7 The Hawke's Bay Littoral Cells: Processes, Erosion Problems and Management Strategies

7.1 INTRODUCTION

Coasts are commonly divided into what is termed "littoral cells", representing a stretch of beach that is partially to completely isolated from other beaches. A littoral cell is most easily defined where rocky headlands provide barriers at the ends of the beach, restricting its exchange of sediment with other nearby beaches. This is the situation at Hawke's Bay where one can clearly define three littoral cells, those that were identified in Section 1 (Figure 1-1). Of interest in this report are the two southerly cells as they are the most heavily developed and constitute the shores of immediate management concern. As a result, nearly all of the studies and reports written about the beaches of Hawke's Bay have dealt with one or both of these cells. As defined in this report the Bay View Littoral Cell extends alongshore for 18 kilometres, from Tangoio Bluff at its north to Bluff Hill (Scinde Island) within the City of Napier at its south end. The second littoral cell of interest in this report is the Haumoana Cell, the 20-kilometre stretch of beach from Napier (Bluff Hill and the Port's breakwater) to Cape Kidnappers at its south end. The rocky headlands that define these cells provide varying degrees of isolation, that is, the extent to which they inhibit sediment exchange with the beaches of adjacent cells. The long Waipatiki stretch of rocky coast north of Tangoio appears to be an effective barrier between the Bay View Littoral Cell and the Wairoa Cell further to the north. Cape Kidnappers at the south end of the Haumoana Cell is certainly also a major barrier to longshore beach sediment movements. On the other hand, as reviewed in Section 6, less clear is the degree to which Bluff Hill has prevented the bypassing of beach sediment from the Haumoana Cell to the Bay View Cell, prior to and following the construction of the Port of Napier's breakwater in 1887-1890. Certainly at present, with the breakwater extending the effectiveness of the natural headland of Bluff Hill, there is no bypassing of beach gravel except for that artificially extracted south of the breakwater and placed as beach nourishment at Westshore to the north.

The objective of this Section is to provide a review of the processes, erosion problems and management issues in the Haumoana and Bay View Littoral Cells, to bring together information from the many reports that have addressed topics such as the sources of sediment to their beaches, the transport of the gravel and sand on the beaches by the waves and currents, and the probable causes of the erosion experienced in the communities of Te Awanga, Haumoana and Westshore. To a large extent this review focuses on assessments of the sediment budgets for these respective littoral cells, with each budget including evaluations of the contributions of gravel and sand to the cell's beach versus its losses, including the natural loss of gravel from abrasion and that extracted for commercial use; the balance in the budget is reflected in the extent of the net beach erosion or accretion experienced in the littoral cell as a whole. This interest in the sediment budgets stems in large part from their practical applications to assess the causes of beach erosion and to evaluate the degrees of success in management activities such as the gravel nourishment program at Westshore, and to consider alternative strategies that potentially could provide enhanced protection to shore-front properties and for the maintenance of the beach for recreation.

In this Section we first examine the processes and management issues of the Haumoana Littoral Cell, and then the Bay View Cell. In many respects these two cells are much different. The Haumoana Cell has significant sources of beach gravel and sand, derived from the erosion of Cape Kidnappers and contributed by the rivers that reach its shore, principally from the Tukituki River. In contrast, at present there is very little new gravel being contributed to the beach within the Bay View Cell, perhaps only a small amount from the Esk River. With the sediment sources located in the southern half of the Haumoana Cell, there is a dominant longshore transport of the beach gravel to the north under the action of the waves arriving primarily from the southeast, with the quantities being transported progressively decreasing to the north due to the loss of gravel by abrasion and from its commercial extraction at Awatoto. In contrast, the shoreline of the Bay View Cell is nearly in equilibrium with the waves that reach its shore from directions ranging from the southeast to northeast, so there are frequent reversals in the directions of the sediment movement along its shore, but with a near-zero net longshore transport. As a result, and will be seen in this Section, there are different patterns of shoreline changes and associated erosion problems in these respective littoral cells, requiring different management strategies.

7.2 THE HAUMOANA LITTORAL CELL

The Haumoana Littoral Cell, Figure 7-1, consists of the 20-kilometre stretch of beach extending from Bluff Hill and the Port's breakwater within the City of Napier, to Cape Kidnappers at its southern-most limit. The principal community along this shore is the City of Napier at the north end of the cell; it has a shore-front reserve along its full length, which contains gardens, the tourist information centre, a concert shell and stage, swimming pools, and an aquarium. Further to the south is Awatoto, nearly midway along the cell's shore, of primary interest because it has been the site for many years of the commercial extraction of gravel and sand from its beach. Still further to the south is the community of East Clive, historically noted for its susceptibility to storm erosion and flooding, and with its shoreline changes also affected by the close proximity of the mouths of the Ngaruroro and Tukituki Rivers, which have tended to shift positions with time. The community of Haumoana in particularly has been afflicted by the episodic impacts of storms that directly threaten homes that have been constructed along its shore, Figure 7-2; the most recent storm damage there occurred as recently as March 2005. The Haumoana shoreline was significantly altered in 1999 by the construction of a groyne to the immediate south of the mouth of the Tukituki River, which to a degree has segmented the shore of the Haumoana Cell into two sub-cells. At the south end of this littoral cell, just north of Cape Kidnappers, the small communities of Te Awanga and Clifton have experienced erosion for decades (Figure 7-2), which continues to be a threat to the shore-front properties. Due to the greatest erosion having been experienced at the south end of this littoral cell, in the communities of Haumoana, Te Awanga and Clifton, this has been the stretch of the Hawke's Bay coast that has seen the greatest proliferation of "hard" shore-protection structures, including seawalls, revetments and unconventional structures such as the use of tires held in place by iron beams, seen in Figure 7-2. Many of these structures provided only temporary protection to the homes, and their failed remnants now litter the beach.

The Haumoana Cell has significant sources of beach gravel and sand, derived from the erosion of Cape Kidnappers and contributed by the rivers that reach its shore. However, as will be reviewed below, uncertainties remain as to the actual volumes of gravel and sand contributed by those sources to the ocean beach. The waves predominantly approach this shore from the southeast, affected by the sheltering and refraction of the waves around Cape Kidnappers, but with it still being readily apparent that the beach sediments contributed by those sources in the southern half of the cell then experience a net northward transport along this beach (see review in Section 3). By the time the beach sediments reach the shore of the City of Napier at the north end of the littoral cell, the volumes transported by the waves are much reduced due to the natural abrasion of the greywacke gravel as they collide under the swash of the waves, and by the commercial extraction of sediment from the beach at Awatoto.

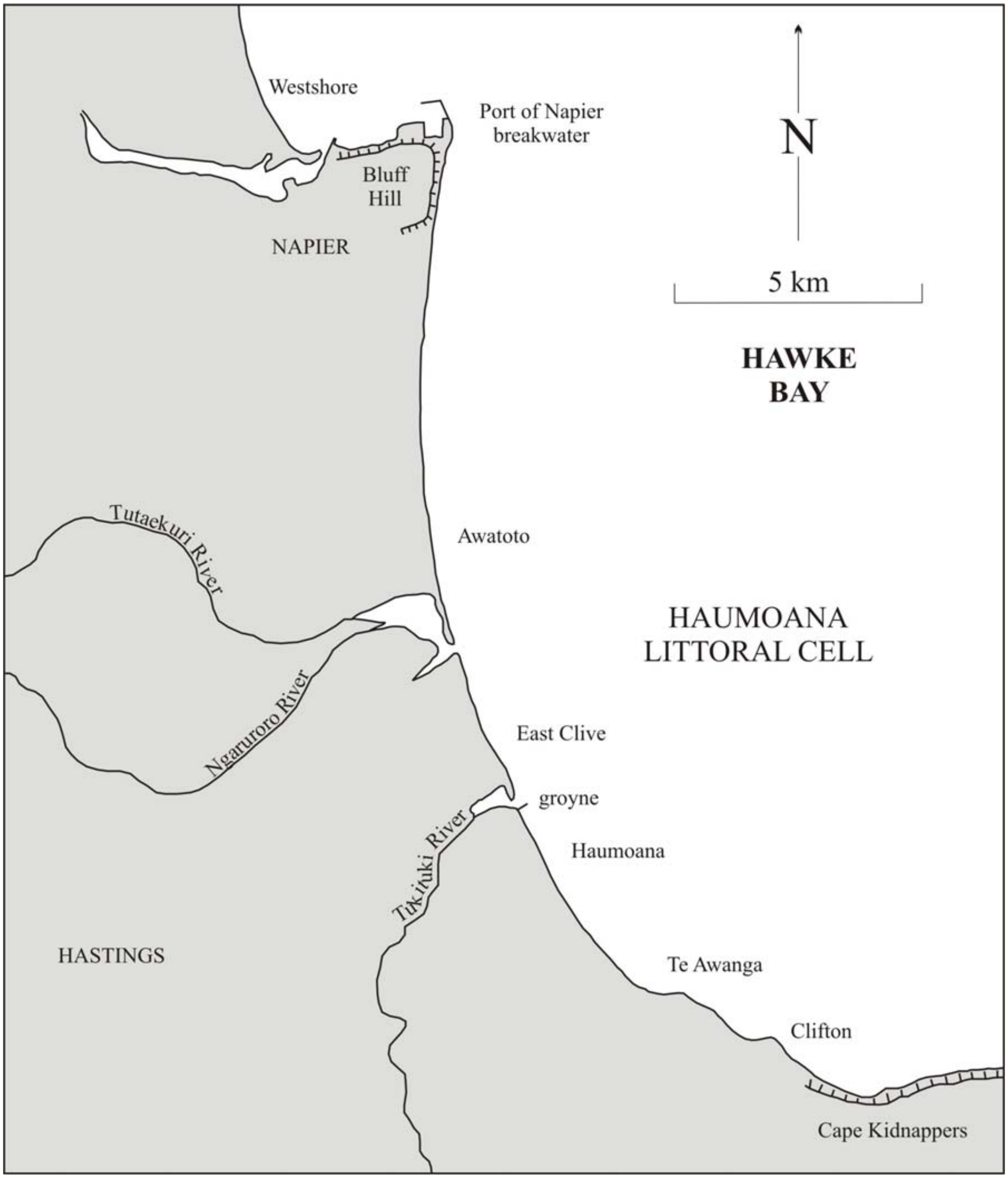

Figure 7-1 The Haumoana Littoral Cell; the communities along its shore, its rivers and coastal features.

In spite of the sediment sources to the beach of the Haumoana Cell being located in its southern half, as noted above and seen in Figure 7-2, the principal problems with beach erosion and associated damage to shore-front properties are also centered along that southern-most stretch of shore. This indicates that at present the northward longshore transport of gravel and sand must exceed the capacity of the sources to supply and replace that lost beach sediment. This may in part be due to decreased volumes of sediment derived from those sources, in particular from the Tukituki River where there has been considerable human impacts in its watershed, including the commercial extraction of sediment from the middle to lower reaches of this river, presumably reducing the volumes that eventually reach the ocean beach (Section 4). At the same time, as seen in Section 2, this stretch of shore experienced subsidence at the time of the 1931 earthquake, which could still in part account for some of the shoreline recession experienced there, contrasting with the Hawke's Bay shore to the north where uplift occurred. Finally, human activities along the shoreline of the Haumoana Littoral Cell have undoubtedly been important to changes in beach sediment volumes and shoreline positions; these have included the construction of groynes that at least temporarily blocked and impounded the northward transport of the beach sediment, and the commercial extraction of significant volumes of beach gravel and sand at Awatoto.

Figure 7-2 The erosion at Te Awanga (upper) and Haumoana (lower), photographed in 2003, with attempts to protect the homes using a variety of shore-protection structures, most of which have failed.

7.2.1 The Beach Sediment Sources

The potential sources of gravel and sand to the beach within the Haumoana Littoral Cell include the erosion of Cape Kidnappers and sediment delivered to the coast by the Tukituki, Ngaruroro and Tutaekuri Rivers (with its small watershed and discharges, the Maraetotara River reaching the shore at Te Awanga is considered to be insignificant). While these are clearly the dominant sediment sources, there have been widely divergent opinions as to which, in fact, are the most important with respect to the volumes of gravel and sand contributed to the beach. Marshall (1929, p. 334) concluded:

> For the greater part the beach is fed with the gravel that is supplied by the Tukituki River; but two miles from this point there is an additional feed from the Ngaruroro River, and to a far less extent from the Tutaekuri River on the north side of the Ahuriri Bluff.

Note that subsequent to this 1929 study by Marshall, the Tutaekuri was rerouted to the south of Bluff Hill in Napier from its course where it had entered the Ahuriri Lagoon, so it now enters the Haumoana Cell and what little sediment it does carry (mainly sand) reaches that shore.

In contrast with this conclusion by Marshall (1929), in his discussion of the coastal landforms of Hawke's Bay including its beaches, Cotton (1956) expressed the opinion that the rapid erosion of Cape Kidnappers principally accounts for the beach gravel. This view was also shared by Smith (1968) in his thesis research, but mainly from the standpoint of his having concluded that the rivers are a minor source of gravel, rather than from his having undertaken a direct evaluation of sediment yields from the erosion of Cape Kidnappers. Smith correctly pointed out that only at times of infrequent floods are these rivers capable of transporting pebble-size particles as bedload. However, although major floods are infrequent, at least in the case of the Tukituki River the occurrence of a flood can deliver hundreds of thousands of cubic metres of gravel and sand to the Haumoana shore.

The most recent analyses of the beach sediment sources to the Haumoana Cell were those undertaken by Gibb (2003) and Tonkin & Taylor (2005), both in connection with their development of sediment budgets. In his assessment of the river contributions, Gibb (2003) concluded that only the Tukituki River supplies significant volumes of coarse-grained bedload to the coast, placed at an average of 28,000 m^3/year; this volume was based on the work of Edmondson (2001), who derived his values of sediment reaching the coast from mass-balance calculations of the sediments contained in the river beds, documented by series of cross-sectional profiles that have been surveyed periodically at incremented distances along the channel length. Gibb (2003) again noted that this river's contributions of gravel occur only during floods, with the derived sediment forming a temporary delta that is then transported alongshore to the north by the waves as a "slug" of beach sediment. Gibb also concluded that the Tutaekuri and Ngaruroro Rivers now yield only fine sand and mud, not gravel. As noted above, the course of the Tutaekuri River was diverted in 1934; prior to that time it had flowed into the Ahuriri Lagoon, but as part of the land reclamation program following the 1931 earthquake and to eliminate its flooding impacts within the City of Napier, the Tutaekuri was rerouted to the south where it joined the Ngaruroro River to share the same mouth where they now reach the coast. However, the lower reaches of the Ngaruroro were diverted in 1960, temporarily eliminating it as a source of coarse sand and gravel to the beach south of Napier. According to Gibb (2003), the gravel in the bed of the Ngaruroro is slowly moving toward the its mouth and the beach, but he estimated that it will not reach that shore until about the year 2400, so the combined Tutaekuri and Ngaruroro Rivers are not presently sources of gravel to the ocean beach, and will not be for many years. However, from the higher concentrations of sand on the beach at their mouths, they may still be significant sources of finer sediments.

The most recent analyses of the sediments contributed to the beach of the Haumoana Cell is that of Tonkin & Taylor (2005), including evaluations of both the contributions from the Tukituki River and from the erosion of Cape Kidnappers. Their assessment of the river contribution was again based on the mass balance calculations of Edmondson (2001) of the sediments in the lower reaches of the rivers. Table 7-1 presented here is derived from the study of Tonkin & Taylor (2005), providing values for both the gravel supplied to the lower reaches of the rivers and of their outputs to the coast, with the former being much greater than the estimated outputs. Only the Tukituki River is assessed to be actually yielding gravel to the coast, again placed at an average of 28,000 m^3/year as accepted by Gibb (2003) in his analysis. Table 7-2 lists the sediments derived from the Tukituki River for the periods 1978-1981, 1981-1987, etc., governed by the channel surveys, also based on the work of Edmondson (2001) as summarized by Tonkin & Taylor (2005). It is seen that there has been a wide range of sediment yields between the time periods, with the years 1990-1993 representing the maximum sediment yield, placed at 159,996 m^3/year, while two periods yielded no gravel to the coast. Curious in Table 7-2 is the absence of a direct correlation between the annual sediment yields and the numbers of annual floods or the more extreme floods having 5- to 20-year recurrence intervals. Tonkin & Taylor (2005) suggested that this results because there is a lag between the floods and the time at which the sediment actually reaches the coast, the likely scenario being that gravel first accumulates in the lower reaches of the river until it achieves a critical volume, at which time another flood is able to carry much of that sediment to the ocean beach.

Table 7-1 Average annual river supplies of gravel and coarse sand to the coast. [*from* Edmondson (2001) and Tonkin & Taylor (2005)]

River	*Gravel Supply to Lower River Reach (m^3/year)*	*Output to the Coast (m^3/year)*
Tukituki	43,000	28,000
Ngaruroro	50,000	0
Tutaekuri	28,000	0

Table 7-2 Average supply of gravel and coarse sand to the coast from the Tukituki River. [*from* Edmondson (2001) and Tonkin & Taylor (2005)]

Period	*Average Supply During Period (m^3/yr)*	*Number of Annual Floods*	*Number of 5- to 20-year Floods*
1978 to 1981	57,830	5	0
1981 to 1987	7,964	4	1
1987 to 1990	0	3	2
1990 to 1993	158,996	2	1
1993 to 1996	0	1	0
1996 to 2000	1,132	2	0

Tonkin & Taylor (2005) also examined the significance of the commercial extraction of sand and gravel from the river channels. Based on a 37-year record, the average annual extraction from the Tukituki River has been 47,800 m^3/year, while extraction from the Ngaruroro River has been significantly greater, on the order of 284,000 m^3/year from 1970 to 2003. It is likely that a reasonable percentage of this extracted sediment would under natural conditions have been transported to the lower reaches of these rivers, and eventually been carried out onto the ocean beach. Therefore, those rivers would likely have been more significant contributors of gravel to the beaches prior to human settlement and the practice of extracting the sediment from the rivers. However, as reviewed in Section 4, this is a complex issue as some impacts of settlement in the river watersheds, principally those leading to deforestation, have increased the rates of erosion and the supply of sand and gravel to the rivers, and potentially to the coast. According to the studies by Grant (1965, 1982, 1985), natural shifts in the Earth's climate have also played a significant role, with periods dominated by intense storms that resulted in greater rates of watershed erosion and presumably sediment yields to the coast. However, changes in the channel gradients along the course of the Tukituki River have tended to result in sediment aggradation where the steep slopes of the mountains give way rather abruptly to the reduced channel slopes of the Heretaunga Plain, limiting the competence and capacity of the rivers to transport their loads of gravel all the way to the coastal beaches (Section 4). In that this aggradation in the river channels has been a contributing factor to floods that can overtop the banks, damaging the settlements and cultivated lands across the Plain, the extraction of sand and gravel from the channels has been viewed as a positive management strategy for the rivers. With some factors, natural and human induced, having tended to increase sediment yields from the rivers while others have acted to reduce the yields, it has not been possible to assess with confidence the net effects on the sediment yields from the river watersheds to the ocean beach. Instead, we have had to be content with limiting our assessments to those provided by the channel surveys in the lower watersheds as analyzed by Edmondson (2001), limited to approximately the past 25 years; of course, these present-day conditions are those of most immediate concern to the maintenance of the beaches and on-going erosion problems.

It has also been difficult to establish a firm estimate of the quantities of sediment derived from the erosion of Cape Kidnappers and contributed to the beach of the Haumoana Littoral Cell. The studies by Tonkin & Taylor (2004, 2005) have provided the only direct analysis of the sediment yields from the Cape's erosion. The first step in their analysis was to determine the rates of retreat of the cliff face; this assessment was based on changes found in two sets of aerial photographs taken 52 years apart (1950 and 2002). They found that the retreat was greatest along the north face of the headland, and the changes there were analyzed at 74 cross-section sites that examined both the toe and crest of the cliff. The average toe retreat in those 52 years was determined to have been 10 metres while the crest retreat was 7 metres, yielding an average retreat of 8.5 metres during those 52 years, or a mean rate of 0.16 m/year. This portion of eroding cliffs contains unconsolidated gravel and sand (conglomerates), with the total exposure of conglomerate estimated to be on the order of 100,000 square metres. Based on that area of the cliff represented by the gravel deposits, multiplication by the rate of cliff retreat (0.16 m/year) yields an estimated volume of gravel derived from the erosion of the Cape as being between 13,000 and 20,000 m^3/year, with a "best estimate" average of about 18,000 m^3/year.

This contribution of sediment to the beach from the erosion of Cape Kidnappers has been episodic, observed to involve the periodic slumping of the cliff face followed by the waves reworking that material and adding it to the beach. For example, in comparing the 1950 and 2002 aerial photographs, Tonkin & Taylor (2005) noted the occurrence of one area of cliff slumping that extended for 225 metres along the shore of the Cape; their analysis measured a retreat of 64 metres of that slumped material in 52 years, equivalent to a rate of 1.25 m/year, much higher than the 0.16 m/year average rate for the entire length of the north face of Cape Kidnappers. It is also believed that the ground shaking during the 1931 earthquake generated a number of slumps along the length of Cape Kidnappers, resulting in a temporary super-abundance of gravel and sand contributed to the beach from that source.

In his study of the sediment sources to the beaches, Gibb (2003) indirectly estimated the contribution from the erosion of Cape Kidnappers by examining the rate at which the beach sediment was then transported to the north by the waves. The construction of the Haumoana groyne to the south of the mouth of the Tukituki River in late February through March 1999 made it possible to estimate this transport, at least for about a three-month period until the groyne was filled to capacity, at which time the continued beach sand and gravel transport to the north bypassed the groyne. The rate at which this sediment accumulated to the south of the groyne was documented by White and Healy (2000) through beach-profile surveys repeated at intervals of about twice a month along a profile line positioned 12 metres updrift (south) from the groyne. Their analyses of the surveys showed a rapid increase in the sediment accumulation along that profile line during the construction phase of the groyne as the shoreline rapidly shifted seaward (White and Healy, 2000, Fig. 5), indicating a significant net transport of beach sediment by the waves to the north. The volume changes between surveys at that profile line ranged from -0.1 to

7.4 m^3/day per metre of shoreline length, with an average of 2.3 m^3/year per metre of shoreline length. Assuming that this average based on a limited period of surveying is representative of an entire year, White and Healy (2000) calculated that the total accumulation at that profile line in a year would be some 839 cubic metres per metre of shoreline length. However, that extent of accumulation was never achieved since the groyne soon filled to capacity and then bypassed the longshore sediment transport, a process that continues today. Although the study of White and Healy (2000) did document the rapid impoundment of the longshore transport by the Haumoana groyne, their limited analysis of survey data along a single profile line cannot be interpreted in terms of the total volumes of sediment involved in the longshore transport.

In his examinations of the sources and sediment budget, Gibb (2003) did analyze the total volumes of the sediment that had accumulated updrift of the Haumoana groyne during its construction, finding an average net northward transport of 110 m^3/day or 40,000 m^3/year for the inferred annual rate of the northward transport of beach sediment. He then added a transport of sediment assumed to take place immediately seaward of the 400-metre length of the groyne, presumably dominated by sand rather than gravel, concluding that the total longshore sediment transport is on the order of 70,000 to 80,000 m^3/year at this Haumoana site to the south of the Tukituki River. This rate is substantially greater than the 13,000 to 20,000 m^3/year volumes determined by Tonkin & Taylor (2005) to be the gravel and sand yield from the erosion of Cape Kidnappers. This difference is made up by the erosion of the beach and backshore along the stretch of shore between Cape Kidnappers and the Haumoana groyne, which is added to the sediment from the erosion of Cape Kidnappers to account for the northward net transport at the groyne. As will be reviewed below, Tonkin & Taylor (2005) also undertook analyses of the changing volumes of sediment on the beaches, calculated for segments of beach between survey lines in the beach-monitoring program. From those analyses they found that the net beach erosion south of the Tukituki River amounted to 48,000 m^3/year, which when added to the sediment contributed by the erosion of Cape Kidnappers (13,000 to 20,000 m^3/year) yields 61,000 to 68,000 m^3/year for the total northward sediment transport; this is in order-of-magnitude agreement with Gibb's (2003) estimate of 70,000 to 80,000 m^3/year at the Haumoana groyne, and is in close agreement with the re-analysis by Tonkin & Taylor (2005) of the sediment impoundment by the groyne, which yielded a total longshore transport of 62,400 m^3/year. Considering the difficulty in evaluating the sediment contributions from the Cape, the volume changes of beach sediment to the immediate north of the Cape, and of the volumes of sediment impounded by the Haumoana groyne, this extent of agreement can be viewed as excellent. However, it needs to be recognized that these assessments represent markedly different periods of time, from 52 years (1950-2002) for the erosion of Cape Kidnappers to about three months of sediment accumulation south of the newly constructed Haumoana groyne in 1999.

7.2.2 The Losses of Beach Sediment

Offsetting the contributions of gravel and sand to the beach within the Haumoana Littoral Cell are its losses, both natural through the abrasion of the greywacke gravel as it is transported by the waves, and by the artificial extraction of the sediment from the beach. While we have reasonably good records at least since the 1970s of the volumes of sediment extracted, it is still difficult to quantitatively assess the losses from abrasion.

Historically gravel has been extracted from the beach at a number of sites along the shore of the Haumoana Cell, including Te Awanga, Haumoana, and especially at Awatoto. Its removal at Awatoto has taken place since the settlement period of the 19th century, with the first record having been its extraction to be used in the construction of the railway line (Hill, 1897). Records of the commercial extraction of gravel and sand at Awatoto are available from 1973, and have been reviewed by Gibb (2003) and Tonkin & Taylor (2005). During the 30 years from 1973 to 2002, this extraction removed a total volume of nearly 1,500,000 cubic metres of beach sediment, with the annual extraction having averaged about 47,800 m^3/year; during the past decade the quantities removed each year continued to be close to that average. It is clear that this represents a substantial volume of sediment removed from the beach, constituting a significant percentage of the volumes contributed by the sources reviewed above, and of the northward longshore transport of the beach sediment estimated by its impoundment at the Haumoana groyne.

Gravel has also been extracted from Pacific Beach at Napier, to be placed on the Westshore beach as part of its nourishment program (Gibb, 2003; Tonkin & Taylor, 2005). The nourishment at Westshore began in 1987, and has continued on nearly an annual basis up to the present; however, from 1987 to 1991 the sediment was derived from the excavation of Wildlife Ponds in the Ahuriri area, not from Pacific Beach. The extraction from the Napier shore began in 1993, and the volumes removed have ranged from about 12,000 to 24,000 m^3/year, with the smaller volumes having been extracted in recent years. Between 1993 and 2002 a total of 146,300 cubic metres had been removed from Pacific Beach, with the average being about 12,800 m^3/year.

The other loss of sediment from the beach of the Haumoana Cell is through the abrasion of the beach-sediment particles as they are washed back and forth under the action of the waves, with the gravel particles colliding while the smaller grains are crushed between the larger. The result is that the larger gravel particles are progressively reduced in size, sometimes producing sand in the process, but with the sand then further reduced to silt by crushing so it becomes too fine to remain on the beach, carried by the waves into the offshore. As reviewed in Section 5, there has been a number of studies of grain abrasion by researchers throughout the world, but of greatest interest are those by Marshall (1927, 1929) as his research focused almost entirely on the gravel and sand of the Hawke's Bay beaches; recently, Hemmingson (2004) extended this research, primarily on the Canterbury beaches but also on the Hawke's Bay beach gravel. The primary focus of those studies was to undertake laboratory experiments in tumblers that contain samples of gravel from the beaches, the objective being to measure their rates of abrasion and how this depends on particle sizes and on mixtures of sizes. Thanks to those studies we now know a great deal more about the factors important to gravel abrasion on beaches, however, uncertainties still remain as to the actual magnitudes of the rates of abrasion due to questions whether the laboratory experiments in tumblers satisfactorily simulate what actually occurs on the beaches under the swash of the waves. While the precise rates of size reduction and ultimate losses of greywacke pebbles from the Hawke's Bay beaches remain uncertain, it is clear that this process is sufficiently rapid to represent an important loss of beach sediment from the Hawke's Bay littoral cells, and therefore needs to be included in assessments of their sediment budgets.

7.2.3 The Budget of Beach Sediments

The development of a sediment budget for a beach involves assessments of its various sources of sand and gravel, and then compares them with the losses to determine the difference, which should be reflected in the changing volumes of the sediment actually found in the beach [see reviews by Komar (1996, 1998)]. A sediment budget can be viewed as being analogous to a monetary budget, and as such the contributions from the sediment sources are often referred to as "credits", which are then compared with its losses or "debits"; the difference between the credits and debits yields the "net balance", which can be either in the "red" as reflected in the progressive erosion of the beach, or in the "black" with the occurrence of beach accretion.

