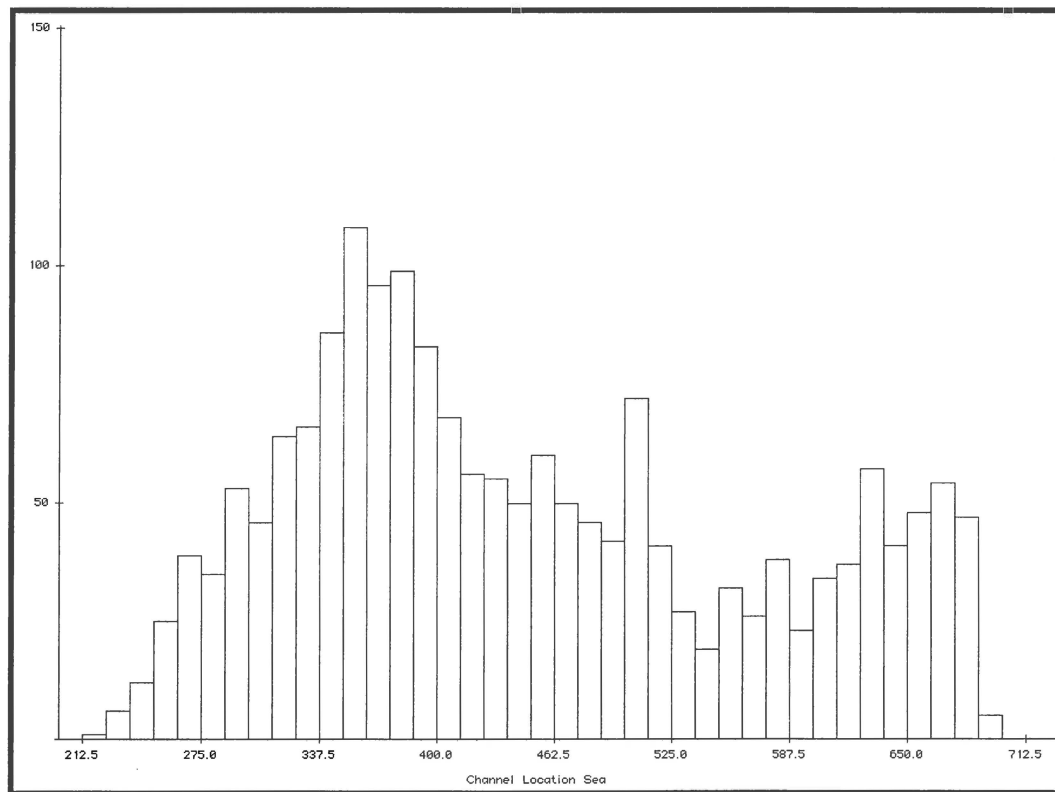


Figure 5.3 — Histogram illustrating the frequency of occurrence of channel locations at the seaward end over the study period. Frequency is plotted on the y-axis and distance from the camera on the x-axis.

The frequency distribution of the location of the lagoon end the channel is less uniform, being located more frequently at several locations along the barrier. This shows as higher peaks and lower troughs in the distribution (See Figure 5.4). Note that the seaward and lagoon ends of the channel most frequently occur at the same location (300 – 400 m from the camera).

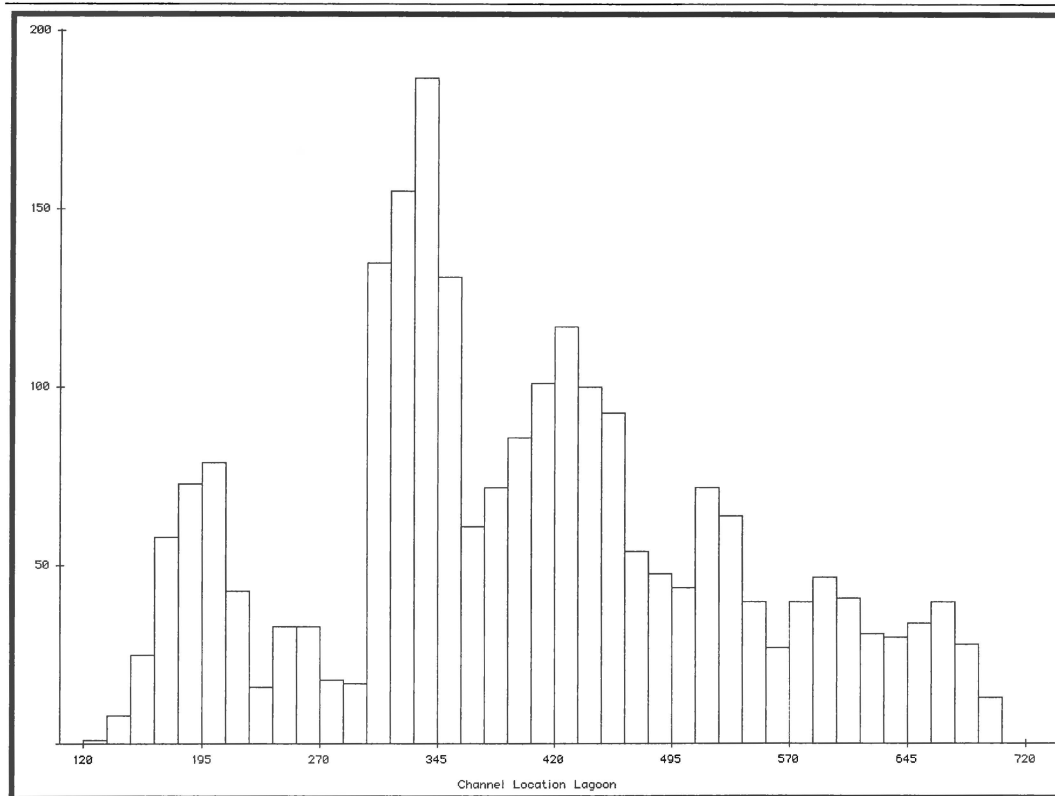


Figure 5.4 — Histogram illustrating the frequency of occurrence of channel locations at the lagoon end over the study period. Frequency is plotted on the y-axis, distance from the camera on the x-axis.

A scatter-plot is presented showing the distance from the seaward end of the channel to the camera, against the distance from the lagoon end of the channel to the camera. This plot shows that the seaward end of the channel is evenly distributed across the field of view in comparison to the lagoon end of the channel. The lagoon end of the channel shows an uneven distribution of data, characterised by a distinctive banding of data points.

It is also clear that the channel is predominantly orientated to the north. The occasions where the channel is orientated to the south are rare and are related to episodic events.

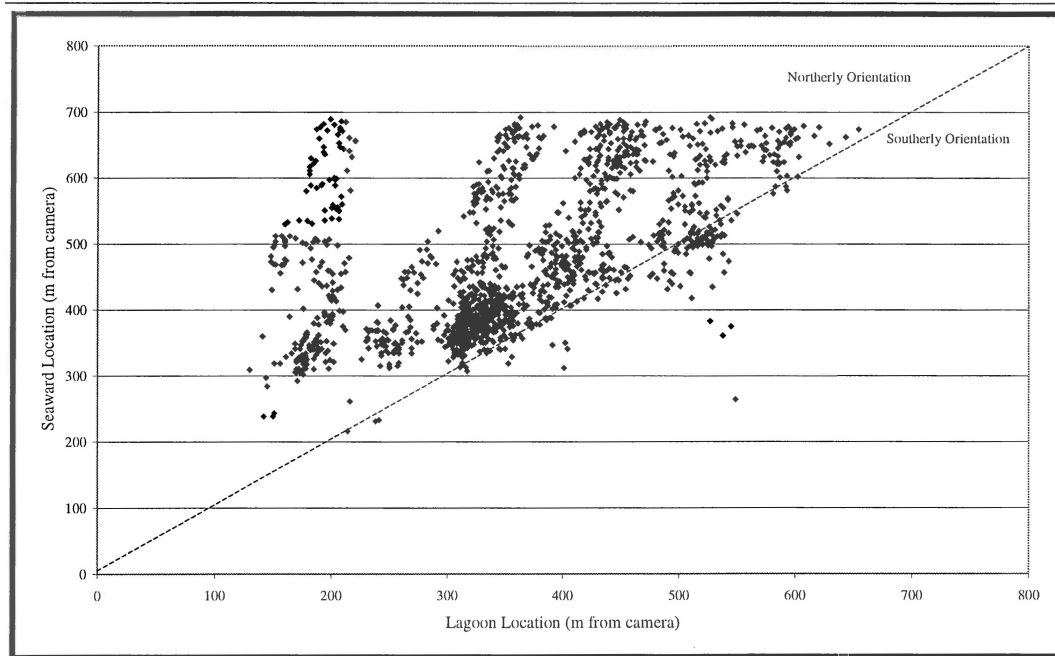


Figure 5.5 — Scatter-plot of lagoon location of the channel versus the seaward location of the channel. Note the distinctive vertical bands of data points. 1:1 ratio line indicates a channel orientated shore normally.

Orientation of the channel plotted over time suggests a cyclic pattern occurs (See Figure 5.6 and Figure 5.7). The pattern of migration consists of a large angle at the outset which, over time, decreases until a minimum value is reached which induces a resetting of the orientation to a high value which again slowly decreases.

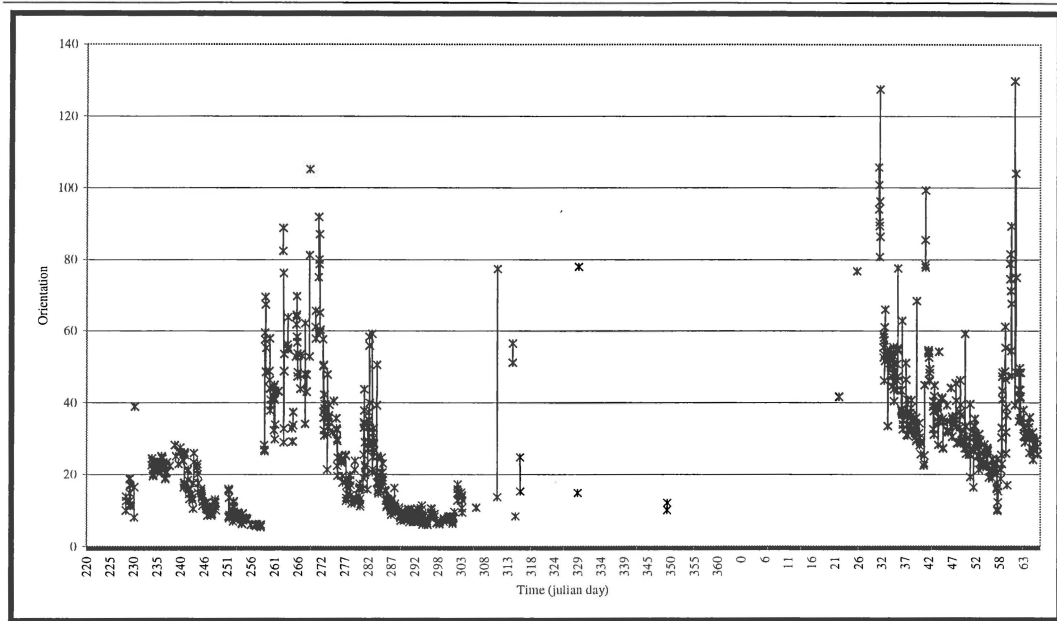


Figure 5.6 — Channel orientation over the first data collection period. Orientation is measured as angle from shore with  $90^\circ$  describing a channel running shore normal.

