Lessons From The Past - A History of Coastal Hazards at South Brighton Spit, Christchurch.

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Frontispiece:
South Brighton Spit looking south to Shag Rock
(Photo: Lloyd Homer, taken on 14 November 1991)

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Abstract

This thesis provides a history of coastal hazards at South Brighton Spit, Christchurch, through the description and documentation of past coastal hazard events. South Brighton Spit is one of the most intensively developed coastal landforms in New Zealand. Together with the natural fluctuations associated with spit landforms, this provides a useful base for an examination of coastal hazards in a dynamic and high intensity-use coastal environment. The study period is from the establishment of the Southshore Ratepayers' Association in 1946 to 1995, and was delineated as such due to the lack of residential development prior to 1946. Conceptually this thesis is based on the small amount of literature on the interaction between dynamic spit environments and the human use system. It is this interaction between the physical and human systems which creates the potential coastal hazards.

There is a popular belief that erosion of the open coast side of South Brighton Spit is the only major coastal hazard to occur there. This is not true. Erosion of the Avon-Heathcote Estuary margin, flooding from the estuary, and tsunami all present major hazards to residents of the spit. The assets at risk include 650 houses valued at $75.6 million. Within the study period there have been five coastal or estuary erosion events, four flooding events, and one tsunami. In total over the last 140 years there has been 38 different coastal hazard events, including 18 coastal or estuary erosion events, nine flooding events, and seven tsunamis - four of which had an impact on the spit. In addition there have been two prolonged periods of erosion - one on the coast and the other on the estuary foreshore. Prior to the construction of stormwater drains in the late 1970s, the area was prone to prolonged periods of flooding. Such a dynamic and hazardous environment requires co-operative and integrated management of the spit between the Regional and City Councils. This thesis provides the first step in managing hazards by identifying those occurring in the area.

Chapter One
Introduction

1.1 Introduction

> Spits and bars in populated areas throughout the world are being encroached upon by some form of human exploitation. Too often after the fact, when the morphology of the structure continues its relentless changes, does the populace become aware of what is then called an emergency condition. Suddenly countermeasures are taken to remedy what was inevitable to begin with (Schwartz, 1972, 1).

This thesis investigates the "inevitable" outcome of populated spits as applied to South Brighton Spit, Christchurch. The aim of this research is described in the following section, together with a brief description of the spit that is under investigation. This chapter then moves on to examine the conceptual context of this research, through an examination of various definitions and conceptualisations of hazard. The importance of researching hazards, especially coastal hazards is also examined. Previous research into the study area and coastal hazards are reviewed. An outline of the following chapters is also given.

1.2 Research Aim

The aim of this thesis is to provide a history of the coastal hazards at South Brighton Spit, Christchurch, in order to gain a fuller understanding of those hazards that occur in the area. Erosion of the coastal side of South Brighton Spit has previously been perceived as the only major hazard that occurs. This research also aims to change this perception by acknowledging that other types of hazard events can and do occur at South Brighton Spit, and that these hazards can have just as large an impact on the study area as erosion of the open coast. A major aspect of changing this present perception requires the description and documentation of all recorded hazard events that have occurred within the study area. In effect this covers the period from the establishment of the Southshore Ratepayers' Association in 1946 to the present. 1946 was also used as the historical cut off point for this study. Prior to this, Southshore was not a residential area.

Management and planning implications of the findings of the research will be discussed in relation to the plans of the Christchurch City Council and Canterbury Regional Council. The literature which provides the conceptual basis for this study is small. Thus this research will be adding to this literature, especially in relation to the interaction between dynamic spit environments and the human use system by taking an integrated geographical approach to the examination of coastal hazards at South Brighton Spit.

South Brighton Spit, which contains the residential suburb of Southshore, is located on the eastern edge of Christchurch and forms part of the long curved part of the Canterbury Coast known as Pegasus Bay, as shown in Figures 1.1, 1.2 and the frontispiece of this thesis. The spit is bounded by the Avon-Heathcote Estuary on its landward side and Pegasus Bay on the Pacific Ocean side. A detailed description of how South Brighton Spit developed and a history of its human use is given in Chapter Two. As the Avon-Heathcote Estuary is part of the Coastal Marine Area, as defined under the Resource Management Act (1991), the investigation into coastal hazards within the study area will look at both the estuary and open coast sides of the spit. The coastal hazards that have been identified as occurring at South Brighton Spit are beach, dune and estuary erosion, flooding and salt water inundation, and tsunami. Of these, tsunamis occur less frequently, however they can have the greatest impact on the study area when compared to erosion or flooding. These latter hazards occur more frequently, have a smaller impact on the whole study area, but have a large impact for specific sites. The study area has been restricted to that part of the spit south of Caspian Street (Figure 1.2), the area is known locally as Southshore.

A holistic approach was taken in the research at South Brighton Spit. This means that both the physical evolution and human development of South Brighton Spit were investigated to gain a full appreciation of the study site. The human and physical aspects of the environment and hazards were also examined in order to obtain a better understanding of the events that have occurred there. The methods undertaken for this research have been mainly humanistic and qualitative in their approach. Archival sources have been the basis for much of the information regarding past hazard events, in particular the archives of the old Christchurch

Drainage Board (now part of the Christchurch City Council) and the Southshore Ratepayers' Association. Local newspapers from the last 150 years were also an important source of information. These have been supplemented with reports from the two local authorities and anecdotal information from interviews with local residents. Quantitative information concerning both the physical and human aspects of the spit and the hazards was gathered from these sources ,as well as through the profiling of six sites around the spit.

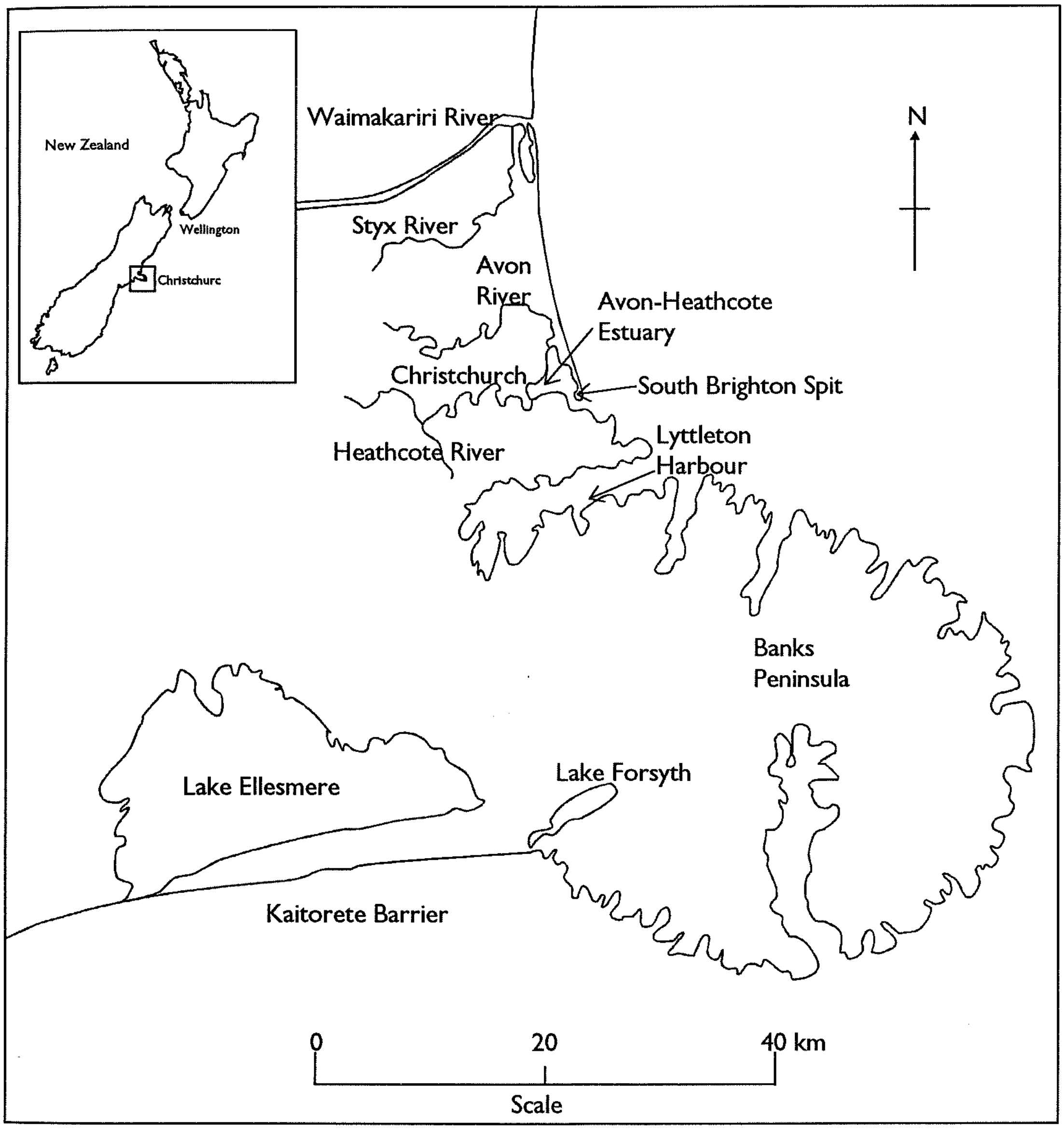


Figure 1.1 **Location Map of Christchurch**

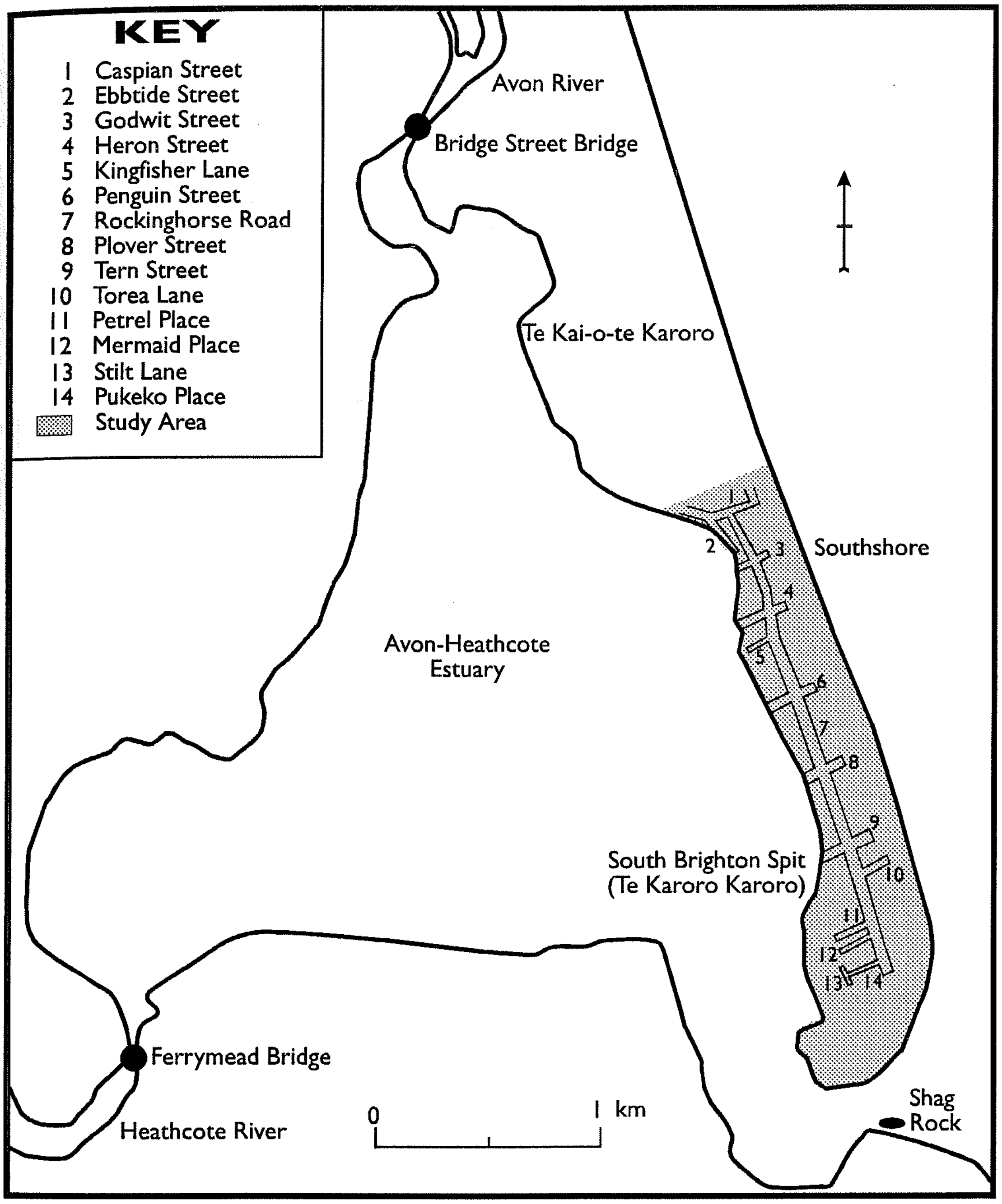


Figure 1.2 Location Map of Study Area.

1.3 The Concept of Hazard and Coastal Hazards

Burton, Kates and White (1978) defined hazard as the risk encountered in occupying a place that is subject to a natural event, such as flooding. They went further and stated that hazard is the negative interaction between the human use system and the natural events system, as shown in Figure 1.3. The human use system includes all possible human uses of land, for example residential, transportation, communication and food production. The natural events system is created through the interaction of the atmosphere, biosphere, geosphere, and hyrdosphere. A positive interaction between the two systems creates resources (the left side of Figure 1.3), while a negative interaction creates hazards (the right side of Figure 1.3). A hazard may lead to a variety of responses which can be executed by either system, and in turn can affect both systems. The important aspect of the model in Figure 1.3 is that it is the interaction between the two systems which may result in a hazard. For example a mountain stream bursting its banks and flooding the surrounding valley does not present a hazard until there is some form of human use of the area, such as a tramping hut next to the stream that is affected. Burton, Kates and White, however state that although the interaction of the two systems creates the hazard, the systems cannot in themselves be equated as causes of hazard. They go on to state that:

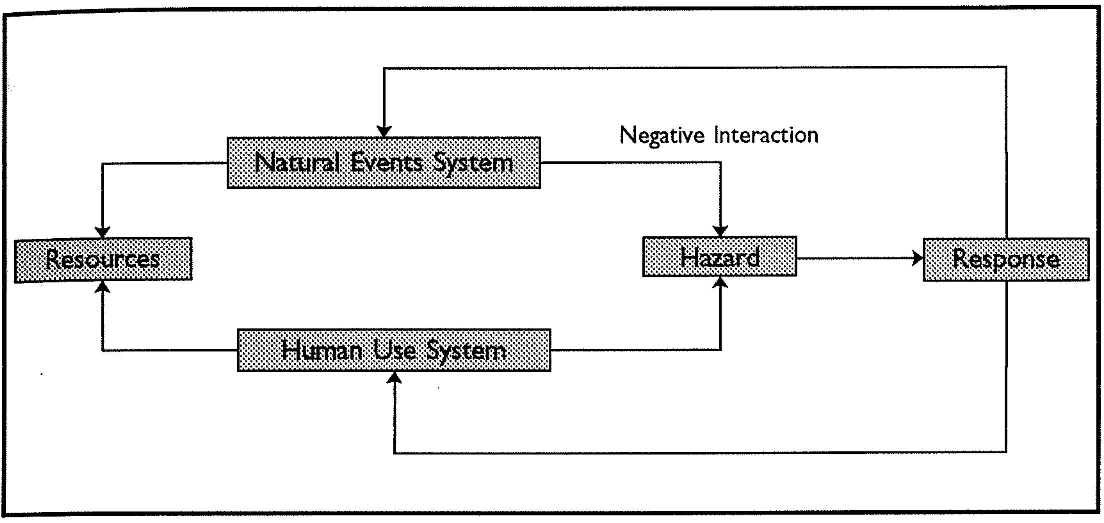


Figure 1.3 The Interaction Between the Human Use System and the Natural Events System. (Source: Burton, Kates, and White, 1978, 20)

> Natural systems are neither benevolent nor maliciously motivated toward their members: they are neutral, in the sense that they neither prescribe nor set powerful constraints on what can be done with them. It is *people* who transform the environment into resources and hazards, by using natural features for economic, social, and aesthetic purposes (Burton, Kates and White, 1978, 19-20).

Thus when a hazard event, such as flooding, occurs it is due to the human use of an environment in which flooding is a natural and normal event, as opposed to the biblical and mythical stories of the wrath of God or Mother Nature.

Erickson and Barbour (1986) on the other hand, believe that hazard is the potential for disaster. In their discussion on natural hazards they state that:

> When extreme natural events occur in an area occupied or used by people, the effect of these events (or their impact) results in a 'disaster' or 'catastrophe'. Natural events and disasters resulting from them are NOT, however natural hazards. The 'hazard' is the *potential for disaster*. The natural hazard is the *relationship* that can be seen between a potential event in a given area and the actual or potential human occupation or use of that area (Erickson and Barbour, 1986, 132).

This is more easily shown in their diagram of the distinction between natural hazards and natural disasters, as shown in Figure 1.4. Thus they believe that an isolated mountain stream presents a flooding hazard due to the streams potential to flood, combined with either the actual or potential use of the surrounding valley. Upon the stream flooding the valley a disaster will result. Although Erickson and Barbour appear to agree with Burton, Kates and White on there needing to be some form of human use of an area that is subject to a extreme natural event, their usage of the word potential in terms of human use alters their perspective altogether. By the inclusion of the word potential in terms of human use, Erickson and Barbour

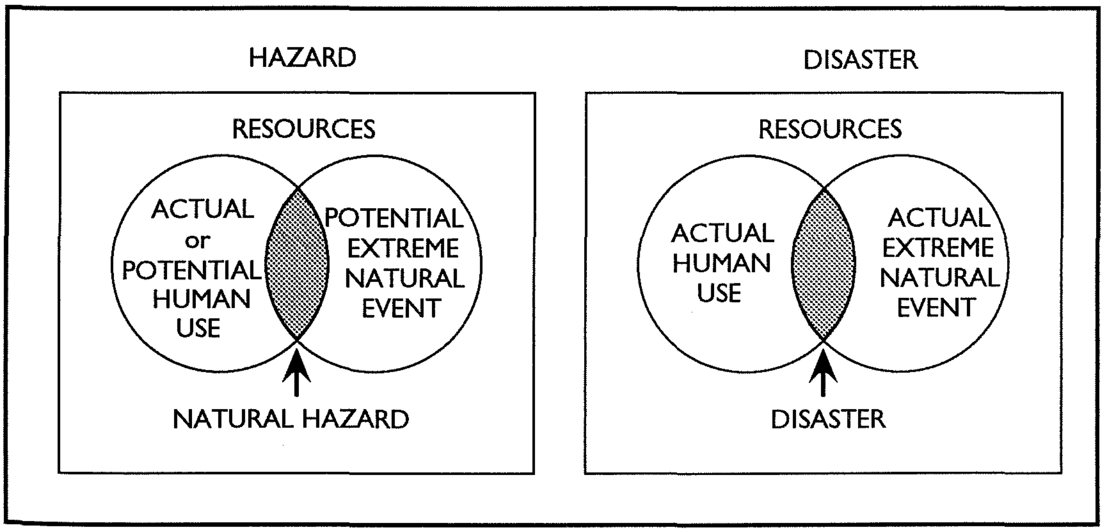


Figure 1.4 The Distinction Between Natural Hazard and Natural Disaster. (Source: Erickson and Barbour, 1986, 133)

are saying that a hazard is present in an area even if there is no current human use, because the area may be subject to use at some point in the future. This could mean for example that a meteor strike on the Moon is a natural hazard due to the potential of human use of the Moon for say residential purposes at some future date.

Erickson and Barbour's definition of a natural hazard is similar to that provided in the Resource Management Act (1991), in that the Act refers to the possibility that the natural events mentioned may affect human life or property. The Act defines a natural hazard as:

> ... any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire or flooding) the action of which adversely affects or may adversely affect human life, property or other aspects of the environment (Resource Management Act, 1991, s.2).

This is a comprehensive definition, however it implies that the natural events themselves are hazardous, rather than there needing to be some form of human use involved. This implication comes from the use of the term 'other aspects of the environment'. This is an ambiguous term that could mean the flooding of the isolated mountain stream, mentioned above, would be a natural hazard because it could adversely affect the surrounding valley. Because of this ambiguity, the concept and definition of hazard provided by Burton, Kates and White (1978) has been adopted for this research, as it implies some form of value associated with the land affected by a natural event. That value takes the form of human activities and assets, including human life, as opposed to aesthetic values.

In trying to conceptualise coastal hazards for this study, Burton, Kates and White's model (Figure 1.3) was expanded to concentrate more specifically on the coastal environment, as shown in Figure 1.5. The coastal environment is dynamic, and the links within the environment between the physical and human systems are shown in Figure 1.5. In the coastal system the atmosphere, biosphere, geosphere and hydrosphere meet in complex interaction. This interaction is the generating force for the coastal processes that underlie and can result in hazards. The processes themselves are not hazardous, and are mainly water and wind related.

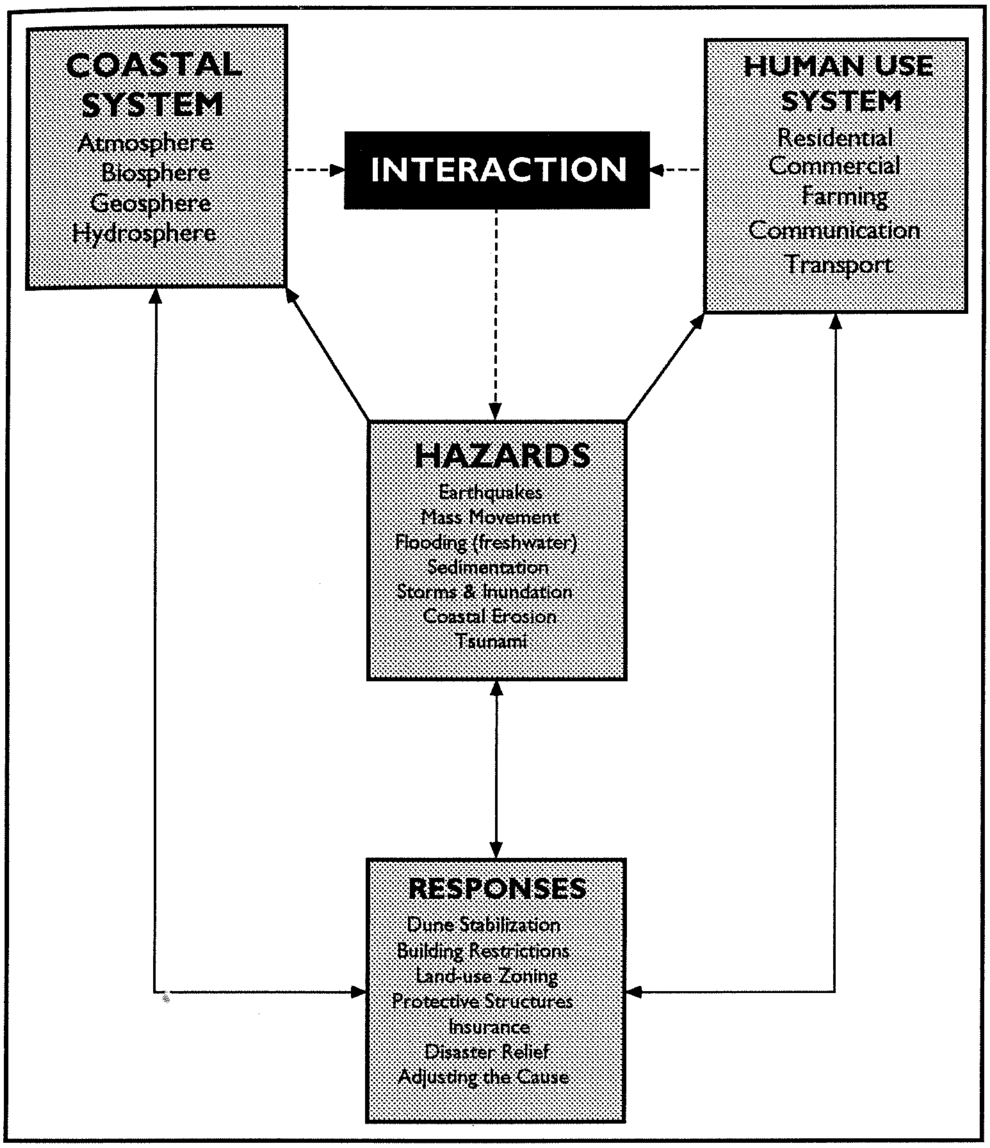


Figure 1.5 **The Coastal Environment as Hazard**

Examples of such processes are barometric lift of sea level, and sediment transport by waves. These processes only become hazardous when there is interaction between the human use system and the coastal environment, as indicated by the dashed lines in Figure 1.5. The human use system takes many forms, including:

- dwellings - from small holiday and rural settlements to large cities;
- urban infrastructure - such as sewerage treatment plants, airports and shopping centres;
- farming - all forms thereof, such as agriculture or horticulture;
- communication links - especially landline telecommunications;
- transportation links - road, rail, and port facilities;

- extraction of sediment; and
- recreation.

The interaction that occurs between the coastal system and any part of the human use system is what creates the hazards. Without this interaction there is no hazard. The hazards that are commonly found on the coast are:

- earthquakes;
- mass movement, typically of coastal cliffs;
- flooding from freshwater sources into estuarine and lagoon systems;
- sedimentation from rivers;
- storms and associated sea water inundation;
- erosion of beaches, dunes, and cliffs;
- tsunami; and
- long term change (after Kirk and Todd, 1994).

These hazards when they occur, have an impact on both the coastal and human use systems, as well as having an impact on the responses undertaken, as shown by the solid lines in Figure 1.5. This impact can be on either a temporary or permanent basis. Examples include damage to assets and loss of life for the human use system. The uplift of a large section of the sea bed during the Napier earthquake in 1931 altering the shoreline configuration and adding many hectares of land above sea level is an example of a more permanent impact of a hazard within the coastal system. The type of hazard that occurs is important, as it will affect the responses undertaken. Typical responses from the human use system to the hazards listed above are:

- dune stabilisation;
- building restrictions;
- land-use zoning;
- protective structures;
- insurance;
- disaster relief; and
- some form of adjustment to the cause (after Kirk, 1987).

Not only can these responses have an impact on the hazard itself, for example the stabilisation of eroding dunes, but they can also have an impact on the two systems. Examples of this are the building of protective structures like seawalls which alter the configuration and processes of the coastal environment, while land-use zoning will affect the human use of the coast. The coastal system may also naturally respond to a hazard event, such as by the gradual replacement of sediment removed from a beach by storm waves.

1.4 The Importance of Researching Hazards

Having outlined the aim of this research and defined what constitutes a hazard, and more specifically a coastal hazard, it is appropriate now to consider the reasons why coastal hazards and hazards in general are an important topic of research. Although hazards affect both the human and natural systems, their greatest effect is felt within the human use system. Thus the burden of dealing with the hazards and their consequences falls on the shoulders of humans. There is a need to understand not only what constitutes a hazard but also the consequences, impacts and history of that hazard. This understanding is imperative, so that appropriate responses to the hazard can be made. Such responses may be directed at the physical processes that underlie the hazard or the human use of the area in question, thereby reducing the potential of future hazards. Other responses that can be undertaken may be directed at the consequences and impacts that the hazard has on the human use system, in order to diminish these the next time the hazard may occur. For decision-makers to make the correct response to the coastal hazard, they must be well informed on all aspects of that hazard. Thus there is a need to understand fully the coastal processes at work, the human element involved, the effects of both these systems separately on the environment, and their combined effect which manifests itself as hazard. By researching any one of these aspects, the knowledge pool on which decision-makers can draw in determining appropriate responses is increased.

The expansion of this knowledge pool can be seen as being the basis of the six internationally recognised principles of coastal resource management as prescribed by Sorensen (1992) and shown in Figure 1.6. These six principles are understanding, identification, quantification, planning, monitoring, and

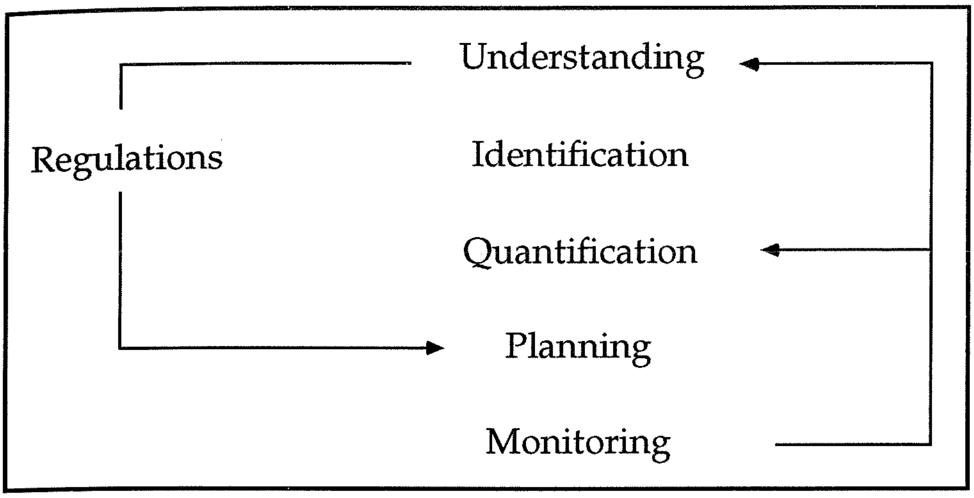


Figure 1.6 **Principles of Coastal Resource Management (Source: Sorensen, 1992)**

regulations. All six principles must be applied in Sorensen's view, if an efficient and effective approach to a particular problem is to be achieved. Thus, in terms of coastal hazards, there needs to be:

- identification and understanding of the hazard, including the physical processes, human element and history;
- identification of the causes of the hazard;
- measurement of variables within the hazard;
- planning, to control either the hazard or responses to it;
- monitoring of the hazard causes; and
- regulations to try to prevent the hazard from occurring again.

By continuously researching and extending the pool of knowledge on coastal hazards, these principles can be met effectively, and thus proficient approaches to the problem of coastal hazards will be found.

Coastal environments and hazards in general have been given further statutory importance with the introduction of the Resource Management Act in 1991. This Act replaced existing planning, water, air, and soil legislation (Milne, 1992). Prior to its inception, there were at least 30 different statutes that governed the land-sea interface along New Zealand's coast (Tortell, 1980). Under the Resource Management Act, a New Zealand Coastal Policy Statement is required, and was published in 1994. Within these two documents importance is placed on the New Zealand coast, and hazards in particular. The approach used falls in line with Sorensen's principles.

Management of the coastal environment has been divided between the Minister of Conservation, Regional Councils, and Territorial Authorities. The coastal environment is not defined under the Resource Management Act, but the definition from the Town and Country Planning Act (1977) can be used. This Act states that the coastal environment is that part of the environment "in which the coast is a significant part or element". Thus the coastal environment extends back from the Coastal Marine Area, which is the delineating boundary between Regional Council and Territorial Authority jurisdiction. These two groups have functions under the Resource Management Act relating to the avoidance and mitigation of natural hazards as outlined under sections 30 and 31 of the Resource Management Act. Section 35 requires these two groups to gather information, monitor and keep records, and when concerning natural hazards they have the duty to keep "records of natural hazards to the extent that the local authority considers appropriate for the effective discharge of its function" (s.35(5)(j)). The main way for these functions to be achieved is through the implementation of plans. The Regional Councils, however, are the only group which are required to have a Regional Coastal Plan, and this plan must not be inconsistent with the New Zealand Coastal Policy Statement.

The New Zealand Coastal Policy Statement is the tool by which national policies in relation to the coastal environment taking into account the Resource Management Act, are set by the Minister of Conservation. Chapter 3.4 of the statement outlines the policies which concern the recognition of natural hazards and provision for avoiding or mitigating their effects. The policies are given in Figure 1.7. These policies require regional councils to have knowledge concerning which areas of the coastal environment within their region are, or are likely to be subject to natural hazards, such as erosion and flooding. Thus policies 3.4.1 and 3.4.2 also fall in line with Sorensen's six principles of effective coastal resource management. The New Zealand Coastal Policy Statement also recognises the importance of natural defence systems, such as dunes and wetlands, and suggests that councils protect such systems. The statement acknowledges that hazard protection works are not necessarily the best option for protecting subdivision, use and development within the coastal environment. Such structures should only be used where needed, to protect existing subdivision, use and development, while any new subdivision, use and development should be located where protection works will not be required. In essence the New Zealand Coastal Policy Statement acknowledges the dynamic nature of the New Zealand coast, including the possibility that such a dynamic environment can lead to hazardous situations occurring. There is a stated need for the identification of actual and potential hazardous sites within the coastal environment. This identification requires not only a knowledge and understanding of the existing situation in terms of coastal processes and human uses, but also an historical appraisal so that there is better understanding of the impacts of hazard events on the New Zealand coast.

Policy 3.4.1 - Local authority policy statements and plans should identify areas in the coastal environment where natural hazards exist.

Policy 3.4.2 - Policy statement and plans should recognise the possibility of a rise in sea level, and should identify areas which would as a consequence be subject to erosion or inundation. Natural systems which are a natural defence to erosion and/or inundation should be identified and their integrity protected.

Policy 3.4.3 - The ability of natural features such as beaches, sand dunes, mangroves, wetland, and barrier islands, to protect subdivision, use, or development should be recognised and maintained, and where appropriate, steps should be required to enhance that ability.

Policy 3.4.4 - In relation to future subdivision, use, and development, policy statements and plans should recognise that some natural features may migrate inland as the result of dynamic coastal processes (including sea level rise).

Policy 3.4.5 - New subdivision, use and development should be so located and designed that the need for hazard protection works is avoided.

Policy 3.4.6 -Where existing subdivision, use or development is threatened by a coastal hazard, coastal protection works should be permitted only where they are the best practicable option for the future. The abandonment or relocation of existing structures should be considered among the options. Where coastal protection works are the best practicable option, they should be located and designed so as to avoid adverse environmental effects to the extent practicable.(Minister of Conservation, 1994, 9-10)

Figure 1.7 Policies 3.4.1 - 3.4.6 from the New Zealand Coastal Policy Statement 1994).

Thus there is importance placed on researching hazards within the coastal environment, not just through the application of Sorensen's six principles but also in the legislation which is designed to promote the sustainable use of that environment. This includes protecting the coast from undesirable activities (those deemed to have an adverse effect), and protecting assets and properties from coastal hazards. The dynamic environment recognised by the New Zealand Coastal Policy Statement is epitomised by a spit landform, in that it is in the nature of spits to change in form in conjunction with changes in their sediment supply, wave environment, tidal, off-shore and long-shore currents, and fluvial process. For this reason a spit landform is the focus of this examination of hazards within the coastal environment, and it is on such dynamic landforms that coastal hazards are very likely to be found. There is also an unique planning environment present under the Resource Management Act, where the Coastal Marine Area borders a spit on three sides, as shown in Figure 1.8. Thus, there is fine line between the areas under the jurisdiction of the Regional and District Authorities, especially on the estuary side of a developed spit where properties directly adjoin the Coastal Marine Area.

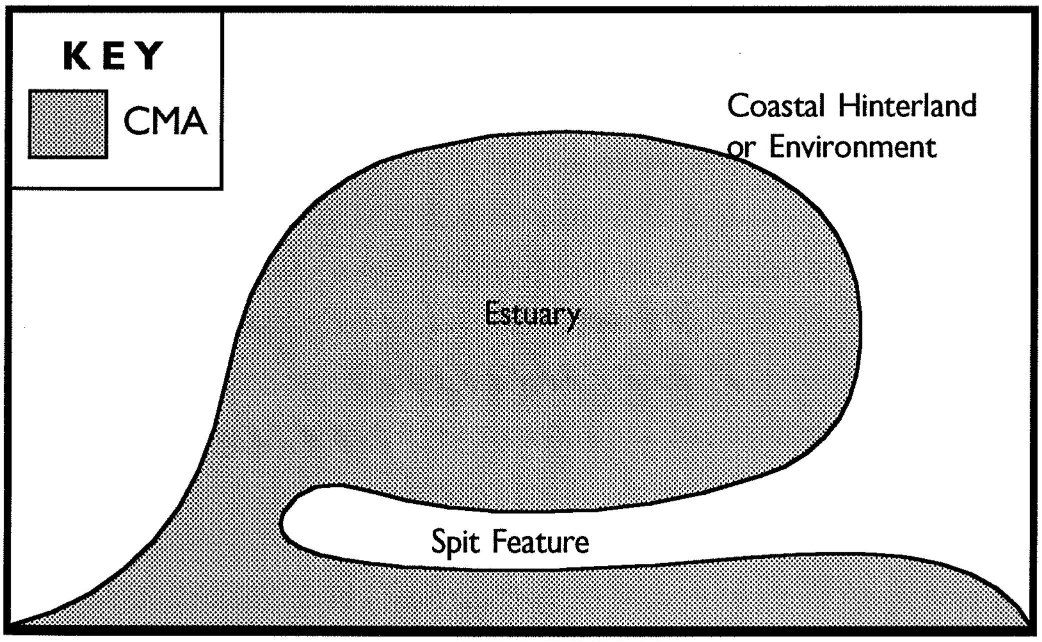


Figure 1.8 **Coastal Marine Area (C.M.A.) Around a Spit.**

1.5 Previous Research

Previous research regarding South Brighton Spit and coastal hazards has been mainly in the form of reports to and by local authorities, and has tended to concentrate on erosion of the open coast. The first report was written in 1978 and was concerned with coastal erosion and shoreline stability along South Brighton Spit. It contains detail on two specific erosion events (Kirk, 1978). This report was followed by a more comprehensive report on the dynamics and management of the Canterbury shoreline from the Waimakariri River to South Brighton Spit (Kirk, reprinted in 1987). This report contains some history and a detailed description of the area and conditions at the time of writing, and was also concerned with the hazard of erosion. Findlay and Kirk (1988) examined changes in the Avon-Heathcote Estuary in relation to development of the estuary's margin from 1847 to the early 1980s. The effects that changes to the estuary have had were also examined. Shore erosion of South Brighton Spit is outlined and a chronology of erosion events from 1847 is also provided. Unfortunately, in relation to this study, the source material for this chronology has been lost. A link between oscillation of the distal end of South Brighton Spit and changes in the Avon-Heathcote Estuary inlet channel is discussed. These three pieces of research provide useful material, but this is limited solely to the hazard of erosion, and only that which has occurred on the ocean side of South Brighton Spit.

Research on flooding has tended to concentrate on high water levels within the Avon-Heathcote Estuary and the lower parts of its tributary rivers, rather than on the effects of those high water levels on South Brighton Spit. A report on high water levels within the estuary was written in 1992 (Oliver and Kirk, 1992). It concluded that of the events studied, freshwater flooding and urban runoff were not the major factors in the high levels recorded, but that storm surges where the main cause.

Very little attention has been paid to the estuary margin of South Brighton Spit. The only research conducted to date has not been published, but was part of a draft inhouse Christchurch City Council report on erosion of the estuary foreshore (Walter, 1995). The report examined erosion of the estuary margin, and looked at different forms of protection from that erosion. The recommendations made from this report are discussed in Chapter Six.

Tsunami research for this section of the new Zealand coast has also been limited, with the Christchurch Engineering Lifelines Project being the only major research to date (Canterbury Regional Council, 1994b). This study examined the impacts of a tsunami hitting the Christchurch coast at peak high tide. Many of the findings from this report are confidential, but there is useful information regarding the areas inundated, including information on South Brighton Spit. These findings are examined in detail in Chapter Three.

