COASTAL MANAGEMENT CONSULTANCY LIMITED

ASSESSMENT OF COASTAL HAZARD ZONES FOR TOLAGA BAY AND ANAURA BAY, GISBORNE DISTRICT, BY GIS COMPUTER MODEL

Report prepared for Gisborne District Council

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EXECUTIVE SUMMARY

On 17 January 1997, the writer was commissioned by Gisborne District Council (GDC) to carry out detailed assessments of Coastal Hazard Zones (CHZ) for both Tolaga and Anaura Bays (Figure 1). The agreed study objectives were to:

i. "*Define Coastal Hazard Risk Zones (CHRZs) for Anaura Bay and Tolaga Bay with Gisborne District Council's (Council) Arc/Info Geographic Information System (GIS)*."

ii. "*Produce CHRZs in a format suitable for inclusion in Council's Regional Coastal Environment and District Plans for the Gisborne Region and to be used after that for any purpose to which such Plans are normally put*."

An Arc/Info GIS computer model developed and standardised by the writer in 1996 in Tauranga District was successfully adapted and used for this study to define Coastal Hazard Zones for both Tolaga and Anaura Bays, inclusive of Coastal Erosion Hazard Risk Zones and Coastal Flood Hazard Zone.

The entire Tolaga Bay and Anaura Bay shorelines are subject to and will continue to be subject to adverse effects from the identified natural hazards of minor wind erosion and major sea-erosion of the foredune complex enhanced by rising sea-levels next century, and significant temporary inundation of coastal hinterland from Tsunami up to 4-6m and Storm Wave Runup (SWRU) up to 5-7m during extreme events.

Coastal Erosion Hazard Zone (CEHZ) widths inclusive of *Extreme*, *High* and *Moderate Risk Zones* and *Safety Buffer Zones* ranged from 35 to 205m in width from the 1997 dune in Anaura Bay and 70 to 200m in Tolaga Bay, for a planning horizon from the present to the year 2100 A.D.

Coastal Flood Hazard Zone (CFHZ) widths inclusive of the effects of both a 4-6m Tsunami and 5-7m SWRU ranged in width from 14 to 225m in Tolaga Bay and 15 to 150m in Anaura Bay from the 1997 duneline for extreme events over the next century.

Within the *Extreme* to *Moderate Risk Erosion Zones* and CFHZ of the CHZ, property, assets, amenity and conservation values have a high probability of being damaged or destroyed at various periods over the next century (1998-2100 A.D.). Landward of the CHZ, the risk to these elements over the next 100 years is likely to be *very low*.

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

i. *ADOPT* the 1998 *Coastal Hazard Zones* for Anaura Bay and Tolaga Bay inclusive of the *Extreme*, *High* and *Moderate Risk Erosion Zones* and *Safety Buffer Zone (Coastal Erosion Hazard Zone)* and *Coastal Flood Hazard Zone*, to control actual and potential use, subdivision and development, and to advise the public of actual and potential risks to beachfront property from natural coastal hazards.

ii. *INCORPORATE* the 1998 *Coastal Hazard Zones* for both Anaura Bay and Tolaga Bay into Councils 1997 *Proposed Regional Coastal Environment Plan* and *Proposed Gisborne District combined Regional Land and District Plan*.

iii. *PROVIDE* for open days at selected venues in both Tolaga and Anaura Bays to disseminate both the findings of this study and Council's decisions with respect to managing use, subdivision and development within the 1998 *Coastal Hazard Zones*.

iv. *ESTABLISH* and maintain ongoing monitoring programmes in both Tolaga and Anaura Bays to record annual changes in the position of the shoreline and elevation of the nearshore seabed and to record the landward extent and elevations reached by both severe Storm Wave Runup and Tsunami events.

v. *REVIEW* the 1998 *Coastal hazard Zones* using the GIS computer model either every 10 years, *OR* after the occurrence of significant natural phenomena (e.g. Severe wave storms, tsunami, large earthquakes, etc), *OR* after significant changes in global and regional Climate Predictions by the Royal Society of New Zealand and Intergovernmental Panel on Climate Change.

vi. *IMPLEMENT* and support appropriate "*Coast Care*" programmes involving local communities to restore, enhance or maintain the protective foredune complex in both Tolaga and Anaura Bays.

vii. *UTILIZE* the standardised GIS computer model used in this study to assess *Coastal Hazard Zones* for other priority coastal areas in Gisborne District including those areas previously assessed in Poverty Bay and Wainui Beach.

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ASSESSMENT OF COASTAL HAZARD ZONES FOR TOLAGA BAY AND ANAURA BAY, GISBORNE DISTRICT, BY GIS COMPUTER MODEL

By

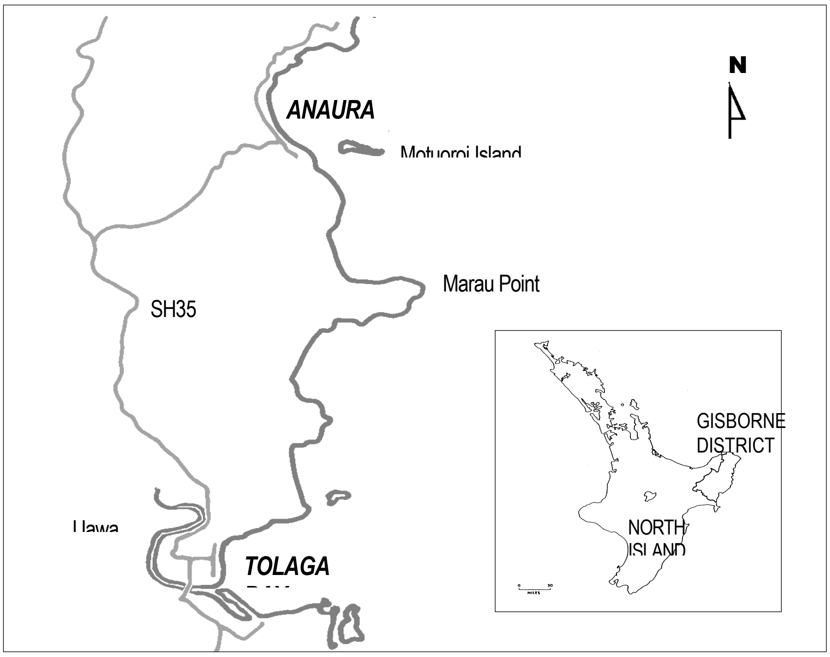
Jeremy G Gibb, Ph.D., B.Sc (Hons), TM IPENZ

"Gisborne District Coast – First to see the Sun"

Sunrise at Anaura Bay on 1 March 1997

1 INTRODUCTION

On 17 January 1997, the writer was commissioned by Gisborne District Council (GDC) to carry out detailed assessments of Coastal Hazard Zones (CHZ) for both Tolaga and Anaura Bays (Figure 1). The agreed study objectives were to:



• Figure 1: Sketch map showing both study areas being Anaura Bay and Tolaga Bay.

i. "*Define Coastal Hazard Risk Zones (CHRZs) for Anaura Bay and Tolaga Bay with Gisborne District Council's (Council) Arc/Info Geographic Information System (GIS).*"

ii. "*Produce CHRZs in a format suitable for inclusion in Council's Regional Coastal Environment and District Plans for the Gisborne Region and to be used after that for any purpose to which such Plans are normally put.*"

Unlike previous Coastal Hazard Zone Assessments for the Gisborne District coast (Gibb 1981a; 1981b; 1994a; 1994b; 1995) a Geographic Information Systems (GIS) computer model developed by the writer (Gibb 1996) was used in this study for the assessments. Following design, testing and standardising in 1995 in the Bay of Plenty the flexible model was incorporated into Tauranga District Council's (TDC) Arc/Info GIS for CHZ assessments between Mount Maunganui and Papamoa (Gibb 1996). The computer model could not be run on GDCs GIS so for this project all CHZ assessments were made on TDCs GIS. During assessments, the computer model was refined by both the writer and Colin Mills (GIS Analyst, TDC) to accommodate the geomorphic complexities of both Anaura and Tolaga Bays.

This report provides the basis to determine the CHZs by the GIS computer model. The parameters used by the model dictated the precise data collections to assess Coastal Hazard Risk Zones for the dominant hazards of erosion and flooding from the sea in both Tolaga and Anaura Bays (Gibb 1981a, 1994b). The report includes descriptions of the methods used for the study, the revised computer model including parameters and CHZs.

1.1 COASTAL HAZARD MAPPING IN GISBORNE DISTRICT

Prior to 1980 the coastal hazards of the old Waiapu and Cook Counties that now comprise Gisborne District had not been identified or quantified. Between 1979 and 1980, the writer 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 1981a).

Identified hazards included sea and wind erosion, flooding from storm wave runup, tsunami and coastal rivers, and landslip. Coastal Hazard Zones (CHZ) were assessed for 14 coastal areas between Lottin Point area and Marau Point. For Anaura Bay, the headlands and Southern two-thirds of the bay were found to be eroding and the Northern third accreting. The CHZ width increased Southward from 50m to a maximum of 174m by the Southern Stream mouth, extending to the toe of the hills (Gibb 1981a, fig.21).

At its June 1980 meeting, the Waiapu County Council unanimously adopted the report and its CHZ assessments for 14 coastal areas, including Anaura Bay, in the County. The 14 CHZs were incorporated into the Waiapu County District Scheme Review and shown on the relevant planning maps (Gibb 1982). 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 adopted by the Soil Conservation and Rivers Control Council in March 1981 for NWASCA, for nationwide application by both the District Offices of Ministry of Works and Development and the Catchment Authorities serviced by NWASCA at that time (Gibb 1983). As a result, Coastal Hazard Mapping programmes were initiated elsewhere in New Zealand by various Catchment Authorities.

CHZs were measured as a horizontal distance inland from the "*seaward toe of foredune or seacliff*", whichever "*reference shoreline*" was the most clearly defined along each section of coast. The coastal hazard lines so defined were then fixed in terms of the existing cadastral survey system with respect to property boundaries. For most areas the CHZs were shown on planning maps in District Schemes whereas for other areas the information was held in a Hazards Register and applied by Territorial Local Authorities to control coastal subdivision and development (Gibb 1995).

In December 1980, the Cook County Council commissioned the writer to assess a Coastal Hazard Zone for Wainui Beach. Using a comprehensive database, a 25 to 55m-wide CHZ was assessed, comprising a 15m-wide "*Zone of Immediate Risk*" and a 10 to 40m-wide

"*Zone of Ultimate Risk*". The "*Zone of Immediate Risk*" was identified as being extremely susceptible to adverse effects from short-term storm induced sea erosion whereas, the "*Zone of Ultimate Risk*" was susceptible to the long-term rate of retreat. The landward extent of the hazard zone so determined represented "*the line beyond which the shoreline (seaward limit of land vegetation) is not expected to lie in the next 100 years. Any assets within the hazard zone may be destroyed by coastal erosion during the next 100 years (1981-2081)*" (Gibb 1981b).

After a process of public consultation, Cook County Council included the Coastal Hazard Zone on the planning maps of the first review of its District Planning Scheme released in September 1982, which became operative on 1 June 1989. Within the 25 to 55m-wide CHZ, which was designated as the "*Wainui Erosion Hazard Area (WEHA)*", the scheme statement prohibited further subdivision of the land and restricted building in accordance with the provisions of Section 641(A) of the Local Government Act 1974. The same restrictions were applied to the "*Makorori Erosion Hazard Area (MEHA)*" which was delineated on the planning maps of the Cook County District Planning Scheme.

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 Tolaga and Anaura Bays. 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 a specific Coastal Sensitivity Indices (CSI) derived for each of the 42 beaches (Gibb 1994b).

CSIs potentially ranged from a minimum of 8 (*Very Low Sensitivity*) to a maximum of 40 (*Very High Sensitivity*). Tolaga Bay was classified as *High to Very High Sensitivity* to natural coastal hazards and Anaura Bay as *High Sensitivity.* For Tolaga Bay, the identified coastal hazards included both long and short-term sea erosion, wind erosion, migration of the Uawa River mouth, landslip along the flanking seacliffs, and flooding from both the sea and river in low-lying land at the mouth. For Anaura Bay, the identified coastal hazards included both long and short-term sea erosion, wind erosion, and flooding of low-lying hinterland from both the sea and local streams. ASCH widths ranged from 100-150m for Anaura Bay and 100-570m for Tolaga Bay, the greater widths reflecting the relative sensitivity of areas to erosion and flooding (Gibb 1994b).

On 3 November 1994, GDC commissioned the writer to assess detailed CHZs inclusive of *Extreme*, *High* and *Moderate Risk Erosion Zones* and *Safety Buffer Zones* for the 21km-long coastline between the Waipaoa River mouth and Makorori Point. Using the 8 variables of the Coastal Hazards Database, CHZ widths ranged from 35-140m for the sand dune coastline between the Waipaoa River mouth and Kaiti Beach, 50-425m for the cliffed coastline between Kaiti Beach and Wainui Beach (including Makorori Point), and 55-115m for Wainui Beach. The CHZs were delineated on Aerial Plans at 1:1000 to 1:5000 Scales and digitised for inclusion in GDCs GIS (Gibb 1995).

After a process of public consultation, the 1994-ASCHs and 1995-CHZs (Gibb 1994b, 1995) were adopted by GDC and incorporated into their Proposed Regional Coastal Environment Plan (PRCEP)(GDC 1997). In addition, the standardised techniques developed by Gibb (1994b, 1995) for both ASCH and CHZ assessments were incorporated into the PRCEP, which states that "*Coastal Hazard Areas within Gisborne District will be assessed in 2 stages. First, an initial assessment of ASCHs for medium* *priority sections of coast. Second, a detailed assessment of risk within Coastal Erosion Hazard Zones (CEHZs) for high priority sections of coast. Priority ranking will be determined by Council staff*'.

1.2 CHZ ASSESSMENT STANDARDS AND CRITERIA

The CHZ may include both a *Coastal Erosion Hazard Zone* (CEHZ) and *Coastal Flood Hazard Zone* (CFHZ). The following standards and criteria for assessing CEHZs along Gisborne District coast and adopted for this study, are set out in Appendix 6 of the PRCEP (GDC 1997).

1.2.1 CEHZ

According to the PRCEP, CEHZs subdivided into *Risk Zones* and a *Safety Buffer Zone* will be assessed for the high priority areas known to be adversely affected by the identified natural hazards of sea and wind erosion, and will be based, where appropriate, on the following combination of factors:

$$CHZ = [(X + R)\,T + S + D]\,F + L$$

Where:

Factor X
Is the Rate in metres per year of shore retreat in response to local relative sea-level rise, determined by:

- The standardised Bruun Rule (Bruun 1962; 1983).
- Standardised estimates for potential sea-level rise by 2050 and 2100 A.D. by the New Zealand Climate Committee (NZCC) and the Intergovernmental Panel on Climate Change (IPCC 1996).
- Subtraction of critical local and regional effects from the projections of global sea-level rise by the IPCC.
- Identification of the seaward limit of onshore-offshore beach sediment movement from field evidence (closure depth) below Mean Sea Level (MSL).

Factor R
Is the Rate in metres per year of long-term (historic) net shoreline advance, retreat or dynamic equilibrium for sand and gravel shores and seacliffs, determined from:

- Coastal Resource Maps at 1:5,000 and 1:2,500 Scales incorporating the most recent shoreline position.
- Analysis of reliable Cadastral and sequential Vertical Aerial surveys spanning the last century for areas not covered by the Coastal Resource maps.

Factor T
Is the Planning Horizon in years extending from the present up to the years 2050 and 2100 A.D. for which CHZ assessments are made.

Factor S

Is the *Magnitude* in metres of either the *maximum* recorded short-term historic shoreline fluctuation along coasts of unconsolidated sand or gravel, or the *maximum* extent of land that has failed from past or present landslides along unstable seacliffs, determined from:

- Coastal Resource Maps at 1:5,000 and 1:2,500 Scales and Photomaps at 1:5,000 Scale.
- Sequential vertical aerial photography.
- Analysis of survey, anecdotal and historical records.
- Field evidence.

Factor D

Is the *Magnitude* in metres of retreat of the top seaward edge of the erosion scarp cut into sand dunes as a result of slumping to attain a stable slope, determined by:

- The angle of repose of dry loose dune sand determined in the field.
- The height of the dunes above MSL.

Where; $$D = \left[\frac{h}{\text{Tan } x^0}\right] F$$

where, h = Height of the main foredune above MSL.

$\text{Tan } x^0$ = Angle of repose of dry loose dunesand.

F = Factor allowing for a retreat of a portion of the erosion scarp.

Factor F

Is the *Safety Factor* that is expressed on a scale from 1.0 (0%) to 2.0 (100%), determined by:

- Averaging the sum of the errors for Factors R, X, S and D.
- Provision for a nominal foredune or primary gravel beach ridge at the end of the Planning Horizon.

Factor L

Is the *Horizontal* distance of representative, relatively unmodified natural features such as the beach, shore platform, foredune complex or primary gravel beach ridge, determined by:

- Measurements made in the field and from sequential vertical aerial photographs.
- Provision can be made for such natural features in the Safety Factor.

Risk Zonation

The CEHZ is subdivided into *Extreme*, *High* and *Moderate Risk Erosion Zones* and a *Safety Buffer Zone*. The *Extreme Risk Erosion Zone* lies adjacent to the coast and encompasses the area subject to high impact short-term shoreline fluctuations and wind erosion. The *High Risk Erosion Zone* lies adjacent and landward of the *Extreme Risk*

Erosion Zone and encompasses the area subject to potential sea and wind erosion, with a high probability of occurring between now and the year 2050 A.D. The *Moderate Risk Erosion Zone* lies adjacent and landward of the *High Risk Erosion Zone* and encompasses the area subject to potential sea and wind erosion, with a high probability of occurring during the period 2050 to 2100 A.D. The *Safety Buffer Zone* lies adjacent and landward of the *Moderate Risk Erosion Zone* and allows for uncertainties in the CHZ assessment.

Reference Shorelines

The CEHZ width is measured landward from the seaward toe of the foredune (duneline) or seacliff (cliffline), top seaward edge of the storm berm on gravel beach ridges, or the line of MHWS where precisely defined by standard survey methods, whichever Reference Shoreline is the most appropriate.

1.2.2 CFHZ

According to the PRCEP (GDC 1997), the extent of land subject to inundation by the sea and/or coastal rivers will be delineated by the contour above MSL, below which land has a high probability of being flooded by either maximum *storm wave runup* during a one-in-100 year storm or maximum *tsunami wave runup*, coupled with rising sea-levels.

Storm Wave Runup

Is the *maximum* elevation above MHWS of wave runup attained during a severe onshore storm with a frequency of occurrence of approximately one-in-100 years, determined by:

- Measurements made from field, anecdotal and historical evidence.

Tsunami Wave Runup

Is the *maximum* elevation above MHWS of runup attained during a local or distantly generated tsunami observed during the last century, determined by:

- Measurements recorded in published scientific papers and anecdotal evidence.

1.2.3 Wind erosion

The extent of sand dune complexes subject to wind erosion will be determined from the most recent vertical aerial photographs by mapping the degree of wind erosion expressed on a scale from 0 (None) to 5 (Extreme), on the basis of percentage area of bare ground defined as follows In Table 1:

- Table 1: Classification of land subject to wind erosion.

Degree of Erosion		Percentage of Bare Ground
None	0	No significant erosion
Slight	1	1 - 10
Moderate	2	11 - 20
Severe	3	21 - 40
Very Severe	4	41 - 60
Extreme	5	> 60

2 METHODS

Unlike past CHZ assessments for Gisborne District, CHZs were defined in this study with a standardised GIS computer model incorporating the standards and criteria set out in the PRCEP (GDC 1997) and Section 1.2 above. The parameters for the GIS model were derived from the combination of field work in February-March 1997 and March 1998, studies of relevant reports listed in the references, historical, cadastral and aerial surveys of the shoreline, hydrographic surveys of the nearshore seabed, new aerial surveys by Air Logistics (NZ) Ltd. in March 1996 and April 1997, photogrammetric analysis in April 1998, and anecdotal observations supplied by the tangata whenua and local residents.

2.1 GIS COMPUTER MODEL

The GIS computer model was conceived, developed and standardised by the writer for the open-exposed sand shores of Tauranga District, Bay of Plenty (Gibb 1996). The initial development and testing of the model was carried out by the author with Colin Mills, GIS Analyst, Tauranga District Council (TDC). Final development, standardising and application of the model was carried out by Harley Prouse, GIS Consultant, Geographic Technologies Unit, Auckland UniServices Ltd., with the writer. During this study, the GIS model developed in Tauranga was further refined by Colin Mills and the writer. The essential features of the GIS model include:

i. *Consistency.* A standardised model means that the same parameters are used to assess Coastal Hazard Risk Zones (CHRZ) for all parts of the Gisborne District coast, providing internally consistent outputs.

ii. *Sensitivity.* The model is sensitive and responsive to natural variability in the various parameters along the coast such as the geology, dune and nearshore topography, duneline fluctuations and long-term shoreline trends. In this sense, it is very sensitive to alongshore variations in the physical natural character.

iii. *Flexibility.* The model allows for individual parameters to be changed if required upon acquisition of new information. Such information could arise from coastal monitoring programmes, new scientific research, changes in forecasts of climatic effects from an enhanced Greenhouse Effect, or from the effects of coastal management schemes and the application of hard and soft engineering solutions.

iv. *User Friendly.* Council staff processing applications for either coastal subdivisions or building permits will be able to retrieve CHRZs at the scale of one or many properties on computer terminals on a fully rectified orthophoto or contour map base. Existing and intending property owners will be able to obtain hard copies at appropriate scales from GDC.

v. *Policy Framework.* The *Coastal Hazard Risk Zones* graduated from *Extreme* to *Moderate*, provide a framework for Council to develop and apply appropriate policies to control human activities in the *Risk Zones* and protect the public, etc., from risk from the identified natural coastal hazards.

2.2 GIS MODEL PARAMETERS

The following parameters were used in the GIS computer model for both Tolaga and Anaura Bays.

i. Digital Terrain Model

A Digital Terrain Model (DTM) was generated by Air Logistics (NZ) Ltd from fully controlled Aerial Surveys flown by Aerial Surveys Ltd (Nelson) of Tolaga Bay, on 27 March 1996 and 22 April 1997 (SN12284J), and of Anaura Bay on 22 April 1997 (SN12284K). Based on the DTM, contours of the coast at 0.5m intervals were generated by Air Logistics, with respect to Mean Sea Level (MSL) Gisborne Provisional Datum 1926. The contours have a positional and vertical height accuracy of better than one decimetre and provide information on the shape, height and volume of the foredune complex for hazard assessment.

ii. Duneline and Crestline

The seaward toe of the foredune complex (duneline) and seaward crest of the complex (crestline) were identified and positioned on the DTM by the writer. Using 3-Dimensional computer images of the coast at Air Logistics the duneline was identified to an accuracy of ±0.5m from the 1996-1997 Aerial Surveys and ±2.0m from the 1955-1957 Aerial Surveys. The crestline was identified at TDC using the 0.5m contours on the GIS computer model to an accuracy of ±0.5m. These lines were then digitally captured by TDC for inclusion in the GIS model.