The development of a sediment budget is challenging since generally it is difficult to arrive at satisfactory quantitative assessments of all of the sediment credits and debits. Often the best established part of the budget is its balance, the net erosion or accretion of the beach, which can be directly measured through periodic surveys over the years, or estimated from long-term average rates of shoreline change revealed in series of aerial photographs. The development of the budget may then involve modifying the assessed credits and debits until their balance is in reasonable agreement with that determined from the beach surveys. Although it is a challenge to establish the sediment budget to the desired degree of precision, its formulation for a stretch of beach (generally an entire littoral cell) is extremely useful since it forces one to think about the many factors and processes that determine the quantities of sediment found in the beach, and the budget can serve as an aid in establishing why the balance is in the red, resulting in the erosion of beach-front properties. As such, the development of a sediment budget is a powerful management tool, a component in maintaining the beach as a resource for recreation and as a natural defense for the coastal properties from the attack of ocean waves and currents.

Of interest here is the sediment budget for the entire Haumoana Littoral Cell, and then later for a portion of that cell, specifically for the sub-cell to the south of the Haumoana groyne to understand the causes of the pervasive erosion that has been experienced there. An analysis first of the sediment budget for the entire cell allows one to simply compare the sediment sources (credits), losses (debits), and then to examine their balance as reflected in the changing beach sediment volumes for the cell as a whole, measured with the profile series from the monitoring program.

The studies by Gibb (2003) and Tonkin & Taylor (2005) made significant contributions in having developed sediment budgets for the Hawke's Bay littoral cells. It was in this connection that they analyzed the sources (credits) and losses (debits) of sediment to the beach contained within the Haumoana Littoral Cell, with their results having been reviewed above. The estimates obtained by the Tonkin & Taylor (2005) analyses are included here in Table 7-3 as the credits and debits in the resulting sediment budget for the cell as a whole. It is seen that the "best estimates" for the credits sum to an annual average of 46,000 m^3/year, but with a potential range from 25,400 to 48,000 m^3/year due to the uncertainties in the estimated contributions from the Tukituki River and from the erosion of Cape Kidnappers. In terms of the debits, important has been the beach sediment extraction at Awatoto and Pacific Beach, with the rates having been reasonably well established by the available records. On the other hand, the debit due to the natural loss of gravel by its abrasion still needs to be viewed as an unknown, and accordingly has been denoted by GA (“gravel abrasion”) in Table 7-3; an attempt will be made below to determine GA from the other components in the budget.

It is readily apparent from the values in Table 7-3 that the credits are significantly less than the debits; smaller volumes of gravel and sand are being contributed by the Tukituki River and from the erosion of Cape Kidnappers than have been removed from the beach by artificial extraction. From the "best estimates" the credits sum to 46,000 m^3/year, while the total extraction represents a debit of -60,600 m^3/year (the negative sign indicating a loss); the net difference between these values is -14,600 m^3/year, so the sediment budget is already seriously in the red, and would be even more so if gravel abrasion (GA) is significant. From this alone one would expect an annual net loss of beach sediment of 14,600 m^3/year from this littoral cell as a whole, or a local average rate of -0.73 m^3/year per metre of shoreline if it occurs uniformly along the 20-kilometre length of the littoral cell (which it does not, as the erosion is concentrated in the southern half of the cell’s shore, while there is actually a net beach accretion to the north of Awatoto due to the northward longshore transport of the beach gravel).

As noted above, often the best established part of the budget is its balance, the net erosion or accretion of the beach, and this is the case for the Haumoana Littoral Cell thanks to the program of monitoring the beaches, which has included the periodic survey of profiles at intervals along its shore (Section 5). Tonkin & Taylor (2005) have analyzed the surveyed beach profiles in the Haumoana Cell to determine the averages listed in Table 7-3 for the Balance of Beach Sediment Volumes, the bottom line in the sediment budget. They specifically used profile lines HB1 through HB12 extending the entire length of the littoral cell, and also the concentrated profile lines at East Clive. A consistent period of data availability existed from October 1989 to April 2002, providing a total time period of around 11.5 years for the documentation of the net-sediment gains or losses. Locally the beaches had been temporarily affected by the construction of groynes that blocked the longshore sediment transport, reviewed above for the Haumoana groyne; in order to avoid that short-term complicating effect, the Tonkin & Taylor (2005) analysis determined the net change in the beach by comparing the beach volumes at the beginning and end of the 11.5-year survey records. From their analyses of each profile line, they concluded that:

- there has been a significant net loss of beach sediment to the south of the Tukituki River, the rate having been approximately -48,800 m^3/year;
- there has been a variable amount of erosion between the Tukituki River and East Clive, except between Groyne 2 and the Hastings sewer outfall;
- erosion has dominated the beaches around East Clive and Awatoto;
- small rates of beach sediment accumulation have occurred to the north (at profile lines HB9 to HB11), but with a small extent of erosion at HB12.

Table 7-3 The Sediment Budget for the Haumoana Littoral Cell based on the analyses of Tonkin & Taylor (2005).

	Estimated Annual Rates (m^3/year) Best Estimates	*Estimated Annual Rates (m^3/year) Potential Ranges*
Sources ("Credits")		
Tukituki	28,000	[12,400 to 28,000]
Cape Kidnappers Erosion	18,000	[13,000 to 20,000]
Total	46,000	[25,400 to 48,000]
Losses ("Debits")		
Awatoto Extraction	-47,800	
Pacific Beach Extraction	-12,800	
Gravel Abrasion	-GA	
Total	-60,600 - GA	
Balance of Beach Sediment Volumes		
South of the Tukituki River	-48,800	
North of the Tukituki River	3,800	
Net Balance	-45,000	

Based on the entire series of profiles collected along the full length of the Haumoana Cell, the total loss of its beach sediment amounted to about 520,000 cubic metres during the 11.5 years from October 1989 to April 2002, the average annual rate having been -45,000 m^3/year (the negative sign again denoting net erosion). This is the value entered into Table 7-3 for the Net Balance of the beach sediment volumes contained within the cell as a whole. As expected, the balance directly demonstrates the occurrence of pervasive erosion within this littoral cell, with a significant net loss of beach sediment during recent decades; this of course reflects the conclusion evident in Table 7-3 that the debits have exceeded the credits, that is, the budget is significantly in the red.

If one accepts the values that have been entered into Table 7-3 as being the best estimates for the sediment credits and debits, and for the net balance determined from the profile surveys, we can then calculate the remaining unknown, the rate of sediment loss by gravel abrasion, GA. This was the approach taken by Tonkin & Taylor (2005) in their analysis, with:

$$\text{Credits - Debits = Net Balance}$$
$$46{,}000 - (60{,}600 + GA) = -45{,}000$$
$$GA = -30{,}400 \ m^3\text{/year}$$

This is the inferred rate of loss of gravel on an annual basis from the natural processes of abrasion, a rate that would yield agreement between the sediment credits, debits and the net balance measured from the surveyed profiles. Assuming that this loss to abrasion occurred uniformly over the full 20-kilometre length of beach within this littoral cell, the average rate becomes -1.5 m^3/year per unit metre shoreline length. According to the budget analyses presented by Tonkin & Taylor (2005), the abrasion losses could range between -9,800 and -32,400 m^3/year, equivalent to the range -0.5 to -1.6 m^3/year per metre of shoreline length. In his development of a sediment budget for the Hawke's Bay littoral cells, Gibb (2003) used an estimate of -7.5 m^3/year per metre of shoreline as being the "upper-bound rate" of gravel abrasion, based on the experimental results available at that time. As well as this having been an estimate of the upper-bound value, the subsequent experiments by Hemmingson (2004) have shown that the greywacke gravel from the Hawke's Bay beaches is more resistant to abrasion than that from the Canterbury beaches, and there is evidence that the laboratory tumbler experiments likely yield higher rates of abrasion than naturally occur on beaches. From this, the values deduced by Tonkin & Taylor (2005) for the Hawke's Bay beaches, -0.5 to -1.6 m^3/year per metre of shoreline length, appear to be reasonable, as does the -1.5 m^3/year per unit metre of shoreline length derived from the budget presented in Table 7-3.

It is apparent from this sediment budget that the dominance of beach erosion in the Haumoana Littoral Cell, with its net balance of -45,000 m^3/year (Table 7-3), will continue into the future unless measures are taken to bring it out of the red. This requires either increasing the credits or decreasing the debits. Although there is the potential for increasing the volumes of gravel and sand transported to the Bay's shore by the Tukituki River through the reduction of sediment extraction from its channel, such a change could lead to increased flooding in the river, and at any rate it would be many years before the increased sediment transport down the river actually reaches the ocean beach. Instead, it is clear that the only viable solution to balancing the sediment budget for the Haumoana Cell as a whole, so it is no longer in the red, is to reduce or entirely halt the commercial sediment extraction at Awatoto. From the best estimates presented in Table 7-4, it is seen that the elimination of its debit of -47,800 m^3/year would in effect balance the budget, changing the existing -45,000 m^3/year net deficit to essentially a balanced budget. This measure has recently been invoked (May 2005), with it having been agreed that the extraction at Awatoto will be reduced to 30,000 m^3/year for the next ten years, and will cease entirely after that time.

It needs to be recognized that even when this budget becomes balanced after the sediment extraction at Awatoto has been halted, there may be periods of time when it is at least temporarily in the red. This is because the sediment budget presented in Table 7-3 considers the long-term average "best estimates" of the sediment credits, in particular the volumes of gravel and sand contributed by the Tukituki River. As seen in Table 7-2 and discussed earlier, the contributions from that river have ranged from 0 to about 160,000 m^3/year depending on climate cycles that determine the rainfall and flood discharges. As a result there could be decades with little or no sediment being contributed to the beach from that river, but followed by a flood that suddenly provides a super-abundance of beach sediment which is then transported to the north by the waves, eventually reaching Pacific Beach in Napier. Accordingly, we can expect to view significant cycles in the quantities of sediment found at any specific shoreline site due to such variations in the natural processes, not a constant steady-state condition as might mistakenly be anticipated from having on average a balanced sediment budget.

Of greater significance, however, even if we can achieve a balanced budget for the Haumoana Littoral Cell as a whole, this would not solve the erosion problems in its southern half, in the communities of Haumoana and Te Awanga (Figure 7-2). This becomes evident in the sediment budget developed specifically for this sub-cell to the south of the Haumoana groyne, drawing on the relevant values from the study of Tonkin & Taylor (2005) listed in Table 7-3:

Credits		
Cape Kidnappers Erosion	18,000	m^3/year
Debits		
Longshore Transport to the North	-62,400	m^3/year
Gravel Abrasion	-4,400	m^3/year
Net Balance	-48,800	m^3/year

This local budget is very simple, with the erosion of Cape Kidnappers being the only source of beach gravel and sand, and with the principal loss of sediment being its longshore transport to the north out of this sub-cell; the loss from gravel abrasion is comparatively minor. With the mouth of the Tukituki River now being located to the north of the Haumoana groyne, it is not included as a sediment source to this sub-cell, although this possibility cannot be ruled out entirely. Also being to the north of that groyne, the extraction at Awatoto is not included; it follows that this local sediment budget will not benefit in the future from halting this extraction. The best-established value in this budget is again the evaluation of the net balance, which Tonkin & Taylor (2005) had determined from the erosion along this stretch of shore, documented by the profile series from the Hawke's Bay monitoring program. Another reasonably well-established estimate is the longshore transport of beach sediment to the north, the 62,400 m^3/year value determine by Tonkin & Taylor (2005) from the sediment impoundment when the Haumoana groyne was constructed in 1999. As before, the -4,400 m^3/year loss to gravel abrasion is simply that needed to balance this budget, the abrasion not having been directly determined. From this simple budget it is readily apparent that the pervasive erosion along this southerly stretch of shore must in large part be a result of the longshore transport of the beach sediment to the north by the waves greatly exceeding the rate at which it can be replaced by the erosion of Cape Kidnappers.

It is seen in this budget for a portion of the Haumoana Littoral Cell that it is necessary to include an evaluation of the longshore sediment transport, in this case it having been a debit as it involved a transport to the north out of this sub-cell. It follows that in the case of the sediment budget for the stretch of shore to the north of the Haumoana groyne, this longshore transport would be included as a credit, with the other credit being the sediment supplied by the Tukituki River. Together they contribute 90,400 m^3/year of gravel and sand to this northerly stretch of shore. Without any losses of beach sediment to extraction or abrasion, one would expect that approximately this volume of beach sediment would accumulate in the northern half of the cell. However, it is offset to a large degree first by the sediment extraction at Awatoto (-47,800 m^3/year), and then by the extraction at Pacific Beach in Napier (-12,800 m^3/year), with the other loss being from gravel abrasion (-26,000 m^3/year). According to the analysis by Tonkin & Taylor (2005) of the monitoring profiles, the net balance for this sediment budget north of the Haumoana groyne is 3,800 m^3/year, a small level of accretion that is the remnant of the 90,400 m^3/year transported into this northern half of the Haumoana Cell; without the artificial extraction, this balance could be expected to be on the order of 64,000 m^3/year, with a significantly greater degree of beach accretion.

The comparatively narrow beach along the stretch of shore from Haumoana south to Clifton reflects its local sediment budget, with the pervasive erosion and resulting narrow beach being the consequence of its budget being in the red. Although the shore to the north of Awatoto has experienced a small net accretion over the years in spite of the sediment extraction, the beach has not attained widths and elevations that are sufficient to provide adequate protection to this shore from flooding and erosion during extreme storm events. The implications of this to the management of this shore will be examined later in this Section.

7.2.4 The Longshore Transport of the Beach Sediments and Numerical Shoreline-Evolution Models

It is apparent from the discussion above that while the occurrence of shoreline erosion versus accretion at any specific shoreline site may depend on the sediment budget for the littoral cell as a whole, important are the locations along the shore of the sediment sources and losses, and depending as well on the patterns of longshore sediment transport that result in the movement and redistribution of that sediment along the shoreline of the cell. Fortunately, powerful numerical analysis techniques are available that permit a computer simulation of the local shoreline changes along the entire length of the cell, that can account for these factors.

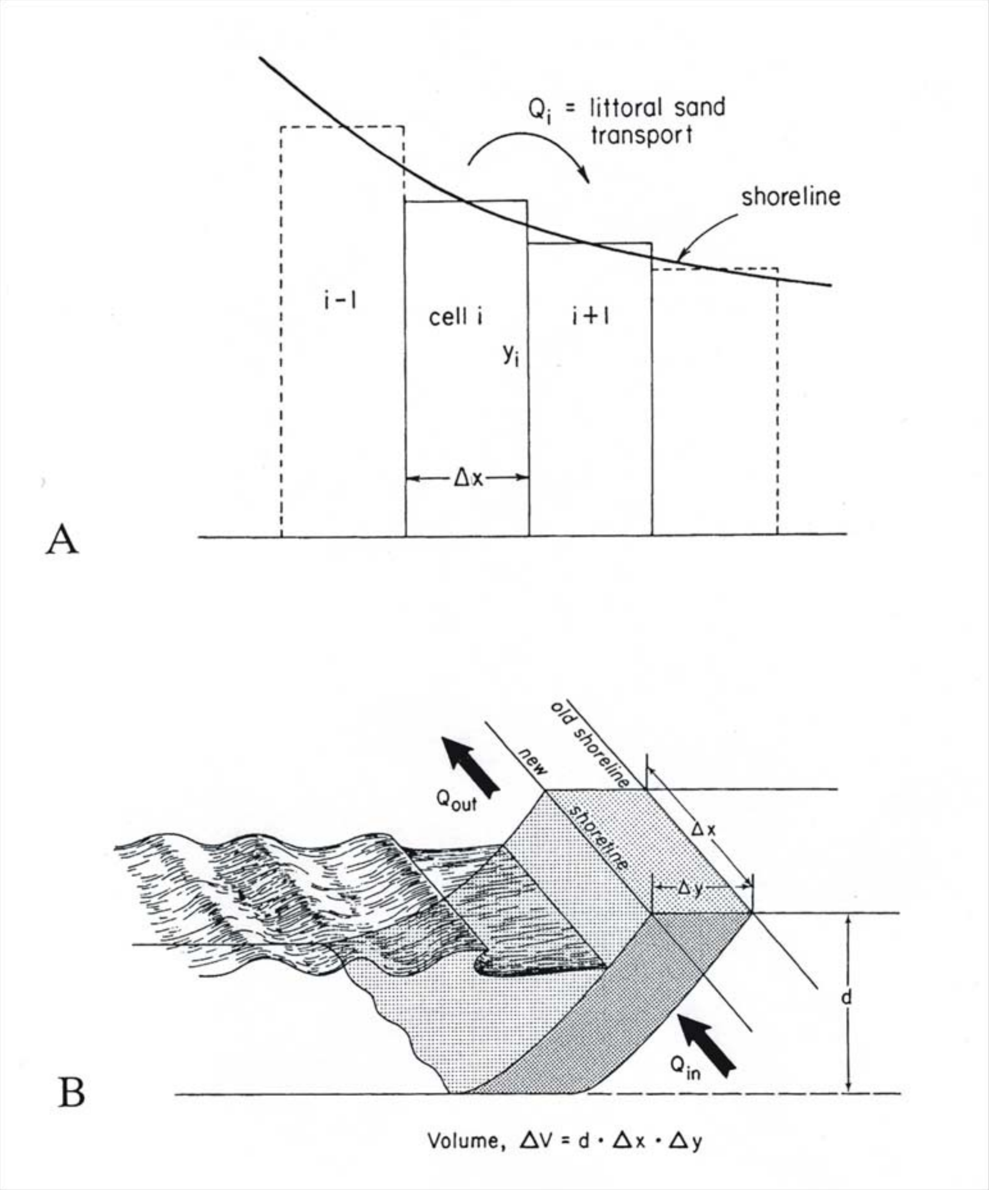

Figure 7-3 A. The smooth shoreline divided into a series of cells to serve as segments in the development of a numerical shoreline-evolution model. B. One shoreline cell, demonstrating how a change in sediment volume and shoreline position (Δy) can result from its local sediment budget, in this case from the difference in the longshore sediment transport into and out of the cell. [*from* Komar (1998)]

Such models involve dividing the shoreline into a conceptual series of segments or "cells" as depicted in Figure 7-3A. For example, the shoreline of the Haumoana Littoral Cell could be divided into 200 such cells, each representing a 100-metre increment [this was, in fact, done in the analyses by Tonkin & Taylor (2005), reviewed below]. The analysis in effect then develops a sediment budget for each of the 100-metre beach cells; as depicted in Figure 7-3B, this includes calculating the sediment input and exit volumes for each 100-metre cell (respectively being its credits and debits), with the net balance for each individual cell determining whether there is a shoreline advance due to accretion or a retreat with beach erosion. As depicted in this diagram the credits and debits involve the longshore sediment transport, with the waves carrying beach sediment into the cell (Q_{in}) on one side, while sand exits in the downdrift direction (Q_{out}). The net balance is then $Q_{in} - Q_{out}$, that is, the alongshore change or gradient in the rates of the longshore transport; with Q_{out} being greater than Q_{in}, that is with an increase in the rate of transport in the longshore direction, there would be a net loss of sediment in this cell and a shoreline retreat, whereas a gradient of decreasing Q alongshore results in a shoreline advance (the case depicted in Figure 7-3B). It is also apparent that with a series of such cells extending along the shore, the quantity of sediment transported out of one cell (Q_{out}) becomes the input into the next cell (Q_{in}). In addition to this consideration of beach sediment exchanges between cells due to its longshore transport, the sediment budget for an individual cell in the model could include sediments contributed by a river or from sea-cliff erosion that happens to occur at that cell's position along the shore, or derived from a beach nourishment program, and sediment losses when it is carried offshore, blown into dunes, lost to abrasion, or is artificially removed when it is extracted from the beach. With those credits and debits determined for each 100-metre cell along the entire length of shore, the numerical computer model then calculates the corresponding changes in shoreline positions at increments of time, generally on the order of a day or less, with the model running sufficiently long to simulate the resulting evolution of the shore spanning decades or longer. A more detailed review of numerical shoreline models can be found in Komar (1998, Chapter 10), including a number of examples of their applications.

In application to the Haumoana Littoral Cell, Tonkin & Taylor (2005) employed the UNIBEST model developed at the Delft Hydraulics Laboratory in the Netherlands. In this application a formula derived by the Dutch was employed to calculate the longshore transport rates of the beach gravel; it has the expected dependence on the wave height, period and angle of wave approach to the shore, and on the sediment grain size (Section 5). UNIBEST brings the waves to the beach from the offshore, accounting for their shoaling transformations and refraction, and evaluates the wave energy losses due to bottom friction. It then calculates the profile of the longshore currents on the beach and the resulting longshore sediment transport rate. Such evaluations were obtained along the length of the Haumoana Cell shoreline in the Tonkin & Taylor (2005) application, providing determinations of the sediment transport into and out of each of the 200 shoreline cells as described above. The model also evaluated the changes in the shoreline that result from the contributions of sediment from the sources, the erosion of Cape Kidnappers and from the discharge of the Tukituki River, and the effects on the shoreline of the sediment extracted from the beach at Awatoto and Pacific Beach in Napier. The model analyses accounted for the losses of gravel from abrasion, by assuming a uniform rate of loss of 0.5 m^3/year per metre of shoreline length, the value that yielded the best results when calibrating the model.

The objective of the Tonkin & Taylor (2005) report in applying the UNIBEST model to the Haumoana Littoral Cell was primarily to simulate the patterns of changing shorelines induced by the sediment extraction at Awatoto and Pacific Beach, extending the analysis well beyond the development of the sediment budget (Table 7-3). The first step in their application of UNIBEST was to calibrate and test the predictions of the model compared with measured changes in beach sediment volumes and shoreline positions along the length of the cell. This comparison included the local effects of the construction of three groynes, the groyne at Haumoana and two at East Clive, which temporarily impounded the northward net transport, inducing erosion to their down-drift sides. The closest agreement between the model and measured shorelines occurred when the sediment derived from the Tukituki River was reduced from its initially assumed value of 28,000 m^3/year as found in the sediment budget (Table 7-3) to a value between 8,000 and 13,000 m^3/year, suggesting that the "best estimate" for that source in the sediment budget may have been too high. Based on this model calibration, its subsequent application included runs where the Tukituki River alternatively supplied sediment at the rates of 28,000 and 13,000 m^3/year.

The power of using numerical shoreline-evolution models in applications is illustrated by the analyses undertaken in the Tonkin & Taylor (2005) report to examine the effects of sediment extraction on the Haumoana shoreline. They approached the problem systematically in a series of model runs, beginning with the historic, pre-development conditions when sediment was supplied to the beach from sea-cliff erosion at Cape Kidnappers and from the Tukituki River, but before the inception of beach sediment extraction at Awatoto and Pacific Beach. Having established the predicted shoreline-change patterns along the length of the littoral cell under those natural conditions, the results served as the base-line case for subsequent comparisons with model runs where the extraction at Awatoto was first added, and then that at Pacific Beach was also included.

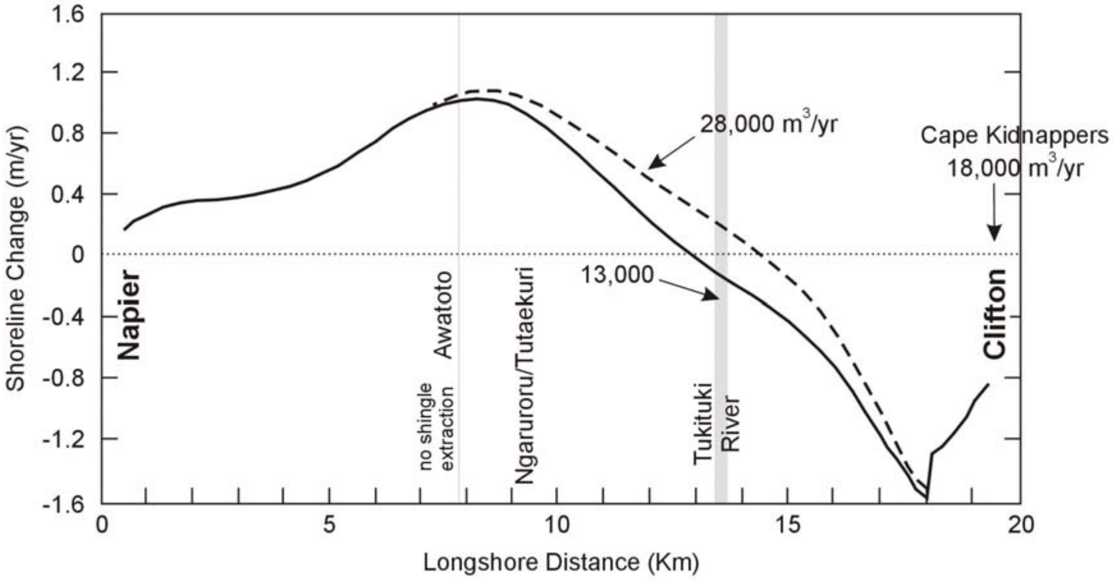

Figure 7-4 UNIBEST model analysis results of the patterns of shoreline erosion and accretion for the conditions prior to sediment extraction at Awatoto and Pacific Beach, with alternative values for the volumes of sediment derived from the Tukituki River. [*from* Tonkin & Taylor (2005)]

Figure 7-4 above shows the model results for the natural condition prior to sediment extraction, with Cape Kidnappers supplying sediment at the rate 18,000 m^3/year and for the alternative runs with the Tukituki River either supplying sediment at the rate 28,000 or 13,000 m^3/year (respectively shown by the dashed and solid curves). The horizontal axis in the graph is the alongcoast distance southward from the Port's breakwater in Napier, with Clifton being at a longshore distance of 20 kilometres; the vertical axis is the annual rate of shoreline change, with positive values representing accretion, negative values being erosion of the shore. The model results show high rates of erosion and shoreline recession in the southern-most part of the cell, and accretion to the north, the cross-over point being located in proximity to the mouth of the Tukituki River. There is not a marked difference between the curves respectively for the Tukituki River supplying 28,000 m^3/year (dashed curve) versus the revised estimate of 13,000 m^3/year (solid curve) that provided better agreement with the measured shoreline changes. In either case the highest rates of beach accretion are found in the area of Awatoto and to its immediate south near the mouth of the Ngaruroro River, the rate of shoreline advance there being on the order of 1.0 m/year. The location of this maximum zone of beach accretion was determined in the model by the changing orientation of the shoreline with respect to the refracted wave directions, such that the gradient in the decreasing rates of the longshore sediment transport to the north were greatest along this stretch of shore.

As noted above, the significance of this model analysis in Figure 7-4 for the pre-development natural condition is that it can serve as a base-line comparison for the computed shoreline changes where sediment extraction is included. The results of that analysis are seen in Figure 7-5 where sediment is extracted at Awatoto at the average rate of 47,800 m^3/year and at Pacific City with a rate of 13,000 m^3/year (Table 7-3). It is seen that according to the UNIBEST analysis this extraction significantly reduces the rates of sediment accumulation along the central shoreline of the littoral cell, reduced from 1.0 m/year without extraction to about 0.2 m/year with extraction taking place at Awatoto. The short-dashed curve in the diagram shows the additional effect of the abrasion of the gravel at a uniform rate of 0.5 m^3/year per metre of shoreline length, shifting the curve downward by a small amount to lower values of accretion or higher rates of erosion.

