COASTAL MANAGEMENT CONSULTANCY LIMITED

ASSESSMENT OF THE 2008 TOKOMARU BAY COASTAL HAZARD ZONE, GISBORNE DISTRICT

Report prepared for Gisborne District Council

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EXECUTIVE SUMMARY

On 19 April, Coastal Management Consultancy Limited (CMCL) was commissioned by Gisborne District Council (GDC) to assess a Coastal Hazard Risk Zone (CHRZ) for Tokomaru Bay. GDC requested that the format and number of risk zones for the CHRZ be essentially the same as those assessed previously by CMCL for other priority areas along the District coast so that the CHRZ could easily be incorporated into Council's Proposed Regional Coastal Environment Plan and Part-Operative Combined Regional Land & District Plan. The CHRZ assessed in this study is defined as the '*2008 Tokomaru Bay Coastal Hazard Zone*'.

Both geologic and historical data revealed a tectonically uplifted accreting sandy shore in central Tokomaru Bay, flanked by retreating seacliffs and headlands, the relatively low-lying areas being subject to occasional inundation during either severe wave storms or tsunami. Although the sand dunes are advancing on average at 0.40m/year, they are subject to short-term duneline fluctuations of 10-50m. The mudstone seacliffs are retreating from the combination of backcutting at -0.1 to -0.3m/year and downcutting of the adjacent shore platform at -0.01 to -0.05m/year, both processes resulting in localized rockfalls, earthflows and eventual destruction of seawalls.

Since 1832 there have been a minimum of 24 tsunami, with maximum tsunami wave runup levels reaching 4-5.5m above MSL during the events of 25 March 1947 and 22 May 1960. Since 1894, about 15-20 severe wave storms have occurred with maximum storm wave runup levels reaching 3.5-5.0m above MSL during Tropical Cyclone Bernie in April 1982. Both the tsunami and storm wave runup levels of 3.5-5.5m are likely to closely approximate the levels reached by events with a 2% Annual Exceedance Probability (2% AEP or 1-in-50 year event).

The 2008 Tokomaru Bay CHZ includes the effects of Climate Change and associated global projected sea-level rise of 0.8m above 1990 levels by about 2100. It includes a 30-75m-wide CEHZ for erosion; a 15-160m-wide CLHZ for landslip; and , a CFHZ for sea flooding defined by both the 4.5 and 5.5m contours above MSL.

It is recommended that Gisborne District Council, after due consideration of this report.

1. **ADOPT** the ***2008 Tokomaru Bay Coastal Hazard Zone*** between Waiotu Road and Koutunui Point for the purposes of controlling coastal subdivision, use and development and alerting the public of the risks to coastal property from the identified natural coastal hazards of erosion and flooding from the sea, and coastal landslip.

2. **INCORPORATE** the ***2008 Tokomaru Bay Coastal Hazard Zone*** into both Council's *Proposed Regional Coastal Environment Plan* and *Part-operative Combined Regional Land and District Plan* to replace the current, and more general, Areas Sensitive to Coastal Hazards assessed in 1994.

3. **REVIEW** the ***2008 Tokomaru Bay Coastal Hazard Zone*** using similar methods either once every 10 years, **OR** after occurrence of significant hazardous events such as severe wave storms, tsunami, or large earthquakes, **OR** after significant changes in global climate change forecasts including potential sea-level rise, by the Intergovernmental Panel on Climate Change.

TABLE OF CONTENTS

ASSESSMENT OF THE 2008 TOKOMARU BAY COASTAL HAZARD ZONE, GISBORNE DISTRICT

by

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1 INTRODUCTION

On 19 April 2008, Coastal Management Consultancy Limited (CMCL) was commissioned by Gisborne District Council (GDC) to assess a Coastal Hazard Risk Zone (CHRZ) for the Tokomaru Bay study area between the southern end of Waiotu Road at the "*Y slip*" and Koutunui Point to the North (Figure 1). The assessment was to be based on a review of previous CHZ assessments for the study area, inspections of the area, on-site consultations with long-standing residents, and relevant survey data. From this, relevant natural coastal hazards were to be identified and quantified, CHRZs delineated and finally, transferred into GDC's Geographic Information System (GIS) for eventual incorporation into Council's Proposed Regional Coastal Environment Plan and the Part-operative Combined Regional Land & District Plan. The CHZ assessed in this study is here termed the *2008 Tokomaru Bay CHZ*. The report was finalized after reviews by GDC and Department of Conservation staff.

2 METHODS

The following is a summary of the methods employed by Dr Gibb for this study.

2.1 DATA COLLECTIONS

- Review of previous CHZ assessments for Tokomaru Bay by Gibb (1981; 1994; 1999) and relevant information contained in both published and unpublished reports. [Note: No other workers or agencies have made CHZ assessments of Tokomaru Bay.]

- Field inspections on foot in September 1977, between May 1979 & June 1980, December 1982, September 1994, May 2002, April & July 2008 over a period of 31 years, including comparative ground photographs.

- Entire duneline & cliffline (seaward toe of foredune & seacliffs, respectively) surveyed in May 2002 by Ian Hughes, Licensed Cadastral Surveyor, GDC, to an accuracy of ±0.5m using a GPS Leica GS50 survey instrument, and the southern duneline & cliffline by Alan Radcliffe, Licensed Cadastral Surveyor, Aorangi Surveys, in July 2008 to an accuracy of ±0.25m.

- Identified duneline & cliffline positions in June 2002 on 1:5000 Scale enlargements of aerial surveys of the study area made in September 1945, 29 January 1960 & November 1982 for digitising by NZ Aerial Mapping Ltd and inclusion in GDC's GIS.

- Identified duneline & cliffline positions in July 2008 on 1:2000 scale fully rectified orthophotomaps derived by Terralink from aerial surveys flown in April-May 2007.

• **Figure 1**: Locality map showing the 39 Station locations used in this study.

- Cadastral survey of High Water Mark in September 1916, digitised by GDC from Survey Office Plans SO 2081 and SO 2084 and assumed to closely approximate the duneline & cliffline positions in 1916.

- Analysed historic duneline and cliffline trends and fluctuations from comparative plots on orthophotomaps at 1:2000 scale for the survey years of 1916, 1945, 1960, 1982, 2002 & 2007-08, spanning a survey period of 92 years.

- Analysed coastal processes on aerial photographs at 1:2000 & 1:5000 scales taken in 1945, 1960, 1982 & 2007 spanning a period of 62 years and on the ground during field inspections over the last 31 years.

- Analysed seabed composition & topography on a hydrographic collector chart at 1:25000 scale compiled by RNZ Navy hydrographic survey from February to April 1996 under Commander L. Robbins, RNZN, on '*HMNZS Monowai*'.

- Analysed historical ground and oblique aerial photographs taken in 1905, 1910, 1911, 1912, 1917, 1925, 1927, 1937, 1948, 1950, 1979, 1980 & 1982, spanning a period of 77 years.

- Analysed topography of coastal hinterland from contours at 0.5m intervals normalized to Mean Sea Level (MSL) datum from GDC's existing contour data compiled in 1997 and 2007, and ground surveys by Alan Radcliffe, in July 2008.

- Interviews with long-standing residents of Tokomaru Bay from June to August 2008.

- Incorporation of the latest global sea-level rise (SLR) projections for this century and beyond by the Intergovernmental Panel on Climate Change (IPCC 2007a, b, c, d) and Ministry for the Environment (MfE 2008) into the 2008 Tokomaru Bay CHZ assessment.

2.2 CHZ ASSESSMENT TECHNIQUES

At the request of GDC, the Coastal Hazard Risk Zone format used previously for the Southern Poverty Bay area, Northern Poverty Bay including Kaiti Beach, Wainui Beach, Tolaga Bay and Anaura Bay (CMCL 1995; 1998; 2001; 2004) was adopted for the 2008 Tokomaru Bay CHZ assessment. As with previous assessments the CHZ may incorporate a Coastal Landslip Hazard Zone (CLHZ), a Coastal Erosion Hazard Zone (CEHZ), and a Coastal Flood Hazard Zone (CFHZ). For Tokomaru Bay, previous CHZ assessments reviewed later in this report, have identified and quantified to a greater or lesser extent all 3 natural coastal hazards (Gibb 1981; 1994; 1999).

2.2.1 CEHZ Assessment

According to best practice, Equation [1] was used to assess the extent of the CEHZ and Extreme (EREZ), High (HREZ), and Moderate Risk Erosion Zones (MREZ), and Safety Buffer Zone (SBZ) within the CEHZ, where:

$$\mathbf{CEHZ} = [\,(S_{max} + D) + (R - X_{50})\,T_{50} + (R - X_{100})\,T_{100}\,]\,F \qquad \text{Eqn [1]}$$

From Equation [1], the 3 Risk Zones plus Safety Buffer Zone were calculated as follows:

$$\mathbf{EREZ} = (S_{max} + D) \qquad \text{Eqn [2]}$$

HREZ = $(R - X_{50})\,T_{50}$ Eqn [3]

MREZ = $(R - X_{100})\,T_{100} - (R - X_{50})\,T_{50}$ Eqn [4]

SBZ = **F** Eqn [5]

The component Factors of Equations [1] to [5] are defined as follows:

Factor R: Average rate in metres per year (m/year) of the long-term (historic) trend of advance or retreat of the duneline relative to the land.

Factor S: Horizontal distance in metres (m) subject to maximum short-term duneline fluctuations about and independent of the long-term trend.

Factor D: Dune instability factor representing the horizontal distance of retreat in metres (m) of the top seaward edge of the sub-vertical dune erosion scarp cut by the sea for the scarp to eventually attain a stable slope determined by the angle of repose (AOR) of dry loose Medium to Fine Sand as a result of slumping.

Factor X: Potential rate in metres per year (m/year) of duneline retreat due to projected sea level rise (SLR) this century.

Factor T: Hazard assessment period in years.

Factor F: Precautionary safety buffer to allow for both unknown factors in the CHZ assessment plus uncertainties in the data utilized, expressed on a scale from 1.1 (10%) for very low uncertainty, up to 2.0 (100%) for very high uncertainty.

Reference Shoreline: Seaward toe of foredune (duneline) defined precisely by the 2002 and 2008 ground surveys, which were used to offset the CEHZ width landward on 1:2000 scale orthophotomaps.

Factors **D** & **X** are defined by Equations [6] & [7], respectively, where:

$$D = \left[\frac{h - Hj}{\tan\beta}\right] y \qquad \text{Eqn [6]}$$

Where:

h = Average height of foredune crest above MSL (m).