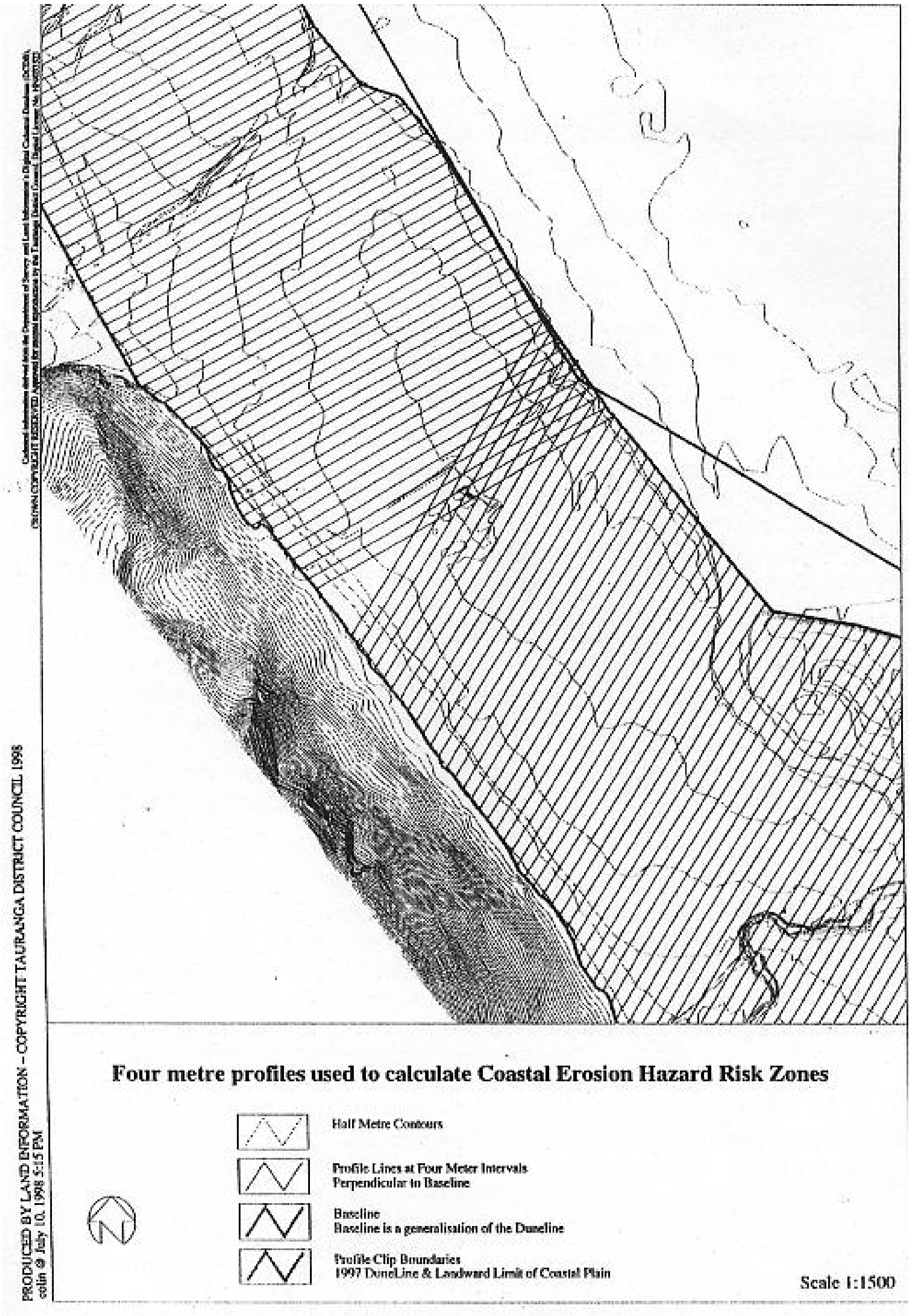
iii. Profiles

Parallel profiles at 4m intervals were constructed with the GIS model perpendicular to a baseline approximating and seaward of the curvature of the shore (Figure 2). The profiles have a seaward and landward limit. The seaward limit was the 1997 duneline, which was the start point for all model calculations along each profile. The landward limit was either the maximum extent of the DTM or where the coastal dune system naturally terminates against the toe of the hills (Anaura Bay) or estuary (Tolaga Bay). CEHZs were calculated along each of the 4m-spaced profiles.

iv. Closure Depth

For Anaura Bay, the seaward limiting depth of exchanges of sediment with the active beach system (closure depth) was identified on 26 February 1997 from fieldsurveys aboard the local Department of Conservation (DoC) 5.8m-long powerboat “Tu Taua”. Field surveys involved a hydrographic survey of the seabed using a Furuno Paper Echo Sounder Model FE 6300 and random SCUBA diver inspections of the sea floor and sampling of bottom sediments.

Survey lines were fixed to an accuracy of better than one metre with a Differential Gobal Positioning System (DGPS) in the boat by AgFirst Consultants Ltd, Gisborne. All soundings were reduced to MSL using a tide gauge installed by GDC for the survey on Tolaga Bay Wharf. The closure depth in Anaura Bay was identified by the writer from the resultant bathymetry and bottom sediments and digitally captured by Air Logistics for inclusion in the GIS Model.



- Figure 2: An example of parallel profiles at 4m intervals in central Anaura Bay constructed by the GIS model perpendicular to a baseline approximating the curvature of the shore.

For Tolaga Bay, a number of attempts were made to carry out an offshore survey in the DoC powerboat "*Tu Taua*" to define the closure depth. The boat was launched in the Uawa River and had to cross a very hazardous shallow shifting sandbar at the river mouth. On the final attempt on 6 March 1997, an increasing swell made it too dangerous to return across the bar to the Uawa landing and the boat returned to Gisborne down the coast after dropping the survey team off on Tolaga Bay Wharf.

As a result of these repeated problems and a persistent heavy swell in Tolaga Bay during 1997, the closure depth was determined by comparing changes to the seabed along selected profiles from hydrographic surveys made in 1904, 1958 and 1996 supplied by the Hydrographic Office, Royal New Zealand Navy (RNZN), Auckland. The appropriate isobath was drawn on the 1996 RNZN precise sounding collector of Tolaga Bay at 1:2500 Scale and digitally captured by Air Logistics for inclusion in the GIS Model.

v. Long-Term Shoreline Trend

The long-term historic shoreline trend of either erosion or accretion was determined on the GIS model by TDC by comparing the 1997 duneline position with that of the earliest most reliable survey of the duneline. Rates of erosion or accretion in metres per year were calculated by the model by dividing the precise horizontal distance between surveys by the relevant survey period along the 4m-parallel profiles (Figure 2).

For Tolaga Bay, historic shoreline positions plotted on East Cape Catchment Board Aerial Plan AP1483, Sheets C1 (Tolaga Bay) and C2 (Uawa River) at 1:2500 Scale were digitally captured by Air Logistics for inclusion in the GIS model. The earliest, most reliable shoreline surveys adopted for this study to determine long-term rates of change were those made in 1875 North of Uawa River (Field Book 7) and 1885 South of the River (ML 711) equating to survey periods of 122 and 112 years, respectively.

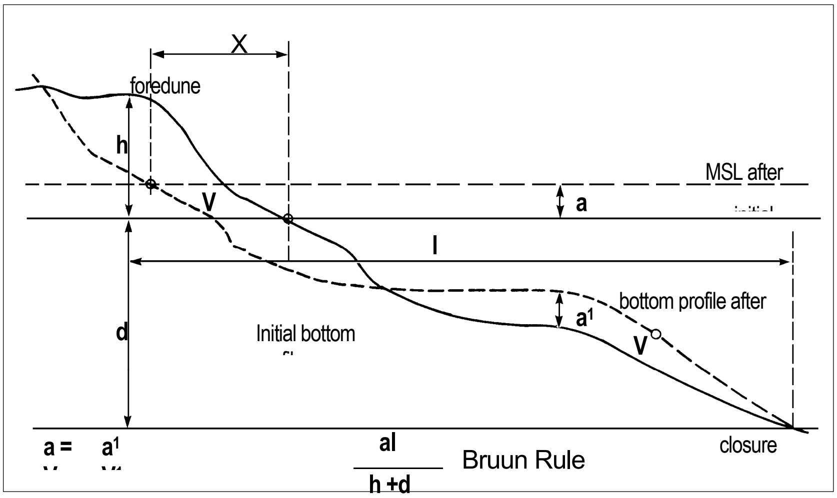
For Anaura Bay, Grant & Cooke, Registered Surveyors, Gisborne, analysed and digitised early cadastral surveys of the shoreline for inclusion in the GIS Model by Air Logistics. On the basis of reliability and shoreline definition the 1909 survey was adopted for the coastline South of Waipare Stream (ML 1620 & 1622) and the 1906 cadastral survey and 1955 aerial survey, North of the stream, equating to survey (ML 1503) intervals of 88, 91 and 42 years, respectively. Appendix 1 provides a copy of the Surveyor's report for this exercise.

vi. Short-Term Duneline Fluctuations

The maximum potential volume of sand in cubic metres involved in short-term duneline fluctuations was determined from the combination of geologic and anecdotal evidence, field observations, historic shoreline positions recorded by Air Logistics and Aerial Plan AP1483, and by the writer on the GIS at TDC for selected profiles along the coast. Sand volumes were not constant and varied from place to place as might be expected. Between the selected profiles, volumes were linearly interpolated by the GIS model along each of the 4m-spaced profiles along the coast.

vii. Erosion from Sea-Level Rise

The standardised Bruun Rule (Bruun, 1962, 1983) was incorporated into the GIS model to assess the effects of sea-level rise. The parameters required to use the Bruun Rule are shown in Figure 3. The horizontal distance between the crestline and closure depth was calculated along the coast by the model from the closure depth below MSL and crestline height of the foredune above MSL already included in the model. The values for sea-level rise adopted for the model were the mid-range best estimate projections by IPCC (1996) for the years 2050 and 2100 A.D. The Bruun Rule (Figure 3) can only be applied to sand coasts and not to gravel or cliffed coasts. It is 2-dimensional and does not allow for longshore sediment movement. For sand beaches, this deficiency is overcome in the GIS computer model by incorporating the long-term shoreline trend.



- Figure 3:Diagram showing the response of the beach and nearshore zone to rising sea-level according to Bruun (1962) and Hands (1983). V = volume; a = Sea-Level Rise; X = erosion amount; h = height of foredune; d = limiting (closure) depth of beach sediment; l = distance to closure depth from crestline.

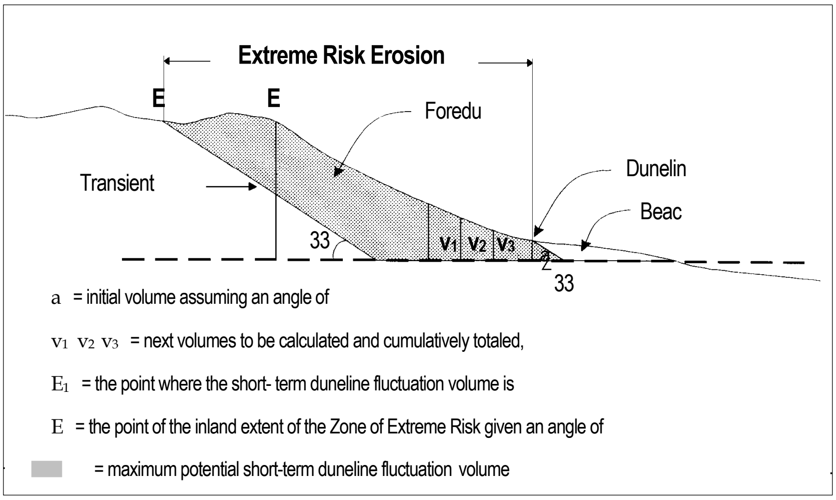
viii. Angle of Repose of Dune Sand

The stable angle of repose (AOR) of dry, loose, Medium to Fine Sand of 33^0 was adopted from field measurements made elsewhere by the writer (Gibb 1995, 1996) and entered into the GIS model. The dunes and beaches along Anaura and Tolaga Bays are composed of Medium to Fine Sand.

2.3 RUNNING THE MODEL

The model is run on the Arc/Info GIS and aims to predict the maximum potential volume of foredune that is subject to, or is likely to be subject to short-term erosion by one or a cluster of severe wave storms, and long-term erosion from existing processes enhanced by sea-level rise over planning horizons of approximately 50 and 100 years. These three scenarios are described as *Extreme Risk Erosion Zone*, *High Risk Erosion* Zone and *Moderate Risk Erosion Zone*, respectively. In addition, there is a *Safety Buffer Zone* which allows for uncertainties in the various parameters used in the model.

The initial start volume (Figure 4) is calculated by assessing the height of the duneline by querying the DTM and projecting a line back seaward at the stable angle of repose (AOR) of dry, loose dune sand of 33^0. The area of the triangle formed is taken as the initial volume (a on Figure 4). The GIS then moves 1m inland along the profile line and calculates the area indicated by V_1 on Figure 4.



a = initial volume assuming an angle of

V_1 V_2 V_3 = next volumes to be calculated and cumulatively totaled,

E_1 = the point where the short- term duneline fluctuation volume is

E = the point of the inland extent of the Zone of Extreme Risk given an angle of

▨ = maximum potential short-term duneline fluctuation volume

• Figure 4: Diagram illustrating the volume calculation method used in the computer model to calculate the *Extreme Risk Erosion Zone*.

The volume V_1 is added to a and the model continues until the maximum short-term fluctuation in dune volume is reached. To define the location of where the volume is reached (E_1 in Figure 4); the model changes from 1m intervals to 0.25m intervals for the area calculations when the target volume for the *Extreme Risk Erosion Zone* is approached.

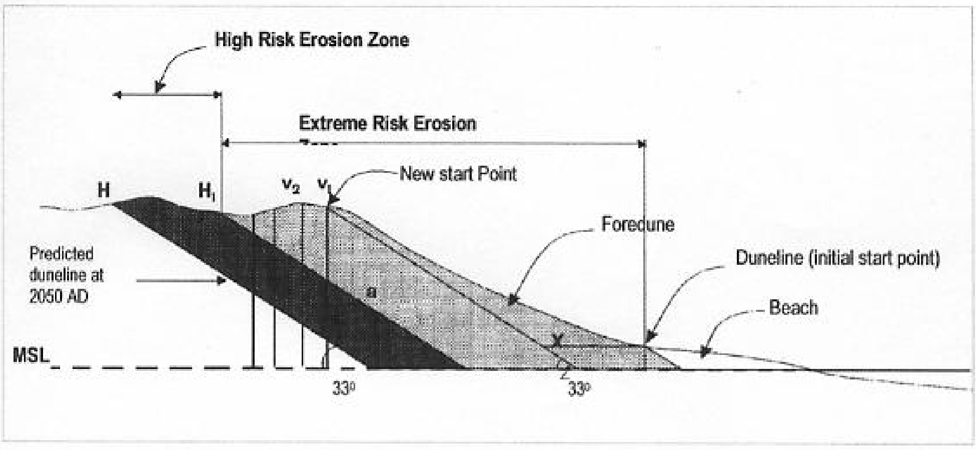
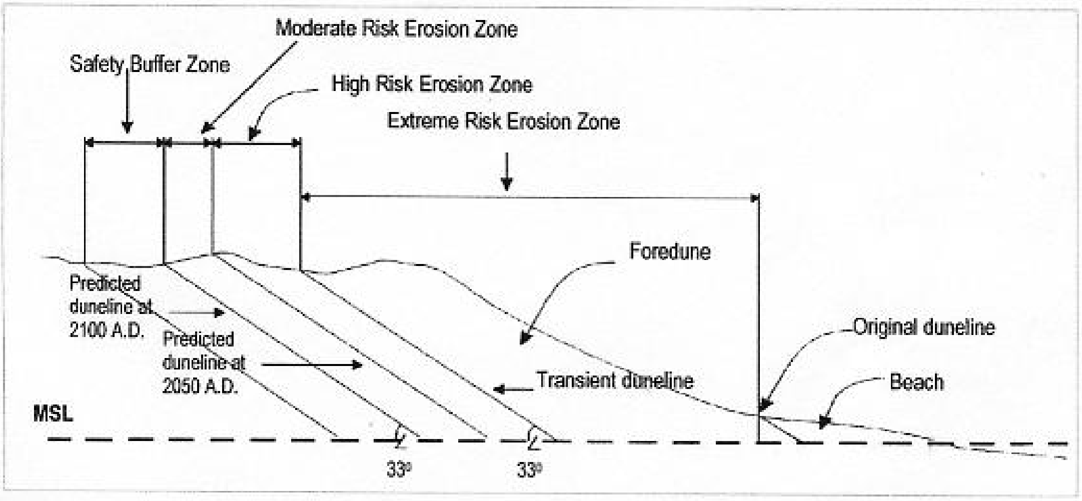


Figure 5: Diagram illustrating the volume calculation method used in the computer model to calculate the High and Moderate Risk Erosion Zones, taking into account the effects of sea-level rise (the Bruun Rule) and long-term erosion and accretion trends.

a = initial volume assuming an angle of repose of 33⁰
x = beach set back (to new start point) due to sea-level rise and erosion (Bruun Rule calculations)
V_1 V_2 = next volumes to be calculated and cumulatively totalled, interval of 1m
H_1 = the point where the short-term duneline fluctuation volume is reached
H = the point of the inland extent of the High Risk Erosion Zone given an angle of repose of 33⁰ with respect to H1
▒ = maximum potential short-term duneline fluctuation volume
■ = additional area potentially eroded – added to the Extreme Risk Erosion Zone to give the High Risk Erosion Zone

- Figure 5: Diagram illustrating the volume calculation method used in he computer model to calculate the *High* and *Moderate Risk Erosion Zones*, taking into account the effects of sea-level rise (the Bruun Rule) and long-term erosion and accretion trends.



- Figure 6: Diagram illustrating the *Risk* and *Safety Buffer Zones* which comprise the Coastal Erosion Hazard Zone on a coast with a past history of either erosion or dynamic equilibrium.

As a beach face is not vertical the AOR of 33^0 is used to assess the final landward position of the *Extreme Risk Erosion Zone* (E in Figure 4). The final position of the *Extreme Risk Erosion Zone* (on each profile line) is retained by the GIS and the next profile line is then processed in the same way. The model ends up with a point on each of the 4m-spaced profile lines which, when joined with all the others, creates a line along the coast which represents the *Extreme Risk Erosion Zone*.

The *High* and *Moderate Risk Erosion Zones* are calculated in a similar way but a new starting point (inland of the duneline) is calculated (Figure 5) using the Bruun Rule (Figure 3). This new starting point is the estimated location of the duneline after a period of sea-level rise and also takes into account any projected historical long-term erosion or accretion trends. That is, it takes the current duneline and moves inland by a distance calculated with the Bruun Rule plus the long-term erosion trend (x in Figure 5). The model is run twice using the Bruun Rule for planning horizons up to 2050 and 2100 A.D. to determine *High* and *Moderate Risk Erosion Zones*, respectively (Figure 6).

If potential erosion from sea-level rise is overcome by the historic long-term rates of accretion, which is quite likely, then the Bruun Rule value is set to zero and in the model, the duneline will stay where it is. Thus it is possible in an area of accreting coast to have an *Extreme Risk Erosion Zone* and one (or none) of the zones of *High* or *Moderate Risk*. Once the three *Risk Zones* have been determined, a fourth zone, the *Safety Buffer Zone*, is calculated (Figure 6). This zone is 30% of the total Risk Zone width in the GIS model and allows for uncertainties in the various parameters used to calculate the Coastal Erosion Hazard Risk Zones.

3 GEOLOGY

The geology for the East Cape area as far as Northern Tolaga Bay is summarised by Gibb (1981a). The tectonic history for both Anaura and Tolaga Bays is described by Ota *et al*. (1992). Both embayments have been sculptured by the sea during the Holocene Epoch from alternating sandstone-siltstone marine sequences of Late Tertiary age. The sedimentary rocks were formed from sediments laid down on the seafloor about 10-15 million years ago which have since been indurated, compacted, uplifted and deformed by tectonic movements. The Late Tertiary sequences have and continue to be subject to sculpturing from sub-aerial weathering and erosion processes resulting in today's evolving topography (Figure 7).

The entire Raukumara Peninsula, including the coast has been elevated by relatively rapid tectonic uplift up to about 4m/1000 years (Pakarae River) during recent geologic times (Yoshikawa 1988; Ota *et al*. 1992). In general, the coast is bordered by a raised Holocene bench which has evolved over approximately the last 6,500 years (Gibb 1981a; Ota *et al.* 1992) at a sea-level within ±1.0m of the present (Gibb 1986). The uplifted bench has evolved from the combination of discrete episodic uplift events and deposition of fluvial and marine sediments to form the coastal plains in both Tolaga and Anaura Bays (Figure 7).

3.1 TOLAGA BAY

At the culmination of the Postglacial Marine Transgression about 6,500 years ago (Gibb 1986), the sea invaded the Uawa River Valley an unknown distance faceting the sides as seacliffs. With the stabilising of sea-level close to the present over the last 6,500 years, the Uawa Valley steadily filled with fluvial sediments transported and deposited by the Uawa River. The shoreline advanced into Tolaga Bay to form a Holocene coastal plain approximately 1,600m deep by 2,850m wide confined between the stranded seacliffs of Late Tertiary rock.

