

PART II – GEOLOGICAL PROCESSES

Rocks are the pages of the book of earth's history. The fundamental principle involved in reading their meanings was first enunciated by the eminent geologist Hutton in 1785, when he declared that "*the present is the key to the past*", meaning that "*the past history of our globe must be explained by what can be seen to be happening now*" (Holmes 1964). Hutton's famous statement may also be interpreted to mean, '*the past is the key to the present*'. In this review, the stratigraphy and dynamic coastal processes have been interpreted to determine the "*postglacial evolution*" of Wainui Beach thus providing a basis for understanding the geologic coastal hazards. For Wainui Beach, the postglacial period spans approximately the last 14,000 years since the culmination of the Last Glaciation 15,000 to 20,000 years ago that enveloped planet Earth (Gibb 1998).

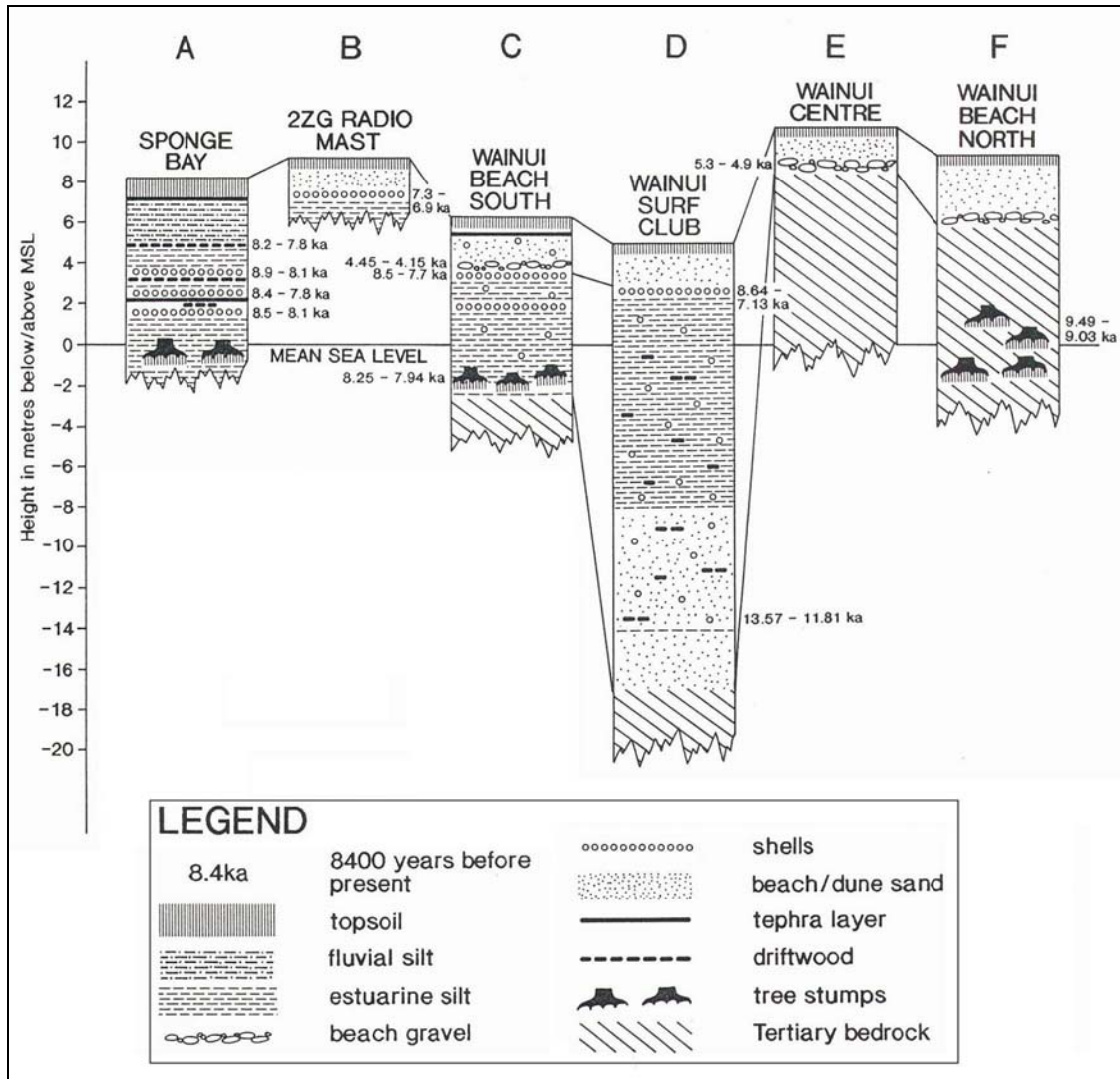
3. GEOLOGY

The Wainui Beach area has been sculptured out of Late Tertiary alternating sandstone-siltstone beds laid down on the seafloor about 20 to 25 million years ago (Kingma 1964). Since that time the ancient seafloor has been uplifted above sea-level, tilted seawards by tectonic movements and modified by both terrestrial and marine erosion processes. The relatively narrow Holocene coastal plain and underlying sediments bordering the beach record the latter stages of the "*postglacial marine transgression*" (PMT) including its culmination at about 6500 years BP (years Before Present 1950) (Gibb 1986b). The chronological history of evolution of the area may be determined from radiocarbon dated shoreline features that were deposited at, or close to sea-level at the time (Gibb 1998).

Figure 6 shows the stratigraphy from 6 sites (see Figure 9 for locations) that the radiocarbon-dated samples were taken from. All levels have been normalised in terms of MSL Gisborne Provisional Datum 1926 and show ground surfaces ranging from 5m above MSL at the Wainui Beach Surf Life Saving Club (mouth of Hamanatua Stream) to about 10.5m above MSL for the "*Wainui Centre*" site located in a paddock west of State Highway 35. Calibrated age ranges are also shown next to the radiocarbon dated deposits sampled.

South of the Hamanatua Stream, Sites A, B, C and D reveal evidence of an emerged estuary that evolved in a sheltered wave environment between about 13,600 and 7200 years ago. The estuarine deposits typically are firm grey silts with remains of driftwood and whole bivalves in life position. At Sponge Bay, pollen spores from mangroves were identified in the estuarine silts, supporting the contention of a warmer climate. Temperatures in New Zealand were thought to have been 1 to 2°C warmer about 8,000 to 8,500 years ago (Royal Society of NZ 1988).

The estuarine deposits of Sponge Bay are conformably overlain by shell-free brown silts interpreted here to be of fluvial origin. In contrast, along Wainui Beach the estuarine deposits are unconformably overlain by beach gravels with broken shell that was deposited about to 4150 years ago, which in turn are conformably overlain by beach and dune sands. The stratigraphic evidence indicates a sharp change from a sheltered estuarine environment at Wainui to an exposed open-coast environment similar to the present about 6000 to 7000 years ago (Gibb 1998).



• **Figure 6:** Stratigraphic sections from the Wainui Beach – Sponge Bay area and calibrated ¹⁴C age ranges for dated sea-level markers. Sites A to F are shown on Figure 8. (Adopted from Gibb 1998, fig.4).

At the Wainui Beach South site (Figure 6) exposed above the beach near Tuahine Crescent, the 3 to 4m thick estuarine deposits overly stumps in growth position representing a forest that grew about 8250 to 8000 years ago. From here the estuarine sediments thicken progressive northwards to about 20 m beneath the Surf Life Saving Clubhouse on the North side of the Hamanatua Stream mouth (Figure 6) where a date of 13,574 to 11,807 years BP was obtained from intertidal dwelling estuarine shells at the base of the estuarine sequence 14 m below present MSL. The ancient estuary formed at a sea-level some 50 to 55 m below the present and

the deposits have been uplifted some 35-40m over the last 12,000 to 13,500 years at a net rate of 2.6 to 3.3m/ka (metres per 1,000 years). In the context of a tectonically active New Zealand this rate is relatively rapid (Gibb 1998).

On the North side of Hamanatua Stream, the estuarine deposits pinch out abruptly against a raised shore platform cut by the sea from the Late Tertiary alternating siltstone-sandstone sequences. The shore platform which extends to Makorori Point is overlain by beach gravels and sands, and dune sands. At Site F (Figure 6), submerged tree stumps in growth position on the foreshore were radiocarbon dated at 9494 to 9033 years BP which is about 1200 years older than the submerged stumps to the south, indicating a relatively higher rate of emergence of Wainui Beach North of Hamanatua Stream compared to the coast to the South.

3.1. TECTONIC UPLIFT RATES

Data to derive rates of tectonic uplift are given in Appendix I. Table 2 provides net rates of tectonic uplift for the study area calculated by Gibb (1998). For Wainui Beach, tectonic uplift rates were determined by comparing the emergent heights of the 15 radiocarbon dated palaeo-shorelines with a New Zealand regional Holocene eustatic sea-level curve (Gibb 1986b) spanning the last 10,000 years and a New Zealand curve spanning the last 20,000 years (Carter et al. 1986).

• **Table 2:** Rates of tectonic uplift calculated for: (A) Wainui Valley near the 2ZG Radio Mast; (B) Wainui Beach south of Hamanatua Stream; (C) Wainui Beach north of the stream; and (D) Sponge Bay. Eustatic sea-levels listed are from sea-level curves for the New Zealand region by Carter *et al.* (1986) and Gibb (1986) for the radiocarbon dated shorelines listed in Table 1 (Appendix II). (Adopted from Gibb 1998, table 2, appendix II). * ka = thousands of years.

| NZ ¹⁴ C NUMBER | DATED SAMPLE | RADIOCARBON AGE RANGE (ka) * | HEIGHT (m) | EUSTATIC SEA LEVEL (m) | TOTAL UPLIFT (m) | TECTONIC RATES (m/ka) * |
|--|--------------|------------------------------|------------|------------------------|------------------|-------------------------|
| 6145 | Shell | 7.27 to 6.92 | 7.6 | 0.0 | 7.6 | 1.1 to 1.1 |
| A. NET UPLIFT RATE FOR WAINUI VALLEY | | | | | | 1.1 |
| 6143 | Shell | 8.29 to 7.68 | 4.0 | -9.0 | 13.0 | 1.6 to 1.7 |
| 7999 | Wood | 8.25 to 7.94 | -1.0 | -9.0 | 8.0 | 1.0 to 1.0 |
| 1881 | Shell | 8.50 to 8.18 | 3.6 | -14.0 | 17.6 | 2.1 to 2.2 |
| 7998 | Shell | 4.45 to 4.15 | 3.2 | 0.0 | 3.2 | 0.7 to 0.8 |
| 4433 | Shell | 5.28 to 4.93 | 8.3 | 0.0 | 8.3 | 1.6 to 1.7 |
| B. NET UPLIFT RATES FOR SOUTHERN WAINUI BEACH | | | | | | 1.4 to 1.5 |
| 5440 | Shell | 8.64 to 7.13 | 3.0 | -11.0 | 14.0 | 1.6 to 2.0 |
| 7992 | Shell | 13.57 to 11.81 | -14.0 | -50.0 | 36.0 | 2.7 to 3.1 |
| 5099 | Wood | 9.49 to 9.03 | 1.0 | -24.0 | 25.0 | 2.7 to 2.8 |
| C. NET UPLIFT RATES FOR NORTHERN WAINUI BEACH | | | | | | 2.3 to 2.6 |
| 5576 | Wood | 8.18 to 7.79 | 4.8 | -8.0 | 12.8 | 1.6 to 1.6 |
| 5573 | Shell | 8.44 to 7.78 | 2.1 | -11.0 | 13.1 | 1.6 to 1.7 |
| 6144 | Shell | 8.40 to 8.07 | 2.0 | -12.5 | 14.5 | 1.7 to 1.8 |
| 6306 | Shell | 8.50 to 8.09 | 1.7 | -13.5 | 15.2 | 1.8 to 1.9 |
| 5574 | Shell | 8.91 to 8.13 | 2.9 | -16.0 | 18.9 | 2.1 to 2.3 |
| 5575 | Wood | 9.08 to 8.51 | 2.1 | -14.0 | 16.1 | 1.8 to 1.9 |
| D. NET UPLIFT RATES FOR SPONGE BAY | | | | | | 1.8 to 1.9 |

For the Wainui Valley area near the 2ZG Radio mast, a net uplift rate of 1.1m/ka was determined from one dated shoreline. For nearby Sponge Bay, a slightly higher net uplift rate of up to 1.9 m/ka was determined from 6 dated shorelines, ranging from 1.6 to 2.3m/ka. Compaction of thick estuarine silts in the Wainui Valley during severe earthquake shaking may explain the slightly lower uplift rate at this location (Gibb 1998).

For the developed Southern Wainui Beach South of Hamanatua Stream, a net uplift rate up to 1.5m/ka was determined from 5 dated shorelines, ranging from 0.7 to 2.2m/ka (Table 2). Once again, differential compaction of estuarine silts and possible differences in the depositional environments of the dated shorelines when they were laid down may explain the local variations in rates.

