8 Summary and Discussion: Science and the Management of the Hawke's Bay Coast

8.1 INTRODUCTION

The focus of this report has been on the 40-kilometre stretch of the Hawke's Bay shore that extends from Tangoio Bluff in the north to Cape Kidnappers in the south. By and large this is a self-contained stretch of coast, at least in terms of the sand and gravel found on its beaches, with these bounding rocky headlands permitting little or no exchange of that sediment with the shores further to the north and south. Two littoral cells are recognized within this stretch of shore, the Bay View Littoral Cell to the north and Haumoana Littoral Cell to the south, separated by Bluff Hill (Scinde Island) located in Napier, which together with the Port's breakwater restricts the exchange of beach sediments between their shores.

This stretch of coast has experienced significant changes, brought about by natural events and processes, but also caused by the impacts humans have had on the physical environments of Hawke's Bay. The rocks in its mountains and those forming features such as Cape Kidnappers and Bluff Hill attest to the significance of its tectonic activity, characterized by major earthquakes and associated changes in the landscape due to the collision of two of the Earth's major tectonic plates along the Hikurangi subduction zone. Direct evidence for the importance of this tectonic setting came with the occurrence of the Hawke's Bay earthquake in 1931 that resulted in the general uplift of the coast by on the order of 2 metres, causing the drainage of much of the Ahuriri Lagoon. Acting without pause on the shoreline of Hawke's Bay have been the natural processes of the ocean, its tides and waves, which at times of storms combine with a force that is able to erode the rocks of the sea cliffs and rearrange the gravel and sand in the beaches. About eight hundred ago with the arrival of the Maori, and especially following the settlement by Europeans during the past two centuries, a new force of coastal change was introduced to Hawke's Bay through our alterations of the natural environment. These have included the deforestation of the watersheds of the rivers that flow into the bay, the mining of gravel from the rivers and beaches, and the construction of the harbour moles and breakwater at Napier. As we see it today, the coast is the product of the forces of Nature and the changes brought about by human settlement.

The uncertain consequences and continued effects of these natural and human forces have made it a challenge to manage the Hawke's Bay shore. In an effort to better understand their respective roles in the evolution of this coast, and thereby to support better management strategies, a number of research investigations have been conducted by coastal scientists and engineers. Their studies have led to the recognition that because the rivers have been important sources of gravel and sand to the beaches, the research cannot be confined to the shore but necessarily must also consider the natural process and human-induced alterations of the watersheds, particularly those that have changed the quantities of sediments that reach the coast. Those research investigations over the years have collectively resulted in a considerable number of reports. While each has made contributions through increasing our understanding of the physical environments of Hawke's Bay and of the processes acting along it shores, at times their conclusions are seemingly at odds with one another; this has led to a degree of confusion when management decisions have had to be made.

The objective of this report has been to provide an independent review of those studies, to yield a synthesis of our present understanding of the causes of shoreline change at Hawke's Bay, particularly those that have been significant to occurrences of beach and property erosion. Important in this review has been an identification of any missing elements in our understanding of the Hawke's Bay shore, in spite of the considerable number of past studies. While each of the individual Sections in this report has provided a summary and discussion of its specific topics, the purpose of this Section is to provide an overall summary, one that includes recommendations as to priorities for future investigations by coastal scientists and engineers. The summary here includes five topics: Tectonics, Natural Processes, Human Impacts, Harbour Development, and Management Issues. To a degree these topics correspond with those of the individual Sections of this report, but with some degree of overlap.

8.2 TECTONICS AND LAND ELEVATION CHANGES

The tectonic setting of a coast is important to its long-term geologic evolution, spanning millions of years, and in the shorter term through its effects on the present-day land elevation changes. On most coasts the tectonic effects are slow and progressive, with the most important aspect being how the elevation of the land changes with respect to the on-going global (eustatic) rise in sea level, the resulting relative sea-level change determining in large part whether the shoreline migrates landward, resulting in the erosion of coastal properties, or slowly shifts seaward.

More so than on most coasts, the tectonic setting of Hawke's Bay has been extremely important to its evolution. With the collision and subduction of the Pacific plate beneath the Australian plate occurring along the Hikurangi Trough close offshore, the resulting compression of the rocks beneath the Heretaunga Plain and in the Ruahine and Kaweka Ranges of mountains has produced earthquakes having magnitudes of 7 to 8. Important has been the accompanying land elevation changes due both to the earthquakes and the compressional folding of the rocks, which has resulted in some areas being uplifted while others have undergone long-term subsidence. Most significant since European settlement was the 1931 Hawke's Bay earthquake, which had a magnitude of 7.8 and produced an uplift on the order of 2 metres along the shore of the Bay View Littoral Cell, but smaller degrees of uplift southward along the shore of the Haumoana Cell until south of Awatoto there was some subsidence of the shoreline. Land elevation changes of that scale have had major consequences to the coast, including determining the degrees of beach erosion and property losses. Prior to the uplift, the low gravel beach ridges were frequently overtopped during storms under the enhanced tides of the storm surge that flooded backshore properties, which were then attacked by the storm waves. With the beach ridges now being some 2 metres higher due to the tectonic uplift, overtopping seldom if ever occurs along most of the shore. The inland portions of those uplifted areas were also considerably altered, most notably having been the drainage of the Ahuriri Lagoon, converting much of it to dry land. At the same time, though limited in its coastal extent to that south of Awatoto, the subsidence there has been a continuing factor in the pervasive erosion of that shore since 1931, and may also have altered the drainage of the Tukituki River so it supplies smaller volumes of sand and gravel to the beaches.