Hj = Average height of the duneline above MSL (m).

β = Angle of repose (AOR) of dry loose Medium to Fine Sand (degrees).

y = Limiting factor for bluff retreat expressed on a scale from 0.1 (very high limits) to 1.0 (no limits) to determine Factor **D**.

$$X = \frac{\ell . a}{h + d} \qquad \text{Eqn [7]}$$

Bruun Rule (Bruun 1962; 1983; 1988).

Where:

a = Rate of local relative SLR this century (m/year).

ℓ = Horizontal distance from the crest of the foredune to the contour representing the beach closure depth below MSL (m).

h = Average height of foredune crest above MSL (m).

d = Average closure depth below MSL (m).

2.2.2 CLHZ Assessment

Equation [8] was adopted from previous work in Gisborne District (CMCL 1995; 2001; 2004) to define CLHZ widths, where:

CLHZ = **[S + R.T] F** Eqn [8]

Where: **S** = Extent of seaward slope that has failed from past landslides (m).

R = Rate of long-term (historic) retreat of cliffline (m/year).

T = Coastal hazard assessment period (y).

F = Safety Factor that is expressed on a scale from 1.1 (10%) to 2.0 (100%).

Reference Shoreline: Seaward toe of seacliffs (cliffline) defined by the 2002 and 2008 ground surveys.

At GDC's request the CLHZ was subdivided into an Extreme Risk Erosion Zone (EREZ), High to Moderate Risk Erosion Zone (MREZ) and Safety Buffer Zone (SBZ), to provide internal consistency with past assessments in Gisborne District (CMCL 2001; 2004), where:

EREZ = **S**

MREZ = **R.T**

SBZ = **F**

Note that the High and Moderate Risk Zones that apply to sandy coasts are combined into a single Moderate Risk Zone for seacliff coasts.

2.2.3 CFHZ Assessment

Anecdotal information from the combination of interviews with long-standing residents and historic photographs was used to establish the landward extent of past sea flood events from either tsunami or severe onshore wave storms. Inundation limits were plotted on 1:2000 orthophotomaps with contours at 0.5m with respect to MSL Gisborne Provisional Datum 1926. Heights of past events were then interpolated from the maps to derive the **2008 CFHZ**. The projected height of sea-level by 2100 from the IPCC (2007) plus a Safety Factor were then added to derive a height above MSL for inundation by the sea by about 2100. A contour representing this height was then used to define the **2108 CFHZ**.

3 PREVIOUS CHZ ASSESSMENTS FOR TOKOMARU BAY

Prior to 1980 the coastal hazards of the old Waiapu and Cook Counties that now comprise part of the Gisborne District had not been identified or quantified. Between 1979 and 1980, Dr Gibb introduced the concept of Coastal Hazard Mapping into New Zealand through the National Water and Soil Conservation Authority (NWASCA). Coastal Hazard Mapping techniques were conceived, developed, tested and standardised in the Waiapu County, East Cape Region, an area featuring most, if not all known natural coastal hazards in New Zealand (Gibb 1981).

Along the 147km-long Waiapu County coastline, including Tokomaru Bay, identified hazards included sea and wind erosion, flooding from storm wave runup, tsunami and coastal rivers, and landslip. The identified coastal hazards at Tokomaru Bay were landslip and erosion at each end of the Bay. For the central part, the identified hazard was short-term erosion along an otherwise advancing shoreline. Provision was made for localised erosion around the mouths of the Mangahauini River and Waiotu Stream. A 35 to 50m CHZ was defined in the 1981 study, extending several hundred metres inland around Koutunui Point. No provision was made for climate change effects from an Enhanced Greenhouse Effect as this issue did not become important in New Zealand until the late 1980s.

At its June 1980 meeting, the Waiapu County Council unanimously adopted the report and its CHZ assessments for 14 coastal areas, including Tokomaru Bay, in the County. The 14 CHZs were incorporated into the Waiapu County District Scheme Review and shown on the relevant planning maps. The adoption by Council followed a comprehensive public consultation programme with a number of hui on coastal marae.

The standardised Coastal Hazard Mapping techniques including those for calculating CHZ widths, were endorsed by the Soil Conservation and Rivers Control Council at its 3 March 1981 meeting and the National Water & Soil Conservation Authority (NWASCA) at its 7 July 1981 meeting, for nationwide application by both the District Offices of the Ministry of Works and Development (MWD) and the Catchment Authorities serviced by NWASCA at that time (Gibb 1983). Arising from this work, a Natural Hazards Policy was developed by the MWD and adopted by NWASCA at its 7 July meeting (Appendix A), and Coastal Hazard Mapping programmes initiated throughout New Zealand.

On 24 August 1994, GDC commissioned the writer to provide an initial assessment of Areas Sensitive to Coastal Hazards (ASCH) for 42 beaches along the Gisborne District Coast, including Tokomaru Bay. The ASCHs were delineated on 42 Photomaps at 1:5000 Scale, based on a comprehensive *Coastal Hazards Database* and various criteria. The Database comprised 8 variables and was developed and tested by Gibb *et al*. (1992) for nationwide application. Each of the 8 variables was ranked into 5 sensitivity classes (1 to 5) in a matrix and specific Coastal Sensitivity Indices (CSI) derived for each of the 42 beaches (Gibb 1994b). The ASCHs are included in the Appendices of Council's Proposed Regional Coastal Environment Plan.

CSIs potentially ranged from a minimum of 8 (*Very Low Sensitivity*) to a maximum of 40 (*Very High Sensitivity*). The identified natural coastal hazards in 1994 included those identified in 1981 plus wind erosion of sand dunes in Southern Tokomaru Bay, rock fall and earthflow landslip along the headlands, and flooding from the sea, river and stream. A Medium to High Coastal Sensitivity Index (CSI) was determined for the Bay along with a 75-230m wide Area Sensitive to Coastal Hazards (ASCH). Provision was made for climate change effects including sea level rise (SLR) in the ASCH assessment. The *Coastal Hazards Database* contains 126 stations of which 8 are located around Tokomaru Bay (Appendix A).

4 FACTS FOUND

Since the CHZ assessments for Tokomaru Bay in the 1980s & 1990s (Gibb 1981; CMCL 1994; 1999), CHZ assessment techniques have been refined and relevant new information gathered to provide the basis for the 2008 Tokomaru Bay CHZ assessment. Relevant facts are summarized as follows:

4.1 GEOLOGY

1. The rocks forming Tokomaru Bay and nearshore seabed are undifferentiated massive and bedded, grey, slightly calcareous mudstone, with rare macrofossils and intercalated beds of fine-grained sandstone and conglomerate of the Mid to Late Tertiary aged Tolaga Group (Mazengarb & Speden 2000).

2. The rocks were formed from sediments laid down on the seafloor some 10-20 million years ago which have since been indurated, compacted, uplifted and deformed by tectonic movements associated with subduction movements along the shore-parallel Australian-Pacific Plate Boundary located about 60-80km offshore along the Hikurangi Trough.

3. The sedimentary strata outcropping around Tokomaru Bay dip 30-33^0 NW at Koutunui Point, 15-40^0 NW along the Waima Road, 10-20^0 N in central Tokomaru Bay, and 5-10^0 S-SW between Waiotu Road and Wairoa Stream (Gibb 1981; Mazengarb & Speden 2000).

4. Because of the structure of the sedimentary rocks in Tokomaru Bay, coastal landslides along the northern and southern headlands are mostly rockfalls and earthflows (CMCL 1994) that contribute sediments to the foreshore and seabed and lead to the establishment of a stable slope angle on the coastal hillslopes.

5. Measurements made at six points along the east facing mudstone seacliffs at Otairi Point just southwest of the Waima Wharf, indicate a stable slope gradient averaging 1 Vertical to 1 Horizontal (45^0) ranging from IV:0.8H to IV:1.06H.

4.2 COASTAL EVOLUTION

6. At the peak of the Last Glaciation, about 18,000 years ago, sea-level stood about 120-130m below present and the shoreline at Tokomaru Bay was some 17-22km east along the seaward edge of the present continental shelf.

7. Global warming of 4-5^{0}C directly resulted in a melting of continental ice sheets and a sea-level rise (SLR) of 10-15m/1000 years (10-15mm/y), known as the Postglacial Marine Transgression (PMT) which caused a widespread landward retreat of the Tokomaru Bay shoreline at net rates of 1.7-2.2m/year.

8. Following the culmination of the PMT at present sea-level about 7200 years ago, sea-level fluctuations have not exceeded ±0.5m (Gibb 1986) resulting in the formation of 150-350m wide intertidal wave-cut shore platforms along the headlands of Tokomaru Bay and the formation of a 200-300m-wide coastal plain in the centre of the Bay tapering to less than 50m north and south.

9. The very narrow coastal plain at the base of the coastal hinterland has formed from the combination of tectonic uplift at about 0.8-1.4m/1000 years (0.8-1.4mm/y) which may be either coseismic in association with moderate to large earthquakes (Ota *et.al*, 1992) or aseismic (gradual uplift) (Wilson *et.al*, 2007), plus the accumulation of Fine Sand over ancient wave-cut platforms.

10. Most, if not all of the residential housing and infrastructure such as roads around Tokomaru Bay are located on the narrow coastal plain.

11. Depending on the magnitude of coseismic uplift there will be an instantaneous advance of the shoreline in proportion to the gradient of the foreshore and amount of uplift. In the period between uplift events which occur about every 300-1500 years along the East Coast (Ota *et al*, 1992), erosion processes predominate.

12. As the dominant wind direction in Tokomaru Bay is offshore and the subdominant wind direction alongshore, a relatively low foredune 2.5-3.5m a.MSL has formed in the centre of the Bay adjacent to a 30-80m wide sand beach.

4.3 BEACH SAND

13. The light coloured Fine Shelly Sand forming the beach is composed predominantly of shell fragments derived from the nearshore seabed and the light mineral plagioclase feldspar derived predominantly from the Tolaga Group sedimentary rocks via the Mangahauini River and Waiotu Stream and erosion of the adjacent headlands and shore platforms (Gibb 1981).

14. Sand particles derived from mudstone do not survive on the beach but are pounded into silt by waves and transported offshore to form the muddy seabed. Only particles derived from relatively harder sandstone tend to survive on the beach.

15. Very low net accretion rates over the last 7200 years of 0.03-0.04 m/year in central Tokomaru Bay decreasing to less than 0.01m/year both north and south indicate an almost finite sand resource which is replenishing the beach at very low rates and is potentially, very sensitive to climate change effects such as a possible acceleration of SLR.