For Northern Wainui Beach a net uplift rate up to 2.6m/ka was determined from 3 dated shorelines, ranging from 1.6 to 3.1m/ka. Two of the dates (NZ 5440 and 7992) are from a deep borehole by the Surf Life Saving Club that penetrated 22m of Holocene postglacial marine sediments overlying the Late Tertiary basement. Compaction of the dated marker at the top of the core during successive earthquakes may be an explanation of the range of rates at this site in which case the dated bottom marker has a higher probability of reflecting the true uplift rate (c.3 m/ka).

The results indicate that the uplift rates for Northern Wainui Beach are almost double those of southern Wainui Beach and Sponge Bay. The absence of Holocene estuarine deposits overlying the Late Tertiary strata north of Hamanatua Stream supports the contention of a more rapid rate of uplift in this area. A possible explanation is that an active fault with its upthrown side to the North runs up the Hamanatua Valley. The easily eroded, weakened rocks along the active fault would provide a natural route to the coast for the stream.

The net uplift rates obtained in this study are higher than those obtained by Ota *et al.* (1992) who determined an average uplift rate of approximately 1m/ka for the Wainui Beach area. They are in excellent agreement with the rates published in Berryman *et al.* (2000, fig.2) who determined net uplift rates of 2.0 ± 0.4 m/ka for Sponge Bay, 1.0 to 1.9m/ka for Southern Wainui Beach, and 3.0m/ka for Northern Wainui Beach. It would appear that Berryman *et al.* used mostly the same data used in this study.

For the East Coast, Ota *et al.* (1991; 1992) recorded maximum net rates of uplift of 4m/ka over the past 7000 years at Pakarae River by Whangara and 8m/ka at Puatai Beach further North, the most rapid coastal uplift rate recorded in New Zealand. The characteristic 'staircase' topography of marine terraces evident in both areas was interpreted as resulting from discrete coseismic uplifts accompanying large earthquakes. The recurrence interval of the large earthquakes was estimated by Ota *et al.* (1992) to be 300 to 1500 years for the East Coast, including the Wainui Beach area.

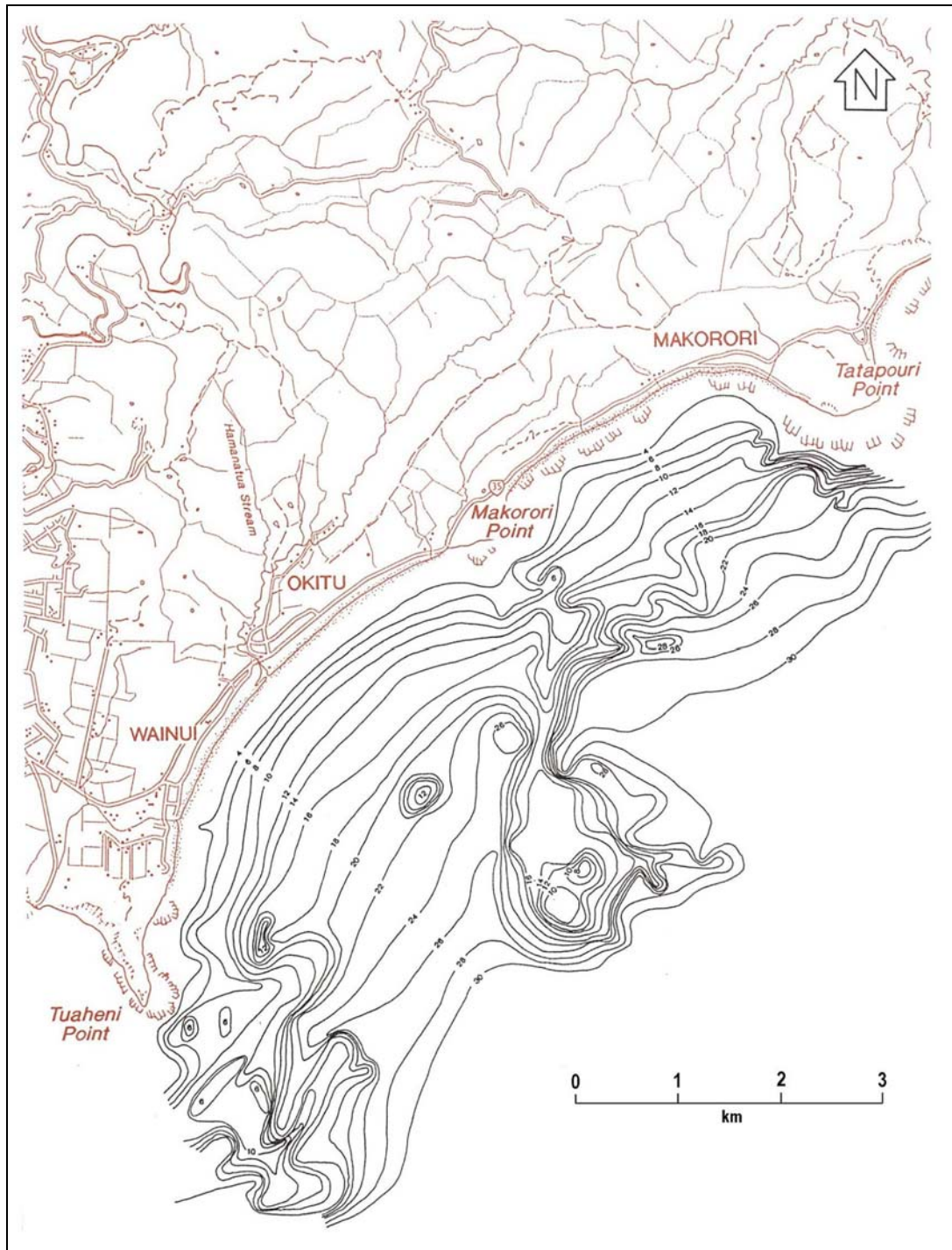
The net rates of tectonic uplift for Wainui Beach should be interpreted in the context that cumulative net uplift in New Zealand is a step function as a result of many discrete episodic earthquake events mostly associated with the colliding Australian and Pacific Plates East of Gisborne District. Examples of such events are, the Magnitude 8.2 Wairarapa Earthquake of 1855 accompanied by about 2.7m uplift and the Magnitude 7.8 Hawke's Bay Earthquake of 1931 accompanied also by a maximum of 2.7m uplift that affected 100 km of coastline (Ota *et al.* 1992).

This means that between major uplift events that occur say, every 300 to 1500 years, the Wainui coast is likely to have remained either static in terms of vertical tectonic movements or undergone possible interseismic subsidence. These effects have been observed from precise surveys in Japan which has a similar tectonic environment to New Zealand (Ota *et al.* 1991) and in Oregon (Komar 1996). Between uplift events, coastal subsidence would certainly enhance coastal erosion by lowering the level of the land with respect to the sea and the effects of storm waves.

3.2. THE SEABED

The bathymetric map in Figure 7 reveals some interesting facts about the morphology of the nearshore seabed within the study area. Wainui Beach is cradled between the arms of two major reef systems that extend southeast from Tuaheni and Makorori Points out to at least 30m-water depth. Although the reefs provide some protection for Wainui Beach from heavy seas from the South, East and Northeast quadrants, there is a window left open for direct attack from seas from the Southeast. History has shown that some of the most severe episodes of erosion have occurred during Southeasterly storms. The seabed morphology has a significant effect on incident wave attack along Wainui Beach by refracting approaching deep-water storm waves.

Between the Tuaheni and Makorori reefs that extend out from these points, the contours are generally smooth and sub-parallel, indicating the presence of sediments and low flat reefs out to at least 30m (Figure 7). The gradient of the nearshore seabed generally tends to flatten beyond both the 10m and 20m isobaths. The presence of steep submarine gullies and valleys dissecting the two major reefs, particularly on their Northeastern sides may indicate a lack of infilling by sediments, whereas the smooth contours along the Southwestern side of the Makorori reef may indicate a net North-eastward movement of sand and silt with transported sediments filling channels in the reef. The seaward offset of the 30m-depth contour off Wainui Beach compared to Makorori Beach (Figure 7), indicates that both the Tuaheni and Makorori reef systems are trapping and holding sediments off Wainui Beach preventing submarine bypassing at these depths to the Northeast.



• **Figure 7:** Indicative bathymetry in metres below MSL interpreted in 1993 by JG Gibb and RD Rice from sounding surveys made by HMNZS "Lachlan" 1956-1957, and DoC vessel "Tu Tuau" April-May 1993 (Adopted from Gibb 1998, fig.5).

3.3. SEDIMENTS

Data on the properties of sediments comprising the adjacent headlands, foredune, beach and nearshore seabed are adopted from Gibb (1998) in Appendix I.

3.3.1. BEACH AND FOREDUNE

Table 3 provides data on the textures and shell content of the beach, dune, and Late Tertiary sandstone sediments between Tuaheni and Tatapouri Points. The sediments were sampled by Dr Gibb in October 1981 and April-May 1993. For Wainui Beach, the beach sand is predominantly Well Sorted Shelly Fine to Medium Sand with shell content ranging from about 38 to 63 percent, averaging 50% (Gibb 1998). The highest concentrations of shell fragments are found in beach sands adjacent to the fauna rich shore platforms at Tuaheni and Makorori Points suggesting these environments to be significant sources of sand. The dune sands at Wainui are Well Sorted Shelly Fine Sand with shell content ranging from 29 to 36%, averaging 33% (Table 3).

• **Table 3:** Percentages of Wentworth size classes for sediment samples from Wainui Beach (WB) Makorori Beach (MB) and Tuaheni and Makorori (WB) and Tatapouri (MB) sandstone strata. (Adopted from Gibb 1998, tables 4 & 5, appendix II).

| STATION | ENVIRONMENT | SAND | | | | | MUD Coarse Silt 4 to 5Ø | CaCO ₃ % | BEACH TYPE Fine to Very Coarse Sand | OFFSHORE TYPE Mud to Very Fine Sand |
|---------|---------------------|------------------------------------|---------------------------|---------------------------|-------------------------|---------------------------------|----------------------------------|------------------------|--|--|
| | | Very Coarse Sand -1 to 0Ø | Coarse Sand 0 to 1Ø | Medium Sand 1 to 2Ø | Fine Sand 2 to 3Ø | Very Fine Sand 3 to 4Ø | | | | |
| WB-1 | Tuaheni Sandstone | 0.2 | 0.5 | 0.5 | 1.1 | 57.5 | 40.36 | N/A | 2.14 | 97.86 |
| WB-9 | Makorori Sandstone | 0.0 | 0.0 | 1.1 | 7.5 | 51.0 | 40.38 | N/A | 8.62 | 91.38 |
| MB-4 | Tatapouri Sandstone | 0.0 | 3.2 | 4.3 | 6.1 | 55.3 | 31.13 | N/A | 13.57 | 86.43 |
| WB-2 | Beach | 0.1 | 3.2 | 55.6 | 40.1 | 1.0 | 0.03 | 58 | 98.97 | 1.03 |
| 5.5 | Beach | 0.0 | 1.8 | 42.7 | 51.7 | 0.8 | 3.0 | 43 | 96.20 | 3.80 |
| WB-4 | Beach | 0.1 | 4.8 | 62.8 | 32.0 | 0.3 | 0.01 | 51 | 99.69 | 0.31 |
| 7.6 | Beach | 0.9 | 11.8 | 63.0 | 17.8 | 1.0 | 5.4 | 60 | 93.60 | 6.4 |
| WB-5 | Beach | 0.0 | 0.2 | 53.0 | 45.7 | 1.1 | 0.02 | 50 | 98.88 | 1.12 |
| 9.5 | Beach | 0.0 | 0.8 | 71.4 | 22.7 | 0.9 | 4.2 | 44 | 94.90 | 5.10 |
| WB-7 | Beach | 0.0 | 2.9 | 71.5 | 25.5 | 0.1 | 0.0 | 46 | 99.90 | 0.10 |
| 12.6 | Beach | 0.0 | 0.1 | 49.2 | 46.3 | 0.7 | 3.7 | 38 | 95.60 | 4.40 |
| WB-8 | Beach | 0.5 | 11.5 | 60.5 | 27.9 | 0.6 | 0.02 | 63 | 99.38 | 0.62 |
| WB-3 | Dune | 0.0 | 0.5 | 24.8 | 70.7 | 3.6 | 0.04 | 29 | 96.36 | 3.64 |
| WB-6 | Dune | 0.0 | 0.5 | 35.7 | 61.5 | 2.1 | 0.16 | 36 | 97.73 | 2.27 |
| MB-1 | Beach | 0.0 | 0.7 | 23.3 | 71.3 | 4.6 | 0.05 | 55 | 95.35 | 4.65 |
| MB-2 | Beach | 0.0 | 0.0 | 0.9 | 88.7 | 10.4 | 0.04 | 32 | 89.56 | 10.44 |
| MB-3 | Beach | 0.0 | 0.0 | 0.6 | 90.6 | 8.8 | 0.04 | 29 | 91.16 | 8.84 |

In contrast, the beach sand along the adjacent Makorori Beach is relatively finer with less shell. The sand is predominantly Well to Very Well Sorted Shelly Fine Sand with shell content ranging from 29 to 55 percent, averaging 39% (Table 3). The relative fineness of this sand compared to Wainui Beach suggests a net Northeasterly longshore drift along the coast with an unknown portion of Fine Sand being transported from Wainui Beach around Makorori Point during Southerly wave storms. Compared to Wainui Beach, Makorori Beach has an historic trend of duneline advance from accretion confirming the net Northeast longshore drift direction and accumulation of sand in this area.