While the tectonics of Hawke's Bay are fundamental to the evolution of its shore, evident in the changes that occurred during the 1931 earthquake which are still important to the alongcoast variability in beach erosion, inclusion of research on this topic is likely beyond the directive of the Hawke's Bay Regional Council or other local agencies. Much of the ongoing research concerned with the tectonics and associated geology is being conducted by the Institute of Geological and Nuclear Sciences. Of particular interest is their research that is directly relevant to the prediction of future land elevation changes and occurrences of earthquakes, which could generate tsunami that are a major natural hazard faced along the Hawke's Bay coast. As reviewed in Section 2, the 1931 Hawke's Bay earthquake reversed the general pattern of land elevation changes, in particular in the area of the Ahuriri Lagoon and along the shore of the Bay View Cell. Prior to that event this area had predominately experienced subsidence for thousands of years, so its uplift appears to have represented a distinct reversal. It is uncertain whether this change from subsidence to uplift signifies a shift in the overall tectonics of the region, such that future earthquakes will again produce uplift, or will result in renewed land subsidence. At the same time there is the threat of fault movements and earthquakes in the offshore that could result in the generation of large tsunami waves, posing a major threat to the Hawke's Bay coast.

Of particular concern are the directions and rates of land elevation changes currently underway along the shores of Hawke's Bay, as this determines the alteration in the level of the land relative to the global rise in sea level, important to the extent of shoreline erosion expected during this century. Research is underway that is based on measurements using the Global Positioning System (GPS), which relies on satellites to establish positions on the surface of the Earth with millimetres accuracy, and how those positions change with time. Its results may eventually prove to be the key in determining the ongoing rates of land elevation changes throughout Hawke's Bay. Thus far those measurements have been employed to detect the horizontal movements of the ground, which are of interest in that wherever there is a change in the rate or in the direction of ground movement, it could reflect the progressive deformation of the rocks with the potential for the generation of an earthquake. In the future we can also expect data that will document the vertical movements of the land, its changing elevations, which are much smaller than the horizontal movements and therefore take longer to determine. Such measurements for the land elevation changes can then be combined with an estimate of the global (eustatic) rise in the level of the sea, to provide us with our first assessments of the relative sea-level changes along the entire length of the Hawke's Bay shore. Such data will be of particular relevance in applications such as the improved evaluations and projections of shoreline changes and areas expected to experience the highest rates of beach and property erosion.

With a recorded history spanning only about two centuries, New Zealand has a short written record of tectonic events such as occurrences of major earthquakes. For Hawke's Bay this record has included only earthquakes generated by faults located within the Australian plate; there has not been a major subduction earthquake along the Hikurangi Trough, which can be expected to be more destructive as evident in the 2004 Sumatran earthquake and tsunami. As reviewed in Section 4, this possibility has been included in assessments by the Institute of Geological and Nuclear Sciences of the potential heights of the tsunami, and they have also considered the potential for tsunami generated by underwater landslides. Their analyses indicate that substantially larger and more destructive tsunami could occur in the future, than have impacted the shores of Hawke's Bay during the past two centuries.

8.3 NATURAL PROCESSES AND BEACH DYNAMICS

Perhaps most fundamental to the management of the Hawke's Bay coast is the collection and analysis of data for the range of ocean processes: the heights and periods of the waves, particularly those that occur during major storms; the elevations of tides, both predicted and measured; the generation of storm surges and their extreme elevations that can result in coastal flooding and erosion; and a determination of the progressive rise in sea level. These processes have been reviewed primarily in Section 4. Also important is the ability to predict how the beaches respond to those processes, in particular how their slopes and elevations change at times of major storms, with the development of beach and property erosion. The prediction of the beach responses has been a problem for Hawke's Bay in that they are composed of mixtures of sand and gravel, a type of beach that has been the focus of much less scientific and engineering research than sand beaches. A review of the beach morphodynamics was presented in Section 5, both in terms of what we know in general from research that has been undertaken on mixed sand-and-gravel beaches throughout the world, with that completed on the Canterbury coast of the South Island being most relevant, and then specifically from research studies of the Hawke's Bay beaches and information derived from the monitoring program. The collection and analysis of data for the ranges of ocean processes and beach responses in Hawke's Bay is crucial to understanding the long-term evolution of this coast, but in particular for determining the causes of shoreline erosion problems, and in that connection it has served as the basis for the establishment of hazard zones designed to maintain homes and other developments safe from future occurrences of extreme erosion and flooding.

While measurement programs are underway to obtain quality data for the tides and waves in Hawke's Bay, their collection was initiated only in recent decades so the record lengths are short, this representing a limitation for their use in applications. Tide-level data have been collected by the Port of Napier's tide gauge only since 1986, with higher quality electronic records available beginning in February 1998. While this length of data collection has been sufficient for the harmonic analyses of the tides, required in the routine prediction of the daily astronomical tides, the record is too short for the confident prediction of extreme tides that are affected by atmospheric and oceanic processes, which are important to projections of potential coastal erosion and flooding, and in the engineering design of shore protection structures and harbour facilities.

Tide-gauge records have been important throughout the world in determining the local relative change in sea level during the past 50 to 100 years, affected by both the global rise in sea level and any local land elevation changes. This approach is not possible for Hawke's Bay due to the short span of available tide measurements; at least another 25 years of tide records would be needed to determine with confidence the relative change in sea level at Napier. This is unfortunate in that an assessment of the present rise in the relative sea level, and its projection into the future with a potential acceleration due to global warming, are important to include in evaluations of coastal hazard zones. It may be, however, that as reviewed in Section 2 and noted above, the ongoing program of measuring the horizontal and vertical changes in crustal positions using the Global Position System (GPS) will provide sufficient documentation of the land elevation changes occurring throughout Hawke's Bay, which can be combined with the tide-gauge record to determine the relative sea-level rise for this coast.