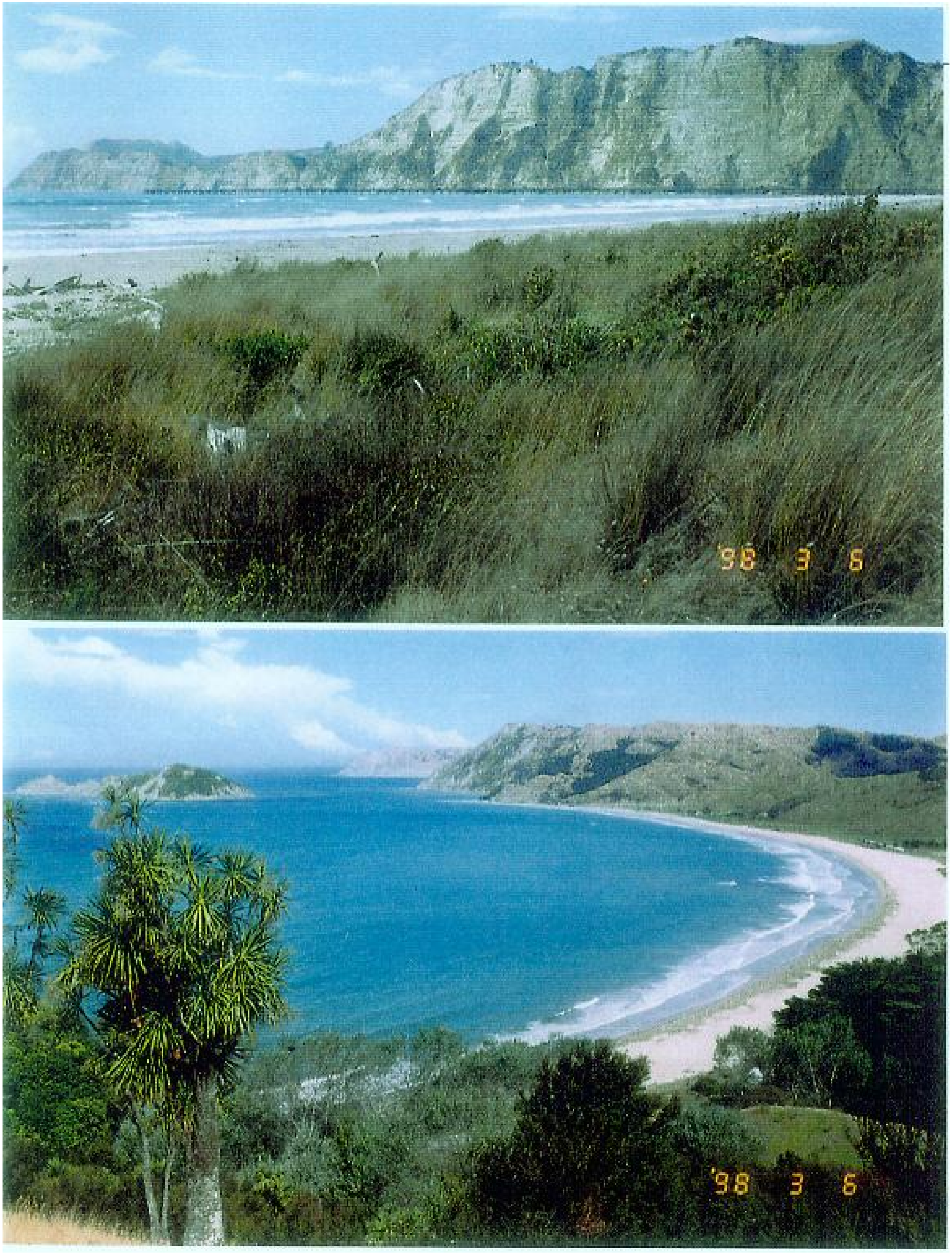
Ota *et al.* (1992) identified 3 terraces on the 1,600m deep Tolaga Bay coastal plain. The oldest terrace (Terrace I) at the back of the plain, South of Uawa River, reaches about 5m a. MSL (Above Mean Sea Level) and formed about 5,500-7,000 years ago. Terrace II, which straddles the mid-plain area either side of the Uawa River reaches about 3m a. MSL and formed about 5,500-3,500 years ago. Terrace III lying seaward of Terrace II, reaches 2-3m a. MSL, and has formed over approximately the last 3,500 years. As sea-level was close to the present about 6,500 years ago (Gibb 1986) and the oldest Terrace (I) is about 2.5m above the present-day forming feature, a net uplift rate of approximately 0.4m/1,000 years is inferred here for Tolaga Bay over the last 6,500 years.

The present-day beach in Tolaga Bay is composed of a light grey Medium to Fine Sand (Figure 8), which generally fines and becomes better sorted away from the mouth of the Uawa River. The sand is predominantly lithic fragments derived from the Tertiary sandstone-siltstone sequences and is thought here to be derived mostly from the Uawa River with a minor amount being supplied from the eroding seacliffs flanking Tolaga Bay (Figure 7). The depth of the embayment ensures the confinement of the sand within Tolaga Bay suggesting a closed system trapping and holding all sand transported to the coast by the Uawa River.

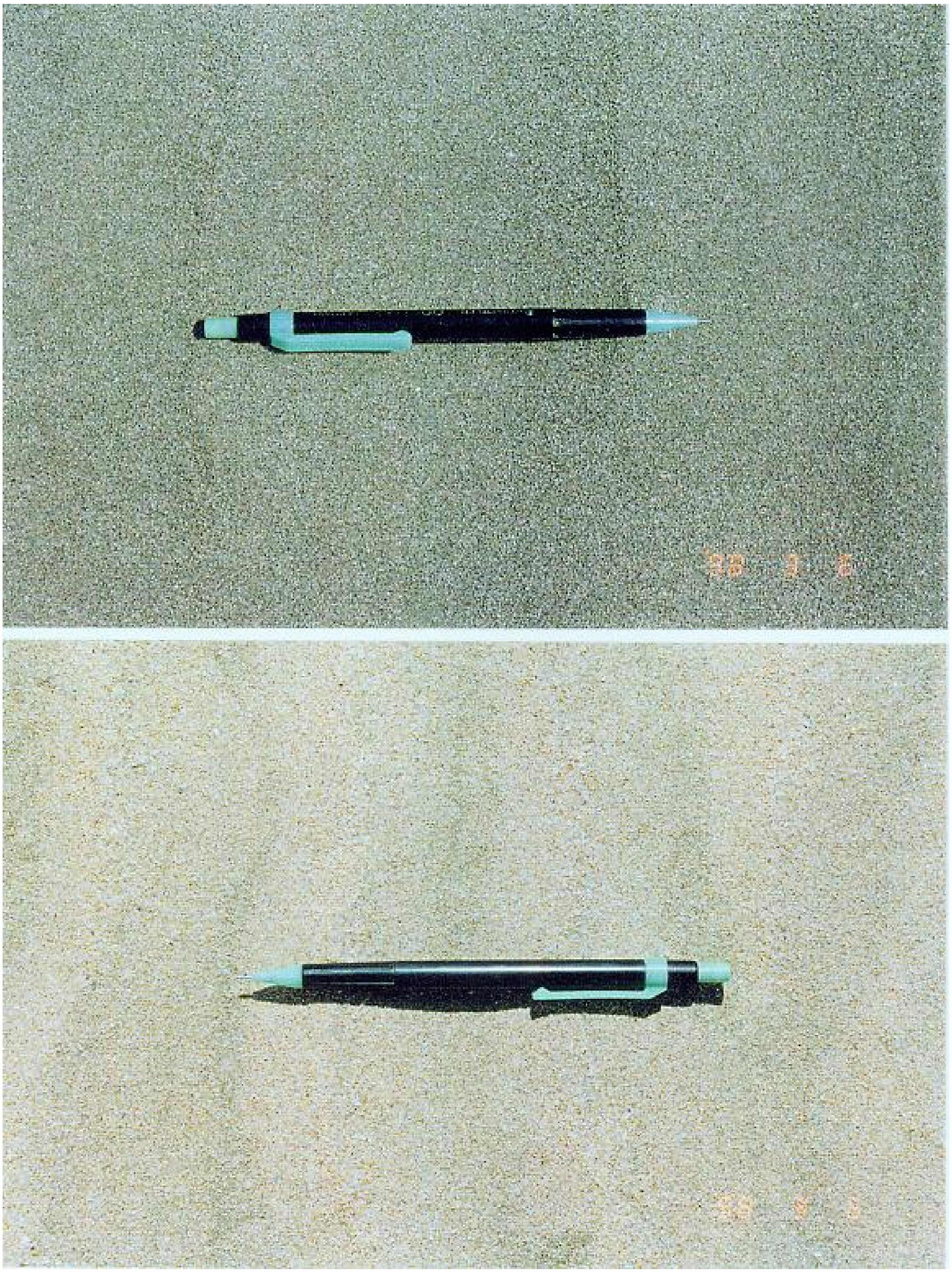
Over the last 6,500 years the Tolaga Bay shoreline has advanced 1,600m at a net rate of 0.25m/year from the combination of accretion of Uawa River derived sand and silt and tectonic uplift at about 0.4m/1,000 years. From about State Highway 35, coalescing belts of low sand dunes formed during the Late Holocene, extending the shoreline about 800m seaward. The age of the shoreline along SH35 and Hauiti Road was estimated by Pullar and Rijkse (1977) to be about 3,400 years and the age of the shoreline along the back of the Uawa Estuary about 300 years old. Over the last 3,400 years, the Tolaga Bay shoreline has advanced at about 0.24m/year. The rates for the last 6,500 years and 3,400 years are remarkably similar indicating the combination of both frequent tectonic events and a constant sediment supply to the coast from large floods.

The earliest plan of Tolaga Bay surveyed by Captain James Cook, 26-27 October 1769 (Hakluyt Society 1968; 1988), provides the earliest recorded survey of the coast. The 1769 plan shows the Uawa River discharging approximately into the centre of Tolaga Bay (Figure 9). To the South of the River mouth is a spit and estuary labelled as "*lagoon of salt water*" in earlier sketches of the coast by R. Pickersgill, Mate on the Bark "*Endeavour*".

The sand spit and estuary were also recorded on the earliest cadastral survey of the area in 1885 and on all subsequent cadastral and aerial surveys. This evidence indicates that the Southern sand spit in Tolaga Bay and associated estuary formed more than 230 years ago. Pullar & Rijske (1977) believed that it formed over the last 300 years. Assuming a constant rate of sedimentation and a long-term rate of advance of the shoreline of



- Figure 7: Photographs taken 6 March 1998, of Tolaga Bay (top) and Anaura Bay (bottom). For both bays the rocks are Late Tertiary sediments and the beaches are sand. Note the 665m-long Tolaga Bay wharf built between 1926 and 1929 and Motuoroi Island in Anaura Bay. Captain James Cook on the Bark "*Endeavour*" landed in both bays in October 1769.



- Figure 8: Photographs taken 6 March 1998, of the Medium to Fine beach sand in Tolaga Bay (top) and Anaura Bay (bottom). Tolaga Bay sand is derived almost entirely from the Late Tertiary sedimentary rocks via the Uawa River and Anaura Bay sand is derived partly from the Late Tertiary rocks and partly from the breakdown of marine shells. The pencil is 138mm long.

approximately 0.25m/year, the age of formation of the spit and estuary is more likely to be of the order of 1500 years.

3.2 ANAURA BAY

At Anaura Bay the narrow Holocene coastal plain generally ranges in width from 100-180m tapering to 10-20m at the Northern end (Figure 7). At the back of the coastal plain are the remnants of a stranded seacliff cut into the Late Tertiary sandstone-siltstone rocks. The seacliff is inferred here to have been cut from the sedimentary rocks about 6,500 years ago along with a wide shoreline platform underlying the coastal plain during the Postglacial Marine Transgression. At its Northern and Southern extremities the coastal plain is composed of stream derived deltaic fluvium overlying the wave cut shore platform. In the central section, the plain is composed of alluvium derived from slope wash along its inner part and a very narrow 20-50m-wide belt of mobile sand dunes along its outer part.

Gibb (1981a) carried out detailed analyses of the texture, mineralogy and bulk density of the golden Anaura Bay beach sand (Figure 8). The density of the sand was 2.67g/cm^3 indicating a predominance of light minerals. The composition of the sand was predominantly shell fragments (30-50%), plagioclase feldspar (15-30%), and volcanic glass (15-30%). Detrital Quartz and heavy minerals were rare (0.3-2%) and rock fragments derived from Late Tertiary sedimentary rocks subordinate (2-15%). The Fine well-sorted Sand had a mean grain size of 2.30ø (Gibb 1981a).

In order of predominance the sources of the Anaura Bay sand are the nearshore seabed, followed by the eroding seacliffs and shore platforms, followed by streams like the Waipara Stream (Gibb 1981a). Like Wainui Beach further South, Anaura Bay and Tolaga Bay are probably closed systems in terms of sand supply with the probability of sand leaving and entering the embayments very low. The predominance of shell content in the sand suggests that it is being renewed at an unknown rate proportional to the breakdown of shells offshore.

Assuming the earliest Holocene shoreline to have formed about 6,500 years ago at the toe of the stranded seacliffs, the Anaura Bay shoreline has advanced at the very low net rate of 0.02-0.03m/year over this period. The height of the earliest Holocene shoreline averages 5m a. MSL and 2.5m above the present day forming feature. Assuming there has been 2.5m uplift over the last 6,500 years, provides a net tectonic uplift rate of the order of 0.4m/1,000 years, the same as Tolaga Bay. This analysis indicates that the Anaura Bay shoreline has advanced at very low rates of the order of centimetres per year over the last 6,500 years from the combination of tectonic uplift and deposition of fluvium and Fine Shelly Sand.

3.3 NEARSHORE SEAFLOOR

Hydrographic survey data record surficial sediments of the seafloor in both Anaura and Tolaga Bays (Robbins 1996) and historical changes in depths in Tolaga Bay. During this study sea conditions only allowed a hydrographic and SCUBA dive survey of Anaura Bay.

Anaura Bay

The seafloor of Anaura Bay is composed of subtidal patch reefs of Late Tertiary sandstone-siltstone interspersed with channels of sand, which often connect with the sand beach. Onshore, the beach is composed of Fine Shelly Sand, which extends seaward to about 8m depth where it becomes progressively finer in texture. From 8m to about 16m depth the sediments overlying the Tertiary substrate are Very Fine Shelly Sand with an increasing amount of Mud content with depth. Although patches of Fine to Coarse Shelly Sand are found in depths of 30-35m, the sea floor is predominantly Mud with broken Shell (Robbins 1996).

Centred on the Waipare Stream, the Northern third of the Anaura Bay sea floor features a 700-800m-wide sand channel extending offshore from the beach to at least 20m depth. North and South of this channel are extensive reefs cut by sinuous channels floored with sand. The Northern channel feature is thought here to be the major pathway for supply of sand to the beach by constructional waves and offshore winds. Within the Northern channel there is a flattening in gradient of the nearshore profile at about 8m depth and a subtle change in sand texture from Fine to Very Fine Shelly Sand. The 8m depth is interpreted here as the seaward toe of the beach or closure depth. The lack of submerged reefs in the channel exposes the adjacent shore to erosion from severe wave attack from the East quadrant from time to time.

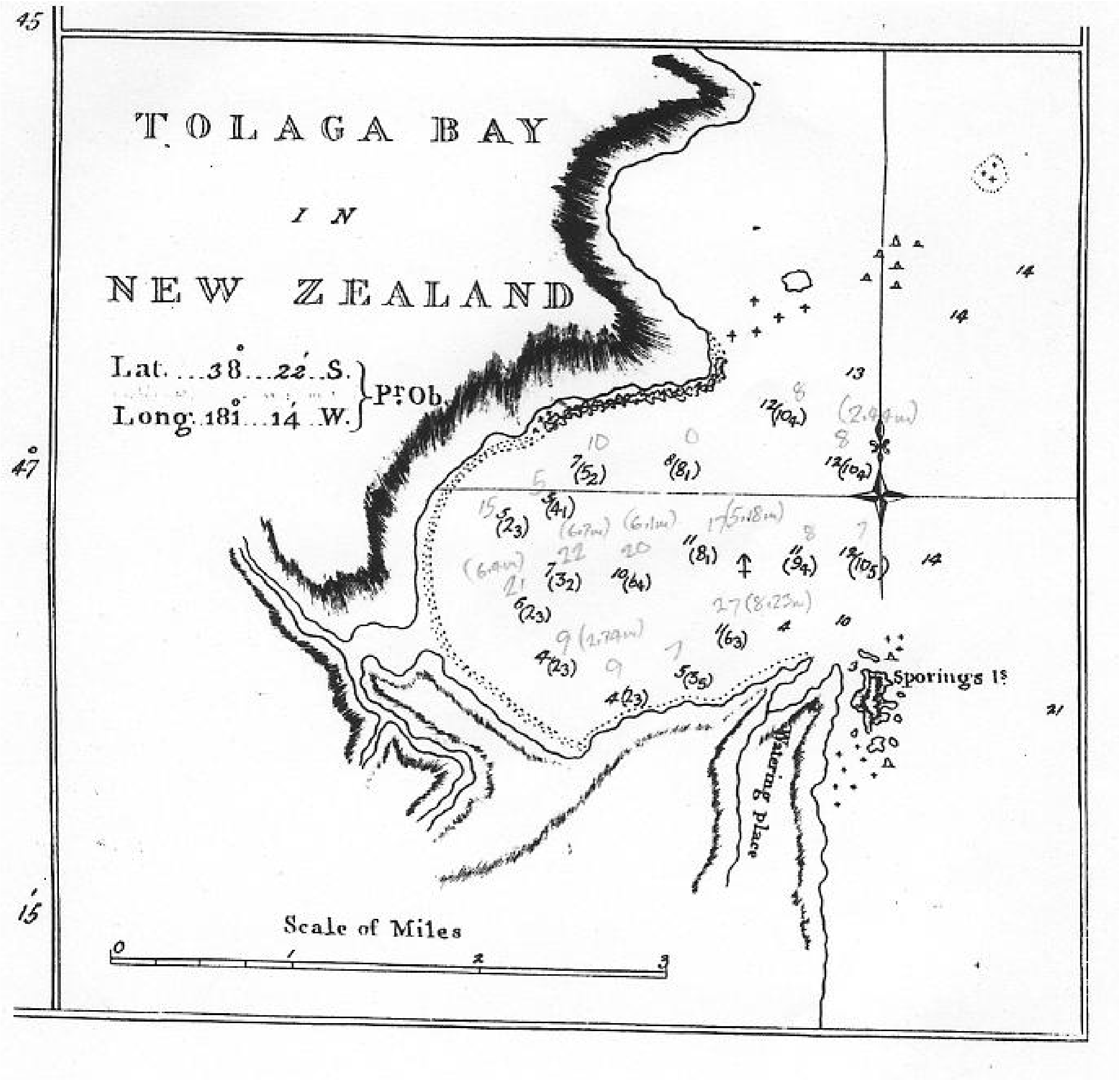
Along the Southern two-thirds of Anaura Bay the beach and nearshore sand terminates against the inshore patch reefs at depths ranging from 2-7m below MSL. The submerged reefs act as natural offshore breakwaters holding the toe of the beach in place and reducing incident wave energy and possibly erosion on the adjacent shore.

When Captain James Cook visited Anaura Bay on the Bark "*Endeavour*" in October 1769, the ships Mate, Richard Pickersgill took some leadline soundings (in fathoms) and drew a rough plan of "*Tegadoo Bay*". A comparison of the soundings with those taken in 1996 shows no significant changes near Motuoroi Island but a probable shallowing over the last 227 years of between 2.4m (10.6mm/year) and 6.1m (26.9mm/year) in the centre of the Bay (Figure 10). The soundings need to be treated with caution but the magnitude of change suggests a trend of nearshore shallowing landward of about the -15m depth contour.

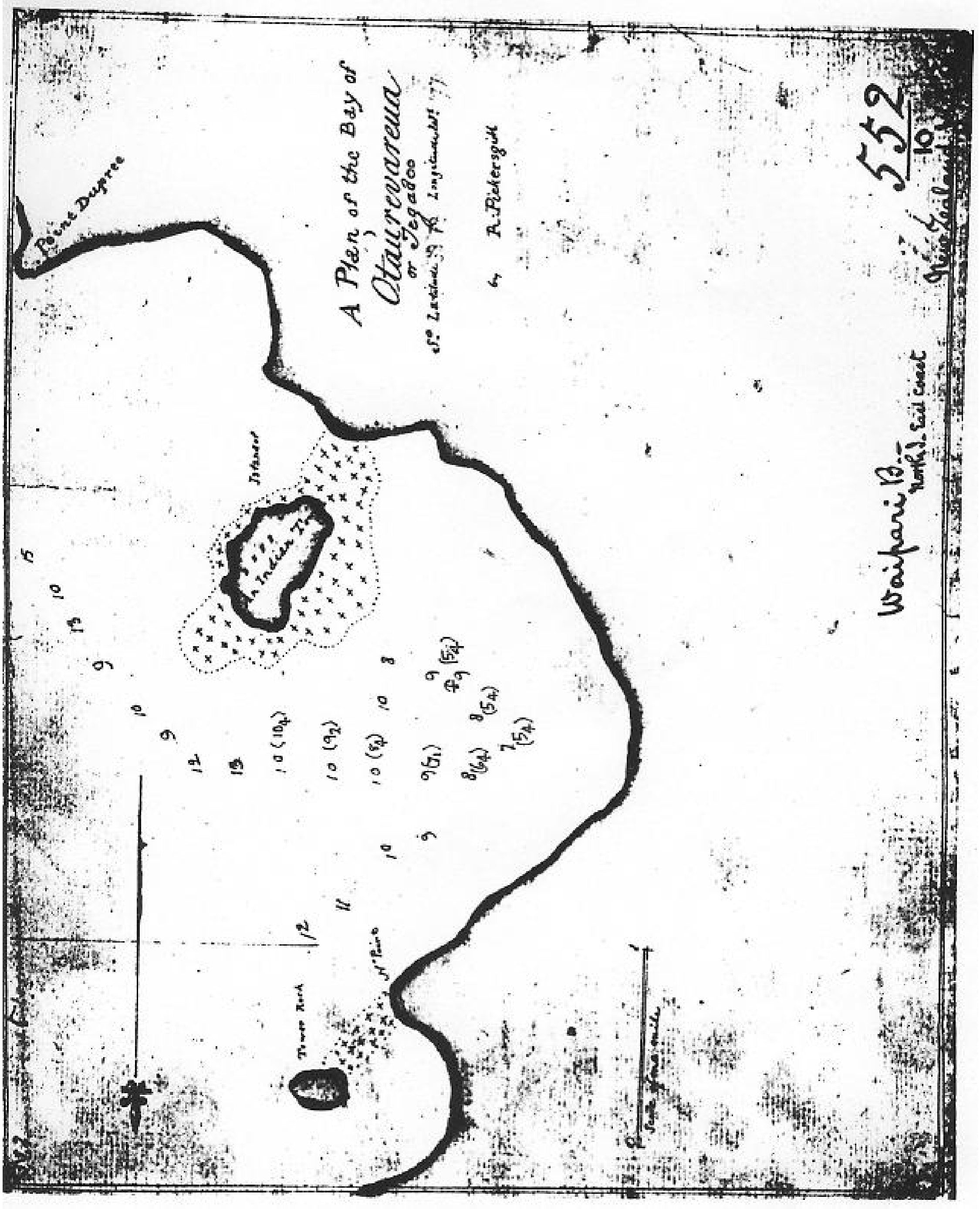
3.3.1 Tolaga Bay

Because of its relatively sheltered nature on the Gisborne District coast and recognised safe anchorage during offshore winds, Tolaga Bay has had repeated hydrographic surveys of the seafloor in 1769 (HMS Endeavour), 1904 (HMS Penguin), 1958 (HMNZS Lachlan) and 1996 (HMNZS Monowai). The 665m-long Tolaga Bay Wharf appears on the 1904, 1958 and 1996 sounding sheets and charts of Tolaga Bay and provides a useful stable '*benchmark*' for comparing changes to the seafloor over the last 92 years (1904-1996) with respect to an unstable dynamic shoreline.

Tolaga Bay was the first harbour chart to be produced (Figure 9) by the great navigator Captain James Cook (Ross 1969). Cook used the hydrographic survey procedures advocated by John Robertson in one of the standard navigational manuals of the day. Soundings were taken by leadline and Robertson recommended they "*should be reduced to low water before being plotted*". For Tolaga Bay, Cook noted that "*the tide flows at full*



- Figure 9: Chart of Tolaga Bay sounded by Captain James Cook on Friday 27 October 1769 by leadline. Soundings in fathoms and soundings in brackets (fathoms and feet) from 1996 survey to show differences over the last 227 years (Chart from Hakluyt Society 1988).