4.4 SEABED

16. Based on sparse sampling in 1996 by the Royal NZ Navy, the seabed in central Tokomaru Bay is composed of Fine Sand out to depths of about 25-30m, Very Fine Shelly Sand out to 35m and Mud seaward of 35m depth.

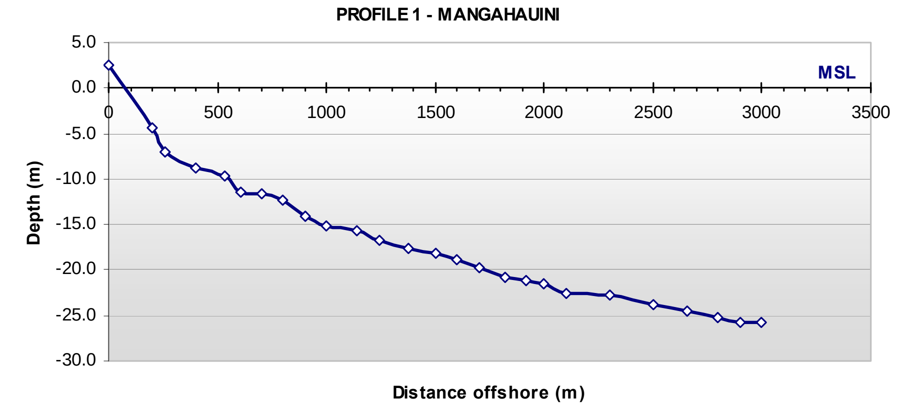
17. North and South of central Tokomaru Bay, the seabed is rocky out to about 25-30m depth and muddy seaward of this depth.

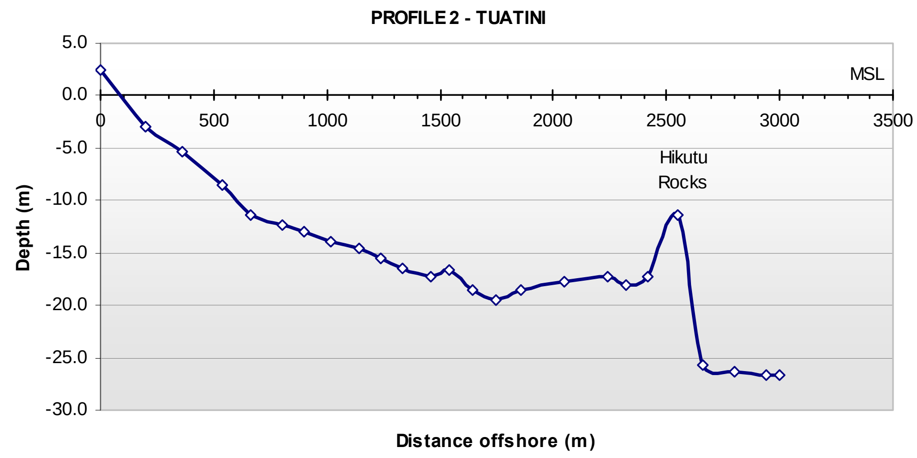
18. The rocky seabed flanking the Bay is a likely source of shellfish that ultimately contribute to the abundant (30-50%) broken shell content of the beach and offshore sands.

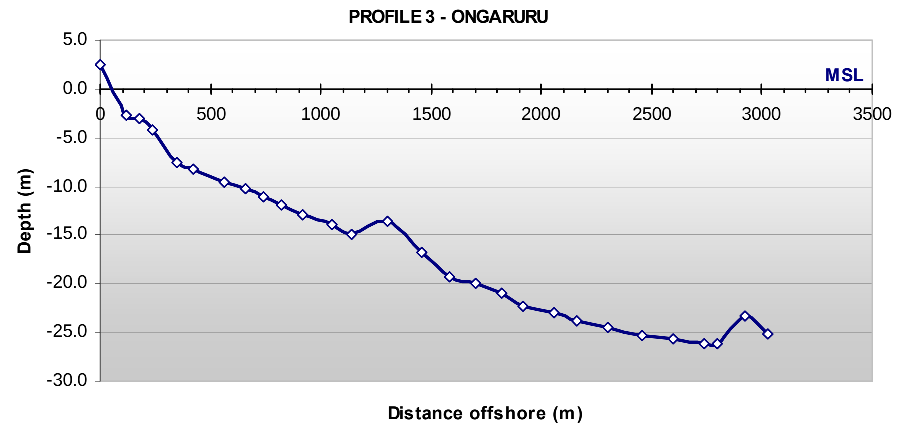
19. In the sediment corridor in the central part of the Bay, the gradient of the seabed flattens progressively from about 1:45 from MSL out to the -8m depth contour, to 1:100 from -8m to -16m, to 1:150 from -16m to -26m depth (Figure 2) largely as a consequence of fining of sediment seaward from Sand to Mud.

20. Although the information for Tokomaru Bay is relatively sparse the data suggest an inner seaward toe of beach at about -8m (closure depth) and an outer toe at about -16m.

21. Based on comprehensive SCUBA dive surveys, comparative hydrographic surveys and sedimentology of seafloor sediments, previous closure depths of -8m were assessed for Anaura Bay, -10m for Poverty Bay and Wainui Beach, and -15m for Tolaga Bay (CMCL 1995; 1998; 2001; 2004).





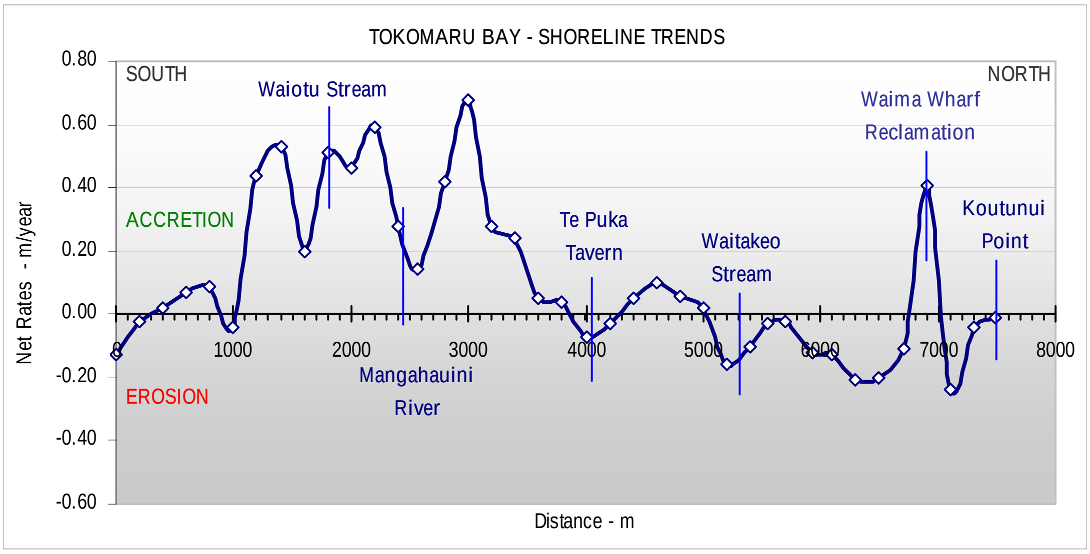


- **Figure 2**: Three nearshore profiles spaced 625m apart in the centre of Tokomaru Bay drawn from data in Table B-2, Appendix B.

22. Taking account of the relative exposure of Tokomaru Bay to severe SE wave storms, sedimentology, and the nearshore seabed gradient, a closure depth of -15m for the central Bay area is here inferred.

4.5 SHORELINE TRENDS 1916-2007/2008

23. The linear regression rate in Table B-1, Appendix B, for the 39 stations around Tokomaru Bay was preferred for the analysis of long-term shoreline trends from 1916-2002/08 as the regression line smoothes short-term shoreline fluctuations that would otherwise weight the trend. Trends are summarized in Figure 3 for the study area between the "*Y slip*" and Koutunui Point. In addition, measurements were made between stations where necessary in this summary.



• **Figure 3**: Long-term shoreline trends in Tokomaru Bay 1916-2007/2008 compiled from data in Table B-1, Appendix B.

24. In September 1916, Mr W.S. Thompson, Licensed Surveyor, surveyed the foreshore of Tokomaru Bay for the Crown between Mawhai Point in the south and Koutunui Point in the north recording the position of Low Water Mark (LWM) and High Water Mark (HWM), the mouths of streams and Mangahauini River, coastal roads and buildings, and the Waima Wharf.

25. The survey traverse was made along the foreshore with measured offsets to both HWM and LWM and is recorded in Field Book 554 and on Survey Office Plans SO2081 to SO2084. Although Mr Thompson did not define HWM, we have inferred that it was most probably the duneline and cliffline on the basis that it lay landward of the survey traverse line along the foreshore and generally fits the present configuration of the reference shorelines used in this study.

26. Survey Office Plan SO 2082 shows Waiotu Road extending along the coast as far as the prominent delta at the mouth of the Waihoa Stream toward Mawhai Point, where there was a house owned by Wi Clark at the time that still exists today and is known locally as the "*green house*".

27. Today, the Waiotu Road terminates 0.4km NW of the "*Y slip*" and 2.3km from the "*green house*" as a result of retreat of the cliffline from erosion at -0.3 to -1.0m/year southeast of the "*Y slip*". According to long-standing locals the road disappeared sometime before World War II which is verified in part by the earliest aerial survey in 1945 which shows the road extending to the "*Y slip*" but no further.

28. For about 200m north of the "*Y slip*" the cliffline has retreated at -0.02 to -0.13m/year, averaging -0.08m/year, resulting in the loss of Waiotu Road since 1945 along this cliffed section of coast.

29. For the next 875m north, the duneline has remained in a state of dynamic equilibrium with rates averaging 0.04m/year, and although the Waiotu Road is only 20m landward of the duneline in places it appears to have not been eroded by the sea since 1916 mostly due to a relatively wide sand beach providing natural protection.

30. Over the next 2400m north, there is a clear cut trend of duneline advance (Fig 3) at 0.14 to 0.68m/year (Table B-1), averaging 0.40m/year, where there is the greatest density of residential development and associated infrastructure in Tokomaru Bay within the Ongaruru, Tuatini, and Waiparapara communities.

31. The 2400m-long area is in central Tokomaru Bay where persistent wave action has concentrated the accumulation of beach sand resulting in the growth of low sand dunes which absorb storm erosion and erosion caused by the Waiotu Stream mouth migrating South and the Mangahauini River migrating North, both of which supply minor amounts of Fine Sand directly to the beach in this area.