The wave climate for Hawke Bay is based on a combination of deep-water hindcasts of wave heights, periods and directions for the years 1979-1998 made by NIWA, and measurements in 15 metres water depth seaward from the breakwater by a wave-rider buoy installed in August 2000 by the Port of Napier. This combination of hindcasts and buoy-measured waves provides a reasonable documentation of the seasonality of the wave climate in terms of monthly changes in wave heights, periods and directions, but uncertainties remain in the projection of potentially extreme values, the waves that could be generated by the 50- to 100-year storms. There is evidence that the hindcast techniques may under-predict the wave heights generated by major storms, so this needs to be resolved by additional research. To date the Port's wave buoy has collected only five years of data, so we can only project with confidence the 15-year "extreme" event, far short of the desired potential extremes. In addition, the Port's program of wave data collection is in relatively shallow water so its measurements are not directly comparable with the hindcast results that are for deep water well offshore. Such a comparison is further complicated by the shallow nature and geometry of Hawke Bay, which becomes even more of an issue when attempting to assess the wave conditions along the shore in analyses of the erosion and flooding hazards. With the wave shelter provided by Bluff Hill and the Port's breakwater, the refraction of the waves as they travel from deep water and approach the beaches of Ahuriri and Westshore results in a marked reduction in wave heights and energy levels along the shore. The recently completed wave refraction analyses by Tonkin & Taylor have made a significant contribution in projecting the deep-water wave climate to the 10-metre depth contour along the coast of Hawke's Bay, but their analyses need to be extended to the nearshore in order to better establish the climates of the surf zone wave processes, to assess the ranges of wave breaker heights and swash runup elevations on the beaches, the processes that are most relevant to beach erosion and backshore flooding.

A significant missing component in the studies of the Hawke's Bay beaches has been in the area of collecting direct measurements of those nearshore processes. While there have been model analyses to predict the wave breaker heights and swash runup elevations along the shores of Hawke's Bay after refracting the waves from deep water, undertaken as part of evaluations of coastal hazard zones, minimal effort has been directed toward the collection of actual measurements of those processes. Such data are needed to at least test the results of the model analyses, but it would be preferable to collect sufficient measurements to more generally evaluate how the heights of breaking waves and runup elevations statistically vary along the Hawke's Bay shore. There is special need for such studies in that the analysis techniques used in the prediction of wave runup levels on mixed sand-and-gravel beaches remain uncertain due to the effects of the proportions of gravel and sand on the overall permeability of the beach deposits. A confirmation of our modeling techniques used to assess these processes on the Hawke's Bay beaches is critical since they are basic to the process-based evaluations of coastal hazard zones, including the potential for property erosion and inundation during extreme storms. In that this application focuses on extreme events, with evaluations of the wave breaking heights and swash runup levels during the 50- to 100-year storm events, my recommendation is the collection of such data at times of major storms be given priority in future investigations. This could involve the establishment of a network of volunteer coastal observers, who can rapidly respond during a storm to obtain visual estimates at select survey sites of wave breaker heights, periods and angles, and measurements of the runup elevations of the wave swash at those sites. This effort needs to be integrated into the beach monitoring program so as to correspond with sites where beach profiles are routinely surveyed, with surveys repeated immediately after the occurrence of the storm to document the beach morphology responses. The collection of such data at a number of sites along the Hawke's Bay shore could then be employed to verify hindcast analyses of the hourly variations in the measured tides plus the calculated swash runup elevations during the storm, which are then compared with the measurements as a test of the model analyses. This effort would also severe as the basis for examinations of the changes in the beach profiles during major storms, including assessments of the cross-shore transport of the gravel and how it alters the beach profiles, its slopes and crest elevations.

Beyond these recommended additions to the beach monitoring program to provide process measurements and beach profile responses during major storms, it is also recommended that a select number of profiles in the program be systematically surveyed more frequently than the present annual basis, preferably once a month or at least seasonally so as to better define their degrees of variability and the cause of this variation with respect to the seasonality of wave heights and runup elevations, and changes in the measured tides that are enhanced by ocean water temperatures and storm surges. As reviewed in Section 5, studies of mixed sand-and-gravel beaches have revealed somewhat different patterns of cross-shore sediment transport from one beach to another, and the resulting profile responses to the seasonal variations in these processes and during major storms, so this needs to be documented specifically for the Hawke's Bay beaches.

While the directions of the longshore transport by waves of the gravel on the Hawke's Bay beaches can be established by the locations of the gravel sources (the Tukituki River and sea cliff erosion at Cape Kidnappers) and the dominant directions of the waves reaching its shores, it is difficult to evaluate the actual quantities of gravel being transported on average each year, and the attempts to do so have yielded divergent results. Assessments of the northward transport of gravel along the shore of the Haumoana Littoral Cell is of greatest interest in that it is affected by the progressive loss of gravel particles through their abrasion, which is also difficult to assess, and by the commercial extraction of beach sand and gravel at Awatoto. Of concern is that the volumes of the longshore gravel transport are much reduced from an estimated average rate that is on the order of 50,000 cubic metres per year at the south end of the littoral cell to on the order of 6,000 cubic metres per year at the north end; the concern is the maintenance of the volume reaching the beaches to the north, sufficient to permit some extraction for its use in beach nourishment at Westshore, while still maintaining a wide safe beach along the Marine Parade. Improvements in the basic analysis techniques used to evaluate the rates of longshore sediment transport on mixed sand-and-gravel beaches, and of rates of gravel abrasion during transport, must await additional research undertaken by coastal scientists and engineers. In the mean time it may be possible to undertake investigations on the Hawke's Bay shore to monitor the longshore transport of the gravel; for example, there have been recent advances in the techniques of tagging individual gravel particles so their movements along the shore can be followed for decades, providing data on their longshore transport rates and even on their rates of abrasion.