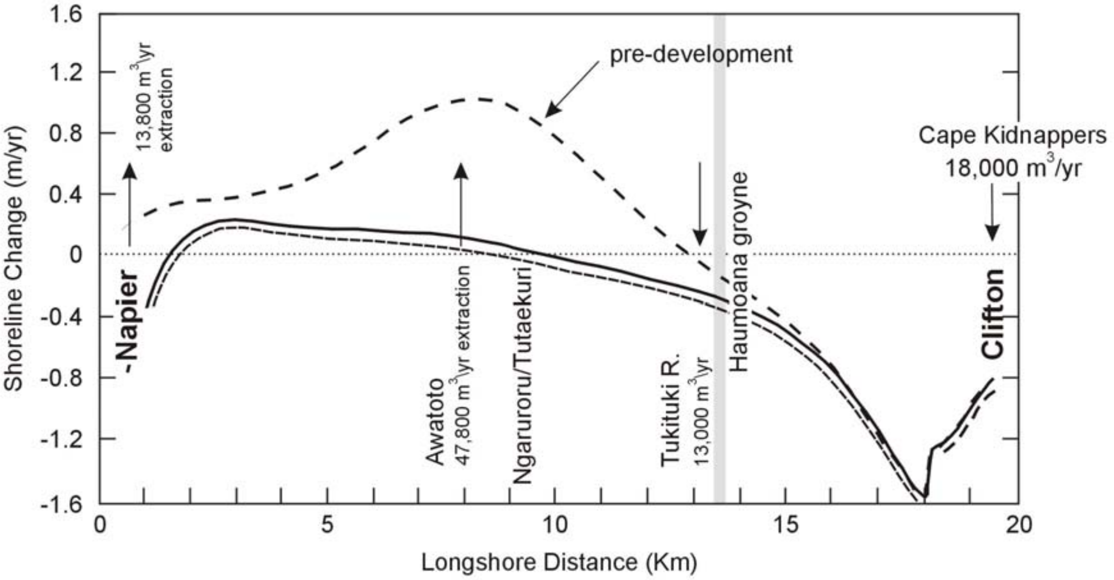

Figure 7-5 Model runs for the patterns of shoreline erosion and accretion affected by the beach sediment extraction at Awatoto, with the long-dashed line being the pre-development results from Figure 7-4 prior to extraction, and the short-dashed line showing the additional effects of gravel abrasion. [*from* Tonkin & Taylor (2005)]

It is apparent in Figure 7-5 that the effects of the sediment extraction at Awatoto span most of the central stretch of shoreline in the Haumoana Cell, with the point of transition between erosion to the south and accretion to the north having shifted northward so that a greater portion of the coast has experienced erosion in response to the extraction. The results are sensitive to the volumes of sediment delivered to the coast by the Tukituki River; with a supply rate of 28,000 m^3/year the shore experiencing erosion is shifted northward by about 500 metres due to the extraction at Awatoto, whereas with a reduced supply of 13,000 m^3/year it is seen in Figure 7-5 that the zone of shoreline erosion expands by some 5,000 metres to the north. Irrespective of which of these values is correct on average, the results make the point that during periods of reduced rainfall and flooding in the Tukituki River, when little or no sediment is delivered to the coast, it can be expected that a considerably expanded stretch of shore would experience beach erosion. This was further illustrated in the Tonkin & Taylor (2005) report with a model run for the even more dramatic case when no sediment is supplied for a period of ten years by either the Tukituki River or the erosion of Cape Kidnappers, recognizing that both tend to be episodic in their delivery of sediment to the coast (Table 7-2).

The model results in Figure 7-5 may seem somewhat counter intuitive with respect to the sediment extraction at Awatoto having affected the beach in the updrift direction to its south as well as in the downdrift direction, inducing erosion along an extended length of shore to the south of its operation. It might have been expected that the main impact of the extraction would be to reduce the longshore transport to the north, so the impacts would be greatest there, perhaps exclusively there. Actually, the greatest effects of the Awatoto extraction are to the north, where it has greatly reduced the rates of beach sediment accretion, but not to the degree that the accretion has reverted to erosion. According to the model results, Figure 7-5, the extraction at Awatoto has a smaller effect to the south, but its consequence is magnified by creating a longer stretch of shore that experiences erosion rather than accretion, an important consequence of the extraction. Being counter intuitive, it is not simple to envision the processes involved in the extraction at Awatoto having an adverse impact on the coast to its south. It needs to be recognized that although there is a net longshore sediment transport to the north, under the natural conditions with waves arriving from a range of directions there would be days when the transport is to the south and other days to the north (Section 5), so the effects of the extraction would be expected in both directions. But even if one were to consider a case where the longshore transport is always to the north, the "draw-down" effect of the sediment extraction would locally alter the shoreline so it induces an increase in the rate of transport arriving from the south, removing sediment from that immediate stretch of shore and altering its orientation. The inverse condition is more commonly seen where sediment is supplied by a river, which builds out a delta centered on its mouth. Even in the case where the delta is growing on a coast that experiences a dominant longshore transport of beach sediment in one direction, the sediment contribution from the river still results in the growth of the delta in the updrift direction as well as in the direction of the dominant longshore transport; the greater the rate of longshore transport compared with that supplied by the river, the more asymmetrical the resulting delta, but still always with some degree of delta growth in the up-drift direction (Komar, 1973).

In their series of model runs to examine the effects of the sediment extraction from the Haumoana Cell, Tonkin & Taylor (2005) also included the extraction at North Beach in Napier, which began in 1993 and has averaged 13,800 m^3/year. The result of the UNIBEST analysis seen in Figure 7-5 shows the localized inducement of shoreline recession at North Beach, with the rate being on the order of -0.8 m/year. This impact is the result of the rate of extraction being higher than the sediment arrival from the south as the remnant longshore transport, reduced from that in the southern part of the littoral cell due to the losses of gravel from abrasion and its extraction at Awatoto. The analyses by Finch (1919) and Fisher (1976) of the volumes of sediment that accumulated when the Port's breakwater was constructed both led them to conclude that the net northward transport along the Napier shore was on the order of 6,000 m^3/year at the time of construction; the value now could be still smaller due to the sediment extraction at Awatoto. From this it appears that the 13,800 m^3/year rate of extraction at North Beach is approximately double the rate of sediment replenishment by the longshore transport from the south, so the local net balance would be in the red, resulting in beach erosion as found in the UNIBEST model analysis of Tonkin & Taylor (2005). While their analyses indicated that this induced erosion would be limited to the Napier shore, the results still suggest that this effect needs to be carefully monitored, at least until the extraction at Awatoto is halted.

7.2.5 Erosion Problems and Management Responses

There has been a long history of erosion in the Haumoana Littoral Cell, with records of occurrences dating back to the period of European settlement in the 19th century. In his study of the Heretaunga Plain reviewed in Section 3, Hill (1897) noted the susceptibility to erosion and associated flooding in the area he termed the Washout, extending along the shore south of Napier (Meeanee) to the mouth of the Ngaruroro River (Waitangi). The erosion there was first brought to Hill's attention by the loss of a Maori church and burying ground. He wrote (p. 522):

> This place is a weak spot in the line of sea-beach, and it has been sadly weakened in past years by the improper usage by the railway authorities of the shingle exactly in the line where the deposit is weakest. If the shingle beach were away the sea would flow at spring tide over a large portion of the flat lands between the Meeanee and Waitangi Bridges. The shingle beach is a protection against the inroads of the sea; but just as it provides a protection, so also it introduces a source of danger to

> settlement. Moving shingle at the mouths of rivers is a distributing factor in time of flood, and the opening of a single mouth for the two rivers Ngaruroro and Tukituki constitutes a line of weakness by the possible denundation of the shingle between Napier and the Waitangi Creek.

Hill (1897) recognized that the beach ridge composed of coarse gravel and cobbles provides a natural defense from erosion and flooding at times of elevated water levels during storms, the ridges generally reaching higher elevations than the Plain immediately landward from the ridge. With this recognition, he further deduced that this Washover stretch of shore would naturally be a weak point in the defense, with the river mouths permitting the entry by the storm surge and to a degree the waves, and that the longshore migrations of the mouths would temporarily wipe away the beach ridges. As seen in the above quote, he also recognized the significance of human impacts, having cited the removal of shingle as part of the construction of the railway line, exacerbating the already natural susceptibility of the Washover to erosion and flooding.

This natural defense of the beach ridge was altered three decades later by the land elevation changes at the time of the 1931 Hawke's Bay Earthquake. As reviewed in Section 2, several studies have documented the elevation changes throughout the Hawke's Bay region, with Hull (1990) having completed the most recent analysis. Along the coast itself, the maximum uplift of 2.7 metres occurred near Oldmans Bluff on the coast just north of the mouth of the Aropaoanui River, about 5 kilometres north of Tangoio. The amount of uplift progressively decreased along the coast to the south, until at Napier it was on the order of 2 metres; the tide gauge at the Port recorded an uplift of 1.8 metres. This trend continued along the length of the shoreline of the Haumoana Cell, being greatest at Napier but reduced to 0 at Awatoto (the so-called "hinge line" in the tectonic movement), with the coast further to the south having experienced subsidence. The greatest degree of subsidence occurred inland, centered on Hastings where the land elevations dropped by about 1.0 metre; on the coast itself the subsidence was on the order of 0.7 to 0.8 metre in the area of Clifton and Te Awanga. These land elevation changes at the time of the 1931 earthquake would immediately have altered the elevations of the gravel beach ridges, later demonstrated by Single (1985) in a series of surveyed profiles undertaken along the Hawke's Bay coast.

It is clear that the elevation changes at the time of the earthquake had a profound effect on the susceptibilities of the coast to erosion and flooding. While the elevations of the land had been altered by the earthquake, the level of the sea had not changed, and it is the relative difference between the land and sea that is important. The rise of the land along most of the Hawke's Bay shore reduced its susceptibility to beach erosion and flooding, where formerly the elevated water levels during storms were able to wash over the tops of the beach ridges, but was prevented after the tectonic uplift. In contrast, the drop in the land along the shore south of Awatoto had the same effect as an abrupt rise in sea level, which would enhance the erosion of the beach and result in the more frequent overtopping of the beach ridges during storms, flooding the inland properties. Therefore, in the Haumoana Cell one would broadly have expected reduced impacts from erosion and flooding to the north where there had been uplift, but with increased impacts occurring south of Awatoto, at Haumoana, Te Awanga and Clifton. Gibb (1973b) noted this direct correspondence between the land-elevation changes and beach erosion during his earliest investigations of the erosion and flooding in this littoral cell:

> It is of interest to note that the hinge point between erosion and accretion along the southern Hawke's Bay coast, almost corresponds exactly in position to the "line of no change" that was determined from the level survey immediately after the 1931 earthquake.

As reviewed in Section 2, the uplift at Napier also created a much wider beach with higher elevations relative to the level of the sea. Prior to 1931 the Marine Parade stretch of shore was frequently inundated by storms, flooding the downtown area of Napier, whereas now there is a broad beach and buffer zone forming the reserve containing gardens, etc. In marked contrast is the concern with the increased erosion and flooding along the shore from Haumoana to Clifton, attributed in part to the land subsidence at the time of the earthquake. The expectation is that the erosion response to the subsidence of the coast experienced there would have been most rapid immediately following the earthquake, but with time would progressively have become less until a new equilibrium is achieved. This response is central to the model developed by Bruun (1962) for the erosional retreat of beaches due to a rise in sea level, the primary application being to predictions of the coastal retreat caused by the on-going global rise in sea level. As reviewed in Section 4, in simple terms the Bruun model assumes that with a rise in sea level the beach will tend to be elevated as it migrates landward, this process involving the erosion of the beach and the transport of its sand to the immediate offshore which also builds upward at the same rate as the sea-level rise. Smith (1977) applied the Bruun model to predict the expected degree of beach erosion and shoreline retreat along the southern Haumoana Cell in response to the earthquake subsidence in 1931. He made his calculations for a subsidence of 0.76 metre, assessed to have been the maximum at the south end of this cell, and used an average slope of 0.0025 for the Heretaunga Plain, the slope up which the beach ridge would have migrated until it eventually reached equilibrium with the change in sea level relative to the land; from this he calculated an expected shoreline retreat on the order of 300 metres.

As derived by Bruun (1962) with the assumption of erosion of the beach and the offshore transport of the sediment, his model was developed with sand beaches in mind. Gravel beach ridges commonly respond by the gravel being transported landward during overwash storm events, so the ridge migrates inland until it achieves an elevation that prevents further overtopping. Although the processes are fundamentally different between the responses of sand versus gravel beaches, as reviewed in Section 4 the underlying geometry turns out to be the same, so Smith's (1977) calculation of a 300-metre retreat of the beach ridge along the south shore of the Haumoana Cell, where subsidence had occurred, can still be taken as an acceptable order-of-magnitude estimate. In that the shore from Haumoana south to Clifton has not retreated by 300 metres in the 75 years since the earthquake, this can be taken to imply that the response continues to be a factor in the on-going erosion along the shore from Haumoana to Clifton. However, applications of these models can be expected to yield only very approximate estimates of the expected shoreline retreat, so that while it is likely that the erosion along this southern-most stretch of shoreline of the Haumoana Cell is still in part the lingering consequence of the 1931 earthquake and subsidence of the land, the degree of its present-day erosional response to that event is uncertain.

It is difficult to separate out the relative significance of the underlying causes of the erosion along the south shore of the Haumoana Cell, that due to the subsidence of the land at the time of the earthquake, still having some effect today, compared with the erosion associated with the balance of the sediment budget being significantly in the red. As seen earlier, the net balance in the sediment budget for the sub-cell south of the Haumoana groyne is estimated to be -48,800 m^3/year due to the northward longshore sediment transport being substantially greater than the erosion of Cape Kidnappers is able to supply gravel and sand to this beach. Prior to the construction of the Haumoana groyne in 1999, it is possible that some of the sediment supplied to the beach by the Tukituki River could have worked its way south to have been an additional supply of beach gravel; however, as seen in the sediment budget of Table 7-3, its total average contribution is placed at 28,000 m^3/year, so even if all of its sediment had moved to the south, the net balance for this sub-cell would still have been in the red (about -20,000 m^3/year). It has not been possible to confidently make estimates of the sediment sources (the credits in the budget) during the more-distant past. As reviewed in Section 3, it is clear that from the earliest stages of European settlement our impacts on the environment were such that they likely would have altered the natural sediment budget. In particular, Hill (1897) reviewed the human impacts experienced in the river watersheds, with deforestation by logging and forest fires, the confinement of the river channels by levees to prevent flooding, and with the extraction of large quantities of sand and gravel from the river channels. Some of these impacts potentially would have increased the quantities of sediment delivered to the coast by the rivers, while others would have decreased the volumes, so while we can be certain that our changes in the environment have altered the sediment budget, it is unclear whether it has represented a net gain or loss to the beaches. Furthermore, while the earthquake had a direct effect on the shoreline erosion through the land-elevation changes, analyzed above, those altered elevations would also have affected the slopes of the river channels, causing them to experience a prolonged period of regrading with altered sediment volumes being transported to the coast. Analyses of this change have not been undertaken by fluvial scientists or engineers, but it is likely that the response would be complex due to some segments of the river channels having been steepened while others became more gradual at the time of the earthquake.

An important question remains: Why is this area of shore from Haumoana south to Clifton so out of equilibrium, with its resulting whole-scale erosion? There is not a simple answer. While the subsidence of this stretch of shore in 1931 due to the earthquake is likely a factor in the continued erosion, the creation of this condition likely dates back at least to the human impacts during the period of first European settlement, and possibly dates still further into the past due to long-term changes in the climate. The key to the answer must exist to a large degree in the credits and debits listed in the sediment budgets, with their values probably having been different in the past, due either to natural environmental changes or human impacts that significantly disrupted the equilibrium. It is unlikely that the deep-water wave conditions in the past couple of centuries could have been that much different, but they could have been altered to a degree by changes in the coast itself. For example, important along this stretch of shore is the shelter provided by Cape Kidnappers; it is possible that its progressive erosion, decreasing its length and thus its ability to shelter this shore, has resulted in progressively increased wave heights along the beach and perhaps altered breaker angles due to the modified degree of refraction. If so, this would have progressively increased the magnitudes of the longshore sediment transport to the north, the debit in the budget due to that transport being greater today than in the past. Any reduction in the length of the Cape could also have decreased the yield of sand and gravel derived from its erosion, so this credit in the budget would now be smaller than in the past. Finally, it is possible that there were additional sources of beach sediment in the past; this most likely would have been from the Tukituki River following a different course than it does today. From the topography of the area it is a distinct possibility that in the past the mouth of the river was further to the south, easily mid-way between Haumoana and Te Awanga, and possibly further south close to Te Awanga. Its more immediate presence at the south end of the cell, which would have been prior to European settlement, could potentially have balanced the local sediment budget, depending on what its supply of sediment was prior to our having altered the watershed of the Tukituki River. It is seen that there are multiple possibilities, and unfortunately at present we are unable to establish with any certainty which are more probable.

Whatever the cause and whenever it developed, of importance today is that along this shore from Haumoana south to Clifton the sediment budget is significantly in the red, and there is little prospect for the improvement of this situation. The resulting erosion of the beach and damage to shore-front properties is readily evident with a number of homes under the immediate threat of loss and with the evidence of past failed structures now littering the beach, built in an attempt to protect the houses from the attack of storms (Figure 7-2). While the northern portion of the community of Haumoana is now sheltered by a beach that has been widened by the construction of the groyne in 1999 (White and Healy, 2000), the beach further to the south continues to be an inadequate buffer between the homes and the forces of the storm waves. This constitutes the area of greatest threat from erosion anywhere along the Hawke's Bay coast, with damage having been sustained as recently as the March 2005 storm. At the end of this Section, various options for the defense of the properties along this shore will be considered.

The community of East Clive is located in the 3- to 4-kilometre stretch of shore between the mouth of the Tukituki River northward to the combined mouth of the Ngaruroro and Tutaekuri Rivers. With this location, the community of East Clive has been particularly vulnerable to erosion and flooding, in large part due to the proximity of those rivers and their tendency to migrate, cutting away the beach ridge. Its erosion problems have been reviewed by Simons and Koutsos (1985), who first examined the long-term factors that have been important, and then described in detail the fairly catastrophic episode of erosion and flooding during a storm in August 1974. According to Simons and Koutsos (1985), the early subdivision plans for East Clive apparently recognized the need for a hazard zone, as the coastal road was set back a significant distance from the beach, with a wide reserve between. However, the steady progress of the erosion during the subsequent century removed most of that buffer, so the ocean processes are now able to attack properties that once were considered to be safe. In the past the Tukituki River had at times shifted its course sufficiently to the north that it joined the Ngaruroro River, and for a time shared a single mouth. But then the Tukituki returned to a southerly course, leaving behind a remnant of its former channel, a long shallow lagoon that runs parallel to the shore, trapped immediately behind the beach ridge. With the progressive erosion along this shore the beach ridge has migrated landward, dumping gravel into the lagoon so it has narrowed considerably.

According to the analyses by Tonkin & Taylor (2005) of the beach profiles that have been surveyed in recent years as part of the monitoring program, there has been a dominance of net accretion of the beaches to the north of the Haumoana groyne, though at reduced rates due to the sediment extraction at Awatoto. For a time the groyne blocked the northward longshore transport of sediment and one might have expected some induced erosion along the immediate downdrift shore, at East Clive; however, as shown by White and Healy (2000) and Tonkin & Taylor (2005), this blockage by the groyne soon filled to capacity so that within a few months the longshore transport was able to bypass that obstacle and again supplied sediment to the downdrift beaches along East Clive and further north.

Particularly significant has been the extraction at Awatoto, seen above in the review of the sediment budget and numerical shoreline models developed by Tonkin & Taylor (2005). The extraction there began as early as the 1940s, so its impacts on the beaches span more than a half-century. The effects of that extraction are readily apparent in Figure 7-6 from the study of Smith (1984), with the distance of shoreline progradation having been established from a series of profiles surveyed in 1948 and 1984 along the shore from Waitangi near the mouth of the Ngaruroro River northward to Ellison Street south of Napier (a longshore distance of just over 5 kilometres). Overall this stretch of beach had experienced accretion with a progradation of the shore during that 37-year time period, in basic agreement with the analyses by Tonkin & Taylor (2005) of the profiles obtained in the beach monitoring program covering a later time period, October 1989 to April 2002. However, of particular notice in Figure 7-6 is the near absence of progradation centered at Awatoto, which clearly must reflect the consequence of the sediment extraction.

Figure 7-6 also indicates the occurrence of small degrees of progradation between 1948 and 1984 south of Awatoto to the mouth of the Ngaruroro River. From his study of the beach profile changes and a review of the work undertaken by others who provided historical evidence and compared series of aerial photographs, Smith (1984) concluded that the beach south of Awatoto over the long term had experienced erosion, while the beach to the north had tended to accrete. This pattern is again in reasonable agreement with the analyses by Tonkin & Taylor (2005) of the beach sediment volumes. According to Smith (1984) the highest rates of erosion have occurred between the mouths of the Ngaruroro and Tukituki Rivers, and to the south at Haumoana, Te Awanga and Clifton.

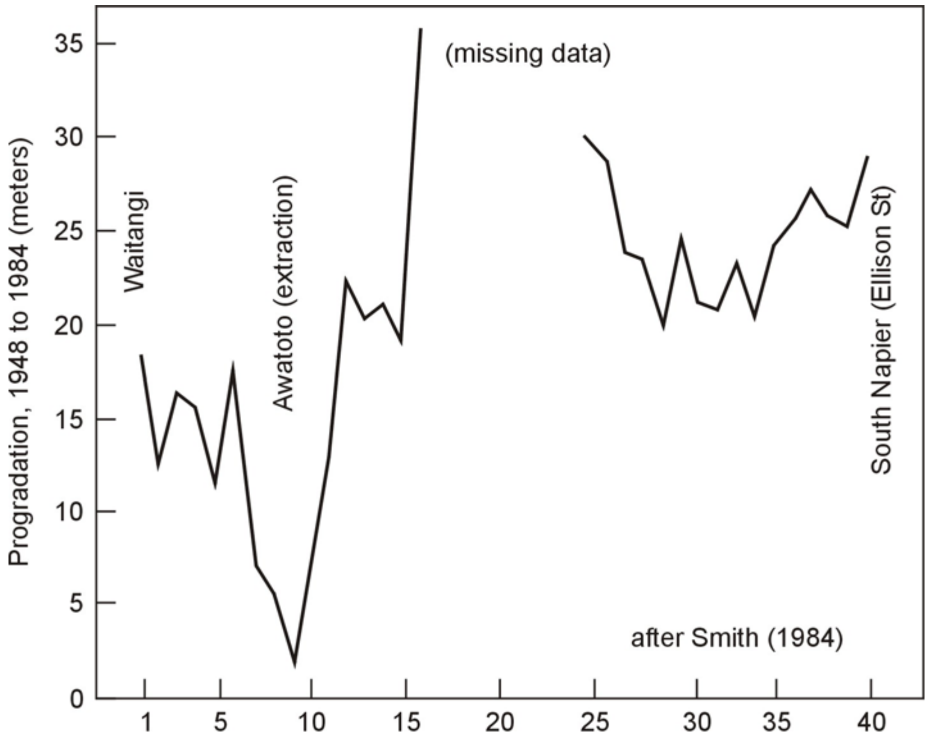

Figure 7-6 The progradation of the shoreline from 1948 to 1984 based on profile sites from approximately the mouth of the Ngaruroro River north to Ellison Street south of Napier, a longshore distance just over 5 kilometres. [*after* Smith (1984)]

Thus far we have focused primarily on what can be viewed as the underlying factors that are responsible for the erosion of the beaches and properties in the Haumoana Littoral Cell: the imbalance in the sediment budget and the land-elevation changes that occurred at the time of the 1931 Hawke's Bay Earthquake. We have seen that these factors closely paralleled one another in their effects on the coast. The hinge line of tectonic movement due to the earthquake was at Awatoto, with uplift of the land to its north and subsidence to its south. Similarly, the analyses by Tonkin & Taylor (2005) of the sediment budget and resulting shoreline evolution for the Haumoana Cell showed a pattern of significant erosion losses in the southern half of the cell and a net gain of sediment in the north, with the sediment extraction at Awatoto having been a factor in the erosion southward to at least Haumoana (prior to the construction of the groyne), and having resulted in the reduced volumes of sediment reaching the beaches to the north. The parallel alongcoast trends between these factors has resulted in the southerly beaches and properties being highly susceptible to erosion, while the northerly beaches for the most part provide a sufficient buffer to protect properties from the attack of storm waves. These patterns are further emphasized by the observations of Smith (1984) of the local volumes of sediment and elevations of the beach ridges. He noted that south of Awatoto to Haumoana [and beyond] the beach barrier is narrow, little more than 100 metres wide, with a crest elevation of only 3 to 4 metres above mean sea level, while north of Awatoto the barrier widens to 200 to 300 metres and the crest elevation increases to 5 to 7 metres above mean sea level. This alongcoast variation in the beach morphology is of course the result of the sediment budget and the northward transport of the beach sediment, and of the land elevation changes that occurred in 1931; it is this variability in the beach widths and elevations that most directly controls the impacts of storms, where their erosion and flooding by overtopping the barrier beach ridges represent the greatest problems to this developed coast.

While the sediment budget and land-elevation changes therefore represent the underlying factors that determine where the erosion and flooding represent the greatest hazards, it is the occurrence of major storms with their surge and high waves that brings about the immediate problem. The record of storm events along the east coast of New Zealand extends back to the early 1800s, documented by the historic losses of ships, while a direct documentation of the storm impacts on the coast of Hawke's Bay extends back to the earliest times of European settlement (Sevenson, 1977; Smith, 1984, Appendix I). From this history it appears that the storms were particularly severe during the late 19th century, at the time the Port of Napier's breakwater was being constructed, with it having been overtopped a number of times, and at the same time with the occurrence of erosion and flooding of the shore along the Marine Parade of downtown Napier. During the 20th century the principal storms of significance took place in 1906, in 1968 (the "Wahine" storm), and that in August 1974, which generated waves of 20 feet (6 metres) with a maximum of 23 feet (7 metres) as measured by the harbour's tug (Smith, 1984). The concern at the time of the 1974 storm focused primarily on the stretch of shore at East Clive between the mouths of the Tukituki River and Ngaruroro Rivers, where this storm eroded and overtopped the gravel beach ridge, resulting in the inundation of about 200 hectacres of urban and horticultural land. The publication by Simons and Koutsos (1985) reviewed the coastal impacts of that event, and included photographs of the property damage. In response to this storm and hoping to reduce future losses, in 1977 the Hawke's Bay Catchment Board undertook the construction of a sea-exclusion bank built parallel to the shore and set back from the beach, with the bank connected to the stopbanks of the Tukituki and Ngaruroro Rivers to provide a complete barrier. The top of the bank reached 10 metres above mean sea level, sufficiently high to prevent overtopping by the storm surge and waves.

The storms during the 1970s produced beach erosion at a number of sites along the Hawke's Bay shore, and this resulted in a strong research focus on the causes of the erosion with an interest in potential shore-protection measures. A storm on 9 August 1973 resulted in erosion between Haumoana and Te Awanga that lowered the beach profile by some 2 metres. That event initiated a reconnaissance investigation by Jeremy Gibb on 6-8 September 1973, leading to a series of reports that included his analyses of shoreline changes documented by series of aerial photographs, and early assessments of the wave climate, sediment sources and losses, and the effects of the 1931 earthquake (Gibb, 1973a, 1973b, 1975). His 1975 paper included a consideration of the various shore-protection alternatives: the construction of a long groyne or a series of short groynes; the construction of a long groyne together with artificial beach nourishment on its updrift side to reduce the erosion downdrift from the groyne; the implementation of beach nourishment without inclusion of any hard structures; the construction of offshore breakwaters; or the construction of a seawall. Consideration was also given to relocating the threatened properties out of the danger zone, or simply to do nothing and allow nature to take its course with the likely eventual loss of the shore-front homes. By and large these are still the options available today as possible remedial measures in the face of the continuing beach and property erosion being experienced along the Hawke's Bay coast; they will be considered again later in this Section.

Along the northern half of the Haumoana Cell shoreline, where uplift occurred at the time of the 1931 earthquake and where there has been a positive net balance in the sediment budget (though reduced by the extraction at Awatoto), the potential hazards from the impacts of storms are much smaller than to the south. However, while there has not been a significant problem with the erosion of the fronting beach due to the continued arrival of some beach gravel from the south, the quantities have been too small to elevate the level beach to a degree that is sufficient to prevent the periodic flooding of backshore properties; for example, the parking lot of the Aquarium is frequently flooded at times of high seas due to the surge and runup of the storm waves. From this it is apparent that the potential 100-year storm with still higher water levels must poses a significant hazard to this northerly portion of the Haumoana shoreline.

This potential hazard in the long term should lessen once the extraction at Awatoto has been halted, expected in about ten years. As discussed earlier, this will increase the net balance in the sediment budget for this stretch of shore from the present-day value of a mere 3,800 m^3/year to about 64,000 m^3/year, with the expectation that the beach will then be raised in its elevations and widths, providing a much-improved buffer from the erosion and flooding of major storms. However, in the mean time this raises concerns regarding the program of beach-gravel extraction at Pacific Beach, the north end of the Haumoana Cell, to be used in the nourishment of the beach at Westshore in the Bay View Cell. That extraction has averaged 12,800 m^3/year, which is about double the estimated volume of sediment presently arriving from the south as the longshore transport by the waves. This stretch of shore therefore needs to be monitored to assess the local effects of this extraction, and analyses should be undertaken to establish the minimum beach sediment volumes and elevations needed to insure the adequate protection of shore-front developments, to serve as a guide as to whether or not additional extraction is permitted. With the arrival of more sediment after the extraction at Awatoto has been halted, its extraction at Pacific Beach may then become a balancing act, removing enough sediment to prevent its bypassing the breakwater where it could enter the Port's Fairway, but not removing so much that it raises the susceptibility to erosion and flooding of Napier during major storms, including the extreme 100-year event.