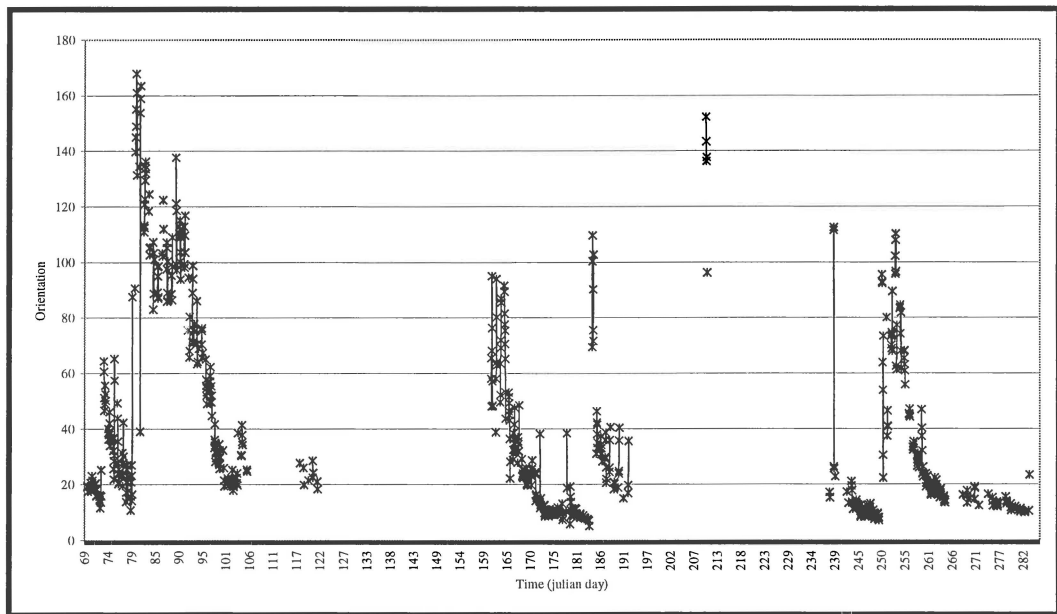


Figure 5.7 — Channel orientation over the second data collection period. Orientation is measured as angle from shore with  $90^\circ$  describing a channel running shore normal.

Examining one orientation cycle provides a clearer picture of the geomorphic trends in that cycle (See Figure 5.8). The orientation of the channel at the beginning of the cycle is shore normal with an angle exceeding approximately  $90^\circ$

to the shoreline. Over time, the angle decreases indicating an anti-clockwise rotation to the north. This continues to a minimum value of around  $5^\circ$  when the channel orientation resets to a value of at least  $90^\circ$ .

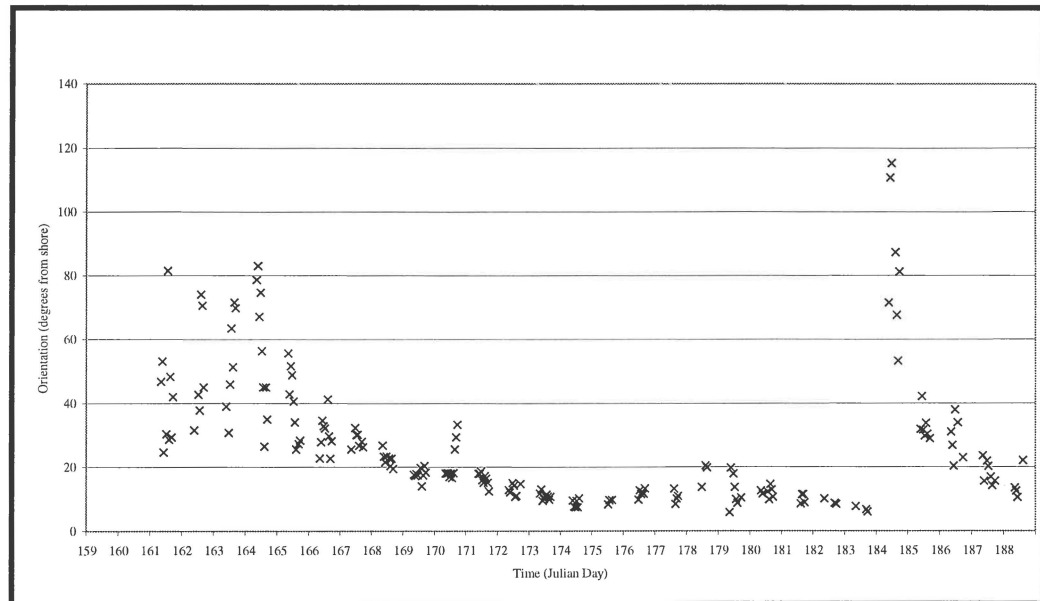


Figure 5.8 — Channel orientation over one cycle. The orientation is highly variable for those parts of the cycle where orientation approaches  $90^\circ$  as small changes in location of the seaward end of the channel cause comparatively large changes in channel orientation.

## **5.4 Discussion**

### **5.4.1 Channel Migration Patterns**

Channel migration is a complex process that varies due to the fluctuating intensity of the forcing largely by waves and the river. This results in complicated patterns that are not easily explained. However, some general trends to the channel migration pattern have emerged.

The trend for the channel to migrate to the north has previously been reported as a result of the predominant northerly longshore transport. Data from this study is consistent with that impression. This northern migratory trend is clearly illustrated in Figure 5.1 and Figure 5.2. at the seaward end of the channel. This

pattern is consistent and is not interrupted by any long periods of fixed channel position. This suggests that the seaward end of the channel is less stable than the lagoon end of the channel which is subject to periods of unchanging channel location.

Not identified in past work is the differing migration patterns of the seaward and the lagoon ends of the channel. It is evident from Figure 5.1 and Figure 5.2, that the channel is much more stable at the lagoon end than at the seaward end, given that instability manifests itself as variations in location of the channel. The difference in stability across the barrier can be explained by the varying influence of forces that drive channel migration. At the seaward end, the effects of waves and longshore transport are dominant. This leads to fluctuations on the same temporal scale as the fluctuations in wave climate. At the lagoon end of the channel the morphology is more stable due to the protection from waves offered by the gravel barrier. The back barrier is therefore subject to less energetic conditions than at the shore, thus the channel position remains fixed for a longer period of time as there is not the energy present that is required to move the channel.

The influence morphology plays on the migratory patterns of the channel seems substantial when examining the full record of oblique images using the \*.avi files. There are sections of the barrier which are higher and more stable than the surrounding barrier. These 'raised banks' create controls on location of the lagoon end of the channel. As a consequence the channel exits the lagoon preferentially through low sections of the barrier between the raised banks. These morphological features are addressed further in section 5.4.2.

Based on these results it can be deduced that channel migration follows a cyclic pattern as it migrates northwards. The pattern is depicted as a schematic in Figure 5.9 and is accompanied by photos illustrating this pattern in Figure 5.10.

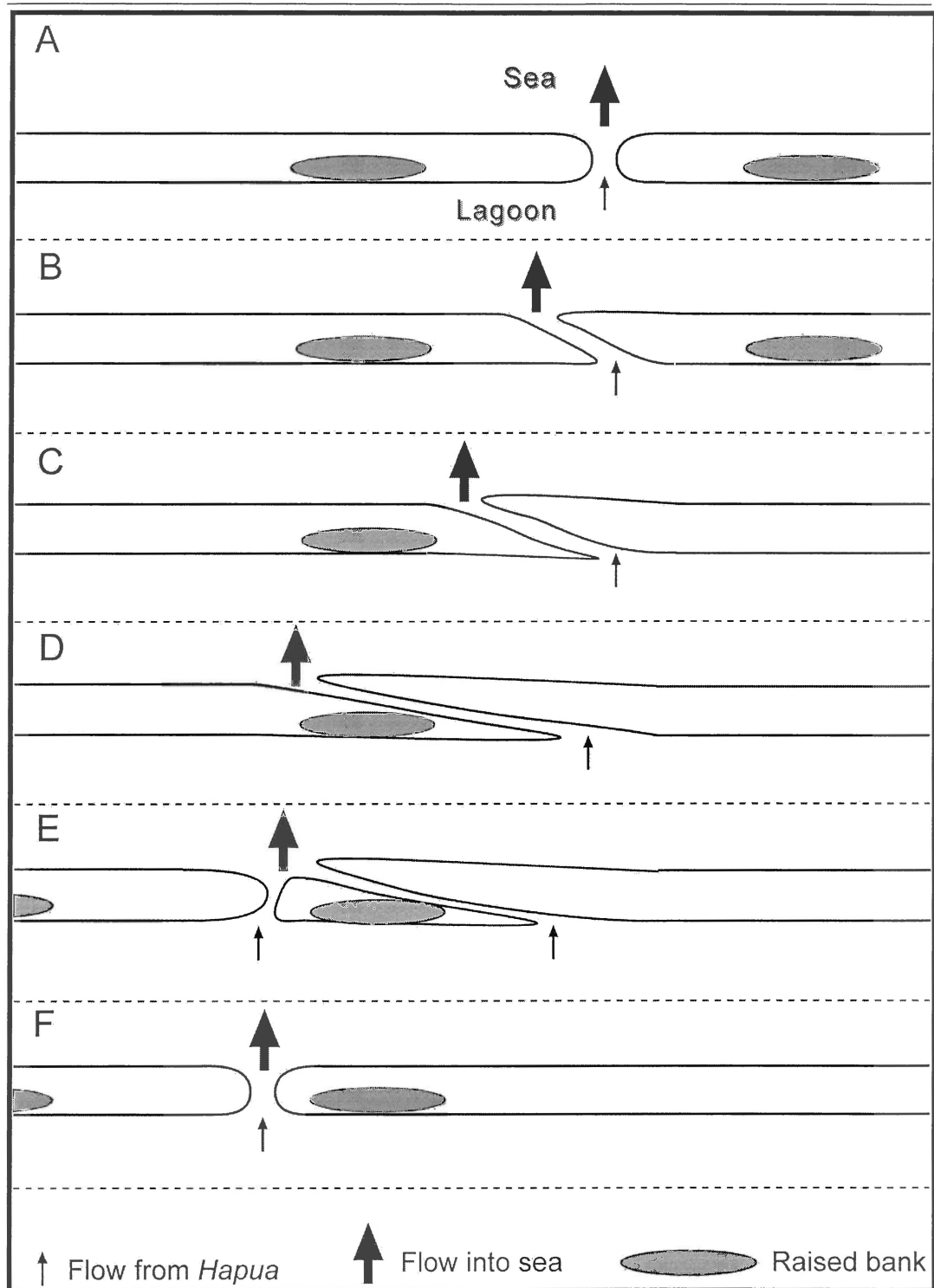


Figure 5.9 — Schematic of the process of channel migration. Note the location of the raised banks. These banks appear to play an important role in determining where the lagoon drains through to the sea.

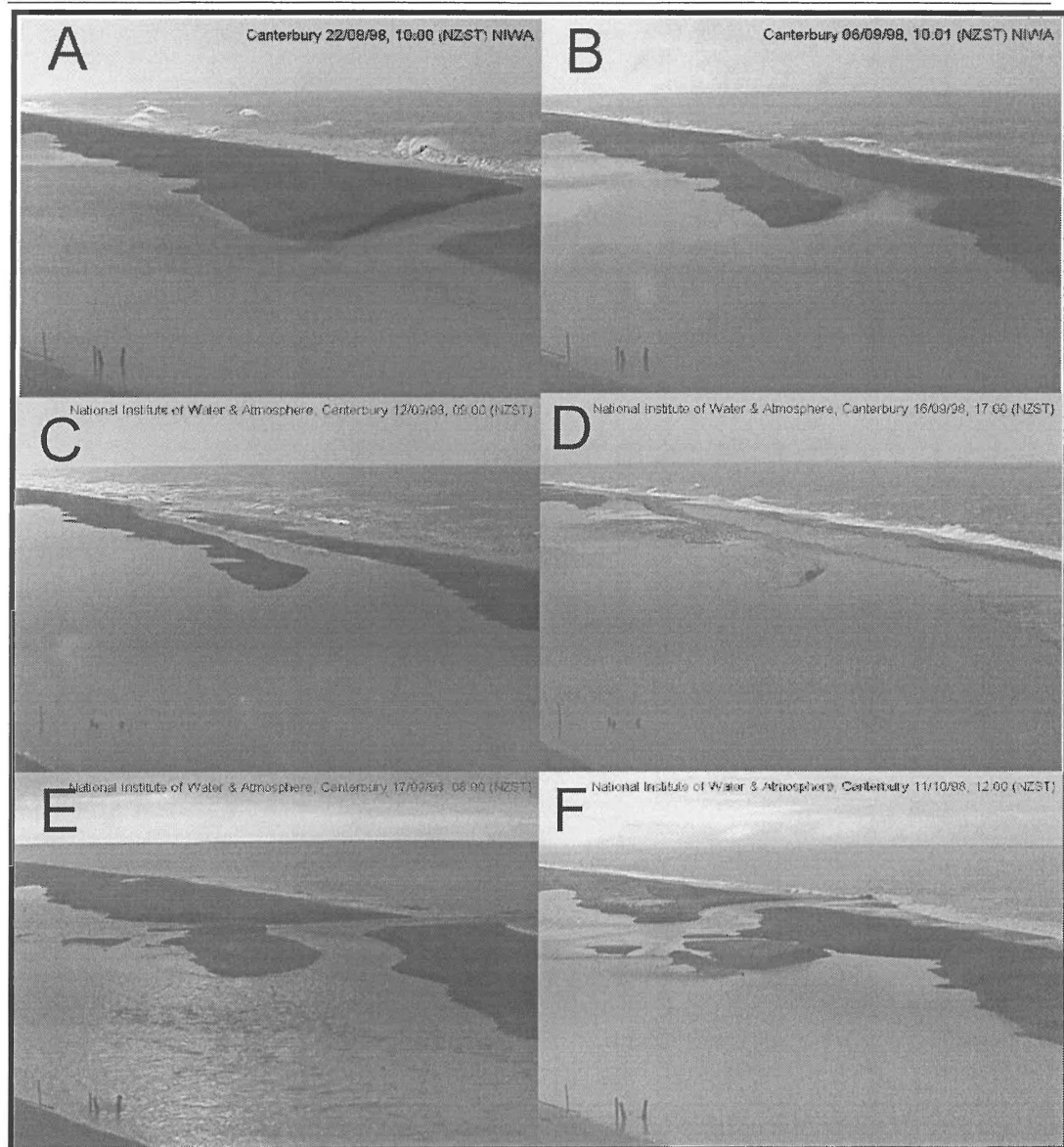


Figure 5.10 — Images illustrating channel migration pattern described in Figure 5.9.