The limitations noted here and discussed in detail in Section 4, in the collection of process data for the Hawke Bay waves, tides and sea levels, can be resolved only by the passage of time so that sufficiently long records become available to satisfactorily define their potential extremes, those expected in a 50- to 100-year time frame. Beyond that, my assessment is that the most significant missing component in our understanding of the Hawke Bay ocean processes are those occurring in the nearshore, the processes of wave breaking and particularly of the swash runup intensities and levels on the beaches. In that predictions of these processes at times of major storms, together with the resulting changes in the beach morphology, are of fundamental importance to analyses of beach erosion and backshore flooding during storms, I recommend that this be given the highest priority in future studies of the Hawke's Bay coast. Additional suggestions for studies are provided in the detailed reviews in Sections 4 and 5, respectively for the ocean processes and beach responses.

8.4 HUMAN IMPACTS ON THE ENVIRONMENT

In addition to the forces of Nature, important to the coast are the impacts humans have had on the physical environment. Our modifications of the Hawke's Bay region began with the arrival of the Maori about eight hundred years ago, but on a much larger scale when Europeans settled this region beginning in about 1830. Our effects on the environment have been wide ranging, including the deforestation of the watersheds of the rivers that flow into the bay, the grazing of cattle on those cleared lands, the extensive modifications made to the rivers including the mining of sand and gravel, and the construction of embankments to prevent flooding of the newly developed agricultural and urban lands. At the same time, there have been changes in the environment brought about by natural variations in the Earth's climate. It can be difficult to separate out the effects of humans versus natural changes, to determine which has been more important to the observed alteration of the physical environment. From the research that has been completed in Hawke's Bay, it is clear that both have been important.

This was the focus in Section 3 of this report, included because it is important in the management of the Hawke's Bay coast to understand the historic and continuing changes in the physical environment produced by humans and variations in the climate. This aspect of the review differed from other Sections of the report, being more historic. Accordingly, much of it focused on the history of human settlement in the Hawke's Bay region, and the scale of the associated environmental changes. Of primary interest were the changes in the river watersheds, this being important to the delivery of sand and gravel by the rivers to the coast, fundamental to the maintenance of the beaches. Particularly important has been the commercial extraction of sand and gravel, from both the rivers and beaches. The extraction of sediment from the rivers is viewed as a positive management strategy undertaken to reduce channel aggradation that can lead to increased flooding, whereas the resulting reduction in the volumes of gravel and sand that reach the ocean beaches represents a negative strategy in terms of the management of the coast. As related in Section 3, there is considerable anecdotal evidence for the mining of the gravel from the beaches, as well as from the rivers, extending back to the earliest decades of European settlement. Today there is active commercial extraction of beach sediment at Awatoto that annually removes tens of thousands of cubic metres. Any mining of sediment, whether from the rivers or after the sediment has reached the beaches, can significantly alter the "budget of beach sediments", the balance between the contributions by the sediment sources versus the various losses after the sediment has reached the beaches, potentially resulting in a greater degree of erosion and flooding of shore-front properties.

The second half of Section 3 was devoted to a review of the scientific research that has been undertaken in the river watersheds, with the primary attention given to the sediment yields and the capacity of the rivers to transport the sediment to the coastal beaches. Of interest were studies that are relevant to the effects of humans and changes in the climate on the sediment yields. The earliest of the published studies was that of Hill in 1897, who took particular interest in the occurrence of destructive floods during the period of early settlement that damaged the outlying communities on the Heretaunga Plain and flowed through the streets of Napier. While much of his study considered the formation of the Plain by the sediments carried in floods spanning thousands to millions of years, Hill was also interested in the impacts humans have had through deforestation of the watersheds, which would have enhanced the discharges of the floods and the quantities of sediment they carried. Hill offered a number of recommendations directed toward the improved management of the watersheds and rivers in order to reduce the problems with flooding and channel aggradation; many of his recommendations have been adopted and continue to be practiced.

The research undertaken by Patrick Grant (a hydrologist with the Hawke's Bay Catchment Board and later with the Water and Soil Division of the Ministry of Works and Development in Napier), resulted in journal publications that range in dates from 1965 to 1985, and his book "Forests of Yesterday" published in 1996. His research demonstrated that variations in New Zealand's climate have greatly affected the forests, with periods characterized by extreme storms that downed trees throughout the country. Specifically in Hawke's Bay, he showed that these periods of storm impacts on the forests immediately resulted in greater rates of erosion of the upper watersheds, and the transport of increased quantities of sediment down streams where it was eventually deposited to aggrade the river channels and form fluvial terraces in the lower watersheds. According to Grant's research, these quantities of sediments were substantial due in part to the geology of the Ruahine Range where the rocks are highly shattered and easily eroded; the sediment yields found in his research were greater than in most other watersheds throughout the world.

In spite of the large quantities of sediments being eroded from the Hawke's Bay watersheds and transported down the rivers, much of that sediment was found by Grant to have been deposited along the middle reaches of the rivers, where there is a sufficient change in channel slope that the coarsest gravel particles cannot be transported any further; this must significantly reduce the quantities of gravel reaching the coast, available to form the beaches. In contrast, the finer grained silt and sand is rapidly carried to the mouths of the rivers, where it enters Hawke Bay, but is generally too fine to form beaches. From this research it is apparent that the conditions found in the watersheds and rivers, and how they are managed, ultimately are important in determining the quantities and grain sizes of sediment that reach the ocean beaches. It is also certain that in the long term both human impacts on the environment and variations in the climate have played important roles.