7.3 THE BAY VIEW LITTORAL CELL

The Bay View Littoral Cell extends alongshore for 18 kilometres, Figure 7-7, consisting of the beach confined between the rocky headlands of Tangoio Bluff in the north and Bluff Hill in the City of Napier at its south end. The principal community fronting this shore is the residential area of north Napier, including South Westshore and the Esplanade, but with most of the homes set well back from the beach behind a wide reserve that is undeveloped except for a surfing club and parking areas. This is the primary recreational beach in this area of Hawke's Bay, with swimming and surfing, and with picnicking in the reserve. The Westshore and Esplanade communities have been the focus of a considerable number of investigations due to past problems with erosion, most recently in the mid-1980s which initiated a beach nourishment program that also serves to maintain this as a recreational beach. The Bay View area to its immediate north, still within the City of Napier, in places lacks a reserve so the homes have been constructed much closer to the beach where there is a potential threat from erosion, and this is also the area of development pressure for the construction of additional homes. The community of Whirinaki in the northern half of this littoral cell, Figure 7-7, again contains a reserve that provides substantial set backs for the homes, sheltering them from the erosion processes of storms.

The Bay View Littoral Cell differs in many respects from the Haumoana Cell reviewed above. While its beaches are similar, composed predominantly of gravel with a significant component of sand, the only present-day natural source of additional gravel is the Esk River, and it is believed to supply only small quantities of sediment to the beach, sand and small-diameter gravel particles. Thus, unlike the Haumoana Cell there are minimal natural gravel sources (credits) in the sediment budget for the Bay View Cell, and with the only debit in the budget being the loss due to the abrasion of the gravel particles. The one additional entry in the sediment budget is the contribution from the beach nourishment program, initiated in 1987 to supply sediment to the beach at South Westshore and the Esplanade. In the absence of significant sediment sources, it is likely that the beach within this cell has in effect adopted an orientation and curvature that are in equilibrium with the wave climate, such that although there can be daily reversals in the directions of the longshore sediment transport along its shore, the long-term average transport is close to being zero. This condition of course differs markedly from the Haumoana Cell where significant beach sediment sources are located at the south end of its shore and there is a net longshore transport of that sediment to the north, distributing the gravel along the entire length of the cell's shoreline (with losses to abrasion and its artificial extraction). An additional important difference is that the entire shoreline of the Bay View Cell experienced uplift at the time of the 1931 earthquake, on average by about 2 metres, and this has significantly reduced its susceptibility to erosion and especially to flooding at times of storms. However, it is uncertain whether this condition will persist indefinitely into the future as the uplifted beach ridge is being eroded at some sites, and may eventually be reduced to the extent that it no longer buffers the coast from the assault of the waves and surge of extreme storms.

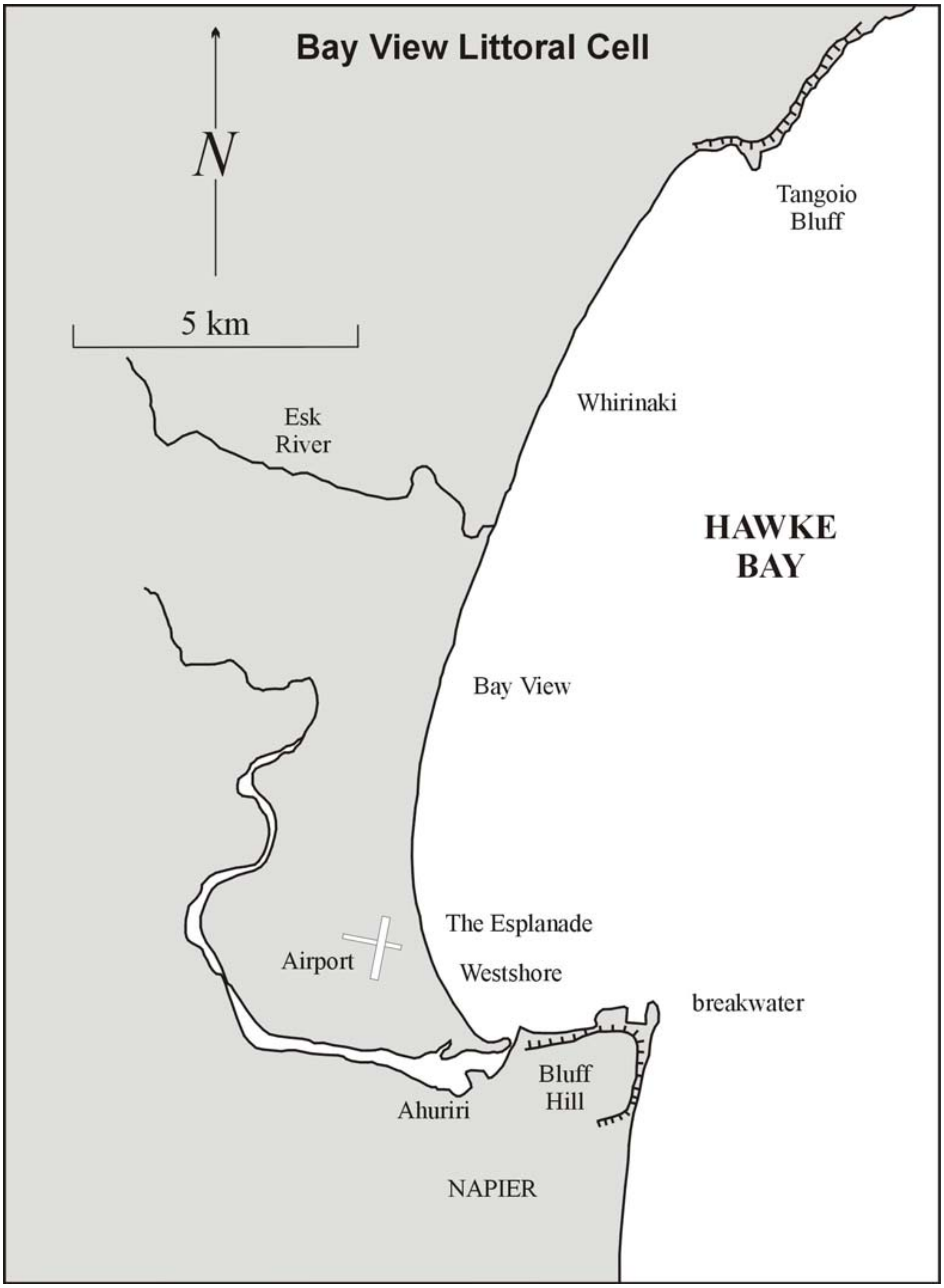

Figure 7- 7 The Bay View Littoral Cell extending from Napier to Tangoio.

7.3.1 Sediment Sources and the Budget of Beach Sediments

While the beaches of the Bay View and Haumoana Littoral Cells are both composed of greywacke gravel, the research investigations by Marshall (1929) and Smith (1968) found distinct differences between the gravels in these respective cells — in their particle sizes, shapes and degrees of surface polish [see the detailed review in Section 5 of this report]. In that the beach in the Bay View Cell is dominated by smaller gravel sizes and with the particles having achieved higher degrees of rounding and acquired a surface polish, Smith (1968) concluded that its gravel must represent an "old" deposit that has been affected by a prolonged period of abrasion under the action of the waves; in contrast, the Haumoana Cell gravel is "new", having only recently reached the beach from the Tukituki River and from the erosion of Cape Kidnappers, so the particles are on average coarser in size and more angular.

Based on his analyses that revealed these differences in the beach sediments, Smith (1968) concluded that the Bay View and Haumoana Cells are separate entities, suggesting that this separation began with the construction of the Port's breakwater in 1887-1890, which he assumed had blocked the previous transport of gravel past Bluff Hill, carrying it from the Haumoana Cell into the Bay View Cell. This possibility was reviewed at length in Section 6 of this report, leading me to conclude that the differences in the gravels in the two littoral cells required a much longer period of time to develop than the century that had passed since the construction of the breakwater, that prior to its construction Bluff Hill had been at least a moderately effective barrier between the two cells. While it was concluded that some gravel had bypassed Bluff Hill prior to the breakwater construction, this involved only relatively small volumes and was episodic in its occurrence, possibly occurring when a major flood on the Tukituki River had supplied unusually large quantities of gravel to the Haumoana Cell so that a portion was able to spill past the barrier of Bluff Hill and enter the Bay View Littoral Cell. Whatever those conditions were prior to European settlement and our modifications of the environment, since the construction of the Port's breakwater in effect enhanced the natural headland of Bluff Hill, there has been no evidence for the beach gravel having bypassed the breakwater, whereas the very fine sand in the shallow-water offshore has been able to move along the breakwater's arm and enter the Bay View Littoral Cell (this will be examined below). Thus, the Bay View Cell is now a closed system for the gravel on its beach, whereas the sand component is freer in its movements, able to bypass Bluff Hill and the breakwater, but is generally too fine to make a significant contribution to the beach.

Prior to the 1931 earthquake the Tutaekuri River flowed into the Ahuriri Lagoon, but was then rerouted (in 1934) to its present course that takes it to the south where it joins the Ngaruroro River and reaches Hawke's Bay on the shore of the Haumoana Cell. It is unclear whether it had been a significant source of gravel to the Bay View Cell prior to the earthquake, as there has been extensive gravel extraction in its watershed beginning in the early period of European settlement. It cannot be ruled out that in the distant past, prior to European settlement, the Tutaekuri River had flowed into the Ahuriri Lagoon for a sufficiently long period of time that it had been a contributor of gravel to the ocean shore of the Bay View Littoral Cell.

At present, the primary potential source of gravel to the beach in the Bay View Cell is from the Esk River, but all of the studies that have investigated this source conclude that it supplies little if any gravel. Marshall (1929, p. 334) commented: "A negligible amount is supplied by the Esk River." McBryde and Koutsos (1989) concluded that the Esk River yields only fine sand and silt, due to the gravel being extracted commercially. In his examination of the sediment sources for this cell, Gibb (2003) indicated that the Esk periodically contributes pea-size gravel, but he estimated that it amounts to only 2,000 m^3/year and noted that the last significant flood in the river took place back in 1988.

From this it is apparent that at present there is almost no gravel being naturally supplied to the beach in the Bay View Cell. However, since 1987 there has been the artificial credit to its sediment budget through the beach nourishment program implemented at South Westshore and

The Esplanade in response to the beach erosion in the mid-1980s. In his review of the nourishment program Gibb (2003) tabulated the volumes involved since the operation began in January 1987 up through October 2002. During that time a total volume of 233,800 cubic metres of predominantly fine gravel had been placed on the beach above mean sea level; of that volume, an estimated 155,100 cubic metres was placed directly on the foreshore of the beach, while 78,100 cubic metres was used to construct an artificial gravel barrier shoreward of the active beach. Considering only the gravel added to the foreshore, the average annual rate of beach nourishment has been about 9,700 m^3/year, but with the decreased placement of gravel in the back barrier in recent years this average is now more on the order of 10,000 m^3/year. It is apparent that this beach nourishment program has become the primary source of new gravel to the beach in the Bay View Cell, well in excess of that contributed naturally by the Esk River. In a sense, this program that now artificially transfers gravel from Pacific Beach at the north end of the Haumoana Littoral Cell to Westshore at the south end of the Bay View Cell, has in effect restored what may have been any natural bypassing of gravel prior to the construction of the breakwater, and likely involves significantly greater quantities than had occurred naturally.

Table 7- 4 Sediment Budget for the Bay View Littoral Cell.

	Estimated Annual Rates (m^3/year) Best Estimate	*Estimated Annual Rates (m^3/year) Potential Ranges*
Sources ("Credits")		
Esk River	2,000	
Beach Nourishment at Westshore	10,000	
Total	12,000	
Losses ("Debits")		
Gravel Abrasion	-27,000	[-9,000 to -28,800]
Balance of Beach Sediment Volumes		
Net Balance	-15,000	[3,000 to -16,800]

These sources of gravel are included as the credits in the sediment budget presented above in Table 7-4 for the Bay View Littoral Cell. The values should be viewed as only rough estimates, mainly involving the gravel on the beach, not the sand component (which will be discussed later). The two gravel credits sum to 12,000 m^3/year, almost all of it being from the nourishment at Westshore. The only debit included in this sediment budget is the loss of gravel due to its abrasion. As discussed in Section 5 and summarized above in connection with the development of the sediment budget for the Haumoana Cell (Table 7-3), it is difficult to assess this loss directly based on the results for the rates of gravel abrasion found in laboratory experiments. Rather than being based on those experimental results, in the budget developed above for the Haumoana Cell the abrasion loss was taken as the rate that would yield agreement between the sediment credits, debits, and the net balance measured from the surveyed profiles; assuming that it occurred uniformly over the full 20-kilometre length of beach within that littoral cell, the average rate was -1.5 m^3/year per metre of shoreline length. According to the budget analyses presented by Tonkin & Taylor (2005), the abrasion losses could potentially range between -0.5 to -1.6 m^3/year per metre of shoreline. The "best estimate" and potential range for the total gravel losses to abrasion listed in Table 7-4 for the 18-kilometre long Bay View Cell have been calculated using these same values from the Haumoana Cell. There is some uncertainty in doing this in that although the gravels in the two littoral cells are composed of the same greywacke rock and might therefore be expected to experience the same rates of abrasion, there are differences in particle sizes and proportions of gravel versus sand, factors that the laboratory experiments have shown exert some control on the rates of abrasion (Marshall, 1927; Hemmingsen, 2004). It is therefore difficult to assess how reasonable these calculated values are for the abrasion losses of gravel in the sediment budget for the Bay View Cell, Table 7-4.

It is seen from the "best estimates" in Table 7-4 that the net balance of the budget is in the red, -15,000 m^3/year, but the potential range extends from the budget possibly being slightly in the black (3,000 m^3/year) to being still more in the red (-16,800 m^3/year), depending on the volumes of gravel lost to abrasion. However, this net balance of -15,000 m^3/year derived from the best estimates for the credits and debits is in good agreement with the analyses of Gibb (2003, Table 4) of the changes in the beach sediment volumes based on the surveyed profiles from the monitoring program. On a cell-wide basis he found a net balance of approximately -13,500 m^3/year, which can be viewed as a tentative confirmation of the budget in Table 7-4, "tentative" in that some of its entries have large uncertainties and Gibb's analyses of the beach profiles included only 7- to 16-year time periods of surveys.

While Gibb (2003) found an overall net loss of beach sediment in the Bay View Cell as a whole, there were stretches of shore that experienced accretion during that 7- to 16-year time frame. Along South Westshore (with a 1,192 metres shoreline length) there was a net erosion of -3,500 m^3/year, while along The Esplanade (1,706 metres) and at Bay View (2,358 metres) there was accretion respectively at the rates of 3,500 m^3/year and 3,000 m^3/year; this pattern is seen in Figure 7-8 based on the series of monitoring sites spanning that area. Of interest, South Westshore had experienced a net erosion in spite of the beach nourishment program, but Gibb (2003) attributed the accretion at The Esplanade and Bay View as being sediment derived from that nourishment, and also in part the consequence of the dredged sand from the harbour having been disposed of immediately offshore from this area of accreting shore, the resulting shore helping to dissipate the energy of the waves. To the north of Bay View up to Tangoio at the northern limit of this littoral cell, Gibb (2003) found net erosion in his analysis of the beach profiles at the rate -16,000 m^3/year.

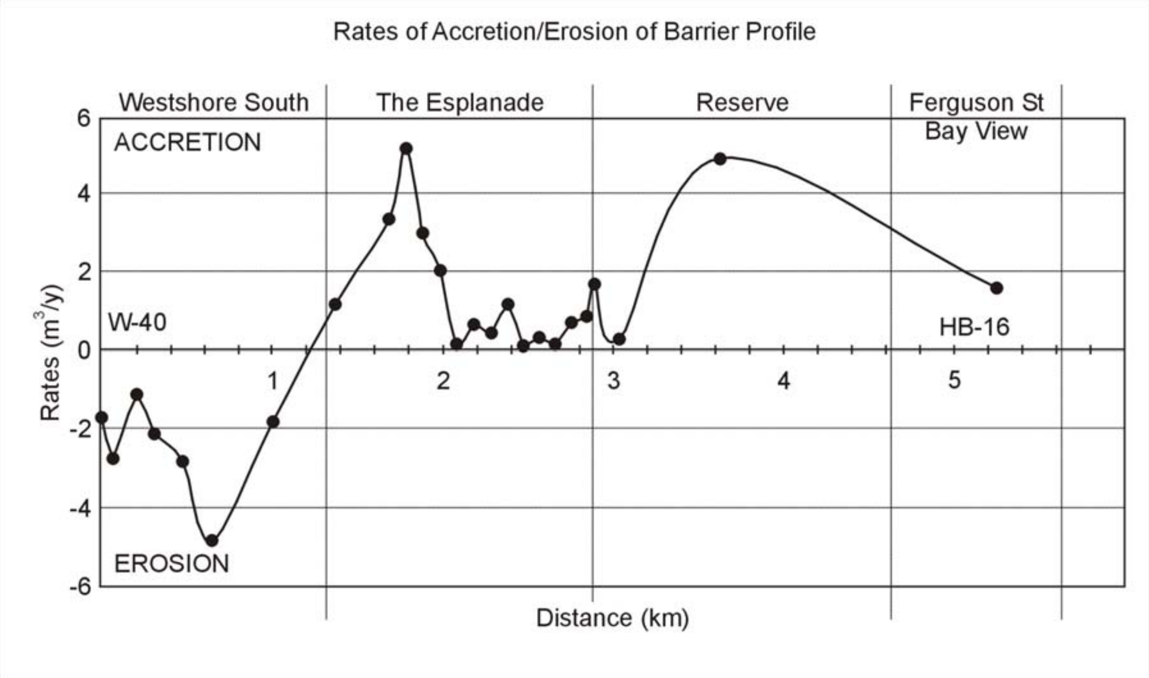

Figure 7-8 The net rates of beach sediment volumes lost (-) or gained (+) from sub-cells along the shoreline from South Westshore to Bay View, since 1987 when the beach nourishment program began. [*from* Gibb (2002)]

Due to these differences in the net balances found along separate stretches of shore within the Bay View Cell, Gibb (2003) developed separate but linked sediment budgets for each of the five sub-cell segments, given here in Table 7-5. This necessitated assessments of the longshore sediment transport, wherein the loss from one sub-cell became a credit for the next sub-cell. This everywhere involved a net transport to the north, reaching a maximum of 9,500 m^3/year at the north end of The Esplanade, supported primarily by beach nourishment along the shores of South Westshore and The Esplanade. To the north of The Esplanade, the longshore sediment transport progressively decreases according to Gibb's sediment budget, with the quantities of gravel being consumed by it loss to abrasion.

7.3.2 The Transport and Accumulation of Sand in Hawke Bay

In Section 5 the sediment compositions of the Hawke's Bay beaches were examined, and it was noted in particular that they are unusual in a global perspective in being mixtures having varying proportions of gravel and sand. While mixed sand-and-gravel beaches dominate both the Haumoana and Bay View Littoral Cells, the occurrence of the sand component in the latter cell has been more significant, particularly in its presence in the recreational beach at Westshore, Figure 7-9. The sediment budgets reviewed above for the Bay View Cell are meant to reflect the totality of beach sediment volumes, the sand as well as the gravel. However, these two contrasting grain-size fractions can behave very differently, with the gravel remaining in the beach ridge while the sand is much more dynamic in its movements within the coastal zone, shifting locations along the length of shore and also with the potential for its movement between the beach and immediate offshore. The result is that one can observe dramatic changes in the volumes of sand at a particular shoreline site, while the volumes of gravel show relatively little change. Such variations in sand contents are expected to be greatest at the ends of the littoral cells, where the longshore movement of the sand is blocked and the headlands also provide shelter from the waves so the sand can accumulate for longer periods of time. This appears to especially be the case at Westshore, Figure 7-9, with the sand accumulation further augmented by the sheltering effect of the breakwater.

The extensive studies of the mixed sand-and-gravel beaches on the Canterbury Bight of the South Island, reviewed by Kirk (1980), can serve as a guide to the expected dynamics of the sand in the similar beaches of Hawke’s Bay. The Canterbury beaches show a distinct difference in the dominant grain sizes of the sand on the beach compared with the sand in the immediate offshore, with the former being coarser grained. According to Kirk (1980) this leads to a dual transport system, with the gravel and coarse sand on the beach being transported by the breaking waves and their swash runup on the beach face, while the finer sand in the offshore is temporarily suspended by the waves and then drifts along under the action of the offshore currents, those driven by the winds and tides. As a result, the coarse sand on the beach and the finer sand in the offshore may follow very different paths when transported, and can also behave differently when their movements face an obstacle such as a rocky headland or structures such as jetties and breakwaters.

Table 7-5 The Beach Sediment Budget for the Bay View Littoral Cell, including the credits (inputs) and debits (outputs) for five sub-cells, lengths of shore experiencing differences in net erosion versus net accretion. [*from* Gibb (2003)]

BEACH SEDIMENT BUDGET
WESTSHORE TO NORTH SHORE ROAD

	m^3/year	m^3/m/year	Percent	Offshore Loss m^3/year
1 WESTSHORE SOUTH (1,192m)				
INPUTS				
Net Drift from South bypassing Ahuriri Entrance	0	0	0	
Ahuriri Harbour	0	0	0	
Barrier Erosion	3,500	2.9	30	
Beach Nourishment	8,000	6.7	70	
	11,500	9.6	100	
OUTPUTS				
Barrier Accretion	-5,500	-4.6	48	
Inferred gravel loss by abrasion	-500	-0.4	4	500
Inferred Net Drift North past Fenwick Street	-5,500	-4.6	48	
NET BALANCE:	**-11,500**	-9.6	100	
2 THE ESPLANADE (1,760m)				
INPUTS				
Inferred Net Drift from South	5,500	3.1	39	
Barrier Erosion	0	0	0	
Beach Nourishment	8,500	4.9	61	
	14,000	8.0	100	
OUTPUTS				
Barrier Accretion	-3,500	-2.0	25	
Inferred gravel loss by abrasion	-1,000	-0.6	7	1,000
Inferred Net Drift North past The Esplanade	-9,500	-5.4	68	
NET BALANCE:	**-14,000**	-8.0	100	
3 NORTH TO BAY VIEW (2,358m)				
INPUTS				
Inferred Net Drift from South	9,500	4.0	100	
Barrier Erosion	0	0	0	
Beach Nourishment	0	0	0	
	9,500	4.0	100	
OUTPUTS				
Barrier Accretion	-3,000	-1.3	32	
Inferred gravel loss by abrasion	-4,000	-1.7	42	4,000
Inferred Net Drift North past Fannin Street	-2,500	-1.0	26	
NET BALANCE:	**-9,500**	-4.0	100	
4 BAY VIEW TO LE QUESNE RD (3,152m)				
INPUTS				
Inferred Net Drift from South	2,500	0.8	25	
Barrier Erosion	7,500	2.4	75	
Beach Nourishment	0	0	0	
	10,000	3.2	100	
OUTPUTS				
Barrier Accretion	0	0	0	
Inferred gravel loss by abrasion	-8,000	-2.6	80	8,000
Inferred Net Drift North past HB-18	-2,000	-0.6	20	
NET BALANCE:	**-10,000**	-3.2	100	
5 LE QUESNE RD TO TANGOIO (8,577m)				
INPUTS				
Inferred Net Drift from South	2,000	0.2	15	
Barrier Erosion	9,000	1.1	70	
Beach Nourishment	0	0	0	
Esk River	2,000	0.2	15	
	13,000	1.5	100	
OUTPUTS				
Barrier Accretion	0	0	0	
Inferred gravel loss by abrasion	-13,000	-1.5	100	13,000
Inferred Net Drift North past Tangoio	0	0	0	
NET BALANCE:	**-13,000**	-1.5	100	

Figure 7-9 The recreational beach at South Westshore, photographed in February 2005 when the intertidal beach face consisted of a high proportion of sand while the backshore was principally gravel.

In comparison with the beach gravels, the sand component has received much less research attention. However, in Hawke's Bay itself there have been important studies that go a long way toward providing an understanding of the origin of the sand, its contents and grain sizes in the sediments of the beaches and offshore, and to a degree its transport processes. The study by White (1994) has provided the most comprehensive investigation of the large-scale processes of the fine-grained sediments in Hawke Bay, based on sediments sampled from the seafloor and in suspension within the water column, with additional samples collected from the potential sources including the major rivers. His analyses of these samples included the total suspended solids, their settling velocities, textural grain sizes, and mineral compositions. It was found that these suspended sediments in the offshore range from very fine sand, to silt and clay. Their transport paths in the offshore were followed using seabed drifters and drogues at mid-water depths. It was concluded that the suspended sediment in Hawke Bay is a complex function that depends on its supply from the rivers, with the Ngaruroro being the primary contributor, and also with some supplied by sea cliff erosion as at Cape Kidnappers. The suspended sediments from those sources are then transported by the waves and offshore currents, where they mix with fine sediments resuspened from the seafloor. Overall there is a northward transport along the coast of these fine sediments in the shallow-water nearshore, but a southward transport further offshore, such that their movement consists of a series of clock-wise flowing circulation cells.

Particularly significant was the research undertaken by Marshall (1927, 1929), which was reviewed at length in Section 5. His investigations focused on the processes and rates of abrasion of the greywacke gravels, in a series of laboratory experiments in which the gravels were collected from the Hawke's Bay beaches. His "tumbler" experiments simulated the processes of the breaking waves and swash on the ocean beaches, with the collisions of the gravel particles leading to their abrasion (termed "wearing" by Marshall). Of significance here, one product of this gravel abrasion was sand, apparently formed by small gravel particles being crushed in the collision between large particles. Initially this formed sand that was sufficiently coarse to remain on the beach, but fairly rapidly this greywacke sand was reduced further to very fine sand and silt, which is too fine to remain on the beach and is therefore carried into the offshore. This accounts for the origin and differences in grain sizes of the sands documented by Kirk (1980) on the beaches and in the offshore along the Canterbury coast, and also found along the Hawke's Bay shore by Marshall.

Marshall (1929) extended his laboratory experiments by undertaking an investigation of the gravels and sand in their natural environments along the Hawke's Bay coast. He collected a series of sediment samples along profiles extending outward from the municipal baths on the Marine Parade, and from the outer end of the breakwater. On the beach itself the sand component was dominated by the size fraction 0.250-0.177 mm, a medium-size sand that he had found to be most stable on beaches throughout New Zealand. However, he found that those grain sizes form only a small percentage of the offshore sands, while the 0.149-0.074 mm size fraction that is generally rare on beaches increased toward the offshore until it becomes 80% of the samples. He collected additional sediment samples in the offshore, in water depths that ranged from 5.5 to 11 metres, from just south of the breakwater, seaward of the breakwater, and westward to beyond the Ahuriri moles. These samples showed remarkably similar grain-size distributions, with the 0.149-0.074 mm fraction again being dominant, and with a significant portion that is finer than 0.074 mm. Marshall (1929) concluded: "These sands are sharply graded and are quite distinct from all the samples of beach sand by their fine nature."

Having found only these very-fine sand grain sizes in the offshore, including seaward from the Port's breakwater, the study of Marshall (1929) indicated that the coarser sand on the beach south of the breakwater does not immediately bypass this structure, it being blocked just as the beach gravel is halted by this barrier. It is likely that both the gravel and coarser sand on the beach are progressively reduced to fine sand and silt, as shown in the experiments of Marshall (1927, 1929), and only then is able to bypass the breakwater in its transport to the north. This is more definitely shown in the study by Hume et al. (1989), who investigated the sediments that accumulate in the Port's Fairway leading into the Outer Harbour from the north side of the breakwater, and the fate of those sediments when they are dredged from the Fairway and disposed of. Their study included making SCUBA-diver observations of the sea floor and collecting sediment samples at about 100 sites. Similar to Marshall (1929), Hume et al. (1989) found that the medium (0.25-0.5 mm) and coarse (0.5-2 mm) sands are largely confined to the beaches. Although they analyzed only a few samples from the beach, they were sufficient to reveal the presence of highly variable contents of these coarser sand sizes, locally reaching a maximum of 70% of the sample. In contrast, in most of their offshore samples this coarser-grained sand amounted to only about 2% of the total sediment. They found that the offshore seabed sediments are instead dominantly fine (0.125-0.25 mm) to very-fine (0.0625-0.125 mm) sand, making up to 80 to 100% of most samples, the remainder primarily being mud. The fine sand is most abundant in the nearshore zone off Westshore Beach where its percentage increases toward the beach (reaching 70% just seaward from the beach), in the vicinity of dump sites in shallower water, and immediately to the north and east of the Port's breakwater where it forms a distinct tongue that achieves concentrations of 70% fine sand (Hume et al., 1989; Figure 4.6). This tongue gives the distinct impression of its having arrived from the south, moving along the breakwater's arm and then entering the Fairway. Its arrival in the Fairway builds out an accumulation of fine sand along the eastern shoulder of the channel, with its rate of accumulation estimated by dredging records to be about 25,000 m^3/year. The distribution of the very-fine sand (0.0625-0.125 mm) is in effect the inverse of the fine sand (0.125-0.25 mm). Seaward from

Westshore, the very-fine sand represents only 10% of the sediment near the beach but rapidly increases offshore, reaching 50% at about the 7-metre depth contour. It is patchy through the central bay, but beyond the 15-metre depth contour it exceeds 70% of the bottom sediment.