The first panel (A) shows the channel exiting through the barrier at right angles to the shore. This is representative of a newly formed channel which has not yet been influenced by gravel transport along the shore. There is little offset between the lagoon and seaward ends of the channel. Longshore transport builds the barrier to the north and offsets the channel in that direction (B). Gravel and sand builds up on the updrift side of the channel and erosion is exacerbated on the downdrift side. The deflection is most notable at the seaward end of the channel as the material is predominately deposited in the more seaward reaches of the channel. The deflection of the channel continues as long as the flow through the

channel is sufficient to maintain the connection to the sea, enabling the channel to further elongate.

As the channel elongates (C, D), the seaward-facing bank of the channel is subject to wave attack. The seaward-facing bank is now susceptible to waves that propagate across the channel and break upon the channel margin. The effect on the bank is an increase in the rate of erosion, greater than can be attributed solely to infilling of the updrift side of the channel.

It is also suggested that the effect of differential current velocities between the channel banks have some effect on the migration rate of the channel. The higher current velocities in a channel are found on the outside bends, whereas on the inside bends the velocities are lower. The seaward facing bank tends to also be on the outside (northerly) bend in the channel so that the erosion of the bank is further accelerated. The faster flow will directly erode the channel edge due to higher current velocities removing sediment directly from the bank along with the swift removal of sediment that collapses into the channel. This collapse occurs as a result of either an over-steepening of the channel edge due to undercutting from the channel, or material eroded as waves attack the bank and act to flatten the slope.

As the channel length increases, the water slope in the channel decreases. As a consequence lower flow and sediment transport rates are accompanied by a decreased capacity to maintain the open connection to the sea. This instability can lead to either closure of the channel or the creation of a new channel with a shorter length and therefore a greater stability. This type of event appears to be associated with extreme events. The episodic nature of the movement of the lagoon end of the channel, which is a good indication as to whether the channel has undergone a dramatic shift, is associated in almost every case with either high flows, or more often, an overwash event.

Through-flow of water through the barrier may also increase pore water pressure on the lagoonal side of the channel. This may contribute to a breakthrough of the channel to the sea, creating a double exit from the lagoon into the channel as exhibited in stage E. Because of a greater head gradient in the shorter of the two

channels, the flow will be greater through one channel. One channel will eventually capture the river flow and become the primary channel, while the other channel will infill through overtopping of the gravel spit and become relict.

The seaward end of the channel migrates causing elongation of the channel as the lagoon end remains in the original position. As the channel length increases, flow rates decrease with the decreasing head gradient and the channel becomes increasingly unstable as its ability to clear material deposited by longshore transport is diminished. As the situation becomes increasingly unstable, one of the following may occur:

- the channel length may shorten as a result of migration of the seaward end of the channel to a position closer to the lagoon end of the channel, or
- the lagoon end may step to a position closer to the channels seaward end.

For either situation to occur most often requires an extreme event, thus the channel can remain in an unstable situation for a considerable period of time before the instability manifests itself in a migrational event.

The effect of large waves and overwash on channel migration is considerable. Periods of overwash introduce water into the lagoon where the water level increases along with a ‘flattening’ of the barrier morphology which lends itself to a repositioning of the channel. As the barrier is overwashed, water tends to flow into the lagoon at several places on the barrier, due to the high water level and low barrier relief (See Figure 5.11). The channels dry up after the event leaving only the most stable channel, often different to the channel that originally drained the lagoon.

Results from this study disagree with Kelk’s (1974) findings that the channel migration, from the south to the north and returning to the original position, occurs over an 18 month cycle. The channel returned to an extreme southerly position over approximately 12 months in this study, however the question of timing of the cycles is variable. It appears that at any time the situation can be altered dramatically such that the cycle may begin again. Long-term monitoring of these cycles is the only way with which we can accurately assess whether the

situation follows regular cycles. The images collected, now and in the future, provide a perfect opportunity to do this.

One of the important stages in this migration pattern is the resetting stage where the channel returns to a shore normal orientation. The point where the channel returns to approximately a shore normal orientation is governed by the location at which the channel exits the lagoon. These exit points are limited to several discrete locations which are highly influenced by the back barrier morphology, in particular the raised banks (See Figure 5.4).

### **5.4.2 Hapua Morphology**

The morphological environment of the Ashburton hapua is highly dynamic due to the recycling of sediment as the channel migrates along the barrier. Few features remain throughout this process as reworking of the sediment by subsequent erosion and deposition destroys most morphological features.

Throughout the study period one type of feature has remained. Raised gravel banks have been observed, welded to the lagoon edge of the gravel barrier (See Figure 5.12 and Figure 5.13). The origin of these banks is not clear. They have persisted throughout the study, although at times of higher lagoon water levels the features are not distinguishable as they are submerged.

Evidence of the endurance of the raised banks while the surrounding barrier undergoes extensive change may be provided by the wildlife of the hapua. The raised banks are a preferred roosting area for the Shags that nest in the cliffs overlooking the coastline. Their excrement causes a discoloration of the barrier that is often observed in the Cam-Era images (See Figure 5.14). That this is observed suggests that the features are persistent on longer time scales than most as the discoloration would be widespread if this were not the case.

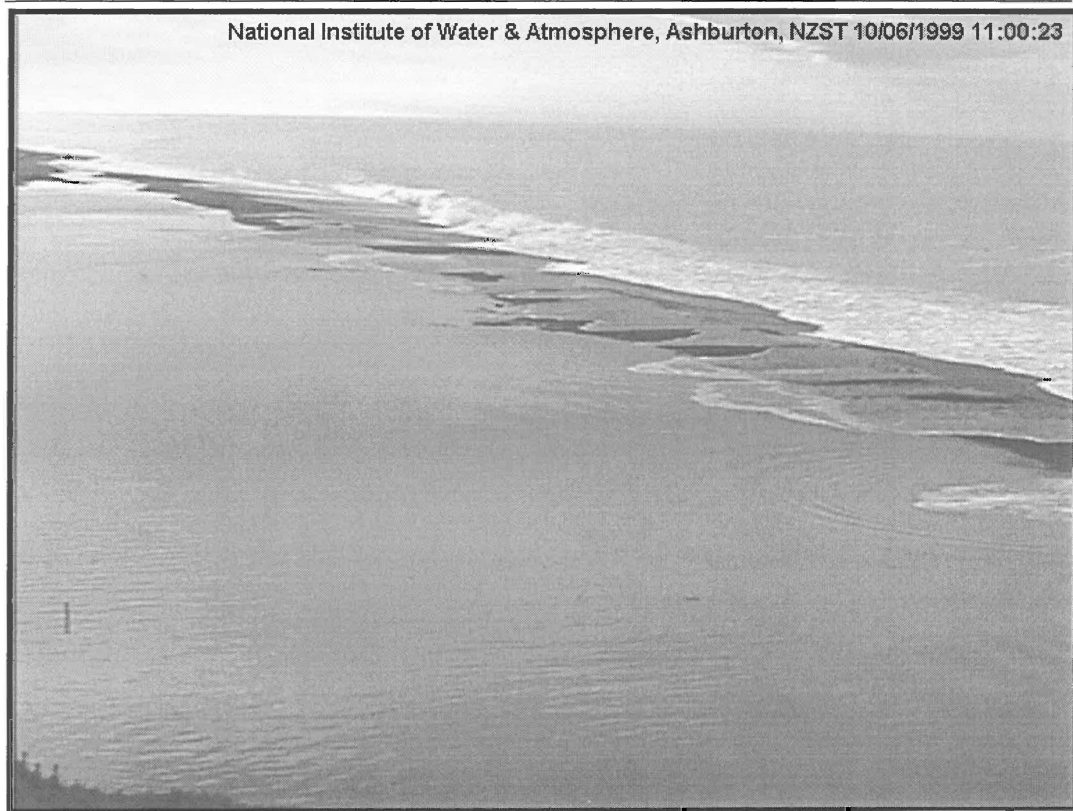


Figure 5.11 — Overwash event where high waves overtop the barrier and increase water levels in the lagoon. Can also prevent accurate identification of channel location.