3.3.2. NEARSHORE SEDIMENTS

Table 4 provides data on the textures of sediments covering the nearshore seabed off Wainui Beach. The sediments were sampled by DML in April 2000 and analysed by the University of Waikato in May 2000. Combined with sediment data in Gibb (1998), the seabed adjacent to Wainui Beach is revealed to be composed of rocky reefs extending from both Tuaheni and Makorori Points separated by a predominantly sandy seabed. The sand grades from relatively coarse inshore to very fine offshore.

Out to about 5 to 6m depth the seabed is composed predominantly of Medium to Coarse Shelly Sand. From about 6m to about 10m-water depth, the seabed is composed of Fine to Medium Shelly Sand. Seaward of 10m out to at least 21m depth sediments gradually fine to Very Fine Muddy Sand. Off Southern Wainui Beach, sand distribution is patchy and is mostly found between low-lying reefs. Off Northern Wainui Beach, sand distribution is continuous out to at least 30m water depth. These data indicate that Wainui Beach sand generally extends out to about 10m water depth. The 10m depth limit was identified in both the 1993 and 2000 offshore surveys.

Table 4: Percentages of Wentworth size classes by volume for nearshore sediments off Wainui Beach, with cumulative percentages of both Wainui Beach type and offshore type sediments. Sediment analyses performed by Department of Earth Sciences, University of Waikato, May 2000, using a Laser Diffraction Particle Sizer.

| STATIONS | DEPTH | SIZE CLASSES IN MICRONS (μ) | | | | | | BEACH TYPE | OFFSHORE TYPE |
|----------|--------|-------------------------------------|-------------------------------|------------------------------|----------------------------|----------------------------------|-----------------------|--|---|
| | m MSL | Very Course Sand 1000-2000 μ | Coarse Sand 500-1000 μ | Medium Sand 250-500 μ | Fine Sand 125-250 μ | Very Fine Sand 62.5-125 μ | Mud $\leq 62.5\mu$ | Fine to Very Coarse Sand 250-2000 μ | Mud to Very Fine Sand $\leq 62.5-250\mu$ |
| 4/1 | -4.00 | 20.00 | 35.53 | 23.61 | 16.27 | 3.17 | 1.41 | 95.42 | 4.58 |
| 4/4 | -10.60 | 10.32 | 31.23 | 29.47 | 22.05 | 4.95 | 1.99 | 93.06 | 6.94 |
| 7/1 | -4.60 | 22.67 | 39.56 | 24.13 | 11.11 | 1.25 | 1.27 | 97.48 | 2.52 |
| 7/2 | -7.10 | 0.00 | 7.75 | 50.75 | 34.05 | 4.44 | 3.01 | 92.55 | 7.45 |
| 7/3 | -10.50 | 0.00 | 4.90 | 44.83 | 38.87 | 7.69 | 3.71 | 88.60 | 11.40 |
| 7/4 | -13.70 | 0.00 | 6.86 | 44.26 | 33.09 | 5.79 | 9.99 | 84.22 | 15.78 |
| 8A/9 | -4.80 | 6.63 | 22.91 | 36.19 | 27.21 | 4.53 | 2.53 | 92.94 | 7.06 |
| 8A/8 | -6.20 | 12.73 | 32.04 | 35.35 | 15.70 | 1.63 | 2.49 | 95.88 | 4.12 |
| 8A/7 | -9.00 | 0.00 | 6.57 | 51.17 | 34.28 | 4.56 | 3.42 | 92.02 | 7.98 |
| 8A/6 | -11.20 | 0.00 | 2.34 | 36.58 | 41.15 | 12.94 | 6.98 | 80.08 | 19.92 |
| 8A/5 | -12.20 | 0.00 | 0.34 | 23.50 | 43.09 | 22.78 | 10.28 | 66.94 | 33.06 |
| 8A/4 | -14.90 | 0.00 | 0.00 | 14.74 | 43.55 | 29.96 | 11.74 | 58.30 | 41.70 |
| 8A/3 | -16.80 | 0.00 | 0.00 | 9.22 | 41.42 | 32.85 | 16.51 | 50.64 | 49.36 |
| 8A/2 | -18.90 | 0.00 | 0.00 | 2.79 | 38.54 | 41.31 | 17.37 | 41.32 | 58.68 |
| 8A/1 | -21.30 | 0.00 | 0.00 | 1.48 | 29.75 | 40.36 | 28.42 | 31.22 | 68.78 |
| 10A/4 | -5.00 | 13.39 | 35.37 | 31.47 | 15.99 | 2.00 | 1.78 | 96.22 | 3.78 |
| 10A/3 | -8.30 | 0.00 | 5.87 | 47.85 | 36.26 | 6.60 | 3.41 | 89.99 | 10.01 |
| 10A/2 | -12.00 | 0.00 | 0.00 | 9.45 | 42.80 | 35.21 | 12.54 | 52.25 | 47.75 |
| 10A/1 | -13.90 | 0.00 | 0.00 | 10.60 | 39.91 | 33.47 | 16.02 | 50.51 | 49.49 |
| 12/1 | -3.40 | 7.99 | 28.84 | 36.31 | 21.70 | 3.19 | 1.98 | 94.83 | 5.17 |
| 12/2 | -7.80 | 0.00 | 3.93 | 46.69 | 39.29 | 6.94 | 3.15 | 89.91 | 10.09 |
| 12/3 | -10.70 | 0.00 | 0.00 | 15.82 | 43.50 | 26.72 | 13.96 | 59.32 | 40.68 |
| 12/4 | -12.10 | 0.00 | 0.00 | 4.72 | 13.69 | 11.28 | 70.32 | 18.40 | 81.60 |
| 12/5 | -13.70 | 0.00 | 0.00 | 12.82 | 41.39 | 32.65 | 13.12 | 54.23 | 45.77 |

3.3.3. HEADLANDS

Samples were taken from the sandstone strata in the exposed Late Tertiary alternating sandstone-siltstone sequences along Tuaheni, Makorori and Tatapouri Points in 1981. Analyses show that these sediments are finer than the beach sand and are composed of predominantly Moderately Well Sorted Very Fine Sand and Coarse Silt (Table 3) similar

to that found in depths greater than 15 to 20m (Gibb 1998). These strata outcrop in the seacliffs, shore platforms and as reefs on the nearshore seabed of the study area.

3.3.4. SOURCES OF BEACH SAND

Petrographic analyses of detrital minerals indicate several *primary sources* for the beach sand at Wainui and Makorori. Pumice, quartz, feldspar (medium plagioclase), magnetite, hypersthene, hornblende and augite are *volcanic-derived* minerals; sandstone-siltstone fragments, fine-grained calcite, glauconite, microcline (K-feldspar), zircon, sphene and barite are *sedimentary-derived*; shell fragments are derived from whole shells from the adjacent *intertidal shore platforms and offshore reefs* that have been smashed by wave action (Gibb 1998).

The light minerals, quartz and feldspar, range in abundance from 30 to 40% along the beach. Next are pumice and sandstone-siltstone rock fragments which constitute 5 to 20% of the sand. These are followed in abundance by the heavy minerals hypersthene, augite, hornblende and magnetite which constitute less than 5% of the sand. Occasional rare grains of sphene, zircon, barite and glauconite occur throughout (Gibb and Jones 1977; Gibb 1981a).

The most likely source for the volcanic-derived minerals are the rhyolitic air-fall ash deposits (tephra), erupted over the last 150,000 years from the Central Volcanic Region. The tephra were transported to the Gisborne area by prevailing West to Northwesterly winds. This episodic process was observed during the 1995 and 1996 ash eruptions of Mount Ruapehu which transported fine ash to the East Coast by Westerly winds to be deposited on the ground.

Tephra deposits mantle the hills and extend on to the seabed, varying in thickness depending on the magnitude and duration of an eruption. The last major eruptive events were the massive Taupo Eruption from Lake Taupo that occurred about A.D. 200, and the Kaharoa Eruption from Mount Tarawera that occurred about A.D. 1350 (Lowe *et al.* 2000).

The sedimentary-derived minerals come from the erosion products of the Late Tertiary rocks forming the Tuaheni, Makorori and Tatapouri headlands, shore platforms and offshore reefs (Gibb and Jones 1977; Gibb 1981a). These rocks are composed of alternating layers of sandstone-siltstone. The sandstone breaks down in the surf zone to supply a very small amount to fine Sand.

As the catchments and flows of the Wainui and Hamanatua streams are too small to supply adequate quantities of volcanic-derived sand eroded from the mantling soils to the beach system, the nearshore seabed is concluded to be the major supply area for Wainui Beach. The next source area is the adjacent eroding coastline and seabed of Late Tertiary sedimentary rocks. Sediment is transported to Wainui Beach by wave and current action. The following abundances of sand supplied from each major physical source area to Wainui and Makorori beaches are estimated from the above evidence:

- i. **Nearshore Seabed:** Nearshore sediments of relict volcanic-derived sands which supply some 50% of sand by volume to Wainui and 60% to Makorori.
- ii. **Shell Beds:** Adjacent shore platforms and offshore reefs which contribute some 50% of shell fragments by volume to Wainui and 40% to Makorori.

- iii. **Headlands:** Eroding Late Tertiary sandstone beds outcropping on the coast and seabed which contribute some 5% by volume of sand to Wainui Beach and some 15% to Makorori Beach. The remaining Very Fine Sand and Mud fractions supplied from the erosion of Late Tertiary rocks are transported offshore by wave action to settle out into water depths greater than 10m.

3.4. POSTGLACIAL EVOLUTION

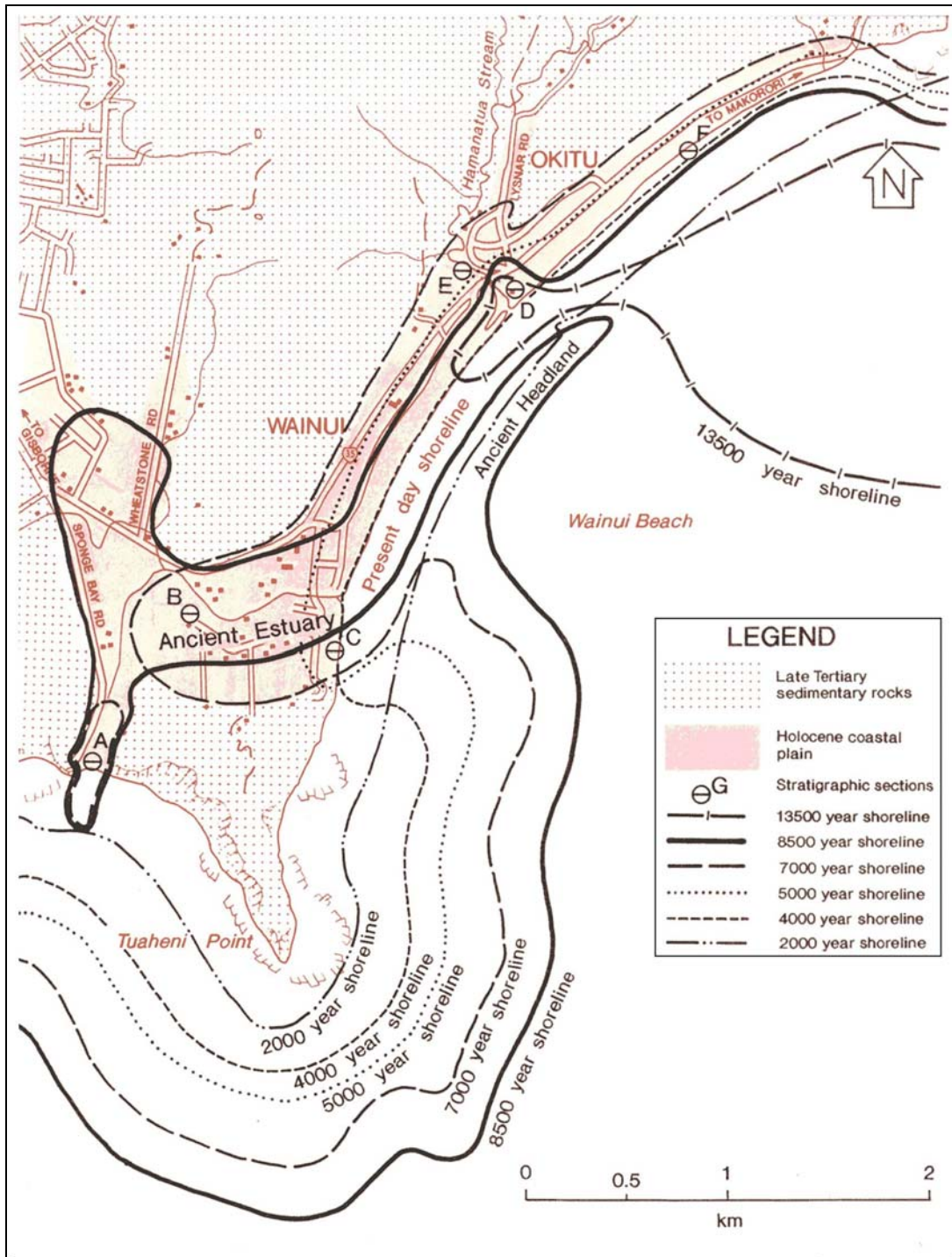
Figure 8 adopted from Gibb (1998) shows the evolution of the Wainui Beach area over the last 13,500 years. The inferred shoreline positions were interpreted by Gibb (1998) from the combination of radiocarbon-dated stratigraphy (Figure 6), an inferred net shoreline retreat rate of -0.15m/year and the geomorphology of the land above and below MHWS.