- Figure 10: A plan of Tegadoo (Anaura) Bay with soundings in fathoms prepared by Richard Pickersgill, Mate on HMS *Endeavour*, on Saturday 21 October 1769. Fathoms and feet in brackets are those from the 1996 survey (Chart from Hakluyt Society 1988).

and change of the Moon about 6 o'clock and rises and falls upon a perpendicular 5 or 6 feet" (1.5-1.8m) (Hakluyt Society 1968; 1988).

On 26 October 1769 whilst Captain Cook and his navigator Green were observing longitude in Tolaga Bay, Richard Pickersgill sounded the Bay from "*Endeavour's*" pinnace (small rowing or sail boat). On Friday 27 October Cook sounded the Bay whilst his crew were loading supplies in Cooks Cove. The soundings by Cook are about one fathom less than those taken by Pickersgill suggesting they were reduced to low water before being plotted. Cook had already observed high and low waters in the Bay (Hakluyt Society 1988).

Figure 9 shows Cooks chart of Tolaga Bay with soundings in fathoms. Added to these are soundings taken in 1996 in fathoms and feet. If we accept the accuracy of the leadline used in 1769 and positioning in Tolaga Bay, plus the assumption that all soundings were reduced to low water, there has been significant shallowing in the Bay over the last 227 years (1769-1996). The 1996 soundings are reduced to Chart Datum (Lowest Astronomical Tide).

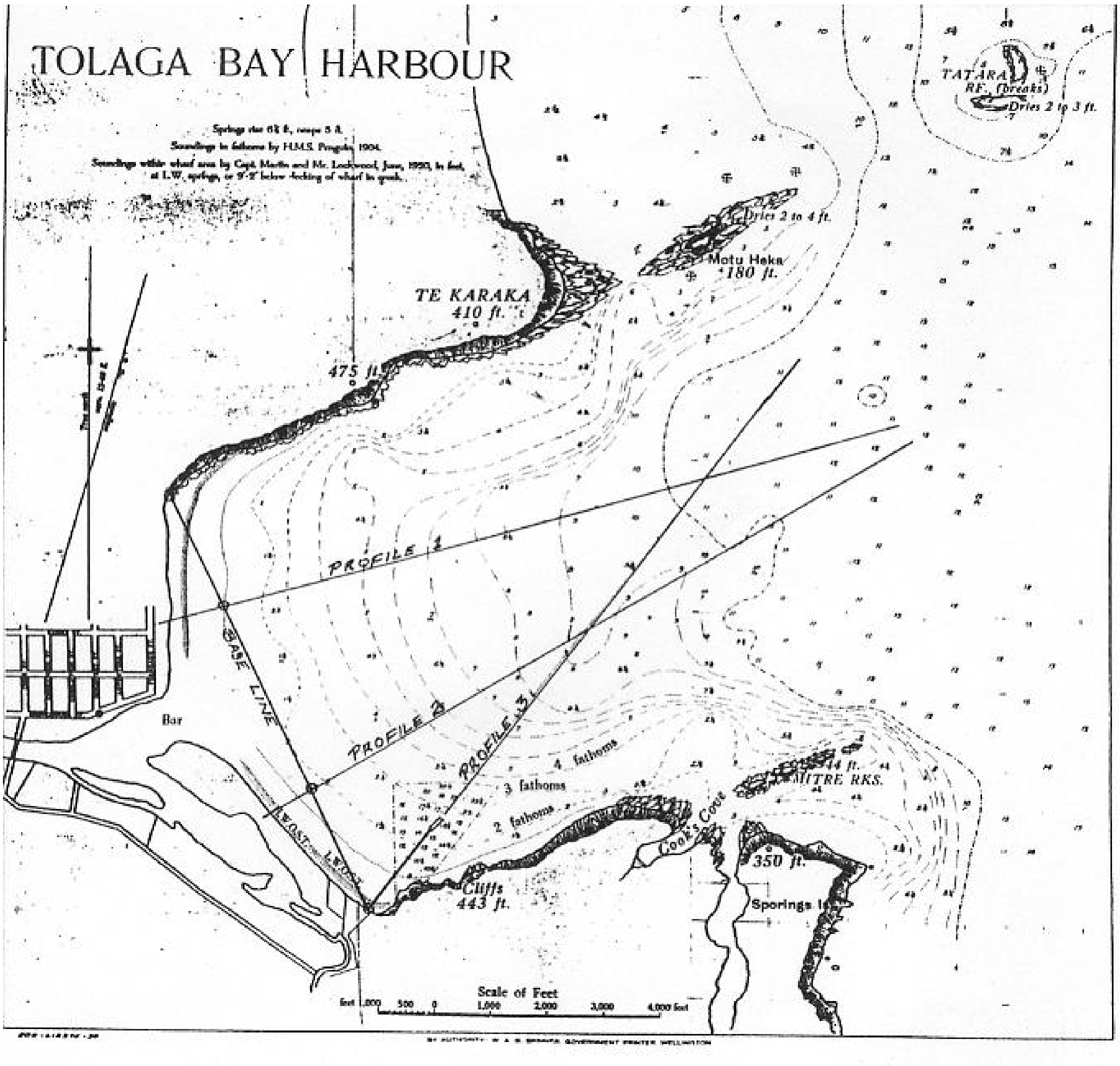
The pattern of shallowing over the last 227 years reveals the greatest deposition in the centre of Tolaga Bay, deposition increasing from 2.4m (10.5mm/year) at the mouth of the Bay to 6.4-6.7m (28.2 to 29.5mm/year) at the head of the Bay by the Uawa River mouth. Like Anaura Bay, the rates significantly increase landward of the -15m depth contour. On the flanks of Tolaga Bay there is less deposition with rates of 0 to 13.4mm/year being recorded over the last 227 years.

An analysis of more recent changes to the seafloor was made here by comparing soundings made in 1904, 1958 and 1996 along 3 representative profiles. All 3 hydrographic surveys were assumed to have used the same sounding datum (Chart Datum) and all soundings were normalised to MSL in this study by adding 1.2m (RNZN 1996). Sounding data and profiles are given in Appendix II and Figure 11 shows the location of the 3 profiles on the 1904 Chart. The tidal range of 6.5feet (1.98m) springs and 5feet (1.52m) neaps recorded in 1904 compares almost exactly with the range observed by Captain Cook in October 1769.

Profiles were established precisely along a baseline laid off from the base of the Tolaga Bay wharf to the rocks at the North end of the beach. All 3 profiles extend both seaward and landward of the baseline, Profile 1 extending from approximately the Tolaga Bay Surf Club, Profile 2 from approximately the Tolaga Bay Motor Camp, and Profile 3 along the Tolaga Bay wharf (Figure 11). A comparison of changes between 1904 and 1996 along each Profile is shown in Figure 12.

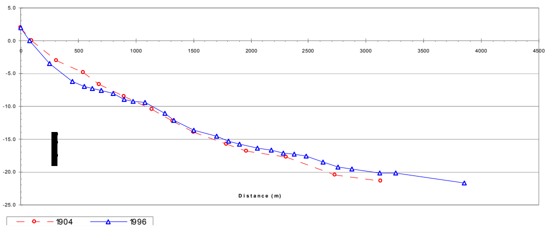
North of the Uawa River mouth Profile 1 (Figure 12) reveals that the seafloor has progressively deepened by up to 1.7m (-18.5mm/year) between about 2 to 8m depth over the last 92 years (1904-1996) which is the reverse of the trend of shallowing over the last 227 years. From about 8 to 14m depth there has been no change and from 14 to about 20m the sea floor has shallowed up to 1.2m (13mm/year) over the 92 year-period.

South of the Uawa River mouth, Profiles 2 and 3 (Figure 12) reveal the opposite trend close inshore with progressive shallowing up to 1.5m (16.3mm/year) between about 2 and 8m depth over the last 92 years, especially along Tolaga Bay wharf. From about 8 to 17m depth no discernable trend is evident. Below 17m there is shallowing up to about 1.0m (10.6mm/year) on the sea floor on Profile 3.

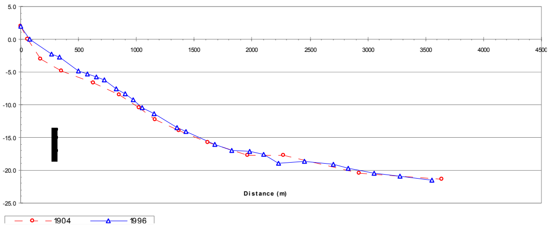


• Figure 11: Chart of Tolaga Bay from surveys by HMS Penguin in 1904 and Captain Martin and Mr Lockwood around the wharf area in 1920, showing the location of the Base Line and 3 Profiles shown in Figure 12.

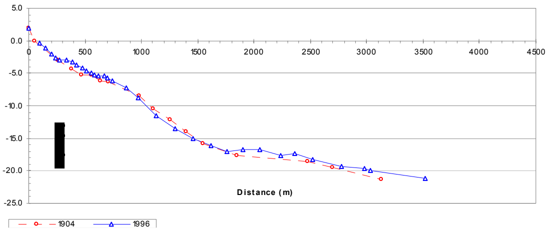
A: Profile 1 - Tolaga Bay North



B: Profile 2 - Tolaga Spit



C: Profile 3 - Tolaga Bay Wharf



- Figure 12: Changes to Tolaga Bay sea floor 1904-1996 with respect to MSL. Data from Appendix II.

There are insufficient survey data to establish whether the changes over the last 92 years represent a long-term trend or a short-term fluctuation. The magnitude of the changes recorded on Figure 12 is well within the envelope expected for fluctuations in the elevation of the seafloor out to about -10m depth. Notwithstanding, deposition rates over the last 92 years are similar to those over the last 227 years, providing more confidence in Cook's survey in 1769. On all 3 profiles there is a noticeable change in both gradient and magnitude of fluctuations at about -15m depth where profiles generally change from convex to concave upward offshore.

Sediment samples taken from the seafloor by the Hydrographic Branch, RNZN, in 1958 and 1996 revealed '*Grey Sand'* from the shore out to about -15m depth and Mud with Fine Sand and pockets of broken shell out to about -30m depth. From about -30m to -200m depth, Robbins (1996) noted the sea floor was "*generally of a glutinous grey-green mud … at least 1.2m thick and uniform in consistency throughout*".

On the basis of sediment and historic survey data the seaward limit of Tolaga Bay beach (closure depth) is inferred to be the -15m isobath. The pattern of sedimentation over the last 227 and 92 years suggests Medium and Fine Sand is deposited inshore to a depth of -15m, the amount of deposition decreasing below -8m depth. Below -15m depth sedimentation rates increase again suggesting the deposition of silts transported to the coast and offshore as suspended load by the Uawa River during floods.

Furthermore, it is possible that between major floods the relatively soft lithic grains in the beach sand are abraded by wave action into silt, which is transported offshore progressively reducing the volume of beach sand. For accretion of sand to be sustained the rate and frequency of supply from the Uawa River must exceed the steady rate of loss from wave abrasion of existing beach sand. Over the last 6,500 years the relatively constant rate of shoreline advance of 0.25m/year indicates sand supply to Tolaga Bay has exceeded loss.

4 SHORELINE MOVEMENTS

Appendix III tabulates historic rates of shoreline (duneline) movements and maximum potential duneline fluctuations for both Tolaga and Anaura Bays. There are 15 Stations spaced at 200m intervals along Tolaga Bay and 18 stations spaced the same along Anaura Bay. Shoreline movements are graphically summarised in Figure 13 (Tolaga Bay) and Figure 14 (Anaura Bay) for each survey interval and for last century in Figure 15 for both bays. For Tolaga Bay the 1.4km-long shore North of the Uawa River mouth is referred to as the Northern shore below and the 1.55km-long shore South of the mouth as the Southern shore.

4.1 TOLAGA BAY

For Tolaga Bay there are 5 reliable survey intervals for which shoreline trends are summarised in Figure 13. In Northern and Southern Tolaga Bay, the earliest most reliable cadastral surveys were made in 1875 and 1885, respectively. The remaining aerial surveys made in 1943, 1957, 1969, 1979 and 1996/97 span the entire 3km-long beach.

From about 1875 to 1943 (68 years), there was a general trend of accretion up to 20m along the Northern shore and erosion up to -40m along the Southern shore. At the Uawa River mouth there was -33m erosion on the North side and 154m growth of the Tolaga Spit tip on the South side (Figure 13).

From 1943 to 1957 (14 years), there was a reversal to a widespread trend of erosion up to -20m along the Northern shore. Along the Southern shore, there was differential accretion up to 20m and erosion up to -5m along the 800m of the shore. At the Uawa River mouth there was no change on the North side and a further –67m erosion of the Tolaga Spit tip on the South side (Figure 13).

From 1957 to 1969 (12 years), there was a reversal to a widespread trend of accretion up to 52m along the Northern shore. Along the Southern shore, there was a continuation of differential erosion up to -4m along a 400m stretch and accretion up to 8m along a Southern 400m stretch. At the Uawa River mouth there was 52m of accretion on the North side and a further -44m erosion of the Tolaga Spit tip on the South side (Figure 13).

From 1969 to 1979 (10 years), there was a continuing trend of widespread accretion up to 35m along the Northern shore. Along the Southern shore, there was a continuation of differential accretion up to 19m along a 1,000m stretch and erosion up to -6m. At the Uawa River mouth there was a further 27m of accretion on the North side and a further -10m erosion of the Tolaga Spit on the South side.

From 1979 to 1997(18 years), there was a reversal to differential erosion up to -25m along the Northern shore. Along the Southern shore, there was a continuation of differential accretion up to 20m with localised erosion up to -27m near the river mouth. At the Uawa River mouth there was a further 43m of accretion on the North side and a further -14m of erosion of the Tolaga Spit on the South side (Figure 13).

For the entire survey period, there was an overall trend of accretion along the Northern shore increasing Southwards from 0.07m/year at Tolaga Domain to 0.34m/year near the river mouth over the last 122 years (1876-1997). Along the Southern shore there was a trend of erosion decreasing away from the mouth from –0.41m/year to –0.13m/year along about 600m of shore, reversing to accretion decreasing from 0.11m/year to 0.05m/year at the Tolaga Bay Wharf along about 400m of shore. At the Uawa River mouth there was a net accretion at 0.73m/year on the North side and net accretion of 0.17m/year of the Tolaga Spit on the South side (Figure 15).

Maximum potential short-term duneline fluctuations are greatest at the Uawa River mouth decreasing from 180m^3 to 110m^3 along the Northern shore and to 140m^3 along the South shore. Along the Northern shore horizontal movements of the duneline increase South from about 33m at the North end of the beach to about 110m at the river mouth. Along the Southern shore horizontal movements decrease South from about 70m at the mouth to 38m at the Tolaga Motor Camp.

For the entire 3km-long Tolaga Bay shore, these short-term fluctuations involve most if not all of the foredune complex. The importance of this landform at protecting low-lying coastal hinterland by absorbing such fluctuations is paramount.

The pattern of shoreline movement over the last century suggests that trends along Northern Tolaga Bay may operate independently of those along Southern Tolaga Bay. The permeable barrier provided by the Uawa River discharging into the centre of the bay

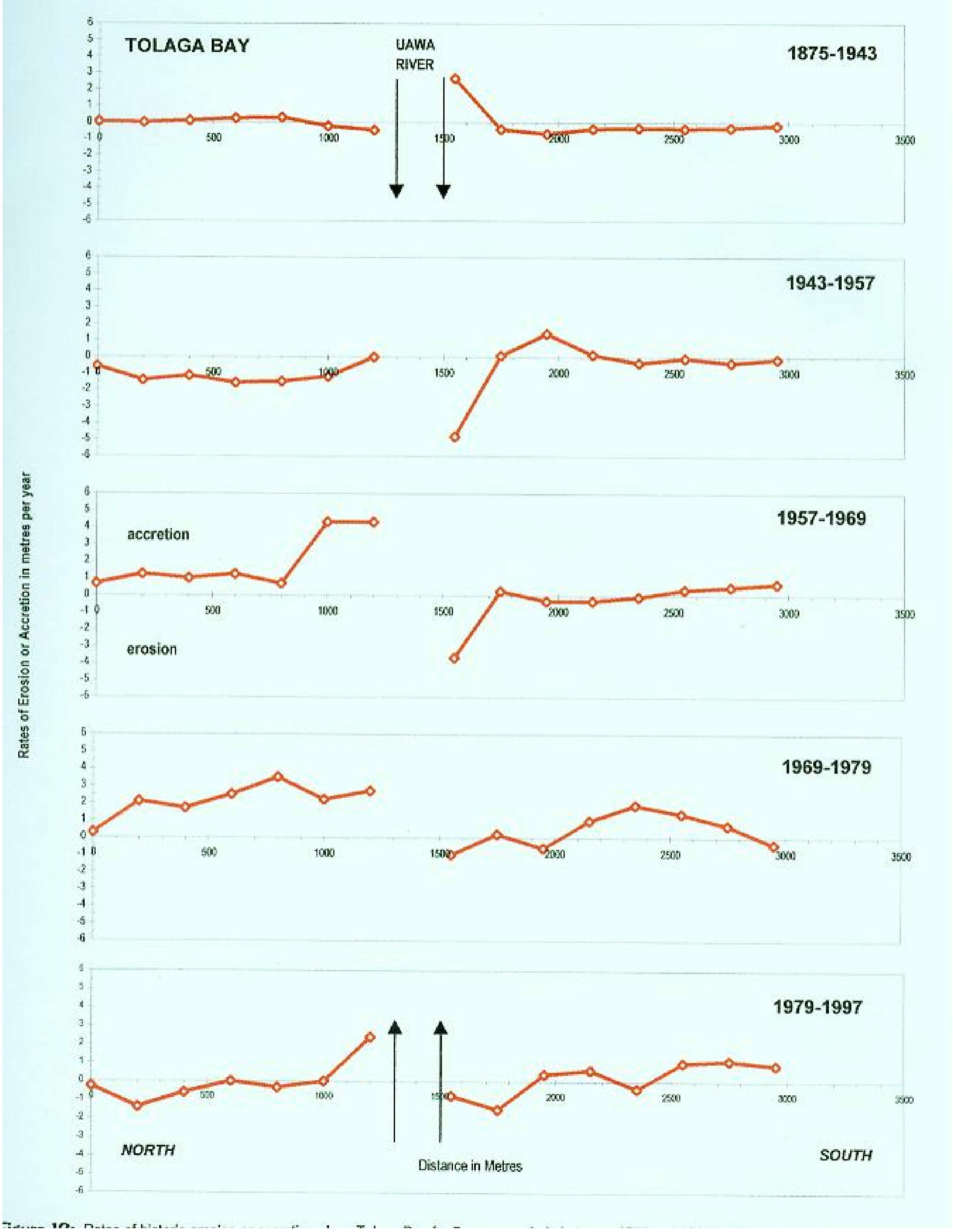
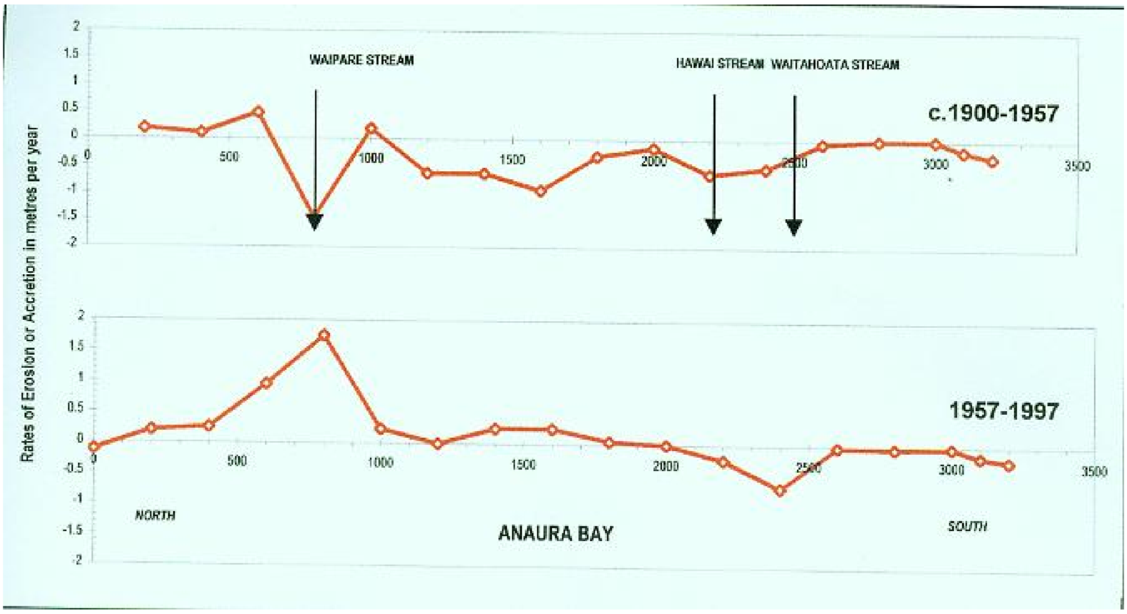
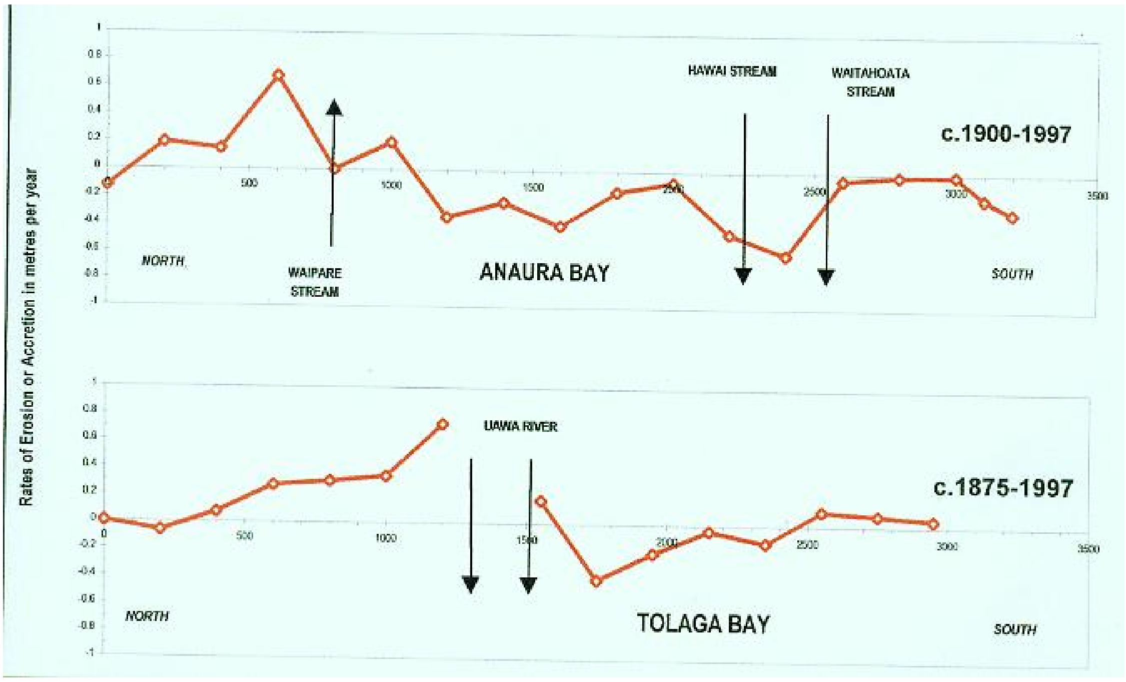


Figure 13: Rates of historic erosion or accretion along Tolaga Bay for 5 survey periods between 1875 and 1997 for 15 stations spaced at 200m. Data from Appendix III (Table IIIA).