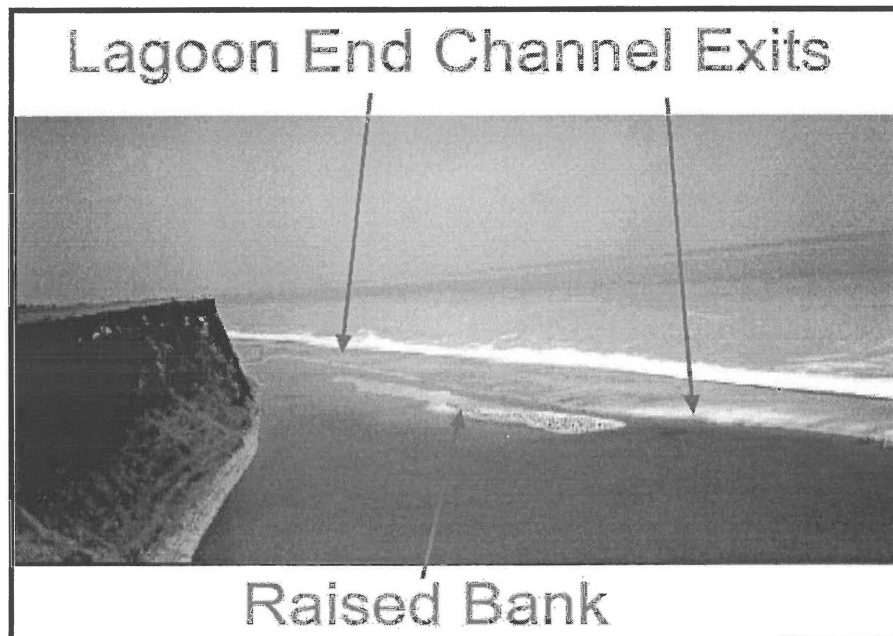


Figure 5.12 — Location of raised bank at Ashburton hapua

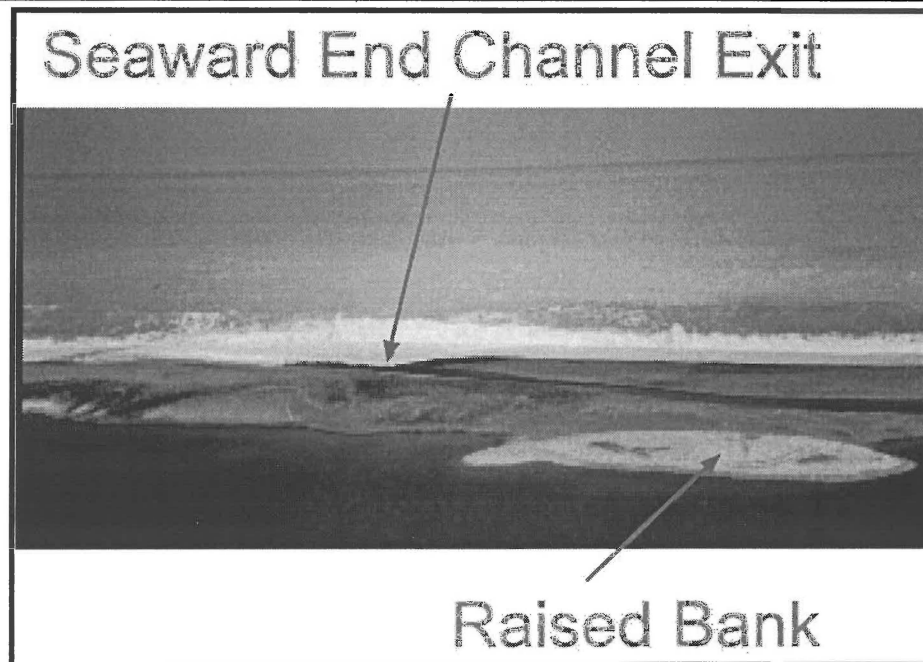


Figure 5.13 — Location of raised bank at Ashburton hapua

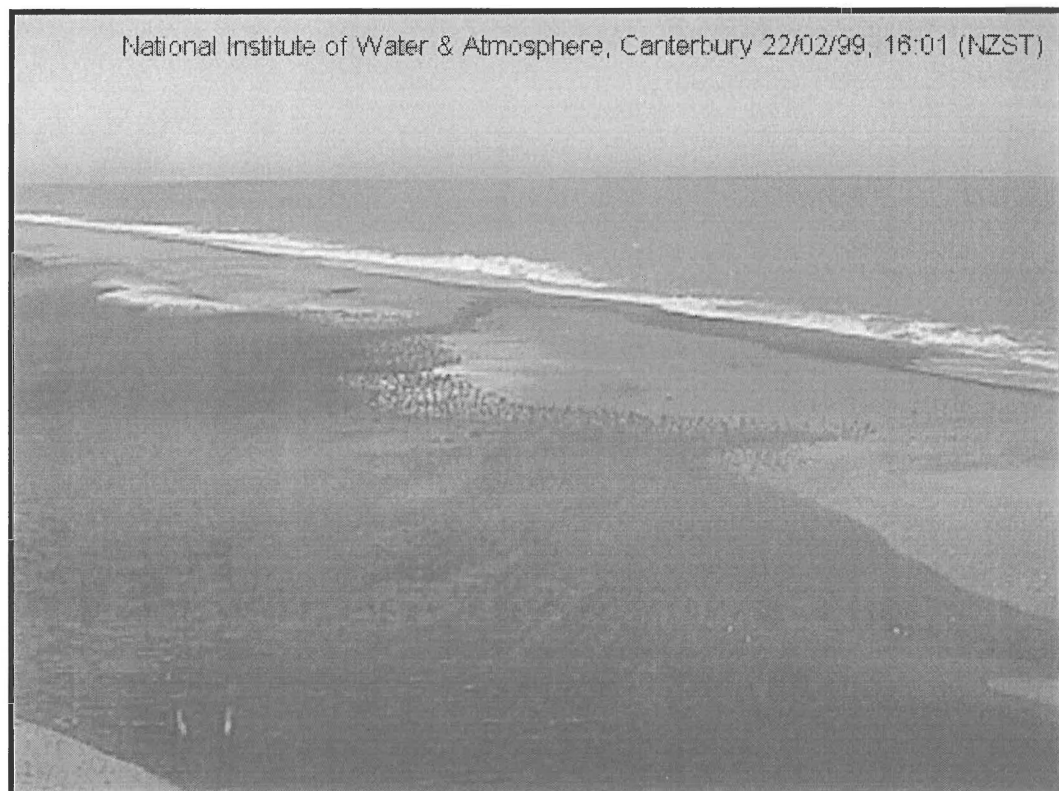


Figure 5.14 — Shags roosting on the back barrier area of the raised banks. Their excrement causes the distinctive lighter coloured areas of gravel.

The raised banks could be a result of the migrational pattern of the channel, or conversely, a feature which influences channel migration, leading to the observed patterns. If the features are a result of the migration pattern then some other process must be driving the pattern of migration. If this is not the case then the origin of the banks is still in question.

If the banks are causative of the migration pattern then their origin may be related to cusp formations that are evident in this environment. Cusps have been noted on several occasions on the shoreward face of the barrier causing regular variations in elevation. These high and low points may translate to height variations on the back of the barrier leading to the formation of the observed elevated banks.

Another theory on the origin of the banks relates to antecedent conditions providing the means for the bank creation. The channel location is associated with low elevation of the barrier due to its recent formation thus the barrier has not achieved its full vertical extent. When the barrier is subjected to storm conditions the area surrounding the channel is more prone to washover. The occurrence of washover creates deposits of shoreward moved material called washover fans. The washover fans have a higher elevation than the surrounding barrier due to the deposition of sediment thus making them distinguishable.

Upon creation of an raised bank further processes may cause increased stabilisation of the bank. Areas where the channel is not often located will be more consolidated than where the sediment is constantly reworked. Without the reworking process material becomes increasingly consolidated as pore spaces are filled by smaller grain sizes, thus the sediment is more resistant to erosion. Further, the size of the banks may cause increased deposition of material as overwash bores are dissipated more effectively on the elevated banks. This will further increase the elevation of the bank, exacerbating this feature and the process.

The vertical extent of these sections of elevated relief can be truncated by overwash events. Overwash exceeding some sufficient size will flatten the topography of the barrier but the horizontal projection of the bank into the lagoon

depression will remain. This provides a base for the successive up-building of bank in the future.

Complete erosion of the raised bank has not been observed at any time during the study period. The only process that erodes the bank is the migration of the river channel along the barrier (See Figure 5.15). The river channel cuts through the barrier when the lagoon water level is low such that no lagoon is formed and the river channel extends through the lagoon area. This event has been observed twice during the study period.

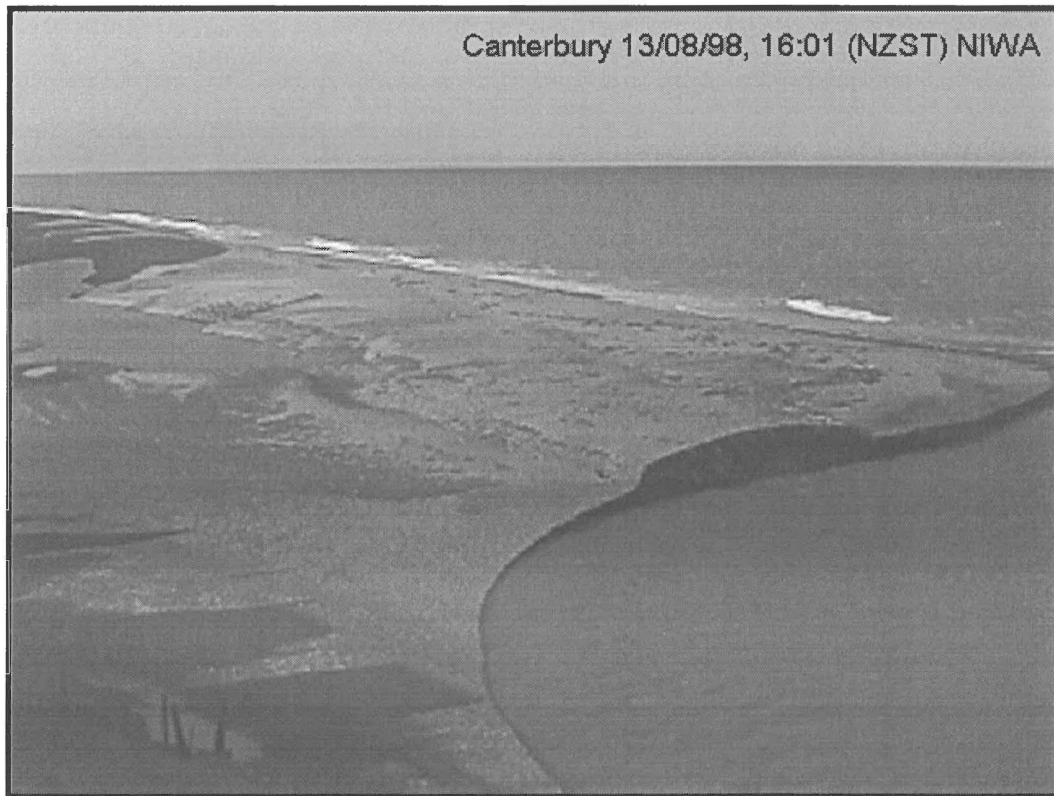


Figure 5.15 — River channel migrating along barrier with no lagoon formed. This process is efficient at recycling material stored in the barrier but does not erode further north than pictured. This enables the raised bank visible in the centre of the image to persist.

The erosion of part of the bank was observed during both river channel migrations but the bank was never entirely destroyed. The distance of the bank from the river channel may contribute to the persistence of the bank. This phenomenon only occurred in the foreground of images. The river channel reached a maximum in northward migration approximately illustrated in Figure 5.15 during both events

when the lagoon filled again. Upon filling of the lagoon the channel became less erosive at the lagoon end leading to a more stable back barrier region.

The location of the channel remained stable until a period of high waves brought about overtopping of the barrier. This caused a new channel to be formed to the north on the far side of the raised bank. Thus the raised bank remains while the channel migrates past the bank and further to the north.

At times the pattern of channel migration at the lagoon end does not follow the stepping pattern explained earlier. This may be a result of the river channel migrating along the barrier when there is no lagoon formed, as discussed above. This process is also the cause of the major morphological changes in the back barrier/lagoon region as it is the only time that the energy in the back barrier is sufficient to move large volumes of sediment.

## **5.5 Conclusions**

Previous works have explored the process of channel migration (i.e. Kelk, 1974; Todd, 1992) however the methods of data capture were less effective than the method which has been available for this study. Through the voluminous data provided using video images it has been possible to more accurately describe the patterns of migration of the channel for a longer time period than ever before.

Results have shown that across the length of the channel there are variations in behaviour attributed to variance in the dominant forcing processes. The seaward end of the channel is far more variable than the lagoon end as the seaward end is subject to the higher energy associated with waves. The lagoon end of the barrier is more stable as the barrier affords some protection to that end of the channel and thus the location is more stable.

Raised banks on the back of the barrier play a role in the migration of the channel. They appear to control the location where the barrier breaches, with breaches occurring in the low areas between the banks. The origin of the raised banks is unclear, but they were the only geomorphic feature persistent during the study.

Previously reported observations that the predominant migration of the channel is to the north are reinforced based on the data presented. The trend is most obvious at the seaward end of the channel where the location is evenly distributed along the barrier. While the distribution is less even, the northward migratory trend is also observed at the lagoon end.

The pattern of migration is driven more by episodic events than previous studies suggest. Migration has been previously attributed to the longshore transport causing a gradual shift to the north, however this study suggests that longshore transport affects the channel by shifting the channel orientation to the north. Migration of the entire channel is driven by episodic events such as high wave or flood events that cause the lagoon end of the channel to move, thus enabling the entire channel to move to the north to begin another orientation cycle.

Episodic events also have the ability to interrupt the migration cycle through resetting of the cycle or causing an unforeseen change to the channel migration pattern. Thus the episodic events are a major control and factor influencing the behaviour of the channel.

# Chapter 6 - Factors Driving Morphological Change

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## **6.1 Introduction**

In the previous chapter issues regarding the patterns of migration of the channel were addressed, however so far no quantitative analysis of the relationships between the driving factors and the morphological response has been undertaken.

How do factors such as river flow and longshore transport affect the migration of the drainage channel of the Ashburton hapua? Theories have been suggested based on small inaccurate datasets in the past but results have consistently suggested the environment is complex, thus proving the hypotheses has been difficult.

In this chapter the Cam-Era images and other data are used to examine the processes that shape the environment and the relationships between those processes and the morphological response. The investigation will be focussed, specifically on the most dynamic part of the environment - the drainage channel of the lagoon.

## **6.2 Data Analysis**

### **6.2.1 Methodology**

Channel statistics on the location of the lagoon end of the channel and the seaward end of the channel were parameterised from the images, which also provided information on several other channel variables including channel orientation. Statistics on the river flow and wave climate (collected hourly) along with other factors, such as lagoon water level, thought to possibly influence channel

dynamics were collated. The origin of this data is presented in chapters three and five.

The relationships between the forcing factors and the channel morphological change were examined using a number of statistical methods. The preliminary investigation involved simple regression and time series comparisons between channel behaviour and the forcing factors using hourly data. Following this analysis daily average data were used in further analysis to compensate for noise and inaccuracy in the following manner.

