THE EROSION OF WAINUI BEACH, GISBORNE
—Causes and Mitigation—

Technical Report
for the
Gisborne District Council

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INTRODUCTION

Beach and bluff erosion have threatened a number of homes at Wainui Beach, northeast Gisborne. In response to the threat, a variety of shore-protection structures have been constructed ranging from groynes to seawalls to the use of gabions. For the most part these attempts have been ineffective, so the danger remains. The objective of this report is to analyze the processes involved in causing the erosion, and to offer suggestions for possible remedial measures and management strategies.

Previous studies of Wainui Beach have been undertaken mainly by Dr. Jeremy Gibb, with the results contained in a series of reports. Reports also have been prepared by Mr. Dean Patterson, Mr. David Peacock and Dr. Martin Single. These and other relevant documents have been reviewed as part of this investigation, and are discussed where appropriate within the present report. Also invaluable has been the collection of photographs contained in the albums compiled by the Gisborne District Council, documenting the occurrences of erosion and the progress of property losses over several decades. In more recent years the erosion and property impacts are covered by series of aerial photographs and periodic surveys of the beach.

I made two site visits to Wainui Beach in order to better understand the erosion processes and impacts. The first was a one-day visit during May 1994, accompanied by Mr. Neil Weatherhead and Dr. Robert Dean. A report was completed soon thereafter (Komar, 1995), based on observations during the site visit and a review of past reports. During April 1996 a second one-day site visit was undertaken, this time accompanied by Mr. David Peacock. Additional reports, photographs, surveys and wave data were made available to me at that time. The present report is based on the two site visits, a review of earlier reports, and on existent data documenting wave conditions and beach profiles. It begins with a review of the site conditions, the occurrences of erosion, and attempts that have been made to protect properties. The second section summarizes the processes of erosion, including a review of the wave climate, tides and nearshore currents, and presents an account of past work that has examined the beach sediments, determined their possible sources, and obtained profiles of the beach to document its changing morphology. In the third section of this report analyses are undertaken of potential water elevations achieved during storms when the run-up of extreme waves is superimposed on high tides. These analyses are applied to assessments of potential bluff and dune erosion. The final sections of this report discuss possible mitigation measures, and the need for additional investigations and data collection.

STUDY SITE AND EROSION HISTORY

The community of Wainui Beach extends along a pocket beach contained within the 4.8-km long embayment between Tuaheni Point to its south and Makorori Point to the north. These Points are headlands composed of Late Tertiary deposits of alternating layers of muddy siltstone and sandstone. The Points have offshore extensions consisting of wide shore platforms and submerged rock reefs. For the most part, the headlands plus their offshore extensions isolate the pocket beach at Wainui from other beaches to the north and south.

The sea cliff and bluff toward the south end of Wainui Beach is composed of the Tertiary deposits, being part of the northern portion of Tuaheni Point. The mudstone and siltstone layers dip 15 to 20 degrees seaward, and this has resulted is some landsliding that has been a potential hazard to homes constructed at the south end of Tuaheni Crescent within Wainui Beach. According to the investigations of Dr. Gibb, further to the north along Wainui Beach up to about Hamanatua Stream, the lower bluff is composed of old estuarine sediments that have formed and been uplifted during the last several thousand years. Contained within these deposits are layers of old dune sand. Toward the northern half of Wainui Beach, the bluff is fronted by an accumulation of modern dunes that are partially vegetated while still being actively moved by winds.

Two minor streams enter Wainui Beach. Wainui Stream toward the south has very little flow, but locally has some effect on the beach morphology and elevation. Hamanatua Stream is located approximately midway along the length of the pocket beach, and is more substantial in its flow and impacts on the beach morphology; during the past it has been a factor in producing bluff erosion when its channel freely migrated north and south (its position is now partly controlled by a wooden groyne).

Settlement in the Wainui Beach community began about 1912 with the construction of small cottages between Wainui and Hamanatua Streams. Following World War II the character of the community changed, from a holiday resort with small baches to a residential district with larger houses. By 1955 there were approximately 70 houses along the immediate beach front, while now there are over 100 properties that potentially could be adversely affected by beach and bluff erosion. Development is still largely concentrated south of Hamanatua Stream, with houses to the north being located landward of State Highway 35.

Problems with storm-induced erosion appear to have been present since the earliest development, although documentation of the problem has occurred mainly since the 1950s. According to the 1993 analyses of Gibb, during the 37 years between 1955 and 1992, severe short-term erosion occurred during at least 10 separate occasions, with bluff retreat locally being up to 15 meters during each event. Based on his detailed revised analyses in 1996, Gibb found that Tuaheni and Makorori Points have retreated at rates of 0.19 and 0.49 m/year since 1982. The 4.2-km length of Wainui Beach has retreated at rates of 0.06 to 0.39 m/year, averaging 0.22 m/year since 1942. A comparison of rates by Gibb for the periods 1882-1942 and 1942-1992 indicated that many areas have either reversed from accretion to erosion since 1942, or the erosion rates have increased substantially in more recent decades. While the 1980s represented a relatively quite period with little storm activity leading to erosion, major storms during 1992 and 1994 have lead to renewed erosion. Gibb found no systematic north to south pattern along the length of Wainui Beach that would suggest a dominance of erosion in one area of the beach versus another. Instead, the pocket beach appears to be retreating uniformly along its length. Gibb has suggested that as the headlands bounding Wainui Beach retreat, the shoreline of this pocket beach retreats at approximately the same rate.

In response to the erosion and threat to properties, there has been a long history of attempts to construct shore-protection structures. The concrete retaining wall just south of Oneroa Road was built prior to 1930, while other walls date from the 1940s. With the progressive retreat of adjacent unprotected areas, these old walls have increasingly projected out onto the active beach and therefore have been subjected to greater wave forces. During the winter storms of 1994, the oldest seawall south of Oneroa Road failed.

Major storms and erosion during the 1950s and 60s prompted increased activities to introduce shore-protection structures. In 1960 a railway and timber seawall was built along the south end of the beach. During 1961-62 a series of 28 sheet-pile spur groynes were constructed, each approximately 20 meters long and 80 meters apart. The groynes proved to be ineffective as beach protection, and became an eyesore as the steel corroded. Most of the original sheet-pile groynes have been removed; seven remain (Numbers 1 through 4, 21, 27 and 28) or were replaced by concrete or wooded groynes where it was believed that the structures were having a positive effect by reducing stream migration or by retaining sand within the pocket beach.

Major storms during 1973-74 removed up to 10 meters from the toe of the bluff and dunes backing the beach, and this prompted the placement during 1975-76 of gabion baskets for shore protection. The gabions were filled with cobbles removed from the beach fronting Makorori Point, and were held in position behind timber posts driven vertically into the beach and underlying mud layer. During storms in 1977 and 1978, the gabion protection collapsed over a 40-meter length. Iron rail tracks were driven vertically at 1-meter intervals to prevent further collapse. The defense line of gabions also was extended further to the north. In subsequent years some effort has gone toward the repair of the gabion defense system, but most of it to the south of the Stock Route has failed, while to the north gabions still remain but are buried beneath the beach sand.

Between 1982 and 1984 rock was placed behind the log-rail seawall at the south end of the beach. Recently, rock revetments have been placed behind the earlier works, which are progressively failing or have been ineffective so that a space exists between the structure and the still retreating bluff and dunes. Increasingly and where possible, people have chosen to move their homes inland by 10s of meters while remaining on the remnants of their lots, having decided to distance themselves from the erosion rather than invest in expensive structures that may provide only short-term protection.

The variety of structures employed — seawalls, groynes and gabions — have been only marginally successful in offering lasting protection to homes within Wainui Beach. In some instances the choice of a structure was unwise, not only offering limited protection, but likely exacerbating the erosion problem (discussed below). Remnants of the failed structures now litter the beach, making it unsightly and dangerous for recreational use. This has resulted in pressure to remove the failed structures, and to abolish further attempts to use shore-protection structures at Wainui Beach. Unfortunately, the danger from erosion is real, and the threat to homes remains.

PROCESSES OF EROSION

Beach and bluff erosion have occurred at Wainui Beach in response to a combination of natural processes, and also due to human-induced factors. Most important and obvious is the occurrence of a severe storm with high waves and elevated water levels, the combination of which allows the surf and wave run-up to exceed the maximum elevation of the beach, thereby reaching the toe of the bluff and sand dunes. Therefore, the extent and morphology of the fronting beach is significant, which in turn depends on sources of sediment to this pocket beach and the grain sizes of the sand. Finally, in the long term, changes in the level of the sea and of the land relative to the sea are important. These various factors are reviewed, based in part on past studies but also on field observations made during my site visits.

Beach Sediments — Sources and Compositions

For the most part, Wainui Beach is a closed pocket-beach littoral cell, with minimal sources of new sediment suitable to build a beach. Gibb (1993) has undertaken detailed analyses of the grain sizes and compositions of the beach sands, making it possible to infer likely sources. The beach itself is mainly fine to medium sand, with individual samples ranging in mean diameters between 0.25 to 0.5 mm. The sand is composed mostly of grains of quartz and feldspar, but with a content of shell fragments ranging from 38 to 63%, with the highest shell contents occurring near the Points. The sand contains a small amount of heavy minerals, the compositions of which indicate that the Taupo Volcanic Zone has been important. Ash falls from this source, particularly during the major eruption in about 130 A.D., mantled the hills surrounding Wainui Beach, and also contributed as to sediments in the offshore. Wainui and Hamanatua Streams draining the inland sources are too small to be significant contributors of sand to the beach, so Gibb concluded that sediments in the offshore are probably the main source, carried into the pocket beach by the action of waves. It has not been established whether this supply from the offshore is continuing, or whether the sand on the beach is largely relict, having been pushed ashore during the last few thousand years of sea-level rise. Some sedimentary minerals in the beach sand are derived from the Tertiary rocks of the Points, but those siltstones are generally too fine grained to be suitable sources of sand for the beach. More important as a sediment source has been erosion of the bluff backing the beach, areas where the bluff consists of old estuarine deposits and dune sands that form layers 1 to 2 meters thick. These old dune sands are not compositionally distinct, ultimately also having been derived from volcanic sources, so this contribution to the modern beach by bluff retreat cannot be evaluated based on compositional analyses.

In summary, according to the analyses of Gibb of the beach-sand compositions, the relative contributions from the various sources are:

(1) Biogenic sources — shells derived from the adjacent shore platforms, forming 38 to 63% of the beach sand.
(2) Offshore Seabed Sediments — offshore volcanic sediments transported by waves onshore to the beach, forming close to half of the beach sand.
(3) Tertiary Strata of the Points — both textural and mineralogical evidence suggest that these fine-grained rocks have contributed only about 5 to 10% of the sand contained in Wainui Beach.
(4) Bluff Erosion - erosion of old dune sands in the bluff backing the beach.