32. Over the next 450m the duneline is in dynamic equilibrium with rates averaging 0.05m/year, owing to protection from a relatively wide sand beach and extensive shore-connected subtidal reefs absorbing and breaking up incident wave energy.

33. Over the next 1300m the Waima Road is "*protected*" from cliffline retreat by a concrete seawall constructed between 1960 and 1965 but which is suffering differential collapse as a result of downcutting of the Late Tertiary sandstone-siltstone shore platform ramp at 12 to 50mm/year (Table B-3, Appendix B), averaging 27.1mm/year (Gibb 1981).

34. Downcutting by corrasion during wave storms is nullified when the shore platform ramp at the base of the seawall is protected by a sand and/or gravel beach at least 0.5m thick. As the sand beach adjacent to the Waima Road tends to come and go, downcutting of the platform ramp is not a constant process (Figure 4).

35. Although Figure 3 shows a net shoreline advance up to 0.10m/year this is not indicative of the long-term cliffline trend and is the result of reclamation (Table B-1) to widen the Waima Road sometime between 1916 and 2002.

36. A better approximation of long-term backcutting rates can be determined at Te Puka prior to seawall construction and at Te Ariuru on the mudstone cliffbase just north of the wall. For the period 1916-1960, backcutting rates at Te Puka ranged from -0.09 to -0.34m/year, averaging -0.21m/year. For the period 1916-2002, backcutting rates at Te Ariuru ranged from -0.10 to-0.16m/year, averaging -0.13m/year (See Stations 20, 21, 22, 27 & 28; Table B-1, Appendix B).

37. On this basis, potential net cliffline retreat at -0.17m/year is here inferred for the 1300m-long stretch of Waima Road "*protected*" by the seawall by averaging, the '*average'* rates of -0.13 and -0.21m/year at both ends of the road.

- **Figure 4**: Photos taken in July 2008 (top) and June 1980 (bottom) showing about 0.20m downcutting of the shore platform plane at Waima, northern Tokomaru Bay, over the last 28 years at 7-8mm/year beneath a section of concrete seawall destroyed earlier by the sea. Photos by JG Gibb.

38. At Te Ariuru, there is a boulder delta perched on a tectonically uplifted mudstone bench that has been built by the Waitakeo Stream to form the 150m-long Te Ariuru Point (SO 2084). Although the actual Point has remained in dynamic equilibrium since 1916, the flanks of the delta have retreated at -0.03 to -0.16m/year, averaging -0.10m/year (Figure 3).

39. For the 250m-long stretch of Waima Road up to the Waima Stream bridge, the road is partially protected by a rock revetment and the shoreline has retreated 4-6m from 1945-2002 at -0.07 to -0.11m/year.

40. About 50-60m north of the Waima Bridge is the property where a house had to be removed after being undermined during Tropical Cyclone Bernie in April 1982. The house was built in 1910 for the freezing works at Waima and following the collapse of a concrete seawall in the 1970s, the bank has retreated 9-11m at about -0.3 to-0.4m/year with almost half the retreat occurring during Tropical Cyclone Bernie.

41. For the 1800m-long seacliffs between the Waima Stream and Waima Wharf, the cliffline has retreated at -0.11 to -0.21m/year, averaging -0.16m/year, from 1916-2002. These results compare well with Gibb (1981) who determined rates for the top edge of the seacliffs south of the Waima Wharf of -0.05 to -0.21m/year, averaging -0.12m/year, from 1945-1980. Maximum rates occurred where concrete seawalls were outflanked by cliffline retreat.

42. In the 1920s, a 30-50m deep reclamation was constructed at the base of the Waima Wharf and encased in a semi-vertical concrete seawall still evident today.

43. In the small bay to the north of the Wharf the actively eroding seacliffs have retreated at -0.24m/year from 1916-2002, the rates decreasing to -0.01 to -0.04m/year at Koutunui Point as a result of a relatively wide shore platform reducing incident wave energy (Table B-1, Appendix B).

4.6 SHORT-TERM DUNELINE FLUCTUATIONS

44. The long-term duneline trend is not a constant process but is punctuated from time to time by significant fluctuations in the position of the duneline. A combination of data in Table B-1, Appendix B, aerial and historic photographs, the 1:2000 scale orthophotomaps, and field observations were used to estimate the amount of maximum duneline fluctuations.

45. Duneline fluctuations increase northwards along Waiotu Road from about 10m at the southern end to about 15-20m along the 875m-long sand dune stretch in dynamic equilibrium, to about 15-35m up to the Waiotu Stream mouth along the accreting stretch of dunes.

46. Between the mouths of the Waiotu Stream and Mangahauini River, duneline fluctuations further increase to 25-50m. For the accreting stretch north of the Mangahauini River to just south of the Waima seawall, duneline fluctuations decrease from 30-40m to 10-15m.

47. Although not strictly a duneline movement, instantaneous storm erosion of the Waima Road of 5-10m following differential collapse of the seawall constitutes a "*short-term shoreline*" fluctuation as such storm cuts along the Waima Road are artificially filled to reinstate both the seawall and road back to its former position along the mudstone shore platform.

• **Figure 5**: Photo taken September 1994 of the relatively low foredune and beach looking north in central Tokomaru Bay. Photo taken by JG Gibb.

4.7 SEA-LEVEL CHANGES

48. Depending on its rate and magnitude, sea-level (SLR) is a well established contributing factor to long-term shoreline retreat (Bruun 1962; 1983; 1988). For past CEHZ assessments along the Gisborne District coast and elsewhere in Australasia, the Bruun Rule (Equation 7) has been the method used to estimate erosion for a given rate of SLR.

49. Following the culmination of the Postglacial Marine Transgression (PMT) about 7200 years ago, sea-level fluctuations around New Zealand have not exceeded ±0.5m (Gibb 1986). During last century sea-level around New Zealand has risen 0.16±0.02m on average at 1.6±0.2mm/year (Hannah 2004).

50. The historical rate of rise for New Zealand is in excellent agreement with the total 20th Century global average SLR of 0.17m (1.7mm/year) much of which has been attributed to an increase in global average temperature of 0.74^{0}C from 1906-2005 (IPCC 2007).

51. Since 1993, global SLR has increased to 3.1mm/year which generally accords with the upper limit of the latest projections of global SLR by the IPCC (2007) relative to the 1980-1999 sea-level average, set out in Table B-4, Appendix B.

52. According to the IPCC (2007) rates of SLR are projected to progressively increase from the present 3.1mm/year, to 3.9-5.2mm/year by about 2055 and 4.8-7.6mm/year by about 2095. Sometime beyond 2100, rates of SLR are expected to reach and exceed 10mm/year (IPCC 2007;

MfE 2008), which equates to the net rate during the PMT during which time there was widespread shoreline retreat around New Zealand and at 1.7-2.2m/year in Tokomaru Bay.

53. Notwithstanding a SLR of 0.16±0.02m around New Zealand last century, there has been accretion in central Tokomaru Bay since 1916 at 0.14 to 0.68m/year, averaging 0.40m/year, a fact which must be taken into account in CHZ assessment using the IPCC (2007) SLR projections for this century.

54. On this basis, and to avoid double counting the effects of SLR for CEHZ assessment, the historic average rate of 1.6mm/year was subtracted from the projected maximum rates of 5.2mm/year by 2055 and 7.6mm/year by 2095 to give values of 3.6mm/year and 6.0mm/year, respectively.

4.8 TSUNAMI

55. Tsunami are potentially highly destructive sea 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 and are relatively common along the GDC coast.

56. Tsunami originate from either distant or local disturbances and are summarized in Table B-5, Appendix B, for the GDC coast. From 1832-2007, a minimum of 24 tsunami were recorded of which 11 were generated from local sources and 13 from distant sources such as Peru, Chile, Ecuador, Indonesia, Kamchatka and the Aleutian Islands (Table B-5).

57. The catastrophic 26 December 2004 tsunami off northern Sumatra was generated by a Magnitude 9.3 earthquake in a similar geological setting to the Hikurangi Trough. Coseismic seabed displacements initially created deep water tsunami wave heights of 0.6m, wave lengths of 100km, and a wave velocity of 840kph. When the tsunami struck northern Sumatra about 1.5 hours later, the 0.6m-high waves had reached 15-20m (King 2005).

58. The potentially active local tsunami source area is only 20-100km offshore from Tokomaru Bay. Assuming a wave velocity of 800kph, indicates that a local tsunami generated offshore would reach Tokomaru Bay in about 1.5-7.5 minutes, leaving precious little time to retreat to higher ground.

59. Little is remembered locally about historic tsunami wave runup in Tokomaru Bay. At Te Ariuru, the March 1947 '*local*' tsunami is thought by long-standing locals to have travelled up the Waitakeo Stream as far as the road bridge, a distance of 150m from the sea. Contours suggest the height reached was about 4.0m a.MSL.

60. According to The Gisborne Herald, the 22 May 1960 tsunami swept "*debris and stones*" across the "*Tokomaru Bay-Waima Road*" which from the contours suggests a wave runup height of 4.5 to 5.5m a.MSL. The early newspaper reports that the strongest tidal surge took place about 0500 hours, was accompanied by a heavy roaring sound, smashed 27m of timber seawall, and surged some distance up nearby creeks.

4.9 WAVE STORMS

61. Temporary flooding of low-lying coastal hinterland can occur from storm wave runup (SWRU) during severe onshore wave storms. SWRU is the result of a combination of astronomical tides, barometric pressure set-up, wind set-up, wave set-up, and wave runup.

62. Long-standing locals have identified that the most common damaging wave storms come from the southeast often generated by distant storm events well to the southeast of the North Island. Severe wave storms from this quarter may cause erosion and flooding of the coast north of the Mangahauini River. The geographical setting of Tokomaru Bay indicates that the southern and central areas are exposed to less common wave storms from the east and northeast.

63. Significant wave storms are known to have occurred along the Gisborne District coast in 1894, 1912, 1936, 1953, 1955, 1963, 1968, 1974, 1976, 1978, 1982, 1988, 1992, 1994, 2002 and 2008 (CMCL 2001; 2004; 2008). Of these, the most severe wave storms are likely to have occurred in February 1936 (tropical cyclone), February 1953 (tropical cyclone), July 1978 (deep depression), April 1982 (Tropical Cyclone Bernie), March 1988 (Tropical Cyclone Bola), April 2002 ('*Jodi Millennium*' storm), January 2008 (Tropical Cyclone Funa) and July 2008 (weather bomb and tropical deep depression).