Daily averages of wave height, direction and period; river flow; and lagoon water level were calculated from the full record. Channel location at both ends of the channel and orientation was gathered corresponding to the high and low tides. This data was assimilated into a new smaller dataset for intensive statistical analysis. The locations of the channel were used to determine migration rates of the channel at each end. This dataset was analysed using Spearman rank correlation, and multiple regression to determine the relative importance of the driving wave and fluvial processes to morphological responses.

The tools used for data analysis included Microsoft Excel for the more basic time series and simple regression analyses, and Datadesk for the more complex statistical analyses. Datadesk provided a better suite of statistical analysis tools including Spearman rank correlation and multiple regression analysis used in this study.

### **6.2.2 Problems and Limitations**

There are a number of problems both in the availability and the quality of the data collected. A serious shortcoming of this study was the lack of coincidental records of morphological change and forcings for the entire length of the study. The video camera required some shifting of its location for various maintenance issues and site improvements. This not only produced gaps in the data set but also split the longest measurement period in two, data from before Julian Day 66 (8 March) 1999, and after Julian Day 69 (11 March) 1999, between which results were not compatible.

Even when rectifiable images were available from the camera further gaps were introduced. The quality of images was an issue at times due to weather and lighting, thus some data could not be collected when the camera was fully operational. These issues are addressed in chapter three. The other problem arose due to the location of the camera. The camera could not accurately portray the location of the channel when its northern offset was too extreme, nor when the channel was not in view of the camera from the southern extreme. When the distance to the north increases it has an associated decline in accuracy due to the increasing size of the pixel footprint. This error was determined to be too large to make use of the data when the channel migrated more than approximately 700 metres from the camera. The cut-off for data when the channel was at the southern extreme was easily identified as the point where the channel was not visible in the image as it was located to the right of the image margin. This occurred when the channel was located immediately seaward of the camera or further south.

Other gaps were found in the wave record from the deep-water wave buoy. The wave buoy was deployed part-way through this study as part of another project. Several problems were experienced when the buoy was first deployed including instrument and mooring failure. The result is that the data is only provided for approximately 75% of the time since the instrument began recording. The lack of lagoon water levels has been supplemented using the video camera as mentioned in chapter three.

The gaps in the data have not created an insurmountable problem in themselves but timing of the gaps has caused a significant problem in achieving the goals of this chapter. For long periods of time during mid 1999 either the wave buoy was out of operation or the channel was located outside of the camera field of view. This has severely limited the investigation of relationships between the forcing factors and response (See Figure 6.1).

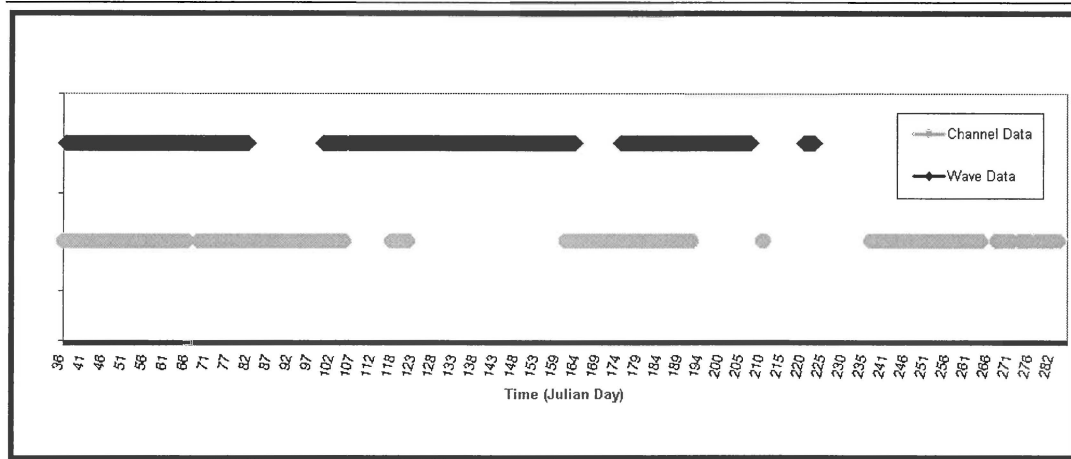


Figure 6.1 — Coincidence of 'useable' data recorded from the video and wave buoy.

To avoid the problems arising from a lack of simultaneous data we decided that the study would focus on a shorter time scale. This would also provide a more concise view on the patterns over short time periods. The period where most data was captured ran from Julian Day 36 (6 February) 1999 to 79 (21 March) 1999. This 7-week period included data from all sources, however it must be noted that the video data spans two periods where data is not equivalent due to image dimensions changing as a result of camera movement.

The preliminary findings suggested unusual trends in data gathered on hourly time scales. Patterns in channel location over the course of a day fluctuated with tidal variations. The relationship between the tidal signal and the channel location was attributed to either a systematic error in data collection or the result of some unexpected process correlating migration with tidal fluctuation.

It was expected that data could be extracted from the images providing data on the breaking wave angle, an important mechanism driving longshore transport. The results however did not indicate a close correlation between the deep-water and breaking wave angles as was expected.

The majority of studies using video analysis have been undertaken on fine clastic beaches. There are major differences between the type of breaking waves on the steep mixed sand-gravel beaches and breaking waves on sandy beaches. On mixed sand-gravel beaches the slope is greater due to a combination of factors

including wave energy and sediment size (Komar, 1998). Breaking waves on the steep mixed sand gravel beaches in the Canterbury Bight are generally confined to a narrow band a short distance offshore where the plunging waves form a narrow surf zone. This can clearly be observed in an average image from the video camera where the band of white indicates the extent of the surf and swash zone (See Figure 6.2). At times it is difficult to identify the direction of propagation of the wave crest on a steep beach as the backwash from a wave is easily mistaken for a wave crest. A wave that propagates across the swash zone may leave a line of foam along the edge of its path as it moves shoreward then turns back towards the sea.

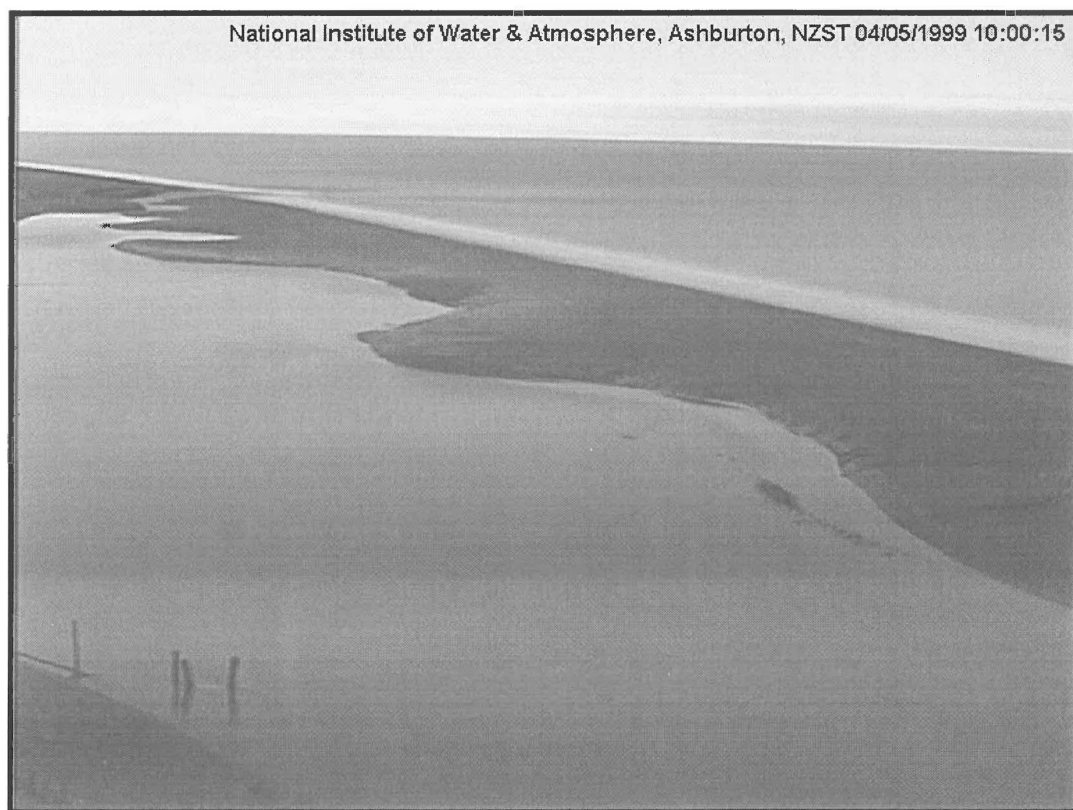


Figure 6.2 — Average image illustrating the limit of the surf/swash zone. The band of white immediately offshore of the coast represents the extent of the breaking waves.

Waves also interact with mass flows of water leading to refraction of the wave crests. The location of interest in this study is subject to a large outflow of water from the lagoon, which is constantly interacting with the incoming waves, further disrupting accurate measurement of the breaking wave angle.

It was anticipated that the factors which most contribute to the migrational behaviour of the channel would be river flow and longshore transport. Measurement of longshore transport in this case is not possible, therefore a surrogate measurement of longshore wave energy flux is substituted. It is assumed that longshore wave energy flux is proportional to longshore transport as suggested by classical longshore transport equations such as the CERC formula (USCERC, 1984)

River flow is also only an approximation for the flow rate of water through the discharge channel. This assumption is also flawed to some degree as the rate is a function of channel characteristics (i.e. cross-sectional area, length) and lagoon water level. Lagoon water level is included as a measured variable but, as in the case of topographic surveying, no technique as yet is available to accurately determine cross-sectional area of the channel from video images alone.

### **6.3 Results**

Initially the entire dataset was used for regression analysis of all pairs of variables to investigate possible relationships that would support existing theories. The results from these regression analyses were poor. The  $R^2$  values were too low and little could be made of the relationships. Relationships were not valid for some data where correlation was expected.

The relationship between deep-water and breaking wave angle was inconsistent. If the data describing breaking waves were accurate, it would be expected that there would be a strong relationship between the two variables. This was not the case however (See Figure 6.3). Neither the data provided from a single wave crest, nor averaged over two wave crests shows good agreement, however the  $R^2$  value of the relationships improves marginally with the use of average data and both regression lines are positively sloped, in accordance with expected behaviour.

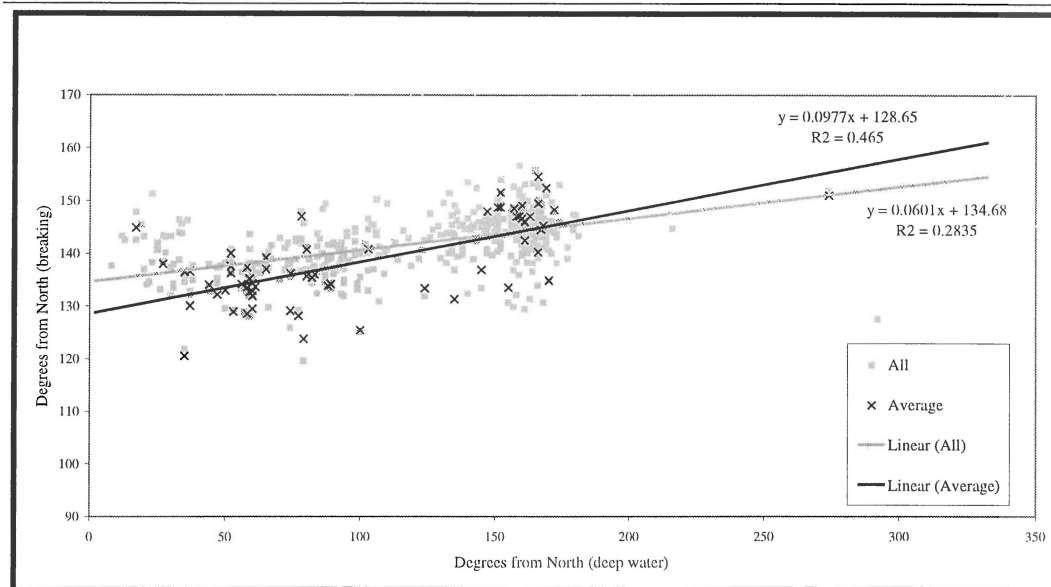


Figure 6.3 — Relationship between breaking and deep-water wave angle. Average wave measurements are supplied when more than one wave crest can be identified and thus an average value recorded.