The adjacent Makorori Beach to the north is finer grained than Wainui Beach, and has some mineralogical differences. Although the occurrence of a small amount of sand movement around Makorori Point separating the two pocket beaches cannot be ruled out, the differences in the sand indicate that this headland and its offshore platform and rock reefs apparently are effective in isolating the two pocket beaches; Makorori Reef acts much like a giant groyne.

The medium-size sand comprising much of Wainui Beach decreases in content toward the offshore, being dominant from the beach to approximately the 5 to 8 meter offshore depths (Gibb, 1993). Beyond those depths, very fine sand becomes dominant, small grains that comprise less than 1% of sediment on the beach.

It has not been possible to develop a "budget of sediments" (Komar, 1996) for the sand within Wainui Beach, an analysis where one makes quantitative assessments of sand contributions from the various sources, similarly evaluates losses of beach sand, and then compares the balance between sources and losses to the resulting beach erosion (net loss) or accretion (net gain). It is apparent that the input of "new" sand into the pocket beach is small, and quantities of possible losses are unknown. In particular, the exchange of sand between the beach and the offshore is not well established, and we cannot be certain whether this exchange at present represents a net gain or net loss to the beach.

The above components of the sediment budget are comparatively long term, representing assessments of sediment sources and losses spanning at least a century. Also important has been the redistribution of sand internal to the Wainui Beach littoral cell, specifically the exchange of sand between the beach and modern dunes backing the beach. For example, a field of partially vegetated but still active dunes has formed in front of the bluff to the immediate south of Hamanatua Stream, an area of greater set-back of the bluff due to the stream having enhanced bluff erosion when it formerly migrated toward the south. Erosion during a storm may cut into these dunes, as occurred during June 1996, but without extending back to produce additional erosion of the old estuarine sediments in the bluff. The eroded dune sand is added to the beach, but with the return of quiet conditions following the storm, sand is blown from the beach back into the dunes. The accumulated dunes thereby serve as a valuable reservoir of sand, to be added to the beach when needed during a storm.

The above discussion has related only to the beach and dune sand contained within the Wainui Beach embayment. Another component of the beach consists of cobbles, in places forming a layer beneath the sand of the beach. The presence of the cobbles is most obvious during an erosion event, when the storm waves remove the sand layer by shifting it offshore and alongshore, exposing the cobble layer. These cobbles are derived mainly from the erosion of the Tertiary sandstone layers of Tuaheni Point. It is possible that during the past there were larger quantities of cobbles on Wainui Beach than are now present. The report *Erosion Protection: Wainui Beach: Cook County Council* (Adye et al., undated) noted that a major slip in August 1962 of some 20 acres, half way between the old lighthouse and Tuaheni Crescent, supplied a large quantity of shingle (cobbles) to Wainui Beach which was filling the compartment between the southernmost groynes. Furthermore, at the April 1965 Meeting on Wainui Beach Erosion, a resident named Mr. Butterworth commented that there used to be large quantities of stone on the beach, but this was removed for use in the Gisborne Harbour works — presumably, these cobbles would have been used as core material beneath the larger armor stones. Mr. Butterworth expressed the opinion that removal of the cobbles had caused the property-erosion problems. If such a removal did occur, there is validity to this opinion that it is a factor in the ongoing erosion. A quantity of cobbles sufficient to form a beach buffer in front of the properties would help to protect them from erosion during a storm by dissipating the wave energy, even after the sand that normally covers the cobbles had been carried away. If Mr. Butterworth was correct in commenting that large quantities of cobbles had been removed sometime before 1965, this might explain the enhanced erosion that has occurred in recent decades.

Beach Profiles and Morphology

Important to the occurrence of property erosion, whether sited atop a sea cliff or within foredunes, is the extent of the fronting beach. With a wide and elevated beach, it is less likely that high tides and the swash of storm waves will be able to reach the toe of the sea cliff or foredunes to cause erosion. Important to the analysis of property erosion, therefore, is the documentation of the beach morphology by surveys obtained over a number of years, and also for various seasons of the year since there tends to be systematic differences between summer and winter.

Surveys of beach and dune profiles have been obtained at Wainui Beach, initially by the former Poverty Bay and East Cape Catchment Boards, and more recently by the Gisborne District Council. Between August 1973 and 1987, beach surveys were made monthly at fourteen longshore positions, eight south of Hamanatua Stream and six to the north up to Makorori Point. Since 1987, beach surveys have been carried out only to measure the maximum beach levels in the summer, and minimum beach levels in the winter. Surveys of the foredunes, at the same fourteen longshore positions, have been carried out at irregular intervals, generally following any major erosion event that affected the dunes. Since 1981, the foredunes have been surveyed in 1985, 1992, 1994 and 1996.

These surveys have been important in establishing the morphology and extent of the beach along the length of the Wainui embayment. Each site shows large variations in the overall elevation of the beach and in the volume of sand, reflecting changes due to cross-shore and longshore movements of beach sand that occur during variable wave conditions, particularly when a storm occurs. Also important is that the profiles provide measurements of beach slopes, a parameter that in part governs elevations achieved by wave run-up on the beach. Later in this report, survey data yielding beach slopes and elevations will be used to make calculations of wave run-up and extreme water elevations, which will be compared with beach elevations to examine the conditions that result in the occurrence of bluff and foredune erosion. The surveys also have been used by Gibb and Peacock to evaluate the cumulative bluff and foredune erosion that has occurred since 1973. For example, Gibb has used the surveys to determine that between 1973 and 1996, about 50,166 cubic meters of sand had been eroded from the foredunes, while Peacock reports that 8,300 cubic meters of foredune erosion occurred south of Wainui Stream during the major storms of 1992. Unfortunately, the beach surveys do not extend sufficiently far offshore and into deep enough water to establish with confidence whether there has been a net change in the total volume of sand on the beach.

Waves, Tides, Currents and Sediment Movements

Of great significance to the occurrence of beach and bluff erosion are waves generated by storms, the high tides that elevate mean-water levels along the shore, and the formation of wave-induced currents such as rip currents. The processes of waves and currents in turn result in a transport of beach sand, both in the longshore and cross-shore directions.

Pickrill and Mitchell (1979) summarized the available wave data for the entire coast of New Zealand in order to establish the wave climate in terms of expected wave heights, periods and directions. They noted then that little data are available, and measurements seldom extend for more than one year at a specific coastal site; this situation does not appear to have improved, especially for the east coast of the North Island. In their summary, Pickrill and Mitchell included wave data from two deep-water sites for the east coast, visual wave estimates obtained in Hawkes Bay from 25 November 1975 to 12 January 1976, and a more-substantial collection from Hicks Bay obtained with a recorder on an offshore buoy during 6 July 1977 to 17 March 1978. In Hicks Bay the significant wave heights generally were in the range 0.5 to 2.5 meters, but reached 6 meters during storms (the "significant wave height" is defined as the average of the highest one-third of the waves). Wave periods ranged between 4 to 12 seconds, centered at about 7 seconds.

More-recently obtained wave data for the area offshore from Gisborne are available from two sources. A long-term documentation of the wave climate is provided by wave observations derived from ships passing the Gisborne coast, and these data have been summarized by Reid (1993) for the area between 38°-39°S and 178°-179°E and for the years 1970 through 1990. The results are given in Table 1 in terms of significant wave heights of observed swell arriving from different directions, expressed in the Table as percentages of all observations. The data suggest that rare storms can generate significant wave heights up to 9 to 10 meters, with a few occurrences between 7 to 8 meters. More common are significant wave heights of 6 meters or less. It needs to be recognized that these are visual estimates, and their reliability is uncertain, particularly the more extreme values.

Table 1 shows that most of the waves arrive from the NE, E, SE and S quadrants, and it is noteworthy that there is a tendency for the largest storm waves to approach from SE-S. This distribution of wave directions reaching the Gisborne coast is in part controlled by the location of Ariel Bank and Rocks directly to the east, 15 km offshore from the coast. This Bank offers partial protection to Wainui Beach from waves approaching directly from the east, especially during storms when the high waves break over the shallow waters of the Bank. Thus, the principal "window" open to waves reaching Wainui Beach is from the SE quadrant.

Table 1: Percent occurrences of waves observed from ships off the Gisborne coast between 1 April 1970 and 31 March 1990 (Reid, 1993)

	SIGNIFICANT WAVE HEIGHT, H_S (meters)										
	1	2	3	4	5	6	7	8	9	10	All H
N	3.3	3.1	8	0.1	0.1	0.2			0.1		7.8
NE	4.7	6.9	3.6	0.8	0.6						16.5
E	2.9	5.4	2.7	1.0	0.5	0.1				0.1	12.8
SE	2.8	5.3	2.2	0.8	0.3						11.4
S	6.9	16.8	7.9	2.8	1.6	0.6		0.3			37.0
SW	1.0	1.1	1.6	0.5	0.4	0.1		0.1			4.8
W	0.1	0.2		0.1							0.5
NW	0.4	0.8									1.2
*	2.7	2.4	0.7	0.2		0.1					6.1
All	24.9	41.8	19.5	6.2	3.5	1.2	0.2	0.5	0.1	0.1	98.0

*Unspecified direction

A better documentation of the wave conditions than the visual estimates from ships is provided by the direct measurements derived from a Waverider buoy that was deployed about 1.8 km offshore from Tatapouri Point, east of Gisborne, about 2.5 km directly out from the northeast end of Makorori Beach (Macky, 1987). This buoy was positioned in about 32-meters water depth; this depth is sufficient to treat the data as being from "deep-water". The buoy deployment spanned the interval from 11 May 1982 to 17 December 1984, during which time a 10-minute record was obtained every 3 hours. Figure 1 presents the values of measured significant wave heights, H_S, for the full time of deployment. A great deal of variability is evident, but some degree of seasonality is present, with high wave conditions being less marked during the summer and with longer intervals of low-wave activity. Within this total record, most significant wave heights are less than 2 meters, but with a large number of occurrences between 2 to 3 meters, while the largest storm-wave heights reached 4 to slightly greater than 5 meters.

In the statistical analyses by Macky of these buoy measurements of waves, the time of deployment was rounded down to two complete years in order to avoid any seasonal bias. Histograms of significant wave heights and periods are shown in Figures 2 and 3. The median of H_S is about 1 meter, while heights exceeding 2 meters represent about 9.4% of the time, and waves above 3 meters occurred less than 1.3% of the time. The most-common wave period is about 7.5 seconds, while the range of measured periods is 4.5 to 11.5 seconds. Macky reported that most waves exhibit a deep-water steepness (the ratio of the wave height to wave length) between 1/150 and 1/25, but during extreme-wave conditions of storms the steepness was between 1/20 and 1/50.