About 18,000 years ago, at the peak of the Last Glaciation, sea-level stood about 130m below present (Gibb 1986b; Carter *et al.* 1986) and the shoreline at Wainui was some 20km East along the seaward edge of the present continental shelf. As climate warmed some 4 to 5°C, sea-level rose at 10 to 15m/ka outpacing tectonic uplift, causing a widespread landward retreat of the shoreline everywhere around New Zealand generally and at Wainui specifically (Gibb 1988).

About 11,500 years ago there was a significant prolonged stillstand of the rising sea at about 55m below the present sea-level. Extensive submerged radiocarbon dated shoreline features on the Otago and Canterbury continental shelves are evidence of this major stillstand (Carter *et al.* 1986). At this time the rising sea had established a small estuary at what is now the Hamanatua Stream mouth protected by a promontory on what is now seabed (see Figure 8). Following the stillstand at 11,500-years ago the sea rose rapidly until there was another prolonged stillstand about 9500 to 8500 years ago at about 24m below the present sea-level (Gibb 1986b).

During the rise, the sea invaded what is now the "*Wainui Valley*" substantially increasing the size of the estuary and causing a change in facies from estuarine sands to silts (see Figure 6). The silts were provided from both coastal erosion of the Late Tertiary hinterland and from the Wainui and Hamanatua Streams. They formed extensive tidal flats that supported abundant beds of the cockle, *Austrovenus stutchburyi*, amongst other estuarine dwelling fauna such as the pipi *Paphies australis* and the mud snail *Amphibola crenata*.

As the *postglacial marine transgression* (PMT) rose at 10 to 15m/ka it easily outpaced net tectonic uplift at 1 to 3m/ka at Wainui resulting in continued retreat of the open-exposed coast at about -0.15m/year. Whilst the headlands retreated, the estuary kept expanding and was colonised by extensive mangroves about 8000 to 9000 years ago (Mildenhall 1994) in response to short-term climate warming of 2°C above the present (Salinger 1991). The present climate pattern, which was established about 2500 years ago, has cooled by the same amount (Royal Society of NZ 1988) over the last 2500 years and mangroves no longer naturally grow at Gisborne. They are presently found in the Uawa Estuary in Tolaga Bay but are known to have been planted there.



• **Figure 8:** Evolution of Wainui Beach over the last 13,500 years displayed by inferred shoreline positions. (Adopted from Gibb 1998, fig.9).

The Wainui estuary existed up to the time of the culmination of PMT about 7000 years ago (Gibb 1986b). With the total destruction of the promontory to become what is now a succession of low-lying reefs partly covered by sand, the estuary was invaded by heavy seas. A dramatic change in sedimentation resulted as shelly sand was driven into the embayment burying the estuarine silts and killing and preserving the shell beds and mangroves. Gravel beach ridges started to form in the new embayment from longshore transport of the erosion products of the adjacent headlands, particularly from Tuaheni Point.

Following the culmination of the PMT at the present sea-level about 7000 years ago, sea-level fluctuations have not exceeded $\pm 0.5\text{m}$ (Gibb 1986b) in response to the generally stable Present Interglacial climate. As a result tectonic uplift at 1.5 to 3.0m/ka has predominated over the last 7000 years, progressively stranding the Holocene coastal plain at Wainui by some 7 to 20m above present sea-level.

From about 7000 to 2000 years ago the shoreline at Wainui continued to advance in response to large earthquake uplifts every 300 to 1500 years, reaching its maximum distance seaward about 2000 years ago. The combination of emergence from uplift and supply of predominantly volcanic-derived sand from the raised seabed and volcanic eruptions like the massive Taupo Eruption about A.D. 200, resulted in a slow advance of the Wainui foreshore over the 5000 year-period in contrast to the continued retreat of the Makorori and Tuaheni headlands. About 2000 years ago shoreline advance at Wainui reversed to retreat in line with the retreat of the adjacent headlands. The alignment of Wainui Beach was now predominantly controlled by the alignments of the eroding headlands, a process that is continuing today.

3.5. SUMMARY

In summary, the pattern of geologic evolution of Wainui Beach over the last 13,500 years has revealed the following significant changes:

- i. The existence of a tidal estuary with mangroves from about 13,500 to 7,000 years ago with its entrance at the present mouth of the Hamanatua Stream.
- ii. The spectacular evolution of the Wainui Beach area over the last 7000 years from a sheltered estuary to an open exposed coastal environment.
- iii. Reversal from very slow shoreline advance to long-term retreat about 2000 years ago, controlled by the retreating Tuaheni and Makorori Headlands.
- iv. Erosion processes have predominated over emergence from tectonic uplift over the last 2000 years compounding the geologic trend of long-term shoreline retreat.
- v. Emergence occurs instantaneously during large earthquakes every 300 to 1500 years during which time the shoreline temporarily advances proportionate to both the amount of uplift and gradient of the beach.
- vi. Between major uplift events erosion processes predominate, possibly assisted by interseismic subsidence, and the shoreline generally retreats.
- vii. More than 90% of the sand at Wainui Beach is derived from both spasmodic volcanic eruptions from the Central Volcanic Zone such as the massive Taupo Eruption about A.D. 200, and the constant breakdown of seashells. The remainder is supplied from

the continual erosion of the Late Tertiary rocks that form the onshore-offshore substrate geology.

- viii. Until the next major eruption from the Central Volcanic Zone the sand of both Wainui and Makorori beaches must be considered a finite resource in need of careful management.

4. COASTAL DYNAMICS

The interaction of dynamic coastal processes with the geology and ongoing postglacial evolution of Wainui Beach has contributed to the natural coastal hazards experienced along the study area.

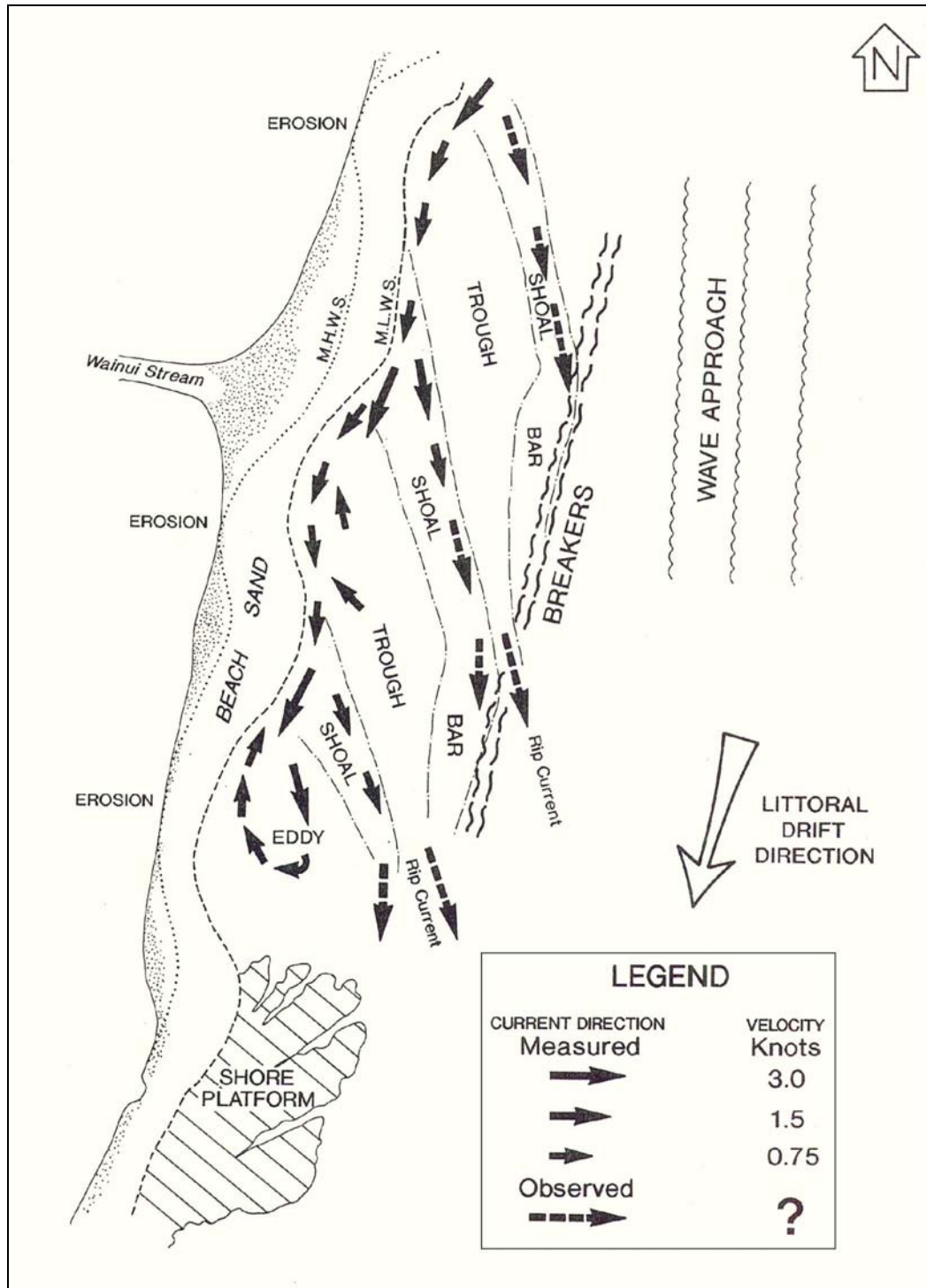
4.1. EROSION PROCESSES

Sedimentary and geomorphic evidence suggests an oscillatory longshore drift of sand along Wainui Beach. Under Northeasterly sea conditions the North end of the beach decreases in width, the South end increases in width and the Hamanatua Stream offsets South, to extend up to 0.5km towards Tuaheni Point from its normal discharge position by the Surf Club. Under Southeasterly sea conditions the opposite tends to happen with a narrow beach at the South end and a wide beach to the North with the Hamanatua Stream offsetting North to cut into Lysnar Domain.

Observations during storm activity have shown that a wide beach absorbs wave energy protecting the dunes behind from erosion. Conversely, a narrow beach exposes the dunes to erosion processes. Thus, the Southern half of Wainui Beach is most vulnerable to erosion during prolonged South-Southeasterly wave storms when the beach is narrowed. Localised beach lowering along the South directed meander channel of the Hamanatua Stream, also promotes erosion of the adjacent foredune.

One of the unique characteristics of Wainui Beach is its undulating rhythmic topography of shoals, troughs and associated rip currents. Breeding (1981) recognised two major wave induced current patterns associated with rhythmic topography. First, when waves parallel the shore, circulation cells are developed. The adjacent cells rotate in opposite directions. The seaward flow of water is a rip current and is directed perpendicular to the shore. Second, when waves arrive at an angle to the shoreline meandering currents develop along the shore, and the rip currents are at an angle to the shore line. In this situation, the rip currents migrate downstream with the shoals and troughs creating marked changes in the elevation of the beach.

Figure 9 shows a typical rhythmic beach topography at the Southern end of Wainui Beach recorded by Gibb in 1973 (Gibb 1998). Under Northeasterly sea conditions rip currents were observed to run out to sea obliquely southwards from the beach under the influence of a southerly longshore drift. Gibb (1998) measured littoral current velocities ranging from 0.75 to 3.0 knots from drifting seaweed, the highest velocities occurring over shoals and the lowest in the troughs where counter eddies often became established. The combination of longshore drift and rip currents was responsible for moulding the nearshore topography of shoals, bars and troughs which accords with the observations of Breeding (1981). The relatively coarse texture and shell content of Wainui Beach sand contributes significantly to its rapid mobility under wave and current conditions.



• **Figure 9:** Typical rhythmic beach topography and nearshore circulation at Wainui Beach observed on 19-21 March 1973 resulting in differential erosion at the head of rip current troughs (Adopted from Gibb 1998, fig.12).