The accumulation of the fine sand in the Fairway to the Outer Harbour has had to be removed by periodic dredging, as have the sediments causing the shoaling of the Ahuriri Inner Harbour. The dredged sediments from the Fairway consist of muddy fine and very-fine sand, whereas that from the Ahuriri Lagoon consists of mixtures of gravel, sand and mud. There has been a scatter of disposal sites across the bay ranging in depths from about 7 to 13 metres, and a prime objective of the Hume et al. (1989) study was to investigate the fates of those disposed sediments. In doing this they documented the sediments at those disposal sites, obtained near-bottom current measurements during October and November 1988, and investigated the types and numbers of organisms living there. In broad terms, while they found a general tendency for these offshore fine-grained sediments to be transported to the north, there is a counter-clockwise "eddy" in the lee of Bluff Hill and the breakwater, where the transport of the sand is to the south and then to the east. As a result of this eddy, dredged spoils dumped at site G to the immediate west of the Fairway apparently have been transported back into the Fairway, where it has accumulated along its western shoulder at an average rate of about 11,000 m^3/year.

Hume et al. (1989) concluded that the sediment dredged from the Fairway is too fine to be placed directly on Westshore as part of its beach nourishment program, as it would be unstable there and would quickly be transported by the waves back into the offshore. However, since the mid-1980s the fine sand dredged from the Fairway has been disposed of just offshore from Westshore, in water depths of 5 to 7 metres. According to the compilation of records by Gibb (2003) the volumes involved have varied: 96,000 m^3 disposed of in 1989; 56,000 m^3 in 1993; 44,000 m^3 in 1995; and 30,000 m^3 in 1997. The objective of this shallow-water disposal is the expectation that its presence just offshore would create shallower water depths that help reduce the erosion of Westshore by dissipating the energy of the waves, and perhaps with some of the sand moving onshore to directly contribute to the beach sediment volumes. According to Gibb (2003), it appears that the net accretion of the beach along southern end of The Esplanade, subsequent to its erosion in 1985, has in part been due to this sand disposal operation on Dump Ground "R".

This interest in the sand component of the Hawke's Bay sediments has also been inspired by the desire to have a sand beach at Westshore, to improve its recreational use. The loss of sand from that beach has been a contentious issue for residents of Westshore, particularly those who remember the existence of a sand beach dating back to the 1950s and earlier, believed to have been formed at the time of the uplift of this area by the 1931 Hawke's Bay earthquake. To a degree the formation of a sandy shore fronting the gravel beach ridge would have been expected due to the 2 metres uplift at that time, exposing what previously had been the offshore sand deposit. However, as reviewed in Section 5, it is curious that Marshall (1933) made no mention of its existence in his reconnaissance of this shore undertaken shortly after the earthquake, curious in that his earlier research had focused on the natural accumulations of sand versus gravel so his attention would certainly have been drawn to the formation of a new sand beach. More recent research undertaken in studies of Westshore have suggested that the sand would have been transported onshore by the waves from the shallow waters where the bottom had been uplifted by the earthquake, so there would have been some delay in its arrival and accumulation on the Westshore beach; however, it is more likely that this fine sand would have been unstable at those shallow depths, and would instead have been transported offshore rather than onshore.

There is historic evidence for the presence of a sand beach at Westshore at some stage following the earthquake. According to Campbell's (1975, p. 161) history of Napier, the earthquake: ". . . changed its beach from a dangerous shingle bank to a placid sandy expanse, [and thereby] became an increasingly popular seaside residential area." By most accounts (e.g., Smith, 1986), this beach progressively lost its sand during the subsequent decades, having remained until the late 1950s or 60s. The report by Mead et al. (2001) contains photographs taken between 1978 and 1981 at Westshore, showing the presence of a sand beach backed by the gravel ridge; at that late date, however, these photographs more likely provide evidence for the periodic but temporary presence of sand in the Westshore area sheltered by Bluff Hill and the breakwater, with its arrival being dependent on certain combinations of waves and currents that transport the sand there, and with its departure controlled by other environmental conditions. As was discussed in Section 5 and depicted in Figure 5-1, such a variability in the presence of sand is characteristic of beaches composed of mixtures of sand and gravel, such that the beach at any particular site can change from a mixed sand-and-gravel beach to a composite beach having a more extensive sand deposit fronting the gravel ridge.

The study by Mead et al. (2001) has been the primary investigation that has focused on the transport of sand at Westshore. They examined the effects of the construction of the Port's breakwater on the movement of the sand as a possible cause in its loss on the beach at Westshore, and in the shallow-water offshore. They compared the water depths in the 1954 and 1981 nautical charts for that portion of the Bay, and with the 1996 and 2000 bathymetric surveys completed by the Port of Napier as part of their monitoring of the sand disposal operation on Spoil Ground R, with the sand having been dredged from the harbour's Fairway. The results showed a consistent net loss in the total sand volumes since 1954 (Mead et al., 2001, Table 6.2), but others have expressed their doubts about this assessment in view of the difficulty in comparing net changes in water depths on bathymetric charts. The primary focus of the Mead et al. (2001) study involved the development of numerical models of the offshore ocean currents and tidal currents, and how they might have been altered by the construction of the breakwater. Model runs for the currents prior to its construction and before the water depths were altered by the 1931 earthquake showed that a current was able to pass around the Bluff Hill headland from the south into the Bay, presumably carrying sand to Westshore. The question remains, however, whether this was only the fine sand present in the immediate offshore, or also included some of the coarser-grained sand on the beach. The subsequent model runs of Mead et al. (2001) included the presence of the breakwater and the shallower water depths after the uplift by the earthquake; those models demonstrated that the breakwater has acted to deflect the path of the sand movement so it is now carried offshore and further to the north where it enters the Fairway (as discussed above, this being the fine sand in the offshore, not the coarse sand of the beach). From these model results, Mead et al. (2001) concluded that the construction of the breakwater has been important to the loss of the sand that had accumulated at Westshore at the time of its uplift by the earthquake. However, while it is certain that the breakwater has acted to divert the movement of the fine sand further to the north, away from Westshore, its effect on the coarser sand that might have contributed to the Westshore beach remains uncertain. Furthermore, the construction of the breakwater would certainly have had positive consequences to the stability of the newly formed sand beach at the time of the earthquake, by providing a significant degree of shelter from the storm waves that dominantly arrive from the southeast. In balance, it is likely that the positive effects of the breakwater in sheltering the sand accumulation at Westshore far outweighed its negative effects in terms of the sand budget and the retention of a sand beach at Westshore. Thanks to the breakwater having sheltered Westshore from the strongest storm waves, it is likely that the sand beach lasted for many more years than it would have without this shelter.

The fate of the sand at Westshore is relevant primarily to the desire to once again have a stable sand beach for recreation. This aspect will be examined at the end of this Section, where we consider the management options for this coast and the potential for the enhanced recreational use of the beach at Westshore.

7.3.3 The Longshore Transport of Beach Sediment and the Equilibrium Shoreline

The transport of beach sediment within the Bay View Littoral Cell was reviewed in Section 4, which broadly examined the coastal processes experienced along the shores of Hawke Bay. It was examined again in Section 6, but in the limited context of whether or not the shoreline changes that occurred in response to the construction of the Ahuriri moles (jetties) and the Port's breakwater were a result of those structures having blocked a net transport of beach sediment that had first bypassed Bluff Hill and was then transported along the Ahuriri shore. This has been the common interpretation by several investigators of the causes of the erosion experienced at Westshore, but in my review in Section 6, I concluded instead that the rapid rate of gravel accumulation to both the east and west sides of the constructed moles is better interpreted as the response to jetty construction on a shoreline that has close to a zero net littoral drift of sediment, with the shoreline accretion next to the moles having been produced by the rapid onshore movement of gravel from the bay-mouth bar.

This condition of there being effectively a zero net littoral drift of sediment along the shore of the Bay View Littoral Cell is to be expected as the natural equilibrium of the shore's orientation and curvature to the absence of significant sources of new gravel to the beach. If there was a significant contribution, for example from the Esk River, the orientation adopted by the shore would be such that it results in wave breaker angles that produce a net longshore transport by the waves, which would carry the sediment away from the river's mouth and distribute it along the length of cell's shoreline. However, as seen in the sediment budget developed above for the Bay View Cell, Table 7-4, the sole natural supply of gravel has been assessed to be a mere 2,000 m^3/year from the Esk River, so small it would not produce a discernible departure from a shoreline orientation that represents an equilibrium condition having a net-zero longshore transport. This natural equilibrium would have been modified to a degree by the introduction of gravel at Westshore in the beach nourishment program that began in 1987, producing a northward transport but of progressively diminishing volumes as the gravel is lost to abrasion, just as found in the sediment budget developed by Gibb (2003) seen in Table 7-5.

Therefore, prior to the beach nourishment program at Westshore, without significant natural sources of gravel to the beach of the Bay View Cell, it can be expected that it would have adopted an equilibrium shoreline orientation and curvature that represent on average a net-zero transport condition along its length. With such an equilibrium, there would be reversing movements of the beach sediment depending on the range of wave directions and heights experienced each year, but in the long term equal volumes of beach sediment would move north and south under the changing wave directions, with the overall net balance being zero. This zero net-transport condition is reflected in the near congruence between the shoreline of the Bay View Cell and the refracted waves, as this condition of zero transport is accomplished primarily by reducing the wave breaker angles to effectively zero.

Smith (1968) contrasted the general orientations of the beaches respectively in the Bay View and Haumoana Littoral Cells, and discussed the significance of this difference in terms of the wave directions and the occurrence of a net northward sediment transport in the Haumoana Cell, while there is little or no net transport along the shore of the Bay View Cell. This difference in orientations is seen in Figure 7-10, adopted from Smith (1968). The shore of the Haumoana Cell is oriented so it faces to the east-northeast, such that with the dominant waves arriving from the southeast (Section 4) the result is a prevailing (net) longshore sediment transport to the north, affected by the refraction of the waves and the partial sheltering by Cape Kidnappers, processes that exert significant controls on the degree of curvature of this shore. In contrast, the shoreline of the Bay View Cell is rotated to face the east-southeast, that is, to correspond more closely to the arrival directions of the prevailing waves from the southeast, again affected by refraction. Having achieved this orientation and curvature, the shoreline of the Bay View Cell has acquired what must be close to a net-zero balance in the longshore sediment transport, in effect being a large pocket beach between headlands.

As reviewed in Section 4, a number of investigators have examined the shapes of such equilibrium, net-zero transport beach conditions, including comparisons with the log-spiral geometric curve and especially with the "crenulate shoreline" formulated by Silvester and colleagues (Silvester and Ho, 1972; Hsu and Silvester, 1997). Worley (2002) compared the shape of the Bay View Cell's shoreline with the crenulate shoreline, and found a nearly perfect congruence, which indicates that the curvature of the cell's shore does represent effectively a net-zero equilibrium condition [see Figure 4-11 for this comparison]. The main departure found by Worley (2002) between the cell's shoreline and the crenulate geometric form was a relatively small difference centered at Westshore; the existing shoreline is seaward from the equilibrium crenulate shape, the implication being that the Westshore beach is not presently in equilibrium with the existing wave conditions, and therefore could be expected to experience some erosion with a small extent of shoreline retreat until it is cut back and conforms with the crenulate shore for the zero net-transport condition. This local departure from equilibrium at Westshore and the resulting erosion would also support a net transport of the beach sediment to the north, but again the quantities would be expected to be small.

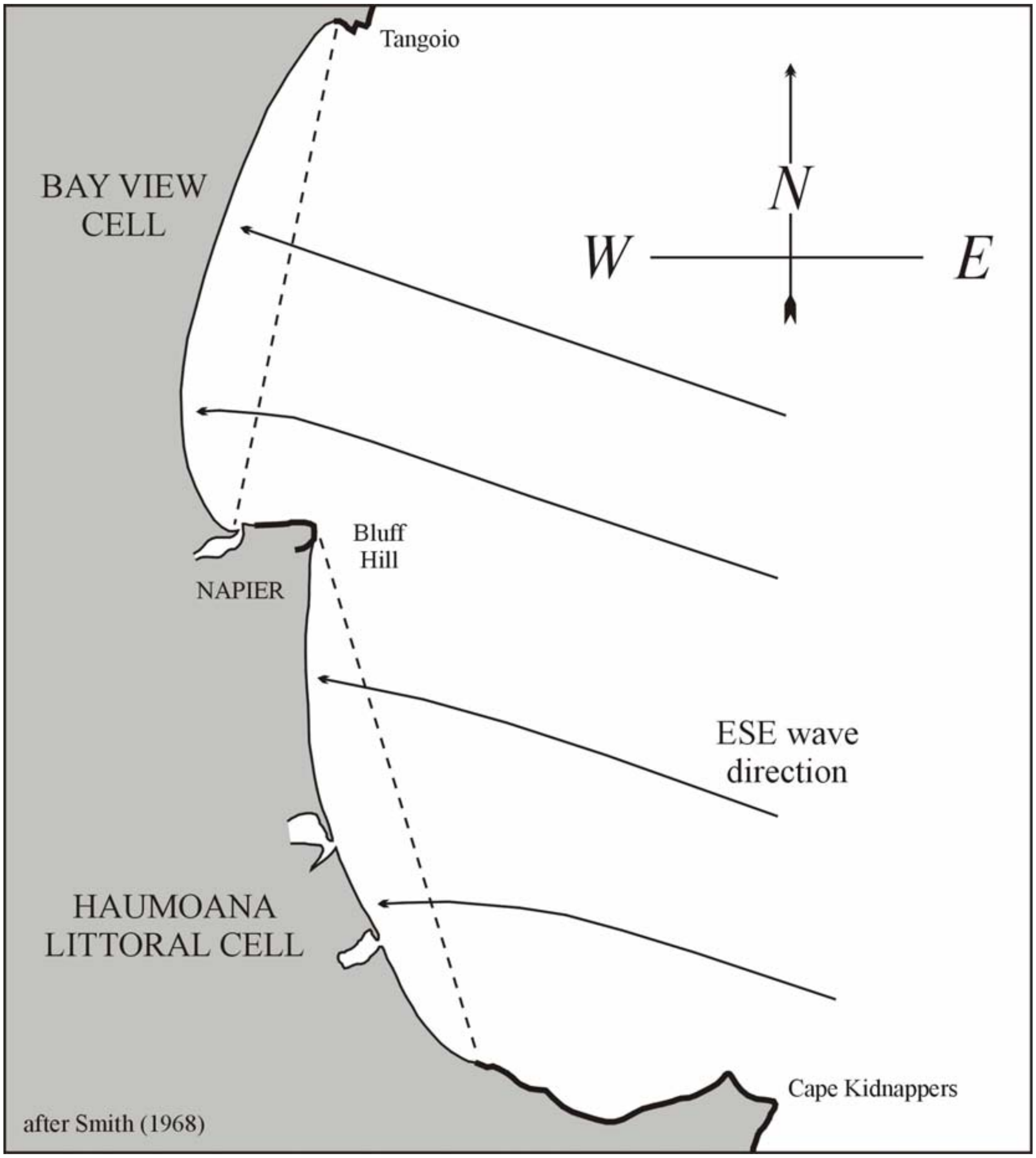

Figure 7-10 The orientations of the shorelines of the Bay View and Haumoana Littoral Cells, compared with the directions of the prevailing waves arriving from the southeast and undergoing refraction as they approach the shore (shown schematically). [modified from Smith (1968)]

In an earlier analysis, Smith (1986, 1993) had similarly compared the shoreline of the Bay View Cell and the log-spiral equilibrium shore, and obtained a much different result from that of Worley (2002). Smith found that the zero-transport equilibrium shore extended some 800 metres inland from the existing shore opposite the Napier Airport, and including a significant stretch of the residential areas of South Westshore, The Esplanade and Bay View. It is something of an art to make comparisons such as these between actual shorelines and the hypothetical zero-transport geometric curves such as the log-spiral and crenulate shorelines, and this undoubtedly accounts in large part for the different results between the analyses of Worley (2002) and Smith (1986, 1993). Smith's results are doubtful in that one would not expect the shoreline of the Bay View Cell to be that much out of equilibrium, such that 800 metres of shoreline erosion would be needed before it achieves a zero-transport condition. The analysis result of Worley (2002) is more reasonable, having shown that one can produce nearly perfect agreement between the actual shoreline and the geometric crenulate shore, implying that the shoreline of the Bay View Cell is nearly in equilibrium with the condition of zero net transport.

I believe it is safe to conclude that with the shift in the overall orientation of the shoreline of the Bay View Cell to face into the arrival direction of the prevailing waves (Figure 7-10), and with the shore having acquired the curvature of the crenulate geometric form, the cell's shore has achieved what amounts to an equilibrium condition where the effective longshore transport of sediment is everywhere zero along its length; again, this equilibrium was to be expected in the absence of significant sediment sources to this cell's beaches. The analysis result of Worley (2002) that found Westshore to have the greatest, though small, departure from the crenulate shore is of interest in that this would result in the erosion of that area and induce a small local northward transport of sediment; the addition of sediment to that beach by the nourishment program would augment this northward transport, but the total quantities of sediment are still relatively minor and constitute a "blip" on the otherwise zero-transport equilibrium shoreline condition.

Although the averaged net sediment transport may be close to zero in the long term along the shore of the Bay View Littoral Cell, as noted earlier there can be short-term periods when the transport is either mainly to the north or to the south, depending on the locations of storms offshore and the directions from which their generated waves reach this shore. Many coasts experience seasonal reversals in the directions of their longshore sediment transport, while decadal shifts in the climate may result in prolonged periods of reversals. A good example of this is the variations experienced on the Oregon coast, where like the Bay View Littoral Cell the beaches are confined between headlands and have a net-zero longshore transport (Komar, 1997). During the summer the waves approach the north-south trending Oregon coast from the northwest, causing sand to be transported alongshore to the south; in the winter the storm waves arrive from the southwest, and the sand moves back to the north. Therefore, during normal years there is a seasonal reversal with the sand oscillating back and forth within the littoral cells, alternately piling up against opposite headlands while some degree of beach erosion occurs at the other end, but in balance over the years this has yielded a net-zero longshore transport. However, every few years with the occurrence of a major El Niño, the storm waves arriving from the southwest have greater heights and energy, and this produces significantly more movement of beach sand northward within the littoral cells, creating "hot spot" zones of beach erosion at the south ends of the cells, north of the headlands. With the sand temporarily piling up at the north ends of the cells, to the south of the headlands, there are vast differences in the quantities of sand on the beaches north and south of each headland. This has been a dominant process in the erosion of the Oregon coast, with the hot-spot erosion north of headlands clearly being associated with strong El Niños.

It appears that similar longshore reversals in the annual to decadal transport of beach sediment occur within the Bay View Littoral Cell and are responsible for alternating beach erosion versus accretion at its ends; unfortunately, the possible climate controls have not been positively identified, but it has been suggested that they are related to the cycle between El Niños and La

Niñas (Gibb, 2002; Oldman et al., 2003), similar to found on the Oregon coast. The effects of the sediment reversals on the beach at Westshore have been documented by Smith (1993) using surveys of beach profiles collected between 1916 and 1984, prior to the initiation of the beach nourishment program. The results of his analyses are given here in Table 7-6 in terms of the total changes in beach volumes along that approximately 4-kilometre stretch of shore, and are also listed as the average changes in volumes per unit shoreline length. Due to the varying time periods between successive profile surveys, the entries in the table range from 1 to 23 years; the early surveys from 1916 to 1961 primarily involved intervals of 1 or 2 years between surveys, while the 1984 re-survey of those sites by Smith (1986) represents the 23-year interval. Of interest are the major shifts between net beach erosion (the negative values in the Table) versus net accretion (positive values); for example, between 1955 and 1956 there was 40,000 m^3/year of accretion, but in the following year this was reversed to -40,100 m^3/year of erosion, this change involving first a gain and then a loss of about 10 cubic metres of sediment per metre of shoreline length. Such shifts occurred throughout the extent of the 68 years of surveys included Smith's analysis, Table 7-6, and can be attributed to periodic reversals in the directions and rates of longshore sediment transport as described above. For the initial sets of profiles from 1916 to 1961, 46 years, the net change in beach sediment volumes was nearly zero, that is, the periods of beach accretion balanced the periods of erosion; if the 1984 survey is included, then the net beach volume change amounted to -9,300 m^3/year in 68 years, a net erosion. Smith (1993) took this value to represent the long-term net transport of beach sediment toward the north, but this assessment is doubtful since during almost any year either the northward or southward transport could be significantly greater, making this net value statistically insupportable.

Table 7-6 Average annual changes in beach erosion (negative values) or accretion (positive values) along a 4-km length of Westshore based on profile surveys, and the equivalent changes per unit shoreline length. [*from* Smith (1993)]

Survey Dates	*Volume Change* *m^3/year*	*Volume Change per unit shoreline length* *m^3/year/m*
1916 - 1925	-19,500	-4.88
1925 - 1927	-17,400	-4.35
1927 - 1929	7,500	1.88
1929 - 1937	19,400	4.85
1937 - 1946	3,300	0.82
1946 - 1948	32,000	8.00
1948 - 1950	-26,100	6.52
1950 - 1952	33,600	8.40
1952 - 1954	-27,400	-6.85
1954 - 1955	-8,800	-2.20
1955 - 1956	40,000	10.00
1956 - 1957	-40,100	-10.02
1957 - 1961	3,600	0.90
1961 - 1984	-9,400	-2.35

In his report, Smith (1986, Table 2) similarly analyzed the beach sediment volumes documented in profiles surveyed between 1977 and 1986 at 22 sites along a 1.1-kilometre length of shore of The Esplanade. Most noticeable in those surveys were the significant episodes of erosion in 1978 and 1985, when the respective sediment losses totaled some 5,000 and 7,600 m^3 (respectively, 5.0 and 7.6 m^3 per metre of shoreline length). Much of that loss involved the erosion of the grass verge, part of the gravel beach ridge that had been uplifted by the 1931 earthquake, in effect representing an addition of gravel to the active beach. During the decade between those two storms, there were alternating periods of beach accretion and erosion, also suggestive of cycles but involving only small volumes of beach sediments, the local change being less than 0.1 m^3 per metre of shoreline length.

In that the volumes of beach sediment losses per unit shoreline found by Smith (1993) in the cycle between erosion and accretion for the period 1916 to 1984, Table 7-5, commonly amounted to on the order of 5 m^3/year per metre of shoreline length and ranged up to 10 m^3/year per metre of shoreline, those periodic losses would have resulted in episodes when there was a noteworthy retreat in the shoreline at Westshore, cutting into the reserve. The effect would have been much like the occurrences of El Niño hot-spot erosion that have been so important in property losses experienced on the Oregon coast (Komar, 1997).

7.3.4 Beach Erosion in the Bay View Littoral Cell and the Sediment Nourishment Program at Westshore

The contrasts between the Haumoana and Bay View Littoral Cells extend to their different degrees of active erosion problems and their general susceptibilities to erosion and flooding in the advent of an extreme storm. Nowhere in the Bay View Cell does one see on-going erosion comparable to that at Haumoana (Figure 7-2). This cell does have a history of erosion problems, particularly in what had been the Western Spit of Napier and is now the developed area of Westshore. But the uplift of this area by about 2 metres at the time of the 1931 Hawke's Bay earthquake significantly reduced the potential hazards of erosion and flooding, and the comparatively minor issues continuing at Westshore appear to be adequately addressed by the beach nourishment program that began in 1987.

During the period of European settlement and extending up through the first three decades of the 20th century, the coast of the Bay View Cell was significantly more prone to erosion and flooding at times of major storms, and with the occasional impacts of tsunami. This was due to its low-lying topography, most significantly along the length of what was then called the Western Spit, extending northward for about 7 kilometres from its tip at the mouth of the Ahuriri Lagoon. This Spit was relatively narrow as the water of the Lagoon still covered the area now occupied by the airport and the highway leading into Napier from the north. Western Spit was therefore both narrow and low in its elevations, so the high tides and waves created by storms were able to wash completely over the Spit, carrying gravel and sand from the beach and depositing it on the Lagoon shore of the Spit; these overwash sediment deposits can still be seen today (Gibb, 2003).

With this susceptibility to the potential inundation by storms, initially there was only limited development on the Western Spit during the settlement period of Hawke's Bay, the latter half of the 19th century (Section 3). The early settlement of Napier did center in part along the shore of the Ahuriri Lagoon, beginning with the whalers who used this site as a shore station. The Lagoon become increasingly important to the growing community, as it was the only sheltered harbour along the east coast of the North Island. This included pressures to use the Lagoon shore of the Western Spit, where dock facilitates were constructed, which in turn led to the building of a hotel, stores, and other infrastructure to support the harbour. That early development focused on the Ahuriri shore and its docks, having avoided the ocean shore of the Western Spit, probably in part because it was susceptible to significant alternations in shoreline positions, with episodes of rapid erosion and inundation during storms.

The early reports by Saunders (1882) and Carr (1893) examined the shoreline changes that had occurred along the Western Spit, and found that the records showed that its beach had gradually eroded from 1854 to 1876, with the expansion of the width of the entrance to the Ahuriri Lagoon at the expense of the tip of the Spit which was cut away. According to Smith (1986, 1993), this increase in the channel width was due in part to the removal of limestone boulders from its shore, to be used as ballast in ships. Therefore to a degree, even at that early stage of settlement the erosion was in part caused by human impacts as well as by the natural changes induced by storms. The response to the widening of the harbour entrance, and particularly to the shoaling that accompanied its expansion, was to construct the Ahuriri moles (jetties), which was undertaken in 1876-1879 to form the Inner Harbour. Soon thereafter the decision was made to develop the Outer Harbour by the construction of a breakwater, which was completed in 1887-1890 (Section 6).

Those years of harbour development corresponded to the beginning of a period of more extreme storms and the erosion of the Hawke's Bay coast, including along the Western Spit. Unfortunately, the harbour construction had induced the greater development of this area, placing the new structures in the path the erosion and flooding. In particular, according to Campbell's (1975) history of Napier, the North British and Hawke's Bay Freezing Works had been constructed in 1886, seven years after the construction of the Ahuriri moles and one year prior to initiating the construction of the breakwater. The Freezing Works was located to the immediate west of the new Ahuriri moles, and according to Carr (1893): "A reference to the records in this office shows that prior to 1882 there was no outer beach at the Western Spit and that where the Freezing Works now stand was water." The conversion of that portion of the Spit west of the moles to developable land was likely due to both the accretion of gravel on the beach as a result of the construction of the moles, and to the practice of disposing the sediment along that shore (mostly sand) which had been dredged from the Ahuriri Inner Harbour. Based on Carr's comment, it appears that the Freezing Works unfortunately had been built in an area that four years earlier had been under water, placed close to a shore that was still prone to erosion.

Erosion of this area on the Western Spit, threatening the Freezing Works, occurred at the time of the construction of the Port's breakwater in 1887-1890, so it has been tempting to conclude it was caused by the construction; the common interpretation has been that the breakwater blocked the northward transport of gravel along this coast, which would have had to first bypass Bluff Hill, carrying it from the Haumoana Cell into the Bay View Cell [e.g., Smith (1968, 1986, 1993); O'Callaghan (1986); Gibb (2003)]. This interpretation has been offered as having been the cause of the erosion at Westshore, but has been arrived at primarily on the basis of there having been many examples throughout the world where the construction of jetties or breakwaters have blocked a longshore transport of sediment, resulting in beach and property erosion in the downdrift direction from the structures. Only the report by Kirk and Single (1999) has argued against this interpretation, observing that erosion had taken place along the Western Spit prior to the harbour development, and that a number of other factors could have contributed to the erosion; in particular, they noted the significance of the cessation in 1888 of the practice of disposing the dredged sediment from the Inner Harbour on that beach, and also the simultaneous occurrence of a series of intense storms that resulted in erosion at other sites along this coast at the time the breakwater was being constructed, not just at Westshore. Due to this lingering debate concerning the significance of the breakwater construction to that period of erosion along the Western Spit, a detailed review of this issue was undertaken in Section 6 of this report — only a brief summary will be offered here.