It was not the intention of this review of the human environmental impacts and of the changing climate to offer recommendations for future research. The review provided in this report has only scratched the surface of those subjects, and was undertaken primarily to demonstrate that these factors have been important in the past, and continue to be so in the management of the coast. Considerations of our coastal beaches cannot be divorced from what happens in the interior, within the watersheds of the rivers where the erosion and transport of gravel and sand to the coast is important to the maintenance of the beaches. Any changes in the watersheds eventually have consequences on the coast.

8.5 HARBOUR DEVELOPMENT AND SHORELINE CHANGES

The construction of jetties and breakwaters along the world's coastlines has commonly resulted in beach and property erosion, wherever those structures blocked the natural movement of the beach sediment along the shore. There was the potential for similar impacts on the Hawke's Bay shore when the moles (jetties) were constructed in 1876-1879 on the entrance to the Ahuriri Lagoon, and then with the construction of the Port's breakwater in 1887-1890. Erosion did occur along Westshore at that time, and some researches have assumed or concluded from their analyses that the construction of the moles, and in particular the breakwater, were responsible. However, other researchers have argued against these structures having caused the erosion at Westshore. More than a century after the construction, this disagreement continues.

Due its continuing importance, the entire Section 6 of this report was devoted to an examination of the question of whether or not the construction of the moles and then the breakwater blocked a net longshore transport of beach gravel and sand that had bypassed the Bluff Hill headland, with the erosion at Westshore having occurred because it is located downdrift from those structures. This in essence has been the interpretation of the coastal scientists and engineers who lay the blame for the erosion on the harbour construction.

Part of the problem faced in resolving these divergent views has been the relatively poor documentation of the changes that occurred along the Hawke's Bay shore at the end of the 19th century when the moles and breakwater were constructed. With this having transpired more than a century in the past, any analysis of the impacts of harbour development depends on an historic reconstruction of the beach responses and shoreline changes, but viewed with our present-day knowledge of what can happen when jetties or breakwaters are constructed on a coast. For this reason, Section 6 began with a review of examples of the impacts of jetties (moles) and breakwaters on other coasts, examples that have been better documented and included research investigations into the effects those structures had on the ocean processes that were responsible for the zones of shoreline erosion. This review included my research on the Oregon coast where jetties were constructed on inlets during the early 20th century, with the resulting shoreline changes having been well documented by frequent surveys.

The typical pattern is that when jetties are constructed that block the longshore transport of the beach sediment, they in effect act like a dam so that sediment accumulates on the updrift side of the jetties while beach erosion occurs on their downdrift side where the sediment can no longer be carried. Of interest in our studies of jetty construction on the Oregon coast was the fact that there is not a net longshore transport of beach sediment to be blocked by their construction; we found that the construction did result in a degree of altered shorelines, but having a symmetrical pattern such that the beaches to both sides of the jetties accumulated sediment, while the beaches more distant from the jetties experienced a small degree of erosion to supply a portion of that sand accumulation. The consequences of jetty construction on the Oregon coast were therefore much less than experienced on coasts where jetties do block a net longshore transport of the beach sediment. The review in Section 6 of the impacts from the construction of breakwaters included the examples of the Santa Barbara breakwater on the coast of California, and the Timaru breakwater on the South Island. In both of these examples the breakwaters blocked a longshore transport of beach sediment, with the general pattern again being beach accretion on the updrift side and erosion in the downdrift direction, but made more complex than the case of jetties due to the patterns of wave refraction and diffraction in the sheltered lee of breakwaters that reduced the wave heights and changed their angles of breaking at the shore. Those changes in turn altered the directions and rates of the longshore sediment transport, but with the sediment in some cases being carried into the wave-sheltered zone behind the breakwater, resulting in harbour shoaling.

The review in Section 6 focused primarily on an examination of what can be discerned regarding the beach sediment movements and resulting shoreline changes when the Ahuriri moles and breakwater for the Outer Harbour were constructed on the Hawke's Bay shore. This review involved reading the historic accounts written at the time of the construction, principally the memoranda of Saunders and Carr written respectively in 1882 and 1893. Being first-hand accounts by the successive Chief Engineers of the Napier Harbour Board, the descriptions of the coastal processes prior to the harbour construction and the subsequent changes in the environment were particularly valuable. This review also included reading the more recent reports prepared by the coastal scientists and engineers who expressed opinions or undertook analyses concerning the possible impacts of the moles and breakwater; their reports were primarily the products of investigations into the causes of the beach erosion experienced at Westshore and recommended measures to mitigate the problem. Even though these investigators arrived at different conclusions regarding the degrees to which the harbour construction was responsible for the erosion, each made significant contributions regarding the ocean processes and beach responses, which I was able to draw upon in undertaking my review. This review considered in turn three stages of development: the coastal environment prior to any harbour development; the construction of the Ahuriri moles and the associated changes in the adjacent shorelines; and the construction of the Port's breakwater and its possible impacts.