64. Although the Wahine Storm of 9-10 April 1968 (Tropical Cyclone Gisele) produced the strongest winds on record (gusts to 138 kph, 75 knots) in Gisborne, the winds were from the northeast backing to northwest which would have been offshore in Tokomaru Bay. In Gisborne a minimum central pressure of 975hPa was recorded for this event which reached a low of 963 hPa when the centre passed SSE over Tauranga (CMCL 1997).

65. In 1994, CMCL observed SWRU elevations of 3-4m and 2-3m above MHWS from driftwood on the coast at Tuatini and Te Ariuru, respectively (CMCL 1994; 1999). Normalised to MSL, these elevations equate to 3.7-4.7m and 2.7-3.7m a.MSL, respectively.

66. That same year CMCL surveyed heights of driftwood on the northern Poverty Bay foredunes of 4.3-4.8m above MSL (CMCL 1995), an area with similar exposure to southeast wave storms as Tokomaru Bay. The driftwood was thought by CMCL (1995) to have been deposited during Tropical Cyclone Bernie (April 1982) and the winter storms of the 1970s.

67. For Tokomaru Bay, photographic records of driftwood lines deposited during Tropical Cyclone Bernie were compared with 0.5m contours to determine SWRU elevations (Figure 6). This exercise produced SWRU elevations of 3.5-4.5m a.MSL along the Waiotu Road, 3.5m between the Waiotu Stream and Mangahauini River, 4.5-5.0m on the north side of the River, and 4.0-5.0m along the Waima Road.

68. From April 1982 to August 2008, SWRU elevations have not exceeded the levels reached by Tropical Cyclone Bernie, the elevations of which are similar to those reached by the tsunami of 1947 and 1960.

69. From personal observations, the 1982 SWRU elevations were also not exceeded during the 1970s storm dominated decade nor during the April 1968 Wahine Storm, suggesting that Tropical Cyclone Bernie may have been at least a 1-in-50 year wave storm with a 2% Annual Exceedence Probability (AEP) in Tokomaru Bay.

70. Considering all available evidence we have adopted a uniform historic elevation of 4.5m a.MSL for all of Tokomaru Bay for both tsunami wave runup (TWRU) and storm wave runup (SWRU) to accommodate the likely elevation reached by a 2% AEP wave storm or tsunami from either the southeast, east or northeast quadrants.

- **Figure 6**: Photo taken May 1982 of driftwood that crossed the Waima Road near Potae Street during Tropical Cyclone Bernie in April 1982. Photo by JG Gibb.

5 2008 TOKOMARU BAY CHZ ASSESSMENT

The *2008 Tokomaru Bay CHZ* incorporates a Coastal Erosion Hazard Zone (**CEHZ**) for central Tokomaru Bay between Waiotu Road and Waiparapara, a Coastal Flood Hazard Zone (**CFHZ**) between Waiotu Road and Hautanoa, and a Coastal Landslip Hazard Zone (**CLHZ**) at both the southern end of the Waiotu Road and Waima.

5.1 CEHZ ASSESSMENT

Equations 1-5 & Equation 7 were used to quantify the various risk zones and Safety Buffer Zone (Factor **F**) as follows:

Factor R: For the long-term shoreline trend, Linear Regression Rates in Column I, Table B-1, Appendix B were averaged for Stations 3-6, 7-10, 11-13, and 14-18 to give values of 0.04, 0.43, 0.44 and 0.35m/year respectively for the period 1916-2008, to smooth inherent survey errors and the effects of short-term duneline fluctuations.

Factor S: Maximum short-term duneline fluctuations were quantified from field evidence, historic shoreline positions from 1916-2008 and sequential aerial photography at 1:5000 scale to give values ranging from 10-40m.

Factor T: Standard hazard assessment periods of 50 and 100 years were used (2008-2058; 2008-2108).

Factor D: As the foredunes average 0.5-1.5m elevation above the backshore, the dune stability factor was combined with Factor **S** as part of the overall short-term duneline fluctuation measured for **S**, (**S + D**), equating to the EREZ. Hence, Equation [6] was not used.

Factor F: A Safety Factor of 1.3 (30%) was adopted to allow for uncertainties in Factors **R**, **X**, **S** & **D**.

Factor a: To avoid double counting the effects of SLR, the historic rate of 1.6mm/year for New Zealand was subtracted from the maximum projected IPCC (2007) rates of 5.2mm/year for 2055 and 7.6mm/year for 2095, to provide residual rates of 3.6mm/year (0.0036m/year) and 6.0mm/year (0.006m/year), respectively.

Factor d: A closure depth of -15m below MSL was adopted and identified as a contour on the 1:25,000 scale Sounding Collector compiled by the Hydrographic Branch of the Royal New Zealand Navy on '*HMNZS Monowai'* from hydrographic surveys in February 1996.

Factor ℓ: Was measured from the shoreline plotted on the 1996 Sounding Collector to the -15m depth contour at each station and ranged from 1300m to 1500m

Factor h: Heights of the foredune crest above MSL to the nearest 0.5m were interpolated from 0.5m contours on the 1:2000 scale orthophotomaps.

Table C-1, Appendix C, provides **CEHZ** calculations for Stations 3-18, over a distance of approximately 3.2km, with **CEHZ** widths ranging from 30-75m in proportion to long-term accretion rates. Maps in Appendix D show the extent of the **CEHZ**.

5.2 CLHZ ASSESSMENT

Equation [8] was used to quantify the various Risk Zones and Safety Buffer Zone (Factor **F**) as follows:

Factor R: For the long-term trend of cliffline retreat, Linear Regression Rates in Column I, Table B-1, Appendix B were averaged for Stations 1-2 and 19-26 with the higher average rate adopted for Stations 32-35 as more representative for this area, and individual rates adopted for Stations 27-31 and 36-37.

Factor S: Seaward hillslopes exposed to extreme risk of either landslip or short-term erosion during severe wave storms were quantified from field evidence, sequential aerial surveys and the 1:2000 orthophotomaps with 0.5m contours, with values ranging from 10-110m.

Factor T: A standard hazard assessment period of 100 years was used (2008-2108).

Factor F: A Safety Factor of 1.3 (30%) was adopted to allow for uncertainties in Factors **R** and **S** and potential adverse effects of global climate change and associated acceleration in SLR. (Note that the Bruun Rule (Equation 7) cannot be applied to seacliffs).

Table C-2, Appendix C, provides **CLHZ** calculations for Stations 1-2, and 19-36 over a total distance of approximately 4.0km with **CLHZ** widths ranging from 15-160m in proportion to heights and erosion rates of seacliffs. Maps in Appendix D show the extent of the **CLHZ**.

5.3 CFHZ ASSESSMENT

Two **CFHZ** were assessed with the **2008 CFHZ** representing the present and historic sea flood contour for both a probable 2% Annual Exceedence Probability wave storm and tsunami, and the **2108 CFHZ** representing a potential sea flood contour incorporating the maximum projected sea-level rise by about 2100 by IPCC (2007) plus a safety factor.

2008 CFHZ: Based on upper levels of storm wave runup reached during Tropical Cyclone Bernie in April 1982 and assuming this storm to be a 2% AEP event plus levels observed during tsunami in 1947 and 1960, a contour of 4.5m a.MSL is adopted for the **2008 CFHZ**.

2108 CFHZ: Using the 4.5m elevation as a base level, plus making provision for a maximum projected rise in sea-level of 0.8m above 1990 levels by 2100 (IPCC 2007; MfE 2008), plus including a safety factor of 0.2m, a contour of 5.5m a.MSL is adopted for the **2108 CFHZ**.

As sea-level continues to rise this century, the actual **CFHZ** for a 2% AEP wave storm event or tsunami of similar frequency can be expected to lie somewhere between the 4.5 and 5.5m contours above MSL in Tokomaru Bay. Depending on the direction of such an event, either the northern, central or southern parts of Tokomaru Bay would be affected by temporary inundation during the event. Based on the historic record it is unlikely that the entire Bay would be uniformly affected during a single sea flood event. Maps in Appendix D show the extent of the **CFHZ**. Note: that although the accuracy of the contours derived in 2008 is ±0.25m along southern Waiotu Road, the error increases to ±1.2m around the rest of Tokomaru Bay from contours derived in 1997 and 2007, significantly constraining the accuracy on the ground of the **CFHZ** assessed in this study.

6 SUMMARY AND CONCLUSIONS

1. In general, the qualitative historical information on natural coastal hazards provided by the 20 local residents of Tokomaru Bay consulted between June and August 2008, was in excellent agreement with the quantitative information derived in this study.

2. Long-term shoreline trends in both the geologic and historic past reveal an accreting sandy shore in the centre of Tokomaru Bay, flanked by retreating seacliffs and headlands.

3. The coastal erosion hazard within the centre of Tokomaru Bay arises entirely from short-term duneline fluctuations, which significantly exceed the long-term trends of accretion and dynamic equilibrium.

4. The identified and quantified coastal hazards in Tokomaru Bay include; landslip between the Waima Road and Koutunui Point in the north and between Waiotu Road and Mawhai Point in the south; long-term cliffline erosion in both areas; short-term duneline erosion-accretion in the centre of the Bay, and; temporary flooding from either tsunami or wave storms between the Waiotu Road and Te Ariuru.

5. Despite net tectonic uplift rates of 0.8-1.4m/1000 years, the Mudstone seacliffs are retreating from the combination of backcutting at -0.1 to -0.3m/year and downcutting of the shore platform at -0.01 to -0.05m/year, causing slope failures in the form of mostly rockfalls and earthflows.

6. Although the sand dunes between Ongaruru and Waiparapara have mostly advanced from accretion at 0.14 to 0.68m/year, averaging 0.40m/year since 1916, they are still subject to short-term duneline fluctuations from 10 to 50m, the fluctuations being greatest near

the mouths of the Waiotu Stream and Mangahauini River and near the many drains that punctuate and destabilize the dunes.

7. Although the Gisborne District coast has experienced a minimum of 24 tsunami since the 1830s, only the effects of the locally generated event of 25 March 1947 and Chilean event of 22 May 1960, were remembered, which produced tsunami wave runup (TWRU) elevations of 4.0 to 5.5m a.MSL in northern Tokomaru Bay.

8. Of the 15-20 severe wave storms that struck the Gisborne District coast between 1894 and 2008, Tropical Cyclone Bernie of April 1982, produced storm wave runup (SWRU) elevations of 3.5 to 5.0m a.MSL between Waiotu Road and Te Ariuru and is likely to have been the most severe wave storm event that has occurred over approximately the last 50 years.

