PROJECT DUNE WATCH

COASTAL HAZARD RISK ASSESSMENT BETWEEN MAUAO AND PAPAMOA, TAURANGA DISTRICT, BAY OF PLENTY

Report prepared for Tauranga Disbid Council

April 1996

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EXECUTIVE SUMMARY

This report provides the basis to determine Coastal Hazard Zones (CHZs) by a computer model incorporated into Tauranga District Council's Arr/Info Geographic Information System. The computer model is a new approach that provides internally consistent outputs, is sensitive to local variations along the coast, allows for revising parameters from new information, and is designed to be easily used by Council staff. The model also has the capacity to satisfy the public interest by providing Coastal Hazard Risk Zones for one or several beachfront properties. The gathering and interpretation of scientific evidence for this study has been considerably enhanced by substantial contributions from local residents.

Geology

1. The 13.9km-long study area coastline comprises a Medium to Fine quartzo-feldspathic sand beach of primarily volcanic origin, bordering a 2 to 6km-wide coastal plain of sand dunes constructed during the last 7,000 years during a relatively stable sea-level.

2. During the last 2,000 years the duneline has advanced about 70 to 80m seaward as the coast approaches a state of dynamic equilibrium, with rates of advance of 0.07 to 0.14m/year being recorded over the last 700 years.

3. Over the last 51 to 106 years, the 13.9km-long study area duneline has generally advanced from sand accretion at rates of 0.03 to 0.51 m/year, punctuated from time to time by differential episodic short-term duneline fluctuations.

4. Papamoa cuspate foreland and the Mount Maunganui and smaller Moturiki tombolos are landforms that have formed over the last 2 to 3,000 years and were fully established by 1852. These landforms have formed in the wave shadows cast by Mauao, Moturiki, Motuotau, and Motiti Islands, which act collectively and individually as giant offshore breakwaters.

5. Between Mauao and Papamoa Domain the longshore drift of sand out to about 20m water depth is mostly oscillatory with a tendency to flow to the southeast. Between the Kaituna River mouth and Papamoa Domain there is a net northwesterly longshore drift, both currents converging at the Domain.

6. The -8.5m depth contour below MSL represents the seaward limit of extreme surf related processes and the maximum depth of active sediment transport by yearly extreme waves, defines the seaward boundary of the Nearshore Transport Zone (NTZ) and is composed of medium to fine beach sand. Seaward of the NTZ the seabed is composed of fine to very fine sand out to about -23m.

7. A discontinuous longshore bar-trough system exists along the entire coastline between Mauao and Papamoa Township and is actively involved in onshore-offshore sand exchanges.
with the beach. There is a higher probability of erosion of the beach and foredune adjacent to areas of nearshore seabed where the longshore bar is absent.

**Shoreline Movements**

8. Over the last 79 years the 2.69km-long duneline along Papamoa Township has shown differential trends ranging from dynamic equilibrium (0.0m/year) in the southeast, to very slow erosion up to -0.06m/year along southeastern Karewa Parade and the Papamoa Recreation Reserve, to advance of 0.06m/year to 0.42m/year along northeastern Karewa Parade, Motiti and Taylor Roads. Over the last 51 to 72 years the 0.60km-long duneline along Papamoa Domain has advanced at 0.1m to 0.33m/year.

9. Over the last 51 to 106 years the 10.6km-long duneline between Te Ara Place and Mauao has generally advanced at 0.01 to 0.51m/year, with long-term retreat of -0.08 to -0.13m/year being recorded near Surf Road and the centre of Main Mount Beach, and dynamic equilibrium (0.0m/year) between Tay and Clyde Streets and near Adams Avenue.

10. Short-term duneline fluctuations occur along the entire 13.9km-long study area coastline involving maximum volumes of dunesand of the order of 140 to 250m$^3$ per metre length of duneline.

**Sand Dunes**

11. Of the 13.9km-long foredune complex in the study area, 12% is presently under extreme stress, 43% is under high stress, 38% is under moderate stress and 7% is under low stress.

12. The low stressed foredune is relatively well vegetated with dune binding species, has a natural dune profile with crest heights 6 to 7m above MSL and a crestline 15 to 25m inland from the 1994 duneline position. It is representative of the natural foredune in the 13.9km-long study area.

13. The moderate to extremely stressed foredunes have a very high sensitivity to erosion and flooding from the sea, whereas the low stressed foredune has a relatively lower sensitivity and is able to adequately absorb the effects of such hazards.

**Natural Hazards**

14. The identified coastal hazards along the 13.9km-long study area coastline include sea and wind erosion and flooding from the sea.

15. The entire 13.9km-long sand dune is subject to both wind erosion and short-term, episodic duneline fluctuations involving some 50 to 250m$^3$ of dunesand per metre length of duneline.
16. Although there is a general trend of historic duneline advance, minor long-term retreat at the very low rates of -0.02 to -0.13m/year has occurred over the last 50 to 100 years along southeastern Karewa Parade, the reserve between Karewa Parade and Motiti Road, adjacent to Surf Road and in central Main Mount Beach.

17. Maximum storm wave runup levels of the order of 5 to 7m above MSL have occurred in the past and have a high probability of occurring over the next 100 years along the entire open-exposed coastline.

18. Where the crest of the foredune is generally less than 5m above MSL, there is a high probability that low-lying coastal hinterland will be adversely affected by temporary saltwater inundation. Tsunami has not posed a flood hazard along the coast in historical times.

19. Climate Change from an enhanced Greenhouse Effect is forecast to cause an increase in the frequency and magnitude of severe onshore wave storms and an acceleration in the rate of historic sea-level rise from 1.2mm/year to 3.6mm/year by 2050 A.D., and 4.7mm/year by 2100 A.D.

20. An increase in both wave storminess and the rate of sea-level rise will increase the magnitude of historic short-term duneline fluctuations and cause a reversal from a long-term trend of very slow shoreline advance or dynamic equilibrium, to long-term shoreline retreat up to -0.26m/year.

Coastal Hazard Zone (CHZ) Assessment

21. The Coastal Hazard Zone (CHZ) assessed in this study incorporates both a Coastal Erosion Hazard Zone (CEHZ) and a Coastal Flood Hazard Zone (CFHZ) along the 13.9km-long study area coastline.

22. The CEHZ ranges in width from about 40 to 100m and comprises an Extreme Risk Erosion Zone (EREZ) of 21 to 53m width, a High Risk Erosion Zone (HREZ) of 0 to 15m width, a Moderate Risk Erosion Zone (MREZ) of 0 to 22m width, and a Safety Buffer Zone (SBZ) of 9 to 20m width.

23. Although the EREZ and SBZ exist along the entire coast, both the HREZ and MREZ are discontinuous and exist only in areas where the predicted erosion rates from projected rises of sea-level of 0.20m by 2050 A.D. and 0.49m by 2100 A.D. exceed the long-term historical accretion rates.
24. Adopting higher or lower parameters for the GIS computer model significantly increases or decreases CEHZ widths respectively. CEHZ widths recommended in this study are regarded as conservative.

25. The CFHZ comprises a High Risk Flooding Zone (HRFZ) delineated by the Sm contour above MSL Moturiki Datum and a Moderate Risk Flooding Zone (MRFZ) delineated by the 6.5m contour.

26. The CFHZ is discontinuous along the entire coast and does not exist where the crest of the foredune equals or exceeds 6.5m above MSL.

**Recommendations**

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

1. RECEIVE and adopt the findings of this report.

2. ADOPT the conservative Coastal Erosion Hazard Zones, inclusive of the Extreme, High and Moderate Risk Erosion Zones and Safety Buffer Zone for the 13.9km-long study area coastline between Mauao and Papamoa Township east, assessed by the GIS computer model in this study.

3. ADOPT storm wave runup elevations for the study area coastline of Sm above MSL to define a High Risk Flooding Zone, and 6.5m above MSL to define a Moderate Risk Flooding Zone to delineate a Coastal Flood Hazard Zone between Mauao and Papamoa Township, on Council's Digital Terrain Model of the dunes.

4. INCORPORATE the Coastal Hazard Information as appropriate into both Council's District Plan and Land and Property Information Memoranda, to both control use, subdivision and development in the CEHZ and to advise the public of both long-term and short-term risks to beachfront property from natural hazards.

5. ESTABLISH and maintain an ongoing Physical Coastal Monitoring Programme between Mauao and Papamoa Township (see S.35, Resource Management Act 1991) in conjunction with Environment BOP, to provide the necessary information to revise, as appropriate, the parameters incorporated into the GIS computer model.

6. PROMOTE a research programme aimed at reliably quantifying the active sediment budget in the Nearshore Transport Zone including the processes responsible for sediment transport between the Kaltuna River mouth and the Tauranga Harbour Entrance.

7. REASSESS the Coastal Hazard Zones defined by the GIS model every 10 years using the same factors used in this assessment, OR after the occurrence of significant natural phenomena (e.g. large wave storms, tsunami, etc.), OR after significant new information becomes available (e.g. Climate Change and sea-level rise, monitoring programme, etc.), OR after significant improvements in the state of the foredune (e.g. dune conservation and restoration, beach replenishment, Dune Care Programme, etc.),

8. ADOPT appropriate policies and rules in the District Plan to promote land uses compatible with the identified coastal hazards within the Coastal Hazard Zone to avoid
and mitigate damage to assets and the coastal environment from such hazards, and
to restore and maintain the integrity of the protective foredune.

9. COMMISSION the establishment of an integrated holistic Coastal Management
Strategy for the long-term sustainable management of the open-exposed physical
coastal system between Mauao and the Kaituna River mouth, including its nationally
significant amenity and conservation values.
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by

Jeremy G Gibb

PART I : BACKGROUND

Figure 1: Location of the 3 areas for Coastal Hazard Zone assessment
INTRODUCTION

On 11 August 1995, the writer was commissioned by the Tauranga District Council (Council) to undertake a "coastal hazard risk assessment for the open exposed coastline between Mount Maunganui and Papamoa". Coastal Hazard Zones (GHZ) inclusive of Extreme, High and Moderate Risk Zones, and Safety Buffer Zones were to be assessed for 3 developed areas over 13.9km of coastline between Mauao (Mount Maunganui) and Papamoa. The 3 areas are shown on Figure 1 and include:

(i) Mauao to 273 Papamoa Beach Road.
(ii) Domain Road area between 500 and 560 Papamoa Beach Road.
(iii) Papamoa Township area between 1009 and 1340 Papamoa Beach Road.

Because of the importance to hazard mitigation of sand dunes along the study area the project was aptly named "Dune Watch".

In accordance with the "Proposed Regional Coastal Environment Plan" (Environment BOP 1995), the GHZ assessments were requested by Council to include the following "Standards and Criteria" set out in Section 13.2.4(b)(i) of Volume 1 of the proposed plan.