There have been two reports published regarding natural hazards in Canterbury, and both have taken a general overview of these hazards. The first, published in 1990, was more concerned with the Civil Defence aspects of these hazards and included a chapter on coastal hazards (Kirk, 1990). This report has since been superseded by a report that serves primarily as a way of pooling scientific knowledge regarding natural hazards in Canterbury, rather than on the civil defence aspects of those hazards (Kirk and Todd, 1994). Both these reports, however, only provide a general overview of the coastal hazards along the Canterbury coast, and no detailed information is given regarding South Brighton Spit.

Masters and Doctoral studies at the University of Canterbury have not specifically concentrated on South Brighton Spit, but have rather investigated the spit as part of a broader study into either the Pegasus Bay coast or the Avon-Heathcote Estuary (Biggs, 1947; Blake, 1964; Millward, 1975; Macpherson, 1978; Deely, 1991; Thompson, 1994). These pieces of research provide a useful background into the study area.

This thesis has assimilated information from various sections of the literature, archival sources, and council reports in regard to the physical evolution of the spit, human history of Southshore, and the coastal hazard events that have occurred there. Thus contributing to the literature concerned with South Brighton Spit, coastal hazards, and the management of coastal environments with high intensity use. In doing so, this study will help local authorities in fulfilling their obligations under the New Zealand Coastal Policy Statement in regards to identifying hazard prone areas.

1.6 Chapter Outline

The following chapter investigates the physical evolution of South Brighton Spit and the human history of Southshore. To understand the dynamics of spit development, a review of some of the literature on spit evolution is provided. The chapter then moves on to investigate how South Brighton Spit was developed. A number of theories have been proposed and these are examined. The human history of the residential suburb of Southshore is relatively short. To understand the extent of hazard within this area there needs to be understanding of its human use.

Chapter Three is the first of three chapters examining specific hazards. The tsunami hazard of South Brighton Spit is investigated. A description of how a tsunami is generated and where those generation areas are for South Brighton Spit is given. The chapter then moves on to examine the incidences of tsunami at both Christchurch and Lyttelton Harbour. Two tsunamis are then described in detail to gain an idea of the possible impacts tsunamis may have on the Christchurch coast. The Canterbury Regional Council's Tsunami Lifelines study is then investigated to gain an understanding of the possible effects of a large tsunami on the study area in particular.

Chapter Four investigates the hazard of erosion at South Brighton Spit. To understand how the hazard occurs, a brief description is given of the processes which cause erosion. Short and long term oscillations of South Brighton Spit are investigated through an examination of a series of beach profiles and maps of the spit's configuration. This then moves on to examine the erosion that has occurred on the estuary margin of the spit. Past erosion events at South Brighton Spit are also examined in detail.

Chapter Five investigates the hazard of flooding along South Brighton Spit. Causes of flooding, such as storm surge, freshwater flooding and sea level rise are described to provide an understanding of these processes. An outline of past events at South Brighton Spit is given, and is followed by a more detailed description of two of the worst flooding events recorded to date.

Chapter Six discusses the results from the previous three chapters and looks at the overall picture of coastal hazards at South Brighton Spit. Current and proposed means of protection of residents' properties from these hazards are examined. A review of how the Canterbury Regional Council and Christchurch City Council propose to manage these hazards and whether they are fulfilling their legal obligations is also undertaken.

Conclusions and comments about areas identified in this study where further research is needed are made in Chapter Seven.

Chapter Two

Physical and Human History of South Brighton Spit

2.1 Introduction

This chapter investigates the physical evolution of South Brighton Spit, and the human development of Southshore. In addition, the dynamics of coastal spit forms are discussed through an examination of some of the research on spit evolution, to provide a basic understanding of how a spit works. This understanding will be applied later in this chapter to the evolution and form of South Brighton Spit. Although an approximate age of both the modern spit and estuary are known, little is still known about the exact geomorphological processes and climatic conditions that built the South Brighton Spit. Several theories have been put forward, and an examination of these follows in Section 2.3. As a residential area, South Brighton Spit was one of the last coastal areas of Christchurch to be developed. The development of the suburb of Southshore is described in Section 2.4, so that an understanding of the human component of the coastal hazards at Southshore can be obtained. As stated in Chapter 1, no hazard can exist without some form of human interaction with the natural events system.

2.2 Spit Definition and Evolution Theory

Research on spit evolution and dynamics has been carried out since the late 1800s. A spit is an accumulation of sediments above sea level, that is attached at one end to land (the root or proximal end), while the other (distal) end is free, ending in open water. They are generally formed in the direction of net longshore transport, typically when there is an abrupt change in the shoreline. Spits are characterised by their dynamic nature and separate the sea from estuaries, lagoons and bays.

The above definition is the product of an examination of approximately 100 years of scientific publications regarding the evolution of all types of barrier formations, including spits. A review of this research follows, outlining the development of theory on spit evolution and dynamics, which has led to the derivation of the above definition.

2.2.1 Literature Review

G.K. Gilbert's 1890 paper on Lake Bonneville was one of the first that reported on the development of shoreline features (reproduced in Schwartz, 1972). In his study of the fossil shorelines, Gilbert describes not only the various elements of shoreline topography, but also attempts to explain the processes that created them. One such element is the spit, part of a group of littoral depositional forms to which Gilbert applies the generic title of embankments.

Gilbert (1972) ascribes the development of embankments to littoral currents. He argues that the littoral current is to a large part controlled by the movement and momentum of the offshore current. When the shoreline diverges, as at the entrance to a bay, the littoral current does not turn, but rather follows the direction of the offshore current. When this occurs, deposition of shore drift (those coarser particles that cannot be moved beyond the zone of agitation) takes place, due to the separation of the current and wave action. The shore drift does not follow the deflected coastline as there is no current accompanying the waves, nor can it follow the current into deeper water, due to the lack of agitation, and thus deposition occurs. Gilbert uses the analogy of the building of a railway embankment, to describe how coastal embankments are formed. Essentially the shore drift is carried by the current along the embankment and dumped off the end, where water depth has increased to the point that agitation of the shore drift is no longer possible. This process continues so long as the supply of sediment by the littoral current also continues. As long as the embankment has one end free of the coast, the embankment is known as a spit (Gilbert, 1972, 30). The initial height of the spit is enough to allow wave action to occur, thus moving the particles of which it is constructed. The processes which form a normal beach, namely the deposition of sediment by waves, also participate on the spit sides, causing it to grow in both height and breadth, until its upper limits are identical with that of a beach subject the same waves and sediment environments.

The littoral current , to which Gilbert ascribes a spit's origin, is not constant but rather is determined by the continuation of the winds driving it. Other, less dominate winds and their accompanying waves also produce smaller currents which have an affect on spits. Those winds which reverse the main littoral current by 180° can retard the construction of the spit, while other wind directions create currents which flow past the end of the spit at varying angles, modifying its form. Sediment is eroded from the extremity of the spit and deposited in the direction of the new current, often forming a hook. Gilbert (1972) states that although rare on lake shores, hooked spits can commonly be found at the mouth of an estuary, where there is a conflict between the littoral and tidal currents.

D.W. Johnson's 1919 book, Shore Processes and Shoreline Development, was the first book in the English language which brought together a full analysis and discussion of the forces that operate along coasts and the development of shorelines (Johnson, reprinted in 1965). In his discussion on the development of spits, Johnson supplies a definition similar to that given by Gilbert, in that he states "so long as an embankment has its distal end terminating in open water, it is called a spit" (Johnson, 1965, 287).

Like Gilbert, Johnson attributes the growth of spits to littoral, or longshore currents. His description of the development of spits is similar to that given by Gilbert, however Johnson also mentions the importance of two other processes on spit growth. These processes are firstly, the increasing velocity of tidal currents as the entrance to the outlet is narrowed by the growth of the spit, and secondly beach drifting. Beach drifting is the process by which sediment particles on the beach slope are moved by the breaking of oblique waves on the beach. Johnson attributes the combination of tidal currents, especially the flood tide, and beach drifting to the growth of hooks on a spit, or as he calls them, recurved spits.

In explaining the building of spits above the water surface, Johnson supports earlier arguments regarding wave-built ridges. He attributes the height of a spit above water to the nature of exposure of the spit to wave action. He states that "... big waves will cast the debris many feet above the mean water, while small waves will raise the surface but slightly above the lake or sea" (Johnson, 1965, 295-97). The length to which a spit may ultimately grow is controlled by a balance between the longshore current and opposing currents. This balance, or equilibrium is not constant or perfect, due to the varying intensity of all coastal processes. Johnson goes on to define what he calls the "zone of equilibrium" which is the envelope of movement in which a spit periodically advances or retreats depending on the intensity of the processes involved (Johnson, 1965, 297). This appears to be the first recognition of the relative instability of the distal end of spits.

Evans' 1942 paper (reproduced in Schwartz (ed) Spits and Bars in 1972) on the origin of spits provides a more detailed definition than those given by Gilbert and Johnson. Evans states:

> A 'spit' is a ridge or embankment of sediment attached to the land at one end and terminating in open water at the other. It is younger than the landmass to which it is attached. The crest of the spit from the land outward for some distance rises above the water (Evans, 1972, 53).

Evans builds on earlier work, most notably that of Johnson. However he finds exception in the explanations of earlier writers on the building of the exposed portion of a spit, that is that part of a spit that is above water. He states:

> It is easy to understand how currents, if strong enough to pick up sediment, may again deposit it under water in the form of ridges; but it is evidently impossible for such currents operating entirely within the water to deposit above its surface (Evans, 1972, 55).

He also disputes Johnson's assertion that wave action is responsible for bringing subaqueous embankments above the water surface, by stating:

> Since direct wave work is incapable of bringing subaqueous embankments above a water surface of constant elevation, it is not possible that spits and bars are built above the water by the processes heretofore supposed (Evans, 1972, 58).

Evans takes this statement as the departure point for his paper, where he examines three spits (one temporary and two permanent structures) in order to determine the processes by which they are built.

Evans came to five major conclusions, the first four of which are important here (Evans, 1972, 70-71). His first conclusion was that spits are not built above sea level by wave action bringing sediment up from the nearshore seabed. Instead Evans concluded that beach drifting is the only process by which that part of a spit that is above water receives material. His third conclusion was that the length of the spit above water is increased only when shore drift and waves move from the direction of the land mass to which the spit is connected. Fourthly, he stated that the direction that spit development takes is the result of the relationship between the following five variables:

- current direction;
- wave direction;
- wave energy;
- amount of sediment; and
- depth of water;

and is not solely due to the direction of net longshore sediment transport. His final conclusion was that hooks are a normal part of spit development and are usually the result of wave refraction. Evans states that "neither change of wind direction nor the presence of tidal or hydraulic currents is necessary for their building" (Evans, 1972, 71). However, he does note that on ocean shores it can be difficult to determine between the work of wave refraction and that of tidal currents.

King (1959, 255) adds another dimension to the definition of a spit, stating that they "frequently form where there is an abrupt change in the direction of the coast", such as at the mouth of estuaries, in an attempt to straighten the coast. She notes the importance of longshore transport in the development of spits and states:

> This supplies the material which is built into the spit by the action of different processes which will vary with the character of the beach material; thus it is important to differentiate between sand and shingle spits (King, 1959, 255).

King also believes that spits are brought above high water level through what she calls "constructive wave action" (King, 1959, 252-253). Waves with a low steepness ratio and a supporting offshore wind will move material towards the shore, often resulting in the building of a ridge or berm on the spit. However, she supports Evans' assertion that recurves are a common characteristic of spits, and that they are most likely the result of wave refraction.

Bird (1965) supports the arguments related to spit growth put forward by Evans and King. He disagrees with Gilbert's assertion that spit growth is due to littoral and offshore currents, by stating that:

> Although currents may contribute sediment to them, they grow in the predominant direction of longshore sediment flow caused by waves, and their outlines are shaped by wave action (Bird, 1965, 76).

Bird, however, does acknowledge the part played by tidal currents. Here he argues that the growth of a spit may force the tidal currents against the shore opposite to the distal end of the spit, which is likely to result in current induced scour (Bird, 1965).

Zenkovich (1967) provides the most detailed account to date on the development of what he terms, accumulation forms - spits. There are two main processes which are involved in this development. They are firstly, the movement of material up and down the submarine slope; and secondly the migration of material along the shore. A spit in Zenkovich's terms is a free form, which he defines as follows: "If a projection extends from the coast a distance greater than the basal width, it is classified as a free form" (Zenkovich, 1967, 384). The development cycle through which an accumulation form passes, is directly related to any changes in the condition of the adjacent section of the coast and sea bed. These forms are stable as long as there is a supply of material along their edge. However most accumulation forms are mobile. This mobility implies a state of dynamic equilibrium of the coastline for a given sediment supply and wave regime. Accumulation forms will grow to a maximum length and width and decay will start only when the condition of material supply deteriorates. Zenkovich (1967, 390) goes on to state that "many accumulation forms can move in the course of their growth". This movement can occur either independently or simultaneously with the retreat of the coast, and are frequently found where there is an extensive flow of material, such as along the shore of straits or bays. He points out that there are several factors which complicate the formation and growth of accumulation forms. These are:

a) alterations in wave energy and direction, which introduce alterations in the nature of currents;
b) variations in the supply of material, partly dependent on a), but also capable of independent manifestations;

c) retreat of the original coast to which the accumulation form is attached; and

d) vertical movement of the coast (Zenkovich, 1967, 414).

Other factors such as the reduction in the total volume of material, and changes to wind conditions can also cause complications in the development of accumulation forms.

As noted earlier, a spit according to Zenkovich is a free form, and he states that the direction of its growth is determined solely by hydrodynamic conditions (Zenkovich, 1967). Any changes in the direction in which a spit grows is due to wave action. Zenkovich looks at a spit produced by simplified wave action, approaching solely from one direction. He states that the width of the resulting spit will be uniform throughout, and that wave refraction will produce a rounded distal end. Although it may be necessary to understand how a spit was produced, Zenkovich points out that is more important to ascertain how a spit will react to temporary changes in wave direction. In examining the spit produced by the simplified wave action, Zenkovich states that as the angle of the waves becomes more obtuse, the distal end of the spit may start to grow in a different direction, such as towards the land. If, however the wave direction is opposite to that which produced the spit originally two things may happen. First, the distal end of the spit may be eroded away and be deposited on the inner side of the spit, closer to the proximal end, or secondly if the spit is recurved, the recurve may become more pronounced (Zenkovich, 1967, 407-416).

Zenkovich moves on to discuss the decay of accumulation forms. Decay occurs when there is reduction in the supply of material (Zenkovich, 1967). Such a reduction may be due to alteration in the amount of erosion in the supply regions, or a reduction in the supply of alluvial material. The former may have as its cause a reduction in the rate of sea level rise, or sea level not rising any further, while the latter may be due to either natural or human causes, such as stream capture or the damming of rivers. The process of decay can be either continuous or intermittent, depending on whether the reduction in the supply of material is a temporary or permanent factor. If the process is intermittent the alternating periods of erosion and deposition are reflected in the beach ridges on the spit. Zenkovich concludes by stating that: "The evolution of accumulation forms is complex, and cannot always be established with accuracy in the present state of our knowledge" (Zenkovich, 1967, 447).

From this point onwards, much of the literature on spits tends to concentrate especially on the dynamics of a single spit, as opposed to general theory. One such article is that of King and McCullagh (1972) which discusses the results of a computer simulation of a complex recurve spit. Of importance from this discussion is the stress placed in their conclusions on differing wave directions and water depth. Increasing the depth of water at the distal end of a spit will not only slow the growth of the spit, but will also allow stronger wave refraction to occur. Recurves are built by a different set of waves to those which initially built the spit. Bird (1984) in discussing the results of King and McCullagh's simulation, notes that the shape of a spit can also be influenced by the space available to it and the topography of the adjacent sea floor. He states: "Spits grow more rapidly across shallow areas than into deep water, and their configuration may be related to variations in exposure to wave action determined by nearby headlands, islands or reefs" (Bird, 1984, 155).

Healy and Kirk (1992) add another dimension to the definition of a spit by noting that they separate estuaries and lagoons from the open sea. In their discussion of coastal barriers on the New Zealand coast, they state that:

> The origin of barrier dunes and spits has caused much debate in the scientific literature, especially in relation to supposed Holocene minor sea level fluctuations (Healy and Kirk, 1992, 172).

They believe that most progradational features, such as spits, were formed after the present sea level was reached. A combination of transgressive dune ridges and the incorporation of uncohesive shelf sand deposits into the littoral system most likely resulted in the development of many coastal barriers (Healy and Kirk, 1992). They state, however, that it does not particularly matter whether sea level is rising or falling, so long as there is an abundant supply of sediment, deposition will occur regardless.

In his Introduction to Coastal Geomorphology, Pethick (1994) states that detached beaches, such as spits, have long intrigued the coastal geomorphologist.

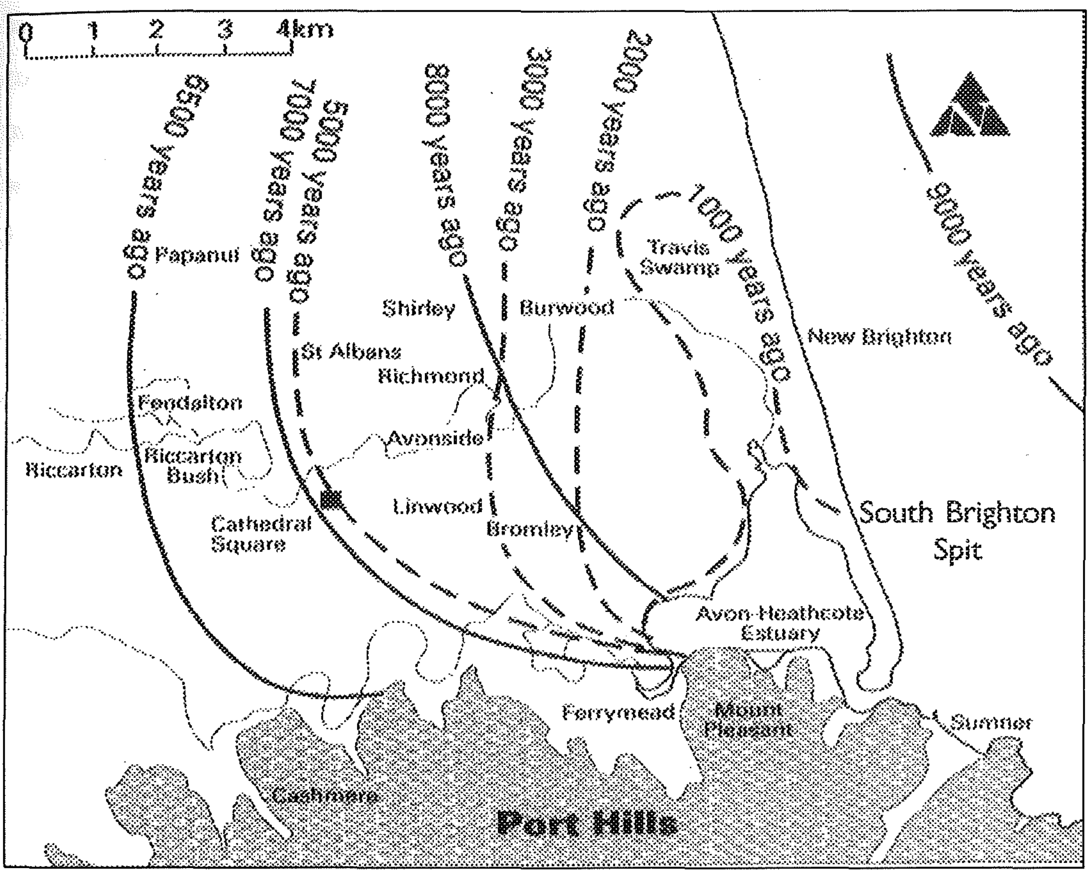
The review of some of the literature from the last 100 years presented here, emphasises this point. No real agreement appears to have been reached on the exact processes to which the origin of spits may be ascribed. This may never happen, due to the reason put forward by Allen (1982). He states that:

> The processes of construction are locally unique and depend on the wind and wave climate, sediment budget, tidal range and the impacts of man [sic] ... [therefore] ... only relative comparisons can be given (Allèn, 1982, 790).

It can be noted from the review above that there are three main groups of processes which contribute to the evolution, characteristics and dynamic nature of spits. They are currents, sediment transport and wave dynamics. The characteristics of a spit are that it is composed of uncohesive sediment, it has a low elevation, and it is a dynamic landform. These characteristics are of more importance for this research than the processes of evolution, as it is from these characteristics that hazards result, but only when there is some human use of the spit. However, the processes which build a spit are also the processes which maintain it, and can destroy it. The following section outlines the evolution of South Brighton Spit, in a moreorless chronological order. It is important to understand how this landform developed before an investigation into the hazards can be undertaken, because as stated above, the processes which developed South Brighton Spit are the ones which control and maintain its configuration, or may lead to its destruction. The section following moves on to examine the history of human use of South Brighton Spit, so that an appreciation of the changing nature of the human component of any hazards present can be gained.

2.3 Physical Development of South Brighton Spit.

The Christchurch coast is geologically young, with the present shoreline being only the latest in a series of varying positions (Figure 2.1). Post-glacial sea level rise resulted in the transgression westward of the shoreline, until about 4500 years BP when sea level reached a position comparable to its present level (Kirk, 1987). Since this time the coast has been prograding in stages, developing a wedge of dunes, swamps, and beach ridges, containing estuaries and the lower channels of the Avon and Heathcote Rivers (Kirk, 1987). Figure 2.1 shows the development of a shallow bay-like formation in the 1000 year BP shoreline, which could possibly be an estuary associated with the Avon River. It is believed however, that there has always been an estuary associated with most of the shoreline positions, and in particular with the Avon River (Kirk, 1995, Pers. Comm.). Evidence for this is found in the numerous peat and swamp deposits beneath Christchurch (Brown and Weeber, 1992).



------------------ Progradation ———————— Transgression

Figure 2.1 Christchurch Shorelines - 9000 years BP to present. (Source: Harris, 1992a, after Brown and Weeber, 1992)

The prograding nature of the Christchurch coast, as shown in Figure 2.1 is the outcome of the interaction of several processes. These processes include the principal off-shore current (which is from the south), wave refraction around Banks Peninsula, tidal currents, transportation of sediment, and a surplus in the sediment budget of the area. As the principal off-shore current moves north up the South

Island's east coast its course is interrupted by Banks Peninsula and an eddy is formed in southern Pegasus Bay (Kirk, 1987). This eddy combined with the refraction of waves around Banks Peninsula and local tidal currents encourages the normally northward transportation of sediment to turn south in Pegasus Bay. This does not mean, however, that there is a net longshore transportation of sediment southwards along the Pegasus Bay shoreline. Longshore transportation of sediment within Pegasus Bay can be either in a northward or southward direction, depending on the weather and wave climate. Banks Peninsula also has a lee effect, in that it shelters southern Pegasus Bay from waves from the south, thus creating conditions conducive to deposition (Kirk, 1987). For deposition to occur, there must also be a surplus in the sediment budget of the area. The two main sources of sediment for Pegasus Bay are the northward transportation of sediment past Banks Peninsula and the Waimakariri River (Biggs, 1947).

Biggs (1947) identified three stages in the progradation of the Canterbury coast. The first phase was the development of the shingle plain built by glacial-fed rivers. The second phase was the development of a beach ridge foreland. While the third phase is the one we are currently in, and involves according to Biggs, the deposition of Waimakariri River sands on the coast. Within the second phase, Biggs (1947) identified three separate dune belts. Blake (1964) went a step further and dated the three dune complexes identified by Biggs. Blake (1964, 157) named these three dune complexes after the local soil types: Pegasus, Kairaki, and Waikuku. In a comparison with work undertaken in the Manawatu District, Blake derived the ages for the three complexes, as shown in Table 2.1. As regards the study area, the majority is comprised of the Kairaki complex, with the outer coastal margin being of the Pegasus complex (Blake, 1964, Fig.36). This would date the Avon-Heathcote Estuary and South Brighton Spit as being around 2000 years old.

Table 2.1 Age of Dune Complexes in Pegasus Bay

	Blake (1964)	Millward (1975)
Pegasus Dunes	200 - 700 yrs BP	0 - 700 yrs BP
Kairaki Dunes	2000 yrs BP	1000 - 2000 yrs BP
Waikuku Dunes	5000 - 6000 yrs BP	4000 - 5500 yrs BP

Millward (1975) in an attempt to establish a maximum age for the Avon-Heathcote Estuary and associated landforms, redated Blake's complexes, as shown in Table 2.1. The reasons given for this redating are the higher sea levels about 4500 years BP, the size and extent of the landforms associated with the estuary, and that there is still sediment being supplied to the beach by the Waimakariri River. Millward goes on to say that the Avon-Heathcote Estuary is associated with all three of these dune complexes, and that South Brighton Spit was most likely developed between the Kairaki and Pegasus phases, due to its existence and vegetation being noted in the oral history of the first people in Canterbury about 700 years BP (Millward, 1975, 50).

Deely (1991) stated that both the Avon-Heathcote Estuary and Travis Swamp are within the Kairaki dune complex, which she states were formed in the last 500 to 2000 years. Through a study of grainsize, mineralogy and carbon dating of sediments from Travis Swamp and the Avon-Heathcote Estuary, Deely concluded that Travis Swamp was once a small bay into which the Avon River flowed, and the Avon-Heathcote Estuary was probably occupied by shallow coastal waters about 2000 years ago. The progradation southward of what is today South Brighton Spit, until it reached a point comparable to its present position, led to the infilling of the small bay and the development of the swamp; while the shallow coastal waters were replaced by the estuary and South Brighton spit. Deely's results show that the modern estuary was formed about 450 years BP. She attributes the progradation of South Brighton Spit, and the development of the modern estuary to accelerated erosion of the Canterbury Plains caused by deforestation from Polynesian activity about 500 - 700 years BP (Deely, 1991, 192-193). The growth of the spit southward would have eventually lead to the ponding of the waters discharged from both the Avon and Heathcote Rivers, thus establishing the Avon-Heathcote Estuary.

Even with these studies, there is still a lack of understanding about the geomorphological history of the Christchurch area within the last 1000 years. However, it can be inferred from Figure 2.1 that a substantial increase in the sediment budget of the area was needed to infill Travis Swamp and encourage the progradation southwards of South Brighton Spit. Deely (1991) has put forward one explanation, however she does not take into account the possibility of either a substantial flooding event associated with the Waimakariri River, or a shift in the position of the river's mouth.

It is widely accepted that the course of the Waimakariri River has undergone significant changes over the last several thousand years, varying greatly the position of its mouth from south of Banks Peninsula into the Canterbury Bight, to just north of its present position. Recent research into the history of Kaitorete Spit (a gravel barrier) has shown that the Waimakariri River's mouth moved from a position south of Banks Peninsula to the north of the peninsula about 700 years BP (Soons and Shulmeister, in press; see Figure 1.1 for locations). A shift in the course of the Waimakariri River about this time may well have supplied the necessary sediments for the southward movement of the Avon River mouth and the development of the spit. The Waimakariri River's sediment load for the last few kilometres of its course consists mainly of sands and silts, and there is no reason to suggest that this was not so at the time of the major change in the river's course (Soons and Shulmeister, in press).

Johnston (1958) provides evidence of forest remains interred in sub-surface gravels. The trees were found in shingle pits to the south-west of central Christchurch, some 10 to 11 feet below the present surface. At the time of writing Johnston had only received two dates from radio carbon dating of samples from the trees. The two dates were 1190 AD and 1265 AD. The area in which these trees were found is well known as a former course of the Waimakariri River, and one which would see the river's mouth on the south side of Banks Peninsula. Johnston (1958) concluded that due to the uniform nature of the deposit and its extent (in excess of 25,000 acres) the deposition of the gravel would have occurred over a relatively short time period. Johnston does not accept however, that a change in the river's course or a flooding event could have deposited the extent of material found. Johnston (1958) infers that some sort of climate change and/or possible deforestation leading to severe erosion of coarse material is the most likely cause.

There is yet another factor that has not been taken into consideration in previous discussions, this is the affect that orographic air flow has on the Waimakariri River and its catchment. Orographic air flow, in particular from a northwest direction, produces large precipitation events in the upper catchment of the Waimakariri River. Such events, including those accompanied by snow melt or snow covered mountains, substantially increase both the sediment yield and water volume of the Waimakariri River. Between the normal characteristics of the Waimakariri River's sediment load and the effects of orographic air flow on the river's discharge, there does not have to be deforestation of the catchment for there to be an increase in the amount of sediment supplied by the Waimakariri River to the coast. All those assumptions outlined above are valid, and no one more so than any other.

The actual development and subsequent progradation of South Brighton Spit, has most likely followed that as outlined in Section 2.2. Authors such as Blake (1964) and Kirk (1987) have noted a general southward movement of sediment in Pegasus Bay. This current combined with the supposed large sediment supply from the north, and a prevailing wind and wave direction from the northeast would have encouraged the southward progradation of South Brighton Spit. Millward (1975) believes this growth occurred in stages and identified six hook formations, as shown in Figure 2.2. The first three formations are wider and more closely spaced than the later formations. Millward (1975) concluded that this was due to a larger supply of sediment, less shelter from Banks Peninsula, and back filling by the Avon River causing growth of the bulk and width of the spit rather than the length. As the spit prograded southwards the lee effect of Banks Peninsula increased, so that the effect of opposing waves, was diminished. This allowed for greater linear growth of the spit before the hooks formed. Eventually the spit encountered the resistance of both the tidal current flowing in and out of the estuary and the volcanic rock of Banks Peninsula to arrive at a semi-permanent position. The position is semi-permanent in that, as noted in Section 2.2, spits fluctuate over a period of time due to changes in either the coastal regime or river and estuarine systems that may affect them. The nature of contemporary fluctuations for South Brighton Spit is discussed in detail in Chapter Four which deals with erosion hazards within the study area.

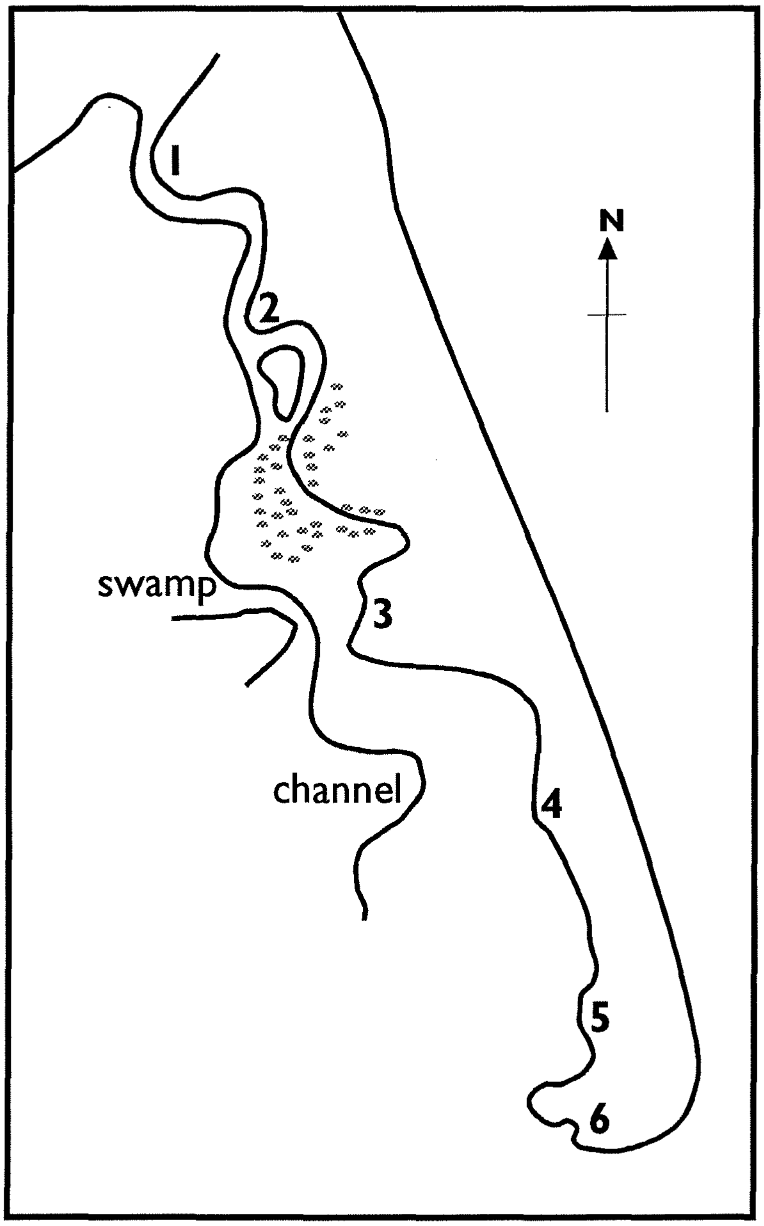


Figure 2.2 **Hooks on South Brighton Spit (not to scale)**
(Source: after Millward, 1975)

There is one major anomaly with the development of South Brighton Spit when compared with the theories on spit evolution outlined in Section 2.2. This is the narrow nature of the spit and its almost constant width from Caspian Street to Tern Street (Figure 1.2). Millward believed this narrowness to be due to a combination of the following factors:

- the estuary not infilling as rapidly as a normal bar estuary;
- the meandering of the Avon River channel within the estuary and cutting into the spit;
- the predominant North-Northeast wind direction; and
- the shelter offered by Banks Peninsula to the erosive and widening effect of opposing waves (Millward, 1975, 53).

There is one other factor that Millward does not mention, and is concerned with the almost constant width of the spit as mentioned above. Zenkovich (1967) states that if the wave action that is building the spit is predominantly approaching from one direction then the width of the spit will be uniform throughout, and wave refraction will produce a rounded distal end. The predominant wind and wave direction is from the northeast quarter and this combined with the refraction of southerly waves around Banks Peninsula, so that they arrive at the beach from a more easterly direction could have resulted in a consistently narrow spit. The refraction of these waves around the distal end of the spit would have produced a rounded end, onto which later hook formations were formed.

The modern estuary and the area of the study site most likely formed around 450 years BP due to a variety of possible causes. These causes include:

1. the general progradation of the coast after post-glacial sea level rise reached a relatively static position;
2. the deposition of large amounts of sediment from the Waimakariri River, due to either storms in its catchment or deforestation;
3. the movement in the position of the mouth of the Waimakariri River from south of Banks Peninsula to the north about 700 yrs BP;

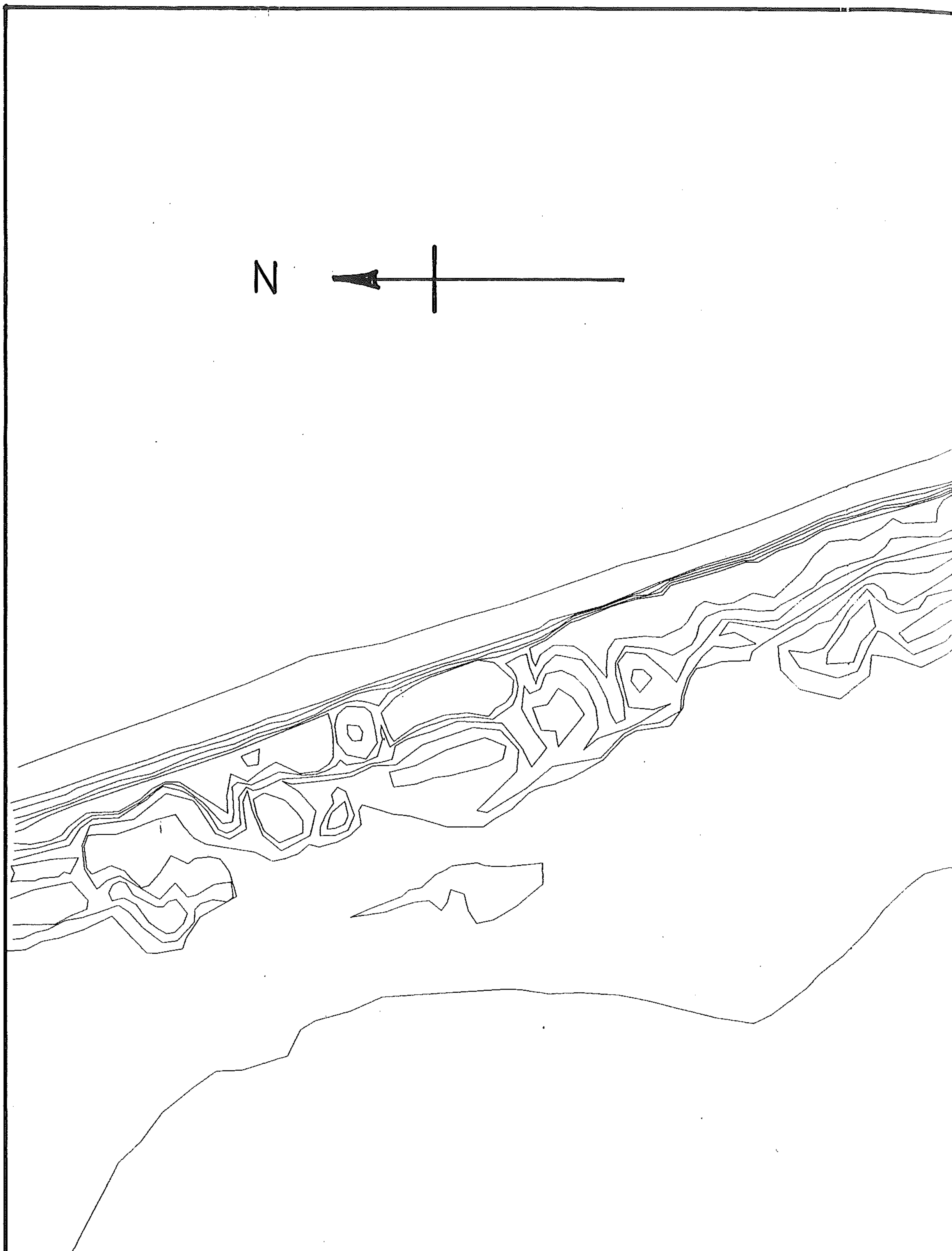
4. a general movement southwards of sediment along the Pegasus Bay coast from the Waimakariri River to Banks Peninsula; and
5. the progradation southwards of the Avon River mouth.

This has resulted in a spit, in terms of the study area, that is about 2.5 km long, and has a minimum width of about 300m at Caspian Street and maximum of about 500m at its distal end. Figure 2.3 shows a contour map of the study area, and although the source map has only a one metre accuracy for the contours, the map gives a good indication of the elevation of South Brighton Spit. As shown by Figure 2.3, the majority of the developed area is westward of the dunes and is less than two metres above mean sea level.