9. The **2008 Tokomaru Bay Coastal Hazard Zone** assessed in this study makes provision for climate change and a projected sea-level rise of 0.8m by about 2100 and includes a **CEHZ** ranging in width from 30 to 75m; a **CLHZ** ranging in width from 15 to 160m, and; a **CFHZ** defined by the 5.5m contour for about 2100, ranging in width from 15m to about 160m.

7 RECOMMENDATIONS

It is recommended that Gisborne District Council, after due consideration of this report and accompanying Coastal Hazard Maps:

1. **ADOPT** the ***2008 Tokomaru Bay Coastal Hazard Zone*** between Waiotu Road and Koutunui Point for the purposes of controlling coastal subdivision, use and development and alerting the public of the risks to coastal property from the identified natural coastal hazards of erosion and flooding from the sea, and coastal landslip.

2. **INCORPORATE** the ***2008 Tokomaru Bay Coastal Hazard Zone*** into both Council's *Proposed Regional Coastal Environment Plan* and *Part-operative Combined Regional Land and District Plan* to replace the current, and more general, Areas Sensitive to Coastal Hazards assessed in 1994.

3. **PROVIDE** for public seminars and open days at the Senior Citizens' Hall, Tokomaru Bay, to disseminate both the findings of this study and Council's decisions with respect to managing subdivision, use, and development within the ***2008 Tokomaru Bay Coastal Hazard Zone***.

4. **MONITOR** and quantify the identified coastal hazards with the help of local residents, of erosion and flooding from the sea, and coastal landslip, to the extent that the data collected by Council can provide the basis for an informed review of the ***2008 Tokomaru Bay Coastal Hazard Zone***.

5. **REVIEW** the ***2008 Tokomaru Bay Coastal Hazard Zone*** using similar methods either once every 10 years, **OR** after occurrence of significant hazardous events such as severe wave storms, tsunami, or large earthquakes, **OR** after significant changes in global climate change forecasts including potential sea-level rise, by the Intergovernmental Panel on Climate Change.

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APPENDIX A

National Water & Soil Conservation Authority (NWASCO) Policy on Natural Hazards as of 7 July 1981

Coastal Hazards Database (CHDB) for Tokomaru Bay (after CMCL 1994; 1999)

Minutes of NWASCA meeting held on 7 July 1981 at MWD Head Office, Wellington.

"RESOLVED:

That the Authority:

a. *Endorse the recommendations set out on page 48 in Technical Publication No 21 for the management of the coastal hazard zones in the Waiapu County, as being adequate to either reduce or eliminate the effects of the identified coastal hazards on both public and private assets;*

b. *Adopt as policy;*

   i. *The general identification of lands subject to hazards such as erosion, flooding and landslip and the promotion of the inclusion of such information in the relevant regional planning schemes.*

   ii. *The promotion of the inclusion in district planning schemes of maps and information describing the location, type and extent of each hazard.*

   iii. *The promotion of the inclusion in regional and district planning schemes of provision for land uses compatible with the type and extent of the hazards identified.*

c. *Request the Director to arrange for the nationwide promotion of:*

   i. *The scientific methods developed in Technical Publication No 21 for identifying and quantifying coastal hazards;*

   ii. *Continued development of standardized techniques for identifying and quantifying other hazards;*

   iii. *Planning procedures setout in (b) (i), (ii), and (iii) above to avoid or mitigate the damage to assets caused by natural hazards and to encourage land uses compatible with the identified hazards."*

Extract from GDC's Coastal Hazards Database that covers Tokomaru Bay (Source: CMCL 1999, Appendix 1).

						VARIABLES							
	STATION	PRCEP	Elevation (m)	Storm Wave Runup (m)	Gradient	Tsunami (m)	Lithology	Landform	Long-Term Trend (m/y)	Short-Term Fluctuation (m)	CSI		ASCH (m)
60	Mawhai Point Z16:790222	34	4 2.5m	4 4-5m	1 30°	3 c.3m in 1947	5 cobbles	4 softrock seacliff	3 c.-0.1m/yr	2 2-5m	26	medium	100m
61	Tokomaru Bay (south) Z16:762257	32	1 200m	4 3-4m	1 45°	3 c.3m in 1947	4 mudstone	4 softrock seacliff	3 -0.21m/yr 1945-1993	3 5-10m	24	medium	150m
62	Tokomaru Bay (mid) Z16:760267	32	4 2.5m	4 3-4m	5 -5°	3 c.3m in 1947	5 sand	5 sand dunes	1 1.04m/yr 1945-1993	4 15-30m	31	high	100m
63	Tokomaru Bay (mid) Z16:761276	32	4 3.4m	4 3-4m driftwood	5 -5°	3 c.3m in 1947	5 sand	5 sand dunes	1 0.94m/yr 1945-1993	5 30-40m	32	high	150m
64	Tokomaru Bay (mid) Z16:765285	32	4 2.1m	4 3-4m	4 2°	3 c.3m in 1947	5 sand	5 sand dunes	2 0.23m/yr 1886-1993	4 15-20m	31	high	100m
65	Te Puka Z16:774292	31	4 2.0m	4 3-4m	1 60°	3 c.3m in 1947	4 mudstone	2 concrete seawall	2 0.0m/yr 1945-1993	1 <2m	21	medium	75m
66	Te Ariuru Z16:782296	31	4 2.1m	4 2-3m driftwood	5 0°	3 c.3m in 1947	5 boulders	5 delta	2 0.0m/yr 1945-1993	2 2-5m	30	high	150m
67	Waima Wharf Z16:792302	31	3 10m	4 2-3m	1 60°	3 c.3m in 1947	4 mudstone	4 softrock seacliff	3 -0.21m/yr 1945-1993	2 2-5m	24	medium	100m

APPENDIX B

Tables and Data

APPENDIX B - Table B-1: Erosion and accretion rates (Column G, H, I) for Tokomaru Bay from south to north calculated from scaled distances (Column F) on fully rectified orthophotomaps at 1:2000 scale for up to 5 survey intervals (Column E) from 1916-2008 at 39 stations (Column A) spaced from 150-200m (Column B), with net shoreline trend over the last 86-92 years (1916-2002 & 1916-2008) (Column J).

A		B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
1	Y' Slip Area	0	Mudstone	Cliffline	1916-1945	-4.00	-0.14			
					1945-1960	-3.00	-0.20			
					1960-1982	-4.00	-0.18			
					1982-2002	0.00	0.00			Sheet 1
					2002-2008	0.00	0.00	-0.12	-0.13	Cliffline Retreat
2	Chaffey's House	200	Mudstone	Cliffline	1916-1945	4.00	0.14			
					1945-1960	-2.00	-0.13			
					1960-1982	-1.00	-0.05			
					1982-2002	-2.00	-0.10			Sheet 1
					2002-2008	2.00	0.33	0.01	-0.02	Dynamic Equilibrium
3	Waiotu Road South	400	Fine Shelly Sand	Duneline	1916-1945	-0.50	-0.02			
					1945-1960	0.50	0.03			
					1960-1982	-0.50	-0.02			
					1982-2002	2.00	0.10			Sheet 1
					2002-2008	0.00	0.00	0.02	0.02	Dynamic Equilibrium
4	Waiotu Road	600	Fine Shelly Sand	Duneline	1916-1945	-4.50	-0.16			
					1945-1960	4.00	0.27			
					1960-1982	0.00	0.00			
					1982-2002	14.00	0.70			Sheet 1
					2002-2008	-11.00	-1.83	0.03	0.07	Dynamic Equilibrium

	A	B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
5	Ongaruru	800	Fine Shelly Sand	Duneline	1916-1945	0.00	0.00			
					1945-1960	0.00	0.00			
					1960-1982	6.00	0.27			
					1982-2002	4.00	0.20			Sheet 2
					2002-2008	-6.00	-1.00	0.04	0.09	Dynamic Equilibrium
6	Ongaruru	1000	Fine Shelly Sand	Duneline	1916-1945	-2.00	-0.07			
					1945-1960	-3.00	-0.20			
					1960-1982	1.00	0.05			
					1982-2002	3.00	0.15			Sheet 2
					2002-2008	-6.00	-1.00	-0.08	-0.04	Dynamic Equilibrium
7	Ongaruru	1200	Fine Shelly Sand	Duneline	1916-1945	0.00	0.00			
					1945-1960	12.00	0.80			
					1960-1982	26.00	1.18			
					1982-2002	-3.00	-0.15			Sheet 2
					2002-2008	-4.00	-0.67	0.34	0.44	Duneline Advance
8	Ongaruru	1400	Fine Shelly Sand	Duneline	1916-1945	14.00	0.48			
					1945-1960	0.00	0.00			
					1960-1982	50.00	2.27			
					1982-2002	-24.00	-1.20			Sheet 3
					2002-2007	0.00	0.00	0.44	0.53	Duneline Advance

	A	B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
9	Ongaruru	1600	Fine Shelly Sand	Duneline	1916-1945	18.00	0.62			
					1945-1960	0.00	0.00			
					1960-1982	5.00	0.23			
					1982-2002	0.00	0.00			Sheet 3
					2002-2007	-4.00	-0.80	0.21	0.20	Duneline Advance
10	Waiotu Stream Mouth	1800	Fine Shelly Sand	Duneline	1916-1945	30.00	1.03			
					1945-1960	12.00	0.80			
					1960-1982	4.00	0.18			
					1982-2002	3.00	0.15			Sheet 3
					2002-2007	2.00	0.40	0.56	0.51	Duneline Advance
11	Tuatini	2000	Fine Shelly Sand	Duneline	1916-1945	45.00	1.55			
					1945-1960	5.00	0.33			
					1960-1982	-25.00	-1.14			
					1982-2002	37.00	1.85			Sheet 3
					2002-2007	-12.00	-2.40	0.55	0.46	Duneline Advance
12	Tuatini	2200	Fine Shelly Sand	Duneline	1916-1945	25.00	0.86			
					1945-1960	26.00	1.73			
					1960-1982	3.00	0.14			
					1982-2002	6.00	0.30			Sheet 4
					2002-2007	-9.00	-1.80	0.56	0.59	Duneline Advance