Of primary interest regarding this stretch of coast prior to the construction of the moles and breakwater is whether or not beach gravel was able to bypass Bluff Hill, having been carried from the Marine Parade beach in the Haumoana Littoral Cell to Westshore in the Bay View Cell. This question is crucial to the interpretations of the coastal scientists and engineers who concluded that those structures did block a net northward transport of beach sediment, with the erosion at Westshore following the typical pattern of downdrift erosion commonly experienced along the world's coastlines. There is some evidence that beach gravel had bypassed Bluff Hill, but only in relatively small quantities and episodically, with no bypassing likely occurring during most years. A navigation chart of Ahuriri prepared by the Harbour Board's engineer in 1873 noted the presence of "shingle" (gravel) along the shore of Bluff Hill, trapped within small pockets along its otherwise rocky shore; although this cannot be taken as definitive evidence for gravel having bypassed Bluff Hill, it is suggestive of that having occurred. Also supporting this conclusion is that while there are clear sources of gravel to the beaches of the Haumoana Littoral Cell, principally the Tukituki River and from sea-cliff erosion at Cape Kidnappers, there have been only limited sources of gravel for the beach in the Bay View Littoral Cell, the small volumes contributed by the Esk River and possibly from the Tutaekuri River whenever it flowed into the Ahuriri Lagoon rather than following a course to the south where it entered the Haumoana Cell. Also significant are the conclusions of the research investigations by P. Marshall in 1929 and R. K. Smith in 1968 of the grain sizes, grain shapes and degrees of surface polish of the beach gravels. They both found that there are distinct differences between the beach gravels within the Haumoana and Bay View Littoral Cells, that is, in the beaches to the south and north of the Bluff Hill headland; the gravel in the Haumoana Cell is coarser grained and angular due to its having recently been added to the beach from the sources, whereas the beach gravel in the Bay View Cell has smaller grain sizes, rounder particles due to the waves having abraded away their edges, and with their surfaces having achieved a higher degree of surface polish, leading Smith to characterize the gravel there as being "old". These differences indicate that while gravel was able to bypass Bluff Hill, the quantities must have been small and that occurrences of bypassing were likely episodic, possibly governed by large floods on the Tukituki River that carried exceptionally large quantities of gravel to the coast, which then moved north along the beach as a "slug" of gravel, part of which eventually was able to slip around Bluff Hill to enter the Bay View Littoral Cell.

Particularly relevant in attributing the erosion at Westshore to the construction of the harbour moles and breakwater is the observation by both Saunders and Carr that episodes of beach erosion actually occurred there prior to the construction. Natural occurrences of erosion along Westshore at that time were to be expected, in that descriptions characterize it as having been a shingle (gravel) ridge, low in elevations so that storm waves and tides were frequently able to erode and wash over its crest. It is also noteworthy that the early development of Westshore apparently avoided the ocean side of the spit, having instead been centered along the lagoon shore. There may have been commercial reasons for this, but it is also likely to have been the desire to avoid the hazards of the frequent erosion and flooding on the ocean side of the spit. It was only much later that development expanded to the ocean side; for example, the North British and Hawke's Bay Freezing Works was constructed there in 1886, seven years after the completion of the Ahuriri moles and one year prior to initiating the construction of the breakwater. According to Carr's 1893 memorandum: "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."

Particularly significant to the erosion at Westshore, prior to the harbour construction and up to the present, is that it is located at the south end of the littoral cell, close to Bluff Hill that acts as a headland bounding the littoral cell. In that location, Westshore can be expected to experience significant cycles between periods of beach erosion and then accretion under the action of the changing directions of wave approach to the shore and the accompanying reversals in the directions of the longshore movement of beach gravel. This cycle has been documented in a study by R. K. Smith, in which he analyzed beach profiles surveyed along Westshore between 1916 and 1984 to determine the changing volumes of beach sediments. His results documented the occurrence of major cycles, with reversals between erosion and accretion having involved beach sediment volumes up to 40,000 cubic metres per year, equivalent to about 10 cubic metres of beach sediment being either lost or gained per year along each metre length of shoreline. Although large, these cycles can be accounted for by subtle shifts in the waves and currents that produce a southward transport of beach sediment for a year or for several years, while the episodes of beach erosion at Westshore have occurred when those processes produced a temporary northward transport of the beach sediment. Although Smith's documentation of this beach cycle at Westshore came after the construction of the moles and breakwater (but before the program of beach nourishment), the processes would have been essentially the same prior to harbour development, and could account for the early history of erosion at Westshore noted by Saunders and Carr.

Although there is evidence for the episodic bypassing of gravel around Bluff Hill prior to harbour development, there evidently was little or no active bypassing at the time the Ahuriri moles were being constructed in 1876-1879. Saunders commented in his 1882 memorandum, written just after the completion of the moles but prior to the construction of the breakwater, that the Marine Parade beach was "much reduced" in its width and sediment volume, suggestive of its having been inadequate to support bypassing. The absence of active bypassing that would have yielded a longshore transport of gravel along the Ahuriri shore is also indicated by the observed shoreline responses at the time the moles were being constructed. Saunders and Carr each reported on the accumulation of gravel and the resulting shoreline advances, which occurred to both the east and west sides of the moles. Of significance, this was not the typical pattern of sediment accumulation on the updrift side of the jetties and beach erosion along the downdrift shore, characteristic of sites where jetties have blocked a net longshore transport of beach sediment. Instead, the observed shoreline changes are better interpreted as having been the response to jetty construction on a shoreline that has a zero net littoral drift of sediment, such as that found on the Oregon coast where jetty construction similarly led to sediment accumulation on both sides of the jetties. Somewhat of a complicating factor in this interpretation for the Ahuriri moles stems from the dredging activities in the Inner Harbour and the disposal of that sediment (mostly sand, but with some gravel) to the west of the newly constructed moles, with this practice having been halted in 1888.

According to Saunders' 1882 memorandum, the rate of gravel accumulation to the east of the constructed moles was so rapid it kept pace with their extension during construction, the rate of accumulation having been on the order of 50,000 cubic metres per year. Such a substantial rate is unrealistic for the quantities of beach sediment that could conceivably have bypassed Bluff Hill, considering the fact that the estimated transport rates along the Marine Parade beach are on the order of 6,000 cubic meters per year. Instead, this rapid arrival of the gravel and its accumulation to the immediate east and west of the moles can only realistically be accounted for by the onshore movement of gravel that had been in the bay-mouth bar; such a response has been found on other coasts when jetties were constructed.