"The following standards and criteria apply to all calculations of Indicative Coastal Hazard Areas (ICHA) and Actual Coastal Hazards Areas (ACHA):

- **Erosion impacts of sea level rise:** This will use the IPCC (1990) Bau best estimate.

- **Shoreline response to storm erosion:** This will need to incorporate the use of scientifically appropriate models, such as those based on (but not restricted to) the Bruun Rule.

- **Planning horizon:** This will be 100 year.

- **Long term trend:** This will be derived from cadastral, aerial photographic and/or GPS surveys - the datum adopted will be the toe of the foredune where these landforms occur, or elsewhere will be the seaward limit of vegetation or some other datum as appropriate.

- **Short term fluctuation:** This will be derived from the most reliable records available at the time for particular stretches of the coast, and shall err on the side of caution.

- **Dune stability factor:** This will be based on the angle of repose (AOR) of dunesands as defined on a local basis.

- **Factor of Safety:** The Coastal Hazard Area assessments will include an appropriate factor of safety, either built into one or more of the above criteria and standards or added on as a final stage in the calculation.

- **All profiles (cross-sections) shall be surveyed to Registered surveyors' standards. All levels shall be in terms of mean sea level to Moturiki datum."
CHA are to be assessed and surveyed to a level of precision appropriate for the exercise of control by district councils, to be determined in consultation with Environment BOP.

ACHA are to be assessed and surveyed to define the specific actual coastal hazard area for each building site. At least one profile should be taken for each building site.

For this study, Council made available its computer-based Arc/Info Geographic Information System (GIS), Digital Terrain Model (DTM), and Digital Cadastral Database (DCDB) which encompassed the study area coastline down to 0.00m Mean Sea Level (MSL) Moturiki Datum (1953). The GIS was used to assess the CHZs as a layer of information for application by Council staff for coastal planning and development matters.

This report is organised into three parts: Background; The Evidence; and, Hazard Assessment. The Background section describes the history of past Coastal Hazard Mapping in the Tauranga District along with the methods adopted for this study. The Evidence section provides a summary of observations by long-standing local residents and attempts to describe and quantify where appropriate, the geology, sand dunes, nearshore seabed, and shoreline movements. The Hazard Assessment section describes and quantifies the identified and potential natural hazards and provides a CHZ assessment. The report concludes with recommendations for consideration for adoption by Tauranga District Council. The report and the accompanying computer-derived Coastal Hazard maps were peer reviewed in Australia by a practising expert (Appendix IV).

COASTAL HAZARD MAPPING IN TAURANGA DISTRICT

The history of Coastal Hazard Mapping along the open-exposed Tauranga District coastline is summarised by Gibb (1995b). 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 1981). Identified hazards included sea and wind erosion, flooding from storm wave runup, tsunami and coastal rivers, and landslip.

The standardised Coastal Hazard Mapping techniques including those for calculating CHZ, 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).

Coastal Hazard Zones were measured as a horizontal distance inland from the "seaward toe of foredune or seaciff", 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 some 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 1995b).

The history of Coastal Hazard Mapping along the Tauranga District Council coast has been piecemeal to say the least (Gibb 1995b). In 1980 the writer was commissioned by Mount Maunganui Borough to assess a CHZ for the south eastern extension of the
Borough. The assessment covered a 1,710m-long stretch of undeveloped sand dunes at that time of which 1,415m lay in Mount Maunganui Borough and 295m in Tauranga County. A "100-year hazard line" was drawn as "a straight line approximating the position of the inland toe of the foredune", ranging in distance "from 60 to 83m inland from the 1981 seaward toe of the foredune generally averaging about 70m" (Gibb 1982). The "100-year hazard line" so drawn was plotted on cadastral maps at 1:1000 and 1:2000 scales with respect to property and road boundaries. Today, the CHZ encompasses the southeastern 330m of Oceanbeach Road, all of Sunbrae Grove, the adjacent Maori land, and all of Pacific Shores residential development.

Following formal adoption of the CHZ by Mount Maunganui Borough Council on 15 September 1981 and incorporation into its District Scheme Review as Proposed Foreshore Reserve Designation, the matter went to appeal before the Planning Tribunal. In its final decision (J.H. Troughton and Ors. v. Mt Maunganui B.C., A53/82, April 1982), Judge Shepherd stated that: We are satisfied that ...... the provision made in the district scheme should preclude building or other development which would disturb the surface of the land. Firstly, it is desirable that the physical form of the ground be conserved in its natural form - both intrinsically, and to enable the foredune to perform its natural functions. Secondly, any buildings there would be in danger of damage from flooding and erosion. We are also concerned that any development may have an adverse effect on the susceptibility to erosion damage of the other lands on either side.

Judge Shepherd went on further to state; "we are satisfied that the boundary which was shown in the proposed review was determined responsibly by an overall judgment of the nature, extent and degree of risk involved". The Tribunal ruled that; ".the extent to which the subject land is vulnerable to erosion and flooding is..." sufficient to justify the proposed foreshore reserve ".extending the full width to the line defined on the planning map...". Today, the area within the CHZ is Coastal Reserve designated as Recreation Reserve (Gibb 1995b).

Despite the fact that the 1982 CHZ endorsed by the Planning Tribunal encompassed the area of land to be developed for the Pacific Shores beachfront development in the 1980s, the developer, Kiwi Coast Developments, commissioned a further assessment by Healy (1988). For that assessment, Healy recommended a 75 to 80m-wide CHZ along the 150m-long beachfront. The recommended width generally conformed with the CHZ determined by Gibb (1982) of 60 to 83m for the same area.

In 1992, Council and Environment BOP commissioned the Centre for Environmental and Resource Studies (GEARS), Waikato University, to make CHZ assessments for two selected areas of coast. The first area (1,830m in length) began at the intersection of Marine Parade and Oceanbeach Road, ending at 217 Oceanbeach Road, Omanu. The second area (2,920m in length) began at Taylor Reserve, Papamoa, ending at Majori Lane, Papamoa. The "reference shoreline" for both assessments was the seaward toe of the foredune (Kay et al. 1994).

For both Omanu and Papamoa, Kay et al. (1994) adopted a "two-zone management approach". Zone A was defined as "subject to, or is likely to be subject to, coastal erosion within the next 100 years". For Zone A, CHZ widths of 70 and 74m were assessed for Omanu and Papamoa respectively. Zone B was defined as "possibly subject to coastal erosion within the next 100 years". For Zone B, CHZ widths of 91 and 97m were assessed for Omanu and Papamoa respectively. Tauranga District Council have adopted the 70 and 74m-wide CHZs for the control of subdivision and development at Omanu and Papamoa (Craig Batchelor, Acting Director of Planning, Tauranga District Council, pers. comm. 1995).
Kay et al. (1994) also evaluated the risk from sea flooding for Omanu and Papamoa from storm surge and dune washover. The design storm-surge level adopted was 5.5m above MSL. The "potential flood area" was identified as the area of land below the 5.5m contour. For Papamoa, a high percentage of Coastal Reserve was found by Kay et al. (1994) to be below the 5.5m elevation whereas for Omanu only selected areas are below. Tauranga District Council have adopted the 5.5m contour line to identify potential flood hazard areas along the open-exposed coast (Craig Batchelar, pers. comm. 1995).

In 1994, the writer was commissioned by a number of individual beachfront property owners along Oceanbeach Road to assess risk from sea erosion, wind erosion and flooding from the sea (Gibb 1994a-<l>). For all assessments the CHZ was subdivided into Extreme, High and Moderate Risk Erosion Zones and a Safety Buffer Zone. CHZ widths ranged from 50 to 65m inland from the seaward toe of the foredune. For flood hazard, the 6m contour was adopted where appropriate to define low-lying areas subject to inundation from the sea during Wahine-type storms.

The Extreme Risk Erosion Zone represented the area adversely affected by short-term dune line fluctuations, ranging in width from 35 to 41 m inland from the dune line (seaward toe of foredune). The High Risk Erosion Zone encompassed the area subject to shoreline retreat from a "best estimate" sea-level rise of 0.3m (NZCC 1990; IPCC 1990) above the present by 2050 AD., ranging in width from 2 to 9m. The Moderate Risk Erosion Zone encompassed the area subject to shoreline retreat from a "best estimate" sea-level rise of 0.66m (IPCC 1990) above the present by 2100 AD., ranging in width from 5 to 15m. The Safety Buffer Zone encompassed the area representing the uncertainties in the factors used to determine the entire CHZ, ranging in width from 5 to 10m.

For the areas not covered by the CHZ assessments of Gibb (1982) and Kay et al. (1994), Tauranga District Council are currently implementing hazard controls within an adopted 70m-wide distance from the toe of the foredune along Oceanbeach Road and within 74m at Papamoa (Craig Batchelar, pers. comm. 1995). For the entire open-exposed Tauranga District coastline, Council presently allow property owners to commission their own assessment of risk from coastal hazard if they do not accept the 70 and 74m-widths. Examples of individual property assessments are those of Gibb (1994a-<l>).

In 1994, the Bay of Plenty Regional Council commissioned the writer to define "Areas Sensitive to Coastal Hazards" (ASCHs) for almost all of the regions open-exposed coastline between Lottin Point to the east and Orokawa Bay to the west (Gibb 1994e). The defined ASCHs deliberately err on the side of caution and thus have relatively large safety factors built into the assessments. According to the Regional Council's "Proposed Regional Coastal Environment Plan" (Environment BOP 1995), the ASCH does not formally constitute a CHZ but rather indicates that any subdivision or development proposal within the area of land encompassed by the ASCH "would require a more detailed hazards analysis". In this context, the ASCHs are early warning instruments of the need for a more precise hazard assessment along the coast such as those by Gibb (1982) and Kay et al. (1994). ASCH widths ranged from 150m along Marine Parade up to 170m at Papamoa Beach (Gibb 1994e).

In total, only 6.46km of the 13.9km-long study coastline between Mauao and southeastern Papamoa is encompassed by professionally assessed CHZs. In contrast, the entire coast is covered by the more general ASCHs which are presently incorporated into the Regional Council's "Proposed Regional Coastal Environment Plan" (Environment BOP 1995).
METHODS

In contrast to previous methods used for GHZ assessments by Gibb (1982), Healy (1988), Kay et al. (1994) and Gibb (1994a-d), a different approach was adopted in this study. In the Willer's knowledge, this is the first time that the following integrated approach has been undertaken in New Zealand. The steps involved were:

I. A public relations campaign at the outset aimed at keeping Council, agencies and beachfront residents periodically informed of the study's progress through the local media news, information pamphlets, and public presentations. Project "Dune Watch" included a specially designed logo for communications with the public and the establishment of a project office in Tauranga.