Although the measured wave data obtained by Macky span little more than 2 years, standard analysis procedures were employed to generate probability of exceedence graphs, from which one can predict extreme events by extrapolation; for example, the parameters associated with the 50-year or 100-year storms. The results are given in Table 2 for a series of projected storm levels, having alternately used log-normal and Weibull graphs for the projections. These estimates must be viewed as being only rough approximations since they are based on little more than two years of measurements. It generally is considered that

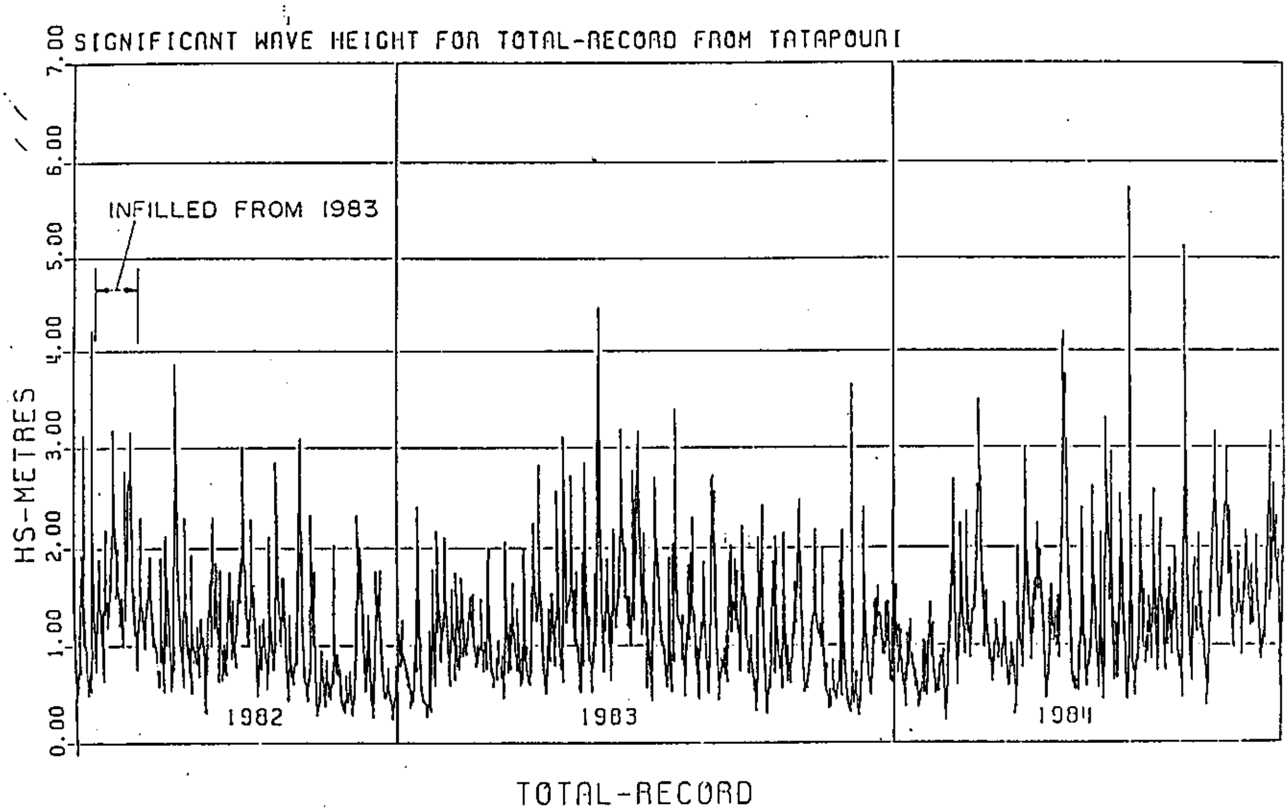

Figure 1: Measured significant wave heights obtained from a buoy deployed 1.8 km offshore from Tatapouri Point (Macky, 1987).

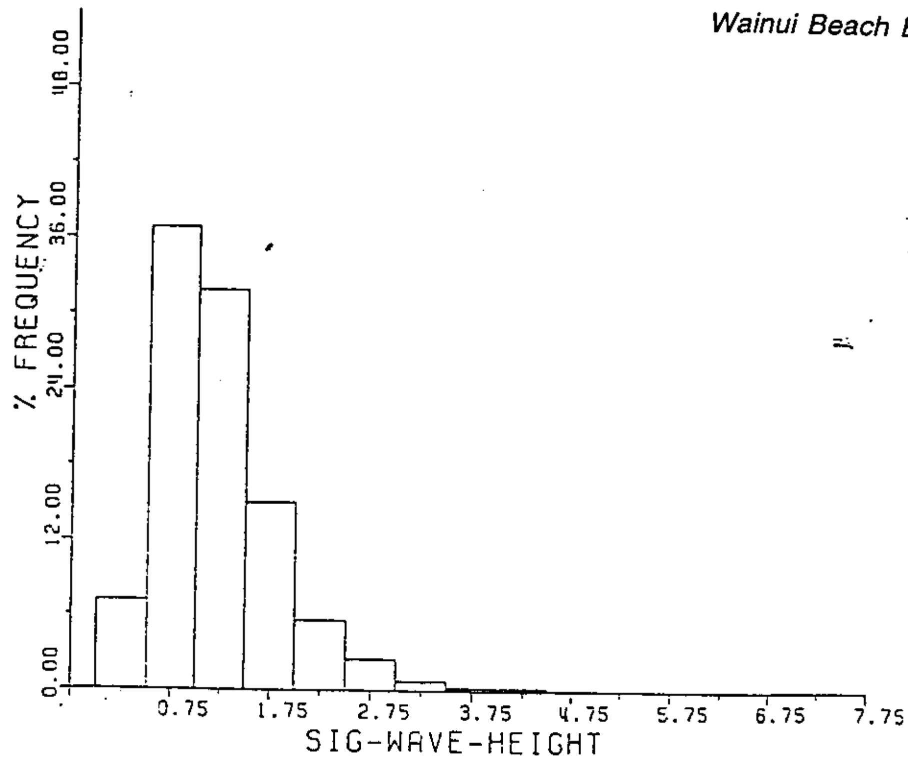

Figure 2: Histogram of significant wave heights measured offshore from Tatapouri Point during September 1982 through August 1984 (Macky, 1987).

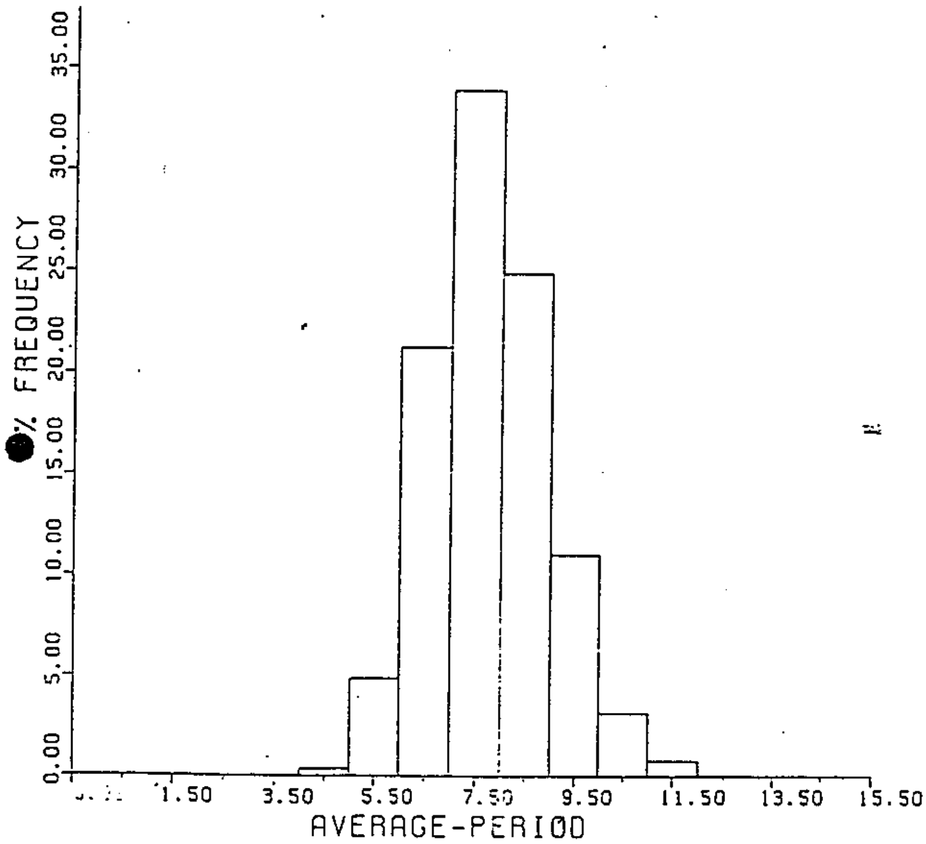

Figure 3: Histogram of wave periods measured offshore from Tatapouri Point during September 1982 through August 1984 (Macky, 1987).

projections can be only to three times the record length; thus, two years of records could be used, at best, to project the most-extreme wave conditions one might expect within six years. Similarly, about 15 years of data would be required to predict extreme wave conditions expected during a 50-year period, the extreme conditions that often are used by engineers to design shore-protection structures. Furthermore, the 1982-84 period of wave data analyzed by Macky may not be representative of normal wave conditions due to the strong El Niño that occurred during 1982-83, an event that is known to have significantly affected weather patterns.

Table 2: Projected extreme storm significant-wave heights (meters) based on two years of buoy measurements (Macky et al., 1987).

	PROJECTED STORM			
	10 years	20 years	50 years	100 years
Log-normal	6.9	7.8	8.4	9.0
Weibull	6.3	6.6	7.1	7.4

It was noted above that there is a SE-oriented window open to Wainui Beach for the arrival of the largest storm waves. Many of the erosion events have been associated with storms approaching the coast from that direction; this was the case during the recent storms of 1992 and 1994, which produced significant beach and bluff erosion. This SE approach direction is important to the ensuing erosion in that the waves break at an angle to the shoreline along the south end of the beach and transport beach sand toward the north within the pocket beach at Wainui. Therefore, during a storm from the SE, beach sand moves both offshore and alongshore toward the north, so the beach at the south end of the pocket looses most or all of its sand while the beach at the north end may actually gain sand and become wider. Under such circumstances, there can be significant sea-cliff and bluff erosion in the south, while minimal bluff and dune erosion occurs toward the north. With the return of fair-weather conditions, the sand generally returns to the south, but it may take months to years for full recovery. Alternately, a storm from the northeast may rapidly return sand to the south, causing erosion at the north end of the pocket beach.

Various lines of evidence demonstrate that there is a north-south oscillation of longshore sand movement within the Wainui Beach embayment in response to the changing wave directions. In addition to the alternately contracting and expanding beach widths at opposite ends of the embayment, the channels of Wainui and Hamanatua Streams can be deflected by the sand movement, locally causing erosion. When the groynes were still present, the sand fill between pairs of groynes likely also responded to these alternating directions of longshore sand movement, and to a degree would have restricted the movement from one end of the beach to the other. Although there is evidence for this north-south oscillation of sand within the pocket beach, there is no evidence for a long-term net longshore sediment transport, that is, more sand moving alongshore in one direction (e.g., north) versus the other (e.g., south), nor would one expect such a net longshore sand transport within this limited pocket beach.