- Figure 14: Rates of historic erosion or accretion along Anaura Bay for 2 survey periods between 1875 and 1997 for 18 stations spaced at 200m. Data from Appendix III (Table IIIB).



- Figure 15: Long-term rates of erosion or accretion for Anaura Bay and Tolaga Bay during the past century. Data from Appendix III (Tables IIIA & IIIB).

may partially separate the 2 beach systems. Erosion phases North of the River may be caused by SE storms whereas erosion phases South of the River may be caused by NE storms.

Despite the fact that the river is subject to and will continue to be subject to large floods, the pattern of very slow long-term accretion-erosion rates suggests that only a minor portion of the river's load is sand, the bulk being suspended silt transported offshore. The historical accretion rates of 0.05-0.34m/year are generally lower than the geological rate of 0.25m/year possibly suggesting a reduction in sand input over the last century coupled with the effects of an historical rise in sea-level.

4.2 ANAURA BAY

For Anaura Bay there are 2 reliable survey intervals for which shoreline trends are summarised in Figure 14. In Northern Anaura Bay the earliest most reliable cadastral surveys were made in 1886 and 1906 as far South as the Waipare Stream, a distance of 730m. South of Waipare Stream, the earliest most reliable cadastral survey was made in 1909 over a distance of 2,470m. The remaining more recent aerial surveys of 1957 and 1997 span the entire 3.2km-long beach.

North of Waipare Stream, the pre-1957 period features accretion of 7 to 24m, the accretion increasing toward the Waipare Stream. The accretion is confirmed by Judy Shanks and the history of the Waipare Homestead built in the 1880s. Sturdy gate posts on the seaward boundary of the property fashioned out of Puriri last century are still there today. If there had been erosion over the past century the posts and fence would have been destroyed by the sea.

Between the Waipare Stream and Waitahoata Stream, just East of the Anaura Bay Motor Camp, the dunes have retreated 7 to 45m between 1909 and 1957, and up to 70m by Waipare Stream. The loss of land was confirmed from observations by the Tangata Whenua at a hui on 6 March 1997 at Hinetamatea Marae, especially in front of the 5 houses in the centre of the bay. Here the duneline has retreated -30m between 1909 and 1957 at -0.63m/year (Figure 14).

East of the Waitahoata Stream the coast has been remarkably stable from 1909 to 1957 especially in front of Hinetamatea Marae and the Woolshed. At the point by the batches in the lee of Motuoroi Island and where the coastal plain grades into eroding seacliffs the coast has retreated -9 to -15m at -0.19 to -0.31m/year (Figure 14). The comment was made at the hui on 6 March 1997 that only 6 feet of land has been lost in front of the Woolshed which was built about 105 years ago.

From 1957 to 1997, the coastline has continued to advance North of Waipare Stream by 8 to 30m, the rates increasing toward the stream. On the true right bank at the mouth the duneline has advanced 70m back to the 1909 duneline position (Figure 14). The relatively large movements of 38 and 70m around the mouth are associated with stream mouth migration.

Between the Waipare and Hawai Stream mouths there has been differential accretion up to 10m and erosion up to -10m between 1957 and 1997 (Figure 14). The reversal from erosion up to -0.63m/year (1909-1957) to accretion up to 0.25m/year (1957-1997) suggests that Anaura Bay was subject to some large erosive events between 1909 and

1957 but has since recovered. The pre-1957 trend of erosion in this 1,500m-long section of Anaura Bay has not continued suggesting the area may now be in dynamic equilibrium.

In front of the Anaura Bay Motor Camp, there has been -28m of erosion between 1957 and 1997 of the low sand dune. East of the Waitahoata Stream negligible erosion of -1 to -2m was recorded as far as the point. At South of the point the erosion rate increases with -7 to -10m of land being lost since 1957 (Figure 14). The erosion rate has been almost constant in this area since 1909 indicating a persistent long-term trend of retreat.

For the entire survey period there was net accretion at 0.15 to 0.19m/year (1886-1997) North of Waipare Stream and up to 0.68m/year (1906-1997) by the stream mouth (Figure 15). The accretion is from the accumulation of sand as a low dune and from deposition of fluvium from the Waipare Stream.

Between the Waipare and Waitahoata Stream mouths there was net erosion of -0.08 to -0.60m/year (1909-1997), the erosion being most prominent in the centre of Anaura Bay and by the Motor Camp. As noted, the erosion rate may not represent a true long-term trend as almost all erosion occurred prior to 1957. The coast may well have reached a state of dynamic equilibrium since 1957.

Between the Waitahoata Stream and the point there was a very slow long-term erosion at -0.01 to -0.05m/year (1909-1997). East of the point the alluvium embankment has retreated constantly at -0.18 to -0.28m/year (1909-1997) (Figure 15). The loss of alluvium is irreversible, as the material is not replaced from time to time like the sand dunes.

Maximum potential short-term duneline fluctuations decrease North from a maximum of 285m^3 by the Waipare Stream mouth to 55m^3 by Waipare Homestead equating to horizontal distances of 100 to 18m, respectively. South of the Waipare Stream dune volumes involved range from 170m^3 on the more exposed sections of Anaura Bay, to 65m^3 on the sections protected by reefs. For this stretch of Anaura Bay, maximum horizontal duneline movements range from 60 to 22m respectively.

East of the Motor Camp short-term duneline fluctuations increase to 100m^3 at the mouth of the Waitahoata Stream, diminishing to 65m^3 further East on the dunes. For the Southeastern part of Anaura Bay the embankment of alluvium is likely to be subject to storm cuts of 35m^3 equating to horizontal movements of 8-15m, subject to the height of the embankment.

The pattern of shoreline movements this century in the 3.2km-long Anaura Bay indicates minor accretion in the Northern 1,000m, very slow erosion in the central 1,400m, a stable section in the Southern 500m, and persistent erosion in the most Southern 300m of coast. Short-term duneline movements are greatest around the Waipare, Hawai and Waitahoata Stream mouths followed by sections of foredunes not protected by offshore reefs. The reefs act as natural offshore breakwaters impounding beach sand on the coast and protecting the adjacent foredune from the full effects of storm waves and tsunami thus reducing the magnitude of short-term duneline fluctuation.

5 NATURAL COASTAL HAZARDS

A natural hazard is defined by Varnes (1984) as the "*probability of occurrence within a specified period of time and within a given area of a potentially damaging natural phenomenon*". According to S.2 of the Resource Management Act 1991 (RMA-91), such phenomena include; "*any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment*".

Although the term adverse effects is not precisely defined in the RMA-91, under S.3 the term may mean; "*any temporary or permanent effect; any past, present, or future effect; any cumulative effect which arises over time or in combination with other effects regardless of the scale, intensity, duration or frequency of the effect. Any potential effect of high probability and any potential effect of low probability which has a high potential impact*".

5.1 SEA EROSION

Since 1972, the writer has carried out extensive research and survey on sea erosion in New Zealand. Coastal erosion is by far the most widespread, most frequently occurring, coastal hazard around New Zealand at present with about 25% of New Zealand's 15,000km-long coastlines having a long-term trend of retreat (Gibb 1984). For the old Waiapu County, Gibb (1981a) found that 47% of the 147km-long coastline was retreating from erosion, 33% was advancing from accretion, and 20% was static (erosion rate less than -0.02m/year).

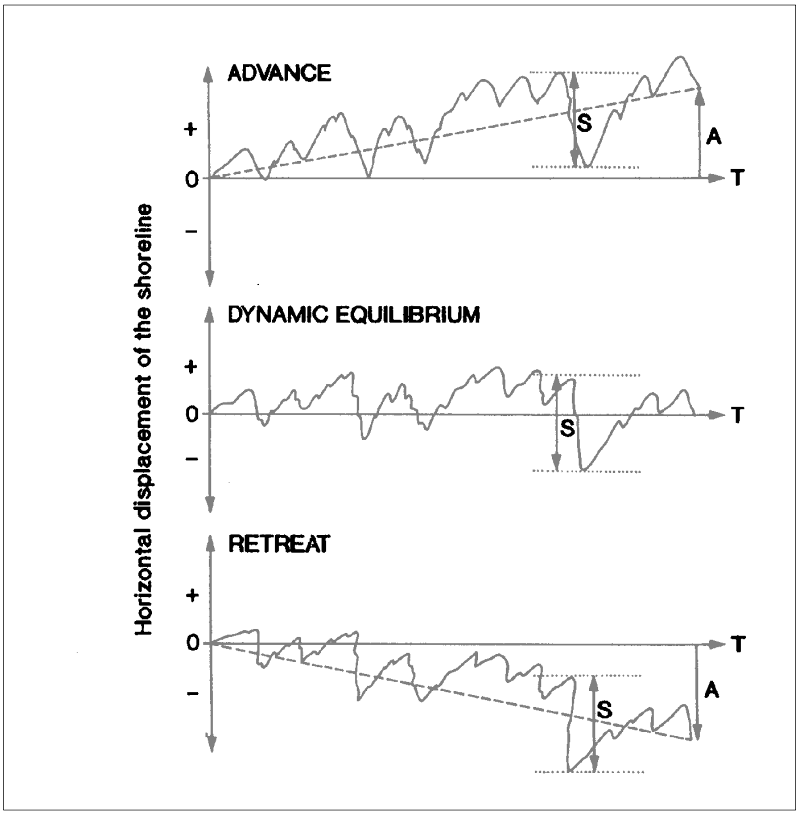
According to the American Geological Institute (1962) *erosion* is defined as:

"… *the group of processes whereby earthy or rock material is loosened or dissolved and removed from any part of the earth's surface* …"

The processes include weathering, solution, corrasion, attrition, abrasion, and transportation by gravity, wind and water, all of which occur to a greater or lesser degree along the coast. Such processes rarely if ever, result in a slow steady landward retreat of the coastline. Rather, erosion occurs episodically with several tens of metres of land being lost from either storm bites or landslides (Figure 16). Between such episodic events, the coastline may either advance from accretion, as in the case of most sandy foreshores, or remain static as in the case of seacliffs cut from hard rock (Gibb 1980; 1984).

If the cumulative effect of the episodic events results in a landward retreat of the shoreline, then the coastline is generally said to be eroding. On this basis we may define coastal erosion as:

"*The process of episodic removal of material at the shoreline leading to a loss of land as the shoreline retreats landward*" (Gibb 1978; 1984).



- Figure 16: Conceptual diagram of shoreline movements. **A**: Shows the interactions of vertical and horizontal movements at the shoreline leading to either a state of *Advance*, *Retreat* or *Dynamic* Equilibrium. **B**: Shows the episodic nature of movement for the 3 shoreline states with Short-Term Fluctuations, S the Long-Term Trend, R, in relation to Time, T (Source, Gibb 1996a).

Clearly, the processes may include not only the work of the sea but also that of the wind, migrating river mouths and tidal inlets, coastal landslides, sea-level rise and tectonics. For wind erosion, studies made along the eastern Australian coastline concluded that loss of sand from the foredune by wind action accelerated the retreat of the shoreline (Beach Protection Authority 1979).

Landslides not only reduce the volume of land above sea-level but are part and parcel of the process of cliff retreat around the New Zealand coast (Gibb 1984). Instantaneous advance or retreat of the shoreline occurs during significant vertical tectonic displacements of the land. For example, during the 1931 Hawke's Bay Earthquake, tectonic uplift of the order of 2m resulted in a net shoreline advance of approximately 20m (Gibb 1996b), whereas during the 1929 Murchison Earthquake tectonic downdrop of the order of 0.5 to 1.0m resulted in a net shoreline retreat and accelerated erosion at Karamea (Gibb 1980).

5.2 SEA FLOODING

Flooding from the sea is an identified natural hazard in the study area and occurs when sea-level is super-elevated instantaneously by *tsunami* or *storm wave runup* (SWRU). Both phenomena have potential instantaneous adverse effects over a short period of time on low-lying land behind open-exposed embayments like Tolaga and Anaura Bays.

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).

Storm wave runup 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. Coastal storms are accompanied by a '*storm surge*' and SWRU. A '*storm surge*' is the resultant of the combination of barometric pressure set-up and wind set-up. SWRU is produced by the combination of the '*storm surge'* plus dynamic wave set-up and runup (Gibb 1997).

A storm surge is generated along the East Coast region by a revolving storm, which may be either a Mid-Latitude Depression or Tropical Cyclone. Of these, the writer found that a severe Tropical Cyclone may generate a storm surge 2-3 times larger than a severe Mid-Latitude Depression (Gibb 1997).

5.2.1 Revolving Storms

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 wave storm, wave runup will extend furthest inland for a period of one to two hours during high tide (Gibb 1997). Foredune elevations less than SWRU levels are overtopped by the sea during such wave storms and low-lying coastal hinterland inundated by the sea.

In the Southern Hemisphere the wind in both Tropical Cyclones and Mid-Latitude Depressions revolves "*with the hands of a watch*" (clockwise) inwards, towards the centre. In the Northern Hemisphere the wind revolves anticlockwise. The track which the centre of the storm takes is called the "*path of the storm*" and the portion of the storm-field on the right of the path is known as the "*right-hand semicircle*", and on the left as the "*left-hand semicircle*" of the storm (Marine Department 1902; RNZN 1996).

A revolving storm passing East of Gisborne District results in clockwise wind shifts from the "*right-hand semicircle*". A revolving storm passing West of Gisborne District results in anticlockwise wind shifts from the "*left-hand semicircle*" (Gibb 1997). In the Southern Hemisphere the most dangerous side of the storm is the left-hand semicircle (RNZN 1996) compared to the right-hand semicircle in the Northern Hemisphere. That means that revolving storms travelling SE down the Raukumara Range will be most damaging on the coast.

Tropical Cyclones have been classified in terms of the intensity of the storm where intensity is defined by the maximum sustained wind speed, or by the central pressure if no wind data are available, or both. Table 2 provides a tentative classification scheme proposed here for revolving storms based mainly on the scheme proposed by Revell

(1981) which is currently used in Tropical Cyclone forecasting procedures in New Zealand (Thompson *et al.* 1992). In addition to the equivalent wind speed range and central pressure for a given cyclonic description, Table 2 also provides estimates of the associated wave heights and potential storm surge. Class 5 (Major Hurricane) corresponds to the North Atlantic terminology for Major Hurricanes (Thompson *et al.* 1992).

- Table 2: Tentative classification of Revolving Southern Hemisphere storms (Tropical Cyclones and Mid-Latitude Depressions) and storm surges around New Zealand, adapted from Thompson *et al.* (1992) [Columns **A** to **F**], the Nautical Almanac 1997 (RNZN 1996) [Colums **D** & **F**], Gibb (1997) and de Lange (pers. comm. 1998) [Column **G**].

A	B	C		D	E	F	G
CLASS	DESCRIPTION	WIND SPEED RANGE		BEAUFORT SCALE	CENTRAL PRESSURE	BEAUFORT WAVE HEIGHT	POTENTIAL STORM SURGE
		knots	kph	Force	hPa	m	m
1	Tropical Depression	28-33	52-61	7	>995	4.0	<0.4
2	Gale	34-47	63-87	8-9	995-985	5.5-7.0	0.4-0.6
3	Storm	48-63	89-117	10-11	986-975	9.0-11.5	0.61-0.8
4	Hurricane	>63	>117	12	974-945	≥14.0	0.81-1.6
5	Major Hurricane	>90	>167	12+	<945	c. ≥18.0	>1.6

5.2.2 Tropical Cyclones

The frequencies of Tropical Cyclones per decade per month in the SW Pacific are given in Table 3 for 5.6 decades between 1939 and 1996. Table 3 shows that the Tropical Cyclone season normally extends from November to April, but occasionally there are early and late season storms. Monthly variation in Table 3 reveals that the peak months are December through to March with February being the month of most frequent occurrence.

For the period 1898-1936, Barnett (1938) also found February to be the peak month. Over the last 5 decades the number of Tropical Cyclones has progressively increased with time in the SW Pacific from a total of 58 in the 1940s to 130 in the 1980s (Table 3). The overall increase may be apparent however, owing to the continuing evolution of more sophisticated detection methods such as weather satellites.

- Table 3: Number of Tropical Cyclones per decade per month recorded in the SW Pacific between Longitude 145^0E and 125^0W (Source: Kerr 1976; Revell 1981; Thompson *et al* 1992; Ready 1996). 1990's cover the period 1989-1996 (from Gibb 1997).

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Total
1940s			1	8	17	18	16	5					58
1950s			2	8	21	20	15	7					64
1960s			6	13	16	23	19	8					72
1970s		1	5	13	23	25	17	13	2	1			100
1980s		1	3	12	26	37	31	15	5				130
1990s			3	10	11	16	17	2	3				49*

* half-dacade.

5.3 CLIMATE CHANGE AND SEA-LEVEL RISE

It is widely recognised that the cumulative effects of a rising sea-level can be a major contributing factor to the coastal hazards of erosion and flooding from the sea (Bruun 1962; 1983; Hicks 1990). Since about 1900, sea-level has risen around New Zealand at about 1.7mm/year with residual rates ranging from 1.2mm/year at Auckland up to 2.4mm/year at Lyttelton (Hannah 1990; Gibb 1991) which is in excellent agreement with the global trend (Gornitz 1993).

During this period global mean surface air temperature has increased by between about 0.3 and 0.6°C and global sea-level by 10 to 25cm. According to the Intergovernmental Panel on Climate Change, much of the rise in global sea-level "*may be related to the increase in global mean temperature*" (IPCC 1996).

Warming of the atmosphere in response to an increased concentration of greenhouse gases next century is expected to lead to an acceleration in the historic rate of global sea level rise IPCC (1996). Research by internationally acclaimed scientists has revealed that even if humanity could stabilise greenhouse gas emissions by the year 2030 AD, "*substantial increases in sea-level are likely to continue for centuries into the future*" (Wigley & Raper 1993).

For thermal expansion of the oceans from atmospheric warming, for example, Wigley and Raper (1993) noted that the ocean lags behind the immediate response of the less dense atmosphere. Only 16% of the final value of sea-level rise from this factor is seen by 2030 AD. The lag effect of the ocean's response to global warming may be compared with starting a car, accelerating to 100km/hour, and then turning the engine off. The momentum generated will carry the car for a considerable distance.

The IPCC (1996) have provided a mid-range best estimate of global mean surface air temperature relative to 1990 of about 2^0C by 2100 A.D., the lowest estimate being a 1^0C increase and the highest 3.5^0C by 2100 A.D. They note that "*the average rate of warming would probably be greater than any seen in the last 10,000 years*", and that there would be significant regional differences from the mean. Between January and July 1998 average global temperatures have exceeded the highest recorded over the last 600 years (NIWA, pers. comm. 1998), suggesting that global warming from Climate Change is right on track.

As a result of a significant rise in global air temperatures average sea-level is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice sheets. The IPCC have estimated mid-range increases in global sea-level of 0.2m above 1990 levels by 2050 A.D. and 0.49 by 2100 A.D. A low estimate of 0.15m and a high estimate of 0.95m were provided for 2100 A.D. (IPCC 1996).

The IPCC note that "*sea-level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature. Regional sea-level changes may differ from the global mean value owing to land movement and ocean current changes*" (IPCC 1996). These predictions are serious and suggest a cautious approach is justified for management of the effects of coastal hazards in New Zealand.

6 COASTAL HAZARD ZONE (CHZ) ASSESSMENT

The CHZ identifies land that "*is subject to, and is likely to be subject to*" the identified hazards of sea and wind erosion and flooding from the sea. In total therefore, the CHZ incorporates both a Coastal Erosion Hazard Zone (CEHZ) and a Coastal Flood Hazard Zone (CFHZ).

6.1 COASTAL EROSION HAZARD ZONE (CEHZ)

In accordance with the requirements the PRCEP (GDC 1997) set out in Section 1.2 of this report, the following factors were taken into account for the GIS computer model to delineate a CEHZ, using techniques practised and continually reviewed by the writer over the last 17 years (BPA 1984; 1989; Gibb 1981; 1983; 1987; 1991; 1994a,b,c; 1995a; 1996a,b; 1998a; Gibb and Aburn 1986; AICE 1991), where:

R = Rate of long-term (historic) trend of net shoreline advance, retreat or dynamic equilibrium (m/year).

S = Area subject to maximum potential short-term duneline fluctuation (m).

F = Safety factor that is expressed on a scale from 1.0 (0%) to 2.0 (100%).

T = Planning horizon (years).

X = Rate of shore retreat (m/year) from local relative sea-level rise calculated by the Bruun Rule (Bruun 1962; 1983), where:

$$X = \frac{la}{} \qquad \text{Eqn [1]}$$

$h + d$

Where: a = Rate of local relative sea-level rise (m/year).
d = Average closure depth below MSL (m).
h = Height of foredune above MSL (m).
l = Horizontal distance from the crest of the foredune to the contour representing the closure depth or seaward limit of beach sediment transport (m).

D = Horizontal distance of retreat of the top seaward edge of the dune erosion scarp (m), from collapse of unstable dunesand, calculated by:

$$D = \left[\frac{h}{\mathrm{Tan}\ x^0}\right] F$$

Eqn [2]

Where: h = Height of the foredune complex above MSL.
$\mathrm{Tan}\ x^0$ = Angle of repose of dry loose dunesand of 33°.
F = Safety Factor of 0.5.

The following equation incorporating the above factors was adopted to assess the extent of a Coastal Erosion Hazard Zone (CEHZ), and to provide a basis to estimate the relative degree of risk (Risk Zonation), where:

$$\mathrm{CEHZ} = [(X + R)\ T + S + D]\ F$$

Eqn [3]

Although Factor L has not been included to accommodate the foredune complexes at both Tolaga and Anaura Bays, the dimensions of this natural feature are accommodated through Factors S, D and F in the GIS computer model assessments.

Factor R

For R, long-term rates of erosion or accretion were computed by the GIS computer model on each of the computer generated profiles at 4m spacing (see Figure 2). For Northern Tolaga Bay the survey period was 122 years (1875-1997) and for Southern Tolaga Bay the period was 112 years (1885-1997). For Anaura Bay North of the Waipare Stream, survey periods ranged from 42 years (1955-1997) to 91 years (1906-1997), and South of the Stream the survey period was 88 years (1909-1997).

For Northern Tolaga Bay there was a long-term trend of accretion increasing South to 0.73m/year by the Uawa River mouth. For Southern Tolaga Bay there was a long-term trend of differential erosion up to -0.41m/year and accretion up to 0.17m/year. For Anaura Bay there was a long-term trend of differential erosion up to -0.40m/year and accretion up to 0.20m/year, increasing to 0.68m/year near the Waipare Stream mouth (see Figure 15).