A		B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
13	Tuatini	2400	Fine Shelly Sand	Duneline	1916-1945	0.00	0.00			
					1945-1960	-20.00	-1.33			
					1960-1982	20.00	0.91			
					1982-2002	20.00	1.00			Sheet 4
					2002-2007	3.00	0.60	0.25	0.28	Duneline Advance
14	Mangahauini River Mouth	2570	Fine Shelly Sand	Duneline	1916-1945	-35.00	-1.21			
					1945-1960	20.00	1.33			
					1960-1982	8.00	0.36			
					1982-2002	7.00	0.35			Sheet 4
					2002-2007	0.00	0.00	0.00	0.14	Duneline Advance
15	Waiparapara	2800	Fine Shelly Sand	Duneline	1916-1945	29.00	1.00			
					1945-1960	-10.00	-0.67			
					1960-1982	9.00	0.41			
					1982-2002	13.00	0.65			Sheet 5
					2002-2007	3.00	0.60	0.48	0.42	Duneline Advance
16	Waiparapara	3000	Fine Shelly Sand	Duneline	1916-1945	0.00	0.00			
					1945-1960	27.00	1.80			
					1960-1982	0.00	0.00			
					1982-2002	30.00	1.50			Sheet 5
					2002-2007	0.00	0.00	0.63	0.68	Duneline Advance

A		B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
17	Waiparapara	3200	Fine Shelly Sand	Duneline	1916-1945	19.00	0.66			
					1945-1960	0.00	0.00			
					1960-1982	4.00	0.18			
					1982-2002	4.00	0.20			Sheet 5
					2002-2007	2.00	0.40	0.32	0.28	Duneline Advance
18	Waiparapara	3400	Fine Shelly Sand	Duneline	1916-1945	7.00	0.24			
					1945-1960	6.00	0.40			
					1960-1982	4.00	0.18			
					1982-2002	4.00	0.20			Sheet 5
					2002-2007	0.00	0.00	0.23	0.24	Duneline Advance
19	Waiparapara	3600	Fine Shelly Sand	Duneline	1916-1945	5.00	0.17			
					1945-1960	0.00	0.00			
					1960-1982	-3.00	-0.14			
					1982-2002	6.00	0.30			Sheet 6
					2002-2007	-3.00	-0.60	0.05	0.05	Dynamic Equilibrium
20	Te Puka	3800	Mudstone	Cliffline	1916-1945	4.00	0.14			
					1945-1960	0.00	0.00			
					1960-1982	-2.00	-0.09			
					1982-2002	3.00	0.15			Sheet 6
					2002-2007	0.00	0.00	0.05	0.04	Dynamic Equilibrium

A		B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
21	Te Puka	4000	Mudstone	Seawall	1916-1945	-10.00	-0.34			
					1945-1960	0.00	0.00			
					1960-1982	0.00	0.00			Sheet 6
					1982-2002	3.00	0.15	-0.08	-0.07	Cliffline Retreat
22	Te Puka	4200	Mudstone	Seawall	1916-1945	-5.00	-0.17			
					1945-1960	2.00	0.13			
					1960-1982	-3.00	-0.14			Sheet 7
					1982-2002	4.00	0.20	-0.02	-0.03	Cliffline Retreat
23	Waima Road	4400	Mudstone	Seawall	1916-1945	1.00	0.03			Sheet 7
					1945-2002	3.00	0.05	0.05	0.05	Reclamation
24	Waima Road	4600	Mudstone	Seawall	1916-1945	3.00	0.10			Sheet 7
					1945-2002	6.00	0.11	0.10	0.10	Reclamation
25	Waima Road	4800	Mudstone	Seawall	1916-1945	2.00	0.07			Sheet 7
					1945-2002	3.00	0.05	0.06	0.06	Reclamation
26	Waima Road	5000	Mudstone	Seawall	1916-1945	-2.00	-0.07			Sheet 8
					1945-2002	3.00	0.05	0.01	0.02	Reclamation
27	Te Ariuru	5200	Mudstone	Cliffline	1916-1945	-10.00	-0.34			
					1945-1960	0.00	0.00			
					1960-1982	-2.00	-0.09			Sheet 8
					1982-2002	-3.00	-0.15	-0.17	-0.16	Cliffline Erosion

	A	B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
28	Te Ariuru	5400	Cobbles	Duneline	1916-1945	-15.00	-0.52			
					1945-1960	9.00	0.60			
					1960-1982	-3.00	-0.14			Sheet 8
					1982-2002	-3.00	-0.15	-0.14	-0.10	Shoreline Retreat
29	Te Ariuru	5550	Cobbles	Duneline	1916-1945	-6.00	-0.21			
					1945-1960	6.00	0.40			
					1960-1982	0.00	0.00			Sheet 8
					1982-2002	-6.00	-0.30	-0.07	-0.03	Shoreline Retreat
30	Te Ariuru	5700	Cobbles	Seawall	1916-1945	2.00	0.07			Sheet 9
					1945-2002	-3.00	-0.05	-0.01	-0.02	Reclamation
31	Lost House	5930	Cobbles	Cliffline	1916-1945	2.00	0.07			
					1945-1960	-2.00	-0.13			
					1960-1982	-4.00	-0.18			Sheet 9
					1982-2002	-6.00	-0.30	-0.12	-0.12	Cliffline Retreat
32	Hautanoa	6100	Mudstone	Cliffline	1916-1945	-7.00	-0.24			
					1945-1960	-1.00	-0.07			
					1960-1982	0.00	0.00			Sheet 9
					1982-2002	-5.00	-0.25	-0.15	-0.13	Cliffline Retreat
33	Hautanoa	6300	Mudstone	Cliffline	1916-1945	-8.00	-0.28			
					1945-1960	0.00	0.00			
					1960-1982	-6.00	-0.27			Sheet 9
					1982-2002	-5.00	-0.25	-0.22	-0.21	Cliffline Retreat

	A	B	C	D	E	F	G	H	I	J
	Station	Cumulative Distance North (m)	Lithology	Reference Shoreline	Survey Interval (y)	Shoreline Retreat (-) or Advance (+) (m)	Rate (m/y)	Net Rate (m/y)	Linear Regression Rate (m/y)	1:2000 Scale Sheets & Trend
34	Hautanoa	6500	Mudstone	Cliffline	1916-1945	-11.00	-0.38			
					1945-1960	0.00	0.00			
					1960-1982	-3.00	-0.14			Sheet 9
					1982-2002	-4.00	-0.20	-0.21	-0.20	Cliffline Retreat
35	Waima	6700	Mudstone	Cliffline	1945-1960	-4.00	-0.14			
					1960-1982	0.00	0.00			Sheet 10
					1982-2002	-3.00	-0.14	-0.12	-0.11	Cliffline Retreat
										1916 survey unreliable
36	Waima Wharf	6900	Reclamation	Seawall	1916-1945	40.00	1.38			Sheet 10
					1945-2007	3.00	0.05	0.47	0.41	Reclamation
37	Waima	7100	Mudstone	Cliffline	1916-1945	-8.00	-0.28			
					1945-1960	-7.00	-0.47			
					1960-1982	-1.00	-0.05			Sheet 10
					1982-2002	-5.00	-0.25	-0.24	-0.24	Cliffline Retreat
38	Koutunui Point	7300	Mudstone	Cliffline	1916-1945	-2.00	-0.07			Sheet 10
					1945-2002	-2.00	-0.04	-0.05	-0.04	Cliffline Retreat
39	Koutunui Point	7490	Mudstone	Cliffline	1916-1945	6.00	0.21			
					1945-1960	-2.00	-0.13			
					1960-1982	6.00	0.27			Sheet 10
					1982-2002	-11.00	-0.55	-0.01	-0.01	Cliffline Retreat

APPENDIX B - TABLE B-2: Three seabed profiles normal to the shore over a distance offshore of 3000m. Depths below Chart Datum were scaled from the "*Waipiro Bay to Gable End Foreland*" sounding collector chart at 1:25,000, surveyed between 1 February and 28 April 1996 by HMNZS Monowai. Depths in metres were normalised to MSL Gisborne Provisional Datum 1926 by adding 1.2m from the NZ Nautical Almanac 2007/08 Edition. Profile 1 is directly off the Mangahauini River mouth; Profile 2 is 625m south, and Profile 3 is a further 625m south. Based on GDC contour data, a height of 2.5m a.MSL is assumed for the shoreline plotted on the 1:25,000 chart.

Profile 1 - Mangahauini			Profile 2 - Tuatini				Profile 3 - Ongaruru		
	Depth Below			Depth Below				Depth Below	
Distance Offshore (m)	Chart Datum (m)	MSL (m)	Distance Offshore (m)	Chart Datum (y)	MSL (m)		Distance Offshore (m)	Chart Datum (m)	MSL (m)
0		2.5	0		2.5		0		2.5
200	3.2	-4.4	200	1.7	-2.9		120	1.5	-2.7
260	5.9	-7.1	360	4.1	-5.3		180	1.8	-3.0
400	7.6	-8.8	540	7.3	-8.5		240	3.0	-4.2
530	8.6	-9.7	660	10.2	-11.4		350	6.4	-7.6
610	9.3	-11.5	800	11.1	-12.3		420	7.0	-8.2
700	10.5	-11.7	900	11.8	-13.0		560	8.4	-9.6
800	11.2	-12.4	1020	12.7	-13.9		660	9.0	-10.2
900	12.9	-14.1	1140	13.3	-14.5		740	9.8	-11.0
1000	14.0	-15.2	1240	14.3	-15.5	Fine Sand	820	10.7	-11.9
1140	14.5	-15.7	1330	15.2	-16.4		920	11.8	-13.0
1240	15.6	-16.8	1460	16.0	-17.2		1050	12.8	-14.0
1380	16.4	-17.6	1540	15.5	-16.7		1140	13.8	-15.0
1500	16.9	-18.1	1640	17.3	-18.5		1300	12.4	-13.6
1600	17.7	-18.9	1750	18.3	-19.5		1460	15.5	-16.7
1700	18.6	-19.8	1860	17.3	-18.5		1580	18.0	-19.2
1820	19.6	-20.8	2050	16.5	-17.7		1700	18.8	-20.0
1920	20.0	-21.2	2240	16.0	-17.2		1820	19.8	-21.0
2000	20.4	-21.6	2320	16.8	-18.0		1920	21.1	-22.3
2100	21.3	-22.5	2420	16.0	-17.2		2060	21.8	-23.0
2300	21.5	-22.7	2550	10.2	-11.4	Hikutu Rocks	2160	22.6	-23.8
2500	22.7	-23.9	2660	24.5	-25.7		2300	23.2	-24.4
2660	23.4	-24.6	2800	25.2	-26.4		2460	24.1	-25.3
2800	24.1	-25.3	2940	25.5	-26.7		2600	24.5	-25.7
2900	24.5	-25.7	3000	25.5	-26.7		2740	25.0	-26.2
3000	24.5	-25.7					2800	25.0	-26.2
							2920	22.1	-23.3
							3030	23.9	-25.1

APPENDIX B - TABLE B-3: Rates of downcutting for the shore platform ramp cut in coherent Late Tertiary (Tolaga Group) mudstone-sandstone rocks at the base of the seawall along the Waima Road in northern Tokomaru Bay (NZMS 260, Sheet Z16 Grid Ref 770290 to 781296) from precise levelling between 1960 and 1980. Column A gives the distance apart northwards of each observation. Column B lists the survey interval. Column C tabulates the erosion as a vertical distance in millimetres for each survey interval. Column D gives the downcutting rate in millimetres per year (mm/y) (Source: Gibb 1981).