When waves approach Wainui Beach from more directly offshore, that is, from the more easterly quadrants, the wave crests are nearly parallel to the shoreline when they break. Under such circumstances the waves do not generate a current that flows continuously along the length of the beach, the current which is important in causing a longshore movement of beach sand when waves break at an angle to the shore. Instead, when waves break parallel to the shore, they are more apt to generate what is termed a "cell circulation", the most important part of which is the development of strong rip currents that flow seaward across the beach and into deeper water. The rip currents can locally hollow out embayments into the beach, at times cutting back to the bluff so they are a factor in causing property erosion. This can occur anywhere along the length of Wainui Beach, and in part accounts for periodic localized erosion in the central portions of the pocket beach. Commonly, rip currents combine with storm waves, so erosion may occur everywhere along the shoreline, but the impact is greatest where the rip currents are positioned.

Tides are also a factor in beach and property erosion in that they control the mean level of the water, and often govern whether the run-up of the waves is able to reach the toe of the bluff or sand dunes. Tides are measured in Gisborne Harbor, yielding data that should be fairly representative of water elevations that occur at Wainui Beach. Unfortunately, detailed analyses of these tide data are not available, and I understand that past investigations have not considered this important component in the occurrence of erosion at Wainui Beach. The Highest Astronomical Tide (HAT), an unusually high Spring Tide when tide-generating forces are at a maximum, is reported to achieve a level of +2.2 meters in Gisborne Harbour relative to the local reference datum. That reference datum elevation is 1.05 meters below mean sea level (MSL) according to Mr. David Peacock (pers. communication), so this extreme predicted high tide is about +1.2 meters above MSL.

In addition to this predicted tide based on the generating forces of the moon and sun, important to the occurrence of coastal erosion are comparisons between the actual measured tides versus the predicted tides. The measured tides are affected by water temperatures and offshore currents, and therefore generally differ somewhat from predicted values. Of particular importance can be the occurrence of a storm surge, an elevated water level well above the predicted tide that is generated by onshore winds and lowered atmospheric pressures of the storm system. To my knowledge, there have been no estimates or measurements of storm-elevated water levels in the immediate area of Gisborne and Wainui Beach. Frisby and Goldberg (1981) calculated the expected storm surge level in Onepoto Bay that occurred during a July 1978 storm, based on wind speeds and the dimensions of the adjacent continental shelf. For that particular storm the calculated surge level was less than 0.4 meters, while estimates for a more severe storm having a 30-year return period yielded a maximum surge of 0.6 to 0.7 meters. Conditions for the generation of storm surges along the New Zealand coast have been reviewed by de Lange (1996), and he concludes that the maximum elevation would be 0.8 to 1.0 meters, this limit applying to the entire coast.

Sea Level and Land Elevation Changes

The change in the level of the sea relative to the land is important to the erosion at Wainui Beach. While short-term erosion occurs during storms, changing levels of the sea and land may be the underlying cause for the continued erosion spanning decades.

The global rise in sea level is estimated to be on the order of 1 to 2 mm/year (10 to 20 cm/century), and since 1900 the net residual rise in regional sea level around New Zealand has averaged 1.7 mm. years (J. Gibb, pers. communication). However, equally important to erosion at Wainui Beach are possible elevation changes of the land relative to sea level. The east coast of the North Island is tectonically active due to its proximity to a zone of plate subduction offshore to the east. Gibb has documented that in the long-term, the land has been rising faster than the global increase in sea level, evident in the uplifted estuarine sediments. He identified a layer of shells in the bluff near Lloyd George Road at a height of 3.4 meters above mean sea level, shells that were dated at about 7,600 years. The presence of raised wave-cut shore platforms underlying the sand dunes at Wainui further demonstrates a long-term emergence due to a net tectonic uplift. Based on such data, Gibb has estimated that at southern Wainui Beach there is a net uplift rate of approximately 1.4

to 1.5 m/1000 years (14 to 15 cm/century), while uplift rates for northern Wainui Beach are almost twice as great.

The uplift of the land appears to be episodic, occurring during earthquakes. This has been demonstrated by the radiocarbon dating of uplifted marine terraces at the Pakarae River mouth, about 20 km north of Gisborne. Ota, Hull and Berryman (1991) identified at least six uplift events that have occurred during the last 6,000 years. Within historic times, major earthquakes in 1855 and 1931 were accompanied by uplift along the east coast of the North Island. This would suggest that the raised dune and estuarine sediments identified by Gibb in the Wainui bluff achieved their elevations as a result of the cumulative uplift that episodically occurs during earthquakes that took place in the past several thousand years. However, the experience along other coasts subjected to plate subduction (including Oregon) is that the land movement between earthquakes is opposite to that which occurs during an earthquake. It appears that between earthquakes, the accumulation of stress in the crust causes a vertical movement in one direction, while the sudden release of that stress when an earthquake occurs causes movement in the opposite direction (much like changes in a spring). It is therefore possible that during recent decades, an interval between earthquakes, Wainui Beach has been subsiding, so that the local relative sea-level rise is presently higher than the 1 to 2 mm/year global value. The measured relative sea-level change since 1930 derived from the Gisborne Harbor tide gauge is approximately 2.3 mm/year, suggesting that the land subsidence is on the order of 1 mm/year (10 cm/century). Although this subsidence is not large, it could contribute to the continued erosion of the bluffs along Wainui Beach during recent decades, opposite to what one would expect on a coast that is otherwise undergoing a net long-term uplift. Counter to this argument are suggestions that the erosion at Wainui started after the 1931 Napier earthquake, apparently caused by the reduced effectiveness of offshore rock "reefs" in protecting the beach from storm waves (see comments by Mr. Ford at the April 1965 Meeting on Wainui Beach Erosion).

Although changes in sea level and land elevations are likely important to the long-term erosion of Wainui Beach, it remains difficult to definitely establish the roles of these processes.

Impacts of Shore-Protection Structures

A variety of structures have been used in shore protection efforts at Wainui Beach. Although some may temporarily have succeeded in reducing property erosion, nearly all structures eventually have failed. Of concern, some may actually have enhanced the erosion.

Groynes generally are used on long stretches of beach where there is a significant net longshore transport of sediment, the purpose of the groynes being to capture some of that sediment drift in order to locally build out the beach. From this, one would not expect groynes to be effective in offering shore protection within an embayment like Wainui Beach, other than to reduce longshore migrations of Wainui and Hamanatua Streams. Furthermore, groynes can act to enhance the offshore flow of rip currents, thereby increasing the shoreline and property erosion. Observations indicate that this often was the case for the groynes constructed along Wainui Beach.

There have been a number of studies that examined the impacts of vertical seawalls and sloping riprap revetments on the fronting beach and adjacent unprotected properties. These have included both laboratory and field investigations, studies that I recently reviewed (Komar, in press). Although some debate remains and uncertainties exist concerning the details of the processes, nearly all of the evidence indicates that seawalls and revetments can enhance erosion of the fronting beach and also of unprotected nearby properties. The presence of the wall can result in greater wave reflection and an intensification of turbulence, processes that result in scour of the beach at the base of the wall, at times leading to its failure. The reduced level of the beach may extend to adjacent properties, causing increased bluff and dune erosion. The impacts usually are greater if the seawall was built to protect foredunes, since the absence of erosion along that property reduces the amount of dune sand that is returned to the beach during the height of the storm. Having denied that sand input to the beach, it has been concluded by investigations that an approximately equal amount of sand is eroded from nearby unprotected properties, resulting in enhanced erosion there. Thus, construction of seawalls and revetments can offer temporary protection to properties, but may have negative impacts on the beach and other properties, particularly if the structures impound dune sand or otherwise affect the budget of sediments.

The most unusual structures used for shore protection at Wainui Beach are the gabions. Their application usually is limited to the protection of low-energy shorelines or the banks of rivers, so the limited success of the gabions and their rapid degradation on the high-energy Wainui Beach is not surprising. Of concern, observations indicate that their presence has had a negative impact by inducing scour of the old estuarine mud layer that underlies the beach sand. Water flow around and beneath gabions is increased during storms, and apparently enhances the local generation of turbulence and causes greater scour of the mud. Peacock (1992) reported that the estuarine mud level has dropped by almost 2 meters adjacent to the gabions near Lloyd George Road, while the average reduction in elevation between 1974 and 1992 was 0.56 meters. While some of this erosion of the mud layer underlying the sand beach certainly represents natural processes, observations indicate that the gabions and other structures have enhanced the erosion. The impact has been much like a net loss of sand from the beach, since even if all of the sand returns after a storm, the beach will have a lower overall elevation relative to mean sea level. With a lowered elevation, the beach is less effective in acting as a buffer between storm waves and properties backing the beach, resulting in greater property losses during subsequent storms. In the case of Wainui Beach, this enhanced erosion of the bluff containing old dunes has supplied sand to the beach, so that the beach has been able to retain its elevation following bluff erosion, in spite of the reduction of the underlying mud layer (D. Peacock, pers. communication).

WATER ELEVATIONS AND THE OCCURRENCE OF EROSION

Bluff and dune erosion occur at Wainui Beach during storms when high waves combine with elevated tides. Important is the run-up level of the wave swash on the sloping beach, and whether that level is sufficiently high for the water to reach the toe of the bluff or dunes. The other factor is the extent and elevation of the fronting beach, and to what degree it offers a buffer between the waves and properties backing the beach. The objective in this section is to undertake quantitative analyses of these processes involved in the occurrence of erosion at Wainui Beach, employing the surveys of beach profiles, predicted or measured levels of tides, and calculations of wave run-up elevations achieved by storm waves. The analyses focus first on the storms that occurred during 1992, which resulted in bluff and dune erosion, a storm during 1996 when run-up elevations were measured, and then on approximate estimates for major storms including the extreme 50-year and 100-year events that would represent "worst case" examinations of the potential for severe erosion.

The analysis approach is diagrammed in Figure 4, where the total level achieved by the water is compared with the elevation of the junction between the beach and the face of the bluff or dunes. The level of the water depends on the summation of the tide elevation at the time of the storm, and the increase due to the waves. There are two components associated with the waves, the so-called "set-up", which represents an increase in the mean water level due to the presence of the waves, their energy causing the water surface to slope upward toward the land as diagrammed in Figure 4. Due to this process, the mean shoreline shifts upward and landward, beyond the still-water shoreline produced by mean sea level and the elevation of the tide. Beyond this elevated mean-water level and shoreline, individual waves produce a run-up of the swash.