The crux of the opinion that first the Ahuriri moles (jetties) and then the construction of the Port's breakwater initiated the erosion of the Western Spit during the late 19th and early 20th centuries, hinges on the assumption that those structures blocked a net northward transport of sediment along this coast, which had bypassed Bluff Hill. As summarized above, my examination of this issue led me to conclude that prior to harbour development it is likely that beach gravel was able to bypass Bluff Hill, but only in relatively small volumes and with the occurrences of bypassing having been episodic, with many years when there was no bypassing; this conclusion was based on the observed differences in grain sizes, shapes and surface polish between the gravels of the two littoral cells, and specifically the beaches to the immediate north and south of Bluff Hill. Beyond that, the other evidence and my interpretations and conclusions arrived at in Section 6 included:

- When the Ahuriri moles were being constructed (1876-1879), according to the observation of Saunders (1882), the Marine Parade beach was "much reduced" in its width and sediment volume, a condition that was unlikely to have supported any significant bypassing of gravel past Bluff Hill at the time of the construction;

- In his analyses of the shoreline changes that had occurred at the time of the construction of the moles, Saunders (1882) determined that the rate of gravel accumulation to the east of the constructed moles was so rapid it kept pace with the mole's extension, the rate of accumulation having been on the order of 50,000 m^3/year; such a rapid rate of accumulation is unrealistic for the sediment volumes that could have bypassed Bluff Hill under any conditions, in view of the estimated transport rates along the Marine Parade beach being on the order of 6,000 m^3/year;

- I concluded that rather than the construction of the moles having blocked a net transport of gravel that had bypassed Bluff Hill, the rapid rate of gravel accumulation found by Saunders (1882) is more logically interpreted as the response to jetty construction on a shore that has a zero net littoral drift of sediment, with the rapid beach and shoreline accretion having occurred due to the onshore movement of sediment from the bay-mouth bar; this interpretation also conforms with the observation that sediment accretion occurred on both sides of the moles, to their west as well as on the eastern side, although the accumulation on the beach to the west was made complex by the practice at that time of disposing the sediment dredged from the Inner Harbour on that shore (most of which, however, would have been sand, whereas it appears that the accretion mainly involved the arrival of gravel);

- The constructed breakwater (1887-1890) had the effect of enhancing the natural headland of Bluff Hill, producing a localized seaward progradation of the shoreline to its south (along the Marine Parade) and a greater degree of wave sheltering at Westshore;

- There is no evidence for beach gravel having bypassed the breakwater during more than a century since its construction, demonstrating that the northward longshore transport of sediment is small along the Napier shore south of Bluff Hill, and that the bypassing of gravel prior to the breakwater's construction would similarly have been small;

From this, the hypothesis that the erosion of the Western Spit (and presently at Westshore) was caused principally by the Ahuriri moles and then the breakwater's construction, is not supported by the evidence. As suggested by Kirk and Single (1999), more important factors appear to have been the cessation in 1888 of disposing the dredged sediment from the Inner Harbour on the beach to the west of the Ahuriri moles, and the fact that this period of erosion corresponded to a time when this coast experienced a series of major storms, resulting in the waves overtopping the breakwater as it was being constructed, causing erosion and flooding of downtown Napier as well as on the Western Spit.

As discussed in previous Sections and reviewed again here, the orientation and shape of the shoreline along the Bay View Littoral Cell in effect represents a quasi-equilibrium net zero transport of beach sediments. But superimposed on that long-term equilibrium, there appears to have been short-term periods dominated by either a transport to the north or to the south under the changing wave directions, resulting in cycles between accretion and erosion of sediments at this south end of the littoral cell, along the Western Spit during the late 19th century and at Westshore today. As seen in Table 7-5 from the analyses of profile changes by Smith (1986), these cycles at Westshore occurred as early as 1916, and certainly could have taken place at the time the breakwater was being constructed, and could still be important to the present-day occurrences of erosion at Westshore.

Although these debates concerning the causes of erosion along the Western Spit during the 1880s and 1890s are of lingering interest, this is ancient history and has little significance to the issues in dealing with the present-day erosion and flooding hazards along the shore of the Bay View Cell. This history was further rendered as being inconsequential by the occurrence of the Hawke's Bay earthquake in 1931, which had a much more profound and lasting effect on this shore than the harbour construction. Most important, as reviewed in Section 2, this event resulted in the coast along the Bay View Cell being raised by on the order of 2 metres. As described above, prior to that event the Western Spit was low in elevations and narrow in its width, with the eastern shore of the Lagoon positioned immediately behind the Spit. Prior to the earthquake the Spit had experienced frequent overwash events during storms, but since it was elevated in 1931 there has been no repeat of overwash occurrences. This has been true for the beach ridge along the entire length of the cell's shoreline, it being clear that the earthquake had been a blessing at least in terms of its having greatly reduced the susceptibility of this coast to erosion and flooding hazards. This was specifically the case for the Western Spit; not only had it been elevated, but the immediate draining of the Lagoon due to its uplift by the earthquake replaced the water with land backing the Spit.

The significance of the increased elevations of this shore at the time of the 1931 earthquake has been documented by a series of studies. Earliest was that of Single (1985), who undertook profile surveys across the elevated beach ridges at a number of sites along the Hawke’s Bay shore to determine their degrees of uplift (see Figure 2-8), and considered the responses to the ocean processes that have produced the subsequent changes in the shoreline morphologies and occurrences of erosion. Figure 7-11 is from the investigations by Oldman et al. (2003) of the shoreline along the community of Bay View, undertaken in connection with the development of hazard zones for that shore. This diagram shows the history of profile changes at Gill Road, including profiles surveyed both prior to and following the uplift by the 1931 earthquake. The surveys clearly demonstrate the 2-metre uplift of the beach ridge, conforming with the analyses by Hull (1990) of the tectonic uplift of this area by the earthquake. Also seen in the post-uplift profiles is the rapid erosion of this newly elevated beach, such that by 1948 an erosional scarp had formed in the ridge and with the formation of a fronting beach. Of interest, Oldman et al. (2003) undertook calculations of the potential total water levels at the shore which might occur during major storms (the tide plus the storm surge and wave runup), concluding that even the most extreme storms could not overtop the elevated beach ridge. This is true along the entire length of the Bay View Cell, except locally at the mouth of the Esk River where the longshore migration of the river's mouth has cut away the uplifted beach ridge.

The effects of the increased elevations along the stretch of coast from Westshore to the mouth of the Esk River have been documented by Gibb (2002), and are shown here in Figure 7-12. He surveyed the elevations of the crest of the uplifted beach ridge, the "crest height" in the diagram, and the elevations at the top of the active beach where it generally meets the toe of the scarp that has been eroded into the ridge subsequent to its uplift (the "edge height"). The surveys show that the barrier crest elevation progressively increases to the north, from an average elevation of 3.6 metres above mean sea level (MSL) at South Westshore to an average of 8.4 metres MSL at Le Quesne Road (and then decrease nearer to the Esk River, having been eroded away by the river). Gibb (2002) interpreted this trend as having resulted from the progressive exposure toward the north to the increased wave heights and runup levels affected by the sheltering of Bluff Hill and the Port's breakwater. The barrier edge similarly increases to the north, from an average of 2.3 metres MSL at South Westshore to 6.3 metres at Le Quesne Road. On average the difference in elevations of the crest of the barrier and its edge is about 1.8 metres, which Gibb (2003) correctly interprets as reflecting the uplift of the beach ridge at the time of the 1931 earthquake, with the present edge height corresponding approximately to the elevation of the ridge crest that had formed by overwash events prior to its uplift. There are seen to be a few anomalies in this comparison; for example, according to Gibb (2002) the pronounced dip in the elevation of the crest between The Esplanade and Ferguson Avenue was produced by earth-moving equipment. The dip in the elevation of the barrier edge along The Esplanade is the result of the beach nourishment, such that the lowered edge (the top of the beach foreshore) reflects the elevations reached by the storm waves only since 1987 when the nourishment program began, whereas elsewhere this elevation reflects the total water levels that had been reached during the most extreme storms that have occurred since the uplift took place in 1931.

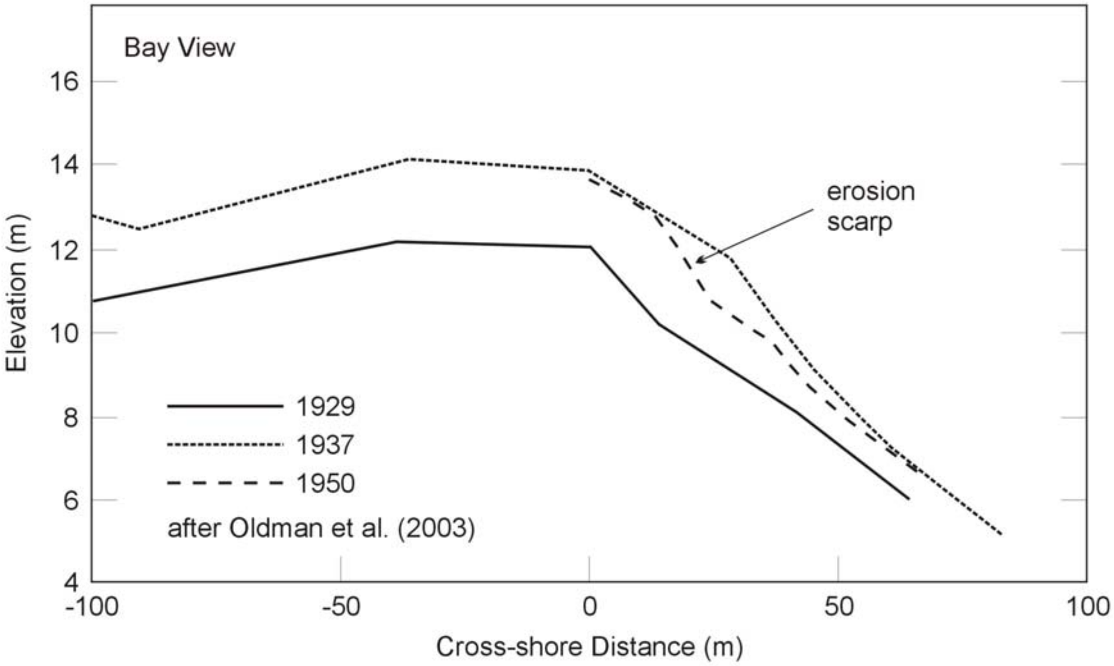

Figure 7-11 Profiles opposite Gill Road in Bay View, surveyed prior to and after the uplift of the beach ridge by the 1931 earthquake. The profile elevations are relative to the old datum used before the earthquake. [*after* Oldman, et al. (2003)]

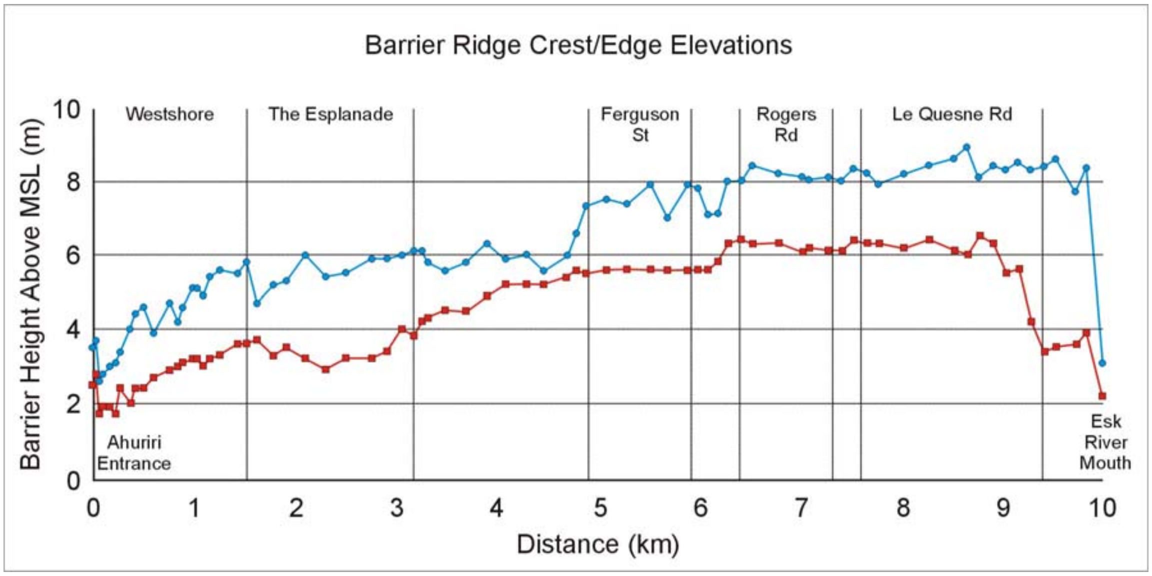

Figure 7- 12 The elevations of the crest of the raised beach ridge and edge of the toe of the eroded scarp on the ridge, where it meets the active beach. [*from* Gibb (2002)]

As noted by Smith (1985) and others, there were no reports of erosion problems along what had become Westshore after the earthquake, that is until about the 1960s. This absence of erosion can be attributed to both the higher elevations of the elevated beach and to the fact that uplift also had the effect of widening the fronting beach; for example, by simple geometry, a beach with a slope of 1-in-10 would have had its mean shoreline immediately shifted seaward by 20 metres in response to the 2-metre uplift. This would instantly have imparted a much greater capacity for the beach at Westshore to act as a buffer between the forces of the storm waves and the backshore properties. As reviewed above, the long-term residents of Westshore recall that the uplift also resulted in the creation of a sand beach that fronted the gravel beach ridge. To a degree it would also have provided an enhanced buffer protection to that area from the storm waves. The return of erosion in the 1960s is generally attributed to the progressive loss of that sand buffer, such that waves where again able to attack the gravel beach ridge, cutting a scarp at times of the most severe storms.

The most significant of the storms in recent years that produced erosion in the Westshore area occurred in 1978 and 1985. Smith (1986) analyzed the extent of the beach and backshore erosion utilizing the set of 22 profile lines extending along a 1.1-kilometre stretch of The Esplanade, and determined that the sediment losses were some 5,000 and 7,600 cubic metres respectively during those two events. A part of that loss involved the erosion of the grass verge, the seaward edge of the uplifted gravel beach ridge, which retreated by 2.1 metres in 1978 and 3.1 metres in 1985 according to Smith (1986, fig. 3), with "six years of quiescence" between. This degree of erosion of the grass verge during those two storm event is actually comparatively small in view of its episodic nature. Furthermore, there is a wide, largely undeveloped reserve between this area affected by the erosion and the homes in Westshore, so they were not under any immediate threat. This continues to be the case, such that the homes in South Westshore and The Esplanade are not in any danger, short of there being another earthquake which this time results in a substantial degree of land subsidence. Accordingly, in analyzing the impacts of the 1985 storm erosion, O'Callaghan (1986, p. 7) concluded that the erosion at Westshore "has not been severe in coastal engineering terms" and is "relatively minor". Its occurrence apparently did alarm those living in Westshore, as there immediately followed a number of investigations and reports dealing with the problem, with the focus on this area continuing up to the present (Smith, 1985, 1986, 1995; O'Callaghan, 1986; Williams, 1986; McBryde and Heslop, 1989; Gestro, 1992; Koutsos, 1993; Ross, 1994; Oldman and Smith, 1998; Gibb, 2003).

Immediate attention was given to the various options available to defend the Westshore area from this perceived threat of erosion, and it appears that the establishment of a beach nourishment program was the unanimous choice amongst the technical experts directly involved. The use of groynes constructed perpendicular to the shore was ruled out as they have the effect of shifting the erosion down the beach, endangering other properties; offshore reefs (detached breakwaters) were deemed to be too expensive; and as reviewed above, Smith (1993) indicated [mistakenly] that the "do nothing" option would lead to massive erosion, based on his comparison with the log-spiral equilibrium shore. Most consideration was given to the beach nourishment option, and following several years of adding sediment to the Westshore beach, Smith (1993, page 15) concluded: "The beach nourishment programme currently being carried out is the best practical option for the preservation of the present beach at Westshore." Somewhat later, Oldman and Smith (1998) provided the most detailed analyses of the coastal protection options, including the application of numerical shoreline models to simulate the beach responses to a variety of "hard" structures such as the construction of groynes, and to the "soft" option of beach nourishment. Their study concluded that no single option provides a complete solution to the erosion problem; the report provides a summary table for the ranking of the various options for the determination of which option, or combination of options, would be most suitable for the protection of Westshore (Oldman and Smith, 1998, Table 4 on page 34).

The beach nourishment program had begun in 1987, with its design based primarily on the analyses and report of O'Callaghan (1986), a coastal engineer. His analyses mainly involved an assessment of the quantities of gravel to be placed annually on the Westshore beach to offset its losses to erosion, which were assumed to represent a net transport of the beach sediment to the north, exiting the Westshore stretch of beach. Accordingly, O'Callaghan (1986) calculated the net transport from the wave conditions, but as reviewed earlier his analysis should be viewed as having been only an approximate estimate since he considered only two sets of waves, one representing the predominant waves from the southeast and the second for waves arriving from the east-northeast. O'Callaghan then theoretically calculated the longshore sediment transport at the Air Gap, Westshore, determining that an estimated 39,000 m^3/year was transported to the north under the action of the waves from the southeast, and 25,000 m^3/year to the south under the waves from the east-northeast, yielding a calculated net northerly transport of 14,000 m^3/year at the Air Gap. In similar analyses for the beach opposite Domain Road, he found a value of 20,000 m^3/year for the net transport to the north. O'Callaghan also calculated the volumes of beach erosion along Westshore from profiles surveyed between 1956 and 1984, and concluded that if this loss was due to the net northward transport, it represents an annual average transport rate of 19,000 m^3/year. In view of this range of estimates, he recommended that the volume of sediment required in the beach nourishment program is approximately 15,000 cubic metres of gravel added to the Westshore beach each year.

As reported by Williams (1986), the technical committee formed to deal with the beach erosion at Westshore reviewed the history of the problem and again considered the various response options, concluding that beach nourishment is the only viable and environmentally sound approach. It was decided to base the volume of nourishment on the longshore transport assessment by O'Callaghan (1986), 14,000 m^3/year, and it was also decided to place that material along a 1.2-kilometre length of the Westshore beach. Originally it was proposed to spread the material on the active beach face, but it was then decided to end-tip it over the eroded face of the grass verge, to build out the reserve along Westshore while at the same time providing a supply of gravel that would be available during subsequent storm events and wave attack along this shore.

The first nourishment undertaken at Westshore occurred in February 1987 (22,000 m^3), and was followed by repeat nourishments in November 1987 (20,000 m^3) and November 1988 (27,000 m^3), for a total of 69,000 m^3 in something of an initial experimental test of this strategy for the protection of Westshore. The sediment for this stage of nourishment was derived from the excavations for Wildlife Ponds in the Ahuriri area, and while it consisted mainly of small gravel it also contained some fine sediment, which would not be expected to remain on the beach. All three placements were along the shore of the Gap in The Esplanade, where the erosion in 1985 had been greatest.

The report by Gestro (1992) provided the first review of the effectiveness of this operation, based on comparisons between cross-section profiles of the nourished beaches surveyed in 1986 and 1991. An example of these profiles is shown below in Figure 7-13, profile E13 at the center of the nourishment site, with the 1986 profile being the eroded beach prior to its nourishment and the 1989 profiles surveyed following the nourishment undertaken to that date. According to the calculated sediment volumes by Gestro (1992), these initial results were discouraging in that he concluded that only 18,000 m^3 of the nourished volume remained as of 1991, approximately 26% of the volume that had been placed on the beach three to four years earlier. The average loss of basic fill had been on the order of 10,000 m^3/year, and he reported that at a number of profile sites the beach had been cut below its 1986 pre-nourishment level. However, an examination of the profiles themselves is less discouraging. The example in Figure 7-13 is typical, and shows the initial build out of the verge and a moderate increase in the elevation of the beach between the pre-nourishment profile in December 1986 and that in February 1989. The subsequent profiles in September and December 1989 reveal the occurrence of some erosion, including the cutback of the nourished sediment that had been end-tipped on the face of the verge, and the return of the beach elevations to their pre-nourishment levels. The E13 profiles shown in Figure 7-13, and nearly all of the others, still show the presence of some 5 to 10 metres of nourished sediment that had extended the position of the verge, indicating that its presence had protected the bluff and prevented the additional loss of the verge beyond that experienced in 1985; at that stage the remaining nourished sediment was still sufficient to provide continued protection, in spite of some losses of the nourished gravel.

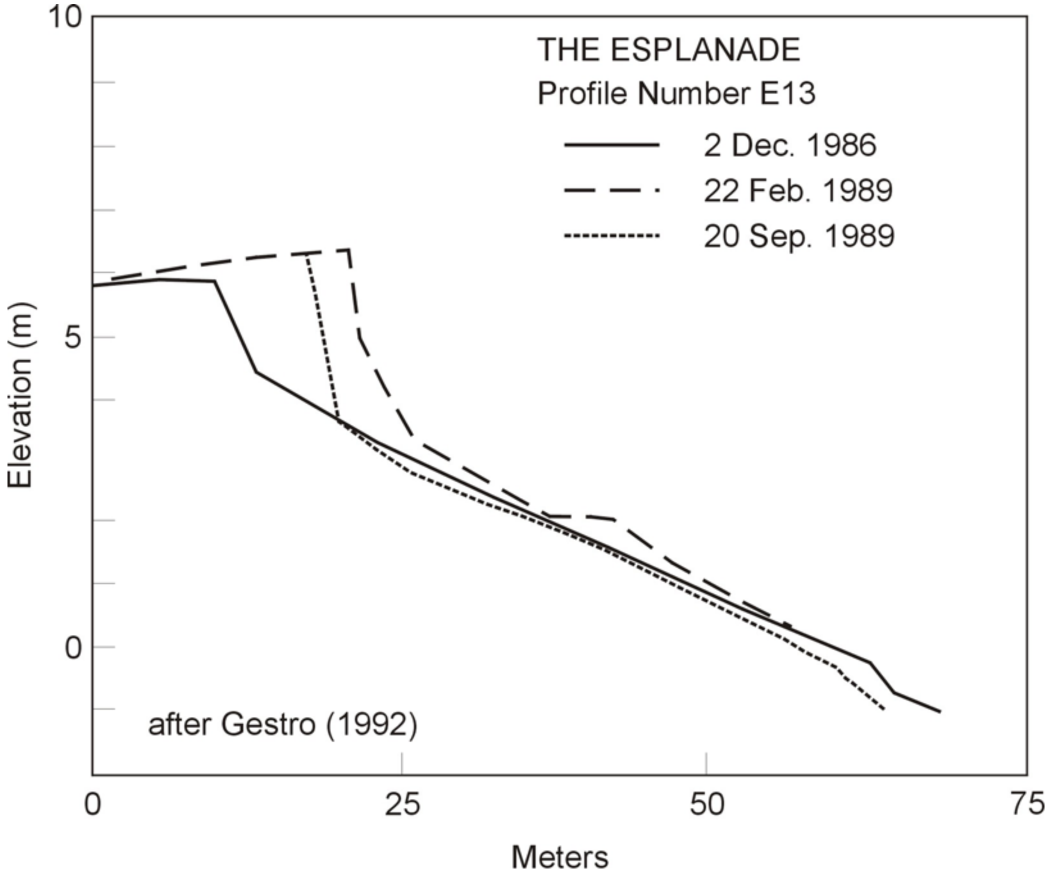

Figure 7-13 An example (E13) of a profile series obtained from surveys of the beach along The Esplanade, prior to and during the program of beach nourishment to restore the beach and to provide protection from erosion. [*after* Gestro (1992)]

Another assessment of the nourishment program was provided by Smith (1995), with positive results concerning the success of the program. His analyses were again based on changes found in the 22 beach-profile survey lines spaced at 50-metre intervals along a 1.1-kilometre stretch of The Esplanade shore. Figure 7-14 from his study shows the changes in the position of the bluff at the back of the active beach face, which until the addition of gravel by the nourishment program had been measured at the edge of the grass verge relative to the curb. The graph includes Smith's measurements of that distance extending back to 1977 and shows that between 1978 and 1985 the bluff had retreated by about 6 metres, having reduced the distance to about 13 metres from the edge of the grass verge to the curb. The changes in the distance after 1987 reflect the effects of the nourishment program on the position of the back-shore bluff, as documented by Smith's resurveys in 1987, 1988 and 1995. It is seen in Figure 7-14 that the nourishment operation had rebuilt the backshore, just as seen in Figure 7-13 from Gestro (1992), increasing the distance from the kerb to the verge from 13 metres following the 1987 erosion to on the order of 21 metres. By the time of the resurvey in 1995 some erosion of that nourished sediment had occurred, but the distance was still 19 metres, comparable to that measured prior to the 1978 and 1985 erosion events. This led Smith (1995, p. 4) to conclude:

> . . . the introduction of the nourishment material had rebuilt the spit deposit backing the beach and has been a source of shingle supply to the beach during storms. This

buffer deposit has functioned as designed, protecting the property and the public domain immediately behind the beach.

Smith (1995) also analyzed a surveyed profile line at Petane to the north of Westshore (site K8 off of Fergusson Drive), which was found to have had a net gain in its beach sediment volume since its loss at the time of the 1978 storm (surveys were not made just before or after the 1985 erosion event, so the probable loss at that time was not documented). Surveys in 1987, 1988 and 1995 showed significant gains in the beach volumes compared with surveys in the early 1980s, leading Smith (1995) to conclude that the sediment placed as nourishment along The Esplanade had been transported to the north by the waves, becoming a source of new sediment to the downdrift beaches, increasing their volumes and their capacity to serve as a buffer in protecting those properties from erosion.

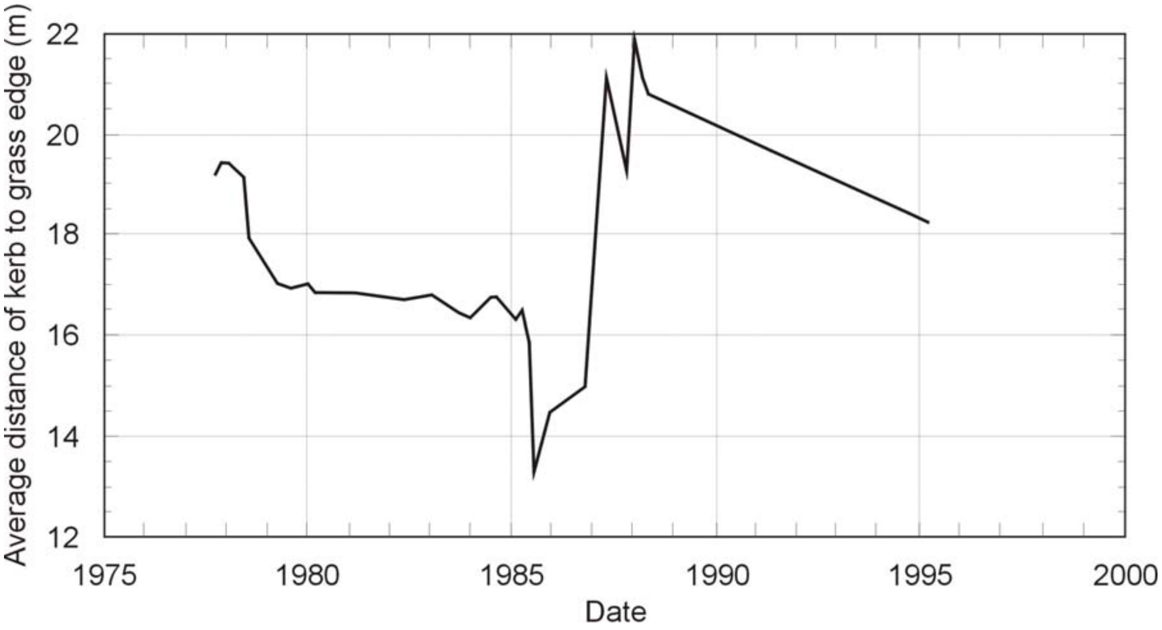

Figure 7-14 The average position of the grass verge, and after 1987 the edge of the nourished gravel placed at the back of the beach, relative to the curb along The Esplanade. [*from* Smith (1995)]

The most recent and detailed examination of the beach nourishment program is that undertaken by Gibb (2003). By that time the operation had been deemed to be a success, at least by the technical experts and individuals responsible for the management of this shore. The objective of Gibb's study was therefore directed more towards determining the sustainability of the operation and its efficiency, rather than undertaking further analyses to establish its success as a shore protection strategy. Most important is its sustainability, whether or not there will be continued sources of gravel suitable for the import and placement along Westshore in the nourishment program. Initially, from 1987 to 1991, this gravel supply had come from the excavation of the Wildlife Ponds nearby in Ahuriri, a project that had already been funded and therefore provided a serendipitous but limited source of sediment. Since 1991 the primary source of the gravel for the nourishment at Westshore has come from the excavation of the gravel that is accumulating at Pacific Beach in Napier, to the south of Bluff Hill at the north end of the Haumoana Littoral Cell; this operation, therefore, in effect represents an artificial bypassing of the Bluff Hill headland, transferring the sediment from the Haumoana to the Bay View Littoral Cell. According to Gibb's assessment, between 1993 and 2002 the total volume of gravel extracted from Pacific Beach amounted to 146,300 cubic metres, at an average rate of 16,256 m^3/year. To answer the question whether this rate of extraction at Pacific Beach is sustainable and to judge its effects on the Westshore beach, Gibb (2003) developed sediment budgets for both littoral cells; his results for those budgets have been referred to repeatedly throughout the review undertaken in this Section. For the stretch of shore of the Haumoana Cell from Awatoto to Napier, Gibb (2003) found that the net balance in the sediment budget is in the black (i.e., a net sediment accumulation in spite of the extraction at Awatoto), leading him to conclude that the extraction at Pacific Beach to serve as the source for the nourishment program is sustainable at an extraction rate between 12,000 and 13,000 m^3/year. However, he did note that the arrival of gravel at Pacific Beach is episodic, produced by stronger southeasterly storms that create an enhanced northward transport of the gravel along that coast. He therefore concluded that the extraction needs to take into account this episodic supply, and must also proceed with caution as the volume of sediment on Pacific Beach provides the natural line of defense for the city from storm-induced erosion and flooding; Gibb noted that the developed park grounds landward from this extraction site are still within the reach of the wave runup during severe storms, so that any plan for the long-term extraction needs to include assessments of the potentially increased hazards.