II. Acquisition of anecdotal information from studies of early photographs of the coast and interviews with long-standing local residents.

III. Designing, testing and standardising a flexible computer model for application by Tauranga District Council's Arc/Info Geographic Information System (GIS) for generating Coastal Hazard Zones at a scale of one or many properties.

IV. Acquisition of professionally defensible scientific data from surveys and relevant literature, to input parameters into the computer model. Literature cited in this study is listed in the References.

The computer model, including its development, is described by Prouse (Appendix I). The initial development and testing of the model was carried out by the author with Colin Mills, (GIS Analyst Programmer, Tauranga District Council). Final development, standardising and application of the model was carried by Harley Prouse, GIS Consultant, Geographic Technologies Unit, Auckland UniServices Ltd., with the writer. The basis of the computer model is shown in Figure 2A. The essential features of the model included:

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

II. **Sensitivity.** The model is sensitive to variability in the various parameters along the coast such as dune and nearshore topography, duneline fluctuations, long-term shoreline trends, and flooding from the sea. In this sense it is sensitive to the physical natural character.

III. **Flexibility.** The model allows for individual parameters to be changed if required, upon acquisition of better information. Such information could arise from continuing monitoring programmes, new scientific research, changes in forecasts of climatic effects from an enhanced Greenhouse Effect, or from the effects of coastal management schemes such as possible beach replenishment or the current Dune Care programme co-ordinated by Council.

IV. **User Friendly.** Council staff processing applications for building permits and coastal subdivisions will be able to retrieve CHRZs at the scale of one or many properties on computer terminals. Existing and intending property owners will be able to obtain hard copies at Council's Public Counter.
COASTAL EROSION HAZARD ZONE (CEHZ)

Primary Dune

Secondary Dunes

ZONE OF EXTREME RISK

$X = \text{rate of shore retreat from sea-level rise using Bruun Rule}$

$A = \text{long-term rate of natural retreat}$

$T = \text{assessment period}$

$S = \text{maximum storm cut}$

$F = \text{safety factor of 30\%}$

$D = \text{slope stability factor}$

where: $D = \tan \theta / 0.5$

whence: $v = \gamma$

NEARSHORE TRANSPORT ZONE (NTZ)

$X(d+h) = a l$

Where: $a = a'$

$v = v'$

Coastal Erosion Hazard Zone

$2050$

$2100$

Safety Buffer Zone

Moderate Risk

High Risk

Extreme Risk

Erosion Zone

Erosion Zone

Erosion Zone

Erosion Zone

duneline

*Figure 2: A: CEHZ Assessment technique for sandy coasts. B: Bruun Rule quantifying responses of NTZ to rising sea-level. C: Risk Zones and Safety Buffer Zone comprising the CEHZ for planning horizons of up to 2050 and 2100 A.D. CHZ (Adapted from Gibb 1995c, fig. 8).*
V. Policy Basis. The Coastal Hazard Risk Zones provide a framework for Council to draft and apply appropriate policies for coastal management in their District Plan. The Risk Zones graduated from Extreme to Moderate, provide an opportunity both for a policy framework to control building work and to allow for effective dune conservation along the coast.

The parameters included in the model are shown in Figure 2. Defining these parameters involved quantifying the:

1. Volume of dune sand involved in the maximum potential short-term fluctuation in the seaward toe of the foredune (duneline).

2. Long-term shoreline trend of either seaward advance of the duneline, landward retreat, or a state of dynamic equilibrium in which there is no discernible trend of either advance or retreat (Figure 3).

3. Potential effects on the duneline of an acceleration in the present rate of local relative sea-level (RSL) rise next century using the Bruun Rule (Bruun 1962; 1983) (Figure 2B).

4. Safety Factor to accommodate uncertainties in the above parameters.

5. Maximum elevation of either storm-wave or tsunami wave runup above MSL Moturiki Datum to determine potential areas prone to flooding from the sea from contours.

Figure 2C shows that the framework for the assessments includes Risk Zones and a Safety Buffer Zone. The Extreme Risk Erosion Zone encompasses the area subject to the maximum potential short-term duneline fluctuation. The High Risk Erosion Zone encompasses the area subject to combination of the effects of a long-term trend of erosion and/or sea-level rise up to the year 2050 A.D. The Moderate Risk Erosion Zone encompasses the area subject to one or the combination of the effects of the long-term erosion trend and/or sea-level rise up to the year 2100 A.D. The Safety Buffer Zone accommodates the uncertainties and is proportionate in width to the total width of the Coastal Risk Erosion Zones.
Input of Local Residents

The observations of 24 long-standing residents between Mauao and Papamoa (see Acknowledgements) since 1930s were recorded from interviews. Contact with local residents commenced by the writer following up responses to early information releases about the project through the local media news. These residents were interviewed, often recommending other local contacts in the process. Many of these were followed up by the combination of telephone and on-site interviews, sometimes involving site inspections and studies of early photographs of the coast dating from 1902 held by residents.

A draft summary of the residents' observations was produced and sent to 14 for feedback. The draft was subsequently revised to produce the summary of observations provided in Part II of this report.

Long-Term Trend

Long-term shoreline trends and short-term duneline fluctuations may be discerned for most parts of New Zealand from survey and geologic data spanning the last several millennia. Comparisons of historical shoreline positions reveal long-term trends of either shoreline advance, retreat, or dynamic equilibrium where there is no discernible trend of either advance or retreat. The long-term trend is not regular or constant but is the resultant of a series of episodic positive or negative short-term movements (Figure 3).

In 1980, the writer commissioned the Survey Section of the Hamilton District Office of Ministry of Works and Development (MWD) to compare historic shoreline positions between Mount Maunganui and Matata at the same scale from early cadastral and vertical aerial photographic surveys from which long-term shoreline trends and possible short-term shoreline fluctuations could be quantified. The work was carried out under the supervision of Mr John H Abum, Chief Surveyor, and the results plotted on 42 sheets at 1:2,000 Scale entitled, "MWD - Water and Soil - Foreshore Information, Mount Maunganui - Matata, Foredune and MHWM Information. Job 21398/5, Code 3204, Sheets 1-42". Sheets 1 to 14 cover the study area coastline. The 42 sheets are held by both Environment BOP and the Department of Conservation Bay of Plenty Conservancy. Sheets 1 to 14 cover the study area coastline.

As part of the 1980 MWD study, a controlled aerial survey of the coast between Mount Maunganui and the Tarawera River mouth was completed in 1981. The 42 Sheets were completed in February 1982 with some amendments being made in December 1985. In 1994, the 42 Sheets were updated by Environment BOP under the writer's direction to include the present position of the duneline, fixed by Environment BOP on the ground by a Geographic Positioning System (GPS) to an accuracy of ±1.8m, as part of a regional coastal hazards survey (Gibb 1994e). The sheets show the relative position of Mean High Water Mark (MHWM) between 1888 and 1981 and the duneline between 1943 and 1994.

Although the historic shoreline positions were carefully plotted on the MWD plans, there is a potential problem with the definition of MHWM used by the early surveyors for their cadastral surveys. Extensive analyses of cadastral survey by Gibb (1978)
revealed that early surveyors in New Zealand generally selected one of 7 different reference shorelines during the past century for fixing the "seaward boundary of the land" (Figure 4).

As the study area is a sandy shore, one of reference shorelines 1 to 6 (Figure 4) would have been adopted by early surveyors in the past. Gibb (1978) found from his nationwide study that "the seaward limit of land vegetation has been the most commonly preferred shoreline". To shed light on this problem the writer commissioned N.M. McBride, registered surveyor, Shrimpton and Lipinski Limited, Tauranga, to determine the relative MHWMs adopted by the early surveyors. His findings are reported in Appendix I and were taken into account in quantifying the long-term trends in Appendix III and in Part I of this report.

**Figure 4:** Seven reference lines used by New Zealand land surveyors to define the shoreline (MHWM) on cadastral plans over the period 1870-1995: 1 = Geodetic MHWS (average height of the high tides over an 18.6yr period); 2 = "Wetted" line; 3 = Driftwood line; 4 = Toe or foredune or seaciff; 5 = Vegetation line; 6 = Crestline of beach ridge or foredune; and 7 = Top edge of seaciff. (Adapted from Gibb 1978, fig.1).

**Short-Term Fluctuation**

The short-term fluctuation is the maximum potential short-term duneline fluctuation possible within the study area, independent of the long-term trend. Short-term duneline retreat may occur in response to one or a cluster of severe onshore wave storms, followed by duneline recovery and short-term advance as low swells bring the sand back to the shore. The volume of sand in m$^3$ per metre length of beach involved in such fluctuations was determined from the combination of geologic and anecdotal evidence, field surveys, historic shoreline offsets recorded on Sheets 1 to 14 of the MWD Survey Plans, and from Council's GIS and DTM for selected profiles along the coast. A summary of short-term fluctuations is provided in Part I of this report.
Sea-Level Rise Effects

The parameters required to run the Bruun Rule (Figure 2B) to assess the effects of sea-level rise were derived from the combination of Council's GIS, field surveys, the recent projections by the Intergovernmental Panel on Climate Change (IPCC), and from previous studies in the Bay of Plenty. The position and height of the crest of the foredune complex was determined from the combination of the pattern of contours at 1m interval on Council's DTM and from field observations. The precise position of the duneline was determined from the 1994 GPS survey by Environment BOP incorporated into Council's GIS. The position and depth of the seaward limit of the Nearshore Transport Zone (closure depth) was determined in September 1995 from a hydrographic survey and digitised and incorporated into Council's GIS.

Horizontal distances from the creaseline of the foredune to the closure depth were determined by the GIS. The most recent projections of sea-level rise up to the year 2100 A.O. by the IPCC in 1995/96, were supplied courtesy of Associate Professor Richard Warrick, Centre for Environmental and Resource Studies (GEARS), of the University of Waikato (Warrick, in press).

Nearshore Transport Zone Boundaries

The topography of the nearshore seabed in the study area was surveyed in September 1995 between Mount Maunganui and Papamoa east by the Port of Tauranga survey vessel "Kairuri IV" under the command of Owen Maynard, Hydrographer. Nine profile lines at right angles to the coast were surveyed from the Mount to about 950m east of Motuotau Island extending from about -2m to -30m water depths. From Motuotau Island to about 700m east of Papamoa, 52 profile lines were surveyed in a continuous sawtooth pattern along the coast from about -2m to -13m depths. In addition, 7 profiles were surveyed in the same area at right angles to the coast between about -2m and -25m depths. All depths were normalised in terms of MSL Moturiki Datum.