A Cumulative Distance Apart North (m)	B Survey Interval (y)	C Downcutting Amount (mm)	D Rate (mm/y)
0	1965-1980	-750	-50.0
6	1965-1980	-180	-12.0
43	1965-1980	-259	-17.3
70	1965-1980	-290	-19.3
77	1961-1980	-470	-24.7
89	1965-1980	-491	-32.7
112	1961-1980	-610	-32.1
236	1960-1980	-521	-26.1
257	1965-1980	-290	-19.3
707	1960-1980	-750	-37.5
		Average Rate:	27.1

APPENDIX B - TABLE B-4: Projected rates of Sea Level Rise (SLR) this century for decades and beyond. All predicted heights of SLR are relative to the 1980-1999 sea-level average. Rates are determined here from 1990 (mid-range) to the mid-range timeframe dates (e.g. 1990-2055). Whilst minimum SLR values are mostly the result of thermal expansion, maximum values include ice melt from continental ice sheets such as Greenland and Antarctica. Adapted from Ministry for the Environment (2008, table 2.3).

Timeframe	Minimum SLR (m)	Rate (mm/y)	Maximum SLR (m)	Rate (mm/y)
2030-2039	0.15	3.3	0.20	4.4
2040-2049	0.20	3.6	0.26	4.7
2050-2059	0.25	3.9	0.34	5.2
2060-2069	0.31	4.1	0.42	5.6
2070-2079	0.37	4.4	0.52	6.1
2080-2089	0.44	4.6	0.66	7.0
2090-2099	0.50	4.8	0.80	7.6
Beyond 2100				10.0

APPENDIX B: TABLE B-5: Twenty-four historic tsunami events along the Gisborne District coast from 1832-2007. Source: Richard Steele, Civil Defence Officer, GDC (pers. comm. July 2008) plus information held by Dr Gibb.

Event Date	Source/Main impact	Source Area	Impact	Trigger
1832 to 1834	Poverty Bay	Local	Immense swell	Earthquake M7
1840	Te Araroa	Local ?	Land strewn with fish	Unknown
13 August 1868	Peru, Poverty Bay	Distant	3-5 metres. Destroyed Maori Village at Muriwai	Earthquake M8.5
11 May 1877	Chile	Distant	2-3 metres	Earthquake M9.0
8 September 1880	Poverty Bay	Local	Land strewn with fish	Earthquake
27 August 1883	Indonesia, Krakatoa	Distant	0.9 metres	Volcano - Atmospheric
2 February 1906	Ecuador	Distant	0.6-0.7 metres	Earthquake M8.5
8 October 1914	Tolaga Bay	Local	Unknown	Landslide Cooks Cove M6.7
11 November 1922	North Chile	Distant	Unknown	Earthquake M8.0
1927	Tolaga Bay	Local	4.5 metres. Smashed wharf piles at Tolaga Wharf	Unknown
2 February 1931	Poverty Bay	Local	1-3 metres at Muriwai	Hawke's Bay Earthquake M7.8
1 April 1946	Aleutian Islands	Distant	Few centimetres	Earthquake M7.4
25 March 1947	Waipiro-Mahanga Beaches	Local	4-11 metres. Runup about 4m a.MSL at Waima, Tokomaru Bay	Tsunamigenic earthquake M5.9 plus
17 May 1947	Loisels Beach	Local	6 metres	Tsunamigenic earthquake M5.6 plus
5 November 1952	Kamchatka	Distant	1 metre (in Port)	Earthquake M8.2
9 March 1957	Aleutian Islands	Distant	Bore up Uawa River	Aleutian Islands M9.1
22 May 1960	Chile	Distant	Runup about 4.5-5.5m a.MSL in north Tokomaru Bay. Surge about 4 metres in Port	Earthquake M9.5
1970	Tolaga Bay	Local	Bore up Uawa River	Unknown
1972	Anaura Bay	Local ?	0.5-1.5 metres. Calm seas, waves broke across Bay	Unknown
1978	Anaura Bay	Local ?	0.5-1.5 metres. Calm seas, waves broke across Bay	Unknown
23 June 2001	Peru	Distant	Trace	Earthquake M8.1
26 December 2004	Indonesia, Sumatra	Distant	0.4 metres	Earthquake M9.3
5 May 2006	Tonga	Regional	0.17 metres	Earthquake M7.9
3 April 2007	Solomon Islands	Regional	Few centimetres	Earthquake M8.1

APPENDIX C

CEHZ and CLHZ calculations

APPENDIX C - TABLE C-1: **CEHZ** computer calculations using Equations [1-5 & Eqn 7], where; **R** = Average linear regression rate from table B-1, Appendix B, for Stations 3-6,7-10, 11-13, & 14-18; **T** = Hazard assessment periods of 50 - 100 years; **S** = Maximum short-term duneline fluctuation measured from 1:2000 orthophotomaps; **F** = Safety Factor of 1.3 (30%) to allow for uncertainties in Factors **R**, **X**, **S** & **D**; **D** = Zero as the foredune is generally only 0.5-1.5m elevation above the beach and so results calculated with Equation [6] are too small but are accommodated in values for Factor **S**; **X** = Erosion rates for SLR calculated with Equation [7] using parameters measured from the 1:2000 orthophotomaps and from the RNZ Navy sounding collector chart (1996) plus adjusted maximum projected rates of SLR of 3.6mm/year (0.0036m/year) by about 2055 and 6.0mm/year (0.006m/year) by about 2095.

	STATIONS															
FACTORS	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
a_1	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
ℓ	1300	1600	1360	1500	1400	1500	1440	1500	1500	1500	1500	1460	1400	1300	1300	1300
h	4.0	4.0	3.0	3.0	3.0	2.5	3.0	3.0	3.5	3.5	3.0	2.5	2.5	2.5	3.0	3.0
d	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
X_1	-0.25	-0.30	-0.27	-0.30	-0.28	-0.31	-0.29	-0.30	-0.29	-0.29	-0.30	-0.30	-0.29	-0.27	-0.26	-0.26
R	0.04	0.04	0.04	0.04	0.43	0.43	0.43	0.43	0.44	0.44	0.44	0.35	0.35	0.35	0.35	0.35
T	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
$(R-X)T_{50}$	10.5	13.00	11.50	13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S+D	10	10	10	10	20	20	20	20	40	40	30	30	20	30	20	20
a_2	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
ℓ	1300	1600	1360	1500	1400	1500	1440	1500	1500	1500	1500	1460	1400	1300	1300	1300
h	4.0	4.0	3.0	3.0	3.0	2.5	3.0	3.0	3.5	3.5	3.0	2.5	2.5	2.5	3.0	3.0
d	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
X_2	-0.41	-0.51	-0.45	-0.50	-0.47	-0.51	-0.48	-0.50	-0.49	-0.49	-0.50	-0.50	-0.48	-0.45	-0.43	-0.43
R	0.04	0.04	0.04	0.04	0.43	0.43	0.43	0.43	0.44	0.44	0.44	0.35	0.35	0.35	0.35	0.35
T	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
$(R-X)T_{100}$	37.00	47.00	41.00	46.00	4.00	8.00	5.00	7.00	5.00	5.00	6.00	15.00	13.00	10.00	8.00	8.00
S+D	10	10	10	10	20	20	20	20	40	40	30	30	20	30	20	20
F	14	17	15	17	7	8	8	8	14	11	11	14	10	12	8	8
EREZ	10	10	10	10	20	20	20	20	40	40	30	30	20	30	20	20
HREZ	11	13	12	13	0	0	0	0	0	0	0	0	0	0	0	0
MREZ	26	34	29	33	4	8	5	7	5	5	6	15	13	10	8	8
SBZ	14	17	15	17	7	8	8	8	14	14	11	14	10	12	8	8
CEHZ	61	74	66	73	31	36	33	35	59	59	47	59	43	52	36	36
Rounded	**60**	**75**	**65**	**75**	**30**	**35**	**35**	**35**	**60**	**60**	**45**	**60**	**45**	**50**	**35**	**35**

APPENDIX C - TABLE C-2: CLHZ computer calculations using Equation [8], where; R = Linear regression rate from Table B-1, Appendix B; T = Hazard assessment period of 100 years; S = Extent of slope subject to landslip measured from 1:2000 orthophotomaps; F = Safety Factor of 1.3 (30%). CLHZ calculated widths are rounded to nearest 5m.

	Factors								Risk Zones	
Stations	S	R_{av}	T	S + R.T	F	CLHZ	Rounded	ERLZ	MRLZ	SBZ
1	55	-0.13	100	68	20	88	90	55	13	22
2	25	-0.02	100	27	8	35	35	25	2	8
19	10	-0.17	100	27	8	35	35	10	17	8
20	10	-0.17	100	27	8	35	35	10	17	8
21	10	-0.17	100	27	8	35	35	10	17	8
22	10	-0.17	100	27	8	35	35	10	17	8
23	10	-0.17	100	27	8	35	35	10	17	8
24	10	-0.17	100	27	8	35	35	10	17	8
25	10	-0.17	100	27	8	35	35	10	17	8
26	10	-0.17	100	27	8	35	35	10	17	8
27	10	-0.16	100	26	8	34	35	10	17	8
28	10	-0.10	100	20	6	26	25	10	10	5
29	10	-0.03	100	13	4	17	15	10	2	3
30	10	-0.02	100	12	4	16	15	10	2	3
31	10	-0.12	100	22	7	29	30	10	12	8
32	46	-0.21	100	67	20	87	85	45	21	19
33	78	-0.21	100	99	30	129	130	80	21	30
34	20	-0.21	100	41	12	53	55	20	21	14
35	10	-0.21	100	31	9	40	40	10	21	9
36	10	0.00	100	10	3	13	15	10	0	0
37	100	-0.24	100	124	37	161	160	100	24	36

APPENDIX D

Coastal Hazard Maps showing CEHZ, CLHZ and CFHZ for 2008 Tokomaru Bay Coastal Hazard Zone