A draft report written for the Water Services Unit of the Christchurch City Council contains the results of levels taken for properties fronting the Avon-Heathcote Estuary in metres above the old Christchurch Drainage Board datum. Crown levels for Rockinghorse Road were also included and are shown in Table 2.2 (Walter, 1995). The properties which face the estuary's margin have a ground level range of RL 10.4 to RL 11.3, while the house floor levels ranged from RL 10.7 to RL 12.5. The current mean sea level for the Avon-Heathcote Estuary is RL 9.3 and mean high water is RL 10.15. These figures show that all of these properties are only one to two metres higher than the current mean sea level for the estuary, and also provide a check on the accuracy of Figure 2.3. Table 2.2 shows the levels recorded along the crown of Rockinghorse Road. These figures also highlight the

Table 2.2 Crown Levels for Rockinghorse Road above old Christchurch Drainage Board. datum. (Source: Walter, 1995)

Street Names	Level (m)
Godwit St & Rockinghorse Rd	RL 10.74
Tern St & Rockinghorse Rd	RL 10.38
Pukeko St & Rockinghorse Rd	RL 10.61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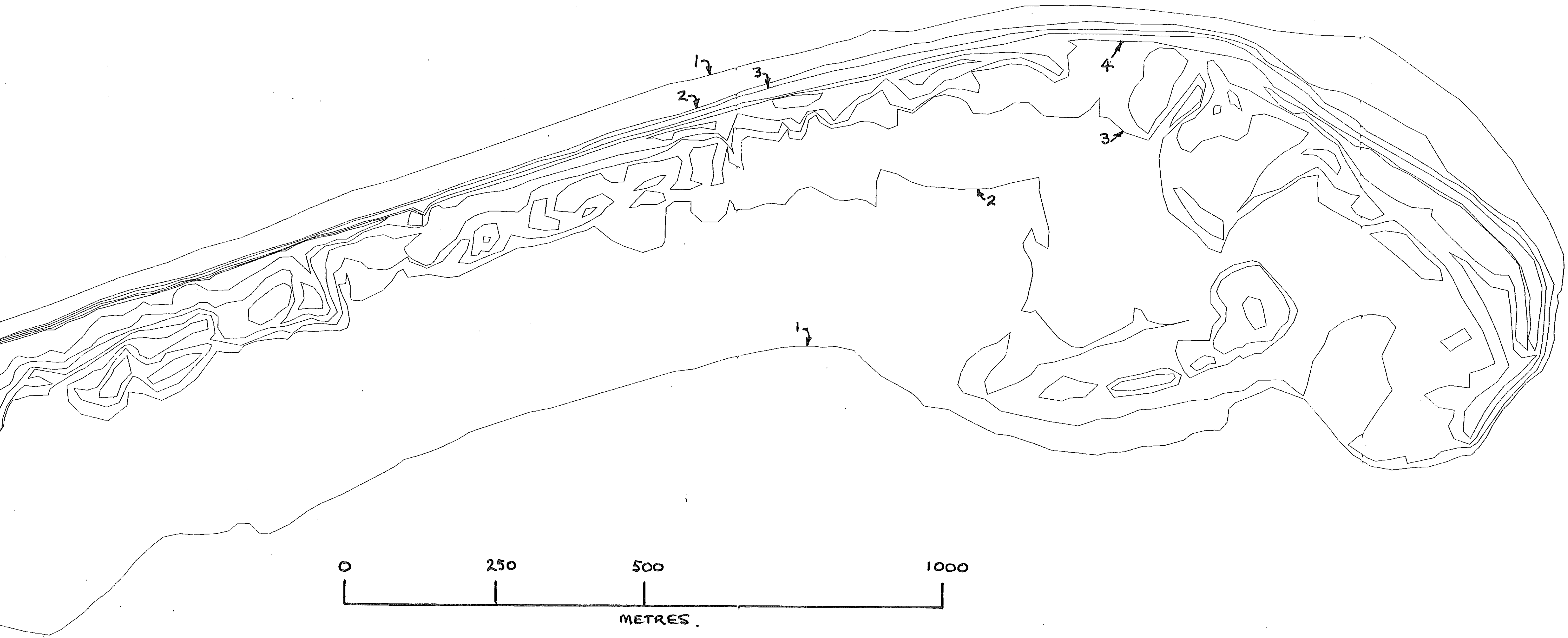

Figure 2.3 Contour Map of South Brighton Spit Study Area.
Source: Waimakariri Floodplain Map
Note: This has not been surveyed or rectified to New Zealand Map Grid

low nature of South Brighton Spit, and show the slope of the spit down from its proximal end to the middle, and then rising again to its distal end. The low nature of South Brighton Spit means that the area may be subject to flooding, and that future, accelerated sea level rise may increase this risk. This subject is examined in detail in Chapter Five.

2.4 Human History of South Brighton Spit - Southshore

The first human settlers on South Brighton Spit, were the early Maori tribe Waitaha (Harris, 1992b). Their *kaika* (settlement) was known as *Te Kai-o-te Karoro,* and was situated beside the mouth of the Avon River outside of the study area, as shown in Figure 1.2. These people named South Brighton Spit *Te Karoro Karoro,* meaning the "place of chattering birds" (Walsh, 1972). Later, the Ngati Mamoe people also occupied this site (Harris, 1992b).

In 1852, after the arrival of the European settlers, and the establishment of the Canterbury Settlement, the majority of South Brighton Spit became part of the Sandhills Run (Biggs, 1947). The Sandhills Run consisted of the coastal dunes which were bounded by the Waimakariri River in the north, the Styx and Avon Rivers in the west, and the estuary mouth to the south. The run was worked as a dairy station and supplied most of the early milk for the new settlement of Christchurch (Biggs, 1947). An area omitted from the run at the tip of the Spit, was withheld by the Provincial Council for a Lighthouse (Penney, 1982). The seaward dunes of the Sandhills Run were grazed as a unit until New Brighton started to develop as a residential area in the late 1800s (Biggs, 1947).

Although there was residential development of the Christchurch coast in the late 1800s, it was not until 1916 that any attempt was made to settle South Brighton Spit. A large area was purchased by a syndicate, who proceeded to have it surveyed and divided into sections for housing. The syndicate had a vision of building a bridge across the estuary mouth from the end of the Spit to Shag Rock

(Penney, 1982). However problems with access to the area saw both the housing development and the bridge proposal fail. During World War I, the Spit was used for gunnery practice and as a rifle range, while World War II saw the area as part of the coastline that had to be defended by the Home Guard (Penney, 1982).

In 1939, a three and half acre block was purchased by P.J.R. Skellerup, who later perished in World War Two. After the war, G.W. Skellerup took an interest in his son's land, and tried to develop a holiday camp for his firm's employees on the area. This camp was a fleeting venture, ultimately failing as the staff of Skellerup wanted a camp cook, so their wives had an opportunity of a better holiday (Penney, 1982). The Skellerup family purchased another 60 acres of land on the Spit in 1945, and formed a road which was named Rockinghorse Road, aptly describing the rough track. Access to the Spit itself at this time, and in particular the southern half was limited to the use of a large mud flat at low tide.

1946 saw the establishment of the Southshore Ratepayers' Association, the area apparently being named for prestige reasons (Walsh, 1972). Although what these reasons were is unclear. A possible explanation may have been the unsavoury reputation that New Brighton had in the early 1900s, and a desire by residents to disassociate themselves from it (Penney, 1982). In 1948 Rockinghorse Road was graded and officially recognised by the Christchurch City Council. Further residential development in the area was slow. In 1958, 49 sections were offered for sale by auction, on the seaward side of Rockinghorse Road (Penney, 1982). Table 2.3 shows the number of houses in the Southshore area from 1948 to 1995. and the population figures for 1972 and 1991. The installation of sewerage and high pressure water pipes was also slow, with the area not being properly served until 1967 (Walsh, 1972). The completion of the installation of stormwater drains was not finished until the late 1970s. The streets formed after Rockinghorse Road were named after the sea birds which can be found around the Spit, echoing the placenames used by the Waitaha. Examples of these are : Heron Street, Tern Street, Plover Street, Stilt Lane, and Godwit Street. Southshore as a residential area has grown substantially over the last 25 years, with a total of 650 rateable properties at the beginning of 1995. These properties had a combined capital value from government valuations of $75.6 million at the beginning of 1995 (Christchurch City Council, 1995). With both the number of houses and population doubling since 1972, South Brighton Spit has become one of the most developed coastal landforms of its type in New Zealand. This is illustrated in the frontispiece.

Table 2.3 Population and Number of Houses in the Southshore Area (Source: Southshore Ratepayers' Association Minutes; Department of Statistics, 1992; Christchurch City Council Rates Unit)

Year	No. Of Houses	Population
1948	7	
1956	58	
1972	220	650
1991	516	1425
1995	650	

2.5 The Contemporary Environment of South Brighton Spit

Zenkovich (1967) points out that accumulative landforms, such as South Brighton Spit, often reach a point in which decay can set in, with the result of the spit being eroded away. Although South Brighton Spit is a relatively young landform, there is no way of knowing whether its physical development is complete or whether it has reached a point of decay. Decay may only start to set in if the sediment supplied to the spit is stopped completely. This may not occur, as the Canterbury Regional Council believes that the current surplus of sediment supplied to the Canterbury coast will continue (Walter, 1995). With the settlement of Christchurch in the 1850s, the urbanisation of the catchments of the Avon and Heathcote Rivers has caused volumetric changes in the Avon-Heathcote Estuary, as well as causing an increase in fine sediment supply (Kirk, 1987; Macpherson, 1978). These changes in the estuarine conditions have also affected the configuration of

South Brighton Spit. As noted earlier, spits are highly sensitive to any change in either the coastal regime or river and estuarine systems, and are likely to change their configuration or position as a result of these changes. This sensitivity has played a part in the development of the last hook formation, as shown in Figure 2.2. This particular hook has developed in the last 70 to 75 years, with distinct fluctuations in shape, form and position (Kirk, 1987; see also Figures 4.8 and 4.9) The oscillation of the Spit creates a hazard on a long-term scale and will be explored in detail in Chapter Four.

While the residential development of South Brighton Spit intensified over the last 40 years , the instability which characterises such landforms became more apparent. Unfortunately very little notice was taken of the potential for a disaster to occur should development of the spit continue at the same rate. Thus the hazards presented at South Brighton Spit are a combination of the uncertainty about the long term stability of the landform, the low lying nature of the spit (which is conducive to flooding), the intensive development of the area, and the unwillingness of human nature to learn from the past. It has thus been left up to the local authorities to take control of the both the development and use of South Brighton Spit.

As stated in Chapter One, local authorities are under an obligation through the Resource Management Act (1991) to avoid and/or mitigate natural hazards within their boundaries. Both the Christchurch City Council and the Canterbury Regional Council have taken some steps in protecting the assets and properties on South Brighton Spit from hazards, the former taking action as early as 1979. These steps have been in the form of planning, and unfortunately were too late to prevent the building of three houses on the dunes at Torea Lane. Plate 2.1 shows the two northernmost houses at Torea Lane. There has been several erosion events over the study period that have posed a hazard to these houses, and these are explored in detail in Chapter Four. In response to a report written in 1979 on the Christchurch coast (Kirk, reprinted in 1987), the Christchurch City Council implemented a new zone for part of the Southshore area. This zone is the Residential Coastal Zone, and is located east of Rockinghorse Road and south of Tern Street. All types of land use within this zone are conditional on the suitability of the site for that use and the affect of the use on the dune system (Christchurch City Council, 1986). At the time of writing, the planning scheme for Christchurch is under review with the proposed plan released in June 1995. The Canterbury Regional Council in their Regional Coastal Environment Plan, have implemented two hazard zones with the objectives of:

a) avoiding or mitigating the actual or potential costs of coastal hazards;

b) controlling the location and design of new use and development so that the need for hazard protection works is avoided; and

c) avoiding significant adverse effects on the environment as a result of methods used to manage coastal hazards (Canterbury Regional Council, 1994a, 47).

Plate 2.1 **The Two Northern Houses at Torea Lane - 15/07/95.**

However both Councils have only considered the hazards presented to the area from the coastal side and have ignored the estuary margin. There are 75 properties that directly border the Avon-Heathcote Estuary, and thus may have the estuary as their main source of hazard. The implications of these planning considerations and of the hazards investigated will be discussed further in Chapter Six, which will also contain a review of both the Christchurch City Council's plans and the Canterbury Regional Council's plan. The most potentially disastrous hazard at South Brighton Spit is tsunami, and the occurrence of these phenomena is discussed in the following chapter.

Chapter Three
Tsunami Hazard at South Brighton Spit

3.1 Introduction

This chapter investigates the hazard of tsunami at South Brighton Spit. The first section examines how a tsunami is generated, and where the major generating areas are for tsunami events on the Christchurch coast. A general overview of tsunami events affecting either the Christchurch coastline or Lyttelton Harbour is given in the second section. Lyttelton Harbour observations are included as they provide the most detail of early tsunami events which would also have affected the Christchurch coast, but about which no information could be found. Two specific tsunami events are described in detail, the first in 1868 and the second in 1960. The fourth section of this chapter goes on to explore the results of a Lifelines study undertaken regarding a hypothetical tsunami event on the Christchurch coast and the hazard of such an event at South Brighton Spit.

3.2 Tsunami Generation

A tsunami (Japanese for 'harbour wave') is a wave system generated by a large scale, short duration displacement of the sea surface that is usually seismic in origin (Ridgeway, 1984; Pugh, 1987). These waves are also known as 'seismic sea waves', or more commonly 'tidal waves'. The latter term is a misnomer, as a tsunami has none of the predicability or regularity associated with tidal motion. This term was apparently adopted by scientists for these phenomena to discourage any notion that they were wind generated waves, and unfortunately the name has stuck (Barnett, 1994).

Tsunamis can occur at two scales - local and global. Locally generated tsunamis for New Zealand are those considered to be generated within the boundary of the continental shelf, and although they have often produced some of the highest waves, their effects are limited to the generating area (de Lange and Healy, 1986). To date there have been no observations or recordings of locally generated tsunami on the Christchurch coastline. An occurrence is seen as unlikely due to the small number of active faults within Pegasus Bay. Thus these particular phenomenon are beyond the scope of this research. The classical tsunami, pictured more popularly as a 'tidal wave', is essentially a remotely generated wave. The generation, propagation and impacts of remotely generated events are the prime concern of most of the literature on tsunami.

There are four main modes of tsunami generation. These are: shallow focus earthquakes; landslides into water; submarine slides and turbidity currents; and volcanic eruptions (Kirk and Todd, 1994). However, it is generally accepted, that for a tsunami to occur there must be a vertical movement of the sea floor, such as that associated with earthquakes along zones of convergence. Ridgeway (1984) goes further to state that these earthquakes must have a magnitude of at least 6.5 on the Richter Scale, and a focal depth less than 50 kilometres. Such shallow earthquakes occur most often in deep ocean trenches formed by the convergence of two plates (Lander and Lockridge, 1989).

A vertical movement of the ocean floor will cause the column of water directly above it to either rise of fall (Lander and Lockridge, 1989). In either case, the ocean will return to an equilibrium surface level through the forces of gravity and horizontal pressure gradients in the water (Chapman, 1994; Pugh, 1987). It is this horizontal motion of the water, either away from (in the case of a rise), or into (in the case of a fall) the epicentre of the earthquake, which generates the actual wave. As there has been no recorded observation or measurement of actual tsunami generation, knowledge in this area is still incomplete. However, through the study of tsunami data five factors appear to be directly related to the size of the tsunami generated. These are:

1. the size of the shallow focus earthquake;
2. the area and shape of the rupture zone;
3. the rate of displacement and sense of motion on the ocean floor in the epicentral area;
4. the amount of displacement of the rupture zone; and
5. the depth of water in the source area (Lander and Lockridge, 1989, 2).

As with the effect of dropping a rock into a pool where the ripples radiate outwards from the centre, tsunami waves radiate from the generating area. The majority of a tsunami's energy, is transmitted at right angles to the activated part of the fault (Lander and Lockridge, 1989). This means that coasts that are parallel to the source fault are most likely to receive higher tsunami waves than coasts which are at an oblique angle to it (Bird, 1965). The effects of these waves extend from the sea surface to the seabed, and as such can be treated in the same way as gravity waves (Kirk and Todd, 1994). Thus it is possible to calculate the velocity of a tsunami.

The formula for the wave velocity (v) of a tsunami is:

$$v = \sqrt{gh}, \qquad \text{[Equation 3.1]}$$

where $g = 9.81\ \text{m.s}^{-1}$ and is the gravitational velocity; and

h = water depth in metres (Ridgeway, 1984, 376).

The average depth of the Pacific Ocean is 4000 metres, thus using equation 3.1 the velocity of a tsunami as it crosses the Pacific can be calculated to be about 198 metres per second, or 713 kilometres per hour (Kirk and Todd, 1994). This formula has been validated through the calculation of travel times for tsunamis recorded on gauges throughout the Pacific ocean (Pugh, 1987). The wave length of tsunamis is considerably long, up to 500 kilometres, and in the open ocean they have a height of about 1 metre. This means that they are often unobservable by ocean going vessels (Ridgeway, 1984; Lander and Lockridge, 1989).

The interaction of a tsunami with the coast is complex, variable, and to a large extent unpredictable. As a tsunami enters continental waters, water depth decreases, resulting in a decrease in velocity, down to about 130 kilometres per hour at a depth of 200m, which wave height increases (Kirk and Todd, 1994). Gilmour (1964) lists nine possible effects of a tsunami on the shoreline. These are:

1. Waves travel more slowly in shallow sea depths. They become more closely spaced and the amplitude increases.
2. Near a coastline or beach the waves may form breakers or bores several feet high that can sweep several hundred yards inland over low lying ground.

3. The weight of water and moving debris tends to raze all obstructions such as buildings, trees, etc.
4. The first observed effect of a tsunami is often a withdrawal of the sea.
5. A number of waves follow the first wave at intervals of 10 to 40 minutes. The second or third waves are often the largest and the series may continue for several hours.
6. The effects are increased at high water.
7. Inlets, harbours and narrowing estuaries may amplify wave heights. These localities are particularly prone to damage by flooding and by rapidly moving water. Bridges and jetties can be demolished.
8. Small boats and houses or sheds low on beaches can obviously be in danger of destruction if large waves arrive.
9. Places which have proved susceptible in the past to tsunami damage are likely to be damaged again in the future (Gilmour, 1964, 2-3).

Tsunamis can be generated from any point around the Pacific Rim where there is a zone of convergence of two continental plates. Generation areas of significance for the New Zealand coast range from the Aleutian Islands to the southern Chilean coast, as shown in Figure 3.1 (Ridgeway, 1984). Figure 3.1 also shows the travel times for tsunamis generated around the Pacific Rim to reach New Zealand. However this travel time does not mean, for example that there is 11 to 12 hours warning of a tsunami generated off the Peru-Chile coast. It takes the International Tsunami Warning Centre in Hawaii about one hour to determine whether the earthquake was of the magnitude required to generate a tsunami, namely greater than 6.5 on the Richter scale, whether the epicentre was in a location where a tsunami could be generated, and whether a tsunami was actually generated (Lander and Lockridge, 1989)

For the Christchurch coast it is the travel time of a tsunami, of about one hour, from the Chatham Islands that is of most importance. This is because it is not until the tsunami has reached the Chatham Islands that the height and strength of the tsunami waves are truly known. Only after this information has been relayed from the Chatham Islands can authorities such as Civil Defence make appropriate response decisions. Kirk and Todd (1994) believe that the establishment of a tsunami reporting system on Chatham Islands would help considerably in the assessment of the consequences of a tsunami on the Christchurch coast. From historical accounts it appears as though tsunamis generated on the Chilean and Peruvian coasts have the most affect on the Canterbury coastline. This relationship is examined in the following section which outlines the tsunami events that have been experienced at Christchurch.

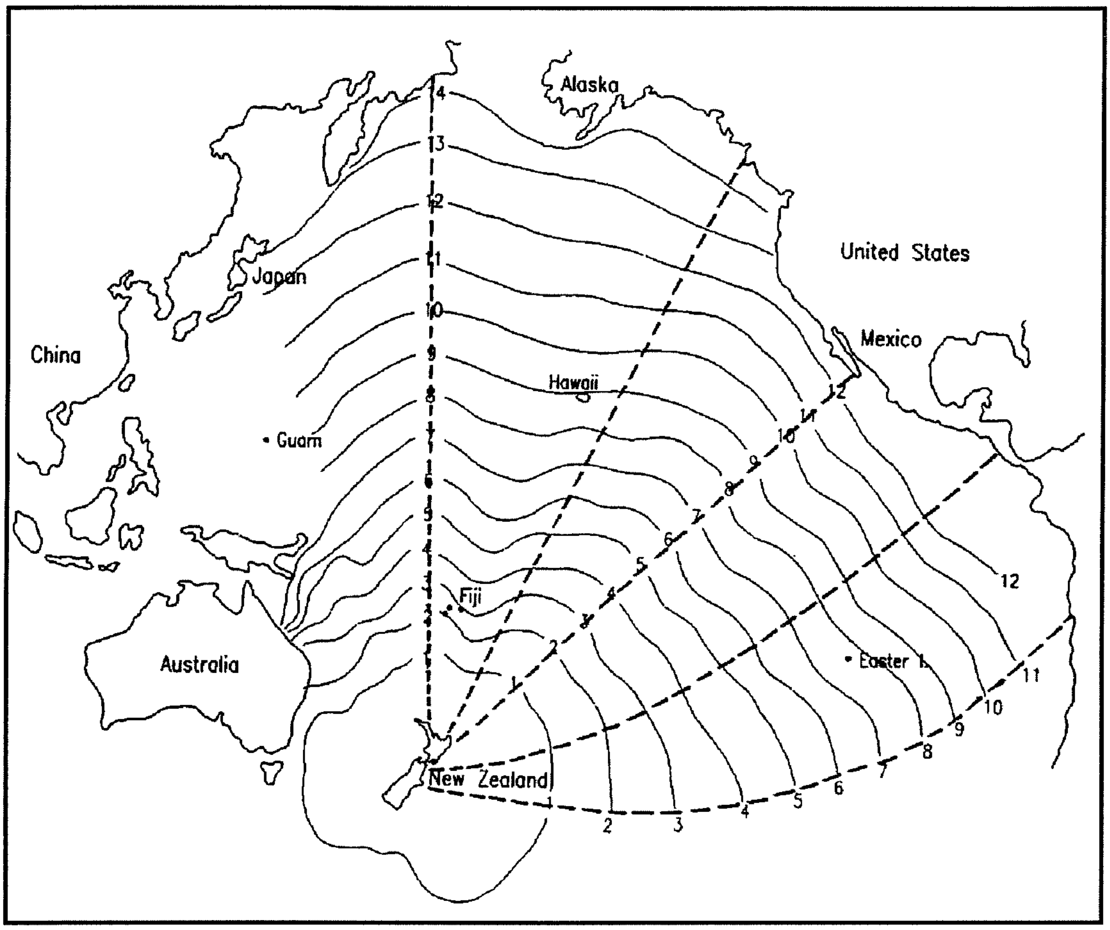

Figure 3.1: **Tsunami Generation Points and Travel Times (in hours) for New Zealand**
(Source: Kirk and Todd, 1994)

3.3 Tsunami Events in The Christchurch Area

3.3.1 Background

There have been seven recognised tsunami events affecting either the Christchurch coast or Lyttelton Harbour since the time of European settlement. Of these tsunami events only one was generated near New Zealand, while the other six were remotely-generated tsunami. Table 3.1 contains the dates, generation areas and causes for these seven tsunami. The one questionable event is that of

1883. It is believed that this tsunami was more a result of atmospheric coupling in the South Pacific basin, than as a direct result of the Krakatoa eruption (de Lange and Healy, 1986). As the 1868 and 1960 events are to be examined in detail, the following is a summary of the observations made regarding the other five events.

The 1855 earthquake in the West Wairarapa produced severe land movements which resulted in a locally generated tsunami. The effects were most felt in Wellington. In Christchurch a small bore apparently travelled up the Avon River during the night following the earthquake. Seaweed was left 0.3 metres above the normal water level (de Lange and Healy, 1986). The 1877 earthquake off the Chilean coast was first noticed at Lyttelton harbour at 7 am. The tide was at half flood, when it suddenly reached above the high water mark on the tidal gauge and fell exceedingly low. A 0.9 metre rise in the Avon River was also reported (de Lange and Healy, 1986). The 1883 tsunami event, as discussed above, appears to have been the result of strong barometric fluctuations. There is no mention of any affect along the Christchurch coast, however at Lyttelton Harbour the water dropped by 0.9 - 1.2m, falling to 0.9m below the low water mark on the tidal gauge. The largest drop in water level was on the 29th August, when the water level reached 1.8m below the low water mark (de Lange and Healy, 1986). In 1922 following another earthquake on the Chilean coast, slight fluctuations in water level were reported along the South Island's east coast. At New Brighton, just north of

Table 3.1 Dates and Generation Areas and Events for Tsunamis Experienced on the Canterbury Coast. (Source: de Lange and Healy, 1986)

Date	Generation Area	Generation Event
23 January 1855	West Wairapapa (NZ)	Earthquake
15 August 1868	Peru/Chile Coast	Earthquake
10 May 1877	Chilean Coast	Earthquake
27 August 1883	Indonesia	Volcanic Eruption
11 November 1922	Chilean Coast	Earthquake
22 May 1960	Chilean Coast	Earthquake
28 March 1964	Alaskan Coast	Earthquake

the study area, the tide modified its direction between ebb and flood numerous times during a 15 minute period, with the largest fluctuation being up to 0.1m (de Lange and Healy, 1986). The latest actual tsunami event recorded on the Christchurch coast was in 1964. There have been warnings issued since this time, the latest on 17 May 1995, but no tsunami was recorded at Christchurch. The March 1964 tsunami produced fluctuations at Lyttelton Harbour of around 0.9m, with the maximum rise in water level of 1.25m in 40 minutes (de Lange and Healy, 1964). Sumner residents reported that the sea was rough, but not unusually so for the time of the year, and that the water level was about 1 foot higher than normal (The Press, 30 March 1964).

3.3.2 The 1868 Tsunami

The August 1868 tsunami was the result of an earthquake off the coasts of Peru and Chile. No magnitude for this event is given in reports of the time. Although de Lange and Healy (1986) report that a small wave was noticed on the Avon River on 17 August 1868, little is noted of this in historical records. The following information is concerned solely with the effects of the tsunami within Lyttelton Harbour. Due to the size of the fluctuations in water levels reported at Lyttelton, even taking into account the affects of a harbour on a tsunami, it is likely that there was some damage to the distal end of South Brighton Spit, and possibly flooding of low areas of the spit bordering the estuary.

Three distinct waves reached the east coast of South Island on the 15 August 1868 (Hector, 1869). These three waves arrived between 3 to 4 am., 7 to 8 am., and 10 to 11 am., respectively. Figure 3.2 shows these three main waves (A, B, and C). Hector states that "from the manner in which the observations were recorded, it must not be expected that they can express the facts in a very reliable manner" (Hector, 1869, 96). However, even though Hector has little faith in the exactness of these observations, Figure 3.2 does provide a general idea of how the tsunami was experienced along the New Zealand coast. The first observations of the phenomenon at Lyttelton were by the night watchman on the railway, Mr. Webb

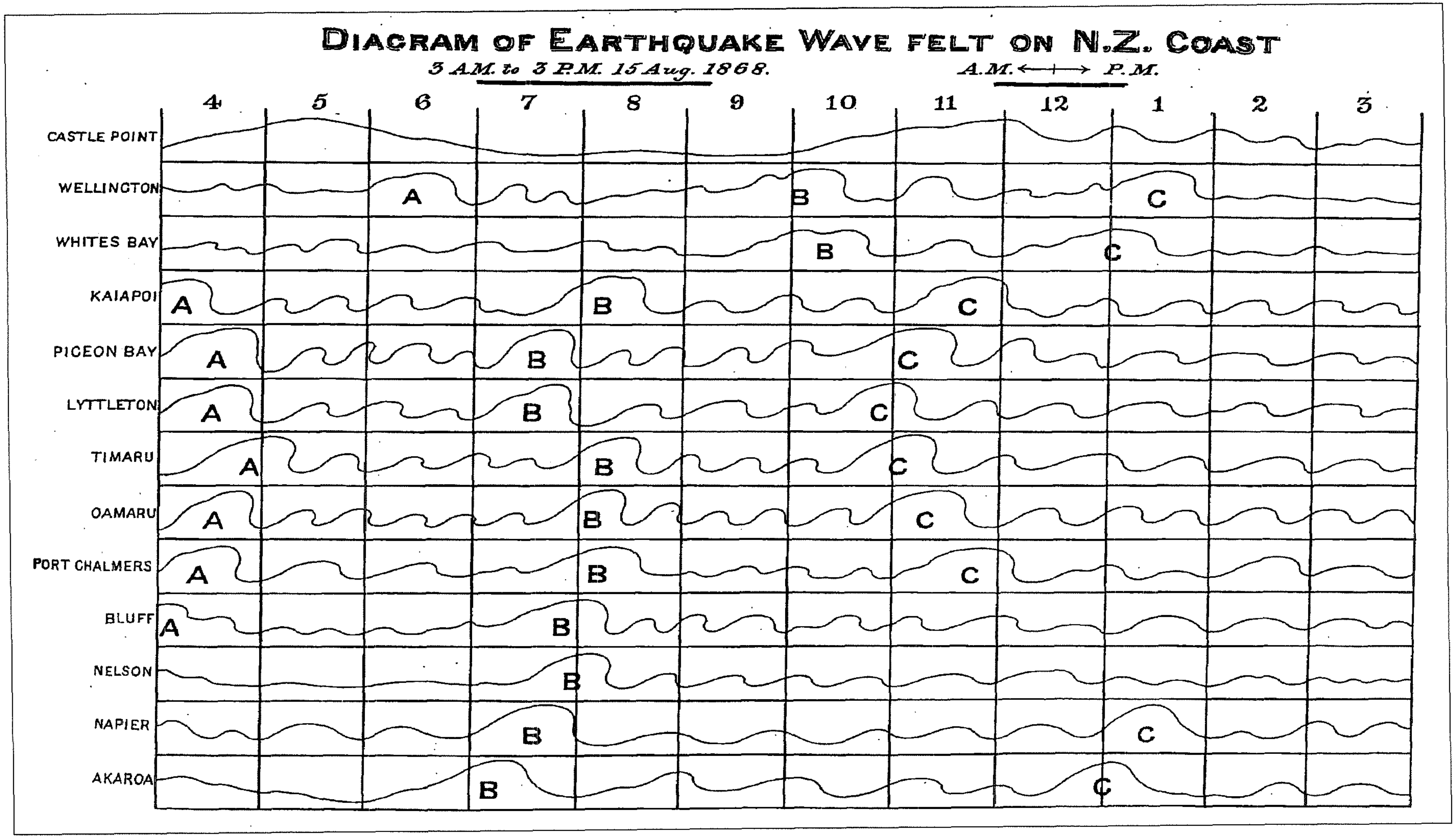

Figure 3.2 Diagram of 1868 Tsunami Waves (Source: Hector, 1869)

and Captain Jenkins of the *John Knox* barque (Lyttelton Times, 17 August 1868). Mr Webb is reported as noting the *John Knox* barque lying on her starboard broadside at 4 am. Figure 3.3 is the report made by Captain Jenkins that was published in newspapers at the time. There is a time discrepancy of half an hour, between the first observations by Mr Webb and Captain Jenkins. The report describes the first and last waves that are shown in Hector's diagram (Figure 3.2), while no mention is made of the second wave. It would appear from this report that the first wave was the largest. However it is clear from Captain Jenkins' report that the velocity and strength of the waves in Lyttelton Harbour were great and that their effect on ships within the harbour was devastating.

> At 3.30 I heard a great noise, and the ship went down on her beam ends. I got on deck with difficulty and found the ship lying with her yard arms on the wharf. I could not imagine what was the matter when hearing a noise like the rushing of water, or a strong wind, I looked out into the harbour. It was all dry as far as the breakwater, and a wave was rolling in about 8 feet high; it came up against the ship with great force. A few minutes afterwards it rebounded, and caught the ship's bow, carrying away two parts of an 8 inch warp and the best bower cable, which was shackled to the wharf, dragging the anchor home with 60 fathoms cable. In 15 or 20 minutes after the wave came in, the water was within 2 feet of the top of the wharf and in less that half an hour the ship was dry again. The water ran in and out at intervals until 10 am., when another rush broke three parts of her stern warp; the ship swinging round again clear of the wharf. ... The starboard quarter was knocked in by being dashed against the jetty by the wave .

Figure 3.3 Report of Captain Jenkins on 1868 Tsunami (Source: Lyttelton Times, 17 August 1868, 2)

The Chief Harbour Master at the time, Captain Fred D. Gibson provided the most information regarding the effects of the tsunami in Lyttelton Harbour (Figure 3.4). Captain Gibson's concise report on the effects of the tsunami on the water levels of Lyttelton Harbour aptly illustrates the nine possible effects of a tsunami on a shoreline, as mentioned above. All three waves, as shown in Figure 3.2, are described by Captain Gibson. Contrary to both Captain Jenkins and Mr Webb, Captain Gibson places the arrival of the first tsunami wave at 4.30 am. on the morning of the 15 August 1868. Less than one and half hours later, the water receded, and less than three hours after the first wave struck, the second wave entered the harbour, at 7.15 am. Between 7.30 am. and 11 am. the water receded and entered the harbour twice. The first wave appears to have been the largest, with a perpendicular rise of 25 feet in twenty minutes. The second, third and fourth waves, although smaller in terms of the rise in water level, appear to have had similar velocities and just as much affect as the first wave. It appears from reports that the tidal flow in Lyttelton harbour took several days to recover from the tsunami, with normal tidal motion returning on Wednesday 19th August 1868.

> At 3.30 am., the tide being half-ebb, the water suddenly receded from the harbour, rushing past the shipping lying in the stream, and vessels anchored near the entrance of the harbour, at a supposed velocity of twelve knots. The water continued falling until 4.30 am., when the end of the breakwater was dry, at which position the average depth at low water is 15 feet. At the before mentioned hour, with a loud roar, a wave of about 8 feet in height rushed up the harbour with great velocity, and at 4.50 the water was within 3 feet of the railway level; in other words, 3 feet above the highest spring tide, having risen 25 feet perpendicular in twenty minutes.
>
> The water at about 5 am. rapidly receded the second time, and at 6 am. the bottom was again visible beyond the end of the Government jetty; at 7.15 it again rushed up in the form of a heavy ground swell, and rose rapidly to 16 feet, and immediately commenced to fall again. At 9.30 am., the inner end of the screw pile jetty was dry, when the reaction again took place, the water returning with even more velocity than at 7 am., until it resumed the level of high water springs. Off, in the stream, the water was very thick and discoloured, boiling up as it were from the bottom.
>
> At 10.15 the water rushed out with the same force for about half an hour, and rose again shortly after 11 am. to 18 feet; throughout the remainder of the day the water rose and fell without any regularity, sometimes at the rate of 3 feet per hour.

Figure 3.4 Captain Gibson's Report on the 1868 Tsunami (Source: Gibson, 1869, 195)

The velocity of the waves was sufficient to shift the Skeleton Buoy from Officers Point, with a 200 kilogram anchor, over 800m as well as removing a 90 m (300 foot) long jetty from the head of the bay (de Lange and Healy, 1986; Lyttelton Times, 17 August 1868). The schooner Dove was seen coming up the harbour about 10.30 am under full sail against a westerly breeze as fast as a steamer, and was swept broadside up the harbour for two miles by the current (The Press, 18 August 1868). Besides the *John Knox*, several other vessels in the harbour at the time were damaged. The ketch *Margaret*, which was lying on the beach, was carried into the harbour by the rebounding wave where she fouled the schooner *Annie Brown*. The *Jeanie Duncan*, *Novelty*, *Georgina*, *Onehunga*, and the *Antelope* were also substantially damaged. The steamer *Taranaki* found a hatch covering from a large vessel and a fully rigged mast outside the heads of the harbour (Lyttelton Times, 17 August 1868).

3.3.3 The 1960 Tsunami

An earthquake off the Chilean coast, with a magnitude of 8.5 on the Richter scale, occurred on the 22 May 1960. This tsunami event is one of the most recent larger remotely-generated tsunami to have reached and been reported along most of New Zealand's east coast. There has not been a tsunami experienced in New Zealand of similar magnitude since this event. Again, as regards the Canterbury coast, the major effects of this tsunami were reported for Banks Peninsula, particularly in Lyttelton Harbour. However, due to the expansion of suburban Christchurch, and the increase in personal transport there are also reports of the effects of this tsunami on the Christchurch coast.

The first evidence of the tsunami was at 9.30 pm on the 23 May 1960, when the water level in Lyttelton Harbour began to drop. A meeting of the Christchurch Drainage Board, reported on the information supplied by the Lyttelton Harbour Board on the phenomenon (Christchurch Drainage Board, 1960). The normal tidal covenant of Lyttelton harbour is a change in water level of 1.8 m (6 feet) over a six and a quarter hour time period. With this tsunami the water level in the Harbour dropped by 3.1 m (10.33 feet) in just under an hour, until it reached 2.1 m (7'1") below zero on the tidal gauge. In the next hour and a quarter the water rose by 5.6 m (18'8") to be 3.5 m (11'7") above zero on the tidal gauge at 11.35 pm. This rise, and subsequent water level represents the arrival of the crest of the first wave. At 2.40 am on 24 May 1960, a smaller wave entered the harbour. However the tide was higher than when the first wave struck. Although smaller in height, this particular wave reached a level 3 inches higher than the first wave. Throughout the remainder of the day the water level fluctuated contrary to the normal tidal motion. The most fortunate aspect of this event is that the tsunami occurred while the tide was at half-ebb. This meant that the effects of the tsunami were less devastating than they might otherwise have been. The increased water levels obtained by the tsunami threatened the electrical mains that run beneath the wharf, with the result that power to the wharves was cut to prevent an accident of fire (The Press, 24 May, 1960). Many small craft moored in Lyttelton Harbour were damaged by the tsunami (The Press, 25 May 1960).

As regards the study area, staff of the Christchurch Drainage Board attempted to determine levels for the Avon-Heathcote Estuary (Christchurch Drainage Board, 1960). No mean sea level for the estuary at the time of the tsunami was given. However in Scott's (1963) Christchurch Data: Notes and Comments on the Christchurch Drainage and Sewerage System, a mean tide figure for a three month period from 14 December 1953 to the 14 March 1954 is given. This figure is R.L. 29.75 feet or 8.925 m above the old Christchurch Drainage Board datum (Scott, 1963, 5). In one of the latest reports on water levels in the Avon-Heathcote Estuary, mean sea level is given as being 9.3 m R.L. to the same datum (Oliver and Kirk, 1992). As the 1953-54 level is closer in time to the 1960 tsunami event than the 1992 level, and given that sea level has been rising at Lyttelton at a rate of 2.4 mm per year (after Hannah, 1990; see also Figure 5.3), all levels in the estuary given in this section are relative to the 1953-54 level.

From the attempts made by the Christchurch Drainage Board staff, it appears that the highest water level at Shag Rock was R.L. 11.85 m (R.L 39.5 feet), just under 3 metres above the mean tide level for 1953-54 (Christchurch Drainage Board, 1960). At the Christchurch Yacht Club's sheds the level was approximately R.L. 11.2 m (R.L. 37.35 feet), while the level recorded at the outlet of a stormwater drain in Moncks Bay of R.L. 10.73 m (R.L. 35.77 feet) occurred during the peak early on the morning of 24 May 1960. At 4 pm on 24 May 1960, the high tide in the Avon-Heathcote Estuary was observed at R.L. 10.65 m (R.L. 35.49 feet), 0.3 m higher than the highest tide recorded between 14 December 1953 and 14 March 1954, which was R.L. 10.26 m (R.L. 34.2 feet). Residents living next to the estuary stated that when the estuary should have been at half-tide, the water level observed resembled a full tide, and they expressed their relief that the tsunami had not struck at the time of high tide (The Press, 24 May 1960). The water level in the estuary is believed to have changed from low tide to a high tide position in about 3 minutes (Scott, 1963).