Factor S

For S, the maximum potential short-term duneline fluctuations were determined as a volume of sand and associated linear distance on selected profiles by the GIS computer model. Unless there was information to the contrary the linear distance was not allowed to exceed the landward toe of the foredune complex. Where the distance was exceeded was around the mouths of the Uawa River and Waipare, Hawai and Waitahoata Streams as a result of mouth migration.

For Northern Tolaga Bay, short-term horizontal duneline fluctuations ranged from 33 to 44m and for Southern Tolaga Bay 38 to 50m. Around the Uawa River horizontal fluctuations ranged from 60 to 110m. For Anaura Bay fluctuations ranged from 8 to 60m increasing to a maximum horizontal distance of 100m by the Waipare Stream (Appendix III).

Factor X

For X, net rates of retreat from sea-level rise were calculated using the Bruun Rule (Eqn 1) in the GIS model. The Bruun Rule (Bruun 1962; 1983) states that: "*for a shore profile in equilibrium, as sea-level rises, beach erosion takes place in order to provide sediments to the nearshore so that the nearshore seabed can be elevated in direct proportion to the rise in sea-level*" (see Figure 3). The following parameters for the Bruun Rule were entered into the GIS model.

For Equation [1], an average closure depth of -8m was adopted for factor d for Anaura Bay and -15m for Tolaga Bay based on hydrographic survey data and nearshore sediments. For factor **h** (Eqn 1), the crest heights of the foredune were determined from the DTM. For factor l (Eqn 1), distances were determined from the crestline of the foredune to the -8m and -15m isobaths by the GIS model.

For factor a (Eqn 1), rates of sea-level rise of 0.0039m/year (3.9mm/year) and 0.0048 m/year (4.8mm/year) were adopted from the IPCC-95 best estimates of 0.20m by 2050 A.D. and 0.49m by 2100 A.D., respectively. No adjustments were made for vertical displacement of the study areas at 0.4m/1000 years from tectonic uplift as uplift events on the East Coast are episodic and occur every 300 to 1,500 years (Ota *et al.* 1992). Between uplift events, erosion from sea-level rise over the next century is likely to dominate.

Factor T

For T, periods of 53 years (1997-2050) and 103 years (1997-2100) were adopted as long-term planning horizons and entered into the GIS model. The basis for adopting such periods is that they encompass the minimum total expected occupation life of residential buildings and services in beachfront developments throughout New Zealand. The periods are also likely to encompass the specified intended life of new residential buildings in accordance with the requirements of the Building Act 1991. A 50 to 100-year planning horizon allows sufficient time for the recurrence of the maximum potential short-term duneline fluctuation, the occurrence of a severe wave storm or tsunami and accompanying flooding from the sea, and for the effects of rising sea-levels and increased storminess forecast to occur with Climate Change next century (Hicks 1990).

Factor D

For D, the stable angle of repose of dry, loose, medium to fine sand of 33^0 was entered into the GIS computer model. Based on the assumption that approximately half of upper erosion scarp cut during storms would collapse onto the beach causing a localised advance of the duneline, a factor of 0.5 was incorporated into Equation [2].

Factor F

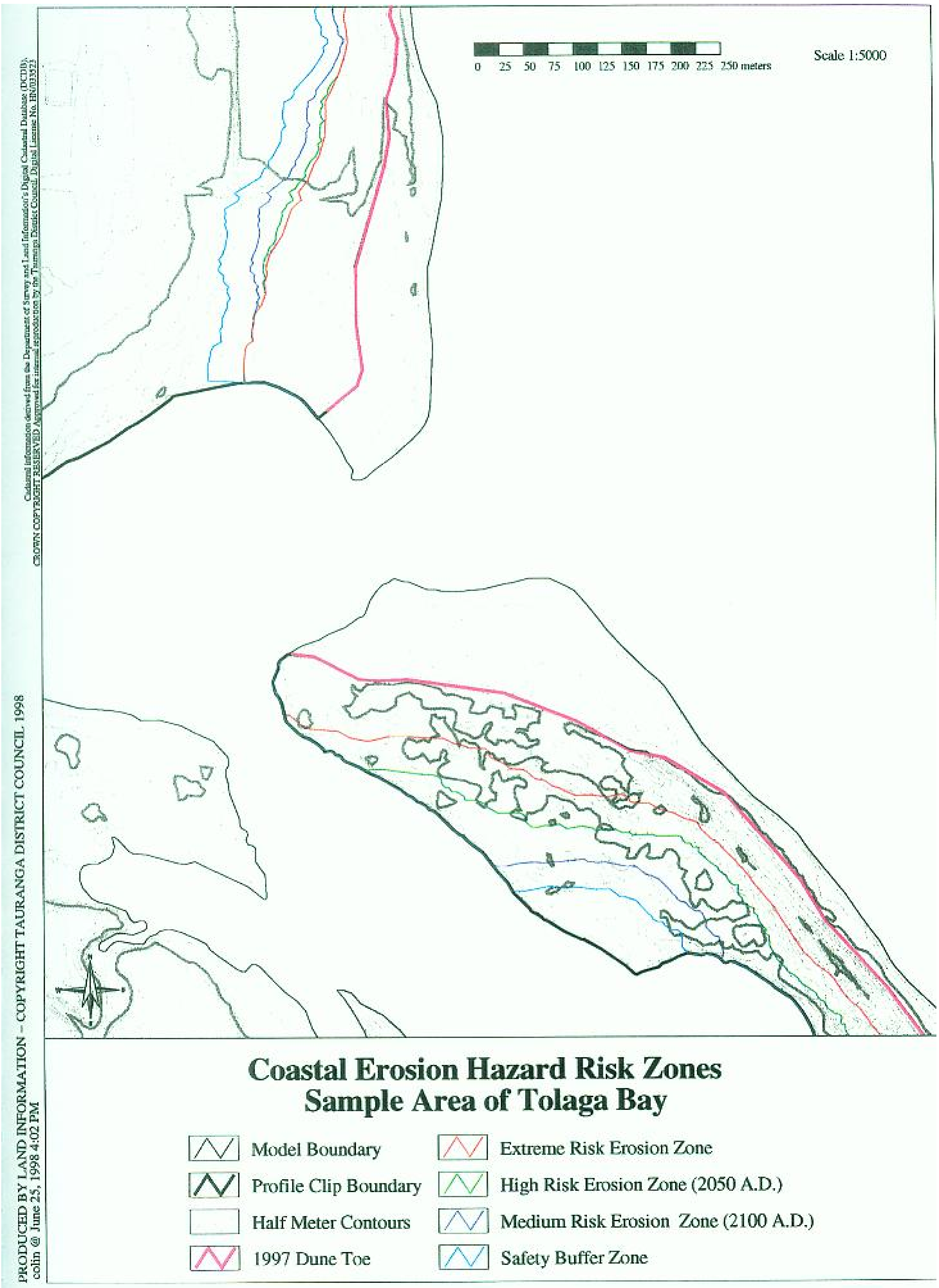
For F, a Safety Factor of 1.3 (30%) was adopted for the GIS model to accommodate uncertainties in Factors R, X, S, and D, particularly with respect to the effects of Climate Change predicted to occur next century and to make full provision for the inclusion of the foredune complex in the hazard assessments. For Queensland, the Beach Protection Authority adopted a Safety Factor of 1.4 to calculate Buffer Zone widths (BPA 1984; 1989). A Safety Factor for 1.3 was adopted for assessment of CHZs in Gisborne (Gibb 1995), Central Hawke Bay (Gibb 1995b), Bay of Plenty (Gibb 1996a; 1998a) and Northland (Gibb 1998b).

6.1.1 Risk Zonation

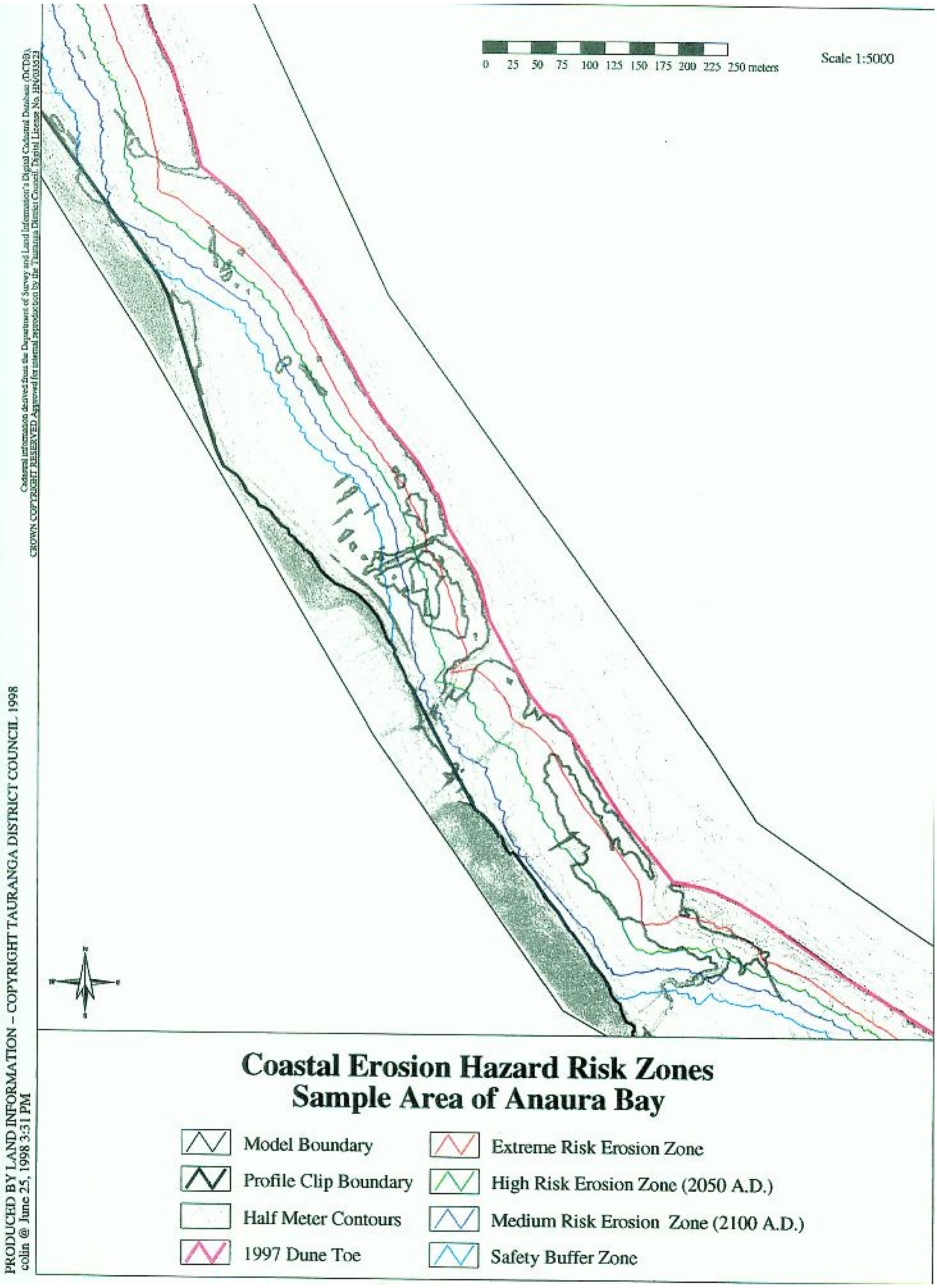
The term "*risk*" is where "*a given element or set of elements is exposed to chance of injury or loss from the occurrence of a natural hazard*" (Sykes 1984; Varnes 1984). Risk Zonation refers to the division of the land surface into areas and the ranking of these areas according to degrees of actual or potential hazard from natural phenomena. It does not necessarily imply legal restriction or regulation by zoning ordinances or laws (Varnes 1984).

Based on CHZ precedents set by the writer for Pauanui (Gibb and Aburn 1986), Hokitika (Gibb 1987), Gisborne (Gibb 1995c), the Bay of Plenty (Gibb 1996a; 1998a), and Hawke's Bay (Gibb 1996b), plus the requirements of the PRCEP (GDC 1997), the CEHZs assessed here were subdivided into ***Extreme***, ***High*** and ***Moderate Risk Erosion Zones*** and a ***Safety Buffer Zone***, which lie adjacent and parallel to each other (Figure 6). As one might expect, relative risk over the next century diminishes landward from ***Extreme*** next to the coast, to ***Moderate*** inland. Examples of the Coastal Erosion Hazard Risk Zones generated by the GIS computer model are shown for Tolaga Bay (Figure 17) and Anaura Bay (Figure 18).

The ***Extreme Risk Erosion Zone (EREZ)*** lies adjacent to the coast and encompasses the area that "*is subject to, and is likely to be subject to*" adverse effects from the maximum potential short-term duneline fluctuation, and wind erosion. The ***EREZ*** includes factors S and D, encompasses most of the foredune complex and has a high probability of being adversely affected at any point in time. The ***EREZ*** on the GIS plots ranges in width from 32 to 120m along Tolaga Bay being widest around the Uawa River mouth. In Anaura Bay the ***EREZ*** ranges in width from 10 to 125m being widest around the Waipare Stream.



• Figure 17: GIS computer model generated map of central Tolaga Bay showing Risk Zones and Safety Buffer Zone.



- Figure 18: GIS computer model generated map of central Anaura Bay showing Risk Zones and Safety Buffer Zone.

The ***High Risk Erosion Zone (HREZ)*** lies adjacent and landward of the ***EREZ*** and encompasses the area that "*is subject to, and is likely to be subject to*" a net shoreline retreat from a predicted sea-level rise of 0.20m above the present by 2050 A.D., wind erosion, and historical long-term retreat (if any). The ***HREZ*** encompasses the period from 1997 to 2050 A.D., and has a high probability of being adversely affected at any time over the next 53 years. The ***HREZ*** ranges in width from 0 to 58m along Tolaga Bay being widest where there is long-term erosion and low foredunes. In Anaura Bay the ***HREZ*** ranges in width from 0 to 42m and like Tolaga Bay is widest for the same reasons. Where there is no ***HREZ*** the historic rate of accretion has neutralised the predicted erosion from sea-level rise.

The ***Moderate Risk Erosion Zone (MREZ)*** lies adjacent and landward of the ***HREZ*** and encompasses the area that "*is likely to be subject to*" a net shoreline retreat from a predicted sea-level rise of 0.49m above the present by 2100 A.D. and historical long-term retreat (if any). The ***MREZ*** encompasses the period from 2050 to 2100 A.D., and ranges in width from 0 to 60m along Tolaga Bay and is widest in the area of historic erosion and zero in the areas of significant accretion. In Anaura Bay the ***MREZ*** ranges in width from 0 to 38m for the same reasons as Tolaga Bay.

The ***Safety Buffer Zone (SBZ)*** encompasses the area determined by the Safety Factor (F) and encompasses the area that "*is likely to be subject to*" adverse effects from natural hazards should either the rate of sea-level rise increase above the best estimate of the IPCC-95, or a negative sediment budget become established, or the maximum potential short-term duneline fluctuation exceed that estimated in this study, or combinations thereof.

The ***SBZ*** lies adjacent and landward of the ***MREZ*** and the risk to elements within this zone is considered to be relatively low. The ***SBZ*** ranges in width from 15 to 36m along Tolaga Bay and 7 to 45m along Anaura Bay and makes provision for a nominal foredune at the end of the planning horizon of 103 years. Landward of the ***SBZ***, the risk from the identified natural coastal hazards of sea and wind erosion is considered here to be ***very low*** until after the year 2100 A.D.

6.2 COASTAL FLOOD HAZARD ZONE (CFHZ)

The CFHZ is the area of coastal hinterland that "*is subject to, and is likely to be subject to*" episodic, temporary inundation by the sea. Such inundation would be caused by seas overtopping the crest of the foredune during high tide possibly enhanced by flooding from runoff from the land. The sensitivity of low-lying coastal hinterland to flooding from the sea is largely a function of the elevations of either storm wave runup (SWRU) or tsunami runup on the coast and the height of the foredune.

Where dunecrest elevations are less than maximum SWRU and tsunami runup elevations, overtopping and inundation of low-lying coastal hinterland will occur. Therefore, the potential CFHZ is delineated by contours of coastal hinterland behind the dunecrest, typically less than dunecrest elevations. For this study, contours are provided at 0.5m intervals by the DTM based on the 1997 Aerial Survey

Along Northern Tolaga Bay the dunecrest is typically 3-4m a.MSL falling to 2-2.5m a.MSL at the North end of the beach and at the Uawa River mouth. Behind the foredune complex is a shallow basin 2-2.5m a.MSL that falls away toward the Uawa River. The shallow basin has potential to be flooded by both the sea overtopping the foredune and peak flows from the river flowing into the basin.

Along Southern Tolaga Bay the dunecrest of the foredune complex along the sand spit is typically 4.5-5m a.MSL falling to 2.5m at the spit tip and 3m by Tolaga Bay wharf. Much of the land at the Tolaga Bay Motor Camp and generally behind the foredune complex is 2.5-3m a.MSL falling away to the Uawa Estuary. The low-lying land has the potential to be flooded by both the sea overtopping low parts of the foredune and peak flows from the Uawa River flooding the estuary.

Along Anaura Bay, the dunecrest North of the Waipare Stream is 3m a.MSL but the land which is a deltaic fan rises to 4-8m a.MSL by most of the batches and Waipare Station. The exception is the batches at the North end of the beach which are on land that is 3.5-4m a.MSL. Between the Waipare and Hawai Streams the patchy foredune complex is 3-4m a.MSL with isolated crests at 5m. In front of the 5 houses in the centre of Anaura Bay which are located in a shallow basin 3m a. MSL the dunecrest is 3.5-4m a.MSL. The basin is subject to flooding by both the sea and runoff from the hills.

Southeast of Hawai Stream, the dunecrest is 2.5m a.MSL increasing to 3-3.5m by the Waitahoata Stream. The Anaura Bay Motor Camp is located on a shallow basin 2.5-3m a.MSL which is prone to flooding by both the sea, runoff from the hills and the Waitahoata Stream. East of the Motor Camp the dunes terminate against an alluvium embankment, the crest of which is 3m a.MSL. The land is a deltaic fan which rises to 3.5-5m by the Hinetamatea Marae and 3-3.5m by the batches. The fan is protected by Motuoroi Island.

6.2.1 Tsunami

For the Gisborne District de Lange and Healy (1986) and White-Parsons (1944) recorded in total a minimum of 8 tsunami between the 1860s and 1990s. The dates of the observed events were 13 August 1868, 11-14 May 1877, 29 August 1883, c. 1927, 25 March 1947, 17 May 1947, 23 May 1960, and 6 October 1994.

Of the 8 events, 5 were generated from sources distant to New Zealand (1868, 1877, 1883, 1960, 1994) and the remaining 3 from local sources on the adjacent continental shelf. In addition, the writer was told of 2 tsunami events in 1972 and 1978 by locals in Anaura Bay where waves broke across the entire Bay in calm seas reforming as swell inside Motuoroi Island. These latter events may have been locally generated as they were not observed in Gisborne or recorded internationally.

During construction of the Tolaga Bay wharf between 1926 and 1929 the driven piles were struck by 3 successive waves "*of unusual size, although the waters of the bay had been only slightly roughened by a moderate easterly breeze*". The waves had begun to break before they reached the wharf structure, submerging the pile-heads, the wave crests "*running at least at deck-level*" which was "*11 feet above high water of spring tides*". (4-4.5m above MSL). The impact of the waves was considerable, smashing the freshly driven wharf piles, which took several weeks to repair (White-Parsons 1944).

For Tolaga Bay, the 1927 tsunami reached about 4.5m (White-Parsons 1944)., the 25 March 1947 event 2.0m, the 17 May 1947 event 3.0m, and the 23 May 1960 event 2.0m (de Lange & Healy 1986). Although no observations of tsunami elevations are available for Anaura Bay the locals informed the writer that the sea has "*flooded over the bank*" on calm days. In the early 1950s the sea overtopped the foredune and flowed under houses. It is not known whether these events were tsunami or storm surges in Anaura Bay. It is highly probable the 1927 tsunami would also have affected Anaura Bay.

Based on the available data it would appear that maximim tsunami in the study area are generated locally by tectonic deformation of the sea floor accompanied by mud volcanism. As the North Island East Coast is subject to continual pressure and disruption from Plate Tectonics, tsunami generated from this source have a very high probability of occurring in the future (Gibb 1995; de Lange pers. comm. 1998) in both Tolaga and Anaura Bays.

A locally generated maximum tsunami wave height of the order of 4-6m is likely to occur in both Tolaga and Anaura Bays (de Lange, pers. comm. 1998). Such a wave would overtop the foredune in both embayments as there are many potential flood corridors where the dunecrest is only 2.5-3.5m a.MSL. Low-lying coastal hinterland below about 3m a.MSL would be temporarily inundated by the sea during such a tsunami event and buildings subject to damage and destruction in the forceful path of the tsunami waves.

6.2.2 Storm Wave Runup

Over the last 100 years (1897-1997), approximately 87 Tropical Cyclones migrated out of the tropics into the New Zealand region. On a decadal basis the number of Tropical Cyclones has ranged from 8 (1940's) to 16 (1960's) since 1939. Between 1940 and 1997, the country has experienced 1 Tropical Cyclone about every 10 months, ranging from zero to 4 (1956, 1988, 1997) per annum. For the period 1898-1936 Barnett (1938) noted that the country had experienced 6.7 cyclonic storms per annum on average and 1.3 severe cyclonic storms per annum, or 1 severe event about every 9 months, which is similar to the trend over the last 57 years (Gibb 1997).

Tropical Cyclones migrating from the Tropics into New Zealand waters generally change intensity from Class 5 (Major Hurricane) to Class 1 (Tropical Depression) as their structure disperses. Of the 87 Tropical Cyclones recorded in New Zealand waters, 3 were Class 4 events, 26 were Class 3 events, 42 were Class 2 events, 9 were Class 1 events, and for 7 events there were no data (Gibb 1997).

No Class 5 (Major Hurricane) events were recorded, although Cyclone Gisele may have approached Class 5 when it combined with a Mid-Latitude Depression near Cook Strait, generating extreme winds and seas which sank the passenger vessel "*Wahine*" at the entrance to Wellington Harbour on 10 April 1968 (Gibb 1997) with the loss of 51 lives (Brenstrum 1997). The winds were so strong (gusting 140 knots) and the seas so high (15-20m) that the ship lost all steerage and was uncontrollable.

Based on these data and accepting their limitations, a Class 4 event (Hurricane) would have approximately a 3% probability of being equalled or exceeded in any given year in New Zealand (3% AEP – annual exceedance probability). The three Class 4 Tropical Cyclones on record occurred on 18-20 March 1918, 1-3 February 1936 and 9-10 April 1968. In terms of minimum central pressures the March 1918 event reached 970 hPa, the February 1936 event 968.5 hPa, and the April 1968 event 965 hPa (Gibb 1997). A Class 3 event (Storm) would have a 29% AEP and a Class 2 event (Gale) a 71% AEP of being equalled or exceeded in any one year. Potential storm surges from such events are given in Table 2.