During the hydrographic survey, the position of the vessel was continuously fixed to an accuracy of ±1.0m by a Racal Micro-Fix System in terms of the Bay of Plenty Meridional Circuit, Geodetic Datum 1949. Micro-Fix stations were established on accurately surveyed geographic positions at Papamoa, Mount Drury, Kopukairoa, and Minden Trig and the vessel's position fixed every few seconds. Continuous soundings of the seabed were recorded to an accuracy of ±0.1m by an Atlas Deso 20 Echo Sounder and the distorting effects of swell heights were removed from the bottom trace by a TSS 3208 Heave Compensator. During the survey the sea was generally smooth with little wind and a ground swell of 0.5 to 1.5m.

All normalised depths were digitised and analysed by the Hydrographic Services branch of the Port of Tauranga Ltd. Thirteen representative profiles between Main Mount Beach and Papamoa were plotted at horizontal and vertical scales of 1:2,000 and 1:50, respectively. In addition, the Geographic Technologies Unit of Auckland UniServices produced bathymetric maps of the area from the digitised data, in terms of the NZ Map Grid at scales ranging from 1:10,000 up to 1:100,000. The bathymetry was generated by a vector-to-raster algorithm known as MING at a contour interval of 1m.
Sea-Flooding

Elevations of both storm wave runup and tsunami wave runup were determined from the geologic and historical records, adding projected sea-level rise for the next century to obtain design wave runup levels. The record includes anecdotal observations by local informants, published scientific literature and reports, and geologic field evidence.

CHRZ Assessment

The GIS computer model was developed, tested and standardised once the above parameters had been incorporated. From the model, Risk Zones and a Safety Buffer Zone were derived on Photomaps at 1:2,000 Scale, based on the fully rectified 1992 vertical aerial photography, to encompass the 13.9km-long study area between Mauao and Papamoa.
PART II : THE EVIDENCE

OBSERVATIONS BY RESIDENTS

The following is a summary of observations of the study area coastline compiled from interviews with 24 long-standing local residents listed in the Acknowledgements:

Wave Storms

I. The 1930s and 1940s were characterised by a large number of very strong "3 day" easterly storms which persisted through until the late 1950s to early 1960s. There have been no severe wave storms over the last 20 years.

II. In 1942 storm wave runup during a northeasterly storm overtopped the foredune at Adams Avenue trickling down the road to Pilot Bay.

III. About May 1953 storm wave runup during an easterly storm washed through the lower terrace of the Mount Maunganui Domain Motor Camp and caused erosion of the foredune at Papamoa.

IV. On 10 April 1968 seas during the Wahine storm overtopped the foredune in many places causing several metres of erosion. At Papamoa Domain the sea deposited logs around the Changing Sheds. The onshore storm was short duration, lasting only 4 to 6 hours during the small hours of the morning. After the Wahine Storm the dunes took several years to recover.

V. About 1970 a severe onshore wave storm overtopped the foredune opposite 24 Taylor Road, washing around the house down on to the road. The foredune between 20 and 24 Taylor Road had been bulldozed and lowered by a previous owner.

VI. The last known severe storm to cause widespread erosion of the foredune occurred in July 1978. Since then other storms of lesser magnitude such as Cyclone Bola in 1988 have occurred causing localised erosion.

VII. Wave storms that erode the dunes came from the north to northeast quadrant. When the wind swings offshore into the west to southwest quadrant the beach and dunes build up again.
VIII. Motiti Island and its associated reefs acts as a giant offshore breakwater creating a wave shadow on the coast protecting Papamoa from the full impact of wave storms from the northeast quadrant. Papamoa, however, is exposed to wave storms from the north and easterly quadrants.

**Ocean Currents and Longshore Drift**

I. Papamoa Domain is the meeting place of currents resulting in most water-borne material being deposited on the shore in this area.

II. The longshore current out to about 20m water depth mostly flows to the northwest between the Kaituna River mouth and the Papamoa Domain.

III. From Papamoa Domain to Mauao the longshore current is mostly oscillatory with a tendency to flow to the southeast.

IV. Northwest of Mauao the longshore drift is always to the northwest with drifting material accumulating midway along Matakana Island in the le of Karewa Island.

V. Offshore, the ocean current tends to flow to the west up to 2 knots but may stop for a period, reverse or flow in the same direction as before. Some believe the ocean current velocity has decreased markedly since about 1980 whilst others have not noticed any difference.

VI. During northeasterly wave storms the nearshore ocean current flows strongly to the west. During a severe storm in the early 1970s, crayfish pots set in 48m (26fathoms) water depth 2 nautical miles (nm) west of Motiti Island were transported 0.5nm west and filled with bottom shell debris.

**Shoreline Movements**

I. Since 1902, the beach has steadily advanced from accretion at the west end of Main Mount Beach. Donkey Rock (Figure 1) which used to stand 2 to 2.5m clear of the beach in the 1930s was just showing in the 1950s and is now completely buried. A 20m-long rock revetment constructed about 10m seaward of the end of Adams Avenue in the 1930s is now completely buried.
II. The foredune has generally advanced and increased in height between Moturiki and Tay Street since 1941. From Tay Street to about 300 Oceanbeach Road the foredune has advanced 5 to 10m since 1965.

III. From about 300 Oceanbeach Road to Papamoa, there has been no perceptible change in the position of the duneline since 1941 and the duneline has remained in a state of dynamic equilibrium.

IV. The recent accretion from Moturiki to the southeastern end of Oceanbeach Road is regarded by some as transient on the basis of past erosion episodes in the late 1930s and 1940s and by others as a permanent long-term trend of advance that will continue.

V. Typical short-term duneline fluctuations of ±20m occur between Moturiki and Tay Street, with maximum fluctuations up to ±40m occurring in more sensitive areas such as adjacent to stormwater outlets.

VI. Opposite "Sharf Alley", the foredune was trimmed back up to 14m in 1992 leaving a 2m-high erosion scarp.

VII. At Papamoa Township, the duneline retreated by about 5m adjacent to Nos 4 and 6 Taylor Road during a severe wave storm about 1970. Since that time the duneline has advanced to its former position.

VIII. In May 1995, a 'storm bite' developed between Nos 39 and 61 Motti Road, Papamoa Township, along approximately 230m of foredune. By January 1996, the duneline had retreated a maximum of 8 to 9m adjacent to 53 to 55 Motti Road from the combined effects of a moderate ENE wave storm on 14 July 1995 and during smaller ENE wave storms in December 1995 and January 1996. The duneline adjacent to the 'storm bite' has not moved over the same period.

IX. Episodes of short-term erosion tend to concentrate on selected lengths of foredune often leaving adjacent lengths untouched. The areas subject to such erosion are random in occurrence.

X. Residential development along the foredune since the 1960s and Marine Parade has disrupted wind patterns reducing the effects of westerly winds eroding the foredune, thus promoting accretion.
XI. Since the 1940s the seabed between the shore and Motuotau Island has shallowed by about 1.0 to 1.3m and by about 0.6m around the rocks in "Shark Alley" (Figure 1), possibly from dumping of dredged sand offshore by the Tauranga Harbour Board and the Port of Tauranga Limited.

Dune Modification

I. Rock revetments were constructed to arrest sea erosion at; Main Mount Beach at the end of Adams Avenue in the 1930s (20m); along the Mount Maunganui Domain Motor Camp in the 1960s (180m); Papamoa Domain in the 1970s in front of the Carpark (80m); and, at Papamoa at 149 Karewa Parade and by 4 and 6 Taylor Road in the early 1970s. In addition, a 15m-long limber seawall was built in the 1960s to protect the Surf Observation Tower at Papamoa Domain.

II. In 1995, all the rock revetments and limber seawalls were buried under the sand as a result of accretion over the last 2 decades and windblown sand building behind these barriers.

III. Bulldozing and levelling of the foredune occurred with Local Authority's consent at; Main Mount Beach and along parts of Marine Parade in the 1960s to provide easy public access to the beach and views of the sea for residents; at Surf Road in the 1960s for the Omanu Surf Lifesaving Club building and public carpark; at Papamoa Domain in the 1960s and 1970s to provide a public carpark and camping areas at Papamoa Beach Holiday Park.

IV. As a consequence, all the levelled and grassed areas are adversely affected by windblown sand during strong onshore and alongshore winds.

V. At Papamoa the dunes were levelled in 1956 between Taylor Reserve and the southeastern end of Karewa Parade to fill the bed of the Wairaki Stream and provide suitable building sites for houses.

VI. As a consequence, the Wairaki Stream has difficulty discharging on to the beach and properties in the old stream depression are adversely affected by flooding during rain storms especially in Taylor Road. At present the stream is discharged by underground pipes boosted by pumps on to the beach adjacent to 1 Taylor Road and in Taylor Reserve.

VII. Planting of dunes with sand binding vegetation by property owners in the past has stabilized the dunes, resulting in them increasing in height and volume.
VIII. Many residents at the Mount believe that the action of beach grooming is exacerbating the problem of wind blown sand being transported inland at Main Mount Beach, through disturbance of the surface of the beach allowing air into it resulting in drying and loosening of sand grains.

IX. Stormwater outlets discharging onto the beach liquify sand, preventing natural accretion fronting the outlets, and causing localised dune erosion.

GEOLOGY

The 25.5km-long open-exposed sand shore coastline administered by Tauranga District Council between Mount Maunganui (Mauao) and the Kaijuna River mouth is part of a 30km-long sand shore slung between Mauao and Okurei Point (Town Point) near Maketu. The consolidated rock promontories of Mauao and Okurei Point act as strong points effectively supporting the unconsolidated sedimentary, generally concave-shaped sand shore between.

Mauao, Mount Drury, Moturiki Island, Mussell Rocks and Motuotau (Rabbit) Island at the northern end of the study area are the remnants of lava domes, formed by the upwelling and outpouring of viscous rhyolite lava about four million years ago during the Late Tertiary Period (Moore 1994). The hard and erosion resistant volcanic rocks are described as Minden Rhyolites (Healy et al. 1964).

Apart from Motuotau Island the other volcanic outcrops are linked together by a sand plain that has accumulated above sea-level over the last few thousand years to form a coastal landform termed a tombola. The 13.9km-long sand beach of the study area between Mauao and Papamoa Township east borders a 2 to 6km-wide coastal plain. The plain is formed from belts of sand dunes separated in places by peaty swales, constructed over the last 7,000 years during the Holocene Epoch (Healy et al. 1964).

Sediments

The Medium to Fine "quartzo-feldspathic" sand which characterises the beaches and dune complexes is predominantly of volcanic origin and includes volcanic glass, heavy minerals and broken shell supplied from the seabed (Healy et al. 1977; Dahm and Healy 1985). The sand was mostly laid down on the seabed during violent volcanic eruptions from sources in Taupo and Rotorua. The last major volcanic eruption that would have supplied significant quantities of sand to the Bay of Plenty coastal zone was the Taupo Eruption that occurred about 200 A.D (Bells et al. in press). Over the last 7,000 years the volcanic-derived sand on the seabed is thought to have been transported by wave action to the coast to construct the present coastal plain.