Reports at the time indicated that half an hour after the first wave had struck the Christchurch coast, the water in the Avon-Heathcote Estuary started to race back out to sea past Shag Rock, at what was estimated at a speed of more than 10 knots. It is noted in the Christchurch Drainage Board's Minutes for the 21 June 1960, that although they had not at the time determined the nature and extent of the scouring caused by the high velocities of the water as it entered and exited the Avon-Heathcote Estuary, it appeared due to the fact that the normal line of breakers was no longer visible, that the bar across the estuary's entrance had been removed. Mr. Keith Wright, a resident of Southshore at the time, remembers that the tsunami had cut a deep straight channel as it exited the estuary, rushing straight out without any apparent restrictions. This change in the Avon-Heathcote Estuary's channel resulted in scouring of South Brighton Spit at its distal end. However the spit itself was not breached at any point (Scott, 1963). A local newspaper reported that at 3 am on the morning of the 24 May 1960, water was flowing onto the south end of Rockinghorse Road but was not threatening the small number of houses on South Brighton Spit (The Press, 24 May 1960). One resident of Southshore at the time remembers being sent home from his place of work in central Christchurch to "secure his property", and although he does not remember any flooding, he did observe sea lettuce on the side of the road at the corner of Caspian and Ebbtide Streets, suggesting that water had flowed over the wall at this point (Keith Wright, 1995, Pers. Comm.).

The rise and fall of water levels in the Avon-Heathcote Estuary, continued throughout the day after the initial wave struck. Large numbers of sightseers lined the margins of the estuary and local beaches watching the half hourly cycle of changes in the water level. Just before the predicted high tide at 4 pm on 24 May 1960, the estuary had the appearance of large river in flood (The Press, 25 May 1960). The increase in water level that occurred with this high tide, was the eighth rise and fall of the tide beyond normal spring limits since the tsunami was first experienced 17 hours earlier. Plate 3.1 shows the difference in the water level around Shag Rock within a half hour period. The large base of the rock had never been so exposed according to the memory of local residents (The Press, 25 May 1960).

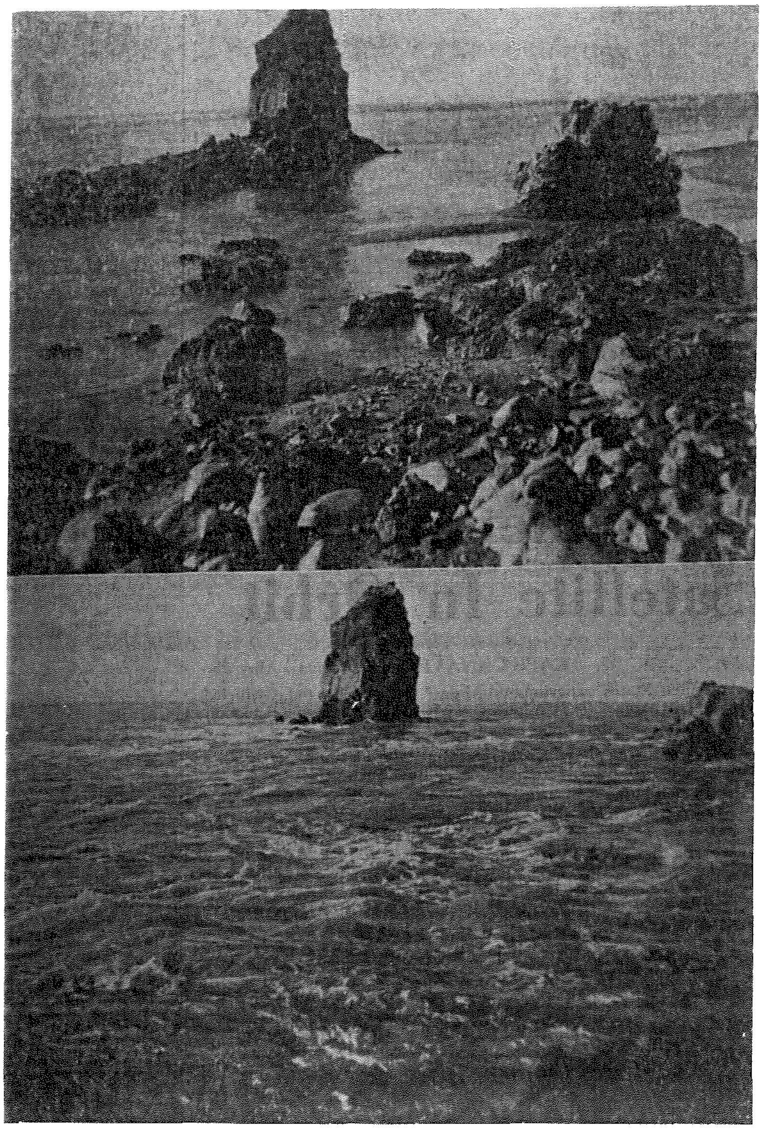

Plate 3.1 Difference in Water Level Over Half an Hour at Shag Rock (Photo: The Press, 26/05/60, 16)

A comparison between the 1868 and 1960 tsunami events reveals that they were similar in their effect on Lyttelton Harbour, however the 1868 was somewhat larger. Both events occurred when the tide was at half-ebb. The 1868 event had a perpendicular rise in water level with the first wave of 7.5 metres (25 feet), while the first wave in 1960 caused a rise of 5.6 metres (over 18 feet). Both events appear to have almost reached the top of the wharves, however more damage occurred during the 1868 event due to the number of large vessels in the harbour. Although no information is available regarding the impact of the 1868 event on the Avon-Heathcote Estuary and South Brighton Spit, it can be inferred that as the 1868 event was larger than that of 1960, the impact would also have been larger. The highest water level given for the Avon-Heathcote Estuary during the 1960 event was R.L. 11.85 metres (above the old Christchurch Drainage Board datum). Thus, it can be inferred that the highest level that could have occurred during the 1868 in the Avon-Heathcote Estuary would have higher than this, but by how much is unknown. Damage to the distal end of South Brighton Spit due to scouring would also have been slightly greater. There may have also been overtopping of dunes along the spit. Grazing of the dunes prior to the 1868 event would have removed vegetation so swash induced blowouts may have resulted. It can be concluded therefore, that although there is no information regarding the impact of the 1868 event on the study area, due to its greater magnitude, those impacts would have been greater than those which occurred from the 1960 event.

3.4 The Lifelines Study

In 1994 the Canterbury Regional Council, undertook a Lifelines study which modelled the occurrence of a tsunami on the Christchurch coast (Canterbury Regional Council, 1994b). Much of the information used and results obtained from the study are confidential, however the tsunami scenario itself, and obvious effects from its incidence are public information. The scenario used for the study was a tsunami generated by a large earthquake centred off the coast of South America, similar to those that occurred in 1868 and 1960. The one difference between these two events and the scenario used, is that the tsunami was modelled to strike the Christchurch coast at the peak of high spring tide, thus presenting a worst case scenario. This section outlines the physical characteristics of the tsunami used, and the effects that such an event may have on South Brighton Spit and the Avon-Heathcote Estuary.

The size of the tsunami used for the study involved a total water level variation of 10 metres inclusive of the tides, that is 5 metres above and below mean sea level (Canterbury Regional Council, 1994b). The wave period of the tsunami would be three hours, with the minimum time from the peak to the trough of the first wave being one hour. The appearance of the wave is thought to be more of a surge, as opposed to a normal breaking wave. As the first wave is theorised as hitting the Christchurch coast at the peak of high spring tide, the tide will fall before the second and third waves , with the third wave coinciding with low tide. Thus the second wave will be one metre lower than the first, while the third wave will be two metres lower. The disturbance of water levels along the Christchurch coast will continue over a three to five day period, with normal tidal motions returning around the fifth day after the tsunami has hit. The tsunami is expected to break in the Avon-Heathcote Estuary, and bores are likely to travel up the rivers. On the open coast side of South Brighton Spit, the tsunami wave will be reduced due to the dissipation of energy in the limited water depths of the wide continental shelf and on the ebb tide deltas adjacent to the estuary inlet. A return period for the tsunami used in this scenario could not be calculated, although it is believed that it would be in excess of 150 years, as no tsunami events of this magnitude have occurred since the colonisation of New Zealand. However this does not mean that a tsunami such as the one used for the study will not occur for another 150 years, but that the probability of such an event occurring in any one year is less than 0.66%.

The calculated effects from the first tsunami wave for the study area, involve runup heights of 8 m RL (where 0 m is mean sea level at Lyttelton) on open beaches, which will result in large scale dune blowouts and wide spread inundation from overtopping of the dunes (Canterbury Regional Council, 1994b). There are six locations on South Brighton Spit which have dune heights below the 5 m RL contour. These locations are to the north and south of Heron Street, north of Penguin Street, north and south of Tern Street, and Torea Lane, while all of the dune system south of Tern Street is below the 6.5 m RL contour, as shown in Figure 3.5. The total length of the sections where overtopping could occur is 835 m, and is likely to result in a water volume of 416,520 m^3 passing over or through the dunes. Inundation of the study site is likely to occur from those areas mentioned above where overtopping may occur, and it is assumed that the water would spread out to inundate or cover a total area of 81 hectares. The depth of inundation from overtopping of the dunes is most likely to be around 0.55 m.

As regards the Avon-Heathcote Estuary, the tsunami bore is expected to travel up the estuary with an initial wave height of 3 m above the tide level. It would travel as a solitary wave with no wave trough (Canterbury Regional Council, 1994b). The water level in the estuary prior to the tsunami is assumed as being at high spring tide, 1m RL, thus with a 3 m tsunami bore, total water level in the estuary is expected to reach 4m RL. The tidal compartment of the Avon-Heathcote Estuary is 10.8 x 10^6m^3, while the water volume expected to enter the estuary from both the mouth and overtopping of South Brighton Spit is 14.1 x 10^6m^3, thus giving a total water volume in the estuary for the first tsunami wave of nearly 25 x 10^6m^3. The speed of the bore as it travels up the estuary is estimated at being 6 metres per second. As the tsunami bore enters the Avon-Heathcote Estuary, the cross-sectional area of the estuary's mouth is expected to increase from 700 m^2 at hide tide to 800 m^2 for the first wave, 1000 m^2 for the second wave, and 1200 m^2 for the third wave. The calculated time of outflow of this water is 45 minutes, from +5 m RL to -1 m RL, and is expected to have a velocity of 7.1 metres per second, or 25 kilometres per hour. This velocity is approximately seven times the velocity of normal tidal outflow.

Due to the low nature of the study area, South Brighton Spit will not only be subject to inundation from the open coast, but will be exaggerated by the increased water level in the estuary. The resulting water levels and inundation heights for three of the streets in Southshore (Caspian, Heron and Tern Streets) would be about 3.2m RL, with depths ranging from 1.5 m to 2 m. In total 190 hectares of South Brighton Spit is expected to be inundated from both the overtopping of dunes and increased water levels in the Avon-Heathcote Estuary, to a maximum depth of 2

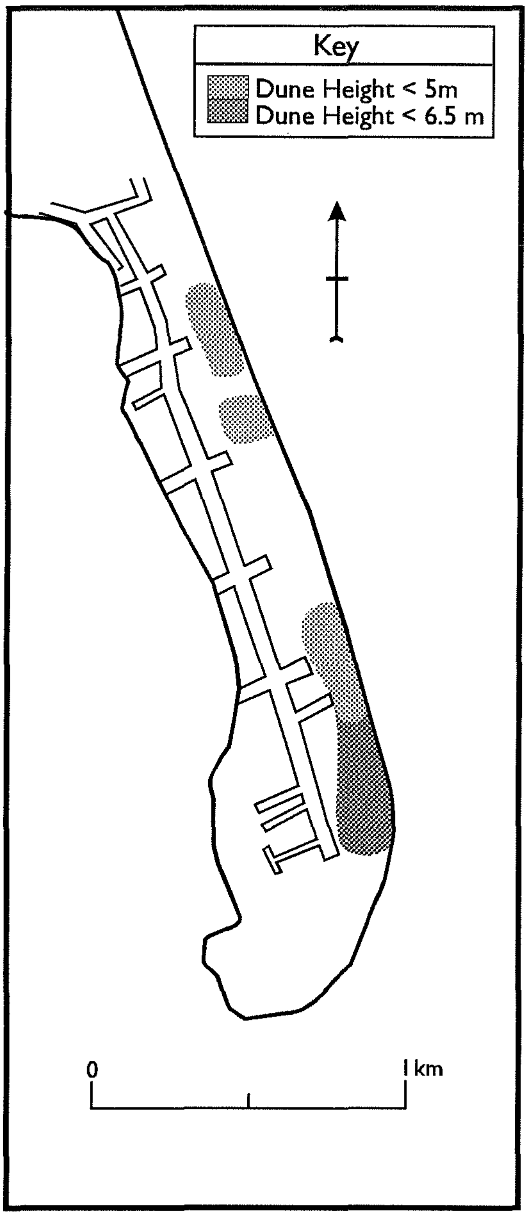

Figure 3.5 Dune Areas Below 5 and 6.5 metre

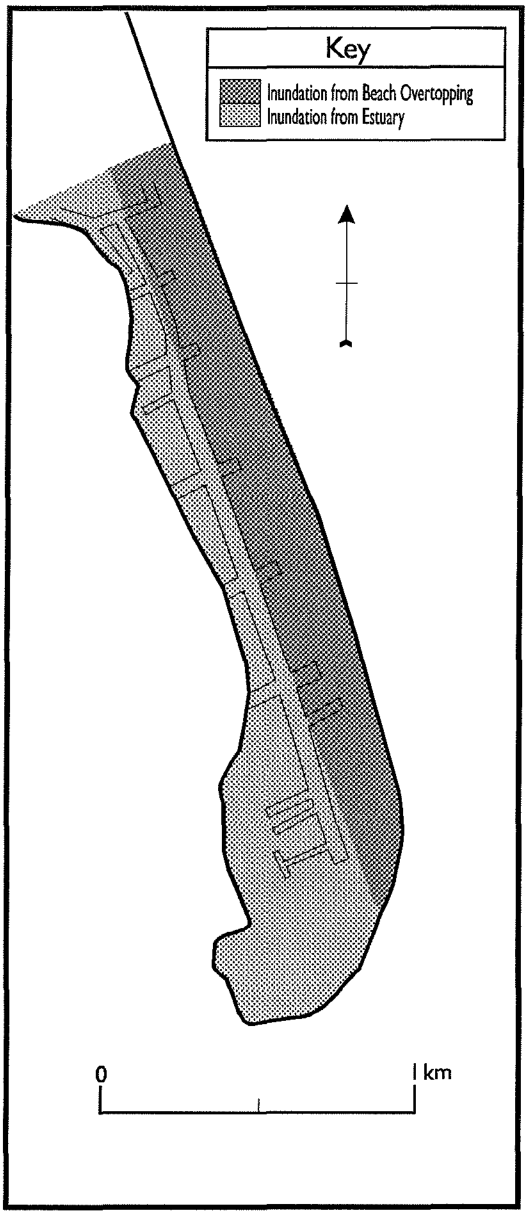

Figure 3.6 Tsunami Inundation Areas

metres. This inundation area is shown in Figure 3.6. With the increase in the cross-sectional area of the estuary inlet, severe scouring of the tip of the distal end of South Brighton Spit is expected to occur as the uncohesive sediments of the spit are more liable to scouring than the hard basalt rock on the opposite shore.

Although the results of the Lifelines Project are confidential, it can be inferred that the impacts of such a tsunami event on the study area would be disastrous. Inundation of properties, even if there is no flooding of houses, will most likely result in severe damage by the salt water to vegetation and soils, scour around houses and fences, and possible destruction of smaller structures. Inundation of houses is the area where the highest cost to residents may be felt, as water levels in the study area are expected to be up to 2 metres deep. Due to the velocity of the wave, it can be expected that all forms of infrastructure will be damaged in some way, such as the felling of communication and power lines, and damage to roads, walkways and bridges.. If this occurs, fire from the downed live power lines is also likely to occur. Fire is a common after-effect of a tsunami, and can cause more damage than the actual tsunami. Thus it can be seen that the potential effects of a tsunami such as that modelled in the Lifelines Project on South Brighton Spit would be catastrophic.

3.5 Summary

There have been seven tsunami events experienced at either Christchurch or Lyttelton since the 1850s. Of these seven events, one was a locally generated tsunami, while the other six were all remotely generated. Although the source area for tsunami experienced at Christchurch consists of most of the eastern Pacific Rim, it is the ocean trenches off the South American coast which have generated the largest number of tsunamis to hit Christchurch. Of the two events examined in this chapter the 1868 tsunami had the larger total water level variation of 7.62 m, compared to 5.74 m for the May 1960 tsunami. Both of these events caused substantial damage to shipping and low areas of Lyttelton Harbour. Due to the increasing population and expansion of personal transport, when the 1960 tsunami occurred there were more observations regarding effects on the Christchurch coast, than with the 1868 event. Severe scouring of the distal end of South Brighton Spit, and possible overtopping of the seawall at the corner of Ebbtide and Caspian Streets appears to be the only damage to occur within the study area. The Lifelines study tsunami scenario involved a total water level variation of 10 m, substantially higher the 1868 and 1960 events. However, the main difference is that the scenario involved the first tsunami wave hitting the Christchurch coast at the peak of high spring tide, with the following two waves occurring through mid-tide. The results of the study show substantial flooding from both the overtopping of dunes and increased water level in the estuary, as well as severe scouring of the distal end of South Brighton Spit would occur. It should be noted however, that as there has not been an event of this magnitude recorded on the Christchurch coast, the study involved a large number of assumptions. As a worst case scenario, the study is useful in providing an idea of the consequences of a tsunami, around the size of the 1868 or 1960 events, hitting the Christchurch coast at times of high water, and to help in guiding planners to make effective decisions regarding the use and development of the coast, and the avoidance and mitigation of a tsunami hazard.

Although a tsunami is the most extreme hazard that can occur at South Brighton Spit, erosion of both the coastal and estuary shores is more common and is the subject of the following chapter.

Chapter Four
Erosion Hazards at South Brighton Spit

4.1 Introduction

Many of the previous works on the topic of coastal erosion of spits have only considered the erosion that occurs on the open coast side of a spit, and have ignored the erosion that can occur on the estuary side of such landforms. This chapter investigates the hazard of erosion on both the open coast and estuary sides of South Brighton Spit. The following section of this chapter outlines what makes a coast susceptible to erosion, the processes by which sediments are removed from a beach, and typical manifestations of erosion on the coast. The third section examines short-term variations at six profile sites around South Brighton Spit in order to gain an appreciation of the short-term fluctuations of such landforms. This section then moves on to examine the long-term instability of the spit, especially at its distal end, by an examination of the vegetation lines on South Brighton Spit over a 54 year period. The fourth section of this chapter investigates the erosion that has occurred on the estuary margin along South Brighton Spit. A review of specific erosion events is given in the fifth section, in order to identify the extent of hazard that has been posed over the years.

4.2 Erosion Processes

Coastal erosion can be defined as the process by which a shoreline retreats landwards, with or without a net loss of shoreline sediments (Gibb, 1984; Kirk and Todd, 1994). King (1959, 297-301) describes seven factors to which the susceptibility of a coast to erosion depends on. These factors are:

1) The exposure of a coast to wave attack. Those coasts that are exposed to prevailing winds and large fetches are more liable to erosion than coasts on the lee side on such winds and fetches.
2) Tidal motion, although not directly related to erosion processes, increases the area on a beach which is subject to wave attack.

3) The sediment composition of the coast can make a shoreline resistant or susceptible to erosion. Described as low coasts by King, those coasts that are protected by superficial deposits, including sand dunes, are liable to rapid modification when there is a change in conditions.
4) The offshore relief and its effect on wave refraction can also make a coast more susceptible to erosion. This can help to explain why some sections of a shoreline are more liable to erosion than others, due to the focussing of refracted waves.
5) Sea level rise will increase the area over which wave attack takes place, and can bring such attacks closer to coastal properties.
6) Artificial structures - the placing of objects such as jetties can inhibit the sediment supply of a region, and thus lead to erosion on the down wave side of the object.
7) The actual longshore movement of sediment - King (1959, 300) states that "the movement of material alongshore is responsible for nearly all coastal erosion, directly or indirectly". If there is no supply of sediment, the natural longshore movement of material will erode the beach. Indirect responsibility is when the longshore movement of material removes sediment eroded by other processes.

Although these seven factors can influence erosion, the actual process of erosion is controlled by wave motion, specifically the motion of destructive, steep waves. The generation of such waves is dependent on three storm factors (Komar, 1983). The longer the duration and fetch area of a storm and the greater the strength of the winds blowing, the more energy that can be transferred to the waves. It is when these storm waves break upon a beach that erosion occurs. As the wave breaks the swash runs up the beach and some water is lost to percolation into the beach sands while the rest returns to the sea as backwash. The short-period storm waves permit a rapid succession of such swashes, saturating the beach and raising the beach water table (Healy and Kirk, 1992). With the beach sand saturated, the stability angle of the sands decreases, and with each successive swash and backwash sediment is moved offshore, thereby eroding the beach.

As stated earlier, the tides can influence the area over which such waves operate. Other factors which can influence the severity of coastal erosion are rainfall and storm surge. Intense rainfall, which often accompanies storms, can also lead to the beach water table rising, and can bring the point at which erosion starts closer (Healy and Kirk, 1992). Storm surge (described in detail in the Chapter Five), like the tides, increases sea level and thus brings the destructive action of the storm waves closer to coastal properties (Komar, 1983).

The erosion of the coast is a complex phenomenon, which results from the interaction of a variety of factors. It can manifest itself on the coast in several ways. These are:

- Erosional encroachments by the sea onto properties or transport corridors leading to loss of support and collapse;
- Damage by direct wave impact on structures, properties and services, and damage from objects carried by the flow;
- Loss of beach material, particularly around buildings and other structures;
- Nuisance and/or damage from sand blown or washed out of dunes; and
- Loss of access to beaches and recreational opportunities (Kirk and Todd, 1994, 38).

It should be noted however, that as a hazard coastal erosion is a historically recent phenomenon. This is due to the increase in population density in coastal areas through the world (Chapman, 1994). Erosion of the coast is a natural process and has been occurring since the dawn of time. The exponential growth of the world's population over the last 900 years is the cause of the increases in population density in many parts of the world (Miller, 1992). As noted in Chapter One there must be some form of human use of the coast for a natural process, such as erosion, to become a hazard. With the rapid development of the coast and high population densities in these areas, coastal erosion is perceived as being a relatively new hazard.

4.3 Short and Long Term Oscillations of the Spit

In an attempt to gain an understanding of the short-term erosion problems at South Brighton Spit six profile sites were established (Figure 4.1). Four of these sites are on the open coast, and are part of the Canterbury Regional Council's beach monitoring profile sites. The last two sites were established on the estuary side of

South Brighton Spit. Table 4.1 shows the Canterbury Regional Council's profile site numbers, street names, map grid references, and map eastings and northings. The Council's site numbers are in order of this study's profile numbers, that is C0362 is Profile One, through to C0271 being Profile Four. Temporary pegs were placed on the backbeach, in line with the Canterbury Regional Council's benchmarks, and surveys were taken from these pegs. Thus any reference to 'peg' means these temporary pegs. At the first three profile sites, the surveys were taken at a bearing of 60°, while at the fourth site the surveys were taken at a bearing of 150°. The two estuary side profile sites were located at two Wildlife Reserve signposts on the estuary margin. These two posts were within surveying distance of two stormwater outfalls, which were used as benchmarks. Table 4.2 shows the distance from those outfalls, map grid references, and map eastings and northings for the two estuary side profile site signposts. The profiles were taken at a bearing of 240° from the front of each signpost. For the four coastal sites, beach profiles were measured monthly over a six month period from 16 January 1995 to 17 July 1995. Four surveys were taken at the two estuary sites over the same time period. An examination of the results of these profiles follows.

Table 4.1 Profile Site Numbers and Map References for Benchmarks

Site No. & Street Names	Map Grid References	Map Eastings/Northings
C0362 - Tern Street	M36: 897-393	2489700 5739300
C0350 - Torea Lane	M36: 898-393	2489800 5739300
C0300 - Sth Pukeko Street	M36: 899-389	2489900 5738900
C0271 - Sth Pukeko Street	M36: 899-389	2489900 5738900

Table 4.2 Location of Estuary Profile Sites.

Profile Site	Distance from Outfall	Map Grid Reference	Map East/North
Estuary 1	63 metres	M36: 895-388	2489500 5738800
Estuary 2	40.5 metres	M36: 894-391	2489400 5739100

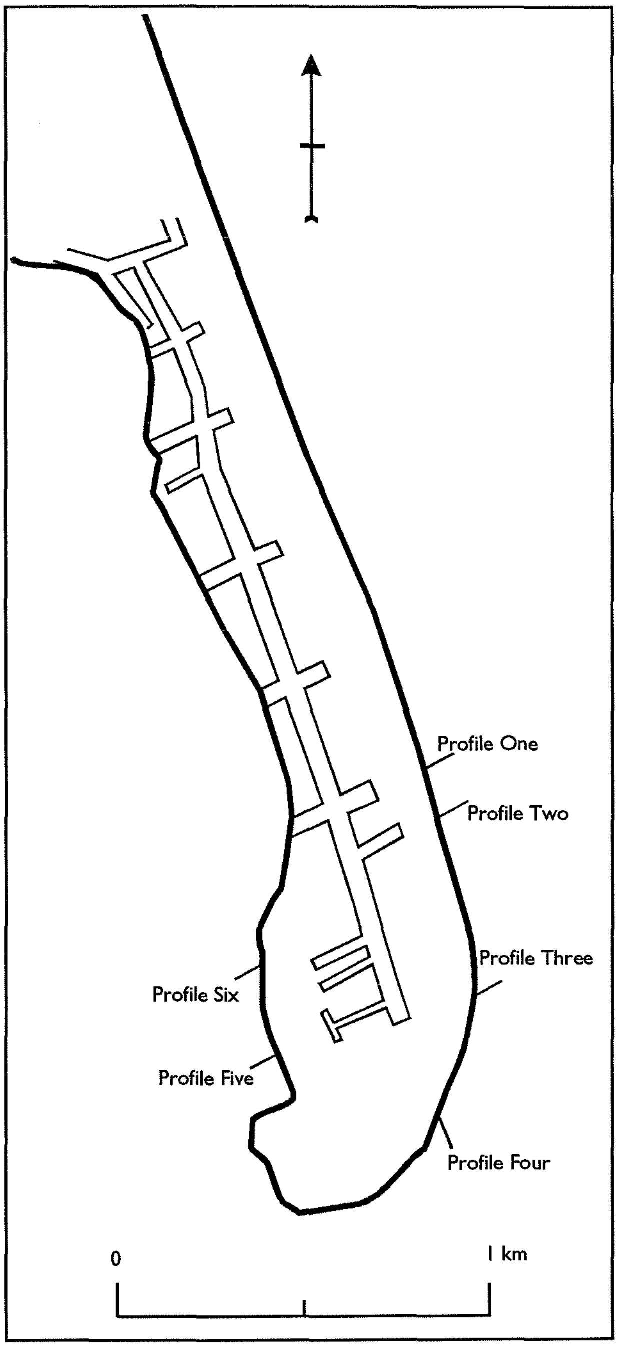

Figure 4.1 Profile Sites at South Brighton Spit

Profile One, at Tern Street, is one of many areas along the spit where there is public access to the beach via a walkway through the dunes (Plate 4.1). Figure 4.2 shows the results of the six beach profiles taken between January and July 1995. There was very little change over the first three surveys. Between the third and fourth surveys however, there was a substantial amount of accretion over the

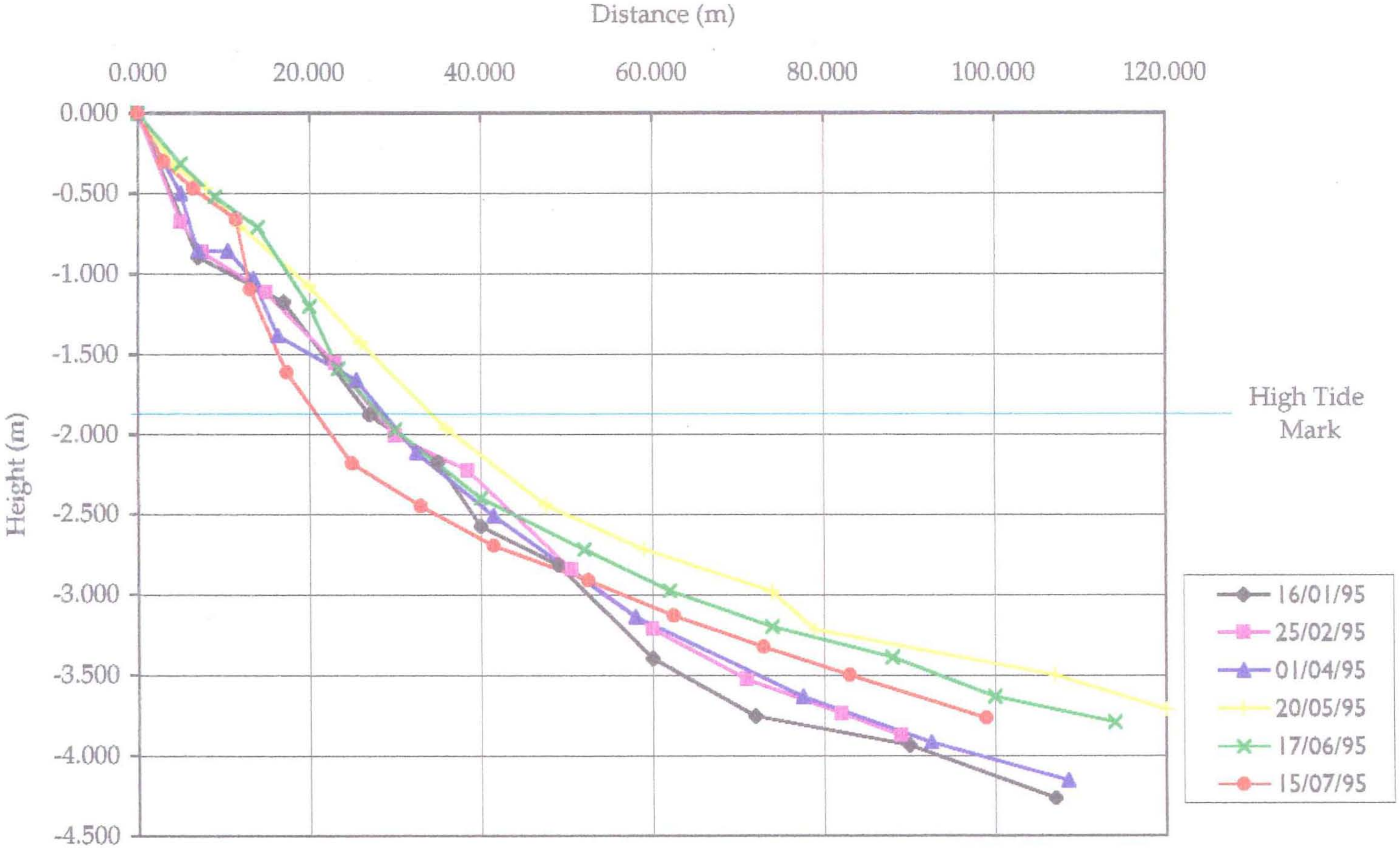

Figure 4.2 Monthly Profiles at Profile Site One

whole beach. The main reason for the build up on the back beach was the landscaping undertaken by the Parks and Recreations Unit of the Christchurch City Council under their Coast Care programme. This entailed fencing along the main access route to the beach, closing off of a second walkway just to the north of the profile site, artificial building up of the front face of the foredune at this point, and considerable planting of both marram grass and ice plant. The fifth monthly profile shows the beach responding to the change in season, from the calmer wave environments of the summer to the harsher wave environment of the winter. Although sediment was removed from this site between the fourth and fifth profiles this by no means constitutes anything more than the normal beach fluctuations that is expected with the different seasons (Blake, 1964). The final profile from 15 July 1995, was the first sign of significant retreat of the profile. A scarp approximately 300 metres long had developed. At this profile site it was 11.5 metres from the peg and 0.5 metres high. A possible reason for this scarp is the very high tides that were experienced in the week before the last profile was taken. As noted above the tide can increase the area over which wave action takes place, thus there does not have to have been a storm for this scarp to have developed. Over the six month survey period, there was a net gain of 7.44 $m^3.m^{-1}$ over the first 13 metres of the profile, a net loss of 16.46 $m^3.m^{-1}$ from the 13 metre mark out to 50 metres, and another net gain of 12.97 $m^3.m^{-1}$ over the lower profile.

Plate 4.1 **Dunes and Beach Access Walkway at Profile Site One**

Profile Two is located between the southernmost and middle houses on the dunes at Torea Lane (Figure 4.1). Although there has been substantial erosion at this site after the initial building of the houses in 1960s, (discussed further in Section 4.5), Figure 4.3 shows that there was very little change over the whole six month surveying period. No temporary peg was used at this site, as the profiles are taken from a signpost in front of the fence to the south of the lefthand house as shown in Plate 2.1. The scarp noted at Profile One in the survey of 15 July 1995, was also evident at this site. Here, however, the scarp was 20 metres from the peg, but was still only 0.5 metres high. The volume of sand lost from the scarp seawards was 5.44 $m^3.m^{-1}$. Towards the south the scarp reached a height of 0.7 metres as it passed directly in front of one of the houses. This scarp is also shown in Plate 2.1. This particular site is relatively stable, as there has not been a major erosion event since the late 1970s, however the very fact that the houses are build on the foredunes makes them prone to damage during a major storm.

Profile Three, located perpendicular to the end of Rockinghorse Road, shows major variations between surveys (Figures 4.1 and 4.4). Between the first and second surveys there was deposition of sediment. A small dune developed in front of a 1.8 metre scarp and a further berm is noticeable about 40 metres from the scarp. Between the second and third surveys, however, the small dune disappeared, while the berm in the second survey moved up the beach by about 10 metres and there was a loss of sediment from this point seawards. The fourth and fifth surveys show little variation over the landward 10 metres, however from this point outwards there was accretion of sediment. The final survey on 15 July 1995, shows the small dune developing again, with more deposition over the whole beach. The scarp noticed at the first two profile sites on 15 July 1995, was not evident at this site. In total over the six month survey period about one metre of sand, in terms of depth, and a volume of 6.04 $m^3.m^{-1}$ was deposited on the beach. The change in this profile may be explained by its close proximity to the channel of the Avon-Heathcote Estuary which is known to fluctuate in its position between the spit and Shag Rock.

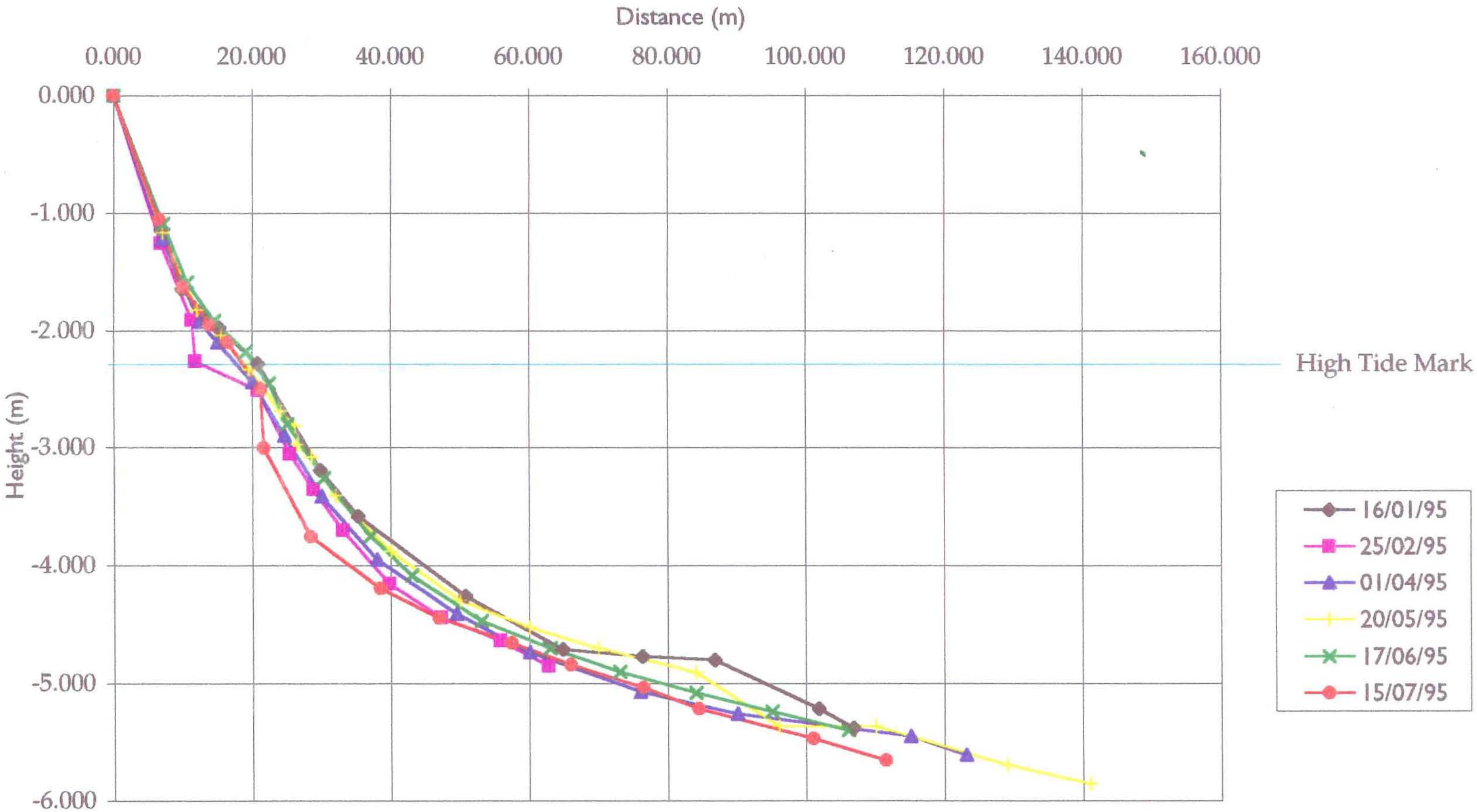

Figure 4.3 Monthly Surveys at Profile Site Two

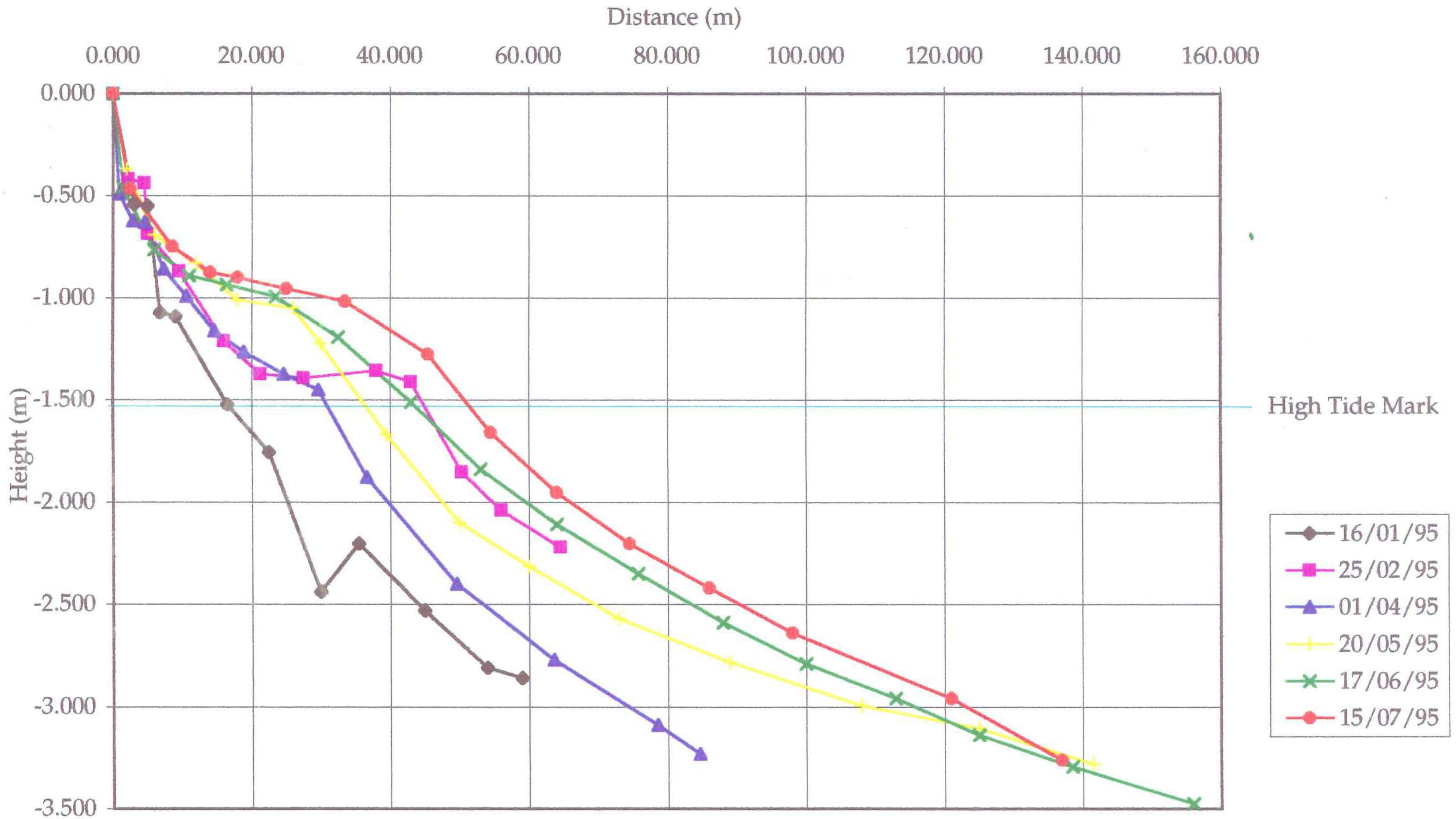

Figure 4.4 Monthly Surveys at Profile Site Three

The fourth profile runs in a line directly off the end of Rockinghorse Road (Figure 4.1). The results of the six surveys at this site show a substantial amount of variation over the survey period (Figure 4.5). The main reason for the variation at this site is that this profile runs onto the Avon-Heathcote Estuary inlet channel between the spit and Shag Rock. Any fluctuations in the position of the channel are reflected in the beach profiles. The growth of a small dune from a height of about 0.2 metres in the second survey to a height of about 0.5 metres in the fourth survey can be seen in Figure 4.5. This dune has since been planted with marram grass by the Parks and Recreations Unit of the Christchurch City Council and appears to be stabilising, its volume as gained 0.83 $m^3.m^{-1}$ of sand over the six months of surveying. In all, the end of the spit has fluctuated by over 100 metres in length, and by about 2 metres in depth, gaining 1.56 $m^3.m^{-1}$ of sand between the second and third surveys, and loosing 10.75 $m^3.m^{-1}$ of sand over the whole six months. The results of the six months of surveying at this site highlight the variable nature of the distal end of the spit during a period in which there were no severe storms.