These data indicate that Tropical Cyclones migrating out of the Tropics frequently produce storm force or gale force winds and associated storm surge around New Zealand. Clearly, the Class 4 event can be expected to produce the highest storm surge along the Gisborne District coast. An all important factor relating to the height of the storm surge is the track taken by the Tropical Cyclone across New Zealand waters. History has shown that because of the intensity of a cyclonic event its effects are mostly site specific depending on such factors as its track, rate of movement and central pressure.

Of equal importance is the synoptic situation that exists over New Zealand during the arrival of the Tropical Cyclone. The cyclone's effects are intensified, for example, if an anticyclone east of the North island blocks its SE progress, intensifying the winds in the left-hand semicircle. These uncertainties in predicting the effects of a Tropical Cyclone on the Gisborne District coast suggest that the probability of a Class 4 event producing a storm surge of 0.8-1.6m above predicted tide level, being equalled or exceeded in any one year, is of the order of 1-3%.

On the North Island East Coast, the writer has observed evidence of maximum historic SWRU elevations of 6 to 7m above MSL in the Bay of Plenty region (Gibb 1996a), Gisborne District (Gibb 1995a), and Hawkes Bay Region (Gibb 1996b). In the sheltered waters of Tauranga Harbour, the 1936 and 1968 Class 4 Tropical Cyclones generated SWRU elevations of 1.1 to 1.7m above predicted high tide levels. In Ohiwa Harbour the 1968 event generated SWRU levels of 1.46 to 1.56m above predicted tide levels. On the open-exposed Bay of Plenty coast SWRU levels reached and exceeded 6m above MSL for both events (Gibb 1997).

For Wainui Beach, Komar (1996) estimated SWRU elevations above MSL of 5.2m for a major storm, 6.1m for a 50-year storm, 7.2m for a 100-year storm, and 8.3m for a major cyclone. Both Tolaga and Anaura Bays are exposed to the same extreme events suggesting that Komar's estimates may apply to the study area as well. In October 1991 David Peacock, Design Engineer, GDC, estimated SWRU elevations of 2.85 to 4.26m in Anaura Bay for 10.7m high waves using empirical techniques in Gibb (1981a). The parameters for the hypothetical storm adopted by Peacock suggest that it represented a Class 3 event.

Field observations of maximum historic SWRU elevations of 6 to 7m above MSL on the North Island East Coast suggest that these levels may have been generated by a Class 4 Tropical Cyclone. On this basis, it is assumed for the purposes of this study that Class 3-4 Tropical Cyclones have the potential to generate SWRU levels of 5-7m a. MSL, and Class 1-2 Tropical Cyclones and Mid-Latitude Depressions SWRU levels of 3-5 a. MSL. These assumed SWRU elevations should be used as guidelines for both Tolaga and Anaura Bays until site specific observations are made of such elevations from Class 3 and 4 events.

6.2.3 CFHZ

For Northern Tolaga Bay the dunecrest is typically 3-5m a.MSL falling to 2-2.5m a.MSL. For Southern Tolaga Bay the dunecrest is typically 4.5-5m a.MSL falling to 2.5-3m a.MSL. A tsunami of 4-6m and SWRU of 5-7m would easily overtop the entire foredune complex in Tolaga Bay flooding the low-lying coastal hinterland. In addition, heavy rain accompanying a Tropical Cyclone would result in peak flows in the Uawa River which would invade the Uawa Estuary and depression behind the foredune in Northern Tolaga Bay.

On this basis a CFHZ delineated by the *3m contour* on the DTM should be adopted for Tolaga Bay. There is a high probability that all land below 3m a.MSL will be temporarily inundated during an extreme event. Flood levels are unlikely to be sustained above 3m as they will drain either directly into the Uawa Estuary or River as the tide ebbs.

For Anaura Bay the dunecrest is typically 3-4m a.MSL falling to 2.5-3m above MSL SE of the Hawai Stream particularly in front of the Anaura Bay Motor Camp. Motuoroi Island, the offshore reefs in the bay, and the Northern Headland afford some protection for parts of the Anaura Bay foreshore from events from the NE and SE quadrants. Notwithstanding, the embayments is exposed to a tsunami of 4-6m and SWRU of 5-7m from the E quadrant which like Tolaga Bay, would easily overtop the foredune.

North of and around the Waipare Stream the *4m contour* should be adopted as the CFHZ landward boundary. South of the Waipare Stream the *3.5m contour* should be adopted as the CFHZ boundary. There is a high probability that all land below these elevations will be temporarily inundated during extreme tsunami and storm events. For the shallow depressions in central Anaura Bay occupied by 5 houses and the Motor Camp, flooding is likely to be enhanced during severe storms by runoff and peak flows in streams.

7 CONCLUSIONS

1. A standardised GIS computer model developed by the writer and implemented by Tauranga District Council on their Arc/Info GIS proved to be an internally consistent, sensitive and flexible model for assessing Coastal Hazard Zones for Gisborne District Council for the 2.95km and 3.2km-long shorelines of Tolaga and Anaura Bays, respectively.

2. Over the last 6,500 years the shorelines of Tolaga and Anaura Bays have advanced about 1,600m and 140m, respectively, from the combination of net tectonic uplift at about 0.4m/1000 years and accretion of sediments at about 0.25m/year and 0.02m/year, respectively.

3. Beach sand in Tolaga Bay is supplied mostly from the Uawa River during large floods compared to Anaura Bay sand, which is predominately, supplied from the nearshore seabed.

4. The Tolaga Bay sea-floor has shallowed by 2.4 to 6.7m since 1769 from sand and silt transported to the embayment by the Uawa River, the shallowing increasing in the centre of the Bay toward the River mouth. Sedimentation rates over the last 227 years 0f 10.6-29.5mm/year (1769-1996) are in good agreement with those of 10.6-16.3mm/year over the last 92 years (1904-1996).

5. The Anaura Bay sea-floor which has shallowed in places by 2.4 to 6.1m since 1769 at 10.6 to 26.9mm/year, is composed of patch reefs separated by a network of interconnecting sandy channels, the largest of which acts as a major conduit for the

supply of sand to the Northern third of the bay where it is distributed alongshore by wave action.

6. During the past century, the foredune complex in both Anaura and Tolaga Bays has been subject to episodic phases of short-term erosion-accretion involving up to about 110-180m^3 of sand per linear metre of duneline in Tolaga Bay and 35-285m^3 in Anaura Bay.

7. For the 2.95km-long Tolaga Bay shoreline, the long-term trend during the past century was accretion at 0.07 to 0.34m/year North of the Uawa River South of the River there was differential erosion at -0.13 to -0.41m/year and accretion at 0.05 to 0.11m/year along discrete stretches.

8. For the 3.2km-long Anaura Bay shoreline, the long-term trend during the past century was accretion at 0.15 to 0.19m/year North of Waipare Stream and erosion at -0.01 to -0.60m/year South of the Stream.

9. The entire Tolaga Bay and Anaura Bay shorelines are subject to and will continue to be subject to adverse effects from the identified natural hazards of minor wind erosion and major sea-erosion of the foredune complex enhanced by rising sea-levels next century, and significant temporary inundation of coastal hinterland from Tsunami up to 4-6m and Storm Wave Runup (SWRU) up to 5-7m during extreme events.

10. *Coastal Erosion Hazard Zone* (CEHZ) widths inclusive of *Extreme*, *High* and *Moderate Risk Zones* and *Safety Buffer Zones* ranged from 35 to 205m in width from the 1997 dune in Anaura Bay and 70 to 200m in Tolaga Bay, for a planning horizon from the present to the year 2100 A.D.

11. *Coastal Flood Hazard Zone* (CFHZ) widths inclusive of the effects of both a 4-6m Tsunami and 5-7m SWRU ranged in width from 14 to 225m in Tolaga Bay and 15 to 150m in Anaura Bay from the 1997 duneline for extreme events over the next century.

12. Within the *Extreme* to *Moderate Risk Erosion Zones* and CFHZ of the CHZ, property, assets, amenity and conservation values have a high probability of being damaged or destroyed at various periods over the next century (1998-2100 A.D.). Landward of the CHZ, the risk to these elements over the next 100 years is likely to be *very low*.

8 RECOMMENDATIONS

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

viii. *ADOPT* the 1998 *Coastal Hazard Zones* for Anaura Bay and Tolaga Bay inclusive of the *Extreme*, *High* and *Moderate Risk Erosion Zones* and *Safety Buffer Zone (Coastal Erosion Hazard Zone)* and *Coastal Flood Hazard Zone*, to control actual and potential use, subdivision and development, and to advise the public of actual and potential risks to beachfront property from natural coastal hazards.

ix. *INCORPORATE* the 1998 *Coastal Hazard Zones* for both Anaura Bay and Tolaga Bay into Councils 1997 *Proposed Regional Coastal Environment Plan* and *Proposed Gisborne District combined Regional Land and District Plan*.

x. *PROVIDE* for open days at selected venues in both Tolaga and Anaura Bays to disseminate both the findings of this study and Council's decisions with respect to managing use, subdivision and development within the 1998 *Coastal Hazard Zones*.

xi. *ESTABLISH* and maintain ongoing monitoring programmes in both Tolaga and Anaura Bays to record annual changes in the position of the shoreline and elevation of the nearshore seabed and to record the landward extent and elevations reached by both severe Storm Wave Runup and Tsunami events.

xii. *REVIEW* the 1998 *Coastal hazard Zones* using the GIS computer model either every 10 years, *OR* after the occurrence of significant natural phenomena (e.g. Severe wave storms, tsunami, large earthquakes, etc), *OR* after significant changes in global and regional Climate Predictions by the Royal Society of New Zealand and Intergovernmental Panel on Climate Change.

xiii. *IMPLEMENT* and support appropriate "*Coast Care*" programmes involving local communities to restore, enhance or maintain the protective foredune complex in both Tolaga and Anaura Bays.

xiv. *UTILIZE* the standardised GIS computer model used in this study to assess *Coastal Hazard Zones* for other priority coastal areas in Gisborne District including those areas previously assessed in Poverty Bay and Wainui Beach.

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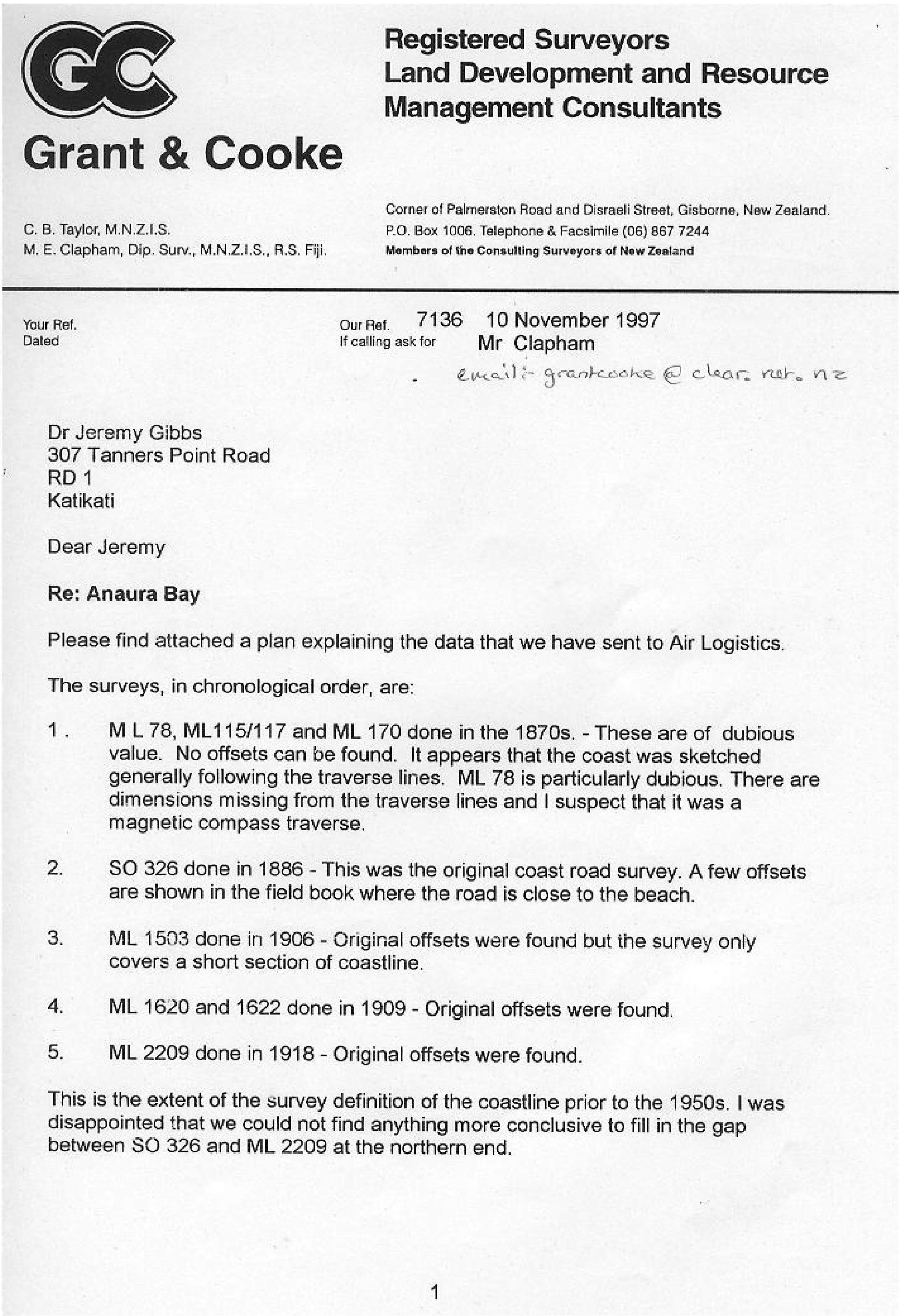
APPENDIX I

Survey Report by Grant & Cooke, Registered Surveyors, Gisborne, on Anaura Bay.



Registered Surveyors
Land Development and Resource
Management Consultants

Grant & Cooke

C. B. Taylor, M.N.Z.I.S.
M. E. Clapham, Dip. Surv., M.N.Z.I.S., R.S. Fiji.

Corner of Palmerston Road and Disraeli Street, Gisborne, New Zealand.
P.O. Box 1006. Telephone & Facsimile (06) 867 7244
Members of the Consulting Surveyors of New Zealand

Your Ref.
Dated

Our Ref. 7136 10 November 1997
If calling ask for Mr Clapham
email:- grantcooke@clear.net.nz

Dr Jeremy Gibbs
307 Tanners Point Road
RD 1
Katikati

Dear Jeremy

Re: Anaura Bay

Please find attached a plan explaining the data that we have sent to Air Logistics.

The surveys, in chronological order, are:

1. M L 78, ML115/117 and ML 170 done in the 1870s. - These are of dubious value. No offsets can be found. It appears that the coast was sketched generally following the traverse lines. ML 78 is particularly dubious. There are dimensions missing from the traverse lines and I suspect that it was a magnetic compass traverse.

2. SO 326 done in 1886 - This was the original coast road survey. A few offsets are shown in the field book where the road is close to the beach.

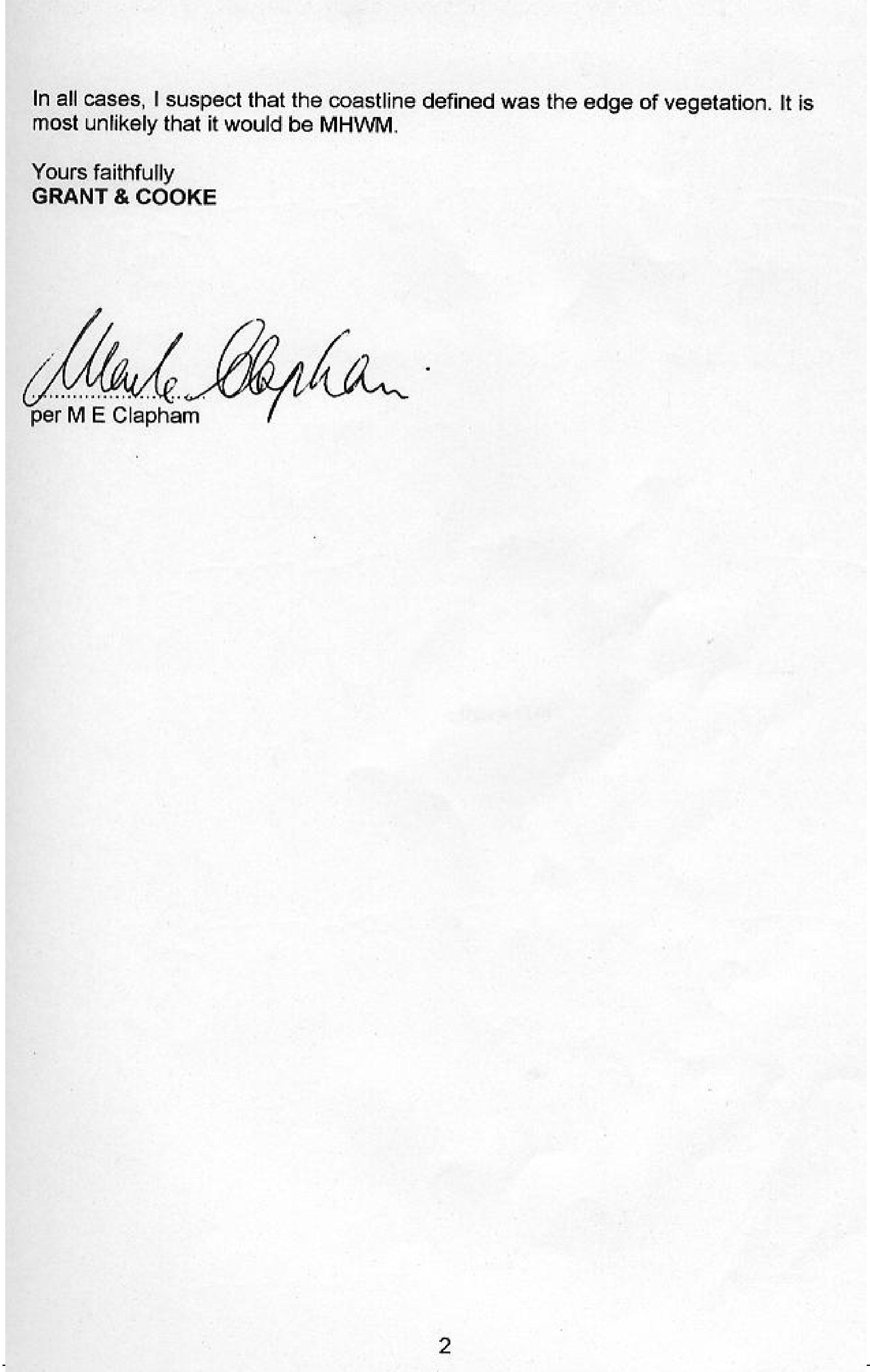
3. ML 1503 done in 1906 - Original offsets were found but the survey only covers a short section of coastline.

4. ML 1620 and 1622 done in 1909 - Original offsets were found.

5. ML 2209 done in 1918 - Original offsets were found.

This is the extent of the survey definition of the coastline prior to the 1950s. I was disappointed that we could not find anything more conclusive to fill in the gap between SO 326 and ML 2209 at the northern end.

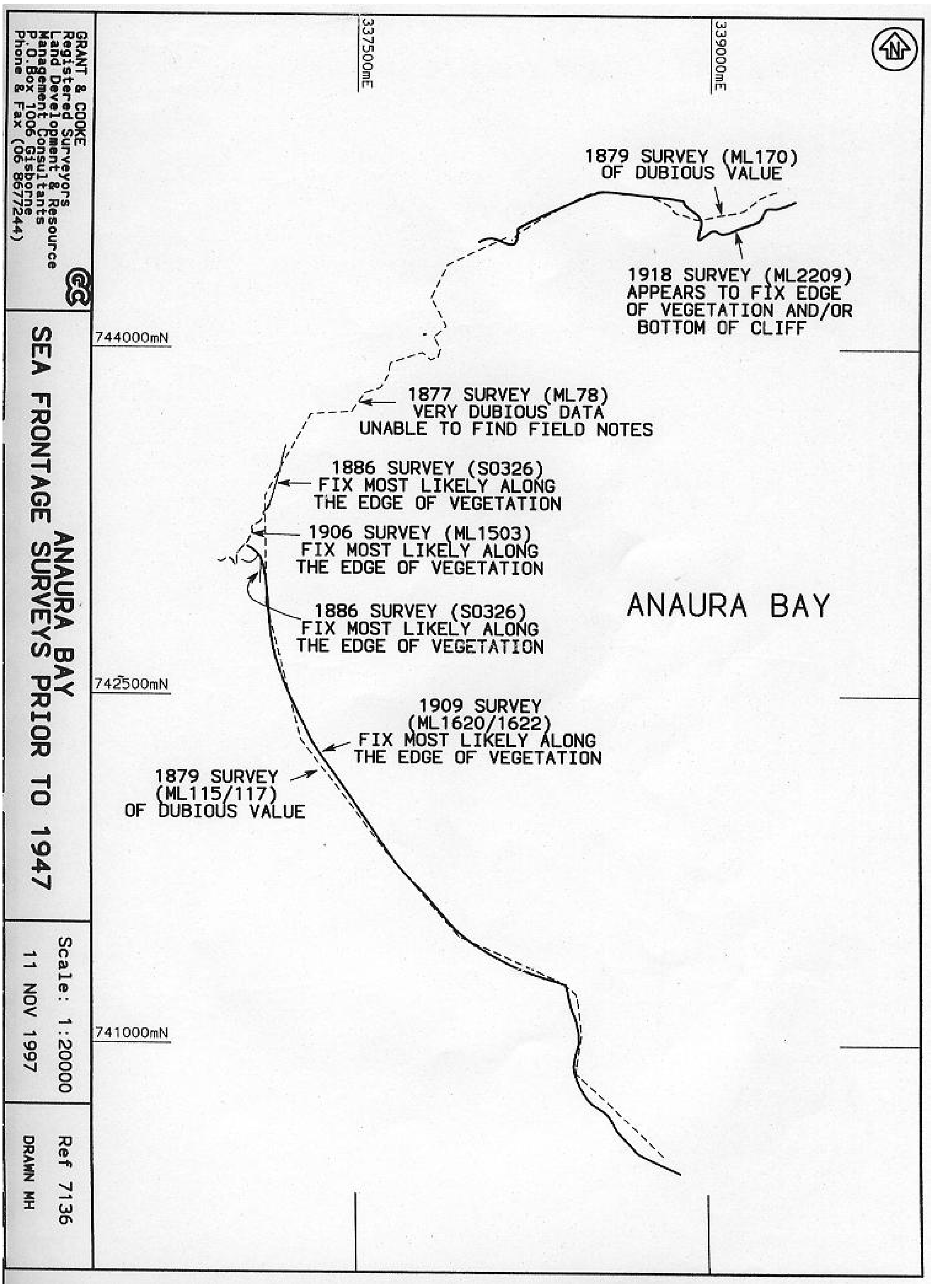
1



In all cases, I suspect that the coastline defined was the edge of vegetation. It is most unlikely that it would be MHWM.