A further reason that may explain the lack of a relationship between deep-water and breaking wave angles may be a lag effect between the measurements made at Banks Peninsula, 110 km to the north-east, and those made using the video camera at the Ashburton River mouth. The lag was assumed not to be of great magnitude as wave field characteristics do not greatly fluctuate on short time scales. This lag effect (if present) is also further minimised when daily averages of the wave data are used.

Due to the lack of success, time-series analysis of the data was undertaken. This was done by visually examining and comparing the time series plots of the measured variables.

Time series analysis revealed few easily recognisable patterns upon first examination. The migration patterns were not associated with a common set of conditions (i.e. high flow rates or wave conditions) which suggests the behaviour of the channel is not as simple as theory suggests. In some cases migration can be attributed to a set of extreme conditions but this is not a consistent pattern. In some circumstances the migration appears to be completely independent of the

measured forces, such as wave angle to the shore at times opposing the direction of channel migration under consistently low river flows.

However close examination of the time series of channel migration and tidal fluctuation suggests a correlation between the two. In particular, an increasing tide appears to coincide with an apparent movement of the channel to the south. This migration then reverses on the falling tide (See Figure 6.4).

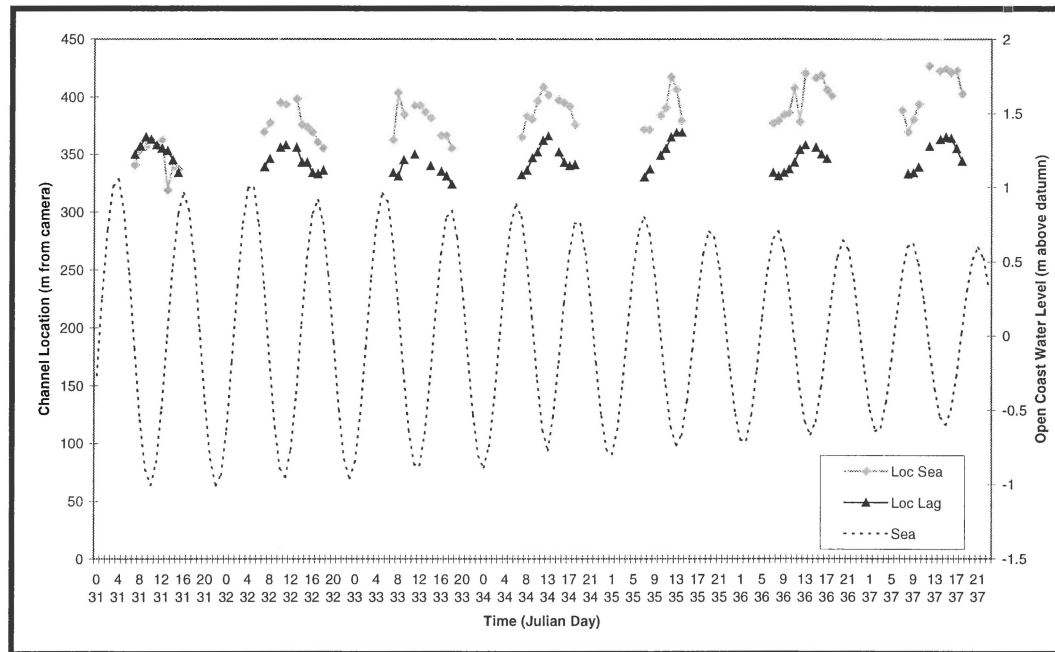


Figure 6.4 — Time series showing a relationship between the location of the channel at the seaward and lagoon ends (Loc. Sea and Loc. Lag) and the fluctuations of the tide (Sea). The increase in tidal elevation appears to be related to a decrease in channel location at both ends of the drainage channel.

### **6.3.1 Spearman Rank Correlation Analysis**

The Spearman rank correlation was calculated using daily measurements of several variables including wave statistics, river flow and lagoon water level. The channel data was recorded in two data sets; data corresponding to high tides and data corresponding to low tides. The summary of the analysis is presented in Table 6.1.

Spearman Rank Correlation		High Tide							
No Selector		Sea M...	Lag M...	Orient...	Av Lag...	Av Fl...	Av Dir	Av T	Av H
Sea M HT		1							
Lag M HT		0.492	1						
Orientation ...		0.018	-0.015	1					
Av LagWL		0.188	0.311	-0.518	1				
Av Flow		0.459	0.266	0.032	0.157	1			
Av Dir		0.295	-0.018	0.042	0.249	0.369	1		
Av T		0.098	0.083	0.255	0.106	-0.286	0.312	1	
Av H		-0.234	0.115	0.171	0.36	-0.097	0.072	0.457	1

Spearman Rank Correlation		Low Tide							
No Selector		Sea M...	Lag M...	Orient...	Av Lag...	Av Fl...	Av Dir	Av T	Av H
Sea M LT		1							
Lag M LT		0.462	1						
Orientation ...		-0.405	0.076	1					
Av LagWL		0.075	0.192	-0.444	1				
Av Flow		-0.041	0.215	-0.025	0.157	1			
Av Dir		0.006	0.482	0.345	0.249	0.369	1		
Av T		-0.433	-0.188	0.342	0.106	-0.286	0.312	1	
Av H		-0.495	-0.152	0.102	0.36	-0.097	0.072	0.457	1

Table 6.1 — Spearman rank correlation of channel data and driving forces at both high and low tides.

Where:

Orientation - channel orientation,

Av. Flow - Average river flow,

Lag M - Migration of lagoon end of the channel,

Av. Dr - Average deep-water wave direction,

Sea M - Migration of seaward end of the channel,

Av. T - Average deep-water wave period,

Av. H - Average deep-water wave height.

Av. LagWL - Average lagoon water level,

A comment indicating whether channel data corresponds to high tide (HT) or low tide (LT) also follows the notation.

Results show a reasonable correlation between a number of the forcing factors under both high and low tides. Wave period and wave heights show reasonable correlation, as do wave period and direction. River flow shows correlation with wave direction and period and the lagoon water level shows a relationship with wave direction (0.249) and height (0.360).

Scatterplots of the relationships were examined to verify that the relationships were valid and not influenced heavily by outliers. This was found not to be the case in any of the relationships. The measures of regression appeared to correspond accurately to the data scatter.

Both sets of data agree with a negative relationship between the orientation of the channel and lagoon water level and a positive relationship with wave period. A negative relationship has also been identified between the migration of the seaward end of the channel and wave height. There also is a negative correlation between the migration of the lagoon end of the channel and river flow. A good correlation exists between both sets of data for the migration of the channel at the lagoon and seaward ends.

Differences between high tide correlations and low tide correlations are evident (See Table 6.2). The low tide data indicates several relationships not backed up by high tide data including a positive relationship between channel orientation and wave direction and the channels lagoon end migration has a positive relationship with the wave direction. The migration of the seaward end of the channel has a negative relationship with orientation and wave period. It is also noted that several relationships are stronger using high tide data than the same relationships using low tide data. These positive relationships include migration of the seaward end of the channel and the average river flow and the lagoon water level. The migration of the seaward end of the channel has a positive relationship with the wave direction.

	Sea M...	Lag M...	Orient...	Av Lag...	Av Fl...	Av Dir	Av T	Av H
Sea M								
Lag M	-0.03							
Orientation ...	-0.42	0.09						
Av LagWL	-0.11	-0.12	0.07					
Av Flow	-0.50	-0.05	-0.06	0.00				
Av Dir	-0.29	0.50	0.30	0.00	0.00			
Av T	-0.53	-0.27	0.09	0.00	0.00	0.00		
Av H	-0.26	-0.27	-0.07	0.00	0.00	0.00	0.00	

Table 6.2 — Differences between correlations attributed to change in tidal state. (i.e. High tide correlation – Low tide correlation)

### **6.3.2 Multiple Regression Analysis**

The same daily data used in the previous examination was again used by Datadesk for multiple linear regression analysis. It was decided that one set of channel descriptors would be used to explore the differences between the tidal situations. The variable chosen was the migration rate of the seaward end of the channel as it is subject to greater variation as it exists in a higher energy environment. It is also noted that the variation in correlation between high and low tides are predominantly associated with this variable.

Multiple linear regression would be more useful in dealing with the migration of the seaward end of the channel. A better fit was expected to the even distribution of seaward locations than the episodic migration of the lagoon end from one stable position to another. This stepping phenomenon would not be well described by linear relationships between forces and the channel migration (See Figure 5.3, Figure 5.4, Figure 5.5).

The forces were eliminated from the multiple regression equations through a process of trial and error to determine the factors that best predicted the migration rate of the seaward end of the channel. Beginning with all factors, the removal of one variable resulted in an F-Ratio that gave an initial indication of the importance of that variable in a predictive role.

Orientation was included as a predictive variable as it was suggested by Todd (1985, 1992) that as a channel becomes further offset, migration rates are affected to different degrees by the processes acting on the channel. For example, as the channel becomes more offset, the effect of waves eroding the channel bank to further accelerate channel migration becomes more pronounced.

Further elimination by trial and error resulted in identifying several factors that were the most important for prediction of the migration rate of the seaward end of the channel. A summary of the trial and error process is presented in Table 6.3 for the low tide data and Table 6.4 for the high tide data.

Cases	Av H	Av T	Av Dir	Av Flow	Av LagWL	Orient	R squared	F-Ratio	Sig 99%?	95%	90%
1	Y	Y	Y	Y	Y	Y	84.2	4.43			Y
2	Y	Y	Y	Y	Y		69.3	3.16			Y
3	Y	Y	Y	Y		Y	72.2	6.22	Y	Y	Y
4	Y	Y	Y		Y	Y	50.9	1.24			
5	Y	Y		Y	Y	Y	50.6	1.23			
6	Y		Y	Y	Y	Y	79.1	4.54		Y	Y
7		Y	Y	Y	Y	Y	83.4	6.04		Y	Y
8		Y	Y	Y		Y	63.3	5.61	Y	Y	Y
9		Y	Y	Y			60.3	7.61	Y	Y	Y
10			Y	Y		Y	56.5	6.06	Y	Y	Y
11			Y	Y			37.9	4.89		Y	Y

Table 6.3 — Summary of the multiple regression statistics based on variations of factors included in the regression. This table is based on low tide data. Note that  $R^2$  values are returned as percentages.

The low tide data suggests that the three variables that best predict the migration rate of the seaward end of the channel are the average wave period, the average wave direction and the average river flow rate (F-ratio is maximised at 7.61 and the  $R^2$  value is high at 60.3). This result is also significant to the 99% confidence interval.

Cases	Av H	Av T	Av Dir	Av Flow	Av LagWL	Orient	R squared	F-Ratio	Sig 99%?	95%	90%
1	Y	Y	Y	Y	Y	Y	46.8	0.881			
2	Y	Y	Y	Y	Y		40.3	0.944			
3	Y	Y	Y	Y		Y	56.5	2.85			Y
4	Y	Y	Y		Y	Y	23	0.417			
5	Y	Y		Y	Y	Y	44.5	1.12			
6	Y		Y	Y	Y	Y	35.9	0.783			
7		Y	Y	Y	Y	Y	45.9	1.19			
8	Y	Y	Y	Y			55.3	3.72		Y	Y
9	Y	Y	Y			Y	13.6	0.474			
10	Y	Y		Y		Y	49.4	2.93			Y
11		Y	Y	Y		Y	49	2.88			Y
12		Y	Y	Y			47.1	3.86		Y	Y
13			Y	Y			38.5	4.39		Y	Y
14		Y		Y			41.5	4.96		Y	Y

Table 6.4 — Summary of the multiple regression statistics based on variations of factors included in the regression. This table is based on high tide data. Note that  $R^2$  values are presented as percentages.

High tide data suggests the most important variables for the prediction of the seaward end of the channel are also the average deep-water wave period and direction and the average river flow rate. These relationships are not as strong, only significant to the 95% confidence interval. When the three above mentioned variables are used for a multiple regression analysis of the migration rate of the seaward channel end neither  $R^2$  nor F-ratio is maximised, however a good balance of the two is achieved. The instances where higher values are achieved of one or the other, while remaining significant, include at least two of the most important variables mentioned earlier.