Profile Five is the first of two profile sites that were established on the estuary side of South Brighton Spit (Figure 4.1). As stated above, this profile site used a Wildlife Reserve signpost at the edge of the estuary margin as the starting point for the surveys. The results of the four profiles taken over the six month survey period are shown in Figure 4.6. There was very little change between the first and second surveys, with the exception of a small movement westward of about 5 to 10 metres of a small channel. This channel is thought to be one of many small meandering channels through which an incoming tide will fill the estuary. Between the second and third surveys there had been some scouring about 10 metres out from the signpost, while the final profile shows a substantial amount of scouring. This latter scouring is most likely due to the very high and low tides experienced in the week before the profiling was carried out. Over the six months of surveying this site has lost 1.75 $m^3.m^{-1}$ of sediment. The channel visible in the first and second surveys, and shown by the dip in the profiles, was not present when the third survey was undertaken. However, by the fourth survey the channel had reappeared, and it was at the edge of this channel that the final survey stopped. This was due to the time the survey was done, as the tide was starting to rise, and the channel was about 0.6 to 0.9 metres wide and 0.15 metres deep.

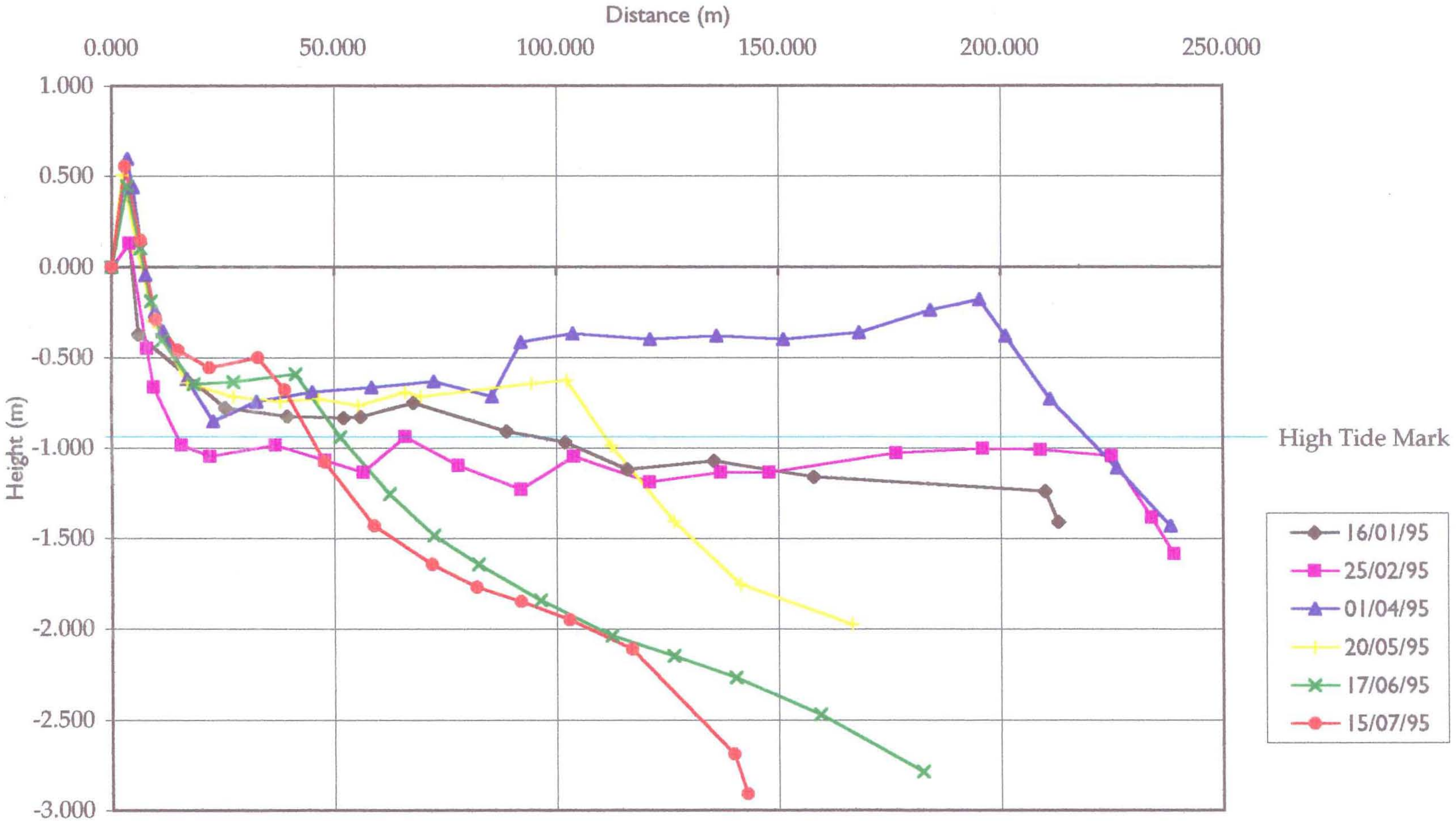

Figure 4.5 Monthly Surveys at Profile Site Four

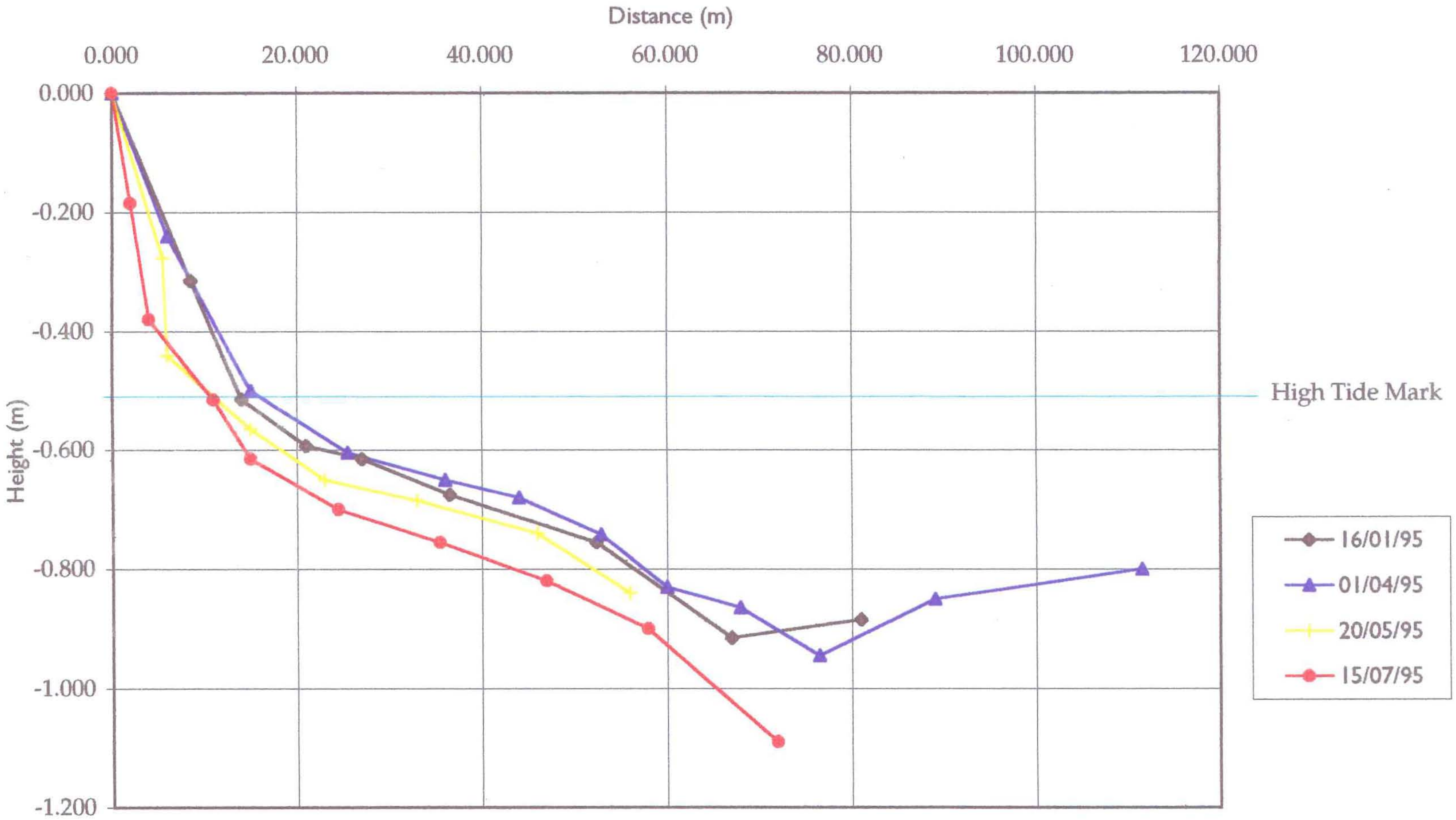

Figure 4.6 Monthly Surveys at Profile Site Five

Profile Six is the second profile site located on the Avon-Heathcote Estuary side of South Brighton Spit (Figure 4.1). This profile site also used a Wildlife Reserve signpost at the edge of the estuary margin as the starting point for the surveys. Figure 4.7 shows that there was very little change over the six month surveying period. However there are two things to note from the results. The dip in the second survey indicates the presence of a small meandering channel, not connected to the one observed at Profile Five, and was only present during this survey. The final survey of 15 July 1995, shows some scouring, again about 10 metres from the signpost, however there is little change in the rest of the profile. The scouring at this profile site, visible in the final survey, is connected to the scouring which occurred at Profile Five, and shows the impact on the estuary shores of the very high and low tides experienced in the week before the surveying was undertaken. As the scouring was visible in the surveys at the two profile sites, it is likely that the effect of the extreme tides occurred along the whole of estuary of South Brighton Spit. There are numerous boundary fences under threat of being undermined if this sort of event occurs at a larger magnitude. More detail of erosion along the estuary margin is given in Section 4.4.

As a whole the six profiles provide a reasonable picture of the changing state of South Brighton Spit during the six month survey period. It can be surmised from this that the spit is neither in an accretional or erosional state over a short time period such as the six months in which the surveying was undertaken, but that it is fairly stable with small fluctuations occurring due to tidal and weather conditions. As there were no major storms during the survey period it is impractical to assert that the fairly stable nature of the spit observed over the survey period is a normal state. However it can be stated that this is a common state for South Brighton Spit in those years in which a major storm does not occur. Whether this summation of the relative stability of the spit over a short time period can be extended into the long term is a difficult question due to the nature of the spit's variability, especially at the distal end. The results of Profile Three and Profile Four support the theory that the distal end of a spit is not stable but rather, it vacillates over an area, accommodating any changes in the conditions of the coastal and estuarine systems in which such landforms are found.

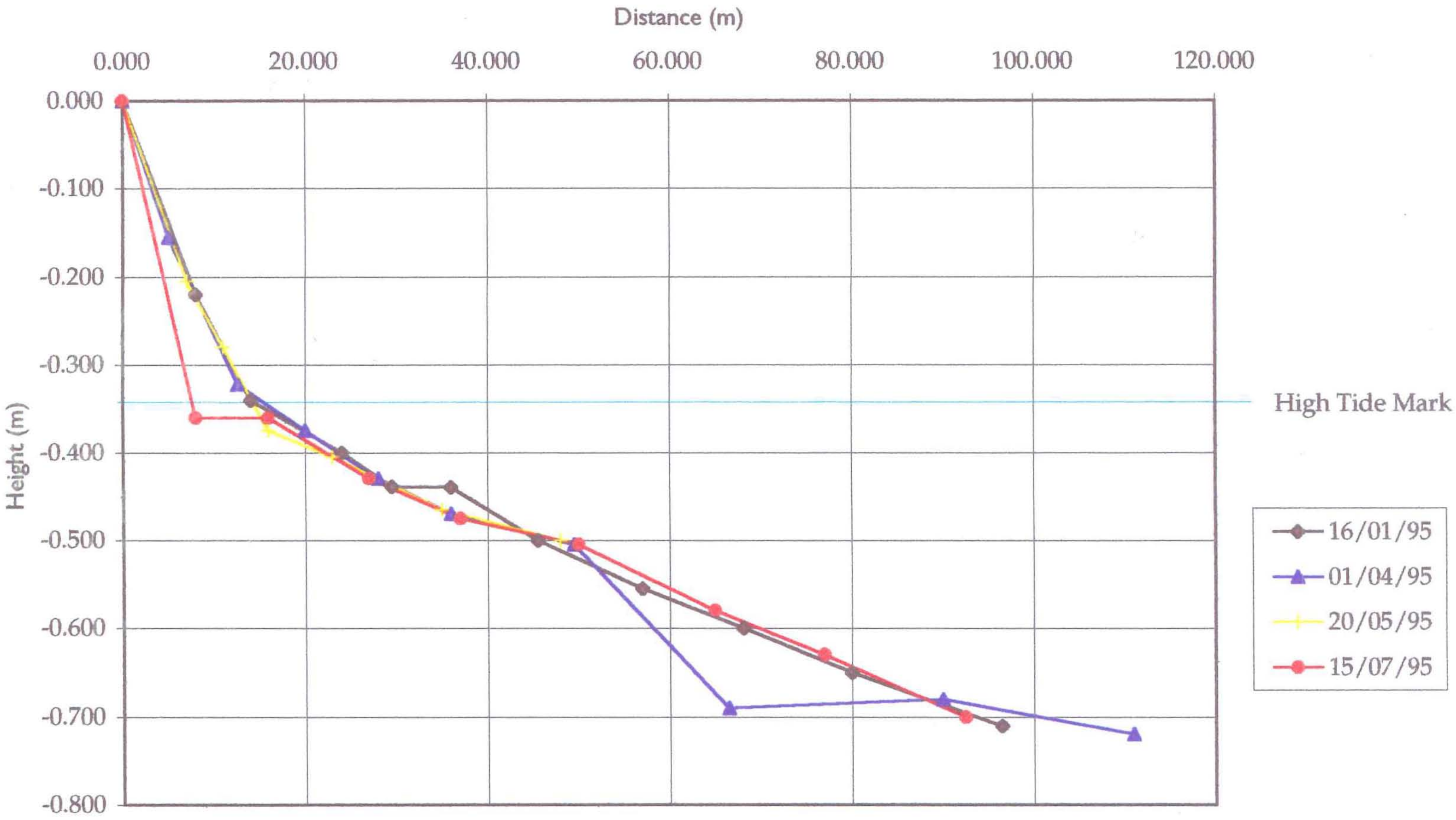

Figure 4.7 Monthly Surveys at Profile Site Six

As stated above, it is believed that South Brighton Spit and associated beaches to the north are neither in a long term accretional or erosional state, but are stable in nature. With the distal end of South Brighton Spit, however, long-term records reveal the instability of such landforms. Figure 4.8 shows this instability through mapping the different configurations of South Brighton Spit at points in time from 1849 to 1977. Prior to 1940 the channel of the Avon-Heathcote Estuary passed the distal end of South Brighton Spit between Shag Rock and Banks Peninsula (Pearse, 1950). About 1940 the channel shifted to the north of Shag Rock, scouring a substantial amount off the end of the spit. The spit lost around 500 metres off its length over a period of a few years (Scott, 1955). The effect that this channel shift had on the spit and the responses undertaken to the erosion will be discussed in detail in the following section. The 1950 configuration is the only one to display a prominent hook formation. This prominent hook has been eroded to produce the more rounded distal end as shown by the 1977 configuration. It is important to note the dynamic nature of the distal end of this spit. Its variability in position can present a major hazard to boating, property, and other assets.

The hazard presented by changes in the spit's configuration is shown more clearly in Figure 4.9, which displays the vegetation lines of South Brighton Spit from 1940 to 1994, relative to property boundaries. This map was compiled by the Canterbury Regional Council from aerial photographs and has been rectified to the cadastral database. Figure 4.9 reveals the slow recovery of the distal end of South Brighton Spit, from the 1940 shift of the Avon-Heathcote Estuary's channel. It should also be noted from this map that a large number of current properties on the seaward side of Rockinghorse Road, are seaward of the 1946 survey line. Although the chances of the spit obtaining a similar state are slim, due to protection works put into place in the late 1940s and early 1950s, the possibility of properties once again becoming part of the sea is still in existence. Compared to the rather dramatic configurations of the 1940s, since 1961 the distal end of South Brighton Spit has been relatively stable. There was a small amount of southward progradation from 1961 until 1994. In 1994 the spit eroded slightly, causing a northwards movement of the vegetation line. Further detail of this erosion is given in Section 4.4.

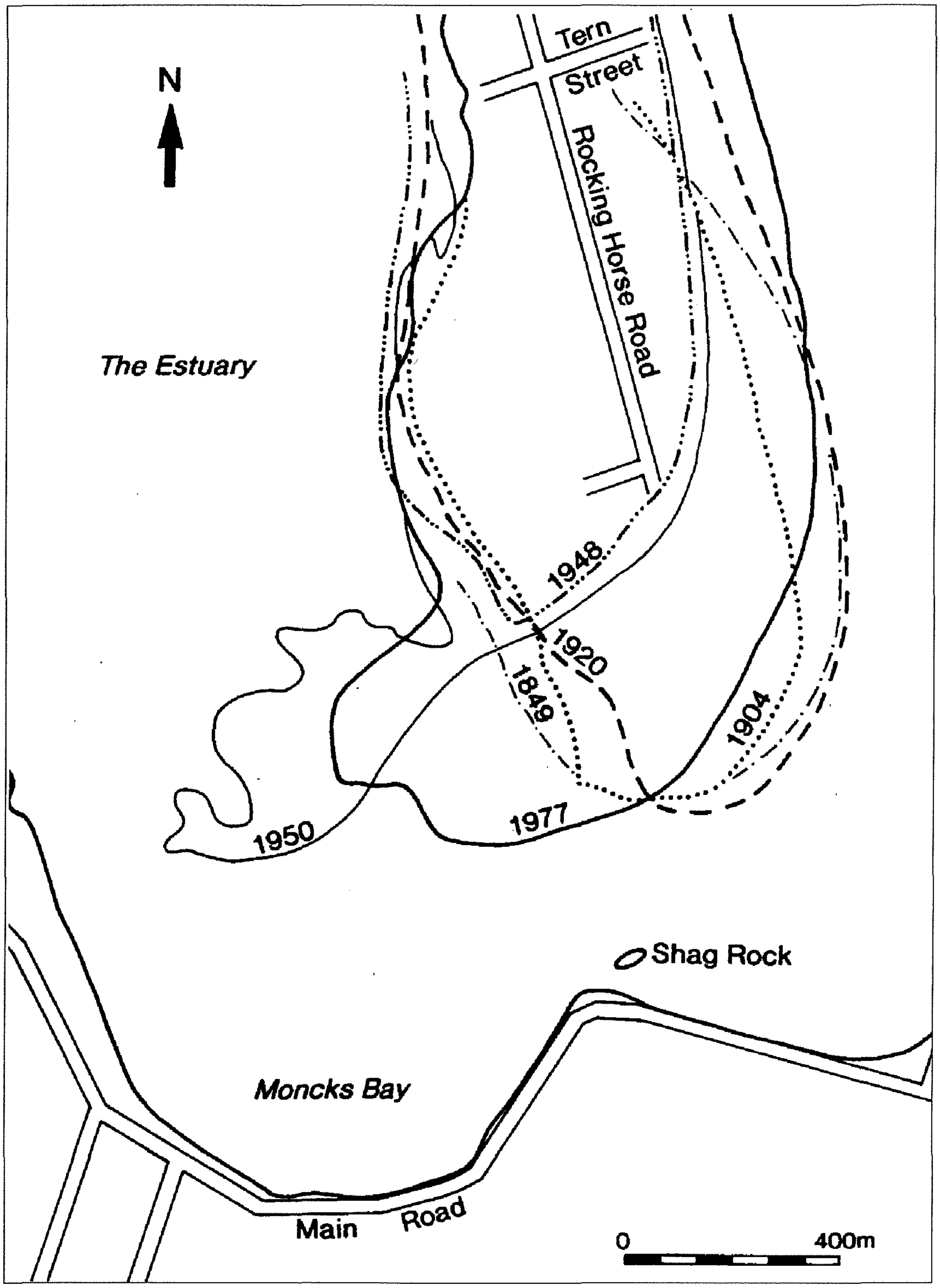

Figure 4.8 Configurations of the Distal End of South Brighton Spit, 1849 to 1977. (Source: Kirk and Todd, 1994)

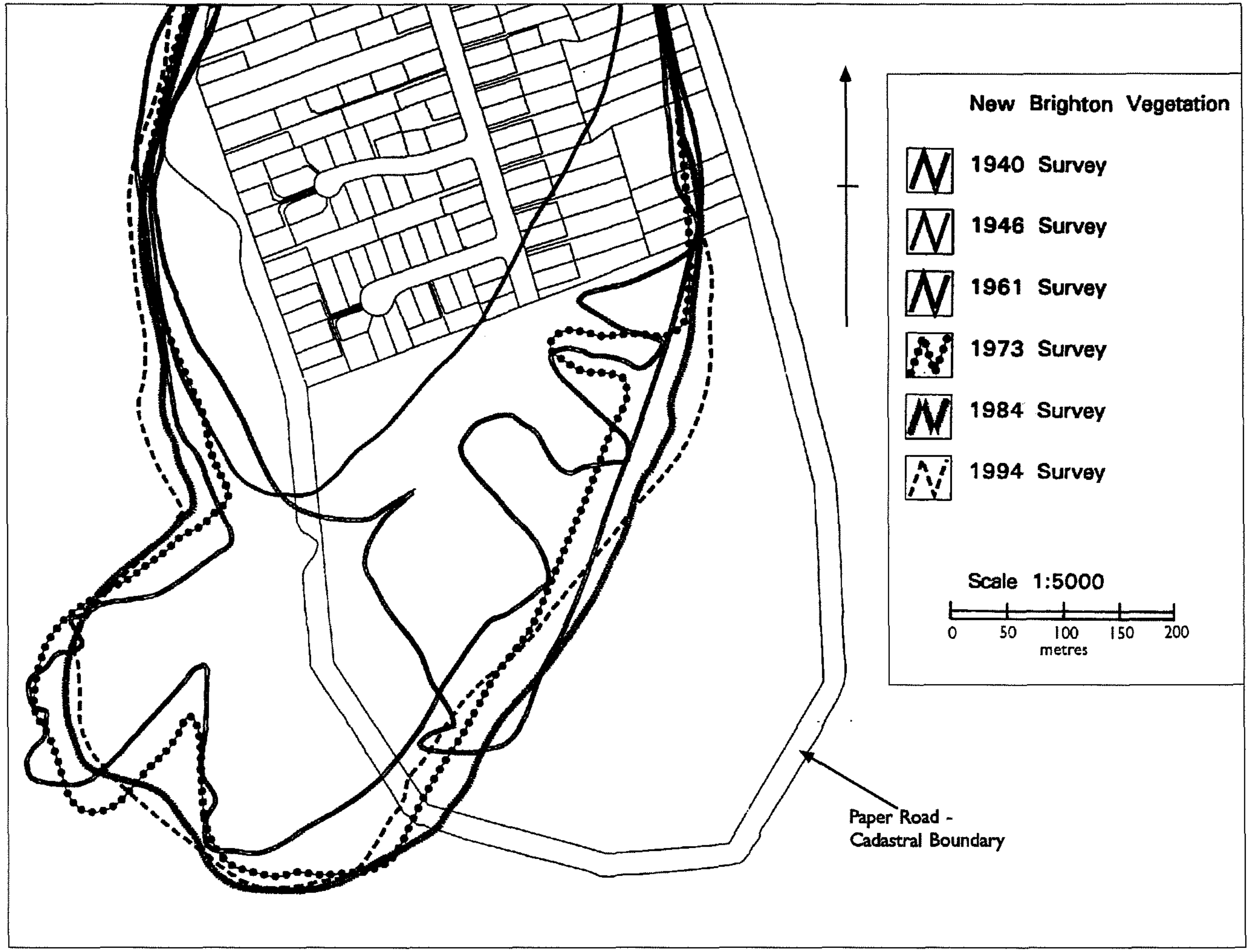

Figure 4.9 Cadastral Boundary and Vegetation Lines at South Brighton Spit, 1940 to 1994
(Source: Canterbury Regional Council)

It would appear from an examination of both Figures 4.8 and 4.9 that the spit has been trying to prograde to a position similar to that portrayed by the lines of 1849, 1904 or 1920. The likelihood of South Brighton Spit returning to a prior configuration such as that of 1849 seems unlikely. The main reason for this is the changes that have occurred in both of the catchments of the Avon and Heathcote Rivers, and the tidal compartment of the estuary since 1849. These changes have been caused by the urban growth of Christchurch over the last 150 years, and have included increases in both runoff into the rivers and sedimentation of the rivers and estuary (Findlay and Kirk, 1988). Such changes have been reflected in the tidal compartment of the Avon-Heathcote, which has increased also over this time period (Findlay and Kirk, 1988). With a modern tidal compartment of 10.805 x 10^6m^3, the velocity of ebb and flood tides is expected to be faster than it was in 1849. This means, that the faster velocity is keeping the entrance to the Avon-Heathcote Estuary open by transporting any sediment deposited in the entrance either back out to sea or into the estuary itself. It is for these reasons that there is little potential for South Brighton Spit to return to a prior configuration, such as that of 1849. As stated earlier, spits are vulnerable to any change in either the coastal or estuarine regimes, and this vulnerability to change is clearly exhibited in both Figure 4.8 and 4.9.

4.4 Erosion of the Eastern Estuary Margin

Erosion of the estuary margin of South Brighton Spit is a much neglected phenomenon. Nearly all research into erosion at South Brighton Spit has only considered the open coast side (Pearse, 1950; Kirk, 1978, 1987; Findlay and Kirk, 1988; Kirk and Todd, 1994; Thompson 1994). Research into erosion within the estuary on the other hand has concentrated on the western edge, specifically around the oxidation ponds of the sewerage disposal works (Millward, 1975, Macpherson, 1978; Deely, 1991, Hicks, 1993). This section summarises an in-house report prepared for the Water Services Unit of the Christchurch City Council on erosion of the estuary foreshore at South Brighton Spit (Walter, 1995) and is the only such report on this topic.

Vegetation along the estuary margin has been dominated by a marine salt marsh, consisting of saline tolerant species such as glasswort (*Sarcocornia quinqueflora*), sea rush (*Juncus martimus*) and sea blite (*Suaeda nova-ezelandiae*) (Walter, 1995; Owen, 1992). In many areas this marsh has suffered significant erosion, and in places has disappeared altogether. In 1962, the Southshore Ratepayers' Association wrote to the Christchurch Drainage Board regarding erosion of the estuary margin and stated that "erosion is taking place at an alarming and increasing rate despite efforts of individual owners to prevent it" (Southshore Ratepayers' Association, 1962). The various means by which property owners have tried to protect their properties will be discussed in Chapter Six. Figures 4.10, 4.11 and 4.12 depict the recession of this vegetation between 1977 and 1991. Although there does not appear to be a clear reason or reasons for this regression in the vegetation and erosion of the margin, Walter identified seven possible causal factors. These are:

1. Lowering of estuary bed levels - 380 mm overall from 1920 to 1972, but relatively stable since although estuary margins have lagged behind the general bed lowering with a loss of 50 to 150 mm from 1962 to 1988.

2. Slowly rising sea level - 180 mm over the last 100 years.

3. Loss of salt marsh due to trampling by estuary margin users including vehicles, pedestrians and beached water craft.

4. Loss of salt marsh due to pollution - this is known to have been a factor along the western shores but is less likely to have been much of a factor along the eastern shore due to greater dilution by sea water.

5. Loss of vegetation due to herbicide application to eradicate spartina - while this eradication programme took place over an extended period beginning in the early 1970s there is no documentation of the effect on native plant species. A lack of complaints may imply little effect.

6. Change in wave climate following initial lowering of the bed and rise in sea level leading to larger waves and more aggressive wave attack. Wave attack here is mostly related to the frequency of south-west storms coincident with very high tides.

7. Reduced wind blown sand supply from the Pegasus Bay beach front due to the replacement of the native pingau by the more efficient sand binder marram grass (Walter, 1995, 9-10).

Figure 4.10 shows the extent of vegetation between Godwit and Heron Streets from 1977 to 1991. In 1977 all of the properties bordering the estuary were protected by a length of about 240 metres of vegetation, that varied in width from 5 metres to 30 metres. By 1991 however, the extent of vegetation in front of these properties had diminished. The vegetation had been eroded away to leave two sections, one of about 85 metres in length and the other only 30 metres in length. The width of these sections varied from about 2 metres to about 20 metres. In total the area of vegetation has decreased from 4500 m^2 in 1977 to 1400 m^2 in 1991, a reduction of about 67% (Walter, 1995, 8). By 1991 less than half of the properties bordering the estuary were still protected by vegetation.

Figure 4.11 shows the vegetation lines from Kingfisher Lane to Penguin Street. There were six pockets of vegetation on the estuary margin in 1977, and although they were still identifiable in 1991, the extent of vegetation had decreased. In front of 66B Rockinghorse Road, some 20 metres of vegetation was lost over the 14 year period. Further towards Penguin Street the loss of vegetation was not as great. The largest pocket of vegetation in 1977, had been eroded away to form two smaller pockets of vegetation by 1991. The smaller pockets of vegetation identified in 1977, have lost some vegetation, but these pockets do not provide protection for adjacent properties. Altogether 26.5% of the vegetation was lost in this section of Southshore, an area of 2100m^2.

Figure 4.12 shows the extent of vegetation to the south of Penguin Street for 1977 and 1991. In 1977 there were two sections to the vegetation in this area. By 1991, parts of the vegetation that had existed at the end of Penguin Street had disappeared, leaving four smaller pockets of vegetation. Although the width of the vegetation had not changed over the 14 years, the length has, with about 65 metres of vegetation vanishing. However those properties bordering the estuary in this area, especially to the south of 90B Rockinghorse Road, are not protected to the same extent as the properties to the north of Penguin Street. The area of vegetation lost in the section shown in Figure 4.12 was about 191m^2 a 24% loss.

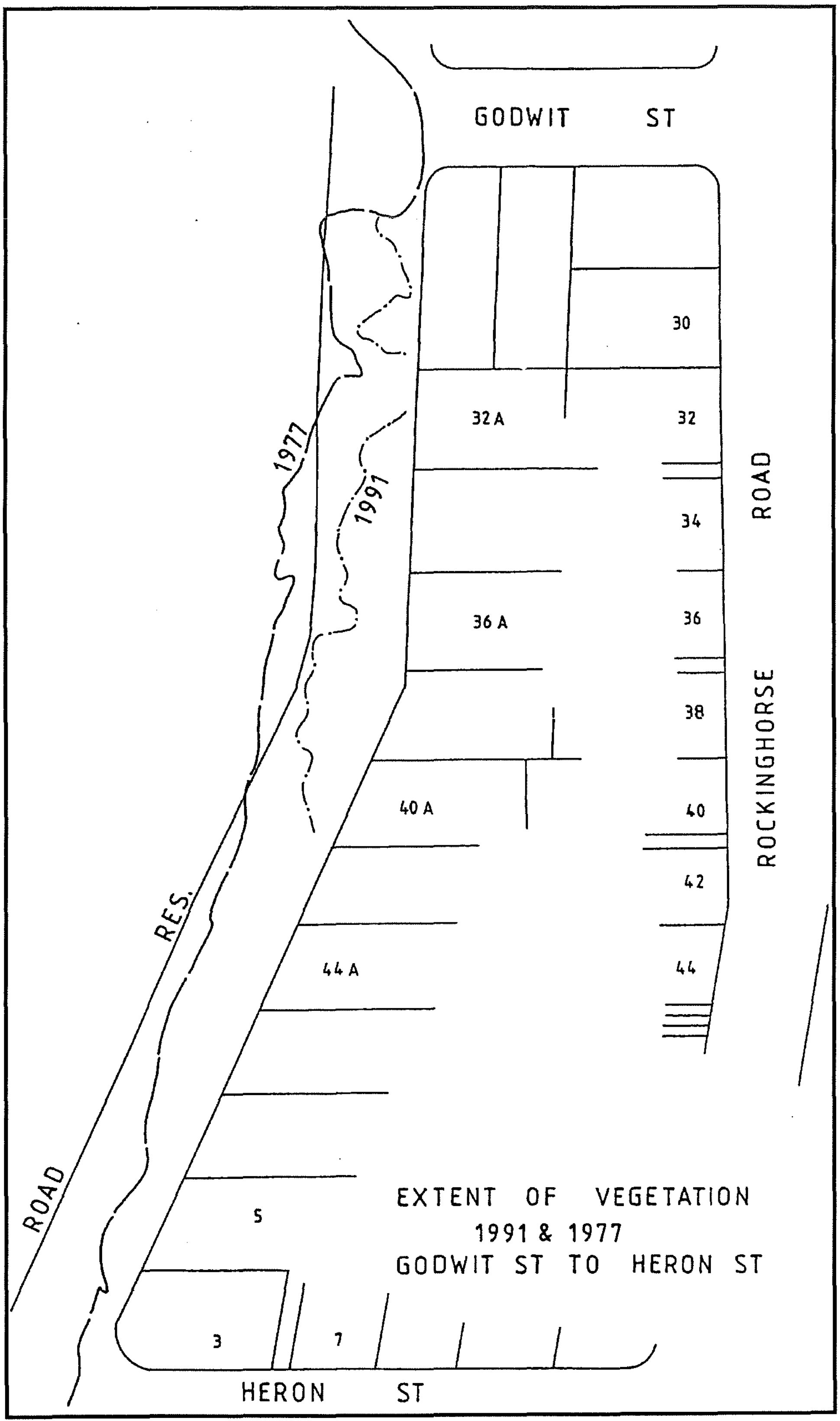

Figure 4.10 Erosion of Estuary Margin - Map 1.
(Source: Walter, 1995; taken from 1:1000 aerial photos)

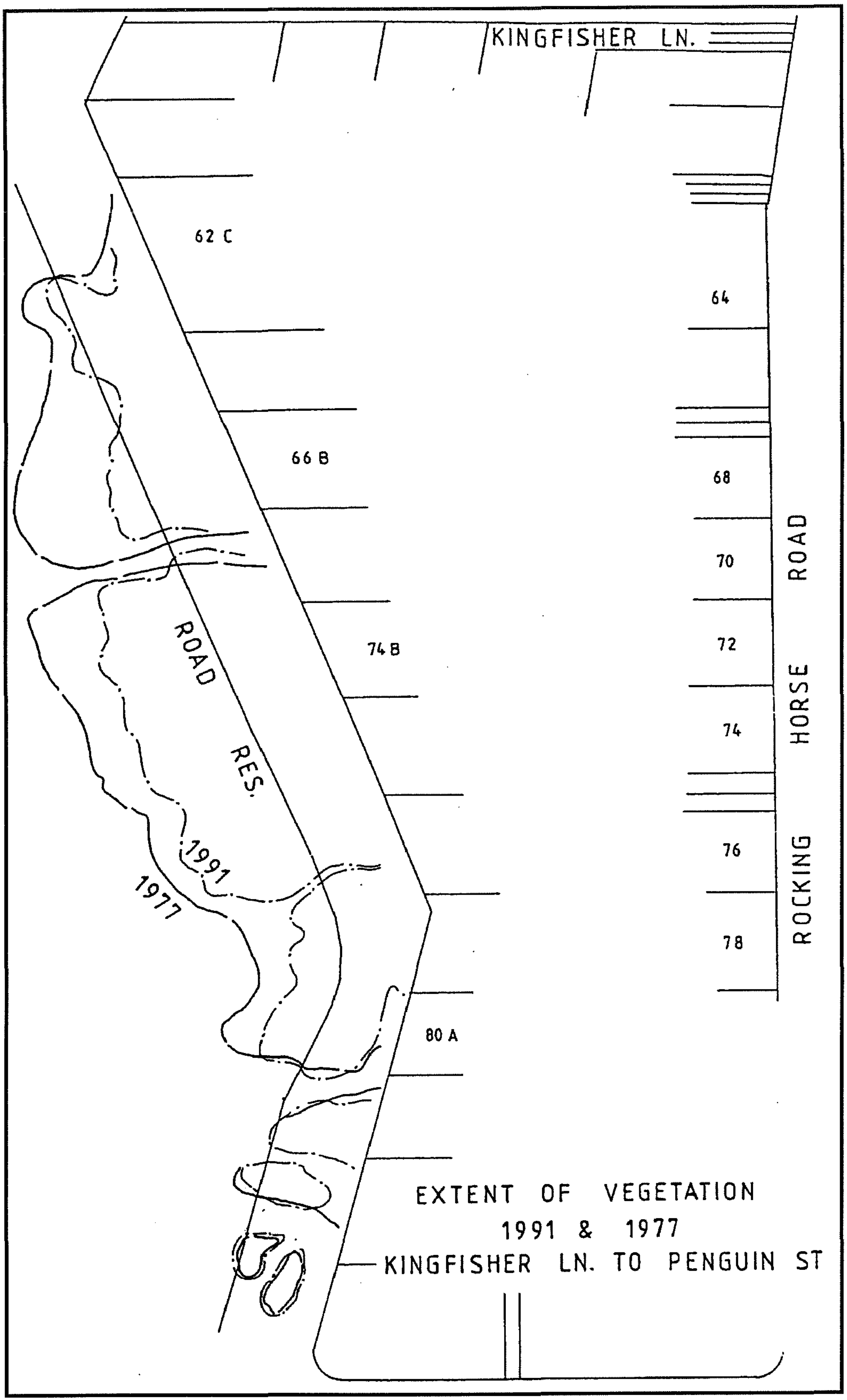

Figure 4.11 Erosion of Estuary Margin - Map 2.
(Source: Walter, 1995; taken from 1:1000 aerial photos)