Sediment Transport

The dune belts in the study area are formed of sand supplied from the adjacent seabed and alongshore sources (Healy et al. 1977; Healy 1980; Dahm 1989). Sand has been observed to be transported shoreward on to the beach from depths of 14 to 20m but more commonly from depths of 4 to 8m (Foster et al. 1991; Port of Tauranga Lid 1991). In addition, sand is transported along the coast by wave generated longshore currents (Figure 5) generated by oblique wave attack, from sources such as the Tauranga Harbour ebb-tide delta to the northwest and the Kaituna River to the southeast (Healy 1980). The
amount of sand supplied to the coast by the latter is unknown, but it is generally thought to be very small (Greg Pemberton, Environment BOP, pers. comm. 1995).

The predominant longshore transport direction of sand is thought to be to the southeast (Healy et al. 1977; Healy 1980; Dahm 1989) and the rate is thought to be of the order of 10,000 to 50,000 m\(^3\)/year (Healy 1980; Dahm and Healy 1985; Dahm 1989). The accumulation of 120,000 m\(^3\) of sand along the eastern edge of the Entrance Channel from the shore out to 14.5 m water depth over the last 18 months (Mr G. Thompson, Design Engineer, Port of Tauranga Ltd., pers. comm. 1995) indicates a northwest longshore transport rate of 80,000 m\(^3\)/year counter to the supposed net southeast drift. These observations suggest an oscillatory longshore drift in the study area may predominate. A southeasterly longshore drift would be generated by waves from the W-N quadrant and a northwesterly drift from waves from the NE-E quadrant. During a short duration cyclonic storm on 24 January 1996 the writer observed a longshore current to the northwest along the entire beach between Papamoa and Mauao.

**Geologic Evolution**

About 18,000 years ago, Planet Earth was in the grip of an Ice Age widely known as the Last Glaciation. About 14,000 years ago, global climate started to warm resulting in the melting of the great ice sheets smothering much of the Northern Hemisphere continents and Antarctica. In response to global warming of 4-5 °C from 14,000 to about 8,000 years ago, global sea-level rose approximately 130 m to reach the present sea-level about 7,000 years ago (Gibb 1986; Moore 1994).

During the period of rapid sea-level rise, there was widespread coastal retreat everywhere around New Zealand as the rate of sea-level rise (10-1 1 mm/yr) outpaced tectonic uplift of the coast (Gibb 1980). The study area is recognised as being of relative tectonic stabilny (Kay et al. 1994).

As the rising sea invaded the coastal valleys and basins in the Tauranga area, Mauao, Drury, Moturiki, and Mussell Rocks became islands separated from the mainland coast by the sea. In the course of coastal evolution Farquhar (1967) has concluded there are three things that can happen to such islands:

1. They may remain about the same size for a very long time;

11. they can be eroded gradually until they cease to exist; or

III. they may be joined to each other or to an adjacent coast.
Where they are joined to other areas of land, the link is usually provided by sand or shingle bars. These are called tombolos which have the general effect of straightening the coast (Farquhar 1967). The occurrence of airfall volcanic ashes (tephra) and sea rafted Taupo pumice on the sand dunes indicates that the Mount Maunganui tombolo has probably formed over the last 2 to 3,000 years, which is very recent in geologic terms. As the coastline advanced into the Bay of Plenty another smaller tombolo formed linking Moturiki Island to the Main Mount beach. The Mount Maunganui and smaller Moturiki tombolos are recorded on the earliest charts of the area dating from 1852 (Figure 6).

East of the Mount tombolo the 7,000 year shoreline is located approximately along the line of State Highway 2 at the base of the hills. Seaward of the Highway, tephra and associated sea-rafted pumice laid down following volcanic eruptions over the last 7,000 years provide useful indicators of the evolution of the shoreline to its present position.

Figure 6: Part of the first Chart of Tauranga Harbour surveyed by Commander Byron Drury RN, on HMS Pandora in 1852, showing the Mt Maunganui tombolo (Adopted from Gibb 1995a, fig.1).

Figure 7: Longitudinal cross-section through the sand dunes surveyed in 1981, about 200m SE of Sunbrae Road, showing the history of coastal advance over the last 2,000 years (Adopted from Gibb 1995b, fig.1).

About 200m southeast of Sunbrae Road, tephra exposed in a cut for the sewer outfall through the 21 Sm-wide dune complex between Papamoa Beach Road and...
the beach provided an excellent record of the evolution of the coast over approximately the last 2,000 years (Figure 7). The cut described by Gibb (1982), revealed Taupo ash and pumice erupted about 200 A.D., Kaharoa ash erupted about 1350 A.D., and Tarawera ash erupted in 1886.

Table 1 shows a continuous advance of the duneline at this site over the last 1,800 years with rates ranging from 0.02m/year (200 to 1350 A.D.) up to 0.64m/year (1981-1995). The highest rates of advance from accretion occurred between 1886 and 1943 (0.58m/year) and between 1981 and 1995 (0.64m/year). Although the position of the duneline in 1886 is inferred it was surveyed in 1943, 1981 and 1995. In total, the duneline has advanced only 86m at a very low net rate of 0.05m/year (5cm/year) over approximately the last 1,800 years.

<table>
<thead>
<tr>
<th>SURVEY INTERVAL (A.D.)</th>
<th>PERIOD</th>
<th>DUNELINE ADVANCE OR RETREAT (m)</th>
<th>RATE (m/yr)</th>
<th>NET RATE (m/yr)</th>
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<td>0.03</td>
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</tr>
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<td>1981-1995</td>
<td>14</td>
<td>9</td>
<td>0.64</td>
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<tr>
<td>200-1995</td>
<td>1795</td>
<td>86</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 1:** Rates of duneline advance over the last 1,800 years for a site located 200m southeast of Sunbrae Road about midway along the study coastline.

Additional field evidence is provided at Hanisons Cut and in a dune blowout and about 1km east of Marjori Lane, Papamoa. At Hanisons Cut, Kaharoa Ash terminates about 100m from the present duneline suggesting 100m accretion over the last 600 years at a net rate of 0.17m/year. East of Papamoa, Kaharoa Ash terminates about 50m from the duneline indicating a net rate of advance of 0.08m/year. The very low net rates of duneline advance of 0.07 to 0.17m/year over the last 600 years suggest parts of the 12km-long coastline between Sunbrae Road and Marjori Lane may have reached or be slowly approaching a state of dynamic equilibrium. This situation may not be representative of the state of the coastline between Sunbrae Road and Mauao.

Although generally concave in planform at a scale of 1:250,000, the 30km-long coastline between Mauao and Okurei Point features two sections that are convex at a larger scale of 1:50,000. At Main Mount Beach, the coastline has a pronounced convex bulge with its apex in the lee of Motuotau Island. At Papamoa Beach, the coastline has a gentle convex planform with its apex in the lee of Motiti Island.
As for similar coastal landforms occurring elsewhere around New Zealand, such as the Kapiti District Coastline west of Wellington, both landforms in the study area are thought to be low cuspate fore/ands that have grown in the wave shadows cast by Motuotau and Motiti Islands, respectively. Such wave shadows reduce the transporting power of breaking waves, enhancing the deposition and accretion of sand, resulting in the growth of cuspate fore/ands toward the island. In this sense, the islands act as giant offshore breakwaters.

Summary

1. The 13.9km-long study area coastline comprises a Medium to Fine quartzo-feldspathic sand beach of primarily volcanic origin, bordering a 2 to 6km-wide coastal plain of sand dunes constructed during the last 7,000 years during a relatively stable sea-level.

2. During the last 1,800 years the duneline has advanced about 86m seaward as the coast slowly approaches a state of dynamic equilibrium between Sunbrae Road and Marjori Lane, with rates of advance of 0.07 to 0.17m/year being recorded over the last 600 years. The most probable source of sand is the nearshore seabed.

3. Papamoa cuspate fore/and and the Mount Maunganui and smaller Moturiki tombolos are landforms that have formed over approximately the last 2 to 3,000 years and were fully established by 1852. These landforms have formed in the wave shadows cast by Mauao, Moturiki, Motuotau, and Motm Islands, which act collectively and individually as giant offshore breakwaters.

4. Between Mauao and Papamoa Domain the longshore drift of sand out to about 20m water depth is mostly oscillatory with a slight tendency to flow to the southeast. Between the Kaituna River mouth and Papamoa Domain there is a net northwesterly longshore drift, both currents converging at the Domain.

SAND DUNES

During periods of shoreline advance successive foredunes may develop forming a series of dunes parallel to the shore. The seaward toe of a foredune is trimmed back by storm waves. During calm weather waves build up a new beach ridge in front of and parallel to the original foredune. As the new beach ridge develops a low lying swale is formed between the developing ridge and the original foredune. Dune grasses colonise the new beach ridge, accumulate wind blown sand, and a new foredune is created (BPA 1981). This is how the 2 to 6km-wide coastal plain in the study area has evolved over the last 7,000 years.

Foredunes are built up at the back of beaches on the crests of berms where vegetation or other obstructions trap wind blown sand. They become higher and wider as sand deposition continues. Onshore winds of sufficient velocity to move sand particles erode sand from the dry parts of the beach and export it landward. Wind action effectively sorts the original beach material. The small particles may be completely removed from the beach/dune area while the largest particles remain (BPA 1981).
Importance of dune vegetation

Vegetation plays a predominant role in determining the size, shape and stability of foredunes. The aerial parts of the vegetation obstruct the wind and absorb wind energy. Wind velocity near vegetation is thus reduced below that needed for sand transport and the sand deposits around the vegetation. A characteristic of dune vegetation such as the native dune-binding grasses of *Spinifex* and *Pingaoa* in the study area, is their ability to produce upright stems and new roots in response to sand covering. Unless the plant continues to grow more rapidly than the rate of deposition, the arresting action of the plant ceases. Successive stages of plant growth and sand deposition result in increased width and height of the dune (Gibb 1995b).

Foredunes act as barriers against the action of waves and tides and are a source of sand for the beach during periods of erosion. They protect areas behind them from wave action and salt water intrusion during storms. Vegetated foredunes are inherently flexible. If they are damaged by storm waves the remaining vegetation traps sand blown from the beach and the dune is reformed thus providing protection against future wave attack. Vegetated foredunes restrict wind, sand and salt spray intrusion into hind dune areas. The protective action of the foredune allows the development of a more complex plant community on the hind dunes (Gibb 1995b).