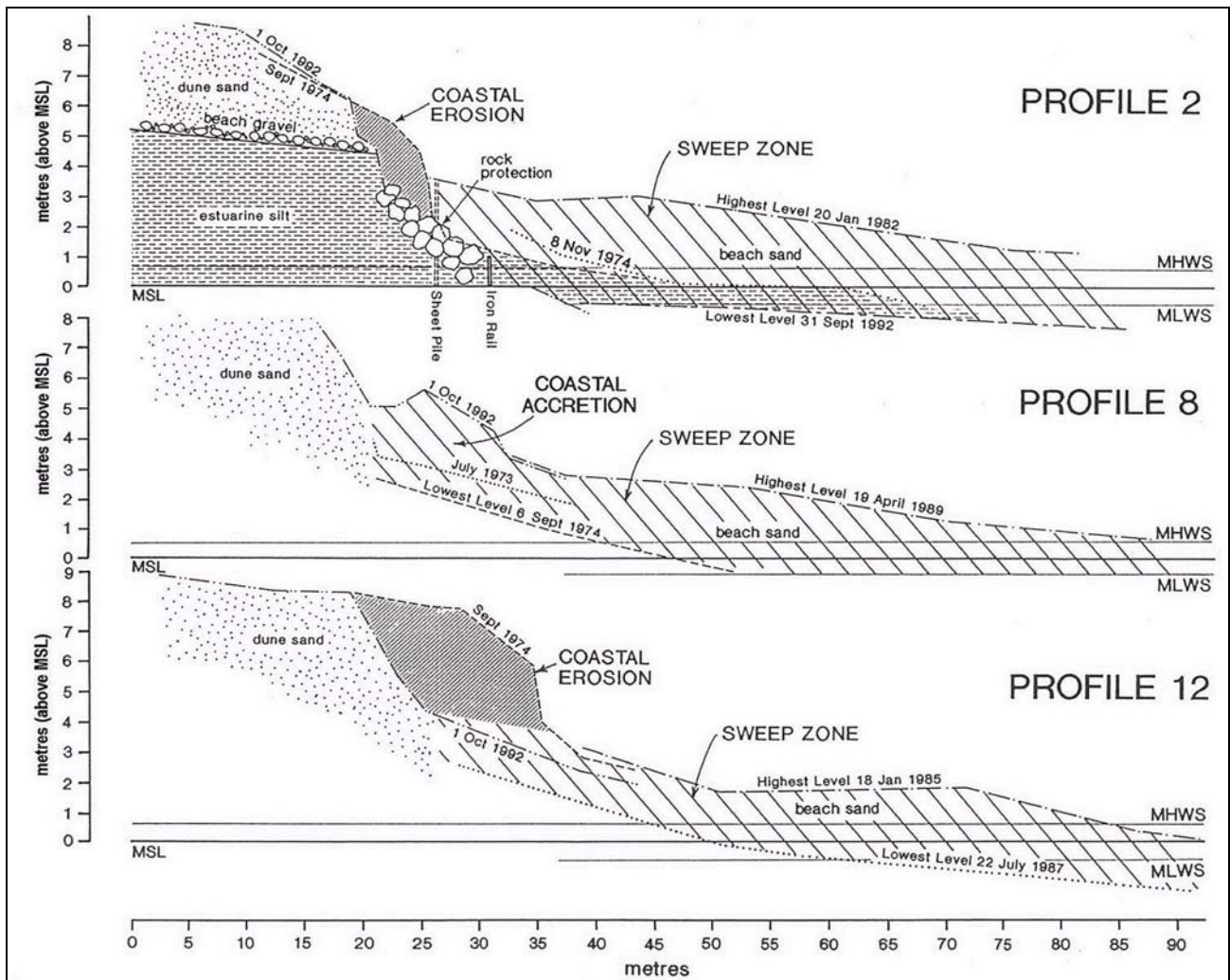
A significant process contributing to the retreat from coastal erosion at Wainui Beach is the formation of rip current troughs at any point along the beach. Breeding (1981) noted that higher wave heights occurred in the troughs than on the shoals which means more wave energy was available for coastal erosion at the head of the troughs. As the beach here is narrow in width compared to that opposite the shoals then the adjacent foredune is more susceptible to differential erosion (Figure 9). At Wainui Beach, the formation and migration of rip current troughs directly results in differential short-term erosion up to 15-20m at unpredictable places along the foredune (Gibb 1998). Between such erosion sites the foredune may show either differential advance or a state of dynamic equilibrium.

Gibb and Jones (1977) observed that waves from the East-Southeast quadrant could cause formation of rip currents at the North end of Wainui Beach whereas waves from the East-Northeast quadrant may cause rip currents at the South end. Waves arriving parallel to the beach were observed to create rip currents along the entire length. The interaction of rip currents with longshore currents in the nearshore zone ensures that the circulation of Wainui Beach sand is complex and dynamic. The optimum conditions for erosion to threaten beachfront development along Southern Wainui Beach is during prolonged Southeasterly wave storms coupled with a narrow beach and the formation of migrating rip current troughs such as occurred during the 1992 winter.

Figure 10 shows the relative magnitude and differential nature of the onshore-offshore transport of sand along Wainui Beach recorded at three selected GDC profile sites. Profile 2 represents the Southern beach near Lloyd George Road, Profile 8 the central area at the North end of Wairere Road, and Profile 12 the Northern area about midway between the Hamanatua Stream and Makorori Point. The sweep zones and erosion or accretion of the foredune are the maximum recorded between July 1973 and October 1992 and are shown with respect to the datums of MSL, MHWS and MLWS.

For all three profiles the dynamic datum elevation of MHWS is shown to migrate horizontally up to 40 to 60 m. The highest and lowest beach levels were all achieved in different years on the three profiles indicating that the onshore-offshore movement of sand is non-uniform and localised along the 4.2 km-long Wainui Beach. Erosion profiles are typically concave-up compared to accretion profiles which are convex-up (Figure 10).

Whilst the foredune surveyed on Profile 12 has retreated about 12m between 1974 and 1992 an incipient foredune has accreted the same amount at Profile 8 during the same period (Figure 10). Profile 2 shows that the Holocene estuarine silt substrate underlying the beach has been downcut by up to 2 m, all of which occurred during the South-Southeasterly wave storms between May and October 1992. As noted previously, the very soft silt substrate underlying the beach extends from Tuahine Crescent to the Hamanatua Stream and is extremely susceptible to irreversible erosion once the protective dune and beach sand cover is removed during localised erosion episodes.



• **Figure 10:** Maximum sweep zones and coastal erosion or accretion at 3 representative beach profiles along Wainui Beach surveyed by ECCB and GDC between 1973 and 1992 (Adopted from Gibb 1998, fig.13).

4.2. SIGNIFICANT WAVE STORMS

During the period 11 May 1982 to 17 December 1984 a wave-rider buoy was deployed off Tatapouri Point by Ministry of Works and Development under Dr Gibb's direction. The buoy was located about 1.8 km offshore in about 32 m water depth. The highest significant wave height (highest one third- H_{sig}) recorded during the 2.6 years was 5.75 m and the median value was about 1 m. Wave periods averaged 6 to 9s for 80% of the time and the median value was 11 seconds (Macky *et al.* 1987). Macky *et al.* (1987) observed that "winter produces higher waves more frequently than summer but there is no strong seasonality. The winter calms have higher wave levels and are of shorter duration than summer calms".

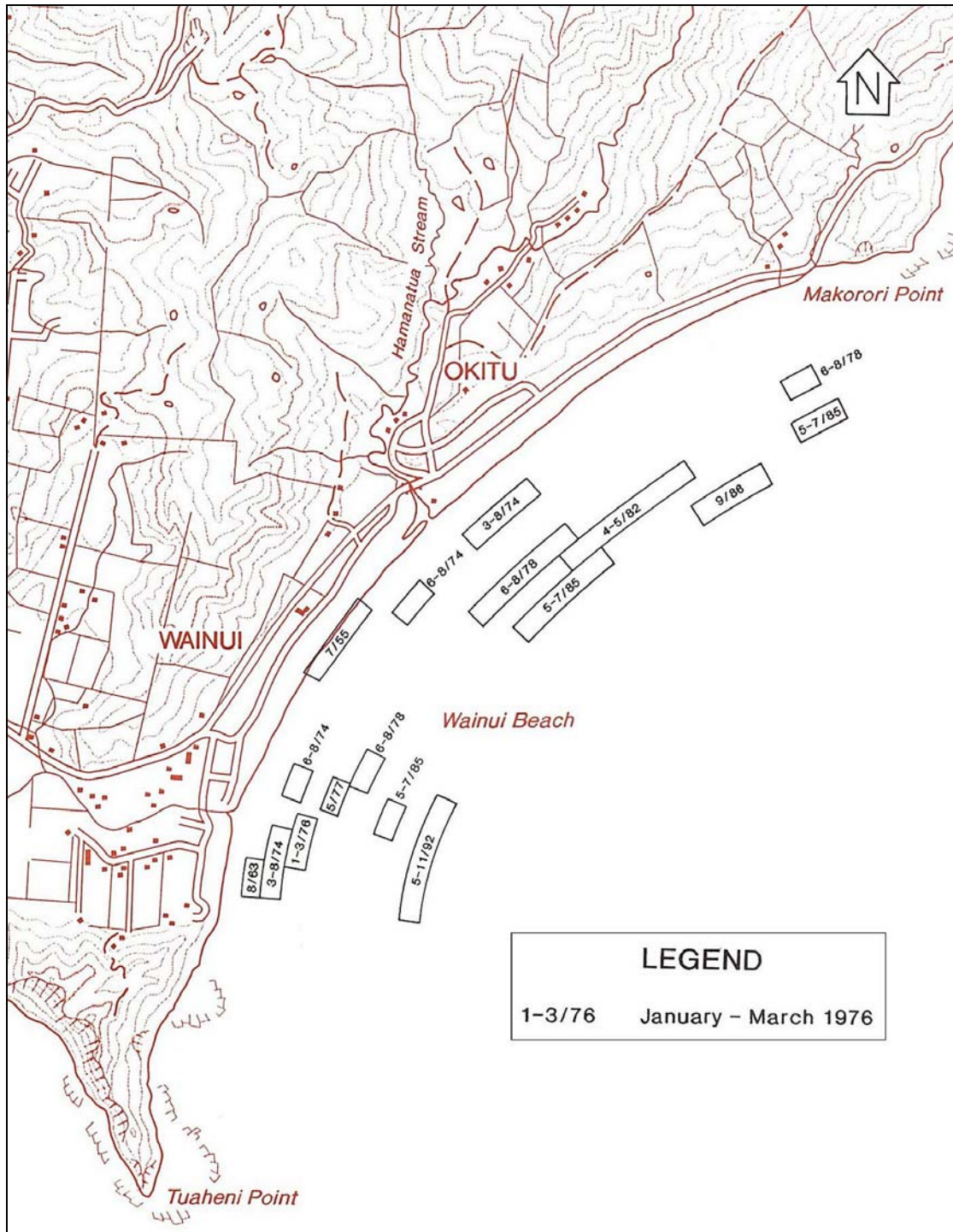
Although these authors noted that the wave heights under an *El Niño* regime appeared to be somewhat lower on average than at other times "*the general nature of the wave environment does not change*" (Macky *et al.* 1987). The fact remains however, that the 2.6-year record was made during an extreme *El Niño* climate regime characterised by East Coast drought and a predominance of offshore winds from the Westerly quadrant which flattened the swell waves.

The wave observations accord with the episodic onshore-offshore cyclic movement of sand especially those observations made during the extreme *El Niño* regime of 1982-1983. Macky *et al.* (1987) noted that the 2.6-year period of wave recording was much shorter than desirable if long-term predictions were to be made for extreme wave conditions likely to be expected in a 50-year period. For such predictions about 15-20 years of continuous data are required (Macky *et al.* 1987) and for 100-year forecasts about 30-40 years of continuous data (Paul Komar, pers. com. 1998).

Ship-borne observations of the wave climate off the East Coast for the period 1970 to 1990 revealed significant wave heights in the range of 1.0 to 3.0m for 88% of the time, with storm wave heights up to 6 to 8m, usually during winter months, for about 2% of the time, and rare events producing significant waves up to 10m (Komar 1996). These sea conditions are somewhat larger than those recorded between 1982 and 1984, clearly indicating that the 2.6-year wave record analysed by Macky *et al.* (1987) should be treated with caution.

Figure 11 shows the times and places of erosion events along Wainui Beach between July 1955 and October 1992 (37 years) during severe wave storms. No reliable data are available before 1955 although it is known that the Southern beach was subject to erosion in the 1940s. On all occasions, erosion occurred at the head of rip current troughs. Although they have shown a tendency to cluster at the Southern end of the beach between Tuahine Crescent and Oneroa Road and around the Hamanatua Stream mouth since 1955, Figure 11 shows that no part of the 4.2km-long Wainui Beach is excluded from such attacks.

In chronological sequence, severe differential erosion has occurred at Wainui Beach in the 1940s, in July 1955, August 1963, March-August 1974, January-March 1976, May 1977, June-August 1978, April-May 1982 (Cyclone Bernie), May-July 1985, September 1986, May-November 1992, June 1994 and during the 1996/1997 summer when 4 Tropical Cyclones struck the North Island. Major short-term differential duneline retreat of 15-20m occurred in the 1940s, in 1955 and in 1978.



• **Figure 11:** Sites of significant short-term erosion between 1955 and 1992 during severe onshore storms. Although similar storm damage has occurred before 1955 no precise data are available (Adopted from Gibb 1998, fig.14).

4.2.1. THE 1992 WINTER STORMS

The 1992 erosion episode at Wainui Beach is well documented by Peacock (1992) and Gibb (1998). Between early May and late October 1992 the North Island East Coast was battered by a succession of 7 South-Southeasterly storms accompanied by heavy seas. Like other open-exposed beaches along the North Island East Coast such as Riversdale, Castle Point and Waimarama, Wainui Beach was adversely affected. Many of the storms coincided with high spring tides and produced deep-water waves from the South-Southeasterly quadrant in excess of 4m. The severest storms occurred on 9-10 May, 3 July, 7-8 August, 28-29 August, 28-29 September, 15-16 October and 24 October 1992 (Peacock 1992).