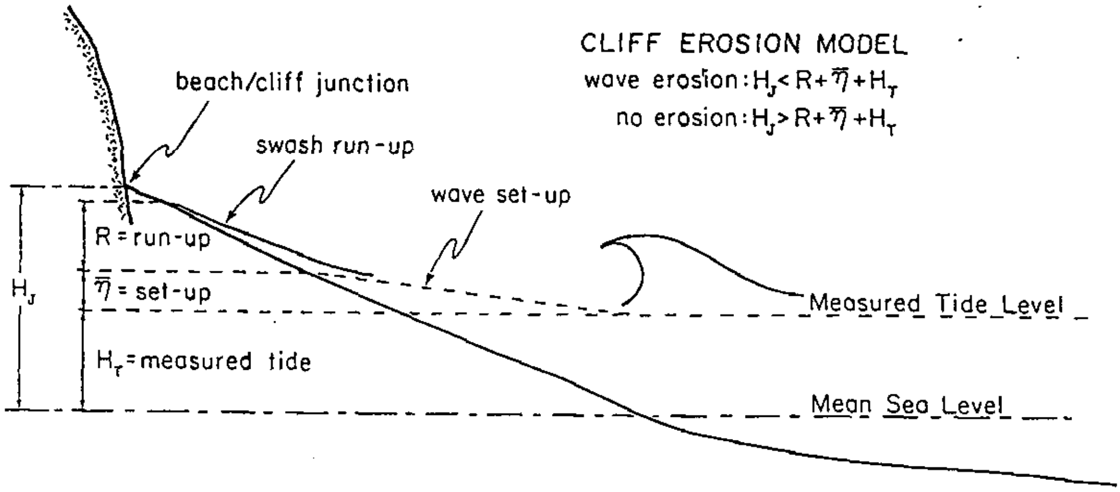

Figure 4: The analysis of potential erosion involves calculations of the set-up and run-up due to the waves, which is added to the level of the tide to establish the total elevation achieved by the water. This water level is then compared with the junction elevation H_J between the beach and bluff or foredunes.

The analyses undertaken here involve calculations of wave-swash elevations on Wainui Beach. The technical approach employed is summarized in Appendix I, where equations are presented that relate the total run-up elevation (set-up plus the run-up of individual waves) to the deep-water significant wave height H_S, the wave period T, and to the slope of the beach face S. At any given time, ranges of wave heights and periods occur on the sea, and as a result, there is a range of run-up elevations when those waves reach the beach. Therefore, a statistical analysis of the run-up elevations is required, yielding evaluations of the mean run-up elevation, various percent exceedence levels, and finally the maximum run-up level achieved by the largest wave. The analyses undertaken here are for the 2% exceedence, denoted by $R_{2\%}$, where only 2% of run-up levels exceed this calculated elevation. This represents an extreme run-up that is only slightly less than the maximum run-up, while occurring for more waves than the one individual maximum event. Occurring more often, the evaluation of $R_{2\%}$ is more meaningful to assessments of bluff and dune erosion than is the maximum run-up event.

The total water elevation is obtained in the analyses by adding the calculated $R_{2\%}$ wave run-up to the tide level at the time of the storm. In the analyses of the 1992 storms, the actual measured high tides on the days of the storms are used, derived from the Gisborne Harbor tide gauge. In considering "worst case" scenarios, it will be assumed that a Highest Astronomical Tide (HAT) having a level +1.2 meters MSL coincides with the major storm. At this stage, potential storm-surge elevations are not included in the water-level assessments, but their potential affects will be discussed. The final step in the analyses is to compare the total water elevation to the level of the junction of the beach face with the toe of the bluff or dunes, derived from the surveys at Wainui Beach. Calculations of water elevations are referenced to the mean sea level datum (MSL), and beach-profile surveys are also referenced to MSL, permitting direct comparisons.

The first series of analyses involve three sites central to Wainui Beach where shore-protection structures are not present and the beach is backed by an eroded bluff containing dune sand. The calculations, therefore, examine the natural condition of Wainui Beach. Selected for this analysis are the following profile stations:

Station #6 — Opposite Wairere Road, northeast of the "Stock Route" beach access;
Station #7 — Northeast along the beach from #6, to the immediate southwest of the "dip" beach access;
Station #9 — Approximately mid-way along the length of the Wainui Beach embayment, to the immediate northeast of Hamanatua Stream, seaward from the grove of pine trees.

Profiles from Station #6 are shown in Figure 5, giving the highest and lowest beach levels within the total set of profile series, and also the contours of the dunes; profiles at Stations #7 and #9 are much the same. The profiles are graphed with a vertical exaggeration, the horizontal scale differing from the vertical by a factor of 2. Vertical elevations are referenced to mean sea level (MSL), while horizontal distances are relative to local bench marks. The division between "foredunes" and "beach" as noted on the diagram is subjective, and reflects the different survey programs more than being a geomorphic classification. As analyzed here, of interest is the division between the lower sloping beach and the steeper face of the foredunes, and under what storm conditions the swash of waves is able to reach the base of the steeper dunes and cause erosion.

Table 3: Analyses of wave run-up and tides to yield total water elevations during the storms of 1992 and for various extreme-wave events.

Storm Event	Tide Level H_T (MSL) (meters)	Sig. Wave Height, H_S (meters)	Wave Period, T (seconds)	Run-up $R_{2\%}$ (meters)	Water Elev. $R_{2\%} + H_T$ (meters)
7/8/92	1.00	3.5	9	2.1	3.1
28/8/92	1.15	4.0	9	2.2	3.4
29/9/92	1.10	3.5	9	2.1	3.2
15/10/92	0.80	3.5	9	2.1	2.9
24/10/92	1.00	3.5	9	2.1	3.1
24/11/92	0.90	4.0	9	2.2	3.1
2-3/6/96	0.95	5.0	10	2.8	3.8
major storm	1.2	7.0	12	4.0	5.2
50-year storm	1.2	8.0	14	4.9	6.1
100-year storm	1.2	9.0	16	6.0	7.2
major cyclone	1.2	10.0	18	7.1	8.3

The first analysis examines the storms that occurred during 1992 (Table 3). No direct measurements are available of wave conditions for those storms, but the report by Peacock (1992) provides significant wave heights predicted by the Meteorological Office, and also tide levels measured by the Gisborne Harbor tide gauge. Six individual storm events are included in the analysis, with the tide and storm parameters listed in Table 3 together with calculated water elevations. For three of the storms, the predicted significant wave heights are 4 meters, while another three storms had predicted heights of 3.5 meters. Data are not available for the wave periods. In the calculations of the wave run-up, the period was assumed to have been T = 9 seconds. This is longer than the dominant period for wave conditions offshore from Gisborne, Figure 3, but there is a positive correlation between wave heights and periods (Macky et al., 1987) so that during storms both wave heights and periods tend to be larger than average. In the run-up calculations the beach slope was taken as S = 0.1, an average value derived from the series of profiles obtained at Stations #6, #7 and #9 (based on the inner portions of the profiles, near the base of the foredunes). This slope is used in all subsequent calculations included in Table 3, assumed to be representative of the swash zone at Wainui Beach.

Successive columns in Table 3 give the calculated $R_{2\%}$ of the storm-wave run-up, and then this run-up plus the high-tide level on the day of the storm, yielding $R_{2\%} + H_T$ which represents the estimated total level achieved by the water during each of the 1992 storms. The results show that both the tides and wave run-up are important components, with the magnitude of the run-up being approximately twice the tide, but with differences in tides affecting the variable levels of the total water elevations achieved by the series of storms. The greatest water levels are reached when the run-up of high storm waves combines with the higher tides. This is most apparent for the storm that occurred on 28 August 1992, when the tide was close to the +1.2 meters HAT level relative to MSL, while the storm-wave height was 4 meters. The calculated values of the run-up, and thus of the total water elevations achieved during these 1992 storms, must be viewed as only rough approximations. First, the calculations are based on predicted wave heights rather than directly measured, and the predictions are often found to be inaccurate (Peacock, pers. communication). Furthermore, no values are available for the wave periods and beach slopes at the times of these storms, so values had to be assumed in making the run-up calculations. However, the results given in Table 3 are probably not too far off, with the run-up being on the order of 2 meters, yielding an elevation of about 3 meters for the total water level relative to mean sea level. An examination of the beach profiles for Stations #6 (Figure 5), #7 and #9 indicate that when the profiles are at their highest elevations, they intercept the foredune bluff at elevations between 4 to 5 meters above mean sea level. Therefore, with a wide and elevated beach profile, none of the 1992 storms would have yielded sufficiently high water levels to reach the toe of the dunes to cause erosion. However, the lowest-level profiles at the three Stations intercept the dunes at elevations between 2 to 3 meters, and with this lowered toe elevation the wave swash during the 1992 storms could have reached the dunes and caused erosion. This illustrates the importance of the condition of the fronting beach in acting as a buffer between the storm waves and properties. It is important to recognize that the profiles represent the extremes in beach levels measured at the Stations, and do not depict the actual profiles during the 1992 storms. It is noteworthy that each storm in 1992 would act to cut back the beach profile, progressively reducing its level and capacity to act as a buffer between the storm waves and properties. It is therefore likely that the later storms during the winter season would have been the cause of property erosion, even though the total water elevations are not always as great as occurred due to storms earlier in the winter. For a satisfactory comparison between water and beach elevations, it is necessary to have beach-profile surveys that are close to the times of the storms. Since such profiles are unavailable, it is not possible to actually assess the occurrence or extent of foredune erosion that occurred during 1992.

The next analysis in Table 3 is for a storm that occurred during 2-3 June 1996, when the predicted significant deep-water wave height was 5 meters, occurring with a tide level +0.95 meters MSL. Assuming a wave period of 10 second for this somewhat larger storm, the calculated run-up is $R_{2\%}$ = 2.8 meters and the total water level is $R_{2\%} + H_T$ = 3.8 meters. Of particular interest in this storm event is that maximum swash levels were measured at three positions along the central part of Wainui Beach, establishing that the maximum water level reached +4.0 to 4.4 meters MSL (D. Peacock, pers. communication). These measurements conform reasonably well with the calculated 3.8-meters elevation in Table 3, especially considering the uncertainties in the predicted wave height, assumed wave period, and in other aspects of the calculations. If the analysis is based on a 6 meter significant wave height, the calculated water level would be 4.0 meters, a result that is also obtained with a 5-meter wave height but with an 11-second wave period. Furthermore, the calculations are for $R_{2\%}$, while the field measurements of the maximum swash elevations are more apt to represent R_{max}, the maximum run-up level of the largest wave at the time of high tide. Although tested with only this one storm event, the good agreement between calculated water elevations and the measured maximum run-up supports the analysis approach.