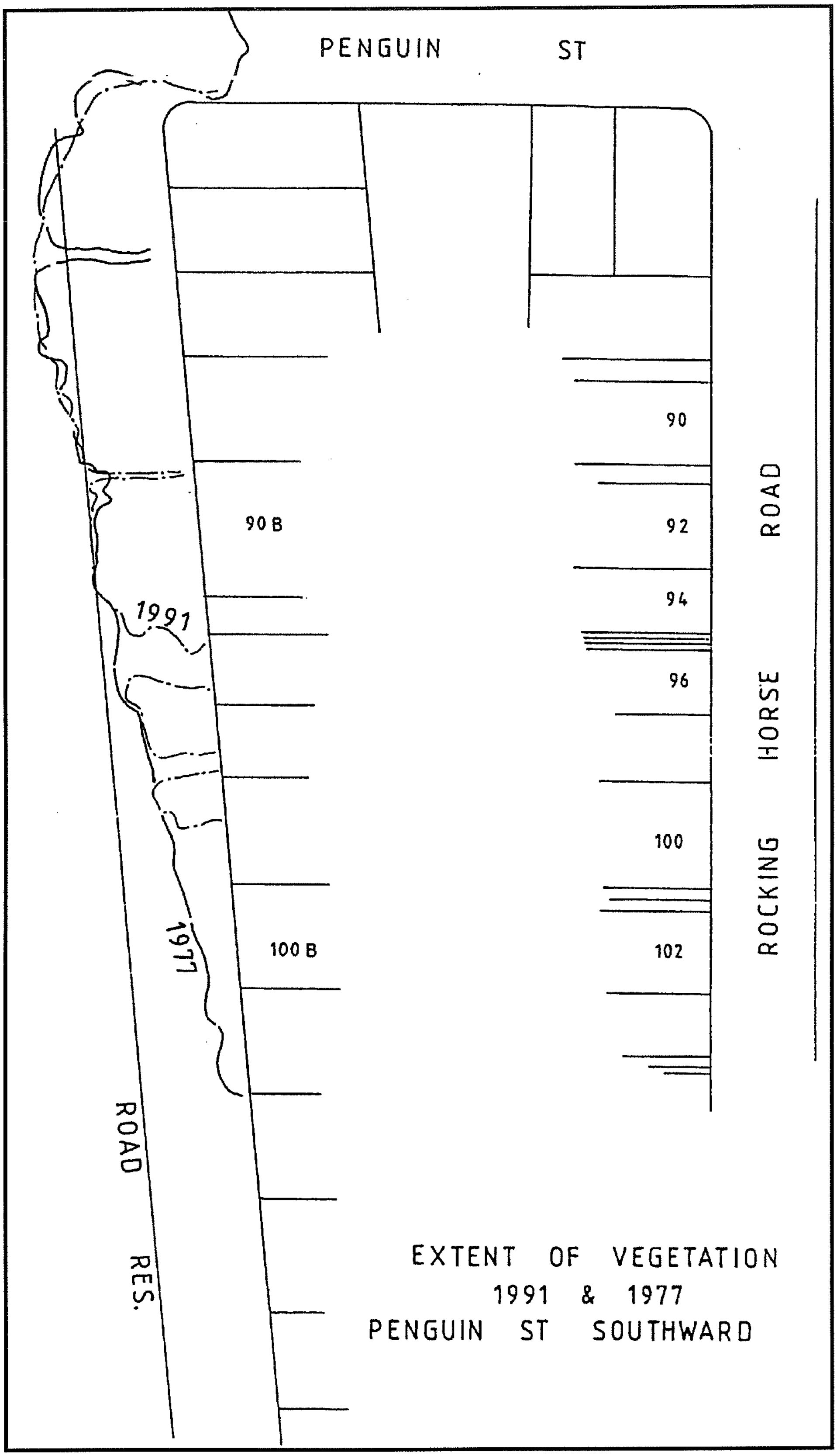

Figure 4.12 Erosion of Estuary Margin - Map 3.
(Source: Walter, 1995; taken from 1:1000 aerial photos)

From the area portrayed in Figure 4.12 to just south of Tern Street, there was no vegetation in 1977, and this has remained the case. Erosion in this section consists mainly of the undercutting of property boundary walls by the estuary as it rises and falls from low to high tide. Further towards the south, on the recurved part of the distal end of the spit, the estuary has been cutting into the spit, as shown in Plate 4.2. Under the definition of hazard used for this study, the erosion of this section of the spit does not constitute a hazard as there is no human use of this area. The area is part of a reserve. If however, the erosion was to start threatening the properties east of this section then this erosion would be defined as a hazard under the terms of this study.

Figures 4.10, 4.11 and 4.12 all show a road reserve on the background cadastral boundary. It can be assumed that when these boundaries were surveyed, that the area set aside for a road was dry land. As this area is now below water level at high tide, it can be inferred that there has either been significant erosion of the once dry land, or that the tidal compartment of the estuary has increased substantially since the initial cadastral survey.

Plate 4.2 **Cut into Estuary as Distal End of South Brighton Spit.**

4.5 Erosion Events

Up until 1940 it is believed that the channel of the Avon-Heathcote Estuary was relatively stable (Scott, 1955). About 1940 the channel shifted from a position between Shag Rock and the basalt rock of Banks Peninsula to the north of Shag Rock, towards the unconsolidated material of South Brighton Spit. The shifting of the channel northwards, cut into the distal end of the spit, and in doing so reduced the capacity of the spit to resist the erosive action of storms. Scott (1955) stated that within a few years the spit had been cut back by over 500 metres (25 chains) leaving the spit extremely unstable. In 1946 the scouring by the channel of the distal end of South Brighton Spit was assisted by heavy seas (Pearse, 1950). These heavy seas vehemently attacked the end of the spit, cutting dunes back to beyond their crests. The Naval Reserve (No. 224) at the end of the spit had an area of 49 acres, and by 1946 this was reduced to 11 acres (Southshore Ratepayers' Association, 1948a). Findlay and Kirk (1988) estimated that the distal end of the spit was cut back northward by 350 metres between 1940 and 1946.

Again, in 1948 the distal end of the spit was attacked by heavy seas. According to newspaper reports, a wide cut had been made through the end of South Brighton Spit opposite Shag Rock (The Press, 21 May 1948). Ten days later, it was reported that six sections in Southshore that faced the beach had been lost to erosion (The Press, 31 May 1948). In the Southshore Ratepayers' Association Chairman's Report for 1948, it was reported that over 50 acres of land had been lost at the end of the spit. Some of this eroded sediment was starting to infill the estuary (Southshore Ratepayers' Association, 1948b). Between 1946 and 1949 the distal end of South Brighton Spit retreated northward a further 150 metres (Findlay and Kirk, 1988).

Such was concern about the erosion of the end of the spit and the associated infilling of the estuary, that a conference was convened by the Christchurch Drainage Board in August 1948, and attended by representatives from the Marine Department, Christchurch City Council, Heathcote County Council, Lyttelton Harbour Board, and the Christchurch Drainage Board. It was felt by the conference members that the stabilisation of the end of the spit, through the rebuilding of the dunes, and the stability of the estuary mouth, was the province of the Local Authority (Christchurch Drainage Board, 1948). In the end, it was the Christchurch Drainage Board who undertook the stabilisation work. This work consisted initially of a small 7.5 metre (25 foot) sandbag groyne which was extended to 54 metres (180 feet) by the end of March 1949 (Christchurch Drainage Board, 1949). A private groyne, consisting of 44 gallon drums, was also erected by local residents in 1949, and a further 100 drums were added in 1950 (Southshore Ratepayers' Association, 1950). The Christchurch Drainage Board made use of the residents' groyne, and added brush fences and marram grass to further stabilise the accumulating sand (Southshore Ratepayers' Association, 1952). Scott(1955) noted that with these two groynes the end of the spit had regained some 400 metres (20 chains) of lost ground.

The next major erosion event occurred from the 6th to the 10th August 1964. The formation of a large, intense low pressure system (970 mb to 985 mb) to the southwest of the South Island, which subsequently tracked northeast past Stewart Island, and then northward along the east coast of the South Island, was the catalyst for this event (Kirk, 1978). The storm created by this low pressure system displayed the established characteristics of a storm-surge (discussed further in Chapter Five). These characteristics resulted in the largest waves produced by the low pressure system hitting Pegasus Bay (see Figure 5.2), barometric lift of sea level (29.6 cm at the centre of the storm on Saturday 8 August), and the creation of a baroclinic current which produced a southeasterly rip at the shoreline. The southerly storm coincided with the highest spring tides of the year (+2.11 metres on the afternoon of Friday 7th, and again on the evening of Saturday 8th August), and thus the erosive effect of the storm occurred at a higher than normal elevation (Kirk, 1978).

Within the study site, the effects of this storm on top of the higher than normal tides was felt the most at Torea Lane. Of the three houses shown in Plate 2.1, the two outer houses were built prior to this storm. It was around these two houses that erosion presented the greatest hazard within the study area. It is estimated that the waterline in front of these two houses advanced some 14 metres up the beach, and a 3 metre high scarp was cut into the foredune (Kirk, 1978). The

City Engineer at the time, Mr P.G. Scoular, was quoted in a newspaper as saying " At South Brighton yesterday, 5000 to 10,000 yards of stuff disappeared in three hours. We couldn't cope with that rate of erosion" (The Press, 10 August 1964). The 3 metre scarp reached within 5 metres of the two houses, threatening to undermine them. As a consequence, engineering staff of the Christchurch City Council placed a 24 metre (80 foot) long barrier consisting of rubble filled drums in a trench seaward of the scarp, to prevent any further erosion (The Press, 10 August 1964). Plate 4.3 shows these protective works. No further erosion was experienced in subsequent days, however the protective works were strengthened with a new row of drums and concrete posts and slabs to help encourage sand retention (The Press, 11 August 1964; Kirk, 1978).

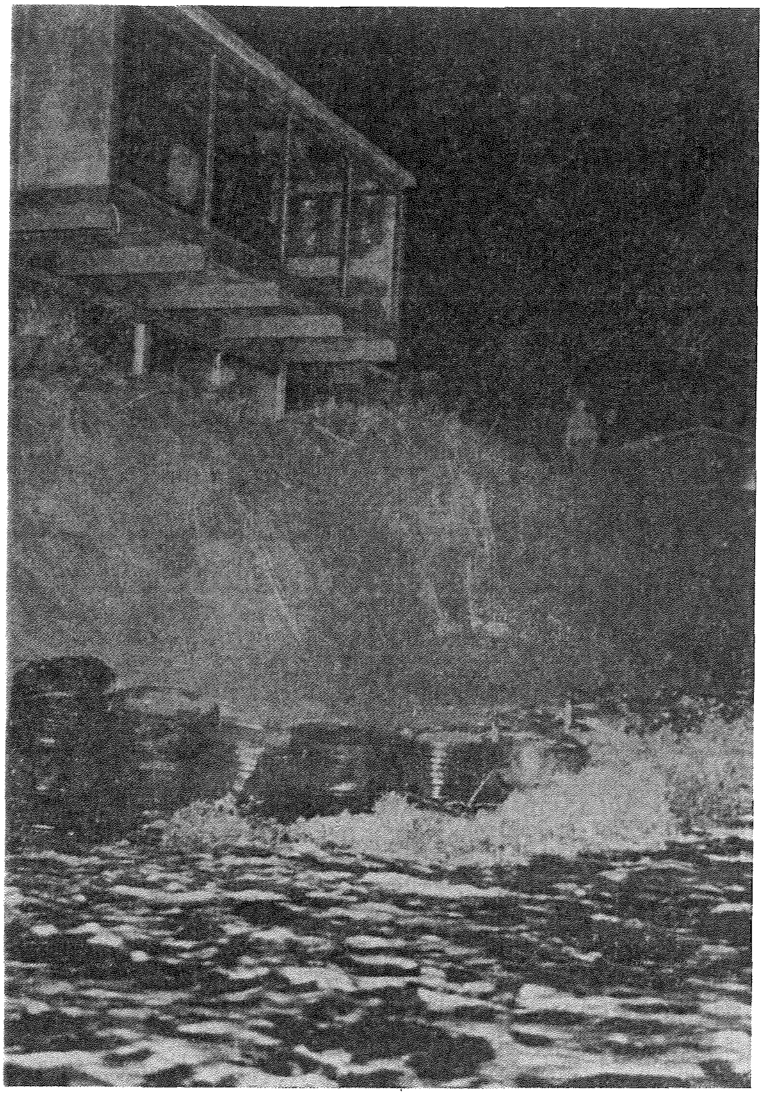

Plate 4.3 Protective Works at Torea Lane 1964 Storm
(Source: The Press, 10 August 1964)

At the beginning of July 1977, a storm similar to that which occurred in August 1964 transpired. A low pressure system developed in the central South Tasman Sea and tracked southeast around the South Island and then northeast long the east coast (Kirk, 1978). The storm produced by this system had all the characteristics, bar one, of the August 1964 storm. The difference between the two storms was the central pressure of the depression. In August 1964 this ranged from 970 to 985 mb, while in July 1977 the pressure range was from 985 mb to 990 mb. Due to the higher central pressure of the depression, the erosive effects of this storm were not as great as those in 1964. However as in August 1964, this storm also coincided with the highest tides for the year, +2.5 metres on Saturday 2 July, and again on Sunday 3 July 1977 (Kirk, 1978).

At South Brighton Spit, it was again the houses located on the beach at Torea Lane that were threatened by this storm. By 1977 the middle house, as shown in Plate 2.1 had been built and the beach in front of these houses had recovered from the 1964 storm. As stated above, the erosive effects of this storm were not as great as those experienced in August 1964, although the beach in front of these three house was again scarped and lowered (Kirk, 1978). The protective works that were put in place in 1964 were still buried at this time. In the following two months there were subsequent storms, which although not occurring with higher than normal tides, were acting upon a beach that was already severely depleted and narrower than before the July 1977 storm. A storm at the end of August 1977, was particular severe, in that it pushed the face of the scarp in front of the houses back a further 5 metres, bringing it to within 10 metres of the houses (Kirk, 1978). The storm also lowered the beach by a further metre, exposing the 1964 protective works, and threatening both the protective structure and the scarp with further attack It is believed that over 500 m^3 of sand was removed from in front of these houses during the August 1977 storm (Kirk, 1978). With the exposing of the 1964 protective works by this and subsequent storms in September 1977, it was discovered that some of the drums were rusting, and the structure was strengthened with the addition of more rubble-filled drums (Kirk, 1987, Plate 4.4). In studying the 1964 and 1977 storms, Kirk (1978) identified a 10 to 15 year 'cycle' in which such storms occur.

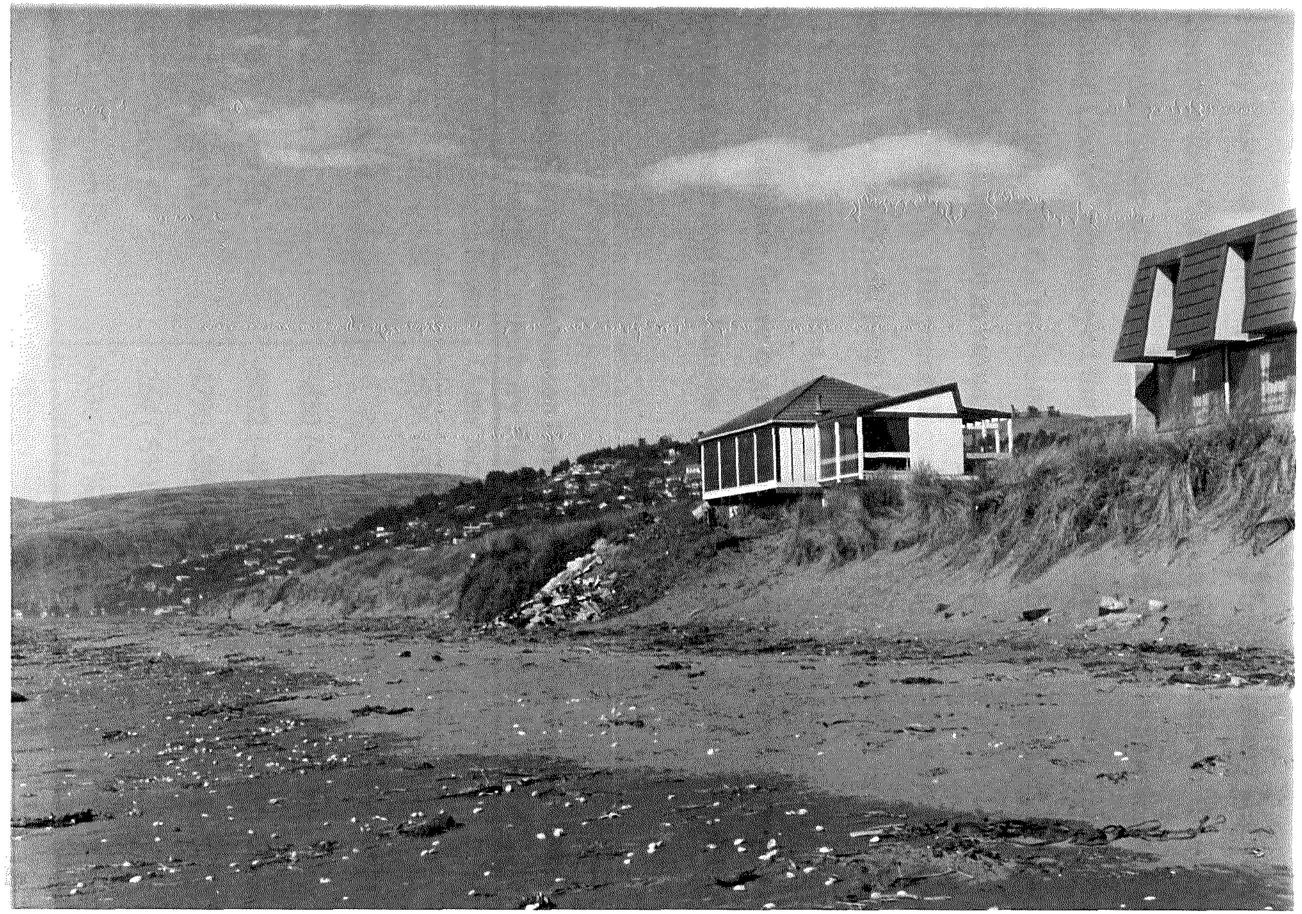

Plate 4.4 Scarp from 1977 Erosion Events - Torea Lane 1978
Note the 'protective' rubble to the left of photo and the overhang of the house
(Photo: R.M.Kirk, University of Canterbury

On Friday 28 August 1992, Christchurch awoke to find the city covered in snow. A southeasterly storm, which brought the snow to Christchurch, moved up the east coast of the South Island resulting in severe erosion along the whole of the Christchurch shoreline. As with the 1964 and 1977 storms, the major contributing factor to the erosion of the shoreline was the storm surge created by the low air pressure and strong southeasterly winds, coupled with a high tide of +2.3 during the early morning of Friday 28 August 1992. The Canterbury Regional Council had undergone their biannual survey of the Christchurch coast on 15 July 1992. Due to the severe impact the storm had on the beaches of Christchurch, the Canterbury Regional Council resurveyed the coast on 2 September 1992. Table 4.3 shows the differences between the two surveys along South Brighton Spit, for the front face of the dune and foreshore in terms of cubic metres of sand either lost or gained per 100 metres of beach. The percentage figures given, are the percentage of the previous survey (15 July 1992) that was lost in the storm. It is assumed that there was little or no change in the beaches between the July survey and the August storm. No dune face figure is given for the Torea Lane site, as there are no dunes presented seaward of the houses. As can be seen from these figures all but one of the sites, Caspian Street, had their dunes severely cut into by the storm. At site C0431, Penguin Street, the foreshore gained sediment compared with the other six sites. This gain would have been due to some of the sediment that had been removed from the dune face being deposited on the foreshore. Otherwise for the

Table 4.3 Differences Between July and September 1992 Surveys
(Source: Canterbury Regional Council Beach Profile Data)

Site Number/Street Name	Dune face (m^3/100m)	Foreshore (m^3/100m)
C0300 - Sth Pukeko St	-2836 (-87%)	-4688 (-49%)
C0350 - Torea Ln		-2099 (-17%)
C0362 -Tern St.	-3830 (-36%)	-2074 (-28%)
C0396 - Plover St	-3002 (-47%)	-5259 (-47%)
C0431 - Penguin St	-4795 (-35%)	+924 (+11%)
C0471 - Heron St	-264 (-5%)	-1731 (-25%)
C0513 - Caspian St.	+338 (+1%)	-2470 (-28%)

whole of South Brighton Spit this storm caused severe damage to both the dunes and beach. The severity of the August 1992 storm can be seen in Plates 4.5, 4.6 and 4.7. Note that the scarp shown in Plate 4.6 is within 20 metres of the house in the background. This photograph was taken about two metres to the north of the third profile site used for this study.

Plate 4.5 Torea Lane 28 August 1992, 4.30 pm.
(Photo: Ian Ellingford, Christchurch City Council)

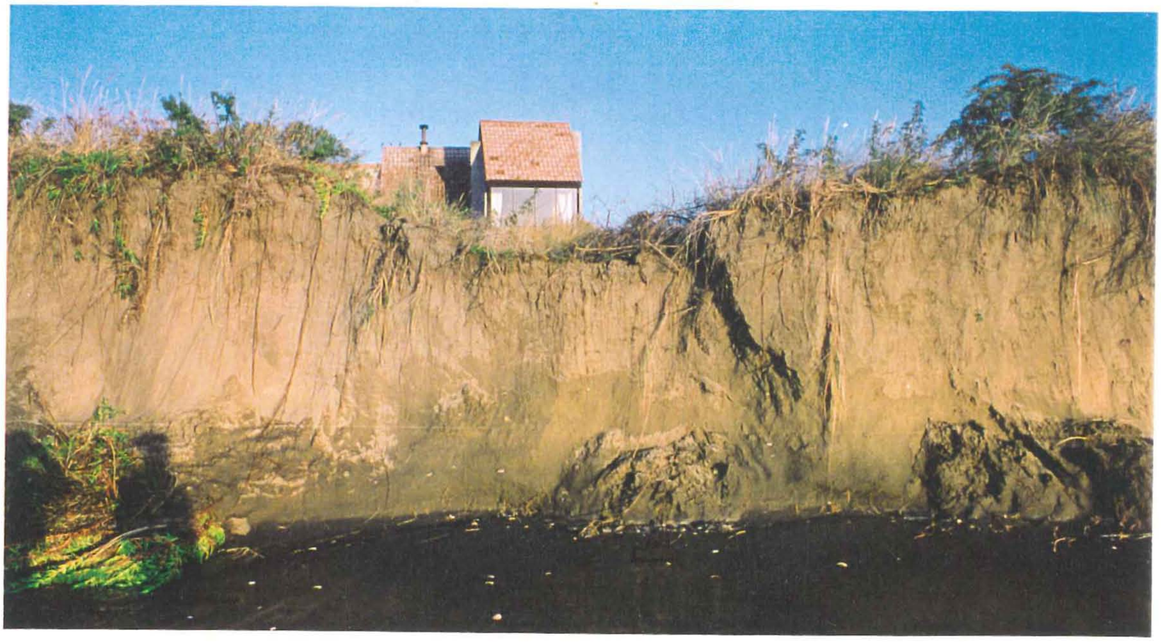

Plate 4.6 Scarp in Front of Last House on Rockinghorse Road, August 1992.
(Photo: Ian Ellingford, Christchurch City Council)

Plate 4.7 **Erosion From August 1992 Storm - Torea Lane**
(Photo: Derek Todd, Canterbury Regional Council

In March 1994, another erosion event occurred at the distal end of South Brighton Spit. Although this event did not pose a hazard as defined under this study, the event is interesting in that it exposed for the first time since the early 1950s the drum groyne that had been built by members of the Southshore Ratepayers' Association. Research at the time indicated that the beach volume in March 1994 was 65% of the beach volume for the preceding month, and that the foredune in existence in February 1994 was totally removed by March 1994 (Thompson, 1994). Plate 4.8 shows the exposed drum groyne.

Plate 4.8 Exposed Drum Groyne March 1994
(Photo: Ian Ellingford, Christchurch City Council)

4.6 Summary

During the survey period of January to July 1995, South Brighton Spit was relatively stable with only minor fluctuations occurring at the profile sites due to changes in tidal and weather conditions. On the long-term scale protracted erosion does not appear to be presenting a hazard. However the natural fluctuations that occur at the distal end of the spit do present a hazard at this scale. Whether there is any difference between the natural movement of a spit and erosion is a moot point, suffice it to say that there is a hazard due to this movement. There has been a substantial loss in vegetation on the estuary margin of South Brighton Spit, with the result that many of the boundary fences on this side of the spit are threatened with being undermined from southerly and southwesterly wave attack. The human responses to this threat of erosion and subsequent damage to their properties has resulted in there being a haphazard collection of means of protection which may or may not be effective.

Since the development of the spit there have been seven erosion events which have threatened property on the spit. There was one erosion event on the estuary margin, while the remaining six events were on the open coast side of the spit. The first of these occurred from 1940 to 1949 and was associated with a northward shift in the Avon-Heathcote Estuary's channel. The other three events were the result of southeasterly storms created by low pressure systems tracking up the east coast of the South Island coinciding with the higher tides that are experienced at South Brighton Spit. The first of these storms in 1964 threatened to undermine the houses built on the dunes at Torea Lane, with the result that protective works were needed to ensure their survival. The 1977 storms exposed the protection works, bringing a scarp face to within 10 metres of the houses at Torea Lane. The August 1992 storm produced a scarp 20 metres away from a house just to the north of Profile 3, but at Torea Lane the protective works of 1964, that were strengthened in 1977, and the subsequent dune built on top of them proved their worth, and there was little threat of the three houses being undermined, as there was in 1964 and 1977. It is not known whether the August 1992 storm was part of the apparent storm 'cycle' of 12 to 15 years, identified by Kirk (1978), as it was the only event during that year. However, as the August 1964 event was also the only erosion event to occur during that year, it can be concluded that the August 1992 storm was part of the erosion cycle that appears to exist along South Brighton Spit. The following chapter examines flooding hazards at South Brighton Spit, which sometimes occur in conjunction with erosion events.

Chapter Five
Flooding Hazards at South Brighton Spit

5.1 Introduction

This chapter investigates the hazard of flooding at South Brighton Spit. Prior to the completion of the installation of storm water drains along the spit in the late 1970s, the whole study site was subject to flooding by fresh or saline water whenever there was a major rain storm (Watts, Pers. Comm.). With the completion of the installation of the drains flooding due to lack of runoff was no longer a problem. Flooding at South Brighton Spit is now associated with storm surge events within the Avon-Heathcote Estuary that coincide with high tide, especially if occurring during spring tides. The following section examines the causes of flooding, including storm surges, astronomical tides, freshwater flooding and long term sea level rise. The third section then moves on to examine the overall picture of flooding within the study area, from both coastal and estuary sources, and then looks at two specific historical events. The first of these events predates the installation of storm water drains, and due to the magnitude of the storm which caused the flooding a significant hazard was presented to residents in the area. The second event is the only known flooding event to have occurred since the installation of storm water drains, and thus may be useful as a benchmark from which to plan for the possible recurrence of such an event.

5.2 Causes of Flooding

5.2.1 Storm Surges

Storm surge is defined as the deviation of sea level from some normal level due to the action of cyclonic storms (Chapman, 1994; Coastal Engineering Research Center, 1984). There are three main factors which contribute to this elevation of sea level. They are low air pressure, wave setup, and wind setup (Oliver and Kirk, 1992). Figure 5.1 shows how the components of a storm surge interact with the tides to increase the water level at the beach. Storm surges are more prevalent along coasts that have relatively shallow waters and are affected by the passage of cyclonic storms (Massel, 1989). As these are atmospherically derived changes in sea level, they are additive to normal tidal motion, and when the two coincide the result is commonly called a 'freak' or 'storm tide' (Oliver and Kirk, 1992). The height a storm surge can reach is dependent on wind speed and direction, fetch, atmospheric pressure, offshore bathymetry, and the nearshore slope, and can also be increased by the funnelling effect of converging shorelines, such as in estuaries (Coastal Engineering Research Center, 1984).

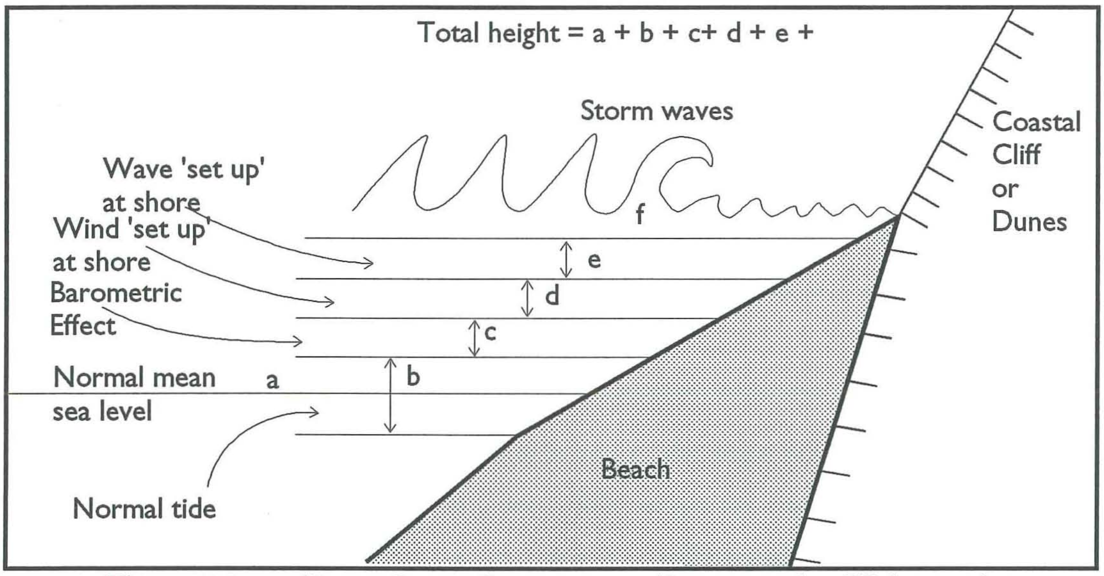

Figure 5.1 Storm Surge Components (Source: after Kirk, 1976)

When the atmospheric pressure over the ocean changes, the forces acting vertically on the sea surface can either raise or lower it (Pugh, 1987). A drop in air pressure will raise sea level, while the opposite will occur for an increase in air pressure. This is known as the **barometric effect**, and is represented by 'c' in Figure 5.1. The general rule is that for every 1 mb change in atmospheric pressure, sea level will change by 1 cm, although in New Zealand the change in sea level is about 0.85 cm (Massel, 1989; Oliver and Kirk, 1992). The average normal air pressure at sea level is 1013 mb (Oliver and Kirk, 1992). A typical year in extratropical regions has an atmospheric pressure range of 980 mb to 1030 mb (Pugh, 1987). This means that sea level can be raised by as much as 0.33 m and depressed by as much as 0.17 m, from some normal atmospheric level. However, sea level does not adjust immediately to changes in atmospheric pressure, but rather responds to the average change in air pressure over a substantial area (Lamont, 1995). As stated above, storm surges occur most often along shallow water coasts. When such coasts are low lying, or contain estuaries within their shores, the increase in sea level can lead to extensive flooding of the low-lying areas or estuary margins.

Out of all the storm surge components **wind setup** often causes the largest increase in sea level at the shore. It is defined as "the vertical rise in the still-water level on the leeward side of a body of water caused by wind stress on the surface of the water" (Coastal Engineering Research Centre, 1984, A-40). This is represented by 'd in Figure 5.1. When a wind blows over the ocean, the horizontal forces exerted on the water create a surface current in the direction the wind is blowing (Chapman, 1994). If the wind is blowing towards and perpendicular to the coast, the surface current will also flow towards the coast and will be impeded by the shallower water, thus piling the water up against, and increasing sea level at the shore.

The third factor, **wave setup** is defined as "the superelevation of the water surface due to the onshore mass transport of the water by wave action alone" and is represented by 'e is Figure 5.1 (Coastal Engineering Research Center, 1984, 3-84). Wave setup occurs between the point at which the waves break and the beach (Chapman, 1994). It is a phenomenon connected to a transformation of the kinetic energy of wave motion to a quasi-steady potential energy, in order to establish an equilibrium water level condition brought about by the action of many waves over a long period of time (Coastal Engineering Research Centre, 1984). Essentially the backwash of the broken wave is inhibited by the breaking of other waves and the water starts to pond, which leads to an increase in sea level at the shore.

Both wave and wind setup are accentuated if they are approaching a coast from the left-front quadrant of the storm. This is due to the Coriolis Force, which produces a leftward deflection in both the waves and the wind in the southern hemisphere due to the rotation of the Earth. Figure 5.2 shows the path taken by the largest waves that are produced by a depression. The largest propagated waves come from the left-front quadrant of a depression because the wind at this point is following the fetch of the waves, thereby accentuating wave height. In New Zealand cyclonic storms tend to take defined paths over the country, and thus not all sections of the coast are equally at risk (Kirk, 1976). It is the cyclonic systems which have northerly or northwesterly tracks passing the east coast of the South Island that are most likely to produce significant storm surges on the Canterbury coast. The usual track of a depression is to move from the southern Tasman Sea eastward along the south of the South Island, and then track northwards along the east coast before moving off into the Pacific Ocean.

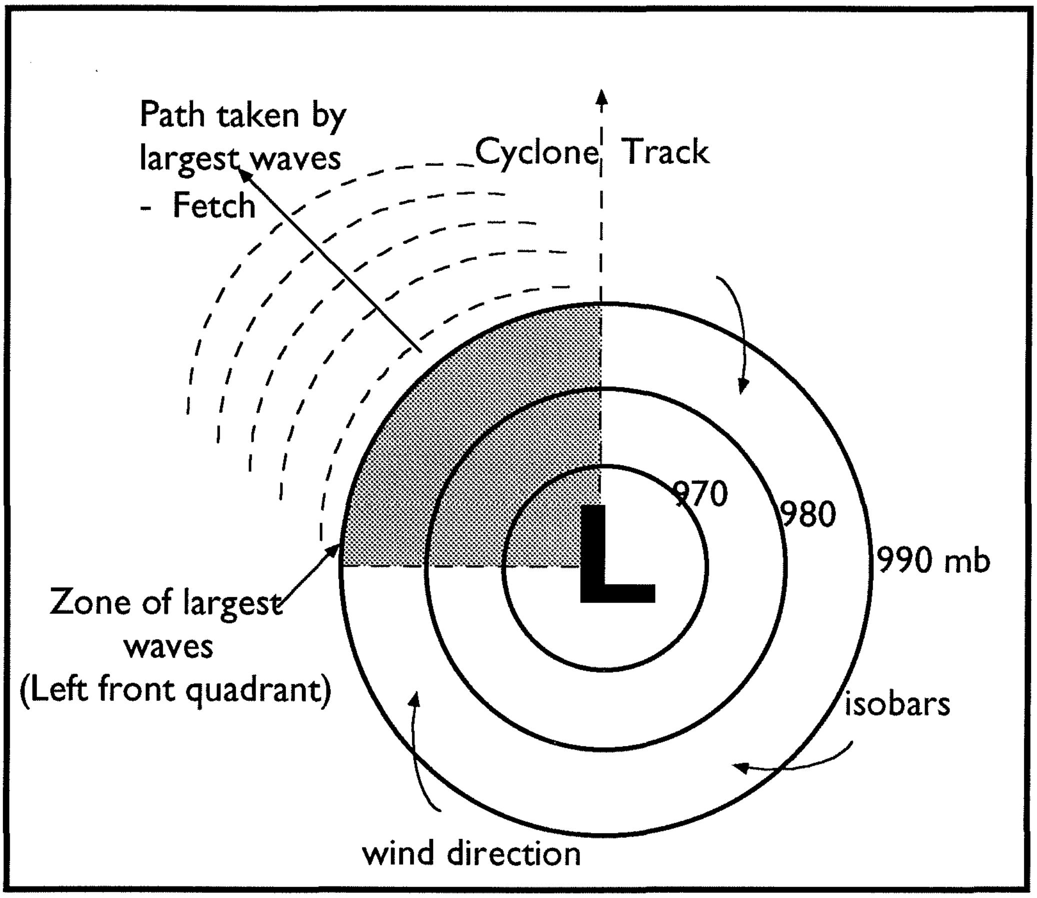

Figure 5.2 Wind Flow and Zone of Largest Waves in a Cyclone in Relation to Track. (Source: Kirk, 1976)

5.2.2 Other Influences on Flooding

Astronomical tides are formed on a continual basis by the gravitational changes in the interactions of the Moon-Sun-Earth system. In Canterbury however the position of the tide is related more to the distance of the Moon from the planet's surface (Walter, 1995). Therefore the usual spring tides that are experienced elsewhere at full moon and new moon (an interval of 14.7 days) are not found along the Canterbury coast. Instead of these spring tides, extra high tides occur when the Moon is at its closest point to the Earth in its elliptical orbit, which occurs about every 27.56 days (Walter, 1995). The tide in itself does not normally cause flooding to occur, but rather is a component that can add to a storm surge. The effect a tide can have on a storm surge is shown in Figure 5.1, where it is represented by the difference between 'a' and 'b' in the Total Height equation.

Flooding of estuaries from freshwater sources and run-off from urban areas can accentuate the rising water levels associated with storm surges. Freshwater flooding, that is flooding of the Avon and Heathcote Rivers, has been proven by Oliver and Kirk (1992) to have very little to do with extreme water levels in the Avon-Heathcote Estuary. In an examination of several extreme water level events in the Avon-Heathcote Estuary, those events which included freshwater flooding were not the most extreme events. Oliver and Kirk concluded that freshwater flooding and urban runoff were not the sole cause of flooding of the estuary margins, and that a combination of storm surges and tides was the basis of the majority of extreme water level events. Freshwater flooding of the estuary can lead to flooding of the estuary margins (such as at Southshore) only when it is combined with either a storm surge or extreme high tide to produce even higher water levels in the estuary than what the tide would normally produce.