During the severe wave storm of 9-10 May 1992 the beach was lowered next to Tuahine Crescent. Successive storms from the same quadrant removed the remaining beach sand exposing the highly erodible Holocene estuarine silt substrate underlying the beach to wave attack. Between May and July 1992 the average downcutting of the silt substrate at Profiles 2 and 3 was 0.56m and the total irreversible loss of silt was 9700m³ (Peacock 1992). During 1992, downcutting of over 1m occurred at Profile 2 (Figure 10) so that the total loss of silt exceeded 10,000m³. Most importantly, sand from elsewhere along the beach filled the erosion depression thus causing an equivalent net reduction in the Wainui sand budget (Gibb 1998).

The relative loss of sand contributed to up to 8m retreat of the foredune between Tuahine Crescent and Oneroa Road. Foredune erosion has added about 8300m³ of sediment to the nearshore circulation system, comprising 5800m³ of sand and 2500m³ of silt (Peacock 1992). The silt has been washed offshore and represents a permanent loss whereas the sand from the eroded foredune has been added to the beach sand budget, partially offsetting losses (Gibb 1998).

During the 1992 erosion episode, Council surveys recorded a minimum total beach sand volume for Wainui Beach in May of 115,031m³, comprising only 7693m³ along the Southern beach and 107,338m³ along the Northern beach, north of Hamanatia Stream. Although the minimum total sand volume along the 4.2km-long beach was not exceptional in the context of surveys since July 1973, the sand volume along the Southern 2.1km of beach was the lowest recorded since the severe winters of 1974, 1975 and 1978 when similar South-Southeasterly storm conditions prevailed.

The directional consistency and intensity of the South-Southeasterly seas during the 1992 erosion episode also resulted in a seasonal longshore transport of sand Northwards along Wainui Beach. The net result was that 97% of the winter sand budget was distributed North of Hamanatia Stream. The relatively wide beach resulting, protected the Northern foredune from erosion. In contrast, the narrowing of the Southern beach between Tuahine Crescent and Oneroa Road exposed the Southern foredune and property protection works to prolonged and severe attack.

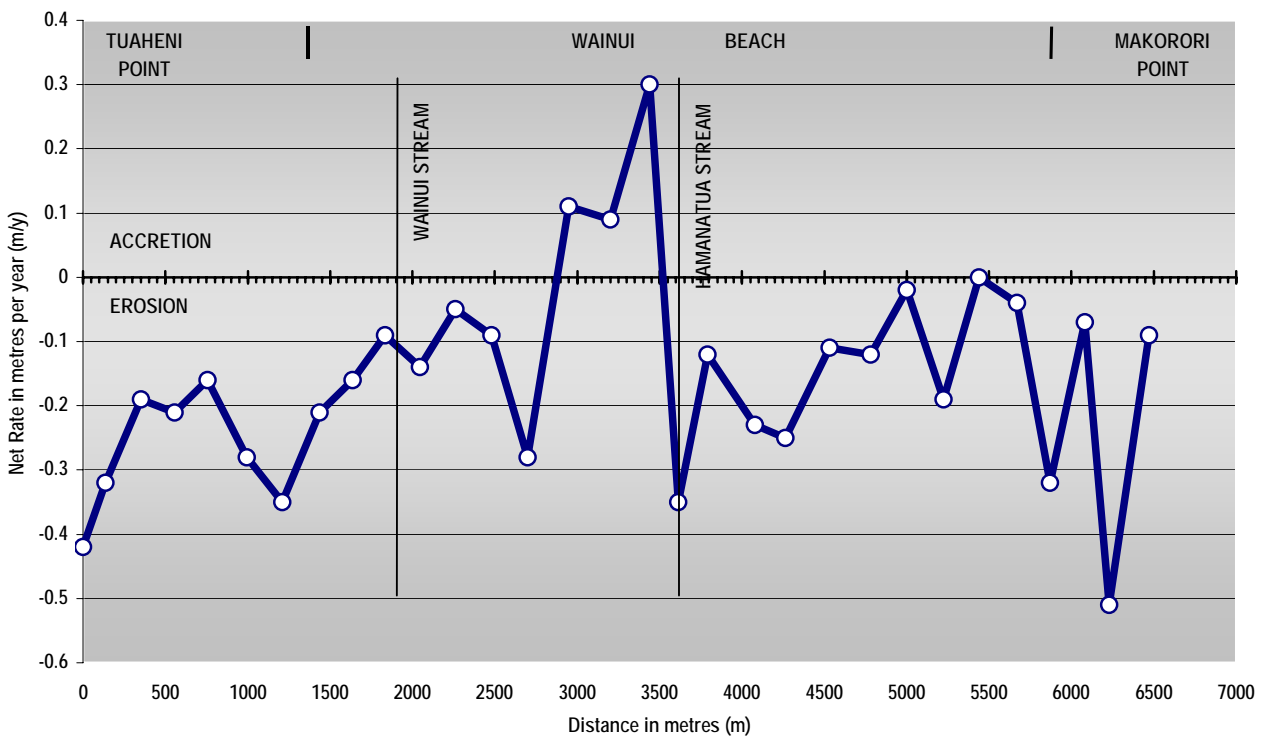
4.3. LONG-TERM SHORELINE TRENDS

Figure 12 and Table 5 summarise the long-term historic shoreline trend between Tuaheni and Makorori Points. The data are summarised from Appendix II where rates of change are provided for 31 Sites spaced approximately every 200m along the 6.2km-long coast between the 2 Points. Appendix II provides rates of erosion or accretion for survey intervals of 1942-1965, 1965-1982, and 1982-1999 and for the entire 57-year survey period

(1942-1999). The 57-year period is regarded here as reliable to quantify the long-term shoreline trend along both headlands and most of Wainui Beach.

• **Table 5:** Average rates of coastal erosion (-) or accretion in metres per year (m/year) for the 6.2km-long Wainui Beach, derived from Appendix II.

| Area | Sites | 1942-1965 | | 1965-1982 | | 1982-1999 | | 1942-1999 | |
|--------------------|-------|----------------|-------|----------------|-------|----------------|-------|----------------|-------|
| | | Range | Av. | Range | Av. | Range | Av. | Range | Av. |
| Tuaheni Point | 1-8 | 0.0 to -0.83 | -0.54 | 0.0 to -1.06 | -0.55 | -0.06 to -0.41 | -0.23 | -0.16 to -0.42 | -0.27 |
| Makorori Point | 27-31 | 0.0 to -0.48 | -0.15 | -0.18 to -0.53 | -0.32 | 0.0 to -0.59 | -0.28 | -0.04 to -0.51 | -0.21 |
| Wainui Beach South | 9-14 | 0.0 to -0.57 | -0.21 | 0.0 to -0.29 | -0.13 | 0.0 to -0.24 | -0.04 | -0.05 to -0.28 | -0.14 |
| Incipient foredune | 15-17 | 0.0 to -0.13 | -0.09 | 0.0 to -0.35 | -0.16 | 0.47 to 1.18 | 0.82 | 0.09 to 0.30 | 0.17 |
| Wainui Beach North | 18-26 | -0.09 to -0.61 | -0.33 | -0.12 to -0.53 | -0.28 | 0.0 to 0.71 | 0.32 | -0.02 to -0.35 | -0.15 |



• **Figure 12:** Net rates of coastal erosion (-) and accretion for 31 sites between Tuaheni Point and Makorori Point, derived from Appendix II, for the period 1942-1999.

For the 57-year period (1942-1999), 28 of the 31 stations (90%) record a long-term trend of retreat from erosion averaging -0.18m/year , ranging from -0.02 to -0.51m/year . Three (3) of the 31 Stations (10%) record a trend of net advance from accretion averaging $+0.17\text{m/year}$, ranging from 0.09 to 0.30m/year . The accretion is from the growth of a 750m-long incipient foredune South of the Hamanatua Stream outlet which has accumulated during the period 1982-1999 behind a groyne at the South side of the stream mouth. Prior to this there was an erosion trend of the main foredune at -0.05 to -0.23m/year for the period 1942-1982. The groyne limits the trend for Southerly migration of the stream thus promoting accretion which temporarily protects the main foredune in places from erosion.

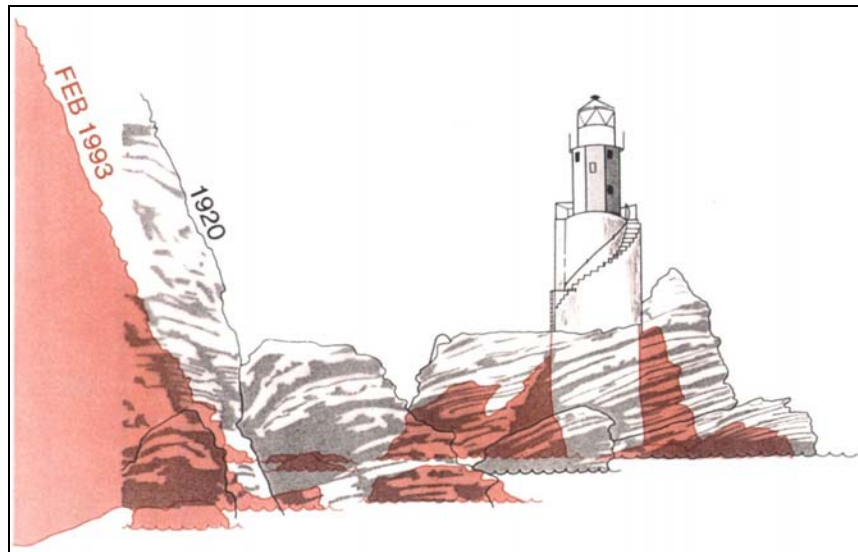
4.3.1. HEADLAND RETREAT

Tuaheni Point has retreated at -0.16 to -0.42m/year , averaging -0.27m/year , from 1942 to 1999 (Table 5). Makorori Point has retreated at -0.04 to -0.51m/year , averaging -0.21m/year , over the same period (Table 5). Long-term historic retreat of both headlands is entirely consistent with the geologic evidence. Headland retreat has left behind wave-cut shore platforms and reefs as well as providing sandstone gravels for beach formation. The headlands retreat through the combination of backcutting and landslip.

Both Tuaheni and Makorori Points play an important role in the long-term stability of Wainui Beach. The relatively '*hard*' headlands act as strong points that hold the line of the 4.2km-long Wainui Beach slung between them. As the '*strong points*' retreat, then it follows that Wainui Beach can be expected to retreat at similar rates (Gibb 1981a; 1995; 1998). The process appears to be irreversible notwithstanding the geologic trend of net tectonic uplift.

Photographic evidence of the abandoned Tuaheni Point lighthouse provides compelling anecdotal evidence of long-term headland retreat. In February 1993, Dr Gibb re-photographed a scene shown in an historical photograph of Tuaheni Point lighthouse in 1920 from approximately the same site occupied by the early photographer. By precisely matching the common "*static*" feature of the Tuaheni lighthouse, the 1993 scene was enlarged to match the 1920 photograph and the changes in the state of the rocks and seacliff compared. Figure 13 shows that the changes between 1920 and 1993 at Tuaheni Point have been dramatic and are consistent with the rates of retreat in Figure 12.

Comparative photography shows that the Late Tertiary sandstone-siltstone rock upon which the lighthouse was built about 1909 has been almost demolished by the sea since that time. Foot access to the lighthouse from the shoreline has disappeared and it can now only be reached by wading through treacherous water at low spring tides. Long-term coastal erosion at about -0.2 to -0.3m/year has progressively separated the old lighthouse from the crumbling Tuaheni Point. When last observed in October 2001 the lighthouse was still standing but the separation distance between Tuaheni Point and the lighthouse is steadily growing.



• **Figure 13:** Diagram compiled from photographs taken from the same position in 1920 and 1993, showing changes to Tuaheni Point from erosion, relative to the lighthouse over the last 73 years (Adopted from Gibb 1998, fig.10).

4.3.2. COASTAL LANDSLIP

Where exposed along Tuaheni headland, especially near Tuahine Crescent, the strata dip 15 to 20° seawards and are extremely susceptible to landsliding. High shear stress on these rocks is continuously induced by coastal erosion removing the lateral support of the land, ultimately resulting in bedding plane failures of the seacliffs at or above high water mark. As a consequence, strata above the level of the beach slide into the sea like a deck of cards. At this level the strata are weathered and disrupted by previous landslip thus promoting constant slope failure.

The recurrence of such landslides is unpredictable and may be triggered by sustained heavy rainfall or by moderate earthquake shaking. Landslip poses an extreme potential risk to houses constructed on the Late Tertiary rock at the Southern end of Tuahine Crescent (Gibb 1981a; 1998). About mid-September 2001 a relatively large slope failure occurred about 50 to 90m South of the houses in Tuahine Crescent (Figure 14). At Makorori Point the slopes are characterised by deep-seated rotational failures resulting in loss of farmland as well as posing a threat to parts of State Highway 35.