The construction of the breakwater in 1887-1890 had the effect of extending the natural headland of Bluff Hill, resulting in the localized seaward progradation of the shoreline to its south and creating a greater degree of wave sheltering to its north, extending along Westshore. The beach to the south of the breakwater was the result of its acting as an extended headland, rather than providing positive evidence for the breakwater having blocked a northward transport of sediment that would have bypassed Bluff Hill. It is especially noteworthy that in the century since its construction, there still is no evidence for beach gravel (nor beach sand) having been able to bypass the breakwater in spite of the beach buildup to the south.

The interpretation by coastal scientists and engineers that the breakwater construction blocked the bypassing of gravel around Bluff Hill and its subsequent longshore transport to the north along the shore of the Bay View Littoral Cell is based almost entirely on the occurrence of erosion at Westshore, their having concluded that this represented another example of downdrift erosion. However, the occurrences of erosion at Westshore when the breakwater was being constructed likely had other causes. It would in part have been the result of halting in 1888 the practice of disposing the sand dredged from the Inner Harbour to the west of the moles; with this disposed sediment having been primarily sand, its contribution to the beach would have rapidly disappeared when this practice was halted. Also significant is the fact that the period of breakwater construction coincided with a decade during which there was a series of unusually severe storms that produced beach erosion and backshore flooding along the Marine Parade, and certainly would also have similarly impacted Westshore.

Furthermore, as related above, R. K. Smith has documented the occurrence of substantial cycles between accretion and erosion at Westshore, apparently under the action of subtle shifts in the wave directions, with the episodes of beach erosion having occurred whenever the waves produce a temporary northward transport of the beach sediment. It is probable that the erosion experienced at Westshore following the construction of the breakwater was part of this natural cycle, enhanced by the extreme storms of that period. I believe it safe to conclude that the erosion experienced at Westshore over the years has had nothing do with the breakwater having prevented gravel from bypassing Bluff Hill. On the contrary, with the breakwater having sheltered Westshore from the full forces of storm waves for more than a century, it undoubtedly can be credited with having prevented the erosion of that shore.

A more detailed account of the construction of the Ahuriri moles and the Port of Napier's breakwater, and analyses of their possible impacts, can be found in Section 6. While their construction undoubtedly altered the environment of the Ahuriri shore, with both positive and negative consequences, the impacts have been minor compared with those experienced on other coasts, for example those that resulted from the construction of the Timaru breakwater on the South Island. Accordingly, the erosion at Westshore was characterized by O'Callaghan, a European coastal engineer, as having been "relatively minor" and "not been severe in coastal engineering terms". I agree. Although disagreements may continue regarding this issue, it has become irrelevant to the successful management of the Hawke's Bay coast, including dealing with the hazards of living at Westshore and the maintenance of its beach for recreation.

8.6 MANAGEMENT ISSUES

The objective in having undertaken the scientific and engineering investigations that yielded the reports concerned with the Hawke's Bay coast, was to collect and analyze environmental data such as the climate of wave heights and periods, or to focus on environmental conditions such as the beach variations and factors related to the budget of beach sediments. These contributions are important in serving as the basis for the management of the Hawke's Bay coast. The purpose of my having undertaken this review is to provide a synthesis of the results from those studies, an assessment of our present understanding of the causes of shoreline changes and erosion problems, and to determine whether there are missing elements that need to be the focus of future investigations to further improve our ability to manage this coast.

As summarized above, particularly important to sound coastal management is the availability of process measurements collected over a sufficient span of time to characterize their extremes, for example, the heights and energies of the waves generated by major storms that have a probability of occurring only once or so during the next 50 to 100 years; these are the events that pose the greatest threat to the erosion and flooding of coastal properties. Within that long time frame the level of the sea relative to the land will have increased sufficiently to also be important in analyses of the potential for beach erosion and backshore flooding. The standard analysis procedures used by coastal scientists and engineers to quantitatively evaluate these combined hazards, commonly as part of an effort to establish hazard zones for the safer development of shore-front properties, depend directly on the availability of these process data and assessments of their extreme values. Ultimately, this involves a determination of the extreme total water levels at the shore during major storms when these processes act in concert, the sum of the tide that is elevated by the storm surge, with the swash runup (and setup) of the storm waves on the sloping beach superimposed on that elevated tide. Such an analysis of the total water levels directly yields an assessment of the potential degree of flooding of the backshore properties, depending on the elevation of the top of the beach ridge and of the properties; this has been the primary context of such analyses undertaken for the Hawke's Bay shore in the establishment of hazard zones.

Analyses of the extreme tides and waves can also serve as the basis for analyses of the expected extent of beach and property erosion at the time of the 50- to 100-year storm. While this has been common practice for beaches composed of sand, such process-based assessments of the potential erosion of the Hawke's Bay beaches have not been undertaken due in part to their being composed of mixtures of gravel and sand. As was reviewed in Section 5 and noted above, the dynamics of mixed sand-and-gravel beaches differ considerably from those composed of sand, and has been the focus of far less research undertaken by coastal scientists and engineers. As a result, considerable uncertainty remains concerning the predictions of the surf-zone processes and expected responses of the Hawke's Bay beaches when impacted by a major storm. For example, we even have the fundamental problem of calculating the runup elevations of the wave swash on mixed sand-and-gravel beaches, because it depends on the proportions of sand within the gravel, which determines the permeability of the deposit and the loss of water from the swash that reduces its energy and runup elevations. We also need to improve our ability to predict the amounts and directions of the expected cross-shore movement of the beach gravel during storms, which results in altered beach slopes and elevations, and whether the elevation of the top of the beach will increase or decrease during the storm, governing the degree of potential overwash of the beach and the volumes of gravel carried into backshore properties. Having the capacity to make such predictions for the Hawke's Bay beaches under the conditions of the projected 50- and 100-year storms is critical to improving our ability to establish meaningful hazard zones that can maintain shore-front developments safe from erosion and flooding.