## **6.4 Discussion**

The lack of readily identifiable patterns is indicative of the complex nature of the environment and relationships between the forces and responses. This was expected given the findings of Todd (1992) who found that data from his study did not agree with existing theories. The behaviour at times may be attributed to

factors that are beyond the scope of this project. Antecedent morphological features may be important in the behaviour of the channel but the measurement of these is not possible without large inputs of manual labour. Presently the only method to record topographic data would be to repeatedly survey the barrier over the study period.

The channel was not expected to migrate alongshore in response to a change in sea level due to tides. Some of this response may be attributed to an effect of the orientation of the channel. The drop in sea level may cause a channel offset both seaward and in the same direction as the channel is oriented (See Figure 6.5).

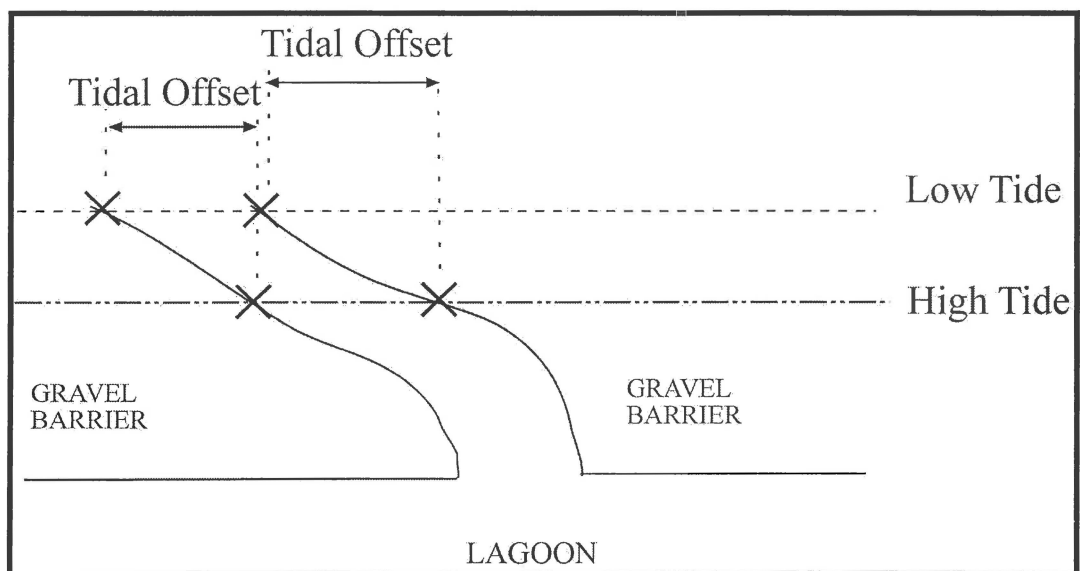


Figure 6.5 — The possible mechanism by which the seaward end may migrate in response to tidal variation. This process however cannot account for migration at the lagoon end.

This effect however would not explain the observed differences in location at the lagoon end of the channel. Thus it was concluded that at least a portion of the error must be attributed to an error in the rectification procedure. To remove this source of error channel data was provided corresponding to high tide or low tide. This would remove variation attributed to tidal variation thus migration rates would be more representative of the actual situation.

When this data was analysed using Spearman rank correlation several relationships were identified. The relationship between wave period and height

suggests that as wave height increases there is a similar increase in the wave period. This relationship is expected given that wave prediction models such as JONSWAP show that an increase in wave height will produce a coincidental increase in period (deLange, 1997). The relationship between period and direction suggests that longer period waves are sourced from the south. These findings reinforce past reports, which state that the wave climate is dominated by swell waves from the southern ocean.

The relationships between river flow rates and wave statistics may be related to the regular progression of cold fronts that move up the coast from the south. The flow rates appear to increase with an increase in wave angle and a decrease in wave period. This suggests that rainfall may be associated with short period waves from the south – such as is associated with a locally generated sea which would occur with a northward moving weather system.

The lagoon water level shows a relationship with the wave direction and height. This may be attributed to the effect of larger waves, which originate from the south, causing a greater setup at the coast which decreases the head gradient in the channel, thus the lagoon level rises as the ability to drain is reduced.

The effect of a raised water level at the coast on the percolation of water through the barrier would cause further increases in the lagoon water level. The higher water level would increase the height of the beach water table, thus decreasing the head and the through flow of water. This concept is discussed further in Nielsen (1999).

The negative relationship between orientation of the channel and lagoon water level is explained by the effect that channel orientation has on the drainage capacity of the channel. When the channel orientation decreases it signifies an increase in channel length as the channel is aligned closer to shore parallel. The longer channel has a coincidental decrease in water surface gradient, thus the discharge from the lagoon is reduced. The decrease in discharge will relate to an increase in water level in the lagoon.

Orientation of the channel is also positively correlated to deep-water wave period. A decrease in wave period is associated with erosive conditions at the shore. The effect of waves on channel migration as suggested in chapter 5 is to increase channel migration through erosion of the landward bank of the channel. When wave period decreases, therefore, it is sensible to expect an increase in the channel migration as an effect of the increased erosion of the channel margin. This effect also explains the negative correlation between wave period and the migration of the seaward end of the channel.

Wave direction does not show a relationship with wave height, contrary to previous reports and findings based on results from this study. This can be accounted for by a larger than normal proportion of waves propagating from the north (See Figure 6.6). A clear statement cannot be made, as to the negative relationship between the migration of the channel at the seaward end and wave height, because there is no clear direction from where large waves are coming from. This is considered to be vital in defining the relationship between wave height and channel migration. This highlights the need for a greater sized dataset for analysis of the relationships between the channel migration and the wave and fluvial driving forces.

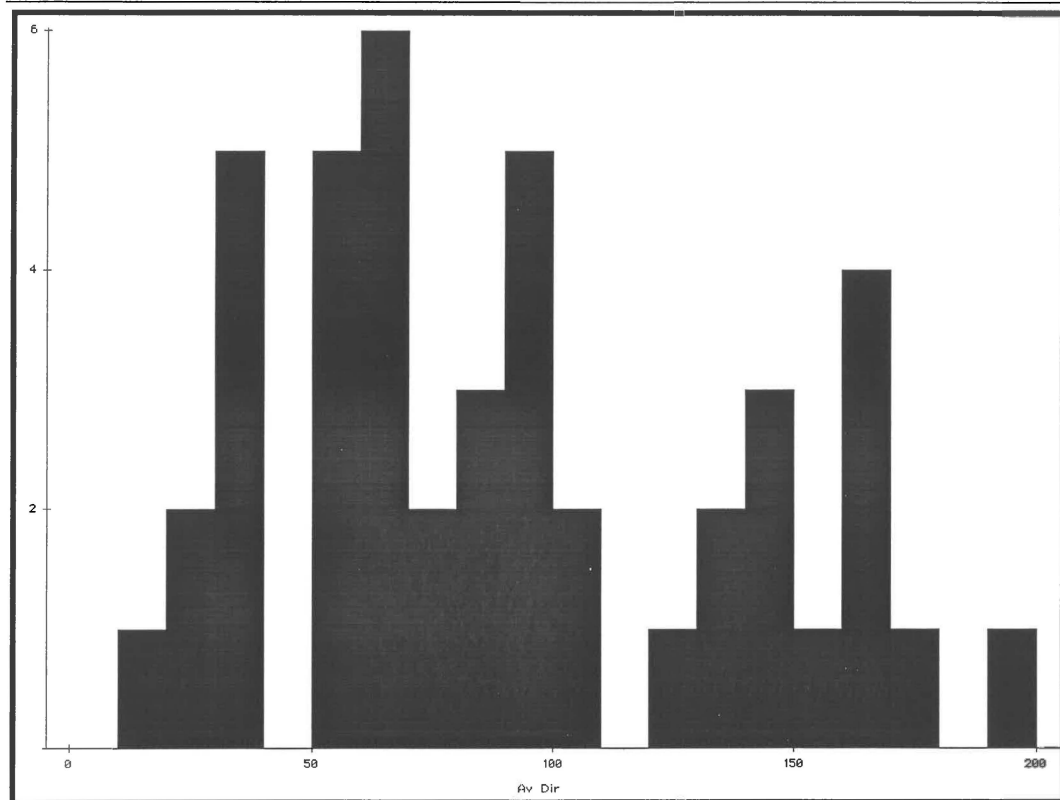


Figure 6.6 — Histogram showing frequency distribution of wave direction during the period 6 February – 21 March.

It is possible however, that the increased wave height may bring about an apparent southerly migration of the seaward end of the channel through an increased landward extent of the swash zone. As wave height increases there is a positive relationship with swash excursion distance (Kirk, 1980). This may cause an apparent southerly migration of the channel in the same manner as a changing tidal elevation as indicated in Figure 6.5. It would be unlikely that this would always be the case however, as this would only occur if a snapshot always captures an image showing the maximum extent of the swash and the channel is consistently angled to the north-east.

Flow rate increases can cause increase in flow through the drainage channel of the lagoon. The increase in flow through the drainage channel will cause accelerated erosion of the banks of the channel. The effect of differential current velocities across the channel causes the outside bank of a bend in the channel to undergo greater erosion than the inside bank. Thus it can be expected that as flow increases a northerly offset of the lagoon end of the channel can be expected.

This may occur up to some undefined flow rate where the channel can no longer cope with the influx by increases in channel cross-sectional area, and the channel becomes unstable, migrating to a point to the south in a breaching event.

The landward and seaward ends of the channel do not behave independently of each other. For the seaward end of the channel to reach its northern extreme offset, the location of the lagoon end of the channel must also move northwards else the channel length would become too great to maintain its connection to the sea. Likewise, as explained in the preceding chapter, the pattern of migration of the lagoon end of the channel requires offsetting of the seaward end of the channel to initiate the lagoon end movement. Thus the positive relationship between these variables is expected.

The differences between correlations at high and low tides were examined using multiple linear regression analysis. The migration rate of the seaward channel end was used for this analysis as it was doubtful that the lagoon channel end migration rate would be well described by linear regression, given the stepping pattern of its migration. The orientation of the channel was therefore not analysed as a dependent variable as it would be related to the migration of the lagoon end of the channel.

The results from the multiple regression analysis suggest that, at both high and low tide, the same variables are best used to predict the migration rate of the seaward end of the channel. Those variables are the average wave period, average wave direction and the average river flow. Noteworthy is that the good relationship between wave height and migration of the seaward channel end, found using Spearman rank correlation, is not supported by the multiple regression analysis.

Wave period shows a negative relationship with the migration of the seaward end of the channel (See Table 6.5). This can be explained in much the same manner as the relationship between channel orientation and wave period found using the Spearman rank correlation results. A decrease in wave period is associated with stormy seas, short steep waves and erosive conditions at the shore. Thus we can

assume that the erosion by waves of the channel bank is exacerbated, leading to increases in migration rates.

Dependent variable is: Sea M LT					
No Selector					
44 total cases of which 25 are missing					
R squared = 60.3%    R squared (adjusted) = 52.4%					
s = 36.27 with 19 - 4 = 15 degrees of freedom					
	Source	Sum of Squares	df	Mean Square	F-ratio
	Regression	30027.3	3	10009.1	7.61
	Residual	19729.4	15	1315.29	
	Variable	Coefficient	s.e. of Coeff	t-ratio	prob
	Constant	196.239	61.82	3.17	0.0063
	Av T	-33.9638	11.66	-2.91	0.0107
	Av Dir	0.263202	0.2144	1.23	0.2386
	Av Flow	-0.00523255	0.001354	-3.86	0.0015

Table 6.5 — Multiple regression results table for low tide data.

The positive relationship between wave direction and channel migration at the seaward end represents the first evidence of a relationship between channel migration and the direction of littoral drift. As the angle of wave approach increases, indicating a more southerly wave climate, the channels seaward end will migrate to the north. The migration is driven by longshore transport filling the updrift margin of the channel, causing spit elongation, and driving the channel location in a downdrift direction. This process is further explained in Chapter two of this work.

The migration of the channels seaward end in response to river flow is described by a negative relationship. This implies as river flow increases, the seaward end of the channel migrates to the south. This can be explained by changes to the drainage ability of the channel that are forced when the river flow increases. As alluded to earlier, the more shore normal the channel orientation the greater the flows through the channel, as the head gradient is maximised. This will occur

when river flow is high as the lagoon tries to discharge the greatest volume of water possible through the existing channel.

A period of *in situ* wave recording would have been useful to better establish relationships between breaking waves and deep-water waves. Modelling of waves from the deep-water wave buoy location to Ashburton River mouth would also be possible if data could be provided for calibration. Data on breaking wave conditions could present better relationships with morphological response.