Formation of Dune Blowouts

Dune blowouts form when strong onshore winds erode a gap in a single foredune. The wind blows through the gap sweeping sand inland from the beach and dune. Where foredunes have been cut back by wave action leaving an unvegetated cliff of loose sand, strong onshore winds may initiate blowout formation. Blowouts also develop in the foredune where the stabilizing vegetative cover has been damaged or destroyed by natural causes (drought, fire, storms) or by human interference (heavy pedestrian and vehicular traffic, clearing, grazing) (SPA 1981; Gibb 1995b).

Unless the gaps in the foredune are repaired by sand accumulations colonised by stabilising vegetation, the blowouts increase in size and migrate inland under the influence of strong northeasterly winds along the Tauranga District coast. A series of consecutive blowouts developed in an unstable foredune may grade into either parabolic or U-shaped dunes or mobile sand sheets. *Wind erosion of the beach and unvegetated foredune resu's in long-tenn duneline recession* (BPA 1981; Gibb 1995b).

Storm Water Outlets

Pipe discharges of storm water on to the beach are a well recognized cause of localised duneline retreat along the Tauranga District coastline (Fraser 1982; de Lange and Healy 1985). When water is discharged through the pipes the focused flow quickly erodes the beach, washing the sand out to sea. During wave storms the lowered beach levels allow the full force of the waves to penetrate further up the beach eroding the foredune either side of the pipe outlet. Wave reflection off the hard structures compounds the problem by causing accelerated scour. The process is irreversible and the foredune is unable to recover.

Many of the storm water pipes in the study area are situated adjacent to major road access points to the beach such as Surf Road and Waiairiki Street. As a consequence, the eroded foredune then suffers further damage from continuous and at times intense pedestrian traffic. Destruction of important dune binding vegetation then opens up the foredune to adverse effects from wind erosion. At Waiairiki Street for example, the duneline has a landward offset of 12m adjacent to the storm water pipe as a result of
localised sea and wind erosion. Figure 8 illustrates the problems caused by a storm water outlet.

**Present State of Foredune**

The present state of the foredune complex was determined from the combination of fieldwork in 1995 and from contoured (1 m intervals) rectified Photomaps at 1:2,000 Scale from the aerial survey flown in April 1992. The crestline along the foredune complex was interpreted on the Photomaps from the DTM contours. The seaward toe of the foredune (duneline) was plotted on the Photomaps from the 1994 GPS survey conducted by Environment BOP under the writer's direction. In addition, the Photomaps provided information on infrastructure and the relative distance of assets including property boundaries from the duneline. Results are summarised in Table 2.

On the basis of actual and potential physical stress levels on the foredune complex from both natural and human induced factors, the 13.9km-long study area was subdivided into 12 coastal areas (Table 2), ranging in length from 0.2 to 2.59km. A relative stress level was assigned to each coastal area, ranging from *Low* to *Extreme*. The relative stress levels reflect the degree of wind erosion, state of vegetation, dune crest line height and distance, and degree of actual and potential human modification involving levelling the foredune complex and intensity of use and pedestrian traffic. In addition, Table 2 lists the broad human assets (excluding Recreation and Esplanade Reserves) and the range of distances of seaward property boundaries from the duneline. The duneline is the important natural boundary between the foredune and the dynamically active beach.

The *low-stressed* area (Table 2) totals 0.95km (7%) of the 13.9km-long study area and lies between 139 and 253 Oceanbeach Road. It features a well vegetated undisturbed foredune with a crest height of 6 to 7m above MSL, and a crestline ranging from 15 to 25m inland from the duneline (Table 2). Here the foredune is well covered in the dune binding native grasses, Spinifex and Pingaoa. Behind the foredune are residential properties ranging in distance southeastwards from 28 to 132m inland from the duneline (Table 2). Pressure from pedestrian traffic appears to be relatively low and controlled. This area may be considered to be representative of a natural foredune complex in the study area and is shown in Figure 9.

The 4 *moderately stressed* areas (Table 2) total 5.02km (38%) of the 13.9km-long study area coastline and include substantial areas of vegetated dunes and revegetated old blowout areas. They also include some active blowouts, mostly adjacent to pedestrian accessways to the beach. Dune crest heights range from 4 to 11m above MSL and crestlines 10 to 80m inland from the duneline, the greater distances and heights reflecting the effects of past and present wind erosion and associated blowouts. Seaward property boundaries of the listed assets in the *moderately stressed* areas range from 12 to 218m inland from the duneline (Table 2).

The 6 *highly stressed* areas (Table 2) total 5.69km (43%) of the 13.9km-long study area coastline and include foredune areas either partly or completely levelled in the past, or subject to damage from past and present wind erosion. The areas that were previously levelled include Main Mount Beach (including the Motor Camp), selected areas between Tay Street and the start of Oceanbeach Road and between 67 to 137 Oceanbeach Road including Surf Road, the Papamoa Beach Holiday Park (Figure 10), and the Papamoa residential area between Taylor Road and Karewa Parade inclusive.
TABLE 2: State of foredune complex for 12 areas along the 13.3km-long study sand shore in terms of relative stress levels. All measurements were made from rectified Photomaps at 1:2,000 Scale held by Tauranga District Council, based on aerial photography flown in April 1992. Column (A) gives physical boundaries of the 12 coastal areas; Column (B) gives lengths of each area; Column (C) gives the range of distances of the foredune crest from the seaward toe (duneline); Column (D) gives the range of distances for developed human assets from the duneline; Column (E) lists the broad human assets excluding Recreation and Esplanade Reserves for each of the 12 areas. Column (G) gives the actual and potential stress levels on the foredune in terms of physical damage, ranging from low to extreme. Column (H) provides general comments about the state of the foredune complex.

<table>
<thead>
<tr>
<th>(A) COASTAL AREAS</th>
<th>(B) COASTLINE LENGTH (km)</th>
<th>(C) DUNE CREST HEIGHT (m)</th>
<th>(D) CREST FROM DUNELINE (m)</th>
<th>(E) SEAWARD PROPERTY BOUNDARY FROM DUNELINE (m)</th>
<th>(F) ASSETS</th>
<th>(G) STRESS LEVELS ON FOREDUNE</th>
<th>(H) COMMENTS</th>
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<tr>
<td>Mount Maunganui Domain Motor Camp</td>
<td>0.20</td>
<td>3-4</td>
<td>7-20</td>
<td>4-10</td>
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<td>High</td>
<td>Levelled and grassed</td>
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<tr>
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<td>4-5</td>
<td>10-30</td>
<td>12-44</td>
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<td>Levelled and grassed</td>
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<td>4-11</td>
<td>20-80</td>
<td>35-90</td>
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<td>Moderate</td>
<td>Past blowouts revegetated</td>
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<tr>
<td>Tay St to 1 Ocean Beach Rd</td>
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<td>7-11</td>
<td>15-55</td>
<td>40-74</td>
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<td>Active blowouts</td>
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<td>6-10</td>
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<td>25-70</td>
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<td>12-40</td>
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<td>High</td>
<td>Part levelled with active blowouts</td>
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<td>15-75</td>
<td>34-104</td>
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<td>40-218</td>
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<td>Motor Camp Carpark</td>
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<td>TOTAL COASTLINE LENGTH</td>
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<td></td>
<td></td>
<td></td>
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</tr>
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</table>
**Figure 8:** A storm water outlet constructed in 1993 adjacent to Grant Place. During severe wave storms the rock fill gabion baskets result in localised erosion of the foredune. Photo taken on 26 January 1995.

**Figure 9:** A representative natural well vegetated low stressed foredune adjacent to 213 Oceanbeach Road. Photo taken on 30 August 1995.
**Figure 10:** An example of a high stressed levelled foredune at Papanoa Beach Holiday Park. Photo taken on 31 1994.

**Figure 11:** Extensive active dune blowouts in a foredune under extreme stress at the southeastern end of Oceanbea Road. Photo taken 30 on August 1995.
From Tay Street to the start of Oceanbeach Road the 1.13km-long highly stressed foredune features crest heights of 7 to 11m above MSL with crestlines 15 to 55m inland from the duneline (Table 2). Limited stretches of intact foredune are punctuated by active dune blowouts. Seaward property boundaries of the listed assets in the highly stressed areas range from 40 to 74m inland from the duneline (Table 2). Pedestrian traffic is relatively high and uncontrolled.

At Main Mount Beach the foredune was flattened in the 1960s to provide easy beach access for the public and to allow beachfront residents a view of the sea (Fraser 1982). At Papamoa the dunes were levelled in the early 1960s between Taylor Road and Karewa Parade to fill in the bed of the Wairaki Stream which used to discharge on to the beach near the Taylor Reserve. At the Papamoa Beach Holiday Park the dunes were levelled in the 1960s and 1970s. For these 3 areas, the levelled dune crest is typically only 3 to 5m above MSL (Table 2), increasing their sensitivity to overtopping and flooding from the sea and deposition of wind blown sand.

The extreme stressed area (Table 2) totals 1.64km (12%) of the 13.9km-long study area and lies between 257 and 451 Oceanbeach Road. It features many active blowouts extending up to 75m inland from the duneline which have increased crest heights by up to 14m above MSL. The blowouts have resulted from past damage and destruction of dune binding vegetation exposing the sensitive foredune to wind erosion. Such erosion is presently enhanced by uncontrolled pedestrian traffic and storm water outlets. For this area, seaward property boundaries in the extremely stressed (Figure 11) area lie 34 to 104m inland from the duneline (Table 2).

Summary

1. Of the 13.9km-long foredune complex in the study area, 12% is presently under extreme stress, 43% is under high stress, 38% is under moderate stress and 7% is under low stress.

2. The low stressed foredune is well vegetated with dune binding species, has a natural dune profile with crest heights 6 to 7m above MSL and a crestline 15 to 25m inland from the 1994 duneline position. It is representative of the natural foredune in the 13.9km-long study area.

3. The moderately stressed foredune is relatively well vegetated, features old revegetated blowout areas punctuated by a few active areas, with crest heights 4 to 11m above MSL and a crestline 10 to 80m inland from the duneline.

4. The highly stressed foredune has either been flattened for development or has an increased number of active blowouts, with crest heights 3 to 12m above MSL and a crestline 7 to 95m inland from the duneline.

5. The extremely stressed foredune is extensively modified by wind erosion featuring many active blowouts, with crest heights 6 to 14m above MSL and a crestline 15 to 75m inland from the duneline.

6. The moderate to extremely stressed foredunes have a very high sensitivity to erosion and flooding from the sea, whereas the low stressed foredune has a lower sensitivity and is able to absorb the effects of such hazards.
7. The Mount Maunganui Domain Motor Camp, Papamoa Beach Holiday Park, Papamoa residential properties, on levelled highly stressed dunes lie as close as 4 to 8m inland from the duneline and are subject to adverse effects from wind blown sand that would otherwise be trapped by robust, natural foredune.