As indicated above, I rank this effort as having the highest priority for future studies, with it having the greatest probability for improving the management strategies for the Hawke's Bay coast through the development of hazard zones. At present, because of the existing uncertainties in evaluating swash runup elevations and other processes on the mixed sand-and-gravel beaches of Hawke's Bay, and in predicting the beach morphology changes at times of major storms, the studies that have had the objective of assessing hazards zones have in some cases arrived at significantly different results. This divergence of course represents a management problem in deciding which set of hazard zones to use, and does not provide confidence in the results on the part of the shore-front home owners. Our goal needs to be the establishment of analysis techniques that are rationally based on considerations of the ocean processes and responses of the mixed sand-and-gravel beaches of Hawke's Bay, techniques to which we all agree.

Also important to the management of the Hawke's Bay coast is the development of a strategy to insure that there are sufficient volumes of sand and gravel on the beaches that provide a natural protection to the coast from erosion and flooding. In particular, basic to this goal are issues to maintain the arrival of sufficient quantities of gravel to the beach along the Haumoana Littoral Cell, where along some stretches of shore the beach sediment volumes are insufficient to provide adequate protection to the backshore properties. The management of sediment resources is based on the development of sediment budgets, which involves evaluations of the sources of those sediments, in the case of Hawke's Bay mainly supplied by the Tukituki River and from sea-cliff erosion at Cape Kidnappers, and assessments of the sediment losses which includes that from the abrasion of the greywacke gravel particles once they reach the shore and the extraction of sediment at Awatoto and Pacific Beach in Napier. The balance in the budget between the gains and losses of beach sediment is reflected in either net beach erosion or accretion (the budget is respectively in the "red" or "black"). While sediment budgets have been developed for both the Haumoana and Bay View Littoral Cells, those efforts and products point to the need for improvements. This is not surprising in that the development of sediment budgets is always challenging, since it is generally difficult to arrive at satisfactory quantitative assessments for all of the beach sediment sources and losses. Often the best-established part of a sediment budget is its balance, the net erosion or accretion of the beach. Both of these aspects are true for the Hawke's Bay sediment budgets. Considerable uncertainties remain in the estimates of the volumes of sand and gravel being contributed by the rivers to the beaches. As reviewed in this report, there have been major impacts in the river watersheds associated with human settlement, countering activities such as the deforestation of the watersheds which would tended to increase the quantities of sediment eroded and reaching the coast, but with the major commercial extraction of sand and gravel from the river bed that removes the sediment sizes that would have been most important to the beaches. In the sediment budgets that have been developed thus far for the Hawke's Bay beaches, while attempting to assess the quantities of sand and gravel still able to reach the shore, they have not directly included considerations of the impacts humans have had in the watersheds that affect those quantities. Included in the loss of beach gravel is that due to its abrasion by the waves, which wears it down to fine sand and silt that is carried offshore. In spite of a number of research investigations spanning many years, including the research of Marshall in the 1920s and that recently completed by Hemmingson specifically for the Hawke's Bay beach gravels, we unfortunately still cannot provide with confidence a satisfactory assessment of this loss as part of the sediment budgets. As has been the case for many other sediment budgets, the best-established part of the Hawke's Bay budget is its balance, thanks to the strong program of monitoring the erosion or accretion of the beach with annual surveys.

As part of the need for improved sediment budgets for Hawke's Bay, research efforts should be directed toward an integration of the coastal beaches with their watersheds, in effect producing a joint budget that can serve as the basis for the improved management of the river watersheds as well as the ocean beaches. Such a linkage would in particular serve as a reminder that environmental changes in the watersheds, whether natural or human induced, may in a relatively short period of time have consequences to the ocean beaches and their capacity to provide protection to backshore properties. The sediment budgets that have been developed for the Hawke's Bay beaches are also "steady state", that is, its components are expressed as long-term averages that do not reflect the variations from year to year, the "unsteady" reality of Nature. This variability is particularly relevant to the river sediment contributions due to the extreme ranges in river discharges and magnitudes of major floods from year to year, and even spanning decades due to climate cycles. While the sediment supplied to the ocean beach from the Tukituki River has been entered into the sediment budget for the Haumoana Littoral Cell as a fixed average annual volume, it is recognized that its primary contribution of sediment actually occurs during periodic major floods, with the largest at times forming a temporary delta at the mouth of the river. With time the delta sediments are driven onshore by the waves to add material to the beach, which then slowly moves northward along the shore under the action of the waves as a "slug" of sediment. A number of years may pass before this sediment reaches Napier and Pacific Beach. The development of an improved "unsteady" sediment budget would account for these natural variations in the sediment sources (and in the ocean wave climate), leading to a better understanding of the observed changes in beach sediment volumes that are found in the surveys of the monitoring program, and better predictions of the expected variations in the volumes of beach sediment found at any specific shoreline site, the factor that is so important to the beach's ability to protect that site from erosion and flooding.

The research undertakings that in my opinion would most improve our ability to manage the coast of Hawke's Bay have been discussed again in this Summary and Discussion, those that I believe should be given priority status in future investigations. The individual Sections of this report have offered additional recommendations that I hope will also be considered. The bottom line, however, is that the coast of Hawke's Bay is extraordinarily well managed, based on an unusually high level of knowledge concerning its ocean processes and how they have been important to the erosion problems; the agencies and individuals who are responsible for the management of this coast have been fortunate in their selection of a strong team of coastal scientists and engineers to undertake these studies. Finally, there is an extraordinary degree of cooperation between the government agencies and people involved the management of the Hawke's Bay coast, and most of all, they should be given the credit for this success.