Gibb (2003, Table 1) provides a record of the placement of the nourished sediment along Westshore from the inception of that operation in 1987 up through October 2002; this includes the locations of the placements, the volumes of sediment involved, the source areas, the nature of the sediment (mainly fine gravel), and the percentage of the sediment placed on the active foreshore of the beach versus used to elevate the back barrier. Overall, his tabulation shows that 155,100 m^3 had been placed on the foreshore at an average annual rate of about 9,700 m^3/year, while 78,700 m^3 was placed in the back barrier. About 40% of this sediment was placed at South Westshore between Whakarire Avenue and Fewick Street, and 60% along The Esplanade.

Important were Gibb's (2003) analyses of the fate of that nourished sediment, following up the more limited analyses of Gestro (1992) and Smith (1995) undertaken early in the program. His analyses were detailed [see Table 4 and 5 in his report], summarizing the beach profile documentation of the net beach volume changes found in the E-profile series (1986-2002) along The Esplanade, the W series (1990-2002) in South Westshore, and the HB profiles (1991-2002) spanning the length of the cell's shoreline. Gibb found that net erosion had persisted at South Westshore with a mean rate of -3,123 m^3/year, in spite of the nourishment undertaken there. For the most part, however, the rates of sediment losses were on the order of -100 to -500 m^3/year at the individual profile sites, except at W-50 and W-51 where for some unknown reason the rates jumped respectively to -688 and -1,224 m^3/year. In contrast, Gibb found that net accretion had occurred along the full length of The Esplanade, but at the smaller rates of about 70 to 800 m^3/year, for a total of 3,364 m^3/year. This pattern of net accretion continued to the north as far as profile HB-16 (Fannin Street), which is about two-thirds the shoreline length from Scarpa Flow to the Esk River. Erosion was again found at profile HB-17 (Rogers Road) and was very high (-5,792 m^3/year) at HB-18 (Le Quesne Road), located about 1.5 kilometres south of the Esk River mouth. The highest rate of erosion along the entire shore was found at HB-19 (North Shore Road), about 700 metres north of the Esk River, where the loss was -13,960 m^3/year. There was a modest degree of accretion from HB-21 (Whirinaki Bluff) to HB-23 (Tangoio) at the north end of the littoral cell. From this it is seen that there had been readjustments of the shorelines and beach volumes along the entire length of the Bay View Cell during the decade from about 1990 to 2002, most of which must have been natural. Gibb (2003) interpreted the occurrence of the net accretion along The Esplanade and at Bay View as having resulted in large part from the nourishment program, with the sediment having been transported there from South Westshore where a net sediment loss had been experienced in spite of the nourishment. I concur with Gibb's interpretation, which shows that the sediment added to the beach in the nourishment program for the most part remains on the beach, although as expected some of it has been carried alongshore to the north by the waves, out of the immediate area of the nourishment operation.

As reviewed earlier, sand dredged from the Inner Harbour and from the Port's Fairway has been disposed of offshore from Westshore, generally at depths between 4 and 7 metres. Gibb (2003, Table 2) compiled the sediment volumes involved, and attributed the development of a shoreline bulge and increased beach width along The Esplanade as being in part due to the accumulation of the disposed sand on Dump Ground R immediately offshore. Some of that sand may have moved onshore so it directly contributed to the beach volumes, but more likely its disposal immediately offshore was important in its having acted to dissipate the energy of the waves and altered their refraction patterns [the reduced rate of advance of the waves over the shoal produced by the sand disposal could be expected to have resulted in a refraction pattern that produces a local bulge on the shoreline (Komar, 1998)]. Accordingly, Gibb (2003) recommended that the fine sand dredged from the harbour and disposed of in Dump Ground R be placed as a shore-parallel bar in 4- to 6-metres water depth, rather than spread evenly over the disposal area as is now required, the expectation being that with this bar configuration, the disposed sand would enhance the protection of the gravel beach through increased wave dissipation, and would have a higher potential for moving up onto the beach itself.

Although the beach nourishment program has proven to be effective during the nearly 20 years of its operation since 1987, some residents of Westswhore may still fell uncertain with respect to its continued success in the future. In 1994 a report was prepared by Vital Information Ltd. for the Westshore Residents and Development Association (Ross, 1994), which expressed their concerns at that time. These included concerns about the continued availability of sediment to be added to the beach, the annual cost of the operation, and the continuation of funding availability that depends on the political will to support the operation indefinitely into the future. The investigation by Gibb (2003) has addressed the sustainability of the operation in terms of the availability of a source for the gravel needed for the nourishment. At the time of that 1994 review by Vital Information Ltd., there appears to have been misconceptions by the Westshore residents concerning the effectiveness of the nourishment program and the expected consequences if it proved to be inadequate in protecting their community from storm erosion or was eventually discontinued. Their assessment of the effectiveness of the nourishment program was unfortunately fired by misrepresentations of the fate of the nourished sediment by the local newspaper, the *Daily Telegraph*: "On two occasions, in July 1986 and November 1987, fill which had been dumped and spread to top up the beach was swept away within months of being deposited - by storms." [quoted from Ross (1994)]. This was clearly a case of journalistic hyperbole, as the sediment was never simply "swept away", and even when it was eventually transported away from Westshore it served to supply the downdrift beaches. The annual re-supply of gravel to the Westshore beach through nourishment can be expected to provide continued protection from erosion and to support the use of its beach for recreation. Another misconception, one that appears to have unduly alarmed the residents, was the projection of the expected extent of coastal retreat if the nourishment program is ineffective or if the operation is discontinued. This resulted from the analysis by Smith (1986) that compared the configuration of the present-day shoreline with the log-spiral geometric shore taken to constitute the equilibrium shoreline, a comparison that implied the potential for massive erosion along Westshore, not achieving equilibrium until the shore has shifted landward by some 800 metres. To be fair to Smith, he did state that this extent of erosion would not be reached until far into the future, so the homeowners would not have been under any immediate threat even under the scenario represented by his analysis. As reviewed here, Worley (2002) has subsequently provided what I believe is a better comparison between the present shoreline and the equilibrium zero-transport beach, finding a near congruence which supports the conclusion that the shoreline is already nearly stable and would not experience the major shifts implied by Smith's analysis. While Worley (2002) did find that locally Westshore extends seaward from the stable equilibrium shoreline and might therefore be expected to experience some erosion, the extent of that shoreline retreat to achieve equilibrium would involve only a modest landward shift of the shoreline, one that should not pose a threat to the homes at Westshore.

While having expressed the concerns of the residents of Westshore, the report by Ross (1994) adopted a conciliatory tone in its comment: "A key issue to be addressed in finding the solution at Westshore will be to ensure it can be sustained environmentally, culturally, socially, and economically." (Ross, 1994, page 36). The report goes on to argue for the adoption of a response that provides direct benefits to the community as a whole, and specifically results in enhanced tourism appeal. My assessment is that the erosion problems at Westshore are now well under control, and agree that future undertakings along that shore should focus on the improved recreational uses of the beach; as will be reviewed below, there is the potential for developments that would improve the recreation, and at the same time could augment the protection of this shore from the hazards of future storms.

7.4 MANAGEMENT STRATEGIES

From the perspective of coastal scientists and engineers, the most important undertakings on any coast include the collection of measurements of the waves, tides and other process data, surveys of the beaches, preferably as part of a long-term monitoring program so one can determine progressive trends of erosion or accretion as well as the responses of the beaches to individual storms, and the development of a sediment budget needed in the management of the coast's most important resource, its beach sediment. All of these aspects have been thoroughly investigated for the Hawke's Bay coast, and in this report I have undertaken their review in Section 4 (the coastal processes), Section 5 (the dynamics of the Hawke's Bay beaches and the results from the monitoring program), and here in Section 7 (the sediment budgets for the Haumoana and Bay View Littoral Cells). The focus will now turn to other aspects that are important to the management of the Hawke's Bay coast, including efforts that have been directed toward the establishment of hazard zones, the potential strategies that could be used for shore protection where erosion is a problem, and the potential development of the coast that would improve its use for recreation.

7.4.1 The Establishment of Hazard Zones

Many coastal communities have found it important to establish hazard zones as part of their management strategy to protect shore-front dwellings from the potential erosion or flooding that could occur during an extreme storm. On some coasts the potential for the occurrence of a tsunami has to be considered as well, but is generally represented by a separate hazard zone that extends further inland from that established for the erosion hazards. The development of hazard zones has been an important management undertaking for the coast of Hawke's Bay, in view of its recognized dangers from storm erosion and flooding, and from tsunami.

Coastal scientists in New Zealand have led the way in the development of methodologies to be used in the establishment of coastal hazard zones: foremost of these investigators have been Dr. Jeremy Gibb and Prof. Terry Healy (Gibb, 1983, 1994; Healy and Dean, 2000). Gibb defined a coastal hazard zone as being the sector immediately landward from the beach that is subject to hazards from the marine environment, a definition that directly relates the hazards to ocean processes that have the potential for damaging or destroying beach-front homes or other developments. Healy and Dean (2000) use the terms "coastal hazard zones" and "setbacks" as more or less synonymous to mean:

> . . . that zone measured as a linear distance landward from a reference feature, . . . to a line on the ground which is subject to hazards from the marine environment, and which, on the balance of evidence and in light of scientific knowledge of the moment, it would be prudent to restrict development."

In my work on the Oregon coast I use the term "coastal hazard zone" specifically for the area of back-shore properties that is under the threat of damage or loss from the natural ocean processes that cause erosion and flooding, whereas the "setback" distance established by the community might also incorporate factors such as the preservation of the natural character of the coast or the protection of sites of cultural or ecological interest.

The assessment of a coastal hazard zone must account for both the long-term changes expected on that stretch of shore and the potential impacts of an episodic extreme storm event. While the projection is for the extent of erosion expected in the future, generally the next 50 to 100 years representing the hoped-for life times of the developments, the assessment of the potential long-term net recession or accretion is based on what has transpired in the past, generally involving analyses of series of aerial photographs or beach profiles spanning decades, the assumption being that the same trends will continue into the future. Since the focus is on the long-term protection of shore-front dwellings, the assessment of the coastal hazard zone must also account for the possible effects of a future rise in sea level, the level it potentially could reach in the next 50 to 100 years; here the primary concern is with global warming and an accompanying accelerated rate of rise in the level of the sea. In addition to being concerned with these long-term changes in the coast, the established hazard zone also needs to be concerned with the short term, how much erosion and flooding might result if a major storm occurs tomorrow or during the next several months, the so-called "one hundred year storm" that has only a 1% probability of occurring in any given year.

Formulae have been developed by Jeremy Gibb and Terry Healy that include these factors for the calculation of coastal erosion hazard zones (Gibb, 1994, 1996; Healy and Dean, 2000); their respective equations are conceptually the same, only differing as to how they are expressed mathematically. In a form that is most applicable to the Hawke's Bay beaches where long-term recession is occurring, the formula provided by Gibb is:

$$CEHZ = RT_p + X_s T_p + S \tag{7-1}$$

where CEHZ is the "Coastal Erosion Hazard Zone", a linear distance measured inland from the demarcation line between the active beach and the backshore, the latter being a foredune or an erodeable bluff. As expressed by this relationship, the calculation of CEHZ depends on the parameters:

R = the long-term average rate of shoreline change (metres/year), having a positive value for erosion, negative for accretion;

X_s = the potential rate of the beach recession that would result from a projected future accelerated rise in global sea level (metres/year);

T_p = planning time for the hazard analysis (e.g., 50 to 100 years);

S = the maximum cut back of the beach during an extreme storm (metres).

As expected from the above discussion, this equation includes evaluations of the long-term trends of shoreline recession or accretion (R) and a projection of the enhanced retreat of the shoreline due to a future rise in sea level (X_s); R and X_s are both rates or shoreline change (metres/year) so need to be multiplied by the time frame (T_p) involved in the planning, the hoped-for life times of the coastal developments.

As noted above, the long-term rate of shoreline recession is usually evaluated from series of aerial photographs or from surveyed beach profiles obtained over a number of years, sufficient to project a meaningful average trend. The value of R, or even more fundamentally whether the shoreline has a trend of erosion or accretion, is dependent in large part on the net balance in the sediment budget for that beach (littoral cell). Therefore, any expected changes in the sediment budget in the future (e.g., the construction of a dam on a river that would block the delivery of its sediment to the coast, or the placement of sediment on the beach as part of a beach nourishment program), would need to be factored into the projected value of R for the calculation of the CEHZ. In more local terms the value of R reflects the gradient in the longshore sediment transport as seen above in the numerical UNIBEST model-analysis results obtained by Tonkin & Taylor (2005) for the shoreline changes experienced along the shore of the Haumoana Littoral Cell.

The shoreline retreat due to a future rise in sea level (X_s) is generally evaluated using a Bruun-type model, reviewed in Section 4 and discussed above in application to the Hawke's Bay littoral cells. The contemporary practice in the development of hazard zones requires that the projected shoreline recession take into account an accelerated rise in sea level expected to occur during the next one-hundred years due to global warming. This requires use of the latest IPCC best estimates for the projected global rise in sea level (IPCC, 2001). Here there is the potential for "double accounting" the factors that are important to the recession of the coast, in that the evaluation of R from past aerial photographs or beach surveys will in part have been the consequence of a rise in sea level during the time frame of those surveys. To eliminate this potential for double accounting in the projection into the future, the evaluation of X_s should be evaluated based only on the enhanced accelerated rate of sea-level rise expected in the future, above that experienced in the past. There is also a significant uncertainty in the resulting evaluation of X_s due to the range in the projected rise in sea level through the 21st century made in the IPCC (2001) report, due to their having to make projections of future omissions of greenhouse gases and how they will affect the global climate. In this most recent report their best estimate is that sea level will increase by 0.43 metre by 2100, but with the uncertainties involved it is possible that the rise could be as much as 0.88 metre (IPCC, 2001). This potential range needs to be considered in the calculations of the CEHZ using equation (7-1), and in the end, due to the uncertainties in these values and the correctness of the Bruun model, the resulting value of X_s should be viewed as being only an order-of-magnitude estimate.

In contrast to these long-term factors, the inclusion of S in the calculation of CEHZ represents the expected horizontal retreat of the beach during the one or two days of an in individual storm, an extreme event represented by the 50- to 100-year storm. Its assessment may be based on surveyed distances of beach retreat experienced during past storms, or on process-based models that analyze the expected extent of beach erosion during the extreme storm from its anticipated surge levels, wave heights and swash runup elevations [e.g., Komar et al. (2002)]. It should not be mistakenly concluded that S is already contained within the evaluation of the long-term recession, even though R is the resultant of a series of such storms that have occurred over the span of years to decades. While the few days of a storm can result in the erosion of the beach and the cut back of shore-front properties, represented by S, that erosion is usually followed by a prolonged period during which beach sediment returns to the zone of erosion, restoring in whole or part the beach and even the properties backing the beach (as in the case of foredunes); the net change is the balance within this cycle between the episode of erosion and the subsequent reformation of the beach after the storm, such that R reflects this completed cycle for a number of storms over the years. It could be the case that ultimately R is effectively zero, or even with there having been a net accretion of the beach over the years in spite of the episodes of erosion; in either of these cases, the coastal properties are still in danger from the immediate occurrence of a storm, so the CEHZ has to include the S assessment of its potential impacts and threat to back-shore properties.

There are uncertainties in the assessments of all of these factors contained in equation (7-1) for the calculation of the coastal erosion hazard zone (CEHZ). These needed to be accounted for in the analysis; there have been two approaches to do this. One approach includes the use of a safety factor, generally denoted by F, that is included as a multiplying factor in equation (7-1). If there were no uncertainty then F = 1, while the greater the degree of uncertainty the higher the value of F above the value of 1. The values F ≈ 1.2 to 1.3 have been commonly used in New Zealand applications. For example, if CEHZ = 100 metres were calculated using equation (7-1), then that value would be multiplied by 1.2 or 1.3 to yield 120 or 130 metres as the recommended hazard zone, one that would include a safety factor to account for the uncertainties involved in these analyses. An alternative approach is to assess the uncertainties in the evaluations of each of the parameters contained in equation (7-1), with the combined uncertainty calculated as the root-mean-square (rms) of those individual uncertainties, which is then added to the CEHZ value from equation (7-1) to obtain the recommended hazard zone.

In summary, the objective of establishing coastal hazard zones is to provide shore-front developments — homes, hotels, and public facilities such as parks — a level of protection from the natural hazards experienced there, from the immediate potential threat of an extreme storm that could erode or flood those properties, and from the long-term changes reflected in the cumulative erosion of that shore spanning the hoped-for life times of those developments. In assessing the coastal hazard zone that will impart the desired degree of safety for the next 50 to 100 years, in applying equation (7-1) it is the role of the coastal scientist or engineer to make the best analyses possible, and for the coastal management official to provide sound judgment in applying those results. However, even in the best of circumstances there can be significant remaining uncertainties, due in large part to the inadequacy of the data for the causative erosion processes and in the documentation of the long-term shoreline changes. It also needs to be recognized that there are basic assumptions in the methodology:

- the long-term trend of shoreline change (e.g., rates of net erosion, R) documented from past records will continue into the future;
- the future rise in sea level will add an erosive component to that long-term trend based on the documented changes in the past;
- the historic short-term fluctuations associated in large part with episodes of erosion during major storms, will remain the same in the future.

Considering the fact that in calculating the CEHZ, the time frame of interest in protecting the coastal processes (T_p) is on the order of 50 to 100 years into the future, these assumptions must necessarily be viewed as tenuous. This is especially so in the face of the apparent on-going changes in the global climate, generally assessed to be the result of the enhanced greenhouse warming caused by human activities that have increased the contents of the greenhouse gases such as carbon dioxide in the atmosphere. As noted above, the IPCC reports have attempted to project the resulting accelerated rate of sea-level rise in the future, but had to report a large range from 0.43 metre to possibly 0.88 metre by 2100 due to the uncertainties in such projections (IPCC, 2001). It is recognized that changes in the Earth's climate will also involve altered rainfalls and changes in the intensities of storms, with the latter possibly resulting in progressive increases in the heights of the waves they generate, such that S included in equation (7-1) will increase, not being constant in the future as assumed. This potential is, to a degree, accounted for by the inclusion of the "safety factor", that is multiplying the computed CEHZ by $F = 1.2$ to 1.3 in arriving at a recommended hazard zone.

Several investigations have been undertaken to develop erosion and flooding hazard zones for the Hawke's Bay coast, ranging in scope from those that focused on one or only a few specific properties, to a study that included the entire Hawke's Bay coast. It is not the intent here to provide a detailed review of their respective efforts, that being well beyond the scope of this report. Of interest instead are their differences in analysis procedures and what they reveal as to insufficiencies in the data availability that to a degree have hindered the analyses. With this objective, the focus of this review is on three investigations. The study by Tonkin & Taylor (2003) developed hazard zones for the entire Hawke's Bay coast, including the three littoral cells containing beaches, the small stretches of beach to the south (e.g. Waimarama), and the rocky coasts between. This required the application of CEHZ equations formulated for the erosion of rocky coasts, in addition to equation (7-1) for beaches backed by erodeable properties. The analyses undertaken by Gibb (1996, 2002) were limited to the shore of the City of Napier between the Ahuriri entrance and the mouth of the Esk River, while those by Oldman et al. (2003) considered only the shore-front properties in Bay View between Gill Road and Franklin Road owned by Foreworld Developments Limited.

The analyses in those studies of the long-term shoreline changes to determine the values of R, the net rate of erosion or accretion, have been based primarily on the surveyed profiles collected as part of the monitoring program (Section 5). Depending on the location, this monitoring began primarily in the 1970s to 1990s, locally extending back to the 1960s or even earlier where profiles had been surveyed for other purposes. Therefore, the collected surveys generally span a couple of decades up to about forty years. In determining long-term trends of shoreline change, one would of course desire very long records, and it can be argued that even these are too short as they do not sufficiently account for climate cycles like that between El Niños and La Niñas, and the regressions of the trends may in some cases not be statistically strong. In spite of these shortcomings, this data base for Hawke's Bay is far superior to that available on most other coasts, many of which have had no monitoring program, and instead have had to rely on series of aerial photographs that can be difficult to interpret in providing a data base for the establishment of hazard zones. At present the availability of survey data for Hawke's Bay can still result in relatively large uncertainties in the trends of erosion rates, but with time and the collection of additional surveys in the monitoring program this will progressively improve, providing better estimates of R with smaller uncertainties.

The analysis procedures to determine the projected shoreline retreat in the future due to an accelerated rate of sea-level rise (X_s) were essentially the same in the three studies to establish hazard zones for the Hawke's Bay coast, and yielded similar results. The uncertainties in the estimates resulted from those inherent in the IPCC projections, as noted above. There is also the uncertainty as to the actual rate of sea level rise underway at Hawke's Bay, due to the very short record available from the tide gauge at the Port of Napier, so the assessments of X_s have had to rely on tide gauge records from elsewhere in New Zealand.

In terms of the analysis methodologies, the primary difficulty in the application to the Hawke's Bay coast has been in the evaluation of S, the maximum cut back of the beach expected during an extreme storm, the 100-year event. Part of the problem has been in defining the processes that constitute that extreme event, the combination of the expected storm surge, the runup levels of the storms waves on the beaches, and the probable levels of the astronomical tides at the time of the storm, to yield the total water levels at the shore during the height of the 100-year storm. Analyses of these processes have been undertaken as part of the establishment of hazard zones for Hawke's Bay, but for the hazards associated with the flooding or inundation of the coastal properties, not their erosion. They have not been used in assessments of the potential erosion of the beaches and properties, due in large part to uncertainties as to how the mixed sand-and-gravel beaches of Hawke's Bay would respond to those processes. As discussed in Section 5, while considerable research has been directed toward determining the erosion responses of sand beaches to major storms, there has been relatively little similar research on mixed sand-and-gravel beaches, and what has been accomplished has revealed diverse responses ranging from most of the beach sediment shifting offshore during the storm, while on other beaches most of the gravel was washed landward by its having been carried over the top of the beach ridge by the waves. Although the limited evidence for the Hawke's Bay beaches is that both offshore and onshore transport occurs during storms (Section 5), the patterns differ from site to site and there has been insufficient research to serve as a quantitative basis for the prediction of S in applications to hazard zone assessments. Instead, the investigations have depended on the short-term variability found in the beach profile surveys, the variations in beach positions and total sediment volumes above and below the long-term trends that established the values for R. In their analyses of the erosion hazard zones, Tonkin & Taylor (2003) considered both short-term shoreline shifts due to climate fluctuations such as the El Niño - La Niña cycles, and the erosion during the duration of a severe storm event; the effects of the climate cycles were evaluated as being equal to 2 times the standard deviation of the annual shoreline movement measured at each profile line, while the storm erosion was taken as 1 standard deviation. Although one can argue regarding this division between the respective effects of climate cycles and individual storms, the bottom line is that the evaluation of S in equation (7-1) for the calculation of the CEHZ is taken as 3 times the standard deviation of the annual shoreline movement that is measured at the profile line. This certainly would represent a major fluctuation in the shore, an unusual degree of erosion, but its relationship to an extreme storm event is unclear. This is especially so for the expected extent of erosion at the time of the 100-year storm, considering that the beach profile surveys that have served for this evaluation have been collected for only a few decades, during which we have not experienced a 100-year storm. In their analysis of the erosion hazard zone for the Bay View shore, Oldman et al. (2003) followed a somewhat similar approach to the evaluation of S based on the surveyed profiles, but employed extreme-value analyses to project the potential retreat distances and volumes of beach erosion for the HB16 Fanning Road profiles. Their projections yielded an estimated inland retreat of 11 to 12 metres for the 100-year event, and an erosion volume of 60 cubic metres of sediment per metre of shoreline length. Technically these projections to the 100-year occurrence are unwarranted, since they are based on only 8 years of beach-profile surveys from 1974 to 1981 (a minimum of 33 years of surveys is generally considered to be required); however, this extreme-value projection by Oldman et al. (2003) could still be employed as guidance in the evaluation of S, to be used in the calculation of the CEHZ.

In view of such problems in the analyses due to the limited availability of data and uncertainties regarding the responses of the beaches to storms, it should not be surprising that the different studies of the Hawke's Bay coast have arrived at somewhat different results for the calculated CEHZ for the same properties. As well as the likelihood of their having employed somewhat different analysis procedures and made different assumptions in those analyses, the investigators involved in these studies will personally have various degrees of conservatism when dealing with coastal hazards, which will affect their results and recommended CEHZ assessments.

7.4.2 Shore Protection and Development Strategies

The protection of coasts from erosion generally involves one of the following options, or sometimes combinations of these options (Komar, 1998, Chapter 12):

(a) take no action
(b) retreat and relocation
(c) beach nourishment (the "soft" solution)
(d) stabilization structures (the "hard" solution).

These responses are ordered from the most passive to the most active in terms of hardening the coast with structures. The most extreme measure (d) involves the construction of sea walls of timber or concrete, revetments built of large quarry stone, groynes constructed perpendicular to the shore having the purpose of trapping and retaining a portion of the sediment that is being transported along the beach, or the construction of offshore breakwaters or artificial reefs that are placed parallel to the shore to block the waves before they can impact the beach and back-shore properties. A review of these various options, including their pros and cons, can be found in Komar (1998, Chapter 12).

The traditional approach for shore protection has been the construction of "hard" structures, mainly sea walls and revetments, as they provide the highest certainty of success; however, they have the drawback of at times adversely affecting neighboring properties by transferring the erosion problem, and can also result in the loss of the beach fronting the structures due to their reflection of the waves. In recognition of these potential adverse impacts of hard structures, many coastal communities have limited their use or banned them outright, opting instead for the "soft" solution of beach nourishment. A major advantage of beach nourishment is that it has the dual advantage of maintaining a recreational beach at the same time it increases the beach width and sediment volumes, which act as a natural buffer between the storm waves and shore-front properties. The downside of beach nourishment is that the sediment placed on the beach will not generally stay there indefinitely, but instead may be carried along the shore by the waves to neighboring beaches (where it then benefits that shore). As a result, a beach nourishment program is usually a long-term investment that requires periodic re-nourishments of the eroding shore. In some cases groynes might be installed to prolong the period of retention of the nourished sediment on the beach, a combination of options (c) and (d) above. In extreme cases of erosion, it may be best to get out of its way, selecting the option (b) retreat and relocation;

there are increasing examples of this option having been chosen, it being the most rational and cost-effective strategy in those cases.

From the review undertaken in this Section of the Hawke's Bay littoral cells, it is apparent that the most active, on-going beach erosion problem threatening shore-front developments is that on the southern-most shore of the Haumoana Littoral Cell; this is the stretch from Cape Kidnappers north to the Haumoana groyne, including the communities of Clifton, Te Awanga and Haumoana. Photographs of the houses in danger from the erosion are shown in Figure 7-2, which also illustrates the variety of "hard" structures that have been installed in an attempt to protect the houses from the forces of the storm waves. I doubt whether any of these structures were designed by coastal engineers, so it is not surprising that most have failed or can be expected to fail in the near future. As analyzed earlier, the sediment budget for this stretch of shore is grossly in the red, evaluated above as having a net balance of -48,800 m^3/year, reflecting its high rate of beach erosion. With this balance for its sediment budget, it can be expected that the erosion problems would continue indefinitely into the future, with the probable eventual loss of the homes and infrastructure, including the coastal road.

It might seem that in the case of the homes in South Haumoana, Figure 7-2, those that were even recently under the threat of damage by a storm in March 2005, that the retreat and relocation option would be the most rational response. The "soft" solution of beach nourishment would require the import annually of a sediment volume of at least 48,800 m^3/year, adding that credit to the budget so its net balance becomes zero. Such an operation would be expensive, and the demand for such large volumes of gravel on an annual basis would not likely be sustainable. This could be an instance where the construction of groynes might be valid, a series of short groynes spaced along this stretch of shore that would act to retain most of the nourished gravel placed in front of the properties threatened by the erosion. This sediment would be impounded updrift from each of the groynes, filled to capacity so that the gravel and sand eroded from the Cape could then bypass each of the groynes and continue to be transported to the north, reducing the downdrift erosion associated with the groyne construction. However, even then the presence of the groyne field would still result in some enhanced erosion to the north, assuming that they are effective in halting the shoreline recession. That recession was seen to be caused primarily by the longshore sediment transport to the north, amounting to about 62,400 m^3/year according to the sediment budget in Table 7-5, which now bypasses the Haumoana groyne and then becomes a sediment input (credit) for the beaches to the north. With the control of the erosion to the south, the longshore transport past the Haumoana groyne and its credit to the beaches to the north would be reduced, so it could be expected that there would be some degree of enhanced erosion at East Clive. These are obviously complicated issues, involving tradeoffs, so the various options require detailed analyses of the processes, followed by management decisions as to which shore-protection strategy offers the best choice.