8. Where the foredune is under low stress, residential properties are 28 to 132m inland from the duneline and are reasonably well protected by a growing foredune which is able to absorb the effects of storms and adequately trap and hold wind blown sand.

NEARSHORE SEABED

Important depth, distance and gradient parameters determined from the September 1995 hydrographic survey are summarised in Table 3 for the nearshore seabed between Mount Maunganui and Papamoa. Table 3 reveals that a longshore bar-trough system exists offshore from the beach along most of the coast. The trough ranges in depth from -3.7m to -4.8m below MSL, averaging -4.1m, and ranges in distance offshore from the duneline, from 160 to 280m, averaging 230m. The bar ranges in depth from -3.0m to -3.8m, averaging -3.5m, and ranges in distance offshore from 205m to 340m (Table 3).

Seaward of the longshore bar-trough system the seabed graded seawards from a moderately convex surface incorporating the outer slope of the longshore bar, into a gentle concave surface and finally into a relatively flat, progressively deepening surface. The boundaries between the convex, concave, and relatively flat surfaces have been labelled the inner and outer closure depths in Table 3 respectively. Both depths are remarkably consistent along the coast with the inner closure depth ranging from -6.1m to -6.9m below MSL, averaging -6.4m, and the outer closure depth ranging from -8.0m to -9.2m below MSL, averaging -8.5m. Figure 12 shows these features on a representative profile from the September 1995 survey.

The inner closure depth ranges in distance offshore from the duneline, from about 310m to 555m, averaging 434m, and the outer closure depth ranges in distance from about 460m to 795m, averaging 625 (Table 3). The gradient of the seabed below the outer closure depth ranges from 1:71 to 1:107, averaging 1:81 (Table 3). The 1:81 average gradient of the nearshore seabed changes abruptly at -14.2m depth on the profiles off 283 Oceanbeach Road and the Papamoa Surf Club at about 915m offshore, and at depths of -21 to -27m, averaging 23m, along the rest of the profiles in Table 3, at distances of 1,475 to 2,695m from the coast.

Surficial (surface) sediments of the beach-nearshore system were not sampled and analysed for this study on the basis of the adequacy of previous work. In the western half of the Bay of Plenty nearshore seabed sediments exhibit 3 texturally distinct facies (Dahm and Healy 1985; Dell et al. 1985; Hume and Hicks 1993). Many beaches are composed of a mixture of medium to fine sands which extend seaward to a limiting depth of -6 to -8m below MSL. Between approximately -8m and -15 to -20m the nearshore seabed is composed of fine to very fine sand. Seaward of -15 to -20m the seabed is composed of medium to coarse sands out to about 40m water depth.

According to Dahm and Healy (1985) the 3 distinct facies have evolved over the last 7,000 years since the stabilisation of sea-level at the present level (Gibb 1986), through a process of mass transport beneath shoaling waves which selectively remove fine and medium sand and pumiceous material and transport this material shorewards. Sand from
According to Dahm and Healy (1985) the 3 distinct facies have evolved over the last 7,000 years since the stabilisation of sea-level at the present level (Gibb 1986), through a process of mass transport beneath shoaling waves which selectively remove fine and medium sand and pumiceous material and transport this material shorewards. Sand from

<table>
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<th>Location</th>
<th>Trough Depth (m)</th>
<th>Bar Distance (m)</th>
<th>Inner Depth (m)</th>
<th>Inner Closure Depth (m)</th>
<th>Outer Depth (m)</th>
<th>Outer Closure Depth (m)</th>
<th>Seabed Gradient Below Other Depth</th>
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<tr>
<td>Main Mount Beach</td>
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<td>remnants Cut</td>
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<td>-3.5</td>
<td>286</td>
<td>-6.4</td>
<td>634</td>
<td>1.81</td>
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**Figure 12:** Profile of the nearshore seabed off 433 Oceanbeach Road, surveyed in September 1995 showing the longs bar-trough system and inner and outer closure depths of 6.4 and 8.7m below MSL Moturiki Datum, respectively.
this source would provide a major contribution to the 86m of accretion that has occurred over the last 1800 years.

Nearshore Transport Zone

The inner and outer closure depths are interpreted to represent the seaward boundaries of the active beach system described here as the Nearshore Transport Zone (NTZ). That is, the average depth limited seaward boundaries of the breaking wave induced exchanges of beach and dune sand with sand from the nearshore seawed.

The preferred boundary limit adopted in this study for the NTZ is the outer closure depth, which averages -8.5m below MSL Moturiki Datum and 625m from the coast (Table 3). This boundary is adopted on the basis that it delineates the average depth limit of the gentle concave surface in the seawed seaward of the longshore bar. As concave surfaces generally represent erosion profiles and convex surfaces accretion profiles, it is the writer's opinion that sand eroded from the concave surface above -8.5m water depth has contributed to the formation of the convex surface comprising the longshore bar above -6.4m. Other sand contributing to the formation of the highly mobile bar would have been eroded from the longshore trough, also a concave surface, and in places, the beach and foredune.

For the study area the average inner closure depth of -6.4m below MSL and the average outer closure depth of -8.5m compare favourably with either observed or theoretically calculated “closure depths” by other workers in the Bay of Plenty. For Ocean Beach north of the Tairua River, Coromandel Peninsula, Gibb and Aburn (1986) determined an inner closure depth of -8m below MSL from extensive SCUBA, bathymetric and sedimentologic evidence. For Pauanui Beach south of the Tairua River, sediment textures of the seawed revealed no distinct changes. However, highly accurate bathymetry revealed a subtle change in gradient at about -7m below MSL.

For the ebb-tide delta off the Tairua Harbour Gibb and Aburn (1986) compared bathymetric surveys made in 1971 and 1983. The comparison revealed significant changes to the morphology of the ebb tide delta above -5m and no significant variation below this depth. On the basis of all available evidence, Gibb and Aburn adopted an average closure depth for the Pauanui to Oceanbeach area of -7±0.5m below MSL. Distances offshore from the dune line to the -7m contour ranged from 680m to 950m off Pauanui Beach.

Further south, Harray and Healy (1978) determined depths of -5.7m and -9.4m for Waihi Beach. In an assessment of a Coastal Hazard Zone for Waihi Beach, Healy (1993) adopted a closure depth of -9.5m by averaging the theoretically estimated depths of -6m and -13m for the Western Bay of Plenty determined by other workers from the methods of Haltemeier (1981a&b).

Although not verified by observations during this study, the NTZ is likely to encompass the medium to fine sand facies characterising many of the beaches in western Bay of Plenty. The flat, gently sloping seawed between -8.5m water depth and -14m and -23m is likely to encompass the fine to very fine sand facies. The relatively flat seawed below -14m and about -23m is likely to encompass the medium to coarse sand facies that generally extends out to about -40m.

For the Waihi and Matakanui coastlines, Hume and Hicks (1993) and Hume et al. (in press) determined a depth of about -7m below “lowest Astronomical Tide” as the seaward boundary of the “modern sand prism” from bathymetric modelling. They described this depth as “the seaward limit of extreme surf related processes and the maximum depth of
active sediment transport by yearly extreme waves". The depth of -7m would equate to -8m with respect to MSL Moturiki Datum, adopted in this study.

Using local wave data collected over 3 years (1991-1993) and the Hallermeier (1981a&b) technique, Hume and Hicks determined a limiting depth of -6.8m for the same area which agreed closely with the observed depth. For the Katikati Entrance ebb tide delta Hume et al.(in press) found that sand transfers were very active to -5m and weak by -10m. These observations agree closely with those of Gibb and Abum (1986) for the Tairua River ebb tide delta.

For the Mount to Papamoa coastline, Kay et al. (1994) adopted the -6m depth below MSL as the inner closure depth at 600 to 700m offshore, and 13m as the outer closure depth at 1,000 to 1,100m offshore for their CHZ assessment. The -6m and -13m depths adopted by them were from previous work using the Hallermeier (1981a&b) technique. For the same area Gibb (1994a&b) adopted the -6m inner closure depth from Kay et al. (1994) for individual property CHZ assessments, and later the -7m depth contour (Gibb 1994c&d) from the observations of Gibb and Abum (1986) and Hume and Hicks (1993).

Further east at Otamarakau, Gibb (1994f) observed morphological changes to the seabed at -5.7m and -7.0m below MSL. Textural and SCUBA evidence revealed the seaward boundary of the beach sand prism to be at -7.0m depth with another textural boundary at -13m depth. Prolific growth of flora and fauna on boulders on the seabed indicated little if any active sediment transport beyond this depth. On the basis of all available evidence, Gibb (1994f) adopted the -7m depth below MSL as the closure depth for assessing a CHZ for Otamarakau.

Summary

1. The inner and outer closure depths of -6.4m and -8.5m below MSL Moturiki Datum determined for the study area are consistent with observations and theoretical calculations of previous studies elsewhere in the western Bay of Plenty.

2. A closure depth of -8.5m below MSL is adopted for this study to represent "the seaward limit of extreme surf related processes and the maximum depth of active sediment transport by yearly extreme waves", and to define the seaward boundary of the Nearshore Transport Zone (NTZ).

3. The NTZ encompasses the medium to fine beach sand facies; the area of seabed between about -8.5m and about -23m the fine to very fine sand facies; and, the area of seabed between about -23m and -40m the medium to coarse sand facies.

4. A discontinuous longshore bar-trough system exists along the entire coastline between Mauao and Papamoa Township, and is actively involved in onshore-offshore sand exchanges with the beach.

SHORELINE MOVEMENTS

Both short-term and long-term rates of erosion and accretion are provided for the 13.9km-long study area coastline in Appendix III. Of the 44 Sites, Papamoa Township has 10 Sites, Papamoa Domain 3 Sites. Both short-term and long-term rates of erosion and accretion are provided for the 13.9km-long study area and Te Ara Place to Mauao 31 Sites. Each site was selected on the basis of providing a representative sample of shoreline trends along the coast and range in distance apart from 170 to 500m. Appendix
III also includes the list of cadastral plans covering the study area from which shoreline positions were plotted on the 1:2,000 Scale MWD Plans.

Long-Term Trends

In general, the 13.9km-long duneline has a long-term historic trend of advance from accretion at 0.03 to 0.51m/year over a survey period ranging from 51 (1943-1994) to 106 years (1888-1994) (Appendix III). The trend of advance is punctuated in places with areas of long-term duneline retreat from very slow erosion of -0.02 to -0.13m/year and with areas of duneline in dynamic equilibrium (0.0m/year).