The predicted significant wave heights for the 1992 storms, 3.5 and 4.0 meters, and even the 5-meter height of the 1996 storm, are small compared with the measured wave heights reviewed earlier, derived from ship observations and buoy measurements. Those measurements indicate that rare but severe storms can generate significant wave heights of 6 to 7 meters, perhaps larger. Included in Table 3 are calculations of wave run-up for such major storm events, and then for the projected 50-year and 100-year storms as given in Table 2 derived from Macky's analysis. The four sets of calculations are for significant wave heights of 7, 8, 9 and 10 meters, but equally important is the progressive increase in wave period as the calculated run-up depends strongly on the period as well as on the wave height [equation (3), Appendix I]. Macky noted that during extreme storms, the wave steepness is generally between 1/20 and 1/50, and it is on this basis that the corresponding wave periods given in Table 3 are derived. With both larger wave heights and longer periods, the calculated run-up levels are more than double those estimated for the 1992 storms. In order to provide "worst case" analyses, it is further assumed that these storms strike the coast during a Highest Astronomical Tide, elevating the total water levels by 1.2 meters. For the "major storm" analysis in Table 3 the total water elevation is calculated as being about 5 meters above mean sea level, while the 100-year storm would reach an elevation of 7.2 meters. Such extreme elevations are above even the highest profile elevations in the beach surveys (Figure 5), implying that extensive bluff and dune erosion would result. Peacock (1992) noted that none of the storms that have caused damage at Wainui Beach since 1955 could be classified as "major" events, defining "major" as a storm where the deep-water wave height is on the order of 7 meters as used in Table 3. Therefore, Wainui Beach fortunately has not experienced such a severe storm and erosion in recent decades. The calculations in Table 3 are suggestive of the conditions and water levels that might accompany such an extreme event, but there are many uncertainties involved at this stage in the analysis. Being a "worst case" analysis, it is likely that the calculated run-up values are too high. In particular, in making the calculations I again used a beach slope S = 0.1, but with the larger waves breaking further offshore during such a major storm, it is likely that the effective beach slope will be smaller. In addition, no attempt has been made to include the effects of wave refraction and bottom friction, processes that would reduce the heights of the waves as they pass from deep water into the Wainui Beach embayment. Furthermore, as discussed earlier, the wave heights and periods of the projected 50-year and 100-year storms are highly uncertain since they are based on only 2 years of measured wave conditions, whereas one should have 15 to 33 years minimum of wave data to satisfactorily project these extreme-storm parameters. On the other hand, while the 1.2-meter HAT was added to provide a "worst case" assessment, this may be under evaluated. It is likely that during such extreme storms, where the waves are generated by strong winds, there will be an accompanying storm surge that could raise mean water levels by 0.8 to 1.0 meter (de

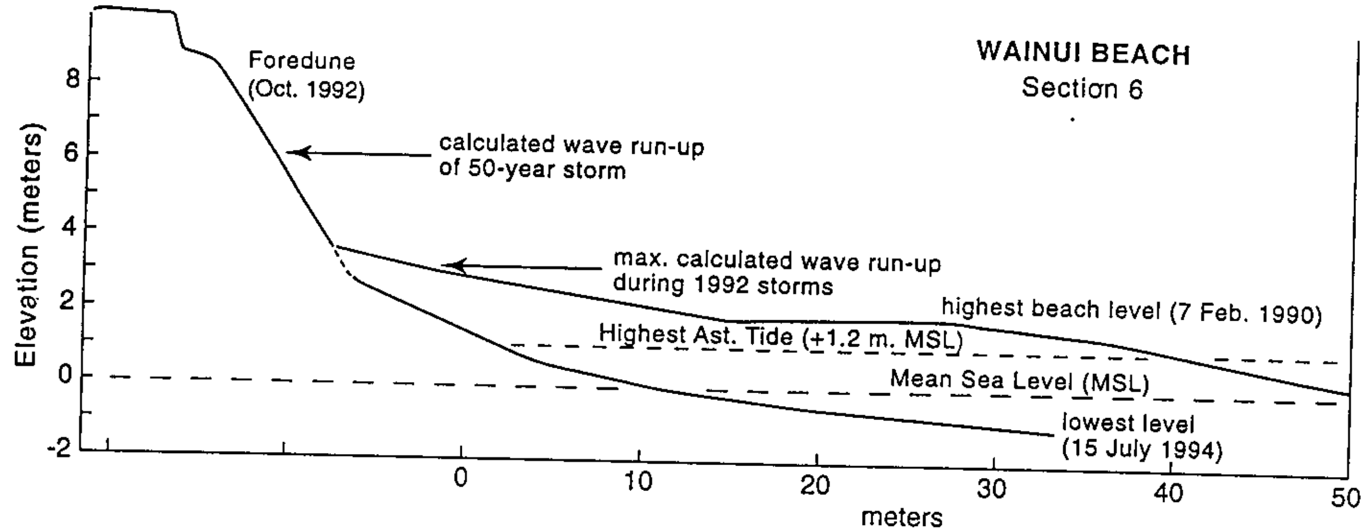

Figure 5: Analyses of wave run-up, tides and the total water elevation during storms that occurred in 1992, compared with beach profiles obtained at Station #6 at Wainui Beach showing the highest and lowest beach elevations that have been surveyed.

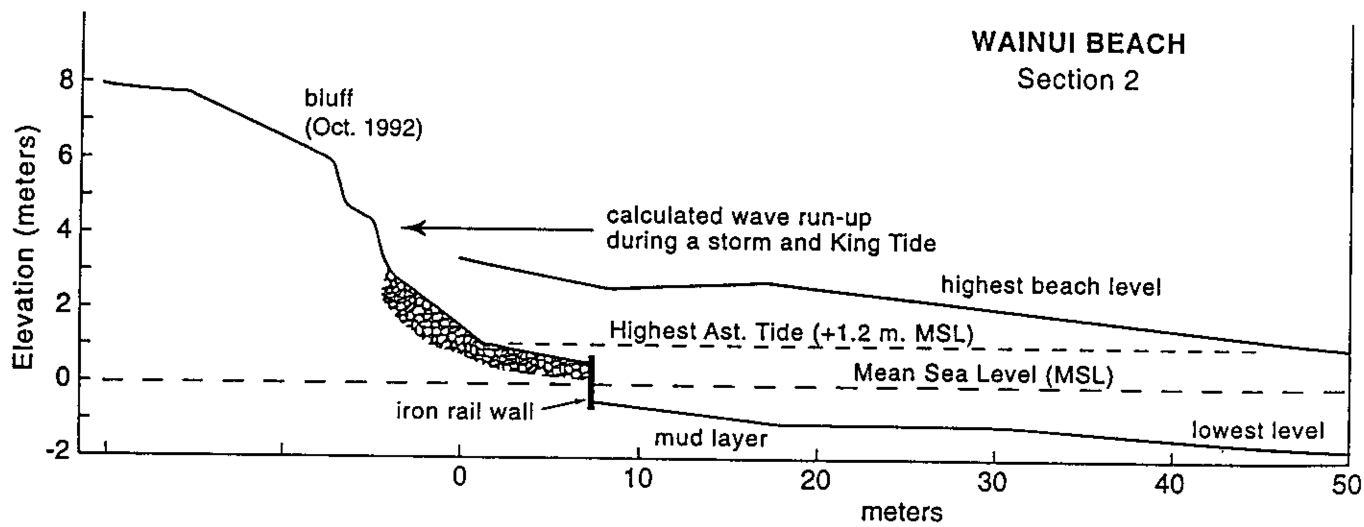

Figure 6: Analyses of wave run-up, tides and the total water elevation during a normal storm, compared with beach profiles obtained at Station #2 located at the south end of Wainui Beach where the sea cliff is protected by a rock revetment.

Lange, 1996). Thus, while the wave run-up during an extreme storm may be less than calculated in Table 3, the tide levels affected by a storm surge may be substantially greater, so the total water levels could be on the order of those estimated.

More complex is the calculation of wave run-up when a shore-protection structure is present at the back of the beach. This is the case for profile Section #2, Figure 6, at the south end of the Wainui Beach embayment. Elevations of the beach profile vary widely, due partly to the offshore movement of sand during storms, but mainly as a result of the northward longshore transport of sand when storm waves arrive from the SE quadrant. With the highest level of the beach, Figure 6, the profile intersects the bluff well up the slope, and completely covers the rock revetment at the base of the bluff. With this extreme level, the beach meets the bluff at an elevation of about +4 meters MSL, so it is unlikely that the swash of storm waves would reach the bluff unless a major storm occurs. But at the other extreme, when the beach has been eroded and the profile in effect reaches the underlying mud layer, a tidal elevation of +1 meter MSL would place the shoreline directly against the revetment, even without a water-level increase due to the presence of waves. In this situation the waves would generally break at the base of the structure and swash up the sloping rock surface. The height of the waves at the base of the structure would be controlled by the water depth. The ratio of the heights of breaking waves to the water depth is on the order of 0.8 to 1.3, depending on the slope of the bottom (Komar, in press). With the water level determined by a HAT, according to the lowest profile in Figure 6 for Station #2, the water depth at the toe of the structure would be about 1.75 meters, which means that waves with heights of roughly 2 meters could break directly against the structure. The storm would generate still larger waves, but these would break further offshore and their heights would be reduced before they reach the structure. These larger waves do play a role in producing set-up, which increases the water depths compared with the still-water depth determined by the tide. Therefore, the water depth could be greater than the 1.75-meter value determined above, and this would permit still larger waves to break at the toe of the structure. Roughly including this effect, breakers at the toe of the structure at Section #2 might be expected to reach 2 to 2.5 meters.

The forces of waves on the rocks forming the structure, and the run-up elevations, depend on this potential wave height at the structure's toe. The run-up calculations use the same analysis techniques as employed above for calculating run-up on the sandy beach, but are based on the approach of van der Meer and Stam (1992) calibrated with laboratory experiments where measurements were made of run-up levels on structures. In this case the correlation is with the wave height at the toe of the structure, rather than with the wave height in deep water. For a structure with a 3-in-1 slope (S = 0.33), a wave period of 9 seconds associated with the 2-meter high wave yields a run-up $R_{2\%}$ = 3.5 meters and a total water elevation $R_{2\%} + H_T$ = +4.5 meters MSL. It is not clear in Figure 6 where the top of the rock revetment is at Station #2, but it appears to be on the order of +3 meters MSL. Therefore, it can be expected that waves would readily overtop the existing structure when a storm occurs at a time of high tide. This has been the experience at the Station #2, and generally toward the south end of the Wainui Beach embayment where storm waves commonly overtop the shore-protection structures and impact the bluff. The results suggest that the rock revetments built along the south end of Wainui Beach were not constructed to sufficient elevations to offer full protection to the eroding bluff.

These calculations of the run-up in the presence of a rock revetment have been approximate, and the results must be considered as only tentative until more detailed analyses can be undertaken. In that the waves are depth limited at the toe of the structure, it is less important to have accounted for wave refraction in the offshore. That process does remain relevant in that refraction would reduce the sizes of the waves toward the south end of the embayment, and this would reduce the scale of the wave set-up that affects the water depth at the toe of the structure. Particularly important, but not included in the analysis, are processes such as a storm surge that along with the predicted tide could control the water depth at the toe of the structure, and thus the wave height and run-up over the structure.

MITIGATION

Past attempts at Wainui Beach to deal with the bluff and dune erosion and the accompanying loss of property have mainly involved the construction of shore-protection structures. This has included the installation of a series of groynes along the length of the beach, and the construction of a variety of seawalls or the use of gabions fronting individual properties. The groynes were removed after they proved to be ineffective and enhanced erosion, while most of the seawalls eventually failed. Some approaches have been unconventional, such as the use of gabions, and they similarly have failed. Many of these structures increased the erosion of the beach due to reflection of the storm waves, or because they augmented the local water turbulence and scour. In recent years, some homes have been moved back on their lots in order to distance them from the eroding bluff and dunes.