The reduction and eventual elimination of the commercial sediment extraction at Awatoto should considerably improve the net balance in the sediment budget for the northern half of the Haumoana Littoral Cell, hopefully reducing the erosion and flooding hazards during even the most extreme storm events. It can be expected that the beach will widen and increase in its total sediment volumes, thereby becoming a more effective buffer between the storm waves and the low-lying back-shore properties in that area. The only measure that might be considered along this stretch of shore would be to undertake a program of beach “scraping”, piling some of the accumulated gravel into a ridge at the back of the beach, whose elevations and volumes would be sufficient to provide protection from the potential surge and waves of the projected 100-year storm event.

For the most part, there are relatively few issues with erosion and flooding hazards along the shore of the Bay View Littoral Cell, due primarily to its uplift by some 2 metres at the time of the 1931 Hawke's Bay earthquake. With that degree of uplift, the natural beach ridge in many respects became comparable to the artificial cobble berms or dynamic revetments that have been constructed along shores to protect them from problems with erosion and flooding; their design to simulate natural gravel and cobble beach ridges, while serving to protect the coast, has been reviewed in Section 5. The 2-metre uplift along the shore of the Bay View cell in 1931 produced an elevated ridge of gravel that no longer experiences overwash events during major storms, in contrast to their common occurrence prior to the uplift. Analyses of potential high water levels during storms confirm that overwash occurrences with the flooding of backshore properties would not be expected even during more extreme events (e.g., Oldman et al., 2003); however, I am not entirely convinced that those analyses have considered storm scenarios as extreme as the 100-year event, so the potential may still exist. The widened beaches created by the uplift also enhanced their buffer capacity to protect backshore properties from erosion. However, there are stretches of shore where this elevated ridge is being progressively eroded by storm waves, having cut a scarp into the seaward face of the ridge. Gibb (2002) has documented the average rates of retreat since 1962 of this scarp along Westshore north to the Esk River, the rates generally being on the order of -0.25 m/year, but reaching -0.50 to -0.8 m/year locally in The Esplanade; the beach nourishment program begun in 1987 has in large part mitigated this problem. Scarp erosion of the beach ridge is more apparent further to the north along the shore of the Bay View Cell, but the rates have not been determined. There remains some concern that this erosion might continue to the extent that the ridge no longer provides protection to the backshore properties from the hazards of erosion and flooding, that some time in the future there will be renewed overwash events during storms along that northern stretch of shore.

Aside from these issues concerned with the long-term protection from erosion and flooding, the stretches of shore in the Bay View Cell that are currently experiencing erosion include the northern-most portion and that at South Westshore (Gibb, 2003). Little concern has been expressed concerning the progressive retreat of the beaches at the far north, presumably due to the sparse development and adequate setback distances of the homes that are located there. In contrast, there has been an extraordinary degree of focus placed on the erosion at Westshore. As discussed earlier, the possibility of there having been erosion as a result of the construction in the late 19th century of the Ahuriri moles and the Port's breakwater to a degree remains uncertain, although the review undertaken in Section 6 of this report concluded that the erosion at that time was due more to the extreme storms that occurred then, and the halting of the disposal of the sediment dredged from the Inner Harbour on the Westshore beach. At any rate, the effects of the harbour construction back in the 19th century is ancient history in terms of the present-day erosion of the beach at Westshore. In present-day terms, in sheltering this stretch of shore from the southeast arrival of the predominant waves in Hawke Bay, the combined Bluff Hill and breakwater have reduced the erosion of Westshore and rendered the beach nourishment program more effective in its protection. The beach nourishment program overall has been a success in restoring this beach for recreation, and in providing a reasonable degree of buffer protection for the backshore from erosion. In analyzing the effectiveness and sustainability of this nourishment program, Gibb (2003) found that there still is a net erosion occurring along South Westshore, amounting on average to about a 3,000 cubic metres per year loss, with evidence that this eroded sediment has been transported alongshore to the north to supply the beaches there. The cause of this lingering erosion is uncertain; as reviewed earlier, there are indications that this short stretch of beach lies just seaward from the equilibrium zero-transport shoreline, so one might expect a small degree of erosion (Worley, 2002), or it could be part of the cycles of periodic erosion versus accretion seen in Table 7-5 from the surveys by Smith (1993), attributed to periodic reversals in the sediment transport directions. In reviewing the nourishment program, Gibb (2003) recommended that the imported sediment be placed mainly along South Westshore (between Profiles W-40 and W-51C), where it would be most effective in first protecting that eroding area and would behave as a "feeder beach", with the sediment being progressively transported northward to The Esplanade where it would continue to offer protection. This recommended nourishment design should enhance the protection of South Westshore, and may be a sufficient response to the continued beach erosion experienced there. Gibb (2003) also made recommendations for physical improvements to the backshore, that would increase crest heights for the artificial beach ridge along South Westshore and the embankment along The Esplanade, in order to further reduce the flood hazards. He also suggested a re-contouring of the backshore topography (Gibb, 2003, Fig. 8) that would reduce the slopes of the backshore at the same time the elevations are increased, the objective being to reduce the degree of wave reflection during storms, which appears to be important in the loss of sediment from the fronting beach. These recommendations are presently undergoing additional investigations to provide more details of the hoped-for improvements.

One completed study of the potential improvements of South Westshore is that of Beca (2003), undertaken specifically of the Whakarire Avenue area immediately west of the Ahuriri moles. Past erosion there resulted in the construction of a seawall, initiated in about 1994 according to the Beca report. The geometry of this structure is unconventional for a "seawall" in that it apparently followed the line of pre-existing wood piles, and therefore took the shape of two groyne-like structures that join to form an enclosed lagoon. While this structure has thus far provided protection to the developed properties along Whakarire Avenue, analyses undertaken by Beca indicate that it could experience failure during a major storm. Furthermore, it was concluded that this groyne-like geometry of the structure "funnels" the incoming waves toward the beach immediately to its northwest, and enhances the erosion there; my interpretation is that this results from the reflection of the incoming waves from the groyne, with those reflected waves then approaching the beach at a marked angle causing a local enhanced sediment transport to the north and the erosion of this beach (a similar effect was experienced following the construction of the breakwater at Halfmoon Bay on the coast of California).

Due to the potential for failure of the existing "seawall" at Whakariri Avenue, the undesirable nature of its geometry with an enclosed lagoon, and that this structure appears to be enhancing locally the erosion of the South Westshore beach, the study by Beca (2003) investigated a series of alternative shore-protection structures to replace this "seawall". Four of the options (W1 through W4) for the most part attempted to live with the existing joined groynes, but making modifications that would provide some improvement; these were in the end all deemed to be inadequate. Option W5 abandoned that configuration with the creation of a beach in the sheltered zone behind what would be an extension of the existing seaward-most groyne, while the second oblique groyne causing the wave funneling/reflection would be abandoned. Based on the analyses by Beca (2003), this became their recommended preferred option. It would provide improved protection to the Whakarire Avenue properties, and at the same time could create a relatively stable beach within the sheltered pocket it forms, one that should be able to retain sand so as to also provide improved recreational benefits. According to the Beca (2003) report, sand would initially have to be imported to create this beach, and it was suggested that it be sand dredged from the Ahuriri entrance channel. An alternative source of sand would be from dredging the channel leading to the Port of Napier, with the expansion of Dump Area R further to the south to include the stretch of shore created by this option W5 beach. The question of course is whether this pocket-beach structure would provide sufficient sheltering from the waves to form a stable beach in spite of the fine-sand grain size of this imported sediment.

The study by Mead et al. (2001) was also directed toward the creation of a sand beach along Westshore. Their study was reviewed above in section 7.3.2, its contents concerned with the history of sand accumulation and erosion at Westshore, and the ocean processes that are important to the transport of the sand. This study also proposed the construction of a groyne-like artificial reef that would consist of geotextile bags, it being located further to the north so as to help retain the imported sand along Westshore and The Esplanade. Although a conventional rock revetment might serve the same purpose, their proposed artificial reef would have the dual benefit of hopefully containing the sand placed in the Westshore area and providing a site for surfing. The shift of the surfing area from its present site to the north may be needed if the Port decides to extend the arm of its breakwater; doing so would expand the stretch of Westshore that is sheltered from the waves by the breakwater, which would greatly enhance the probability of retaining sand placed at Westshore, but this reduction in the waves would be at the expense of the surfing conditions along Westshore, so would have to be shifted to the north where the waves are not sheltered.

All of these potential developments of the Westshore area require additional investigations, in that the reports by Beca (2003) and Mead et al. (2001) were both of a preliminary nature, directed toward the selection of a potential solution from several options, but without providing the necessary detailed analyses of the recommended options that would be needed in construction and to understand in full the environmental consequences. Furthermore, analyses would be needed where these options are linked, with both the W5 groyne at Whakarire Avenue holding one end of a stretch of sand beach while the artificial reef proposed by Mead et al. (2001) holds its north end. However, even with these two structures limiting the longshore movement of the sand placed on the beach, if this is the fine sand derived from dredging the Port's Fairway, it would still be exposed on the waves arriving from directly offshore and could be expected to be lost into the offshore. Its retention on the beach would then depend primarily on the reduction of the waves by the sheltering of the breakwater, dependent in large part on the future extension of its length. An alternative possibility is to find another source of sand for this beach, one that provides coarser-grained sand that would be stable under even the largest waves expected along this shore.

In that the existing beach nourishment program appears to be sufficient in providing the desired degree of protection of Westshore from erosion and flooding hazards, these proposed developments involving the formation of a sand beach and surfing reef would have the primary objective of improving the recreation at this shore. However, at the same time they could enhance the protection of this shore by creating a composite beach; as reviewed in Section 5 and depicted in Figure 5-1, this type of beach consists of a dissipative sand beach fronting a reflective gravel ridge, the two most stable types of natural beaches when attacked by the forces of the storm processes.

7.5 SUMMARY AND DISCUSSION

The earlier Sections of this report had the objective of reviewing specific aspects of the Hawke's Bay coast, including its tectonic setting, its ocean processes such as the wave conditions and tides, the dynamics of its mixed sand-and-gravel beaches, and questions such as the environmental effects of the construction in the late 19th century of the Ahuriri moles and the Port's breakwater. In contrast, this Section has been more encompassing in its attempt to review the present-day conditions found in the two littoral cells that have been the focus of this report, the Haumoana and Bay View Littoral Cells. This has been a challenge as the review has had to bring together information from a considerable number of reports that have addressed topics such as the sources of sediment to the beaches, the transport of the gravel and sand along the ocean shore by the waves and currents, and the impacts of operations such as the commercial extraction of the beach sediment at Awatoto, and the beach nourishment program at Westshore initiated in 1987. An underlying objective of this review has been to examine the probable causes of the erosion experienced in the communities of Haumoana and Te Awanga in the Haumoana Littoral Cell and at Westshore in the Bay View Cell, and what measures might be taken to alleviate those problems.

It has been seen in this review that these two littoral cells are much different with respect to their beach sediment sources, the transport of that sediment along their shores by the waves, and in the severity of the beach erosion and hazards to shore-front properties. Specifically, the most important differences include:

- The Haumoana Cell has significant sources of beach gravel and sand, derived primarily from the erosion of Cape Kidnappers and contributed by floods in the Tukituki River; in contrast, at present there is very little new gravel being supplied to the beach within the Bay View Cell (the beach nourishment program at Westshore now being the primary source);

- In the Haumoana Cell there is a dominant longshore transport of the gravel and sand to the north under the action of the waves arriving primarily from the southeast; the shoreline of the Bay View Cell is nearly in equilibrium with the waves that reach its shore from directions ranging from the southeast to northeast, so there are frequent reversals in the directions of the sediment movement along its shore but with a near-zero net longshore transport;
- The quantities of beach sediment transported to the north in the Haumoana Cell progressively decrease to the north due to the loss of gravel by abrasion and especially its commercial extraction at Awatoto; the sediment placed on the beach at Westshore in the Bay View Cell is transported to the north where it contributes to those beaches, but again in diminishing volumes as it is lost to abrasion;
- While the beach gravel has not bypassed the Port's breakwater since its construction, and probably only in small amounts prior to that construction, the find-grained sand immediately offshore from the beach continues to be carried past the breakwater, where much of it enters the Fairway to the Outer Harbour;
- The sediment budget for the Haumoana Littoral Cell has a net balance that is significantly in the red (-45,000 m^3/year; Table 7-3), with the debits due to the sediment extraction at Awatoto (-47,800 m^3/year) and gravel abrasion (-30,400 m^3/year) exceeding the credits from sediments contributed to the beach from the Tukituki River and the erosion of Cape Kidnappers; the budget for the Bay View Cell (Table 7-4) is also calculated to be in the red (-15,000 m^3/year), but this assessment is uncertain due to the difficulty in evaluating the loss of gravel to abrasion, the sole debit in the budget;
- The two littoral cells experienced different directions and degrees of land elevation changes at the time of the 1931 Hawke's Bay earthquake, with subsidence having occurred south of Awatoto in the Haumoana Cell, while varying degrees of uplift took place along the shore of the northern half of that cell; in contrast, the full length of the Bay View Littoral Cell experienced a significant degree of uplift, on the order of 2 metres.

As a result of the above differences between the two littoral cells in their sediment sources, overall sediment budgets, associated patterns of sediment transport along their shores, and land-elevation changes at the time of the 1931 earthquake, they have experienced different patterns of shoreline changes and associated erosion problems, requiring different management strategies. Specifically, in the Haumoana Cell:

- In general, the southern half of this littoral cell has experienced significant erosion and flooding problems during major storms, while the northern half has had fewer problems; this pattern results from the northward transport of beach sediment along the shore of this cell, and the land-elevation changes in 1931 with subsidence in the south, uplift in the north;
- The sediment sources in the southern portion of this cell are insufficient to support the high rate of longshore transport to the north, so that significant beach erosion has occurred along the stretch of shore from Cape Kidnappers north to the Haumoana groyne, threatening shore-front properties in Clifton, Te Awanga and Haumoana;
- There are few options available to mitigate the erosion along that south stretch of shore; a program of beach nourishment would require on the order of 50,000 cubic metres of gravel and sand be placed on the beach; the construction of a series of short groynes might help to retain that nourished sediment in front of the threatened homes, to provide the desired level of protection;
- While net sediment accumulation has prevailed along the shoreline in the northern half of this cell, the quantities of sediment reaching that shore have been greatly reduced by the commercial extraction at Awatoto that has averaged

47,800 m^3/year in recent years; the agreement to reduce that extraction to 30,000 m^3/year for ten years and then to halt this operation should result in greater rates of beach sediment accumulation, so the beaches will become an improved buffer between the forces of the storm waves and the shore-front properties;

- The extraction of beach sediment at Pacific Beach in Napier, averaging 13,800 m^3/year, to be used in the nourishment of Westshore, can be expected to be sustainable, especially after the extraction at Awatoto has been halted.

In the Bay View Littoral Cell:

- The uplift of this stretch of shore by about 2 metres at the time of the 1931 earthquake has greatly reduced its susceptibility to erosion and flooding;
- With the absence of significant sediment sources, it can be expected that the orientation and curvature of the shoreline has evolved toward achieving a condition of zero net longshore sediment transport, with the shoreline being approximately congruent with the dominant refracted waves;
- The comparison undertaken by Worley (2002) between the cell's shoreline and the shape of the geometric crenulate shoreline determined by Silvester and colleagues to represent the condition of zero net transport, in part confirms that the cell's shoreline has approximately achieved that equilibrium condition; the main departure between the actual shoreline and the crenulate form is found along Westshore, and this may in part account for its continued erosion, but only a small amount of erosion and shoreline retreat at Westshore should bring it into equilibrium, at that point effectively halting its tendency to erode and to supply a localized longshore sediment transport to the north;
- The shoreline changes at Westshore appear to have been caused primarily by cycles between accretion and erosion of sediments on its beach, the accretion having occurred whenever there is a subtle shift in the waves and currents that produce a southward transport of beach sediment for a few years, while the episodes of beach erosion have occurred when those processes produce a temporary northward transport of the beach sediments;
- The beach nourishment program at Westshore has for the most part been successful in alleviating its beach erosion; the nourished sediment has been transported to the north so it is progressively lost from the South Westshore beach, but it has accumulated along the shore of The Esplanade and further to the north, enhancing their protection from storm erosion and flooding; the placement of more of the nourished sediment on the South Westshore beach, to serve as a feeder beach, should reduce the erosion impacts of storms that have been experienced there.

With the erosion and flooding hazards now largely under control along Westshore, future developments can focus on improvements that would support the increased recreational use of its beach, which at the same time could provide a still greater level of protection from erosion. Interest in such developments have primarily centered on the formation of a sand beach. As reviewed in this Section, this could involve the construction of a groyne that trends obliquely to the shoreline along Whakarire Avenue, having the purpose of replacing the existing seawall in protecting the properties there, but also having the benefit of establishing a sheltered pocket where a stable sand beach could form. There has also been interest in the development of an artificial surfing reef further along the shore to the north, positioned to act as a groyne to help retain sediment placed along the shores of South Westshore and The Esplanade. It is possible that together these two structures might be able to contain a stretch of sand beach between them, which would be a recreational asset while at the same time providing additional protection from erosion. However, at this stage the potential for these undertakings and their expected success are speculative, as only initial investigations have been completed. But if further investigations indicate that they are feasible, such an undertaking would benefit the community as a whole, perhaps resulting in enhanced tourism, and as expressed by Ross (1994, page 36) with respect to finding a solution for the perceived problems at Westshore: " . . . ensure it can be sustained environmentally, culturally, socially, and economically."

7.6 REFERENCES

Beca (2003) *Remedial Work to Counter Erosion at Westshore, Napier*: Report to the City of Napier, November 2003, Beca Carter Hollings & Ferner Ltd.

Bruun, P. (1962) Sea level rise as a cause of shore erosion: *Journal of Waterways and Harbors Division*, Amer. Soc. Civil Engrs., v. 88, p. 117-130.

Campbell, M. D. N. (1975)*Story of Napier 1874-1974 (Footprints Along the Shore)*: Published by the Napier City Council, 252 pp.

Carr, J. T. (1893) *Report to the Board by the Chief Engineer*: Napier Harbour Board, 18 July 1893, Port of Napier Ltd.

Cotton, C.A.C. (1956) Hawke Bay coastal types: *Trans. Royal Society of New Zealand*, v. 83, n. 4, p. 687-694.

Edmondson, G. (2001) *Lower Tutkituki River: Assessment of Gravel Supply and Sustainable Annual Extraction Volume*: report to the Hawke's Bay Regional Council.

Finch, F. (1919) *Engineers Report to the Harbour Board, Napier.*

Fisher, S. M. (1976) *Hawke's Bay Harbour Board, Breakwater Harbour South Groyne*: Report to Napier Harbour Board, Napier, 4 typed pages plus diagrams and Appendix.

Gestro, B.L. (1992) *Westshore Beach Nourishment - Progress Report*: Hawke's Bay Regional Council, Technical Services Department Investigations.

Gibb, J.G. (1973a) *Report on Coastal Processes and Erosion: Southern Hawke's Bay, Haumoana to Clifton*: report to the Hawke's Bay Catchment Board from the Ministry of Works and Development, 18 pp.

Gibb, J.G. (1973b) *Report on Coastal Processes and Erosion, Southern Hawke's Bay*: Haumoana to Clifton: 4 pp.

Gibb, J.G. (1975) *Coastal Engineering, Southern Hawke's Bay: Haumoana to Clifton*: 21-22 Feb. 1974, 5 pp.

Gibb, J. G. (1983) Combating coastal erosion by the technique of coastal hazard mapping: *New Zealand Engineering*, v. 38, n. 1, p. 15-19.

Gibb, J. G. (1994) *Standards and Information Requirements for Assessing Coastal Hazard Zones for New Zealand*: Coastal Management Consultant, 73 pp.

Gibb, J. G. (1996) *Coastal Hazard Zone Assessment for the Napier City Coastline between the Ahuriri Entrance and Esk River Mouth*: Report prepared for Napier City Council, C.R. 96/2, 80 pp.

Gibb, J. G. (2002) *Review of the 1996 Coastal Hazard Zone Between Ahuriri Entrance and Esk River Mouth*: Report prepared for Napier City Council, C.R. 2002/1, 56 pp + Appendix.

Gibb, J. G. (2003) *Review of the Westshore Nourishment Scheme — Napier City*: Report prepared for Napier City Council, 40 pp + diagrams.

Grant, P. J. (1965) Major regime changes in the Tukituki River, Hawke Bay, since about 1650: *Journal of Hydrology (New Zealand)*, v. 4, n. 1, p. 17-30.

Grant, P. J. (1982) Coarse sediment yields from the Upper Waipawa River Basic, Ruahine Range: *Journal of Hydrology (New Zealand)*: v. 21, p. 81-97.

Grant, P. J. (1985) Major periods of erosion and alluvial sedimentation in New Zealand during the Late Holocene: *Journal of the Royal Society of New Zealand*, v. 15, n. 1, p. 67-121.

Healy, T.R., and R. G. Dean (2000) Methodology for delineation of coastal hazard zones and development set-back for open duned coasts: In *Handbook of Coastal Engineering*, v. 4, edited by J. B. Herbich, pp. 19.1-19.

Hemmingsen, M.A. (2004) *Reduction of Greywacke Sediments on the Canterbury Bight Coast, South Island, New Zealand*: Ph.D. thesis, University of Canterbury.

Hill, H. (1897) Hawke's Bay plain: past and present: *Transactions New Zealand Institute*, v. 37, p. 515-537.

Hsu, J. R. C. and R. Silvester (1997) *Coastal Stabilisation*: Advanced Series on Ocean Engineering, v. 14, World Scientific Publishing Co.

Hull, A.G. (1990) Tectonics of the 1931 Hawkes Bay earthquake: *New Zealand Journal of Geology and Geophysics*, v. 33, p. 309-320.

Hume, T., D.S. Roper and R.G. Bell (1989) *Dredge Spoil Disposal Offshore from the Port of Napier*: Report prepared for Port of Napier Limited, 55 pp + diagrams.

IPCC (2001) *Climate Change 2001: The Scientific Basis*: Editied by Houghton, J. T., and others, Cambridge University Press, Cambridge, UK.

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

Kirk, R. M., and M. B. Single (1999) *Coastal Change at Napier with Special Reference to Erosion at Westshore: A Review of Causative Factors*: Land and Water Studies International Ltd., Christchurch, 55 pp. + diagrams.

Komar, P. D. (1973) Computer models of delta growth due to sediment input from rivers and longshore transport: *Geological Society of America Bulletin*, v. 84, p. 2217-2226.

Komar, P. D. (1996) The budget of littoral sediments — concepts and applications: *Shore & Beach*, v. 64, p. 18-26.

Komar, P. D. (1997) *The Pacific Northwest Coast: Living with the Shores of Oregon and Washington*: Duke University Press, Durham, North Carolina, 195 pp.

Komar, P. D. (1998) *Beach Processes and Sedimentation*: 2nd edition, Prentice-Hall, Upper Saddle River, New Jersey, 544 pp.

Komar, P.D., J.J. Marra and J. C. Allan (2002) Coastal-erosion processes and assessments of setback distances: *Proceedings, Solutions to Coastal Disasters Conference*, Amer. Soc. Civil Engrs., p. 808-822.

Koutsos, P. 'Takis' (1993) *The Westshore Beach Nourishment Scheme*: IPENZ Conference, 9 pp.

Marshall, P. (1927) The wearing of beach gravels: *Transactions of the Royal Society of New Zealand*, v. 58, p. 507-532.

Marshall, P. (1929) Beach gravels and sands: *Transactions of the Royal Society of New Zealand*, v. 60, p. 324-365.

Marshall, P. (1933) Effects of the earthquake on the coastline near Napier: *New Zealand Journal of Science and Technology*, v. 15, p. 79-92.

McBryde, D, and P. Koutsos (1989) *Heretaunga Plains Gravel Resource Management Plan*: Hawke's Bay Catchment Board, 42 pp + Apendices.

McBryde, D, and I. Heslop (1989) *Westshore Main Beach Coastal Erosion*: Hawke's Bay Regional Council, 24 pp + Appendices.

Mead, S., K. Black, and P. McComb (2001) *Westshore Coastal Process Investigsation*: ASR Consultants, prepared for the Napier City Council, 142 pp + Appendices.

O'Callaghan, R. B. (1986) *Report on the Coastal Protection of Westshore Beach, Napier*: 11 pp + diagrams.

Oldman, J.W., and R.K. Smith (1998) *Westshore Coastal Protection Options Study*: Unpublished report to Napier City Council, NIWA, Hamilton, 38 pp.

Oldman, J.W., R. K. Smith and R. Ovenden (2003) *Coastal Erosion Hazard Assessment of the ForeshoreSites between Gill Road and Franklin Road, Bay View, Hawke Bay*: NIWA Report for Foreworld Development Ltd., Napier, 64 pp.

Ross, M. (1994) *Westshore Beach Erosion: An Analysis of the History and Issues and Recommendations for Effecting Change*: Unpublished Report by Vital Information Ltd., Napier to the Westshore Residents and Development Association, 42 pp.

Saunders, F. (1882) *Memoranda on the Port of Napier*: Napier Harbour Board Report, 5 pp.

Silvester, R., and S. K. Ho (1972) Use of crenulate-shaped bays to stabilize coasts: *Proceedings of the 13th Coastal Engineering Conference*, Amer. Soc. Civil Engrs., p. 1347-1365.

Simons, P.K., and P. Koutsos (1985) The East Clive Experience: *Proc. 1985 Australasian Conf. on Coastal and Ocean Engineering*, Christchurch, v. 1, p. 453-467.

Single, M.B. (1985) *Post-Earthquake Beach Response, Napier, New Zealand*: Master of Arts Degree, University of Canterbury, 150 pp.

Smith, R.K. (1968) *South Hawke Bay Beaches: Sediments and Morphology*: M.A. thesis, University of Canterbury, Christchurch.

Smith, R.K. (1977) *Coastline Changes and Beach Sediments in Southern Hawke Bay*: Unpublished report, Ministry of Works and Development, Napier.

Smith, R. K. (1984)*Beach Changes Between Napier and Clifton, southern Hawke Bay*: Water Quality Centre Publication No. 5, Water Quality Centre, DSIR, Hamilton, 63 pp.

Smith, R. K. (1985) *Historical Beach Surveys of the Western Spit, Hawke Bay, 1916-1984*: Internal Report No. IR/85/4, Water Quality Cetre, Hamilton.

Smith, R. K. (1986) *Coastal Erosion at Westshore, Hawke Bay*: Ministry of Works and Development, Water Quality Centre, Hamilton, Internal Report No. IR/85/11.

Smith, R. K. (1993) *Westshore Beach Erosion Review*: Report to Napier City Council, NIWA, Hamilton, Consultancy Report No. NAP004, December 1993, 17 pp.

Smith, R. K. (1995) *Assessment of the Westshore Beach Protection Scheme and the Effectiveness of the Beach Nourishment Programme in Stabilising the Beach and the Coast Downdrift*: prepared for Napier City Council, NIWA Consultancy Report NAP300, 11 pp.

Stevenson, H. K. (1977) *Port and People: Century at the Port of Napier*: Hawke's Bay Harbour Board.

Tonkin & Taylor (2003) *Regional Coastal Hazard Assessment*: Volume I Assessment; Volume II Sumaries for Local Communities; Volume III Beach Profile Data Analysis; prepared for the Hawke's Bay Regional Council.

Tonkin & Taylor (2004) *Hawke's Bay Coastal Cliff Mapping and Shoreline Erosion Assessment*: report to the Hawke's Bay Regional Council.

Tonkin & Taylor (2005) *Shoreline Modelling Report*: report to the Hawke's Bay Regional Council.

White, J. L. (1994) *Coastal Processes — Nearshore Suspended Sediment in Hawke Bay*: Hawke's Bay Regional Council, Technical Services Department Investigations, 125 pp.

White, J. L., and T.R. Healy (2000) Volume changes on a sand gravel barrier at a groyne construction, Haumoana, Hawke Bay, New Zealand: International Coastal Symposium 2000, *Journal of Coastal Research*, Special Issue 34, p. 295-305.

Williams, G. J. (1986) *Westshore Beach-Nourishment Scheme*: Hawke's Bay Catchment Board and Regional Water Board, 13 pp.

Worley (2002) *Port of Napier: Shoreline Effects of Stage 1 and Ultimate Development*: 28 November 2002 report to the Port of Napier, Worley Infrastructure Pty Ltd, Perth, Australia.