Long term sea level rise has received a large amount of attention from the media over the past decade, with predictions for the rate of rise to accelerate due to possible climatic changes. Various figures have been issued for the rise in sea level, an example of such figures are those proposed by Gibb (1988, 9), where he states that "To be on the safe side planners, managers and developers of the coastal zone should allow for a +0.5 metre increase in sea level by 2050 AD, and a +1.5 metre increase by 2100 AD". Hannah (1990) on the other hand examined historical sea level rise and noted that sea level was most likely to rise by 0.09 -0.2 metres by 2025 AD and 0.18 - 0.4 metres by 2050 AD. Hannah's figures are an extrapolation of historical sea level rise from four New Zealand ports and include ice-melt and thermal expansion of the oceans. Interestingly, Hannah also noted that the average rate of sea level rise at Lyttelton Harbour from 1900 was 1.8 mm ± 0.17 mm, and that this rate of change was linear in nature. Hannah found no evidence of acceleration in the rate of sea level rise at Lyttelton. Figure 5.3 shows sea level recordings for Lyttelton Harbour from 1900 to 1989 and the net rate of change which was determined by linear regression.

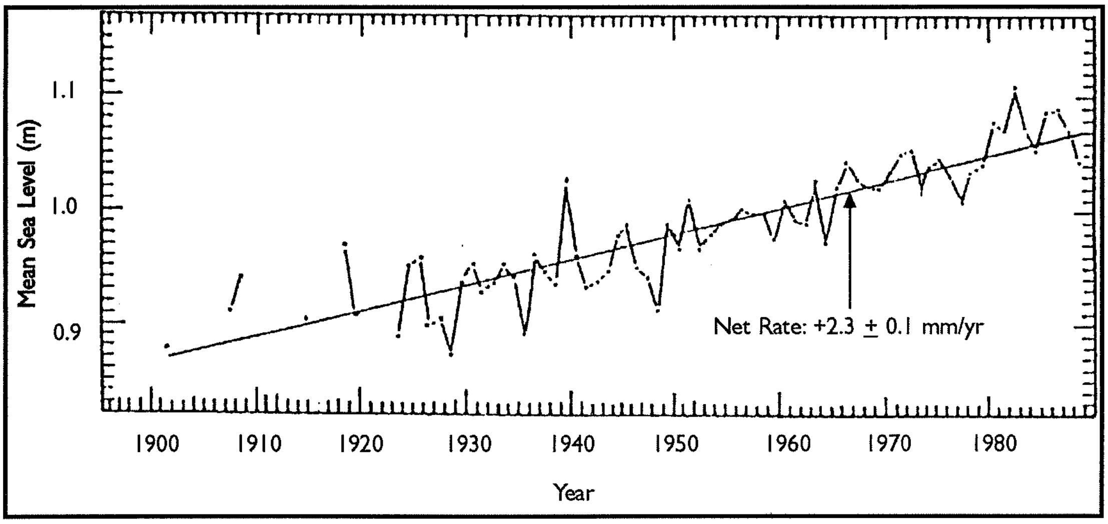

Figure 5.3 Sea Level at Lyttelton Harbour 1900 - 1989.
(Source: Gibb (1991) adapted Hannah (1990))

In considering the Avon-Heathcote Estuary, Oliver and Kirk (1992) have suggested that sea level rise in the estuary is most likely to continue along the lines of the historical trend, which would result in a rise of approximately 0.16 - 0.20 metres over the next 100 years. However, they also note that by using Hannah's extrapolations mean sea level in the estuary could rise by 0.4 metres by 2050 AD. An increase in sea level in the estuary may be offset by an increase in sedimentation. Although this may keep the tidal compartment at a similar volume, the height of mean sea level in terms of the local datum would change. It is this increase in the height of mean sea level in the estuary which, although not likely to cause flooding by itself, will increase the risk of flooding in times of storm or extreme high tides.

5.2.3 Summary

Although factors such as sea level rise, freshwater flooding and extreme high tides can cause flooding to occur around the margin of the Avon-Heathcote Estuary, the main cause of flooding is when one or all of these three factors coincides with a storm surge event. Not all of the components of a storm surge event need to occur for flooding to happen. An extreme high tide and a strong southerly wind across the Avon-Heathcote Estuary will force the water level along South Brighton Spit to rise, thereby inundating low areas and creating a localised storm surge within the estuary itself. Therefore flooding of low areas along the estuary margin of South Brighton Spit requires some interaction between the components of a storm surge event, freshwater flooding, and high tide. Long term sea level rise in the estuary may result in inundation of low areas of South Brighton Spit, and will increase the area over which flooding may occur when a storm surge event transpires. Storm surges are relatively common on our coasts as a whole and, in Kirk's opinion, have "probably cost us more in property and other damage than any other type of ocean hazard" (Kirk, 1976, 17).

5.3 Flooding Events

5.3.1 Background

Flooding along South Brighton Spit was a constant phenomenon until the late 1970s when the installation of storm water drains was completed. A major rain storm was not needed for flooding to occur (Watts, 1995, Pers. Comm.). Flooding of roads and properties occurred whenever there was a significant rain storm. One such storm was the 60 hour storm which hit Christchurch in April of 1968 and caused extensive flooding along South Brighton Spit. With the completion of the installation of the drains, flooding along the spit became a rare phenomenon, with only one event recorded to date. This event, in 1992, was the result of extreme high water levels in the Avon-Heathcote Estuary. Recorded extreme high water levels in the estuary which have resulted in flooding along South Brighton Spit occurred during a combination of high tides (or higher than normal tides) freshwater flooding or runoff, and storm surges as described above.

In a letter to the North Canterbury Catchment Board in 1948, the Southshore Ratepayers' Association expressed their concern regarding erosion of the distal end of the spit, as discussed earlier in Section 4.5 (Southshore Ratepayers' Association, 1948a). They also noted at the time that there had been exceptional high tides which had "cut into the perimeter of the sandhills with disastrous results, many sections being flooded by sea water". Unfortunately there is no other source against which this information can be checked, thus there is some question over the validity of this statement. If this event is accurate, then it is the only recorded event where there was inundation of properties along South Brighton Spit from the coastal side. The flooding that occurs along South Brighton Spit has the Avon-Heathcote Estuary as its main source. Two significant flooding episodes are the 1968 and 1992 events. These are discussed in detail in sections 5.3.3 and 5.3.4.

5.3.2 Flooding from the Avon-Heathcote Estuary

The first record of flooding at Southshore was in 1947, when the Southshore Ratepayers' Association wrote to the Christchurch City Town Clerk (Southshore Ratepayers' Association, 1947). The concrete seawall located at the end of Caspian Street and along Ebbtide Street had a large gap in it. Extreme high tides at the time caused extensive flooding of the corner of Caspian and Ebbtide Streets. The seawall was subsequently filled and raised to prevent the problem occurring again.

The problem of flooding was again noted in 1955. At a meeting of the committee of the Southshore Ratepayers' Association in October of that year a comment was made by one member in support of the dredging of the Avon-Heathcote Estuary. The Minutes of the meeting recorded this statement of support and the reason behind the support being that "building up along the western side of Southshore would minimise the danger of flooding" (Southshore Ratepayers' Association, 1955). The member felt that the material recovered from the dredging of the estuary was best used to protect the estuary margin of South Brighton Spit from flooding at times of high tide. In 1962 the problem of flooding from extreme high tides was still a worry for the Association. In a letter regarding the erosion and flooding of the estuary margin of the spit to the Christchurch Drainage Board, the Association stated that "flooding has now become a certainty with every monthly spring tide" (Southshore Ratepayers' Association, 1962).

In the early 1970s the problem of ponding of stormwater on the carriageways, especially Rockinghorse Road, was brought up at two meetings of the Southshore Ratepayers' Association (1972a, 1972b). By August of 1972 ponding just south of Heron Street had been solved with the completion of stormwater drains in that area. Figure 5.5 shows the location of the stormwater outfalls. As regards the rest of South Brighton Spit, the stormwater was still ponding notably towards the south of the spit, around Tern Street. A comment at the Annual General Meeting of the Association in October 1972, suggested that within minutes of the rain starting, water was ponding on Rockinghorse Road and threatening to flood properties.

On the night of 16 April 1974 torrential rain hit Christchurch, with many areas being flooded. In the 24 hours to 9 am on the 17 April 1974, a record 124 mm (4.89 inches) of rain was recorded at the Botanic Gardens in central Christchurch (The Press, 18 April 1974). This was the heaviest rainfall event recorded since 1928 (Christchurch Drainage Board, 1974). The Christchurch Police supplied the media with a list of areas and streets flooded at 2 am on 17 April 1974, which noted that the whole of South New Brighton was flooded. The definition of flooding used by the Christchurch Police was "flooding of roads to the extent that they couldn't be driven along" (The Press, 17 April 1974). From section 5.2, it can be seen that freshwater flooding of the estuary does not in itself cause flooding of low areas around the Avon-Heathcote Estuary, but requires the co-occurrence of either a storm surge or high tide. Thus high tide in the Avon-Heathcote Estuary during the early morning of 17 April 1974 aggravated the problem of flooding around the estuary margins, with Rockinghorse Road being one of the worst affected streets around the estuary. The total cost of flood damage for Christchurch was estimated at about $1,000,000 (The Press, 20 April 1974).

Just over one month later on 30 May 1974, Rockinghorse Road was inundated, with up to 225 mm (9 inches) of water covering the southern end of the road (Christchurch Star, 30 May 1974). One Southshore resident complained that the road flooded every time it rained. As mentioned above, prior to the completion of the installation of stormwater drains this was a common occurrence. From about 1975 onwards flooding was to become a rare occurrence along South Brighton Spit due to the stormwater drainage system. On 23 June 1986, it was reported that exceptionally high spring tides had flooded the lower parts of the Heathcote River, and that the water level in the Avon-Heathcote Estuary was lapping the top of the sea wall on its western shores (The Press, 23 June 1986). Surface flooding was reported in parts of South New Brighton, but whether this included the study area of Southshore is unclear. Otherwise there have been no reported incidents of flooding until the storm of August 1992.

5.3.3 The 'Wahine' Storm - April 1968

During the Easter of April 1968, Christchurch experienced a 60 hour storm that was to become known as the 'Wahine' Storm, due to the foundering of the Christchurch-Wellington ferry in Wellington Harbour. Precipitation in Christchurch was concentrated in the south and east of the city, with about 225 mm (9 inches) of rain falling between 10 and 12 April 1968 (Christchurch Drainage Board, 1968). Most of Christchurch was flooded, but not to the extent of the April 1974 storm, which had a higher intensity but over a shorter time period (Christchurch Drainage Board, 1968, 1974). The storm was due to a subtropical low which tracked southeast over the north of the South Island. Many of the normal storm surge characteristics were not present along the coast of Christchurch. However within the Avon-Heathcote Estuary storm surge was a factor of the high water levels recorded (Walter, 1995). According to Oliver and Kirk (1992), the minimum air pressure recorded for 10 to 12 April 1968 was 986 mb, which indicates the possibility of about a 0.23 metre rise in water levels due to barometric lift.

Oliver and Kirk (1992) also presented wind data for the event. Maximum wind gusts were recorded at 46 knots and coming from a south-southwest direction (240°), at an angle perpendicular to the South Brighton Spit estuary margin. This means that both wind and wave setup within the estuary also contributed to the high water levels recorded.

Within the study area, the whole of Southshore experienced considerable flooding. In their report on the storm, the Christchurch Drainage Board (1968) noted that the whole of Rockinghorse Road was flooded to an average level of 10.59 metres (RL 35.3 feet above the old Christchurch Drainage Board datum). The only known mean sea level figures for the Avon-Heathcote Estuary are for December 1953 to March 1954, which had a mean level of 8.925 metres (RL 29.75 feet above the Christchurch Drainage Board's datum). This indicates that the water level in the estuary was up to one and half metres above mean tide along South Brighton Spit. As mentioned above, this was the result of the three storm surge components of barometric lift, wind, and wave setup, and was augmented by tidal action, with high tide occurring in the early afternoon. It was noted by a Christchurch Drainage Board worker that at 2 pm on 12 April 1968, the combination of high tide and a strong southwest wind was driving waves of about 0.6 metres (2 feet) in height over the sea wall along Ebbtide Street (Christchurch Drainage Board, 1968). Waves were also reported to have been breaking over the wall at the estuary end of Plover Street, while a flooding level of RL 10.75 metres (1.725 metres above mean sea level) was recorded just to north of Plover Street at Pump Station 55 (The Press, 13 April 1968; Walter, 1995). Figure 5.4 shows an estimate of the extent of flooding along South Brighton Spit. The estimation does not include properties as the extent of inundation of private sections is not known.

As a result of these high water levels in the estuary, five families were evacuated by the Christchurch police, while many other residents left voluntarily (The Press, 13 April 1968). All of Rockinghorse Road was inundated, as were most of the side streets, with some houses reported to have a" few inches" of water running through them. Plate 5.1 shows an army truck travelling up Rockinghorse Road on 12 April 1968, note the extent of coverage of the water shown in the photo. When the tide ebbed during the mid-afternoon on 12 April 1968, the crisis lessened,

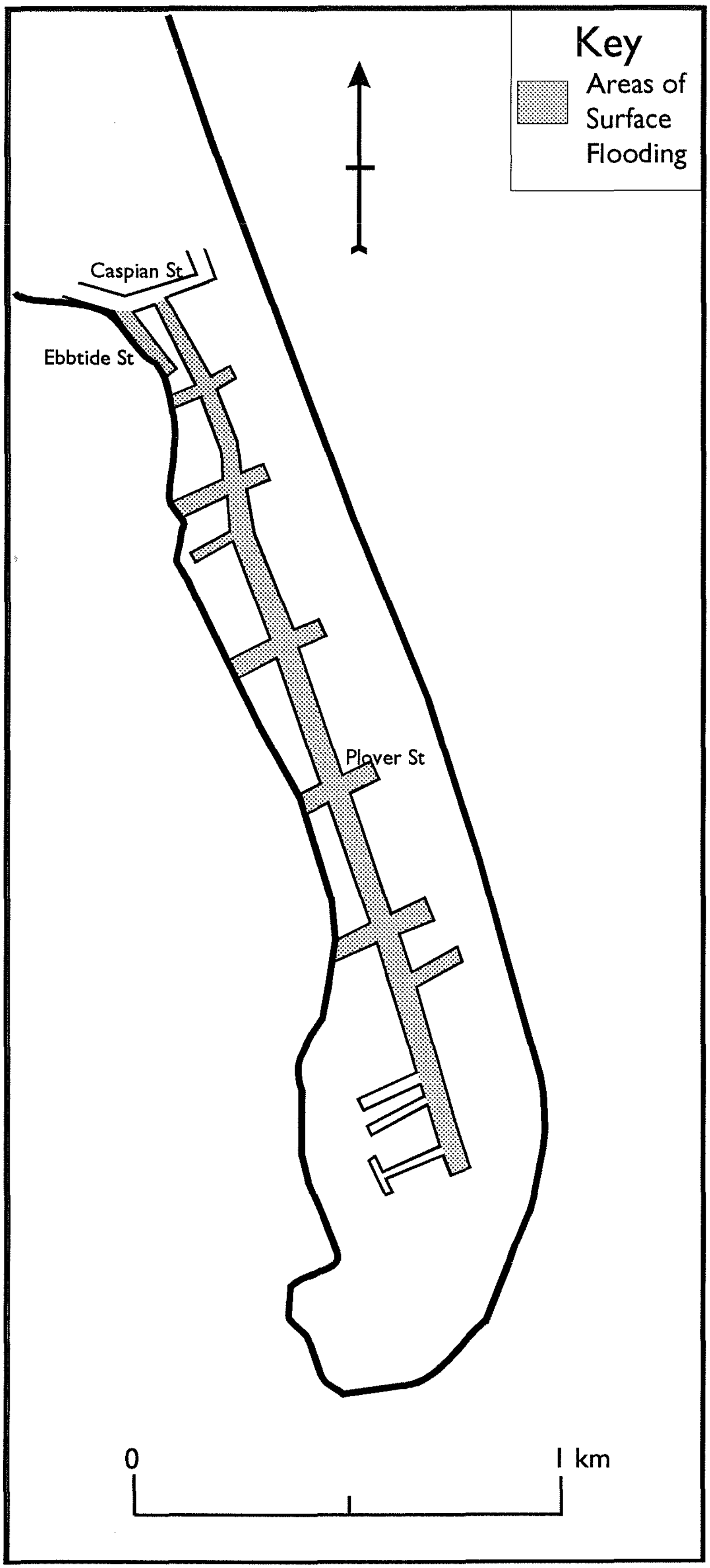

Figure 5.4 Estimate of Extent of Flooding - April 1968.
Note: Flooding of properties not shown, as exact extent not known.

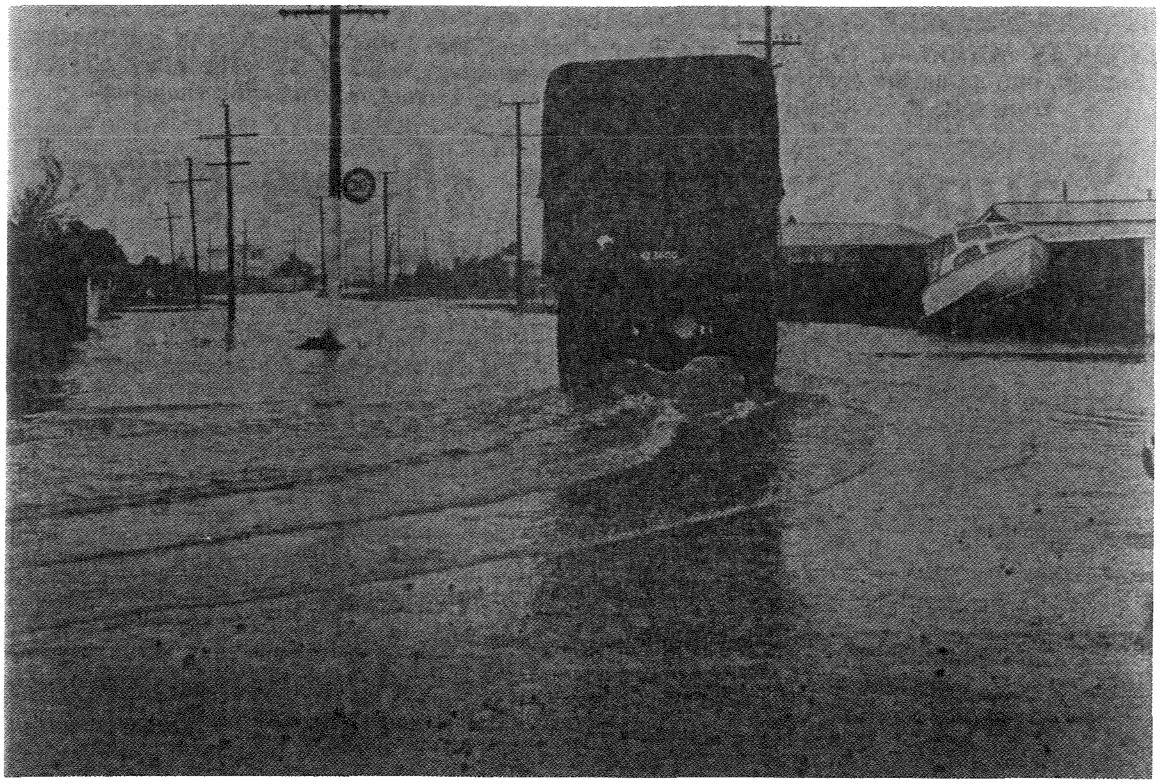

Plate 5.1 **Flooding Along Rockinghorse Road - 12 April 1968**
(Photo: The Press, 13 April 1968, 12)

and the emergency control centre set up by the Police at the corner of Caspian Street and Rockinghorse Road was dismantled after 5 pm. Although the Southshore area was not properly serviced by stormwater outfalls during this storm, the flooding that occurred is worth noting as the lack of stormwater runoff was not the only source of the problem. Insufficient flood protection along the estuary margin of South Brighton Spit was also to blame. The ways in which both the residents and Christchurch City Council have attempted to protect properties from estuarine flood inundation will be examined further in Chapter Six. However, it should be noted that the majority of the structures that are protecting the residents' properties are little more than boundary fences (see Plate 5.2). Many of these have gates with either steps or ramps providing direct access to the estuary. Very few of the gates provide protection from extreme high water levels as there are gaps beneath the gates or those gates are like the one shown in Plate 5.2 and are made of wrought iron.

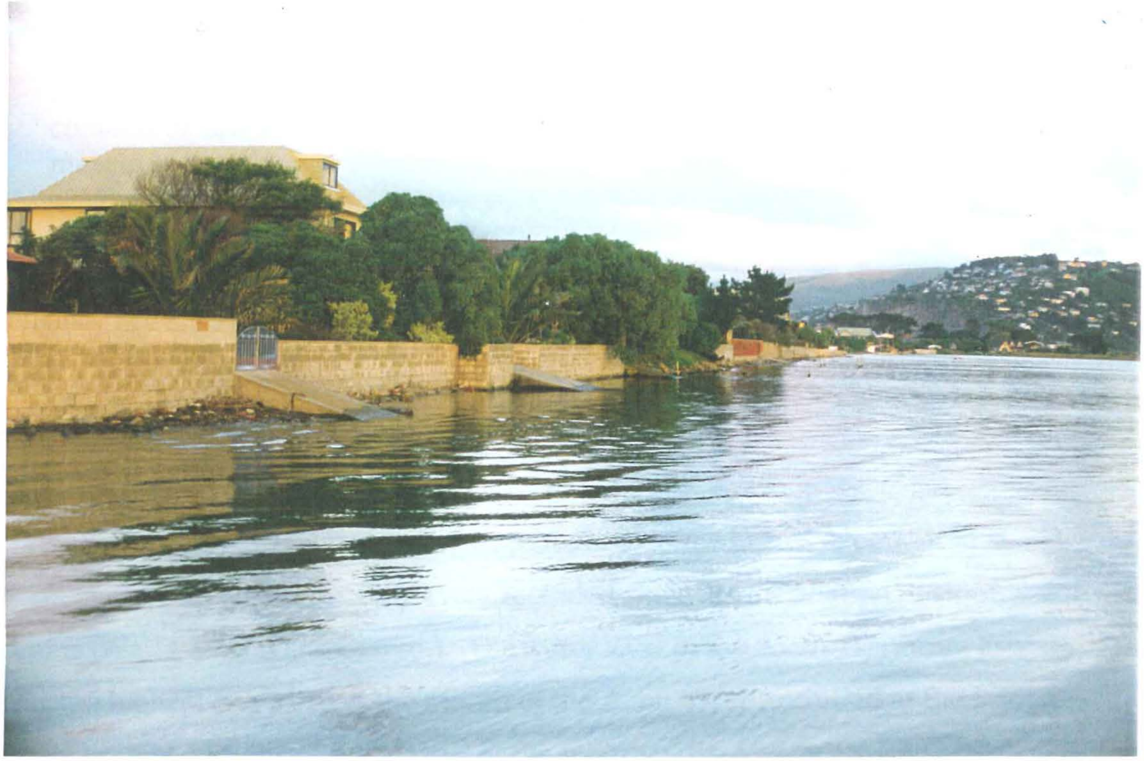

Plate 5.2 Gates and 'Protection' South of Plover Street

5.3.4 The August Snow Storm - August 1992

The southeasterly storm which brought snow to Christchurch and eroded the beaches on 28 August 1992 also caused flooding problems throughout Christchurch, including parts of South Brighton Spit. Although the high water levels recorded in the Avon-Heathcote Estuary are believed to be due to a combination of high tides and storm surge (Walter, 1995), the impact of snow melt within the catchments of the Avon and Heathcote Rivers can not be discounted as a factor in the increase of the estuary's water level. Thus for the study area, which was without snow, the problem was the snow melt from other areas, high tides and storm surge conditions within the estuary late on the 28 August 1992, and again on 29 August 1992. Unfortunately there is no quantitative information regarding the areas flooded along South Brighton Spit. From Christchurch City Council records it appears as though no Council staff member was sent to examine the problem. The only official information is an unsubstantiated comment in a report to the Christchurch City Council by the Acting City Manager where he states:

> With the flooding which occurred around the estuary margins in the Southshore area, the question was raised as to consideration being given to a continuous low stopbank being constructed along the whole of the estuary margin to supplement the existing protection (Christchurch City Council, 1992, 4239).

This lack of information is of concern and its implications will be discussed in Chapter Six. However anecdotal information was available from residents of the area, and this with the minor media coverage of the flooding is all the information that could be obtained.

This event is believed to be one of more extreme events experienced at Southshore, and is also the only event recorded since the installation of stormwater drains (Watts, 1995, Pers. Comm.). The water level in the Avon-Heathcote Estuary was the highest on record at the mouth of the Avon River (recorded at the Bridge Street bridge) and one of the highest at the mouth of the Heathcote River (recorded at the Ferrymead bridge). The level reached at the mouth of the Heathcote River was RL 10.77 (to the old Christchurch Drainage Board datum), while the level at the Avon River mouth was RL 10.95. The difference in the two levels is probably due to wind and wave setup at the mouth of the Avon River, whereas the Heathcote River's mouth is relatively sheltered. With this fact and the two levels in mind, an approximate level was calculated for Southshore of RL 10.85, due to the lessening effect of wind and wave setup for this area (Walter, 1995). At the mouth of the Heathcote River, mean sea level, mean high water level, and mean high water spring tide are known, and are shown in Table 5.1. From these figures, it can be seen that the water level obtained within the estuary was 0.42 metres higher than mean high water spring tide at the Heathcote River mouth. This resulted in

Table 5.1 Levels for Heathcote River Mouth, to Christchurch Drainage Board datum (Source: Oliver and Kirk, 1992)

Mean Sea Level	9.300 meters
Mean High Water Level	10.030 meters
Mean High Water Spring Tide	10.350 meters

extensive flooding of the carriageways and surface flooding of properties in northern Southshore, due in part to foreshore overtopping on the estuary side, but also to backflow through the stormwater drains (Walter, 1995). The backup of water in the stormwater drains was due to the failure of the tide gates on the drains (Watts, 1995, Pers. Comm.). Although only eight properties reported surface flooding, it is believed that there were more than this number with surface flooding that went unreported (Brien, 1992; Ellingford, 1995 Pers. Comm.).

Figure 5.5 shows an estimate of the areas flooded during this event. This has been compiled from anecdotal information from local residents. Most of the surface flooding was restricted to the northern half of South Brighton Spit, with the worst affected area being between Godwit and Plover Streets (Ellingford, 1995, Pers. Comm.). With regards to the overtopping of the seawalls at the end of the side streets, Plover Street was the worst affected, a repeat of the April 1968 event. Plate 5.3 shows the overtopping of the wall at Plover Street on the 29 August 1992. It was reported that with the high tide at 5.30 pm on 28 August 1992, water was up to a metre deep in some parts of Southshore (The Press, 29 August 1992). This is supported by a resident who stated that while driving along Rockinghorse Road, between Godwit and Plover Streets, the water was covering the axle of the car at a height of about 0.5 metres (Ellingford, 1995, Pers. Comm.). The majority of this water would have been from back up of the stormwater drains between Caspian and Plover Streets, as shown in Figure 5.5.

The area marked on Figure 5.5 just to south of Tern Street (marked by **X**), is an empty section which was flooded due to lack of protection along the estuary margin. It is believed that the water from this area may have flowed back towards Rockinghorse Road, but there is no evidence for this other than anecdotal comments (Arlington, 1995, Pers. Comm.). The water was pooled here after the tide had ebbed, and a pump had to be brought in to remove the water (Arlington, 1995, Pers. Comm.). The Christchurch City Council has since constructed a stopbank in this area and a new drain to prevent the recurrence of ponding water. This stopbank is shown in Plate 5.4, which also shows the ponding that still occurs at high tide, although on the estuary side of the stopbank. A report has been written for the Water Service Unit of Christchurch City Council on both the erosion and flooding of the estuary margin of South Brighton Spit, and the recommendations from this will be discussed in Chapter Six (Walter, 1995).

Plate 5.3 **Overtopping of Seawall by Estuary at Plover Street, 29 April 1992. (Photo: Ian Ellingford, Christchurch City Council)**

Plate 5.4 **Stopbank in Front of Estuary Properties, South of Tern Street.**

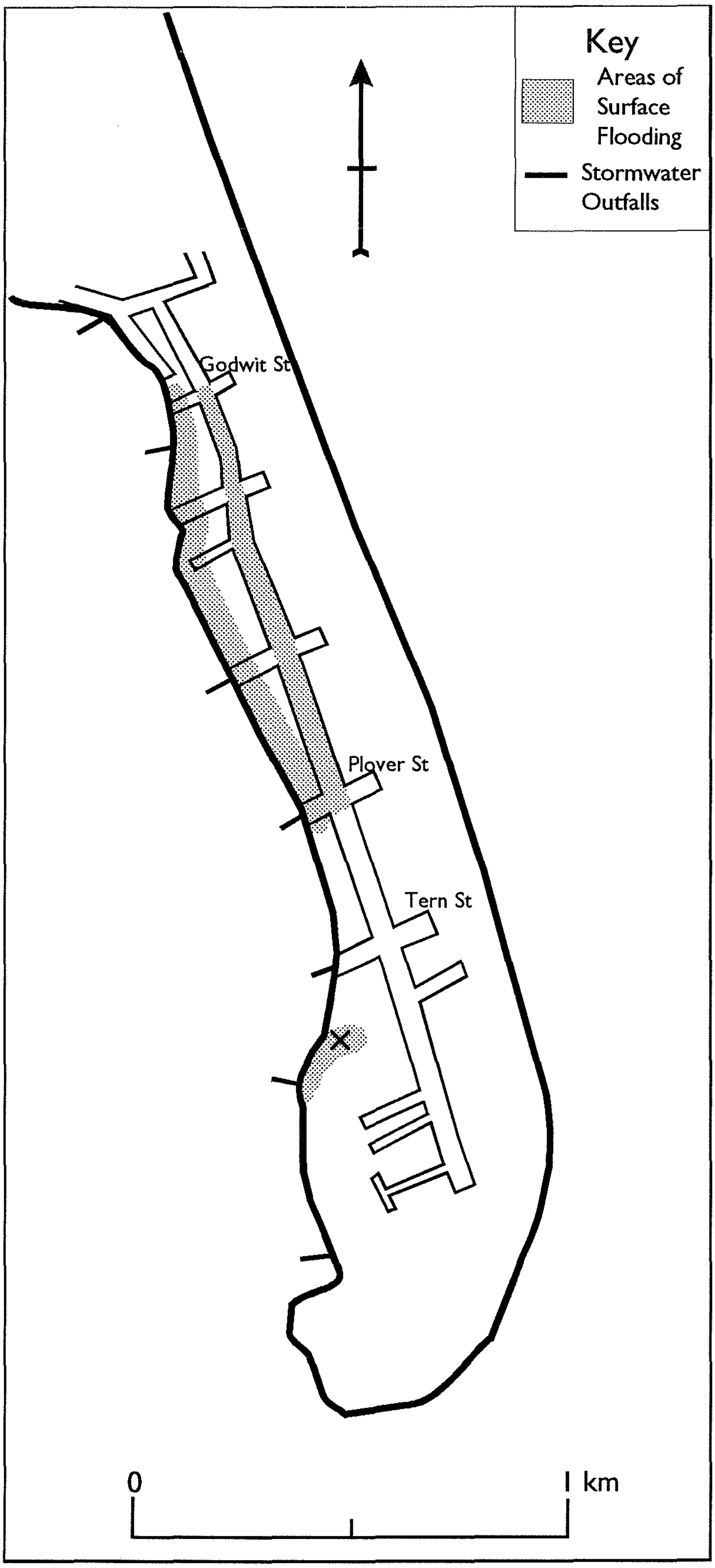

Figure 5.5 Areas of Surface Flooding - August 1992 and Location of Stormwater Outfalls.

5.4 Summary

The occurrence of inundation of South Brighton Spit from the coastal side, appears to be very rare with only one event noted in the records of the Southshore Ratepayer's Association. Thus the major source of flooding along South Brighton Spit is from the Avon-Heathcote Estuary. Before the whole of the study area was properly serviced with stormwater drains flooding was a common phenomenon, occurring whenever it rained or when there was an extreme high tide. The 'Wahine' Storm of 10-12 April 1968 proved to be the worst event during this period, and resulted in the evacuation of at least five families due to the rising water level. After the completion of stormwater drain installation in the late 1970s, flooding was no longer a common problem with only one event recorded to date. The flooding from the August 1992 snow storm was due to a combination of overtopping of the estuary margin and the backflow of water through the stormwater drains.

In both the 1968 and 1992 events the high water levels in the Avon-Heathcote Estuary were due to a combination freshwater flooding of the estuary, high tides, and storm surge. As the August 1992 episode is the only event to be recorded since the installation of stormwater drains and had one of the highest water levels recorded in the Avon-Heathcote Estuary, the event could serve as a useful benchmark for planning purposes. Unfortunately, the only quantitative information there is about this event is related to water levels recorded at the Ferrymead and Bridge Street gauges. There is no quantitative information regarding exact flooding levels along South Brighton Spit. The application of the gauge levels to South Brighton Spit may not be correct, as there are other influences on water level such as wave and wind setup. The implications of this lack of information will be discussed in Chapter Six, together with a full discussion on the results of this investigation into hazards at South Brighton Spit.

Chapter Six
Management of Coastal Hazards at South Brighton Spit

6.1 Introduction

This chapter discusses the results of this investigation into coastal hazards at South Brighton Spit. How the two local planning authorities propose to manage these hazards is also discussed through an examination of their plans. The following section discusses the findings of the previous three chapters and examines how residents have attempted to protect their properties. Secondly this section reviews the recommendations of a report into erosion on the estuary margin of South Brighton Spit, and thirdly the implications of the lack of quantitative information regarding the flooding of 28-29 August 1992 is explored. The third section examines the plans of the Christchurch City Council and Canterbury Regional Council to outline how they plan to manage the hazards that have been identified in this study. The final section summaries the discussion of the findings of this research and their planning implications.

6.2 The Coastal Hazards of South Brighton Spit

This study into coastal hazards at South Brighton Spit has shown that the perception of erosion of the coastal side of the spit as being the only major type of hazard to occur within the study area is wrong. Both flooding and tsunami can have as large or greater an impact on the study area as erosion, and erosion of the estuary margin is a hazard that previously has remained unidentified.

Seven tsunami events have had an impact on either the Christchurch coast or Lyttelton Harbour. Of these seven events one was a locally generated event, while the remaining six were remotely generated. It is widely believed that there have only been two tsunami events that have affected the Christchurch coast. These are the 1868 and 1960 events. This belief is incorrect. There have been four events that have had observed impacts on the Christchurch coast - January 1855, May 1877, November 1922, and May 1960. The tsunami of 1868 would have also had an impact, but due to the lack of transport and development of the Christchurch coast at this time no observations of fluctuations in water levels either along the coast or in the Avon-Heathcote Estuary were recorded. The remaining two events of August 1883 and March 1964 which were recorded at Lyttelton Harbour, help to emphasis the point that there have been more tsunami events than what is popularly believed. The Christchurch Engineering Lifelines Project carried out by the Canterbury Regional Council (1994b) shows the potential effects along the Christchurch coast of a tsunami event that is of a magnitude similar to or greater than the 1868 and 1960 events. The effects are potentially disastrous due to the large increase in population along the Christchurch coast, combined with a high value of assets and property. Within the study area the population was 1425 at the 1991 census, while the current combined capital value from government valuations of the study area is approximately $75.6 million. Thus for this small section of the Christchurch coast the potential costs of a tsunami event of a magnitude similar to the 1868 and 1960 occurring are very high.

There does not appear to be any long term protracted erosion at South Brighton Spit. However, at a long term scale the natural fluctuations of the spit have proven to be a hazard and may well be again in the future. The substantial loss of the vegetation along the estuary margin of South Brighton, although not necessarily a direct hazard, has increased the potential of undermining boundary fences and flooding properties. From the time of the establishment of the Southshore Ratepayers' Association in 1946 there has been six erosion events and one major period of erosion. The latter was from 1940 to 1949 and involved the northward retreat of the distal end of the spit due to the shift in the Avon-Heathcote Estuary inlet channel. Of the other six events five occurred on the coastal side of the spit, while the sixth event was erosion of the spit's estuary margin. The five coastal erosion events were due to southeasterly storms which coincided with very high tides at South Brighton Spit. These events appear to be part of the 10 to 15 year 'cycle' of years of increased storminess proposed by Kirk (1978). One of these events, in August 1992, also caused major flooding of a large part of the study area. The cause of erosion of the estuary margin is unclear, however southerly storm wave attack within the estuary is probably the major factor.

Inundation from the coast is a rare phenomena at South Brighton Spit, with only one event noted. Thus the major source of flooding is from extreme water levels in the Avon-Heathcote Estuary. Flooding was a constant problem until the completion of stormwater drains in the late 1970s, due to the ponding of rain water on properties and roads. However there have been four specific events recorded. The first was during the 'Wahine' storm in April 1968, where a combination of both lack of stormwater runoff and overtopping of seawalls on the estuary side of the spit resulted in five families having to be evacuated. In 1974 two major storms, in April and May, again caused flooding problems for residents along South Brighton Spit. The most recent event, in August 1992, was caused by a combination of the failure of the stormwater drains' tidal gates, which resulted in backup of water in the drains, and overtopping of seawalls along the estuary margin of the spit.

There is thus more than one type of hazard at South Brighton Spit. Table 6.1 outlines the hazard events identified in this study and also includes those identified by Findlay and Kirk (1988). Unfortunately with these latter events the file which contained the sources was unattainable, thus these events have not been verified for this study. Table 6.1 shows that between 1855 and 1992 there have been 38 different hazard events within the study area, including the two tsunamis which were observed at Lyttelton. There have also been two significant periods of erosion. The first between 1940 and 1949, was the northward retreat of the distal end of South Brighton Spit, while the second between 1977 and 1991, was the retreat of vegetation along the estuary margin of the spit. Between 1946 and 1977 (approximately) there was a significant period where flooding was a hazard to residents. This was mainly due to the lack of storm water runoff. Of those events added to Table 6.1 from Findlay and Kirk (1988) there are thirteen open coast erosion events, five flooding events from the Avon-Heathcote Estuary, and one flooding event from the coastal side of the spit. It should be noted that between the periods of erosion, particularly on the coastal side of the spit, there have been corresponding periods of accretion, thus replenishing eroded sediment.