The objective of this section is to reexamine potential approaches that can be taken to respond to the Wainui Beach erosion, and to offer suggestions regarding the management of this developed coast. In general, potential responses to erosion involve one or more of the following (Komar, in press):

1. do nothing
2. retreat or relocate
3. beach nourishment
4. hard structures (seawalls, etc.)

These are considered below in terms of their feasibility or appropriateness for Wainui Beach. In this examination, the approach must be considered in terms of "normal" storms such as have occurred in recent decades, versus the potential for a "major" storm which could result in extreme water levels and erosion. It is also necessary to consider the possible impacts of the approach on the overall environment, including effects on the beach by altering the processes of waves and currents, or by changing the budget of sediments when cutting off a potential source of additional beach sand.

Do Nothing

The "do nothing" reaction is most appropriate where no infrastructure is threatened by the erosion, at least within the foreseeable future. This is the situation to the northeast of Hamanatua Stream, where only parking areas might be affected by short-term erosion, and near-catastrophic erosion would have to occur before Moana Road is in danger. The "do nothing" approach does not preclude efforts to stabilize dunes using natural vegetation, and to control human traffic to and from the beach so the dune bluff and vegetation are not degraded.

Retreat or Relocate

This response is often the most effective and least costly approach to save homes threatened by erosion, in effect eliminating the problem by removing the structures from the danger area. This is the preferred approach at Wainui Beach, in view of the chronic erosion that has occurred over the decades and the potential for extreme erosion should a major storm strike the area. Generally the options are retreat or relocate versus the construction of a seawall or revetment. The retreat option is often less expensive than a seawall, and as has been demonstrated at Wainui Beach, seawalls and other structures often fail and therefore do not provide lasting protection. Furthermore, the retreat or relocate response does not adversely affect the environment, either aesthetically or by inducing erosion of the beach as do seawalls and other structures.

Beach Nourishment

Beach nourishment generally involves the introduction of sand to the beach, sand that has been obtained from some outside "borrow" source area such as a river or from dredging offshore on the continental shelf. The objective is to widen and elevate the beach in order to provide an improved recreational beach as well as enhanced buffer protection for homes backing the beach. Beach nourishment has been used extensively throughout the world, including widespread application on the coasts of the United States, and has been increasingly used in New Zealand to restore beaches (Healy, Kirk and de Lange, 1990). The techniques involved in the design of a successful beach-nourishment project are now reasonably well established (Seymour et al., 1995).

Beach nourishment is a viable response to the erosion problems at Wainui Beach, and the site is ideally suited for this approach. Specifically, the pocket-beach nature of Wainui with apparently little or no losses of sand to deep-water offshore largely insures that beach nourishment would be successful so long as grain-sizes of introduced sediments are selected to conform with the natural beach sediments. Although one thinks in terms of beach nourishment involving the introduction of additional sand — and this would be the chief objective of such a project at Wainui Beach — the introduction of gravel or cobbles can also enhance shore protection. At Wainui, the introduction of gravel and cobbles would replace those materials that may have been removed in the past (discussed earlier), and would form a layer at the back of the beach beneath the sand. This layer of cobbles would help protect properties from erosion even when the sand is shifted offshore and alongshore during the height of a storm. Thus, beach nourishment at Wainui should consider the introduction of gravel and cobbles as well as sand. The specifics of this are discussed below.

Hard Structures

Seawalls and revetments are used to "harden" the shoreline in order to reduce or prevent erosion. Their installation has been the chief response to past erosion at Wainui Beach, but while offering temporary protection, these structures eventually have failed. In many cases this failure is due to inadequacies in design, in part resulting from the need to devise low-cost structures and attempts to use rather unconventional approaches that are inappropriate to the high-energy conditions experienced at Wainui Beach. The run-up analyses undertaken above also indicate that the structures have been placed at too low elevations so they are often overtopped, making them less effective in offering protection and also more susceptible to failure.

Hard structures can adversely affect the fronting beach and enhance erosion of adjacent properties (Komar, in press). Observations indicate that this has been the experience at Wainui Beach. The groynes stabilized positions of rip currents and may have increased the velocities of their currents, leading to localized erosion. It is probable that the seawalls and gabions increased the rate of offshore sand movement during storms, and it is clear that they induced erosion of the underlying mud layer, leading to an overall reduction in the beach elevation. It is possible to reduce these adverse impacts by using low-sloping rock revetments that cause less wave reflection and local turbulence. Properly designed structures can be an effective response to erosion at Wainui Beach, and are appropriate where retreat or relocate are not viable or acceptable options. An additional consideration is whether the structure would impound dune sand, the erosion of which serves as a sediment source to the beach. This may be old dune sand found within the bluff along with the uplifted estuarine sediments, or active to vegetated dunes backing the beach that have accumulated during recent years to decades. Hard structures of any type are to be avoided that would prevent this addition or return of dune sand to the beach.

Recommendations for Management Strategies

As recounted above, there are various response options available for mitigation of the property erosion at Wainui Beach. Each choice has positive and negative aspects that need to be considered. Furthermore, one would not expect that any single response would be best suited to the entire length of Wainui Beach, considering the alongshore variability in the environmental conditions, the extent of the erosional impacts, and different levels of development.

The south end of Wainui Beach has experienced the greatest erosion as beach sand shifts offshore and alongshore to the northeast when storms approach the area from the southeast. The erosion cuts back the sea cliff and bluff composed of Tertiary siltstone, with landsliding being an additional potential hazard. The greatest effort to construct shore-protection structures has centered on this area, and the beach is littered with the partially destroyed remnants of these structures. The beach is ugly, with the rusted iron beams and other parts of structures representing a hazard to beach users. Although the retreat and relocation of homes in this area is to be encouraged, the use of hard structures is likely required. Shore protection would be best provided by the construction of a uniform structure along this stretch of sea cliff, since a piecemeal approach consisting of different structures and with gaps would likely fail. Prior to the construction of a new structure, however, it is recommended that all failed structures be removed, particularly the remnants of the rail and timber seawall and gabions. Cobbles contained in the gabions should be returned to the beach, where unbounded they are more effective in protecting the properties. It may be possible to leave seawalls that still offer some protection to properties, incorporating them into the new structure or having them back up the new structure. The decision should be on an individual basis, governed by the degree of protection offered, how far the wall extends out onto the active beach and is in line with the eroded bluff, and on the expense of removal.

For the new structure along this southern portion of Wainui Beach, I recommend consideration be given to the construction of a hybrid structure, consisting of a conventional rock revetment and a dynamic revetment. Such a conceptual structure is sketched in Figure 7; a more-detailed analysis by an engineer is required to establish rock sizes and elevations. The distinction between "conventional" and "dynamic" forms involves the degree of expected stone mobility. The conventional rock revetment would consist of sufficiently large boulders that they remain stable under the expected forces of waves. This structure would be at the base of the sea cliff, having a sufficient elevation to provide protection during major storms and to support the landslide-prone cliffs. The slope of this conventional revetment should be on the order of 3-to-1 in order to be stable and to conform with the existing slope of the gravel beach. The second component of the recommended structure is a dynamic revetment, which in essence is a natural cobble beach (Muir Wood, 1970). This addition of cobbles to form a protective beach can also be viewed as a nourishment project, as discussed above, where gravel and cobbles are used in addition to sand. Sufficient volumes of material would need to be added to Wainui Beach to form a cobble layer that is of sufficient elevation and width that the deposit dissipates some of the wave energy before it reaches the stable revetment. Furthermore, the cobble deposit should be sufficiently thick to armor the estuarine mud layer beneath the beach, so its erosion would be reduced or eliminated; isolated cobbles resting on the mud would result in additional scour. With this fronting

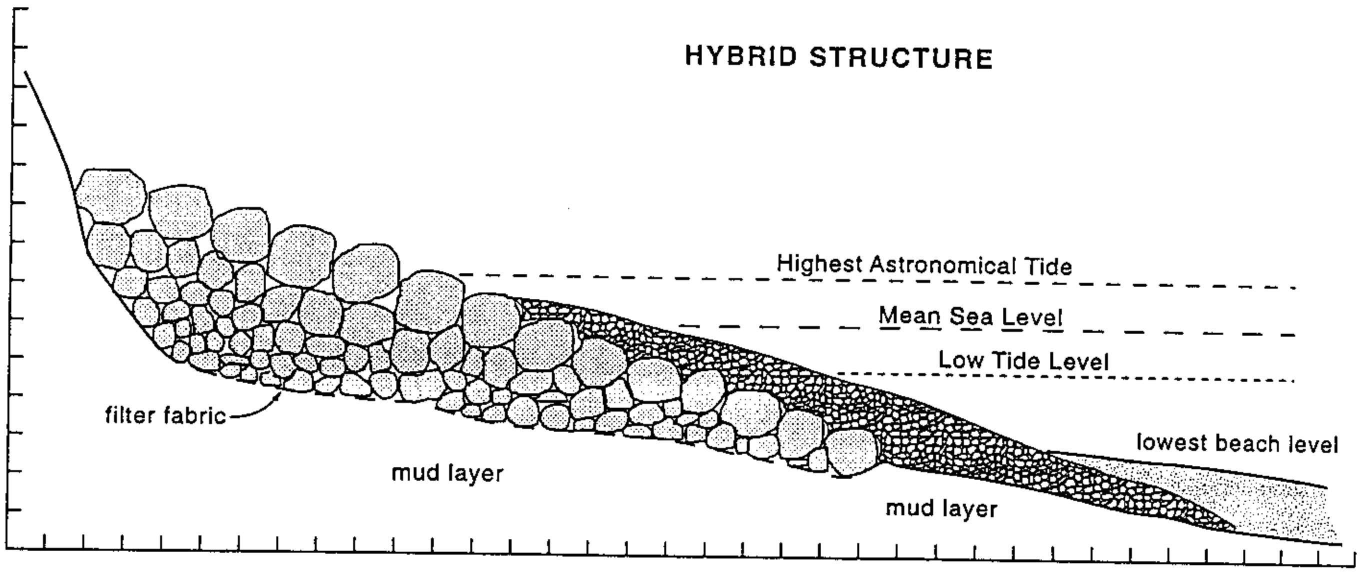

Figure 7: Proposed hybrid structure for bluff protection at Wainui Beach, consisting of a conventional rock revetment together with a fronting gravel beach that can be viewed either as beach nourishment or as a "dynamic revetment" that moves under the action of the waves. The gravel will help dissipate wave energy before it reaches the bluff and fixed revetment, and with sufficient thickness can armor the underlying mud layer and prevent its continued erosion.

cobble beach, the scale of the stable revetment composed of large boulders could be reduced, lowering the cost of the total shore-protection effort. It can be expected that much of this hybrid structure, particularly the cobble beach, will be covered by sand during normal times, and would only be exposed during storms that cut back the sand beach, leaving the cobble layer to dissipate the waves and the stable boulder revetment to act as back-up protection for the coastal properties.