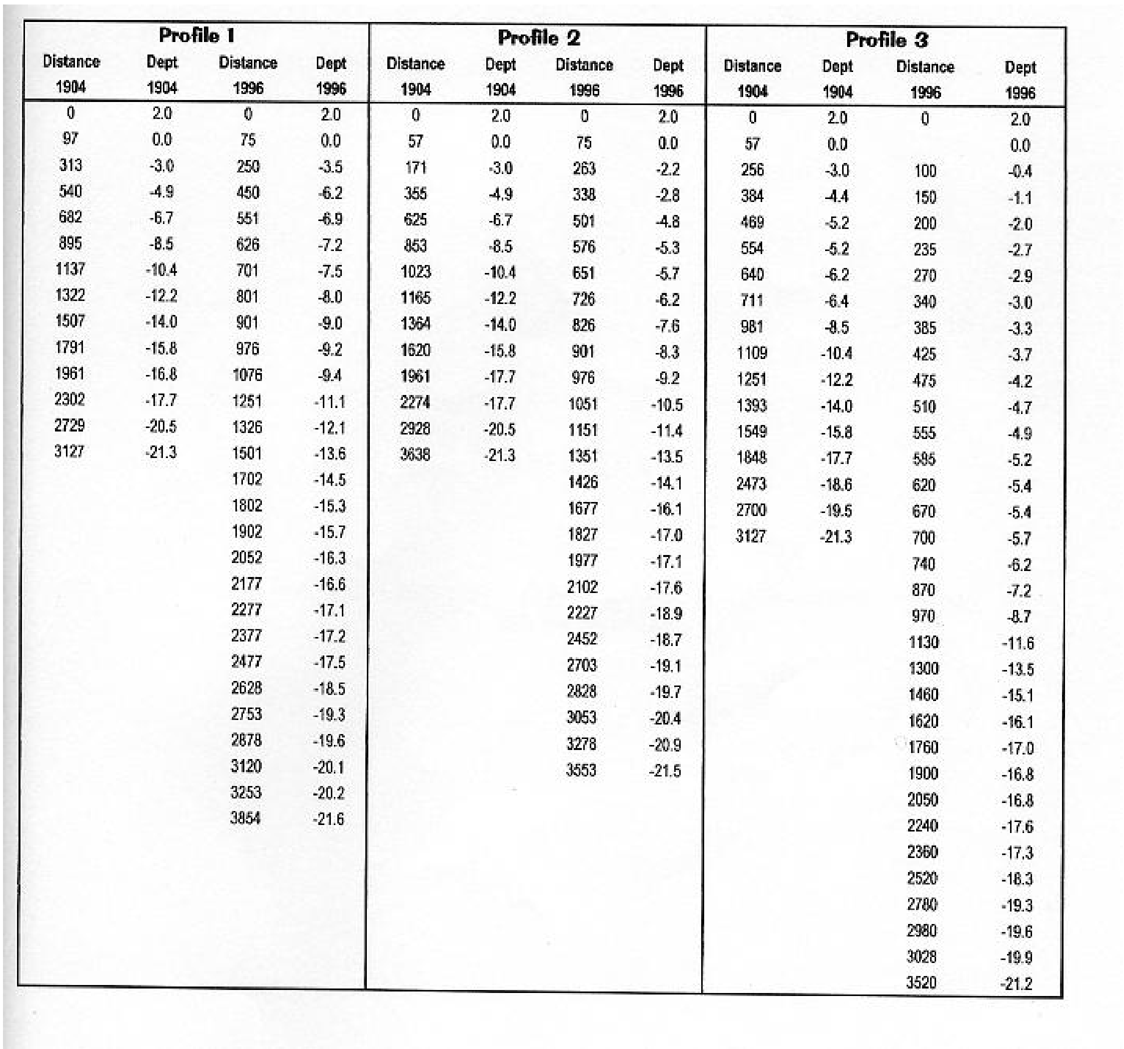
Yours faithfully
GRANT & COOKE

Merle Clapham
per M E Clapham


GRANT & COOKE
Registered Surveyors
Land Development & Resource
Management Consultants
P.O.Box 1006 Gisborne
Phone & Fax (06 8677244)
ANAURA BAY
SEA FRONTAGE SURVEYS PRIOR TO 1947
Scale: 1:20000
11 NOV 1997
Ref 7136
DRAWN MH
337500mE
339000mE
744000mN
742500mN
741000mN
1879 SURVEY (ML170) OF DUBIOUS VALUE
1918 SURVEY (ML2209) APPEARS TO FIX EDGE OF VEGETATION AND/OR BOTTOM OF CLIFF
1877 SURVEY (ML78) VERY DUBIOUS DATA UNABLE TO FIND FIELD NOTES
1886 SURVEY (S0326) FIX MOST LIKELY ALONG THE EDGE OF VEGETATION
1906 SURVEY (ML1503) FIX MOST LIKELY ALONG THE EDGE OF VEGETATION
1886 SURVEY (S0326) FIX MOST LIKELY ALONG THE EDGE OF VEGETATION
ANAURA BAY
1909 SURVEY (ML1620/1622) FIX MOST LIKELY ALONG THE EDGE OF VEGETATION
1879 SURVEY (ML115/117) OF DUBIOUS VALUE

APPENDIX II

Sounding Profile Data for Tolaga Bay.



Profile 1				Profile 2				Profile 3			
Distance 1904	Dept 1904	Distance 1996	Dept 1996	Distance 1904	Dept 1904	Distance 1996	Dept 1996	Distance 1904	Dept 1904	Distance 1996	Dept 1996
0	2.0	0	2.0	0	2.0	0	2.0	0	2.0	0	2.0
97	0.0	75	0.0	57	0.0	75	0.0	57	0.0		0.0
313	-3.0	250	-3.5	171	-3.0	263	-2.2	256	-3.0	100	-0.4
540	-4.9	450	-6.2	355	-4.9	338	-2.8	384	-4.4	150	-1.1
682	-6.7	551	-6.9	625	-6.7	501	-4.8	469	-5.2	200	-2.0
895	-8.5	626	-7.2	853	-8.5	576	-5.3	554	-5.2	235	-2.7
1137	-10.4	701	-7.5	1023	-10.4	651	-5.7	640	-6.2	270	-2.9
1322	-12.2	801	-8.0	1165	-12.2	726	-6.2	711	-6.4	340	-3.0
1507	-14.0	901	-9.0	1364	-14.0	826	-7.6	981	-8.5	385	-3.3
1791	-15.8	976	-9.2	1620	-15.8	901	-8.3	1109	-10.4	425	-3.7
1961	-16.8	1076	-9.4	1961	-17.7	976	-9.2	1251	-12.2	475	-4.2
2302	-17.7	1251	-11.1	2274	-17.7	1051	-10.5	1393	-14.0	510	-4.7
2729	-20.5	1326	-12.1	2928	-20.5	1151	-11.4	1549	-15.8	555	-4.9
3127	-21.3	1501	-13.6	3638	-21.3	1351	-13.5	1848	-17.7	585	-5.2
		1702	-14.5			1426	-14.1	2473	-18.6	620	-5.4
		1802	-15.3			1677	-16.1	2700	-19.5	670	-5.4
		1902	-15.7			1827	-17.0	3127	-21.3	700	-5.7
		2052	-16.3			1977	-17.1			740	-6.2
		2177	-16.6			2102	-17.6			870	-7.2
		2277	-17.1			2227	-18.9			970	-8.7
		2377	-17.2			2452	-18.7			1130	-11.6
		2477	-17.5			2703	-19.1			1300	-13.5
		2628	-18.5			2828	-19.7			1460	-15.1
		2753	-19.3			3053	-20.4			1620	-16.1
		2878	-19.6			3278	-20.9			1760	-17.0
		3120	-20.1			3553	-21.5			1900	-16.8
		3253	-20.2							2050	-16.8
		3854	-21.6							2240	-17.6
										2360	-17.3
										2520	-18.3
										2780	-19.3
										2980	-19.6
										3028	-19.9
										3520	-21.2

APPENDIX III

Long-term erosion-accretion rates and short-term duneline fluctuations for Tolaga Bay and Anaura Bay.

APPENDIX III

Tolaga Bay (Table IIIA) and Anaura Bay (Table IIIB) long-term erosion-accretion rates and short-term duneline fluctuations.

Columns

A = Stations identified on Air Logistics (NZ) Ltd Sheets (AL) at 1:2500 Scale.

B = Cumulative Distance in metres along the shore.

C = Lithologies of dunes or embankments.

D = Survey years derived from data sources in Column I.

E = Accretion or erosion (-) amounts tabulated as horizontal distance in metres (m) measured for each station from Air Logistic Sheets.

F = Rates of accretion or erosion in metres per year (m/y) for each survey interval.

G = Net rates (m/y) for entire survey period.

H = Maximum short-term duneline fluctuation in both cubic metres (m^3) of sand above MSL and corresponding horizontal distance in metres (m) from the duneline computed by GIS model and measured from TDC sheets.

I = Data sources from which rates were calculated.

	A	B	C	D	E	F	G	H		I
	STATION	CUMULATIVE DISTANCE	LITHOLOGY	SURVEY INTERVAL (y)	ACCRETION (+) or EROSION (-) (m)	RATE (m/y)	NET RATE (m/y)	DUNELINE FLUCTUATION (m^3)	(m)	DATA SOURCE
TABLE IIIA:										
TB.1	Tolaga Bay North	0	Loose Fine Sand	1893-1943	2	0.04				
				1943-1957	-8	-0.57				
				1957-1969	8	0.67				
				1969-1979	3	0.30				
				1979-1997	-5	-0.28	0.00	110	33	AL 2682-5, Sheet 1
TB.2	Large Urupa	200	Loose Fine Sand	1875-1943	0	0.00				
				1943-1957	-20	-1.43				
				1957-1969	15	1.25				
				1969-1979	21	2.10				
				1979-1997	-25	-1.39	-0.07	110	33	AL 2682-5, Sheet 1
TB.3	Tolaga Domain	400	Loose Fine Sand	1875-1943	7	0.10				
				1943-1957	-16	-1.14				
				1957-1969	12	1.00				
				1969-1979	17	1.70				
				1979-1997	-11	-0.61	0.07	125	37	AL 2682-5, Sheet 1
TB.4	Surf Club South	600	Loose Fine Sand	1875-1943	15	0.22				
				1943-1957	-22	-1.57				
				1957-1969	15	1.25				
				1969-1979	25	2.50				
				1979-1997	0	0.00	0.27	135	44	AL 2682-5, Sheet 1
TB.5	Tolaga Domain	800	Loose Fine Sand	1875-1943	20	0.29				
				1943-1957	-21	-1.50				

				1957-1969	8	0.67				
				1969-1979	35	3.50				
				1979-1997	-6	-0.33	0.30	135	42	AL 2682-5, Sheet 1
TB.6	Playing Field	1000	Loose Medium Sand	1875-1943	-15	-0.22				
				1943-1957	-17	-1.21				
				1957-1969	52	4.33				
				1969-1979	22	2.20				
				1979-1997	0	0.00	0.34	180	66	AL 2682-5, Sheet 1
TB.7	Uawa River Mouth North	1200	Loose Medium Sand	1875-1943	-33	-0.49				
				1943-1957	0	0.00				
				1957-1969	52	4.33				
				1969-1979	27	2.70				
				1979-1997	43	2.39	0.73	180	110	AL 2682-5, Sheet 1
UAWA RIVER MOUTH		1400								
TB.8	Tolaga Spit Tip	1550	Loose Medium Sand	1885-1943	154	2.66				
				1943-1957	-67	-4.79				
				1957-1969	-44	-3.67				
				1969-1979	-10	-1.00				
				1979-1997	-14	-0.78	0.17	160	70	AL 2682-5, Sheet 2
TB.9	Tolaga Spit North	1750	Loose Medium Sand	1885-1943	-25	-0.43				
				1943-1957	1	0.07				
				1957-1969	3	0.25				
				1969-1979	2	0.20				
				1979-1997	-27	-1.50	-0.41	180	60	AL 2682-5, Sheet 2

TB.10	Tolaga Spit North	1950	Loose Fine Sand	1885-1943	-40	-0.69				
				1943-1957	20	1.43				
				1957-1969	-4	-0.33				
				1969-1979	-6	-0.60				
				1979-1997	7	0.39	-0.21	180	50	AL 2682-5, Sheet 2
TB.11	Tolaga Spit Narrow	2150	Loose Fine Sand	1885-1943	-23	-0.40				
				1943-1957	2	0.14				
				1957-1969	-4	-0.33				
				1969-1979	10	1.00				
				1979-1997	11	0.61	-0.04	140	36	AL 2682-5, Sheet 2
TB.12	Tolaga Spit Centre	2350	Loose Fine Sand	1885-1943	-20	-0.34				
				1943-1957	-5	-0.36				
				1957-1969	-1	-0.08				
				1969-1979	19	1.90				
				1979-1997	-7	-0.39	-0.13	140	38	AL 2682-5, Sheet 2
TB.13	Tolaga Motor Camp	2550	Loose Fine Sand	1885-1943	-23	-0.40				
				1943-1957	-1	-0.07				
				1957-1969	4	0.33				
				1969-1979	14	1.40				
				1979-1997	18	1.00	0.11	140	38	AL 2682-5, Sheet 2
TB.14	Tolaga Motor Camp	2750	Loose Fine Sand	1885-1943	-19	-0.33				
				1943-1957	-5	-0.36				
				1957-1969	6	0.50				
				1969-1979	7	0.70				
				1979-1997	20	1.11	0.08	140	38	AL 2682-5, Sheet 2
TB.15	Tolaga Bay Wharf	2950	Loose Fine Sand	1885-1943	-12	-0.21				

APPENDIX III

Tolaga Bay (Table IIIA) and Anaura Bay (Table IIIB) long-term erosion-accretion rates and short-term duneline fluctuations.

Columns

A = Stations identified on Air Logistics (NZ) Ltd Sheets (AL) at 1:2500 Scale.

B = Cumulative Distance in metres along the shore.

C = Lithologies of dunes or embankments.

D = Survey years derived from data sources in Column I.

E = Accretion or erosion (-) amounts tabulated as horizontal distance in metres (m) measured for each station from Air Logistic Sheets.

F = Rates of accretion or erosion in metres per year (m/y) for each survey interval.

G = Net rates (m/y) for entire survey period.

H = Maximum short-term duneline fluctuation in both cubic metres (m^3) of sand above MSL and corresponding horizontal distance in metres (m) from the duneline computed by GIS model and measured from TDC sheets.

I = Data sources from which rates were calculated.

	A	B	C	D	E	F	G	H		I
	STATION	CUMULATIVE DISTANCE	LITHOLOGY	SURVEY INTERVAL (y)	ACCRETION (+) or EROSION (-) (m)	RATE (m/y)	NET RATE (m/y)	DUNELINE FLUCTUATION (m³)	(m)	DATA SOURCE
TABLE IIIA:										
TB.1	Tolaga Bay North	0	Loose Fine Sand	1893-1943	2	0.04				
				1943-1957	-8	-0.57				
				1957-1969	8	0.67				
				1969-1979	3	0.30				
				1979-1997	-5	-0.28	0.00	110	33	AL 2682-5, Sheet 1
TB.2	Large Urupa	200	Loose Fine Sand	1875-1943	0	0.00				
				1943-1957	-20	-1.43				
				1957-1969	15	1.25				
				1969-1979	21	2.10				
				1979-1997	-25	-1.39	-0.07	110	33	AL 2682-5, Sheet 1
TB.3	Tolaga Domain	400	Loose Fine Sand	1875-1943	7	0.10				
				1943-1957	-16	-1.14				
				1957-1969	12	1.00				
				1969-1979	17	1.70				
				1979-1997	-11	-0.61	0.07	125	37	AL 2682-5, Sheet 1
TB.4	Surf Club South	600	Loose Fine Sand	1875-1943	15	0.22				
				1943-1957	-22	-1.57				
				1957-1969	15	1.25				
				1969-1979	25	2.50				
				1979-1997	0	0.00	0.27	135	44	AL 2682-5, Sheet 1
TB.5	Tolaga Domain	800	Loose Fine Sand	1875-1943	20	0.29				
				1943-1957	-21	-1.50				

				1957-1969	8	0.67				
				1969-1979	35	3.50				
				1979-1997	-6	-0.33	0.30	135	42	AL 2682-5, Sheet 1
TB.6	Playing Field	1000	Loose Medium Sand	1875-1943	-15	-0.22				
				1943-1957	-17	-1.21				
				1957-1969	52	4.33				
				1969-1979	22	2.20				
				1979-1997	0	0.00	0.34	180	66	AL 2682-5, Sheet 1
TB.7	Uawa River Mouth North	1200	Loose Medium Sand	1875-1943	-33	-0.49				
				1943-1957	0	0.00				
				1957-1969	52	4.33				
				1969-1979	27	2.70				
				1979-1997	43	2.39	0.73	180	110	AL 2682-5, Sheet 1
UAWA RIVER MOUTH		1400								
TB.8	Tolaga Spit Tip	1550	Loose Medium Sand	1885-1943	154	2.66				
				1943-1957	-67	-4.79				
				1957-1969	-44	-3.67				
				1969-1979	-10	-1.00				
				1979-1997	-14	-0.78	0.17	160	70	AL 2682-5, Sheet 2
TB.9	Tolaga Spit North	1750	Loose Medium Sand	1885-1943	-25	-0.43				
				1943-1957	1	0.07				
				1957-1969	3	0.25				
				1969-1979	2	0.20				
				1979-1997	-27	-1.50	-0.41	180	60	AL 2682-5, Sheet 2

TB.10	Tolaga Spit North	1950	Loose Fine Sand	1885-1943	-40	-0.69				
				1943-1957	20	1.43				
				1957-1969	-4	-0.33				
				1969-1979	-6	-0.60				
				1979-1997	7	0.39	-0.21	180	50	AL 2682-5, Sheet 2
TB.11	Tolaga Spit Narrow	2150	Loose Fine Sand	1885-1943	-23	-0.40				
				1943-1957	2	0.14				
				1957-1969	-4	-0.33				
				1969-1979	10	1.00				
				1979-1997	11	0.61	-0.04	140	36	AL 2682-5, Sheet 2
TB.12	Tolaga Spit Centre	2350	Loose Fine Sand	1885-1943	-20	-0.34				
				1943-1957	-5	-0.36				
				1957-1969	-1	-0.08				
				1969-1979	19	1.90				
				1979-1997	-7	-0.39	-0.13	140	38	AL 2682-5, Sheet 2
TB.13	Tolaga Motor Camp	2550	Loose Fine Sand	1885-1943	-23	-0.40				
				1943-1957	-1	-0.07				
				1957-1969	4	0.33				
				1969-1979	14	1.40				
				1979-1997	18	1.00	0.11	140	38	AL 2682-5, Sheet 2
TB.14	Tolaga Motor Camp	2750	Loose Fine Sand	1885-1943	-19	-0.33				
				1943-1957	-5	-0.36				
				1957-1969	6	0.50				
				1969-1979	7	0.70				
				1979-1997	20	1.11	0.08	140	38	AL 2682-5, Sheet 2
TB.15	Tolaga Bay Wharf	2950	Loose Fine Sand	1885-1943	-12	-0.21				

				1943-1957	-2	-0.14				
				1957-1969	8	0.67				
				1969-1979	-4	-0.40				
				1979-1997	16	0.89	0.05	140	50	AL 2682-5, Sheet 2

TABLE IIIA:

AB.1	Anaura Bay North	0	Alluvium	1877 survey unreliable		-	-			
				1957-1997	-5	-0.13	-0.13	-	5	AL 2682-15, Sheet 1
AB.2	Anaura Woolshed	200	Loose Fine Sand	1877 survey unreliable		-	-			
				1886-1957	13	0.18				
				1957-1997	8	0.20	0.19	55	18	AL 2682-15, Sheet 1
AB.3	Waipare Homestead	400	Loose Fine Sand	1877 survey unreliable		-	-			
				1886-1957	7	0.10				
				1957-1997	10	0.25	0.15	60	24	AL 2682-15, Sheet 1
AB.4	Anaura Domain	600	Fluvium/Sand	1877 survey unreliable		-	-			
				1906-1957	24	0.47				
				1957-1997	38	0.95	0.68	185	84	AL 2682-15, Sheet 1
WAIPARE STREAM		730								
AB.5	Waipare Stream South	800	Loose Fine Sand	1877 survey unreliable		-	-			
				1909-1957	-70	-1.46				
				1957-1997	70	1.75	0.00	285	100	AL 2682-15, Sheet 1

AB.6	Maize Field	1000	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	9	0.19				
				1957-1997	9	0.23	0.20	170	47	AL 2682-15, Sheet 1
AB.7	Anaura Bay Centre	1200	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-30	-0.63				
				1957-1997	0	0.00	-0.34	170	60	AL 2682-15, Sheet 1
AB.8	Five Houses	1400	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-30	-0.63				
				1957-1997	10	0.25	-0.23	125	38	AL 2682-15, Sheet 1
AB.9	Creek Mouth North	1600	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-45	-0.94				
				1957-1997	10	0.25	-0.40	124	40	AL 2682-15, Sheet 1
AB.10	Paddock	1800	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-15	-0.31				
				1957-1997	2	0.05	-0.15	65	22	AL 2682-15, Sheet 1
AB.11	Paddock	2000	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-7	-0.15				
				1957-1997	0	0.00	-0.08	65	25	AL 2682-16, Sheet 2
AB.12	Hawai Stream North	2200	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-30	-0.63				
				1957-1997	-10	-0.25	-0.45	85	32	AL 2682-16, Sheet 2

HAWAI STREAM		2200								
AB.13	Motor Camp	2400	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-25	-0.52				
				1957-1997	-28	-0.70	-0.60	65	25	AL 2682-16, Sheet 2
WAITAHOATA STREAM		2500								
AB.14	Waitahoata Stream South	2600	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	-3	-0.06				
				1957-1997	-1	-0.03	-0.05	100	31	AL 2682-16, Sheet 2
AB.15	Hinetamatea Marae	2800	Loose Fine Sand	1879 survey unreliable		-	-			
				1909-1957	0	0.00				
				1957-1997	-2	-0.05	-0.02	65	23	AL 2682-16, Sheet 2
AB.16	Batches	3000	Alluvium	1879 survey unreliable		-	-			
				1909-1957	0	0.00				
				1957-1997	-1	-0.03	-0.01	35	15	AL 2682-16, Sheet 2
AB.17	Batches	3100	Alluvium	1879 survey unreliable		-	-			
				1909-1957	-9	-0.19				
				1957-1997	-7	-0.18	-0.18	35	10	AL 2682-16, Sheet 2
AB.18	Stranded Seacliff	3200	Tertiary Rock	1879 survey unreliable		-	-			
				1909-1957	-15	-0.31				
				1957-1997	-10	-0.25	-0.28	35	8	AL 2682-16, Sheet 2