Table 6.1 Hazard Events at South Brighton Spit
(Adapted from Findlay and Kirk, 1988)

Date	Type of Hazard	Description
25 January 1855	Tsunami	Small bore travelled up the Avon River
15 August 1868	Tsunami	Major fluctuations in sea level at Lyttelton Harbour, 8 large ships damaged
10 May 1877	Tsunami	0.9 metre rise in the Avon River
27 August 1883	Tsunami	Minor fluctuations in sea level at Lyttelton Harbour
1917 *	Erosion - Coast	Sandhills at distal end of spit cut back
1918 *	Flooding - Estuary	Sea floods Tern St from Estuary, extends to Rockinghorse Road
	Erosion - Coast	Erosion of distal end continues
1919 *	Flooding Erosion - Coast	Caspian Street area flooded Erosion of distal end continues
1921 *	Erosion - Coast	Erosion on both western and eastern side of distal end of spit
1922 *	Flooding - Coast	Sea cuts through sandhills
11 November 1922	Tsunami	Fluctuations in tide at New Brighton
1930 *	Erosion - Coast	Erosion of distal end recommences
1931 *	Erosion - Coast	Erosion of distal end continues
1932 *	Erosion - Coast	Erosion of distal end continues
1933 *	Erosion - Coast	Erosion of distal end continues
1940 - 1949	Erosion - Coast	500 metre northward retreat of spit
1946 *	Flooding - Estuary	Extensive flooding of southern end of Estuary Road [estuary end of Caspian Street]
July 1947	Flooding - Estuary	Flooding of Caspian and Ebbtide Street at extreme high tides
May 1948	Erosion - Coastal	Wide cut through distal end of spit, six sections lost.
	Flooding - Coastal	Many sections flooded by the sea
1952 *	Flooding	Flooding in Caspian Street
25 May 1953 *	Flooding	Rockinghorse Road flooded
1955 *	Erosion - Coast	Foredune scarp at back of properties at eastern end of Torea Lane
22 May 1960	Tsunami	Major fluctuations in estuary water levels and scouring of distal end of the spit.
August 1962	Erosion - Estuary	Erosion of estuary margin causing problems for residents

Continued on next page.

Table 6.1 (continued) Hazard Events at South Brighton Spit (Adapted from Findlay and Kirk, 1988)

Date	Type of Hazard	Description
28 March 1964	Tsunami	0.9 metre fluctuations in sea level at Lyttelton Harbour
6 - 10 August 1964	Erosion - Coast	3 metre scarp in foredunes, houses at Torea Lane threatened.
1968 *	Erosion - Coast	More erosion at Torea Lane
10 - 12 April 1968	Flooding - Estuary	Flooding of spit due to lack of stormwater runoff and overtopping of seawall by estuary
16 April 1974	Flooding - Estuary	Whole of study area flooded
30 May 1974	Flooding - Estuary	225 mm of water covering southern end of Rockinghorse Rd
July 1977	Erosion - Coast	Scarp developed in front of houses at Torea Lane
August 1977	Erosion - Coast	Scarp brought closer to houses at Torea Lane
September 1977	Erosion - Coast	Scarp brought closer to houses at Torea Lane, 1964 protection works partly uncovered
1946 - 1977	Flooding	With lack of stormwater runoff flooding occurred with every major rain storm
1978 *	Erosion - Coast	Further erosion in front of houses at Torea Lane
1979 *	Erosion - Coast	Further erosion at Torea Lane
1980 *	Erosion - Coast	Further erosion at Torea Lane
1977 - 1991	Erosion - Estuary	Retreat of vegetation along estuary margin, possibly starting earlier and still continuing
28 - 29 August 1992	Erosion - Coast	Major erosion on margin and dune face along whole of spit.
	Flooding - Estuary	Major flooding from backup of water in stormwater drains and wave overtopping of estuary seawalls

Note: * Events identified by Findlay and Kirk (1988)

Figure 6.1 shows these events on a diagrammatic timeline. Each dash represents a year in which one or more hazard event occurred, while the solid blocks represent an almost continuous period in which either erosion or flooding occurred. This diagram clearly shows that there is more than one type of coastal hazard at South Brighton Spit. From 1917 onwards the number of observations concerning erosion and flooding at South Brighton Spit increased due to a

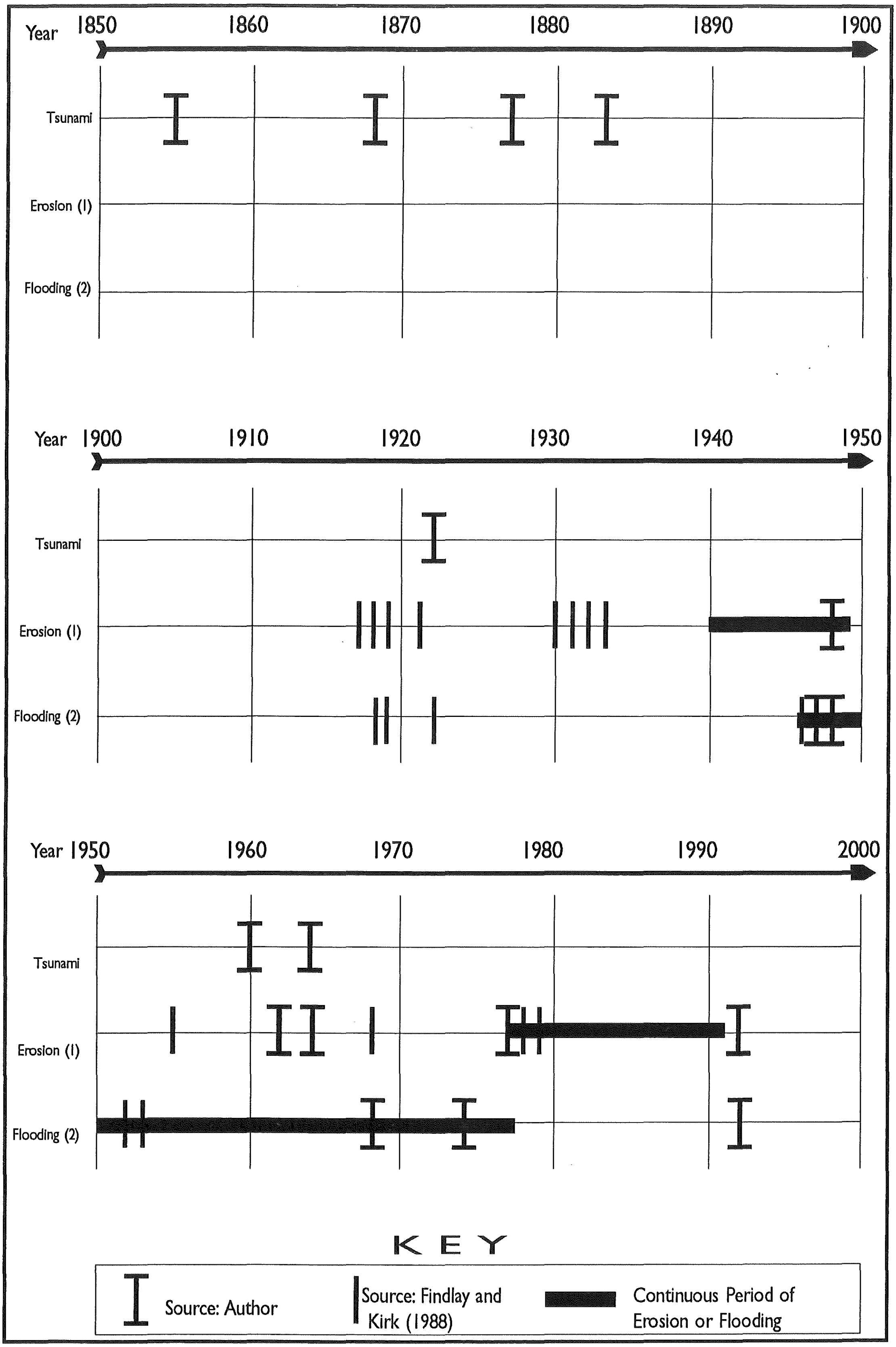

Figure 6.1 **Diagrammatic Timeline of Hazard Events at South Brighton Spit.**

Note: **1** **Includes erosion on the coastal and estuary sides of the spit**

2: **Includes flooding from coastal and estuary sources**

corresponding growth in interest in the area for residential development. As the residential development of the area increased, especially from 1946 onwards, so has the occurrence of hazard events. Of the type of hazard events identified, both flooding and erosion have presented more of a hazard to residents than tsunami. But it must be noted that there has not been a significant tsunami in 35 years, nor has there been a tsunami event that coincided with high tide.

As erosion and flooding have been the main hazards with which residents of South Brighton Spit have had to live with, it is appropriate to discuss how they and the Christchurch City Council have attempted to protect their properties from these hazards. In 1949 with the northward retreat of the distal end of the spit threatening properties, the Christchurch Drainage Board erected a small sandbag groyne at the end of the spit to prevent further loss of sediment. The Southshore Ratepayers' Association in 1949 also erected a groyne, but this consisted of an unknown number "44 gallon" drums. A further 100 drums were added in the following year. These two groynes were effective in preventing further loss of sediment, and also helped to trap sand moving through the inlet channel, resulting in a gain in length to the spit of some 400 metres by 1955 (Scott, 1955). These groynes remained covered by sand from 1950 until 1994, when erosion at the very tip of the distal end of the spit uncovered them (see Plate 4.8).

When erosion took place in front of properties at the end of Torea Lane in 1964, protective structures were needed to prevent the undermining of the houses. This work was carried out by the Christchurch City Council and involved the placing of a 24 metre long barrier consisting of rubble filled drums in a trench seaward of the houses (see Plate 4.3). This structure proved effective in preventing further undermining of the houses at that time. In 1977 three major storms again caused erosion at Torea Lane, threatening the houses once more (see Plate 4.4). The protective structure erected in 1964 was exposed, and was strengthened after it was discovered that some of the drums were rusting. Since this time a small dune has built on top of this structure, helping to protect the three houses.

Houses along the estuary margin of South Brighton Spit have been subject to both erosion and flooding and a variety of means have been used to protect these properties. Many of the protective structures erected are little more than boundary fences, similar to those which would face a road. Along Ebbtide Street, at the northern end of the study area, is a seawall standing some 0.75 to 0.9 metres high from the estuary bed. This wall is shown in Plate 6.1. Overtopping of the wall first occurred in 1947, resulting in extensive flooding of both Ebbtide and Caspian Streets. When the 1960 tsunami occurred sea lettuce was observed on the corner of Ebbtide and Caspian Street, suggesting that the seawall had again been overtopped. In 1968 with the 'Wahine' storm, the seawall was once more overtopped. Waves of about 0.6 metres in height were observed breaking over the wall. An embankment has subsequently been built up behind the wall to try and prevent overtopping water flooding inland. To the south of this wall is a section of dumped concrete rubble as shown in Plate 6.2. It is believed that this protective measure was put into place by the Christchurch City Council (Shearer, 1994). Over

Plate 6.1 **Seawall at Ebbtide Street - High Tide 27 June 1995**

twenty properties are protected either by the rubble itself, or by a mixture of rubble with either a block wall, tyres, or ice plants. Such structures are not safe, as the broken rubble can be lifted by either waves or flowing water during times of extreme high water levels and storms.

Many other forms of protection have been employed along the estuary margin. The most common form is the upright concrete block fence as shown in Plate 5.2, and these range in height from 1.10 to 2 metres. Such structures seem to offer protection from flooding, however many of these fences have gateways or ramps which effectively lower the height of the walls thus allowing water to enter properties. There is also no consistency between individual properties in the height or alignment of the fences. There are gaps between some adjacent walls, thus allowing flood waters direct access to the properties behind them (Shearer, 1994).

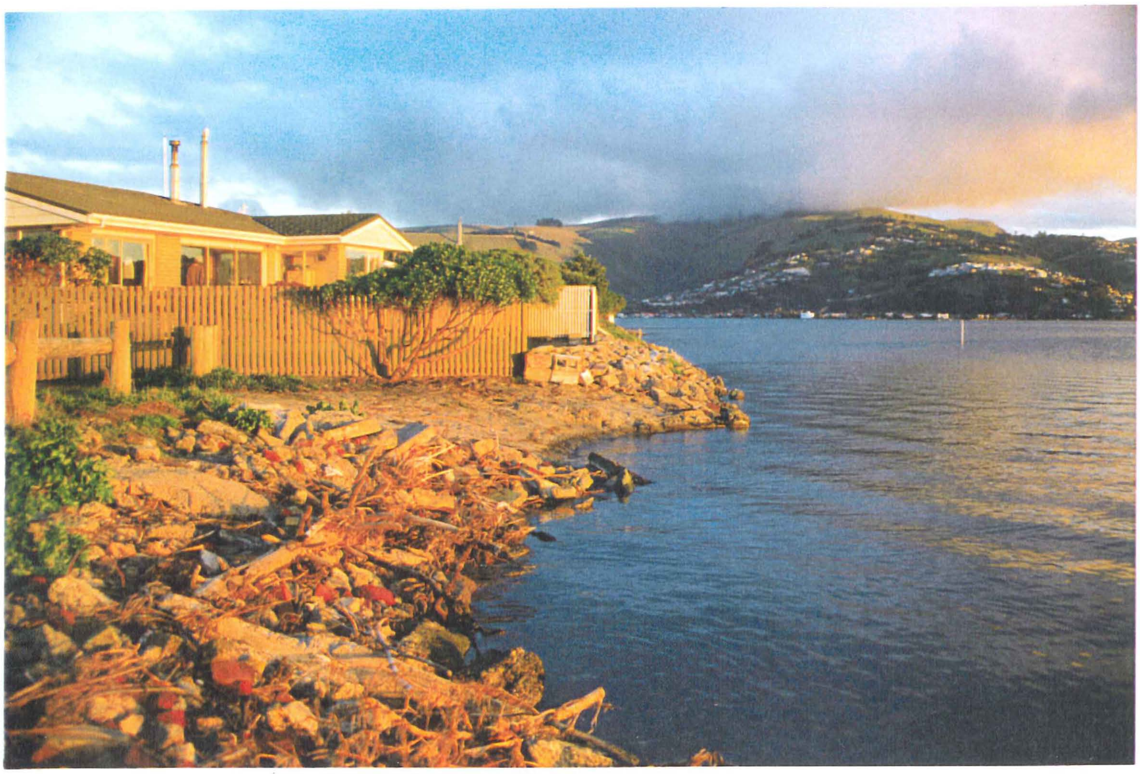

Plate 6.2 **Dumped Rubble, end of Heron Street Looking South - High Tide 27 June 1995.**

Scouring around the bottom of these block fences has resulted in some residents using rubble to protect their fences, or as in the case shown in Plate 6.3 a concrete wave swash apron has been installed to dissipate wave energy thus reducing scouring around the wall. A close inspection of Plate 6.3 reveals that this structure itself is being undermined at times of high wave energy, as the toe of this structure is visible in the middle of the photograph. This photograph also shows the entranceway ramp that is common along the estuary margin of South Brighton Spit. Other forms of protection that have been employed by residents are wooden/timber fences, banks covered with either grass or ice plant, and in one case sandbags. This haphazard collection of protective structures runs from Godwit Street to just south of Tern Street, where houses are set further back from the estuary, and are behind a stopbank put in place by the Christchurch City Council after the August 1992 storm. This stopbank is shown in Plate 5.4.

Plate 6.3 **Protecting the Protective Structure - Plover Street 23 November 1994.**

A draft report written on erosion of the estuary foreshore of South Brighton Spit, investigated seven different types of protective works (Walter, 1995). These ranged from replacing all of the existing walls with a consistent design to doing nothing and leaving it up to the residents. The recommended option in the report was the rebuilding of an estuary beach together with the revegetation of that beach to form a salt marsh environment, similar to that around Penguin Street. This beach would be backed by sea walls to minimise the chances of overtopping in times of high water and storms. The option is likely to provide the best protection for residents from erosion and flooding, as it should provide a consistent method of protection for the whole of the estuary margin along South Brighton Spit.

The report recommends that a design level benchmark of RL 11.2 metres (above old Christchurch Drainage Board datum) should be used (Walter, 1995, 10). This would be the level of the top of the seawall behind the rebuilt beach. This level has been calculated from an estimated maximum water level reached during the August 1992 storm at South Brighton Spit of RL 10.85, plus an addition 0.35 metres to allow for such aspects as increased sea level rise over an estimated 20 year design life of the seawall and beach. The 1992 storm water level at South Brighton Spit is an estimation calculated from levels obtained at the Ferrymead Bridge (RL 10.77) and Bridge Street (RL 10.95) bridges. The difference between these two levels is thought to be due to the shelter that the Ferrymead site has from southerly winds. The level of RL 10.85 for South Brighton Spit may be correct. However as there is no quantitative information on the actual water level reached during the August 1992 to verify this estimation, the applicability of using this level as a benchmark is in doubt. Walter's report recommends that this design level benchmark is reviewed after a five to ten year period. This will allow for a greater understanding of such factors as sea level rise and the impact of southerly winds on water level along the estuary margin. Altogether the suggested level and the recommended option may help in protecting properties at South Brighton Spit from erosion and flooding.

Protection from a tsunami is a different matter, and the recommended option may offer little protection if a tsunami similar to those experienced in 1868 and 1960 occurred at high tide. Very little may be able to be done to protect properties from a tsunami, as there is a range of water levels that may be reached in the Avon-Heathcote Estuary. This range is from normal high tide of RL 10.03 metres (above old Christchurch Drainage Board datum) to that estimated in the Christchurch Engineering Lifelines Study, which was 3 metres above mean high water spring tide of RL 10.35 metres. This latter water level would require a stopbank or seawall that is at least three to four metres higher than mean high water springs to prevent overtopping and flooding from such an extreme tsunami event. Such a seawall would have negative physical and visual impacts on the Avon-Heathcote Estuary, and may also infringe Policy 3.4.6 of the New Zealand Coastal Policy Statement (Minister of Conservation, 1994). This policy states that the use of protective structures, such as seawalls, within the coastal environment should be avoided, unless they are the best option available and will not have an adverse effect on the environment.

6.3 Proposed Management of Hazards By Local Authorities

Chapter Nine of the Notified Regional Coastal Environment Plan deals with coastal hazards in the Canterbury region (Canterbury Regional Council, 1994a). Of the coastal hazards identified in this study, this plan deals mainly with erosion of the open coast and sea water inundation. Areas of sea water inundation identified in this plan fall outside the study area. This study has shown that this type of event has been rare at South Brighton Spit. However proposals regarding erosion of the open coast are of importance.

The Canterbury Regional Council has taken a planning response to erosion of the open coast, and has defined two hazard zones along the Canterbury coast. These two zones are defined as:

Hazard Zone 1	This is a zone delimited by a line approximately parallel with the shoreline, set inland from mean high water mark springs which contains land which is at risk from coastal erosion within 50 years of the Plan being produced.
Hazard Zone 2	This is inland from Hazard Zone 1 and marks land which is at risk from coastal erosion in the period 50 to 100 years of this Plan being produced (Canterbury Regional Council, 1994a, 47).

The Council has identified one objective and one policy regarding coastal hazards. These are based on the premise that the main aim of managing natural hazards is to minimise the cost of any damage that may occur through the adoption of the principle of avoiding hazards rather than protecting people and property from them. The Council's objective to managing coastal hazards and its policy regarding that management are similar. The Council's policy is given as:

> The Canterbury Regional Council will:
> a) Control new and existing use and development within the defined Hazard Zones 1 and 2 so as to avoid or mitigate an increased in the actual or potential cost of coastal hazards and avoid the need for hazard protection works.
> b) Control or seek to control the location, type, design and alternative to damage minimisation measures in order to avoid, remedy or mitigate the adverse effects of these works.
> c) Provide information, including information on the incidence of natural occurrences, to enable people to avoid location in hazard prone areas (Canterbury Regional Council, 1994a, 48).

This policy is employed through three rules which describe permitted activities, discretionary activities, and prohibited activities. Permitted activities are those activities which do not need a resource consent as long as the activity complies will the conditions as laid out in the plan; a discretionary activity is an activity for which a resource consent must be applied for before it is carried out; while a prohibited activity is an activity for which no resource consent will be granted (Resource Management Act, 1991, s.2). Thus the Canterbury Regional Council can control further development and use of the coastal environment, as well as controlling the forms of protection that are used. Within the study area both hazard zones have been identified, and these are shown in Figure 6.2. Although this map is from the Christchurch City Council's new plan the zones identified by the Regional and City Councils are the same. Thus there are controls in place so that there will be no more development of the dunes such as that which occurred at Torea Lane. Forms of protecting existing houses must also comply with the Council's plan.

Tsunamis have been identified in the Plan as a natural event that effects the Canterbury coast. Although they have not been included for direct management under the two hazard zones, the Canterbury Regional Council do state the need for more investigation into the magnitudes, frequencies, and possible effects of

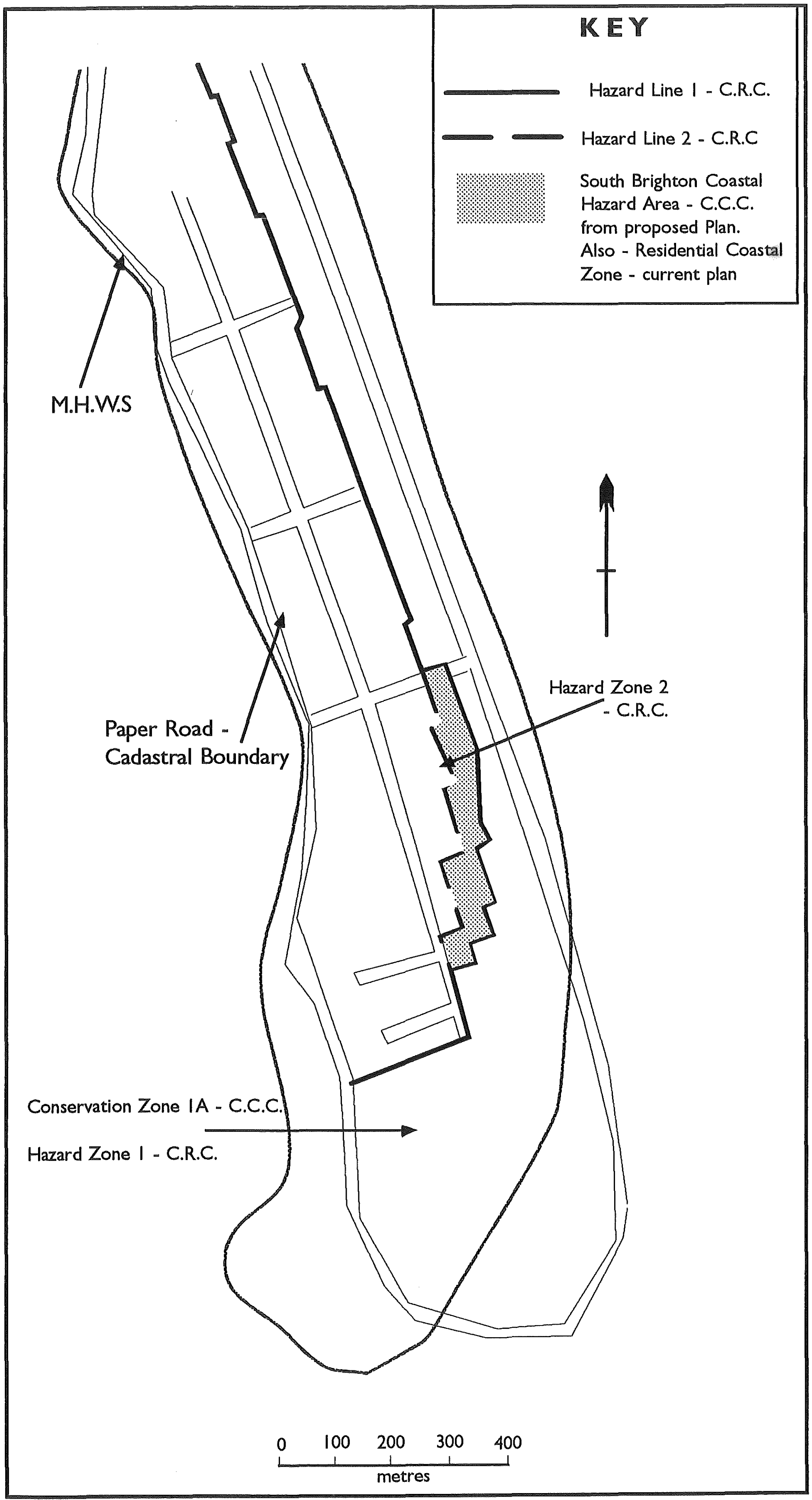

Figure 6.2 **The Different Zones at South Brighton Spit**
(Sources: Canterbury Regional Council, 1994a; Christchurch City Council, 1995b)

tsunamis. One such investigation was the Christchurch Engineering Lifelines Project carried out by Canterbury Regional Council in 1994. This and other investigations into the effectiveness of warning systems, should help to reduce the potential impacts of a tsunami occurring on the Christchurch coast.

Tsunamis are a difficult hazard to plan for as their occurrence is unpredictable and their interaction with the coast is complex and variable. Thus more investigations similar to the Lifelines Project need to be undertaken so a better understanding of the hazard posed by a tsunami to the Christchurch coast can be obtained. Such investigations would include examining the effects of a hypothetical tsunami, similar to the one modelled, at different locations. More specific investigations into the impacts of a tsunami at South Brighton Spit and within the Avon-Heathcote Estuary are needed. This would include a detailed investigation into the impacts of a range of tsunami magnitudes on the inlet channel and estuary margins.

There is no mention of erosion and flooding of the estuary margin of South Brighton Spit in the Council's plan. Whether this is an oversight or not is unclear. However the rules of this plan will apply to any activity within the estuary if that activity falls below mean high water springs - the jurisdictional boundary between the Canterbury Regional Council and the Christchurch City Council. The Avon-Heathcote Estuary and any hazards that are identified there may be included in future coastal plans, or they may fall under the jurisdiction of another plan such as the Natural Resource Plan.

The Canterbury Regional Council is basically a resource manager, as opposed to a service provider, which means that unless the problem or hazard is of regional significance or transcends territorial boundaries the Council will only act in its role as Consent Authority. An example of a hazard of regional significance is flooding of the Waimakariri River. The Regional Council has taken a role in preventing major flood damage through the installation of stopbanks. This example also transcends territorial boundaries. Thus as erosion and flooding of the estuary margin of South Brighton Spit only affects a small number of people, the Regional Council will only act as a Consents Authority in association with any protection structures if they fall below mean high water springs, or if the Council objects to a proposed structure's physical or visual impact on the estuary.

The proposed City Plan for Christchurch considers erosion of the open coast along the spit as the main hazard for the area (Christchurch City Council, 1995b). The Plan acknowledges the open coast erosion that occurs within the study area, and has designated a special area within Living Zone 1 - the South Brighton Coastal Erosion Area. This area has come from the City Council's current plan, and is called in that plan the "Residential Coastal Zone". This was the result of a report written on the dynamics and management of the Christchurch coast in 1979 (Kirk, reprinted in 1987). This zone is located on the eastern side of Rockinghorse Road south of Tern Street and places conditions on all uses so that each proposal can be assessed for its effect on the dune system and its suitability for the site (Christchurch City Council, 1986). Figure 6.2 shows the South Brighton Coastal Erosion Area, which is no longer a separate land-use zone. This area and Hazard Zone 2 from the Regional Council's coastal plan are the same. The Regional Council's Hazard Zone 1 and the City Council's Conservation Zone 1A are also the same for the open coast.

Tsunamis have been identified as a serious hazard issue for the Christchurch coast under Issue 3.4.5 which deals with earthquake hazards (Christchurch City Council, 1995b, Vol. 1, 3/8). As noted above, tsunamis are a difficult hazard to plan for, however an examination of the objectives and policies of the Plan reveals no mention of tsunami as a hazard in relation to Christchurch's coast. Erosion and flooding of the estuary margin of South Brighton Spit has not been identified as a hazard. However Policy 2.6.4 attempts to protect the margins of the Avon-Heathcote Estuary from activities that will detract from the estuary's natural character (Christchurch City Council, 1995b, Vol. 2, 2/20). Whether the implementation of this policy will result in management of the estuary margin of South Brighton Spit in such a way as to try to protect residents from erosion and flooding from the estuary remains to be seen. The proposed rebuilding and revegetation of the estuary margin of the spit, does fall in line with this policy as it is attempting to recreate the supposed natural character of the estuary margin.

The City Plan also identifies inundation due to possible future sea level rise as being a potential future hazard. The Council hopes to avoid high intensity development in those areas which could be subject to inundation should sea level rise. One of the areas identified is the margin of the Avon-Heathcote Estuary. The effects of sea level rise on the estuary are uncertain. It is believed that sea level rise within the estuary will continue along the lines of the historical trend, meaning a rise of approximately 0.16 to 0.20 metres over the next 100 years (Oliver and Kirk, 1992). The extrapolation of sea level at Lyttelton Harbour carried out by Hannah (1990) could mean a rise in sea level of 0.4 metres by 2050 AD. A comparison between the mean sea level given for 1953-54 by Scott (1963) of 8.925 metres (above the old Christchurch Drainage Board datum) and the 1992 mean sea level of 9.3 metres (above the same datum) given by Oliver and Kirk (1992), shows that there has been an increase of 0.375 metres over a 38 year period. This means that mean sea level in the Avon-Heathcote Estuary has risen by about 9.87 mm per year from 1954 to 1992, substantially greater than the 2 mm per year over a 100 year period given by Oliver and Kirk (1992). This change in the mean sea level datum may be the result of more than just sea level rising. Sedimentation of the estuary through the increase in development of the catchment of the estuary may have increased the level of the estuary's bed, thus increasing mean sea level. This increase in mean sea level may also be the cause behind the erosion of vegetation along the estuary margin of South Brighton Spit.

Chapter One highlighted the roles of both the Christchurch City Council and the Canterbury Regional Council in the management of the coast, and also their functions of avoiding and mitigating natural hazards. Section 35(5)(j) of the Resource Management Act (1991) requires the two councils to keep "records of natural hazards to the extent that the local authority considers appropriate for the effective discharge of its function". The Canterbury Regional Council (1994a) in their policy regarding natural hazards have stated that they will provide information regarding the occurrence of natural events so that the public will be able to avoid locating in hazard prone areas. This is to be carried out in two ways. Investigations into and the monitoring of the actual and potential hazards and the effects of those hazards on the coastal environment will be instigated and this information will be made available to the public so that they can be educated and informed on what to do or not to do regarding the identified hazards. Through these measures the Canterbury Regional Council is fulfilling its obligations under Section 35(5)(j) of the Resource Management Act (1991) and in their role as resource managers.

The Christchurch City Council are also required to hold a register of natural hazards that occur within their boundaries. Policy 2.9.2 of the proposed plan states that the Council will "provide information in respect to the presence of natural hazards and to increase public awareness of them" (Christchurch City Council, 1995b, Vol. 2, 2/27). This is to be achieved through the Council's Hazard Register. The point of this policy is to make developers aware of the risks before undertaking any decisions regarding the development of hazard prone areas. This register does comply with Section 35(5)(j) of the Resource Management Act. However, as discovered in this research there is no quantitative information regarding the extent of flooding of South Brighton Spit in August 1992. The water level recorded at the Bridge Street bridge gauge was the highest ever recorded, and it has been recommended that this level be used as a benchmark for design purposes.

Section 35(5)(j) states that the Council must keep this record of natural hazards to the extent that it "considers appropriate for the effective discharge of its functions". Just acknowledging that a hazard event has occurred is not enough. There needs to be records of the type of event and its causes (for example a cyclonic storm), the extent or area over which this hazard event had an impact and the amount of damage that occurred (for example the number of properties flooded, m^3 of sand eroded). This information needs to be collected not just for those hazard events that occur after the Register is setup, but also requires information of the history of those hazards so that patterns of occurrence, causal factors and damage can be identified. This will enable the identification of all hazard prone areas to be made. This would provide the Council with a concise description of the event and the impacts that this event had within its administrative boundaries. Thus the lack of information regarding the August 1992 storm is alarming, as the Council's records on this storm do not have any of the above information. Therefore the true extent and impacts of the storm are not known.

Both the Canterbury Regional Council and the Christchurch City Council appear to be fulfilling their obligations under the Resource Management Act (1991) regarding natural hazards in the coastal environment. However, South Brighton Spit is a dynamic and complex environment which has a high intensity use and there needs to be co-operative and integrated management of the coastal hazards that occur there. Current management of South Brighton Spit is split between two departments of the Christchurch City Council - the Parks and Recreations Unit and the Water Services Unit, while the Canterbury Regional Council manages the area below mean high water springs. Effective management of hazards at South Brighton Spit needs to be properly co-ordinated as the spit is susceptible to any changes in either the coastal or estuarine systems which have helped to build and maintain it, and human activities and developments in the area..

6.4 Summary

This study has identified 38 different coastal hazard events at South Brighton Spit occurring over the last 140 years. These hazards consist of more than just the periodic erosion of the open coast. Erosion of the estuary margin, flooding from the estuary, and tsunami also present a hazard to local residents. Although there does not appear to be any long term protracted erosion of the spit, the natural fluctuations associated with such landforms have proven to be a hazard. Such fluctuations in the configuration of the spit may occur again. The incidence of tsunami at South Brighton Spit is relatively rare, with only four events in the last 140 years. However, due to the increase in the human use of the coastal environment since the last event in 1960, there is considerable potential for damage should a tsunami occur at a future date. Flooding was a major hazard prior to the installation of stormwater drains in the late 1970s and still occurs when there is a combination of storm surge conditions within the estuary and high tide.

Many forms of protective structures have been used within the study area in an attempt to prevent flooding or further erosion. On the coastal side of the spit, these have traditionally consisted of drum groynes. However, the estuary margin has a haphazard collection of seawalls, dumped rubble, and grass banks. A draft report recommends replacing these structures with a consistent seawall and to rebuild the estuary shore in front of this wall. The design level benchmark for the top of the wall has been set by using an estimation of the water level reached along the spit in the August 1992 storm. There are doubts as to how correct this estimation is, and thus those doubts are then transferred onto the benchmark level.

Both the Canterbury Regional Council and the Christchurch City Council have taken a planning response to the hazard of erosion on the open coast. However, they both fail to identify any hazard around the estuary margin, in particular the erosion and flooding that occurs at South Brighton Spit. The Resource Management Act (1991) requires councils to keep records of natural hazards within their boundaries. Such records should contain the type of event and its cause, the spatial extent of the event, and the amount of damage that occurred. These records also need a historical base so that patterns of occurrence, causal factors, and damage can be identified. This then allows for ease in the identification of those areas which are the most hazardous.

Integrated management between the two councils concerning the hazards at South Brighton Spit is needed. The spit is a dynamic and intensively developed area, where any change in either the physical or human use system will have an affect on the area. Thus all the hazard types need to be managed as a group. The management approach taken needs to be consistent between the two councils.

Concluding statements and areas where further research are needed are discussed in the following chapter.

Chapter Seven
Conclusions and Further Research

7.1 Conclusions

This thesis aimed to provide a history of the coastal hazards at South Brighton Spit, Christchurch, and to change the common perception that the only hazard that occurs is the erosion of the coastal side of the spit. This was undertaken so that a better understanding of the hazards in this area could be obtained and then applied to the management of the area. South Brighton Spit was used for this study as it is the epitome of the dynamic coastal environment that is recognised by the New Zealand Coastal Policy Statement. It is a young environment, probably forming no later than 700 years BP, and is one of the more intensively developed areas of the New Zealand coast.

A holistic, integrated geographical approach was undertaken for this research as it provided the scope for which a complete examination of natural hazards could be made. As a natural hazard is the result of a negative interaction between the natural events system and the human use system, an approach which allowed for the examination of both the physical and human aspects of the development of South Brighton Spit and the hazards which occur there was needed. Such an approach should also be used in the management of this and similar environments where the systems are connected in such a way that any change in either the physical or human system will affect the other system. This approach requires the co-operation between the two councils in regards to the preparation of hazard management plans for the area, as well as for the day to day management of the coastal, estuarine, and residential aspects of the spit.

Over the study period of 1946 to 1995 the use of the spit for residential development has intensified. There are now about 650 rateable properties worth approximately $75.6 million within the study area. Thus the assets at risk are considerable. As residential development increased, so has the number of coastal hazard events that have been observed. In the last 140 years, 38 hazard events were recorded. There were seven tsunami events, 22 erosion events including two extended periods of erosion, and thirteen flooding events including one prolonged period of flooding. Approximately 58% of these were recorded in the last 55 years.

The main conclusions from this investigation into the history of coastal hazards at South Brighton Spit are:

1. The major coastal hazards at South Brighton Spit are erosion of the open coast and the estuary margin, flooding from the estuary, and tsunami.

2. Over the study period, 1946 to 1995, there have been five erosion events (coastal and estuary), four flooding events (coastal and estuary), and one tsunami at South Brighton Spit.

3. From 1855 to 1995 there has been 38 different hazard events, two prolonged periods of erosion, and one prolonged period of flooding (includes tsunamis recorded at Lyttelton, and events from Findlay and Kirk(1988).

4. There has been four tsunamis (not two as popularly thought) that have had an impact on the Christchurch coast. The 1868 event would have also had an impact due to its magnitude, but the lack of development of the Christchurch coast meant there was no recorded observations.

5. The potential impacts of another tsunami on the study area similar to or greater than the 1868 and 1960 events are disastrous.

6. The natural fluctuations of the spit are a hazard on a long term timescale.

7. Erosion of the estuary margin of the spit has been occurring for a prolonged period, and has the potential to undermine boundary fences and increase flooding of properties.

8. Flooding of properties was a hazard prior to the installation of stormwater outfalls in the late 1970s. Widespread ponding was common whenever there was a rainstorm.

9. After the installation of stormwater drains, flooding was not a problem. There has only been one flooding event since the late 1970s.

10. Storm surges within the Avon-Heathcote Estuary in combination with high tides present a major flooding hazard to residents of the estuary margin by the overtopping of seawalls.

11. There appears to have been an increase in the mean sea level datum for the Avon-Heathcote Estuary of 9.87 mm per year from 1954 to 1992.

12. There needs to be co-operative, integrated management between the Canterbury Regional Council and the Christchurch City Council of the whole of South Brighton Spit. This is due to it being a dynamic environment where changes to either the coastal, estuarine or human systems can have an impact on the whole of the spit.

13. Records of natural hazards need to contain the type of event and its causal factors, the spatial extent of the event, and the amount of damage sustained. This needs to be done for all past hazard events, as well as for any new events.

7.2 Areas for Further Research

There are four main areas for further research that have arisen as a result of this study. The first is the need for an investigation into the exact geomorphological processes and climatic conditions that formed South Brighton Spit and the Avon-Heathcote Estuary, about which little is actually known. This thesis has suggested that the Waimakariri River may well have had an influence on the physical development of the spit. This area needs to be explored further.

Related to this is the current influence of the Waimakariri River on the spit, such as its role as a sediment source and in maintaining the spit's configuration.

The second area for investigation concerns the difference in the mean sea level datums of 1954 and 1992 for the Avon-Heathcote Estuary. They show a 9.87 mm per year increase over the 41 years. Whether this is the result of normal sea level rise or sedimentation of the estuary needs to be discussed. This rate of rise is higher than the 2.4 mm per year rise at Lyttelton Harbour. The implications of this rate of water surface rise for the estuary margins need exploring and need to be compared to estuary margin changes identified by previous research.

The impacts of the recommended option for the protection of the estuary margin of South Brighton Spit is the third area which needs further research. Such aspects as any changes to the spit's configuration, effects on the tidal compartment and sea level datums for the estuary need to be explored fully before any construction of the seawall or artificial beach is started. The design level benchmark used for the seawall needs further investigation as it is only based on an estimation of the highest water level reached at South Brighton Spit during the August 1992 storm. This benchmark also needs to take into consideration the results of the investigation into the changes in the mean sea level datum for the estuary.

The final area of further research has two components. The first is the continued monitoring and recording of all hazard events at South Brighton Spit and an investigation into the ways in which these hazards can be efficiently and effectively managed. The second component is the replication of this study in those areas of the environment, not just the coast, where it is believed there are significant hazards to local residents. This study and others of similar type are the first step that has to be taken for there to be proficient management of hazards. There needs to be identification of the types of events and the locations in which they occur before effective planning and management responses can be made.

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