Another strategy is recommended further to the north, approximately the stretch between Wainui Stream and Hamanatua Stream. Erosion of the bluff there has been a source of old dune sand to the beach, and portions of the beach are backed by modern dunes, particularly to the immediate southwest of Hamanatua Stream. Therefore, placement of hard structures would cut off these sources of sand to the beach. Furthermore, in most cases retreat is possible by shifting the homes back on their lots, and some homes already have been moved and are no longer in immediate danger from bluff erosion. Efforts should be directed toward moving back the rest of the homes, this being the most assured form of lasting protection. Any hard structures should be allowed to fail without efforts made to repair them, and should then be removed.

Northeast of Hamanatua Stream there is little development beyond parking areas for beach visitors. As discussed above, the "do nothing" approach is suited to this stretch of shore, with management efforts at most directed toward the maintenance of vegetation on the dunes and controlling the movement of people to and from the beach through designated pathways.

SUMMARY AND SUGGESTIONS FOR FURTHER INVESTIGATIONS

The review of past investigations and additional analyses undertaken as part of this study have led to the following conclusions:

1. The erosion experienced at Wainui Beach has been caused by a combination of natural processes, including storms that generate large waves at times of elevated water levels due to high tides. Particularly important have been storms out of the southeast, as the resulting approach direction of the waves causes the beach sand to move alongshore to the northeast, depleting the beach of sand in the southwest part of the embayment and allowing the waves to surge directly against properties. Another factor has been the occurrence of rip currents, which locally cut back the beach and reduce its elevation, allowing the run-up of waves to reach properties backing the beach. Other factors such as rising sea levels and changing elevations of the land are likely important to the long-term continued erosion at Wainui Beach.

2. Only moderate storms appear to have produced erosion at Wainui Beach during recent decades, storms that generated significant wave heights of 6 meters or less. There is the potential for the occurrence of a major storm where the significant wave height is greater than 7 meters, while an approximate estimate of the projected 100-year storm suggests that the significant wave height could reach 8 to 9 meters. Erosion under such extreme storms would be substantially greater than experienced during recent decades.

3. Calculations were undertaken of wave run-up added to high-tide elevations. For the waves and tides experienced during recent storms, the total water levels were sufficient to produce bluff and dune erosion only if the elevation of the beach was low, caused by the offshore and alongshore movement of the sand or where a rip current had locally cut back the beach. Approximate estimates of the run-up during major storms,

including the 50-year and 100-year projected storms, yield total water elevations that would exceed the highest levels of the beach and would overtop all existing shore-protection structures.

4. Shore-protection structures that have been used at Wainui Beach — groynes, gabions and a variety of seawalls — have offered only temporary protection, with most having eventually failed. In many instances these structures have induced erosion of the beach sand and underlying mud layer.

Based on these analyses and conclusions, recommendations were made concerning responses to the erosion and for management strategies. The recommendations included:

1. Remove remnants of failed structures, which continue to enhance scour of the beach and represent a hazard to beach users.

2. Construct a hybrid structure at the south end of the beach, approximately south of Wainui Stream, consisting of a low-sloping rock revetment at the base of the cliff, designed with large boulders to be stable, fronted by a cobble beach that would act as a dynamic revetment to dissipate waves and protect the underlying mud layer.

3. Use the "retreat or relocate" response along the stretch of shore between Wainui Stream and Hamanatua Stream, principally moving houses back on their lots. Hard structures should not be used as they would impound sand that supplies the beach, derived from the erosion of old and modern dunes.

4. Use the "do nothing" response to the northeast of Hanamatua Stream where there is little infrastructure that could be damaged by erosion.

The review and analyses undertaken as part of this study have revealed major deficiencies in data availability, resulting in an inadequate understanding of the erosion processes. Most important to the occurrence of erosion, present and potential, is a documentation of the wave climate, yet little more than two years of buoy measurements are available and the ship observations of waves are unreliable. Therefore, we cannot with confidence project expected extreme-wave conditions that might occur off the Gisborne coast due to major storms, the principal long-term threat to Wainui Beach. Wave energies and directions would change substantially due to refraction and bottom friction as the waves travel from deep-water and approach Wainui Beach, yet no analyses have been undertaken of these processes. There is also poor documentation of water-level factors, the predicted tides plus processes such as a storm surge that could significantly elevate the mean water level within the Wainui Beach embayment. In the absence of sufficient wave data and analyses of refraction effects, the calculations of wave run-up on Wainui Beach undertaken in this report must be viewed as approximate, with the uncertainty increasing when the tide is added to yield the estimated total water elevation. The results appear to be reasonable for moderate storms that have occurred in recent years, but are highly uncertain for the projected major storms such as the 50-year and 100-year events. Additional efforts toward data collection and analysis are needed if we are to better understand the erosion hazards at Wainui Beach, present and projected, and if we are to satisfactorily respond by the rational implementation of management strategies.

REFERENCES

de Lange, W.P. (1996) Storm surges and tsunamis: Risks, effects and planning aspects:

Douglass, S.L. (1990) *Estimating runup on beaches: A review of the state of the art*: C.R. CERC-90-3, U.S. Army Engr. Waterways Experiment Station, Vicksburg, Miss.

Frisby, R.B., and E. Goldberg (1981) Storm wave run-up levels at Onepoto Bay, East Coast, North Island, New Zealand: *Water and Soil Technical Publication*, v. 21, p. 59-63.

Gibb, J.G. (1981) *Assessment of a Coastal Hazard Zone for Wainui Beach, Gisborne*: Unpublished report of Water and Soil Division, Ministry of Works and Developmnent, Wellington, 40 pp.

Gibb, J.G. (1993) Unpublished statement of evidence for hearing regarding the Resource Management Act 1991: 68 pp.

Gibb, J.G. (1995) *Assessment of Coastal Hazard Zones for Northern Poverty Bay and Wainui Beach, Gisborne District*: Report for the Gisborne District Council, 51 pp.

Gibb, J.G., and I.E. Jones (1977) *Coastal Erosion Protection and Development at Wainui Beach, Gisborne*: Unpublished report of Water and Soil Division, Ministry of Works and Development, Wellington, 40 pp.

Healy, T.R., R.M. Kirk and W.P. de Lange (1990) Beach renourishment in New Zealand: *Journal of Coastal Research*, Speical Issue 6, pp. 77-90.

Holman, R.A. (1986) Extreme value statistics for wave run-up on a natural beach: *Coastal Engineering*, v. 9, p. 527-544.

Komar, P.D. (1995) *Wainui Beach Erosion — Causes and Suggested Remedial Measures*: Unpublished report submitted to Mr. Neil Weatherhead, February 1955, 5 pp.

Komar, P.D. (1996)The budget of littoral sediments — concepts and applications: *Shore & Beach*, v. 64, no. 3, p. 18-26.

Komar, P.D. (in press) *Beach Processes and Sedimentation*: to be published by Prentice-Hall, Englewood Cliffs, N.J.

Macky, G.H., E.M. Valentine, M.G. Webby and R.N. Croad (1987) *Sea Wave Climate at Tatapouri Point, East Coast*: Central Laboratories Report 3-87/2, 98 pp.

Muir Wood, A.M. (1970) Characteristics of shingle beaches: The solution to some practical problems: *Proceedings of the 12th Coastal Engineeering Conference*, Amer. Soc. Civil Engrs., pp. 1059-1075.

Ota, Y., A.G. Hull and K.R. Berryman (1991) Coseismic uplift of Holocene marine terraces, Pakarae River area, North Island, New Zealand: *Quaternary Research*, v. 35, p. 331-346.

Patterson, D.C. (1993) Unpublished statement of evidence for hearing regarding the Resource Management Act 1991: 19 pp.

Peacock, D.H. (1992) *Options for Wainui Beach*: Engineering & Works Technical Report EWTR 92/1, 39 pp + Appendices.

Pickrill, R.A., and J.S. Mitchell (1979) Ocean wave characteristics around New Zealand: *New Zealand Journal of Marine and Freshwater Research*, v. 13, p. 501-520.

Reid, S. (1993) *Gisborne Area Swell*: Unpublished report from NIWA, 3 pp.

Seymour, R.J., et al. (1995) *Beach Nourishment and Protection*: Committee on Beach Nourishment and Protection, Marine Board, National Research Council, National Academy Press, Washington, D.C., 334 pp.

Single, M. (1993) *Environmental Impact Information*: Unpublished report to Gisborne District Council, 31 pp.

van der Meer, J.W., and C.-J.M. Stam (1992) Wave runup on smooth and rock slopes of coastal structures: *Journal of Waterway, Port, Coastal and Ocean Engineering*, Amer. Soc. Civil Engrs., v. 118, p. 534-550.

APPENDIX I — CALCULATIONS OF WAVE RUN-UP

There have been many scientific and engineering publications that examined the run-up of waves on structures such as jetties and seawalls, and on natural beaches. Douglass (1990) provides a recent review, and van der Meer and Stam (1992) have undertaken a synthesis of the extensive laboratory results. The analysis approach used here is based mainly on the measurements of Holman (1986) obtained on ocean beaches under a range of wave conditions. Holman analyzed the run-up in terms of the mean level achieved by the swash, the significant run-up level (elevation of the highest one-third), the 2% exceedence elevation, and the absolute maximum run-up elevation achieved during a 20-minute measurement record. In the analyses undertaken in this report, the 2% exceedence is used, denoted by $R_{2\%}$. Similar to earlier studies, Holman found that this run-up elevation can be predicted by the relationship

$$\frac{R_{2\%}}{H_s} = C\xi \qquad (1)$$

where H_S is the deep-water significant wave height, C is a dimensionless empirical constant established by the measurements, and ξ is the dimensionless Iribarren number defined as

$$\xi = \frac{S}{(H_s/L_o)^{1/2}} \qquad (2)$$

where S is the slope of the beach face and L_o is the deep-water wave length given by $L_o = (g/2\pi)T^2$ in which g is the acceleration of gravity and T is the wave period. Combining the above equations yields

$$R_{2\%} = CS(H_s L_o)^{1/2} = C\left(\frac{g}{2\pi}\right)^{1/2} SH_s^{1/2}T \qquad (3)$$

for the run-up elevation as a function of the deep-water significant wave height and period, and of the beach slope. Equation (3) accounts for the total run-up elevation due to the presence of waves, that is, it combines the wave-induced set-up which raises the elevation of the mean shoreline, and the swash elevation of individual waves beyond the mean shoreline. The relationship is dimensionally homogeneous, so that any consistent set of units may be employed.

In making the run-up computations on the medium-sand beach at Wainui, the value C = 0.90 is used for the empirical proportionality coefficient, based on the field results of Holman on a beach of similar grain size. In making run-up calculations on the Wainui rock revetment, the value C = 0.70 has been used, based on the empirical curves of van der Meer and Stam who demonstrated that C depends on the roughness and permeability of the beach or rock slope. They found two separate empirical curves for "smooth" versus "rough" surfaces, and the latter was used for calculations of run-up on the revetment.