A better understanding of the relationships between wave conditions and longshore transport of gravel would undoubtedly prove useful for further analysis of the migrational behaviour of the channel. The assumption that longshore transport is proportional to alongshore wave energy flux has been made. This assumption needs to be validated or refuted to determine the precision of channel migration theories.

Water level is often measured in conjunction with video camera studies, which, in retrospect, is judicious given that modelling of the tidal elevation to supply this data appears to introduce errors in rectification. The level to which images are rectified is the elevation at which measurement will be most accurate. As this level changes over time it must be determined for each image. The use of the tidal model has introduced a systematic error in the estimation of the channel ends, thus requiring our data to be reduced to daily averages.

Analysis of wave statistics provides results which support previous descriptions of the wave climate of the Canterbury Bight. The predominant direction from which long period waves are sourced was determined to be the south. Relationships between the wave climate and the river flow rates are also attributed to the regular frontal weather systems moving along the coast.

## **6.5 Conclusions**

Problems with the full dataset gathered over this study resulted in only a fraction of the total available data being used. The dataset that was eventually provided was not representative of the wide range of channel conditions that have been

experienced over the study period. Due to these problems results must be considered qualitatively as opposed to quantitatively.

The use of video cameras to record wave angle at the shore on steep gravel beaches may be less appropriate than on low gradient sandy beaches where waves shoal and break more gradually and reflected waves are rare. Variations in breaking wave type are responsible for this inaccuracy, thus beach slope and consequently breaking wave type should be considered when video cameras are used to record wave angles.

The complex nature of interactions between the forcing processes and morphological response requires a more intensive statistical analysis. While simple regression and time series analysis provides some insight into these relationships, with a larger dataset, multiple regression analysis and Spearman rank correlation should provide better and more statistically significant results.

It has been identified that the lagoon water level is influenced by wave conditions. It is suggested that this is a result of the wave setup at the coast causing decreased drainage ability of the lagoon. The drainage through both the channel and through the barrier by percolation will be reduced under higher open coast water levels as the head difference is reduced. This finding contradicts Kelk's (1974) suggestion that percolation is not an important factor at this location.

Orientation of the channel has been shown to be controlled by the wave period and the lagoon water levels. A decrease in wave period may accelerate erosion of the channel in a manner described in chapter 5 such that northerly migration of the seaward end of the channel is increased, thus orientation is decreased, given that the lagoon end of the channel remains stationary. The effect of a decrease in orientation on lagoon water level is that the channel head gradient will decrease as the channel lengthens, to retain a connection with the sea, causing a reduction in drainage capacity of the channel.

The migration of the lagoon end of the channel is related to the river flow rate. The lagoon end channel migration can be attributed to an erosion of the channel margins from the differential current velocity of water moving through the

channel. This process will cause an offset of the channel location to the north, given that the channel is predominantly offset to the north.

The migration of the two ends of the channel are correlated as neither operates independently of the other. Northward migration of the lagoon end of the channel requires and preempts a northward migration of the seaward end based on the patterns of migration that have been presented. Likewise the location of the seaward end of the channel is correlated to the location of the lagoon end of the channel.

While it is expected that there will be differences between the processes in operation and their effect at high and low tides, based on multiple linear regression analysis of the data we have gathered, the best predictors of the migration of the migration of the seaward end of the channel are found to be average river flow, average wave period and wave direction.

River flow causes a straightening of the channel to maximise the flow rate and thus drainage capability of the channel. As the channel is predominantly oriented to the north, this straightening requires either a northerly migration of the lagoon end of the channel or, southerly migration of the seaward end of the channel.

Wave direction is positively correlated with migration of the seaward channel end which agrees with existing theory. As wave direction increases, signifying waves propagating from the south, the channel moves to the north in response to littoral drift of gravel also being directed to the north.

# Chapter 7 - Summary and Conclusions

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## 7.1 Summary of Key Findings

The morphodynamics of a river mouth and lagoon on a mixed sand-gravel shore were studied utilising data from a Gravel Transport Sensor (GTS) and a computer controlled video camera system.

The GTS was used to measure gravel transport in the swash zone. The instrument was modified and calibrated so that it returned a volumetric rate of longshore transport based on the number of particles impacting upon the GTS deployed in the swash zone. After trials on a similar beach in Napier, the instrument was deployed at the Ashburton hapua on the Canterbury coast but with limited success. It was discovered that the beach sediment dynamics of Napier and the Canterbury Bight coast differ considerably. In particular the sediment size distribution varied greatly over the period of measurement at the Ashburton river mouth where the instrument was not able to provide precise measures of longshore transport.

A video camera, mounted on a pole took images hourly of the barrier and lagoon. Methods were developed to assess and account for various factors affecting image quality including camera movement. Rectification procedures were affected to differing degrees because of varying water levels in the lagoon, river and offshore. Tidal predictions were used but retrospectively a more precise method should be employed using *in situ* instruments to measure all water levels thus giving providing more accurate image rectification.

Techniques to extract data from the video images were developed. While it was a relatively simple procedure to digitise morphologic features, considerable thought and trials were necessary to define the features worth parameterising, such as the channel edges. Morphological definition was difficult when the barrier was

overwashed, for cases of more complex channel forms, instances when the lagoon water level was extremely low and for variations of the open coast water level causing inconsistencies in digitised points. Combining the hourly images into \*.avi movies was found to be a useful medium for analysing morphodynamic change.

It was found that some limitations were imposed on data resolution as pixel footprint size increases with increasing distance from the camera such that important geomorphic parameters such as the channel location were not readily parameterised at distance from the camera. Increased resolution also would have provided more accurate measurement of features in the foreground, such as the lagoon water level.

Over 6500 images of the channel and hapua environment have been collected during daylight hours. There were a few interruptions as a result of system failure. However, the record could be improved if there was a location to site the camera where a greater length of the gravel barrier could be viewed so that the river mouth could be recorded more frequently. Interpretation of the results would have been improved if the records of supporting data from the wave buoy and tides were more continuous.

Despite these shortcomings, the use of a video camera to monitor and study the hapua environment has been very successful in that most previous studies of hapua have been forced to rely on infrequent and relatively expensive traditional survey methods to record changes in the morphodynamics. In contrast the camera provides a relatively inexpensive tool supplying voluminous data to the user for minimal inputs of labour.

Existing theories of channel migration on mixed sand-gravel shores are based on inlet stability theories which describe offset of an inlet or channel as a result of the direction of the prevailing littoral transport. Balancing this process is the river flow or tidal prism acting to maintain a connection to the sea. At the Ashburton hapua this theory holds true, in at least a qualitative sense, as the predominant direction of longshore transport and channel migration is to the north. While the

seaward end of the channel migrates to the north over time at varying rates, it has also been observed to migrate to the south on occasions.

It was found that the seaward and lagoon ends of the river channel behave differently, but not independently. The seaward end of the channel has a more variable location that is fairly evenly distributed across the field of view. Its variability is attributed to the higher energy of that end of the channel due to wave breaking and the resultant gravel transport.

In contrast the lagoon end of the channel moves about less on a daily scale and in a series of discrete 'steps'. Its behaviour is driven by extreme episodic fluvial or marine events, such as river floods or barrier overtopping by waves. For much of the time the lagoon end of the channel is protected from the littoral processes by the gravel barrier.

It is considered that episodic events play a greater role in the river mouth and lagoon morphodynamics than previously thought. Migration of the channel as a whole is strongly influenced by the nature of the events and the order with which they occur. It is suggested that processes such as longshore transport make changes to the channel orientation and the location of the seaward end of the channel, but that episodic events make changes to both these points and the location of the lagoon end of the channel.

The pattern of northward channel migration at the Ashburton hapua is schematised in Figure 7.1. The pattern that is described expands on work from Kelk (1974), Kirk (1983) and Todd (1983, 1985, 1992). The channel migrates north under the influence of longshore transport with the length of the channel extending during this process. Eventually the channel becomes unstable and a new exit to the sea, through a shorter channel, is formed. This pattern however, may be interrupted by an extreme event. River floods breach the barrier to the south. After such an event, and given northward littoral transport, northward migration of the channel reoccurs.

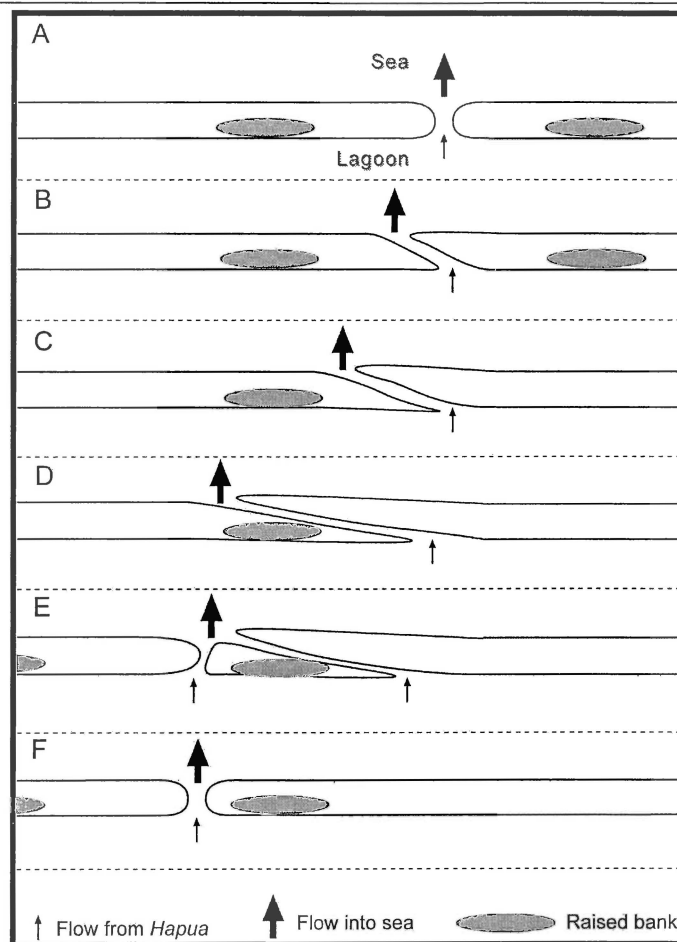


Figure 7.1 — Channel migration pattern as determined using the record of video images from this investigation.

An important finding of this study is that the migration of the channel is influenced by ‘raised banks’, which are the only morphological features having any permanence on the barrier. Surrounding these banks are several locations from which the channel preferentially exits. The origins of the banks are unclear, however the fact the channel to the sea never cuts through the raised banks suggests they have a strong influence on the channel migration patterns.

Statistical analysis has explored the relationships between the measured wave and river processes and the morphological responses. It was found using Spearman rank correlation, that lagoon water level was influenced by wave conditions, primarily the wave height, which may relate to drainage of the hapua being impeded under stormy wave conditions.

The wave period and the lagoon water level are related to the orientation of the channel. The channel may become more shore normal under longer period waves and more shore parallel under short period waves. This may affect the lagoon water levels again by influencing the drainage ability of the channel.

Migration of the lagoon end of the channel was found to relate to the river flow rate. At the seaward end of the channel the migration is best predicted by a combination of the average river flow rate, average wave period, and the average wave direction. Most importantly, the relationship between the average wave direction and the migration of the seaward end of the channel is the first quantitative evidence of channel migration being correlated to the direction of longshore transport.

This study has provided observations, quantitative measurements, and a model of the migration of the drainage channel of the hapua. Relationships that occur between the wave climate and river flow rate and the migration of the channel are complex, but the presence of 'raised banks' on the barrier, the average and extreme wave climate and flood events are the most significant factors defining the observed patterns.

## **7.2 Recommendations for Future Research**

There are few instruments available for the measurement of longshore transport. The GTS may play a role in future work in this field. However further development of the instrument is required to better understand the relationship between impacts counted and the volume of material being transported. This will require improved understanding of the processes of longshore transport and sediment dynamics on gravel and mixed sand-gravel beaches.

Rectification of images requires the measurement of planes of rectification. In situations like the Ashburton hapua, where water levels vary between the lagoon, the river channel, and the open sea, the development of a technique to rectify to an inclined plane, or measurement of all planes to which images must be rectified is ideally necessary.

Measurement of wave angles on steep beaches using video proved difficult. At this site measurements of breaking wave angle should be made using traditional instrumentation. With data on breaking wave angle provided through other means, averaged images can be used rather than snapshot images. This will provide more accurate definition of the points which describe the channel.

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