4.3.3. WAINUI BEACH

Table 5 shows that Southern Wainui Beach has retreated at -0.05 to -0.28m/year, averaging -0.14m/year, from 1942 to 1999. Over the same period, Northern Wainui Beach has retreated at -0.02 to -0.35m/year, averaging -0.15m/year (Table 5). The process of long-term retreat is not uniform but rather the resultant of many site-specific erosion cuts by storm waves at the head of ever-changing rip current troughs. Between this process, either short-term accretion or dynamic equilibrium occurs along discrete parts of Wainui Beach.



• **Figure 14:** Oblique aerial photograph taken 19 September 2001 of a landslide near houses at Tuahine Crescent that occurred a few days earlier (Photo courtesy of David Peacock, GDC).

4.4. SHORT-TERM SHORELINE FLUCTUATIONS AND STORM CUTS

Both the duneline and cliffline fluctuate in position about the long-term trend of retreat. Along both Tuaheni and Makorori Points landslip is an important component of retreat. Differential landslip temporarily pushes the 'cliffline' further seaward by up to 20 to 25m. Over the following months the landslide toe of rock debris and mud is trimmed back by the sea to roughly the pre-landslip cliffline position. By this process the sandstone beds are crushed into broken slabs which are abraded by wave action to form beach gravels (Gibb 1995).

Along Wainui Beach, parts are subject to irreversible storm cuts and others to duneline fluctuations involving episodic cycles of short-term erosion-accretion. Along Southern Wainui Beach, the 750m-long incipient foredune area is subject to duneline fluctuations, whereas the ancient raised foredune landward and South of the incipient dune is subject to irreversible short-term erosion cuts that do not recover. Along Northern Wainui Beach, the foredune is mostly subject to duneline fluctuations.

For most of the foredunes along Wainui Beach, maximum short-term duneline fluctuations of typically 10 to 20m occur (Gibb 1981a; 1998). In the area of the incipient foredune, fluctuations of 20 to 25m occur increasing to 30m near the mouth of the Hamanatua Stream. These larger fluctuations involve not only the main foredune complex but also the incipient foredune at the toe which was almost entirely removed during severe erosion episodes in the early 1970s and suffered differential erosion in 1996/97. North of the Stream duneline fluctuations of 15 to 20m occur. Between Wainui and Hamanatua Streams 15m of retreat occurred during the severe storm of July 1955 (Gibb 1981a) and along Northern Wainui Beach up to 15 m retreat occurred during the severe storm of July 1978.

The GIS was used at TDC to determine volumes of dune sand involved in maximum short-term duneline fluctuations and storm cuts along Wainui Beach. Volumes were calculated above MSL at specific sites for which evidence existed, between the 1999 duneline position and the ground surface recorded on the 1999 Aerial Survey. The following volumes were calculated; Tuahine Crescent to Wainui Stream = 105m³/m length of duneline; Wainui Stream to Wainui School = 110m³/m; Wainui School to Hamanatua Stream = 155m³/m; Northern Wainui Beach = 110m³/m. Note that these volumes are confined to the foredune and are calculated independently of the beach volumetric changes.

There has been a minimum of 11 significant erosion events over approximately the last 60 years (1940-2000) of which at least 3 caused short-term retreat of the foredune of about 15-20m along Wainui beach that was not associated with erosion from the Hamanatua Stream. This would suggest that major localised short-term erosion events have a return period of approximately 20 years at Wainui Beach, with a 5% annual exceedance probability (5% AEP), a 92% AEP of being reached and exceeded over 50 years, and a 99% AEP over 100 years (Gibb 1998).

4.5. SHORE PLATFORM EROSION RATES

Retreating seacliffs bordered by extensive intertidal wave-cut shore platforms are part of the natural character of the Gisborne District coast. Shore platforms have three main morphological elements: the *plane*, *ramp*, and *seacliff*. The seacliff retreats by backcutting and the plane and ramp are lowered by *downcutting*. Shore platforms extend around both Makorori and Tuaheni headlands where the seacliffs are retreating by backcutting at average rates of -0.2 to -0.3 m/year. Both the *plane* and *ramp* are evident around these headlands. The *plane* is the near horizontal part of the platform that has reached an

equilibrium level between MSL and MLWS and is either flat or slopes very gently seawards notwithstanding net uplift of 1.5 to 3.0m/ka. In places, erosion resistant sandstone strata form ramparts that are higher in elevation than the plane, but are generally covered at high tide. The planes are dissected by numerous channels along areas structurally weakened by fractures and minor faulting. A geologic downcutting rate of 1.5-3.0mm/year may be inferred from the tectonic uplift rates as the platforms tend toward an equilibrium position close to sea-level.

At the landward edge of the plane there is a marked steepening of gradient between the plane and the seacliff. This area is termed the ramp and is generally covered by mobile beach sediment ranging from sand to gravel. Short-term downcutting rates for the Late Tertiary siltstone-sandstone ramp at southern Wainui Beach near Tuahine Crescent were determined from Groyne 27 which was built in late 1975. When constructed, the base of the concrete groyne was flush with the level of the shore platform. In December 1992, the base was measured to be 100 to 150mm above the platform level, indicating downcutting rates of 6 to 9mm/year over the 17-year period. When observed in March 2001 cracks were observed in the concrete groyne suggesting that the reducing platform level was weakening the rigid structure.

The short-term localised rates of 6-9mm/year by Groyne 27 are considerably greater than the inferred geologic downcutting rates of 1.5-3.0mm/year. The localised rates, therefore, cannot be considered representative of the overall net downcutting rate for the platforms. Direct measurements against an array of steel pins placed in the Tuaheni Point platform by GDC indicate downcutting rates of 1-2mm/year (Dave Peacock, GDC, pers. comm. 2001). The preliminary measured rates are in good agreement with the inferred geologic rates.

For Northern Tokomaru Bay, short-term downcutting of the shore platform ramp at average rates of 27 mm/year (Gibb 1981b) had resulted in sections of concrete seawall similar to Groyne 27 collapsing 15 to 20 years after construction. Considerable turbulence set up by reflecting waves off the seawall at high tide had kept the platform ramp bare of the protective sand cover and allowed locally-derived gravels to act as corrosive agents abrading the platform ramp. Depending on the amount of sand and gravel cover, the same erosion process can be observed at southern Wainui Beach in front of the longitudinal protection works south Tuahine Crescent constructed on Late Tertiary sedimentary rock.

4.6. SEA FLOODING

Contributing factors to potential flooding of coastal land by the sea include; sea-level rise (SLR), storm wave runup (SWRU), and tsunami wave runup (TWRU). Flooding from the sea on the coastlines of New Zealand generally occurs when sea-level is "super-elevated" instantaneously by storm tides, storm wave runup and tsunami.

4.6.1. HISTORIC SEA-LEVEL RISE

It is widely recognised that the cumulative effects of sea-level rise (SLR) can be a major contributing factor to the coastal hazards of erosion and flooding from the sea (Bruun 1962, 1983; Hicks 1990). According to Hannah (1990a), average MSL has risen around New Zealand at about 170mm/century since about 1900, with residual rates ranging from 120mm/century at Auckland up to 240mm/century at Lyttelton. More recently, Bell *et al.* (2001) updated the analysis for Auckland to determine a net rate of SLR of 1.4mm/year for the period 1899-2000. Port of Auckland is supposedly New Zealand's most accurate long-term tide gauge record (Bell *et al.* 2001).

For Gisborne, an indicative rate of SLR of 230mm/century was tentatively determined for the period 1926 to 1990 from sparse tidal data from the Port of Gisborne by the Department of Survey and Land Information, Gisborne, (Radcliffe 1993). The tide gauge is sited in an area subject to episodic tectonic uplift at a net rate of 1-2m/ka (Berryman *et al.* 2000) during large earthquakes, yet still records a relatively rapid rate of local relative SLR comparable with that of 240mm/century further South in Lyttelton where there is evidence of net tectonic downdrop (Gibb 1980; 1986).

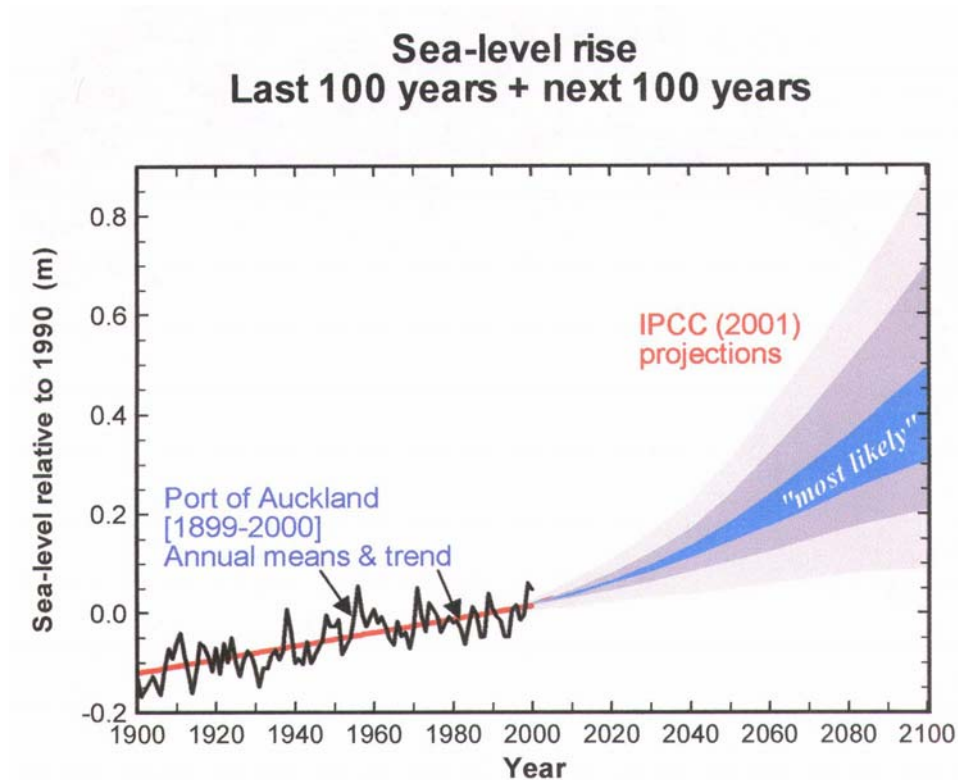
These results may suggest possible interseismic subsidence between major earthquakes of the order of 60-100mm/century for the Gisborne Harbour area which may or may not extend to Wainui Beach. The results may also suggest a component of slow sinking of the tide gauge within the Harbour up to 1mm/year. Therefore, the relatively high rates of SLR should be treated with caution when applying them to Wainui Beach. The very reliable net historic rate of SLR of 1.4mm/year from Auckland between 1899-2000 may be more applicable to Wainui Beach as a minimum rate.

4.6.2. FORECAST SLR AND CLIMATE CHANGE

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). IPCC was charged with assessing the most recent scientific, technical and socio-economic research on climate change, including actual and potential global SLR. IPCC produced major assessment reports in 1990, 1995 and 2001. Their most recent Third Assessment Report (IPCC 2001), was compiled over 2.5 years by 122 lead authors and 515 contributing authors, and was reviewed by 420 specialists (Bell *et al.* 2001).

Figure 15 shows the projected SLR up to 2100 by the IPCC (2001) with respect to the Auckland trend since 1899. In response to a projected increase in global surface air temperature of 1.4 to 5.8°C by 2100, global MSL is projected to rise 90 to 880mm between 1990 and 2100. The “*most likely*” mid-range projections are 140-180mm above 1990 levels by 2050, and 310-490mm by 2100 (IPCC 2001). Figure 15 indicates a forecast acceleration in SLR from about 1.3mm/year (1899-1990) to about 3.6±0.9mm/year (1990-2100) in response to global warming from an enhanced Greenhouse Effect.

Apart from sea-level rise there are other impacts forecast by the IPCC (2001a, 2001b) that could adversely affect the coastlines of New Zealand including Wainui Beach. The extent and severity of storm impacts, including storm-surge floods and storm-induced erosion will increase as a result of climate change. There is likely to be an increase in both tropical cyclone and mid-latitude storm peak wind and precipitation intensities and concomitant wave heights. Higher maximum temperatures and intensified droughts and floods associated with *El Niño* events are likely as the climate changes to a more *El Niño*-like average state (IPCC 2001b).



• **Figure 15:** IPCC-2001 projections of global SLR with respect to the historic Auckland trend since 1899. The "most likely" range of SLR contrasts with the least likely estimates shown as light coloured zones (Adopted from Bell et al. 2001, fig.10).

4.6.3. STORM WAVE RUNUP (SWRU)

Storm wave runup (SWRU) is the resultant of the combination of astronomical tides, barometric pressure set-up, wind set-up, wave set-up and wave runup above the elevated still water level. SWRU is produced by the combination of a storm surge plus dynamic wave set-up and runup. A storm surge is the resultant of the combination of barometric set-up and wind set-up and typically reaches 0.5 to 1.5m above predicted tide level in New Zealand during severe events.

Maximum SWRU levels are produced by the complex interaction of the wind, the sea, the seabed topography, and the configuration of the coast. During a severe storm, SWRU will extend furthest inland for a period of one to two hours during high tide. Between East Cape and southern Hawke Bay, maximum historic SWRU levels were measured from driftwood levels, ranging from 3.0 to 7.5 m above MHWS (Gibb 1994a; 1995). For Wainui Beach, Komar (1996) has tentatively estimated SWRU levels above MSL of 5.2m for a major storm, 6.1m for a 50-year return period storm, 7.2m for a 100-year storm, and 8.3m for a major cyclone (Gibb 1998).

Patterson (pers. comm. Dec. 1997, WBM Oceanics Australia) estimated a SWRU level of 6.9m for Wainui Beach for a significant deep-water wave height of 7m. At Wainui

Beach, SWRU levels of 4.1m above MSL were surveyed by East Cape Catchment Board during the winter of 1976. Similar levels between 4.0 and 4.5 m were surveyed by Gisborne District Council following moderate wave storms in June 1994 and June 1996 from estimated offshore swell heights of 4 to 5m. As a rule of thumb, these observations indicate a close correlation between SWRU levels and offshore swell heights at Wainui Beach, i.e. offshore swell heights of 7 to 9m would produce SWRU elevations of 7.2 to 8.3m.

4.6.4. TSUNAMI WAVE RUNUP (TWRU)

Tsunami are waves with an extremely long wave length that originate from large short-duration submarine disturbances such as faulting, landslides, volcanic eruptions, or possibly from earthquake vibrations. They have a small wave height in the open ocean which increases dramatically on reaching shallow water (Gibb and Aburn 1986). Locally, New Zealand tsunami may be generated by earthquake dislocation, earthquake-initiated submarine and coastal landslip, submarine sediment slumps or volcanic eruptions (Downes *et al.* 2000).

Tsunami data available in New Zealand are sparse and generally only from populated areas. A review of such data by de Lange and Healy (1986) showed that those locally generated are potentially larger than distantly generated tsunami and therefore, pose the greatest inundation hazard. Although most parts of New Zealand were found by de Lange and Healy to have experienced tsunami, the Bay of Plenty-East Coast-Wellington regions were found to be the most sensitive with up to 9 tsunami being recorded in the Bay of Plenty during the period 1840 to 1982 and a minimum of 6 along the Gisborne to Tapatouri coastline being recorded over the 142-year period (Gibb 1995).

Of the 6 tsunami events recorded between 1840 and 1982 (de Lange and Healy 1986), the event of 26 March 1947 was by far the most significant and has been described by Eiby (1982a & b) and in early reports in the Gisborne Herald. There is speculation over the likely causes of this relatively large, locally generated tsunami. According to Eiby, mud volcanism associated with a diapiric intrusion on Aerial Banks about 10 nautical miles east of Wainui Beach, initiated the March 1947 tsunami after a Magnitude 5.9 earthquake shook the Gisborne District.

Recent work by Downes *et al.* (2000) indicate that the epicentre for the March 1947 earthquake was 27-32nm offshore and within 5-8nm of the Hikurangi Trough. The epicentre coincides with a past submarine slump location, suggesting a possible, but yet unproven, submarine landslide source for the March 1947 tsunami (Downes *et al.* 2000). Aerial Banks which border a Plate Boundary between the Australian and Pacific Plates, are tectonically active suggesting the area has a high probability of generating further tsunami. Equally, Hikurangi Trough delineates the Plate boundary and the flanks are characterised by many old submarine landslides which would also have had the potential to generate large tsunami similar in magnitude to the 1947 event.

According to the Gisborne Herald of 26 March 1947, the tsunami adversely affected both Poverty Bay and Wainui Beach. In Gisborne Harbour, "*three large surges of approximately 12 feet*" occurred. At Kaiti Beach, "*the water swirled up around the base of the Cook Monument and over the road. The water entered baches on the road level at the far end of Kaiti Beach, and it is believed a small amount of structural damage was caused*". The base of the Monument is 3.5 m above MSL and the road level at Kaiti Beach is 3.1 to 3.7m (Gibb 1995).

The Gisborne Herald graphically describes the effect of the 1947 tsunami at Wainui Beach where; *"Both ends of the beach where the road slopes down a little received the worst impact"*. At Wainui Stream a house on the north side *"suffered considerably"* with the bank being *"partly washed away"* and the water *"mounting it, sweeping away the fence and entering the house"*. Further north, *"a caravan on the lawn was lifted into the air, completely switching around, and thrown on to a fence. A wireless pole and fence were washed down"*. At Okitu (Hamanatua) Stream the Wainui Surf Club's hut was knocked over with the water passing *"right through the hut, forcing open the doors, travelling for some 50 yards up the bank behind, and then rushing back through the shed, bringing with it all manner of debris"* (Gibb 1995). On the basis of these observations a tsunami wave runup height of ≥ 10 m above MSL for Wainui Beach was adopted by Gibb (1995).

Although the crest height of the foredune is mostly above this level there are many areas, especially around the Wainui and Hamanatua Streams and the Stock Route, where elevations are lower and the land is potentially at risk from similar magnitude tsunami and to a lesser extent SWRU. Tsunami penetration would be greatest in the catchment area of the Wainui Stream where, depending on the magnitude of TWRU, the sea could temporarily extend landward for several kilometres.

4.7. WAINUI SAND BUDGET

The total sand budget available for Wainui Beach is unknown. The unknowns include the total volume of sand stored in the dunes, beach and nearshore seabed, supply and loss rates to that system, and the various seasonal onshore-offshore and alongshore paths for sand transport. The three possible states for the Wainui Sand Budget include negative (sand loss exceeds supply), positive (sand supply exceeds loss), and dynamic equilibrium where sand supply equals loss.

Compelling geologic and historic evidence for a long-term trend of very slow shoreline retreat at Wainui Beach suggests a negative sand budget from a long-term net loss of sand. Previous crude attempts have been made to quantify the inferred sand loss. Based on an analysis of repetitive surveys at 14 beach profile sites, Gibb (1993) determined a net loss of sand from the 4.2km-long foredune of about 77,200m³ between July 1973 and October 1992, at about 4010m³/year. Of this volume, about 80% was supplied from Northern Wainui Beach and the remainder from South of the Hamanatua Stream (Gibb 1993). In 1998, the rate of loss of sand from the foredune was reviewed to produce an estimate of 1000 to 5000m³/year (Gibb 1998).

In 2001, Air Logistics Ltd undertook an analysis of volumetric change to the 4.2km-long Wainui Beach foredune for the period 1942-1999. A 3-dimensional DTM surface was built by digital photogrammetry over the beach area from both the 1999 and 1942 aerial photography. A least squares adjustment was then applied to take out the height discrepancy between the 2 models before undertaking a 'cut-and-fill' calculation. The result of this was a very tight correlation between the 1942 and 1999 surfaces in the areas where there were minimal expected changes in height over the 57 years. The main variations were found to be along the foredune complex.

In total, 467,437m³ of erosion and 149,932m³ of accretion were found to have occurred along the 4.2km-long Wainui Beach foredune from 1942 to 1999. For accretion, 78% occurred along Southern Wainui Beach and the balance North of the Hamanatua Stream. Part of the accretion to the South included the 0.75km-long incipient foredune and part

included a carpark. The incipient foredune mostly accumulated from 1982 onwards after the severe erosion phase in 1974 (Gibb 1993).

The analysis by Air Logistics Ltd revealed that over the 57-year period (1942-1999), there was a net loss of sand of 317,505m³ from the foredune at a net rate of 5,570m³/year. Of this loss, 95% occurred North of the Hamanatua Stream and the remainder to the South. These findings are in good agreement with those estimated previously, confirming that the Wainui Beach sand budget is in a negative state with net losses of the order of 5,000 to 6,000m³/year. The net loss is contributing to very slow shoreline retreat.

4.7.1. BEACH CYCLES

Wainui Beach has been monitored since 3 July 1973 at 14 beach profile sites every one to 7 months. Along a 50m by 4,000m strip, a mean sand volume above low water of approximately 580,000 m³ has been determined. A minimum volume of 430,000m³ was recorded in July 1978 and a maximum of 730,000m³ in March 1998. The minimum resulted from prolonged onshore winds and steep waves, particularly from the 18-20 July 1978 severe Tasman Depression (970hPa). The minimum volume was only slightly lower than a minimum that occurred during the 1974 winter under similar conditions. The maximum volume occurred during prolonged low flat swells and offshore winds during the severe 1997-1998 *El Niño* climate phase. The 1997-98 maximum volume was only slightly higher than a maximum that occurred during the 1981-1983 severe *El Niño* (Gibb 1998).

Over the 25-year period of analysis (1973-1998), seasonal and annual beach cycles involving 50,000 to 250,000m³ of sand movement have occurred. Low beach levels generally occur in winter and high beach levels in summer. The fluctuating sand volume since 1973 has revealed a beach in dynamic equilibrium with no apparent gain or loss of sand to the beach. There is some evidence of a long-period cycle affecting beach volumes moving from a negative phase in the mid to early 1970s through to a generally positive phase in the 1980s and 1990s. A narrow beach promotes duneline erosion whereas a wide beach protects the duneline from erosive events.

Beaches are known to respond to conditions produced by climatic cycles of different frequencies that occasionally resonate in phase to produce extreme effects such as severe localised erosion or landslip. Two well-known climate cycles are the aperiodic *El Niño-Southern Oscillation* (ENSO) phase which occurs about every 2 to 7 years, and the *Interdecadal Pacific Oscillation* (IPO) which provides climate regimes that last 20 to 30 years or so with rapid transitions (Bell *et al.* 2000).

In New Zealand, a positive IPO appears to enhance *El Niño* resulting in lowering sea-levels and sea surface temperatures, less storminess and net beach accretion along the East coast. In contrast, a negative IPO appears to enhance *La Niña* resulting in higher sea-levels and sea surface temperatures, more storminess and net beach erosion along the East coast (Gibb 2001). Positive IPO phases occurred in 1922-1944 and 1976-1998 and negative phases in 1890-1922 and 1944-1976 (Bell *et al.* 2000). Existing knowledge of shoreline movements at Wainui Beach indicates significant duneline and cliffline retreat between 1942 and 1976 and relatively less retreat between 1976 and 1998. In 1997-1998, the IPO switched to a negative phase thus providing favourable conditions for both duneline and cliffline retreat over the next 20 to 30 years at Wainui Beach.

The fact that the beach sand volume has remained almost constant since 1973 on a retreating coastline like Wainui suggests that the potential shortfall in beach sand volume is made up by periodic supply from erosion of sand stored in the 4,000 year old tectonically uplifted foredune. The loss of about 5,000 to 6,000m³/year of sand from the main foredune is proof of a long-term net negative sediment budget at Wainui where losses of sand exceed supply. A negative sand budget is consistent with the mineralogy of the beach sand which requires periodic large volcanic eruptions of sand sized material from the Central Volcanic Zone to offset natural sand losses.

On an open-exposed eroding coastline like Wainui Beach it is quite reasonable to expect a net sand loss between infrequent large volcanic eruptions. These findings indicate the importance of recognising that the ancient main foredune on which much of the beachfront houses are placed, is an important supply source of sand to sustain the 4.2km-long beach at times of erosion and associated loss of sand alongshore and offshore out of the Wainui Beach compartment. If this source were to be locked up by protection works for example, beach replenishment of about 6,000m³ of sand would be required annually to sustain the amenity of Wainui Beach.

4.8. SUMMARY

The complex coastal dynamics of Wainui Beach may be summarised as follows:

- i. Wainui Beach is retreating landward very slowly at an average rate of -0.15m/year in direct response to retreat of the supporting headlands of Tuaheni and Makorori Points at an average rate of -0.24m/year , net loss of dune sand at 5,000-6,000m³/year, and net downcutting of shore platforms at about 1-3mm/year.
- ii. Erosion processes are very complex and occur when the beach is narrowed at the head of rip current troughs exposing the foredune to seasonal losses of the order of 105-155m³ of dune sand per lineal metre of foredune.
- iii. Mean beach sand volumes of $580,000 \pm 150,000\text{m}^3$ have remained constant since 1973, as the coastline has retreated, owing to the net addition of 5,000-6,000m³ of sand per annum from the retreating foredune offsetting beach sand losses alongshore and offshore.
- iv. Tuaheni and Makorori headlands are extremely unstable and landslip prone, the optimum conditions for landslip being the combination of coastal erosion, saturated soil, and vibrations from both earthquakes and heavy breaking surf.
- v. Locally generated tsunami along the boundary between the Pacific and Australian Plates, with runup heights reaching and possibly exceeding 10m above MSL, provide a potentially serious hazard with a frequency that has yet to be properly assessed. Owing to the height of the tectonically uplifted foredune, maximum storm wave runup elevations of 7 to 8m do not pose the same potential hazard as tsunami.
- vi. Although episodic large earthquake events every 300-1,500 years accompanied by coastal uplift result in instantaneous coastal advance, between such events local relative sea-level rise at 130-230mm per century contributes significantly to erosion.

- vii. Climate change and projected global sea-level rise of 310-490mm by 2100 will enhance both erosion and landslip along Wainui Beach progressively increasing hazard risk to beachfront property and assets this century and beyond.
- viii. The geologic process of very slow shoreline retreat and landslip at Wainui Beach is irreversible and will continue into the foreseeable future, possibly accelerating over the next 20 to 30 years with a switch to a negative IPO in 1997-98, becoming worse during the passage of this century owing to the effects of climate change.