For the 2.69km-long Papamoa Township shoreline the long-term trend over the last 79 years (1915-1994) ranges from dynamic equilibrium adjacent to Marjori Place; to erosion up to -0.06m/year along the southern third of Karewa Parade; to accretion up to 0.06m/year along the northern two-thirds of Karewa Parade; to erosion up to -0.06m/year for the entire coastline adjacent to Motiti Reserve; to a trend of accretion along Motiti Road increasing from 0.06m/year in the southeast to 0.42m/year at Taylor Reserve. The relatively higher rates of accretion of 0.42m/year are not typical of the long-term trend in this area and have arisen through the blocking off of the Wairaki Stream outlet at Taylors Reserve in the late 1950s during subdivision and development.

For the 0.6km-long Papamoa Domain shoreline there has been a long-term trend of duneline advance of 0.10 to 0.33m/year over the last 51 to 72 years. A similar trend occurs for the 10.6km-long shoreline between Te Ara Place and Mauao. Over the last 51 to 106 years, the duneline has generally advanced at 0.01 to 0.51m/year, punctuated by two areas of dynamic equilibrium between Tay Street and Clyde Street and near Adams Avenue, and by two small areas of long-term retreat up to -0.13m/year near Surf Road and up to -0.08m/year in the centre of Main Mount Beach.

The highest rates of accretion occur adjacent to the Mount Maunganui Domain Motor Camp (up to 0.51m/year), between Pacific Avenue and Sutherland Avenue (up to 0.51m/year), between 181 and 269 Oceanbeach Road (up to 0.33m/year), and between about 150 Maranui Street and Te Ara Place (up to 0.24m/year). In all cases, significant historic duneline advance is generally associated with the retention of sand by a well vegetated, stable foredune complex.

For the study area, the pattern of long-term trends determined in this study differs in places with that determined by Harray and Healy (1977) and Gibb (1994a; 1995b). Harray and Healy compared relative duneline positions on vertical aerial photographs of the study area taken in 1943, 1959 and 1977. For the relatively short 34-year period they concluded a pattern of "conditional stability" with "areas of stability, erosion and accretion". They did not utilise existing cadastral surveys of the shoreline. Gibb used the 1:2,000 MWD Sheets and concluded a trend of duneline advance from Moturiki Island to the start of Oceanbeach Road, dynamic equilibrium from Oceanbeach Road to Papamoa Township, and duneline retreat along Papamoa Township over the last 51 to 106 years. Gibb did not have the benefit of a report on the surveyor's definitions of MHWM (see Appendix II).

Short-Term Fluctuations

Data in Appendix III indicate that both MHWM and the duneline have fluctuated in relative position during the last century along the entire 13.9km-long study area coastline. Because the surveys record a snapshot in time of the position of the shoreline and the survey intervals vary significantly, they may not have recorded the maximum duneline fluctuation that has occurred historically along the Tauranga District coast. Thus, the
fluctuations that are recorded in Appendix III are regarded here as being a minimum horizontal distance.

For Papamoa Township, the period 1915 to 1950 (35 years) was generally characterised by short-term duneline retreat of -2 to -15m with the exception of the area between 15 Motili Road and 28 Taylor Road where the duneline advanced 6 to 13m. In contrast, the period 1950 to 1981 (31 years) was generally characterised by 2 to 20m duneline advance with exception of the area adjacent to 111 Karewa Parade where the duneline retreated 2m. The period 1981 to 1994 (13 years) was also characterised by duneline advance of 1 to 20m with the exception of the area between Marjori Lane and 111 Karewa Parade where the duneline retreated -6 to -10m (Appendix III).

For Papamoa Domain, the period 1922 to 1943 (21 years) was characterised by 8 to 10m duneline advance; the period 1943 to 1981 (38 years) by an oscillating duneline between -8m retreat and 15m advance; and the period 1981 to 1994 (13 years ) by a duneline showing no change in position to 5m advance (Appendix III).

For the duneline between Te Ara Place and 357 Oceanbeach Road, the period 1904 to 1943 (39 years) was characterised by 8 to 13m advance; the period 1943 to 1981 (38 years) by a duneline oscillating in places by up to -20m retreat, 4m advance, to no change in position; the period 1981 to 1994 (13 years) by a duneline advance of 1 to 20m generally with -4m duneline retreat occurring adjacent to Sunbrae Grove (Appendix III).

For the duneline between 307 and about 1 Oceanbeach Road, the period 1914 to 1943 (30 years) was characterised by oscillations between 0.5 and 10m advance and -6 to -10m retreat. Similarly, the period 1944 to 1981 (37 years) was characterised by oscillations between -5 to -7m duneline retreat and 1 to 10m advance. In contrast, the period 1981 to 1994 (13 years) was characterised by 2 to 24m advance (Appendix III).

For the duneline between 209 Marine Parade and Tay Street, the period 1888 to 1943 (55 years) was characterised by retreat of -2 to -7m; the period 1943 to 1981 by retreat of -2m generally with a localised advance of 7m occurring adjacent to 194 Marine Parade. In contrast, the period 1981 to 1994 was characterised by duneline advance of 4 to 22m (Appendix III).

For the duneline between Tay Street and Mauao, the period 1888 to 1943 (55 years) was characterised by an advance of 8 to 28m with localised retreat of -10m occurring near 1 Marine Parade; the period 1943 to 1981 (38 years) by oscillations up to -15m localised retreat and 20m localised advance; the period 1981 to 1994 by duneline advance of 4 to 17m with localised retreat of -3m occurring near 1 Marine Parade (Appendix III).

The magnitude of short-term duneline fluctuations have been estimated for the study area previously by Harray and Healy (1977), Gibb (1982), Healy (1988), Kay et al. (1994) and Gibb (1994a-e). Harray and Healy (1977) recorded a trend of duneline retreat of -4 to -25m from Papamoa to Main Mount Beach with 2 to 11m advance along Papamoa Township between 1943 and 1959 (13 years). From 1959 to 1977 (18 years) they recorded an overall trend of duneline advance of 1 to 17m with small erosion or no detectable change along Papamoa.

From an extensive study of coastal processes between Te Ara Place and Sunbrae Grove, Gibb (1982) found, "episodic short-term fluctuations in the position of the dun toe of ±35m can be expected to occur in the future". For the same area Healy (1982) concluded that it was "quite possible to cut out up to 140m/m of beach above MSL and a maximum likely cut is believed to be about 250m/m as the 1-in-100 year event". He recommended to plan "for a reservoir of at least 400m/m", based on an approach taken in The
Netherlands. This volume represented a horizontal setback from the duneline of 40 to 75m depending on the crest height of the dunes. Healy (1988) later adopted these estimates for the Pacific Shores residential subdivision CHZ assessment. His values of 250m$^3$ and 400m$^3$ were not based on observed changes in the study area.

Kay et al. (1992) adopted a short-term maximum duneline fluctuation of ±30m for Papamoa Township and Oceanbeach Road from previous work. Gibb (1994a-d) determined duneline fluctuations from sparse survey evidence of 25 to 28m for individual properties along Oceanbeach Road. In a reconnaissance survey of the Bay of Plenty Region’s coastline, Gibb (1994e) estimated duneline fluctuations of 15 to 20m for Papamoa Township, 15 to 30m for Papamoa Domain, and 15 to 30m from Te Ara Place to about Pacific Avenue.

Summary

1. Over the last 51 to 106 years, the 13.9km-long study area duneline has generally advanced from sand accretion at rates of 0.03 to 0.51m/year, punctuated from time to time by differential episodic short-term duneline fluctuations.

2. Over the last 79 years the 2.69km-long duneline along Papamoa Township has shown differential trends ranging from dynamic equilibrium (0.0m/year) in the southeast, to very slow erosion up to -0.08m/year along southeastern Karewa Parade and Motiti Reserve, to advance of 0.06m/year to 0.42m/year along northeastern Karewa Parade, Motiti and Taylor Roads.

3. Over the last 51 to 72 years the 0.60km-long duneline along Papamoa Domain has advanced at 0.10 to 0.33m/year.

4. Over the last 51 to 106 years the 10.6km-long duneline between Te Ara Place and Mauao has generally advanced at 0.01 to 0.51m/year, with long-term retreat of -0.08 to -0.13m/year being recorded near Surf Road and the centre of Main Mount Beach, and dynamic equilibrium (0.0m/year) between Tay and Clyde Streets and near Adams Avenue.

5. Maximum short-term duneline fluctuations in the range of 35±20m involving volumes of dunesand of the order of 100 to 250m$^3$ per metre length of duneline, occur along the entire 13.9km-long study area coastline.
PART III : HAZARD ASSESSMENT

NATURAL HAZARDS

A natural hazard is defined by Vames (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), 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" [Emphasis added].

Although the term adverse effects is not precisely defined in the RMA, under S.3(RMA) 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".

For the 13.9km-long coast the identified natural hazards are erosion and flooding from the sea (Healy et al. 1977; Healy 1988; Kay et al. 1994; Gibb 1982, 1994a-e; 1995a&b). Erosion may be subdivided into wind and sea erosion, the latter including both long-term shoreline retreat and short-term duneline fluctuations.

Sea Flooding

Flooding from the sea occurs when sea-level is super-elevated instantaneously by tsunami storm surges and storm wave runup. Both phenomena have potential instantaneous adverse effects over a short period of time on open-exposed coastlines such as the Bay of Plenty.

*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 Aurn 1985).

*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 (Figure 13). Maximum storm wave runup levels are produced by the complex interaction of the wind, the sea, the seabed topography, and the configuration of the coast. During a severe storm, wave runup will extend furthest inland for a period of one to two hours during high tide.

For the Tauranga Harbour area, de Lange (1996) calculated maximum storm surge elevations above Mean High Water Springs (MHWS) of 0.6m, 0.8m and 1.0m for events with return periods of 1-in-10 years, 1-in-100 years and 1-in-1,000 years, respectively. The "Wahine Storm" of 10 April 1968 was considered to be a 1-in-140 year event. He noted that northeastern parts of New Zealand, like the Bay of Plenty, experience more storm surge events during *La Niña* extremes. During *La Niña* conditions cyclonic
depressions tend to track towards New Zealand, whereas during El Niño conditions they track further east (Dr Reid Basher, NIWA, Wellington, pers. comm. 1996).

![Diagram showing wave run-up levels](image)

**Figure 13:** Schematic diagram showing the components of wave run-up level (Adapted from Gibb 1981, fig.30).

For the study area, Gibb (1994e) recorded maximum storm wave runup elevations of 5.3 to 6.3m above MSL from field evidence. At Adams Avenue at western Main Mount Beach, waves overtopped the foredune in the early 1940s and “trickled down the road as far as Pilot Bay” (Ian Boyce, pers. comm. 1995). Here, the levelled foredune is about 5m above MSL suggesting wave runup levels reaching and exceeding 5m, which accords with the observations of Gibb (1994e). About 200m southeast of Sunbrae Road, the occurrence of a beach deposit of sea rafted Taupo Pumice at 7m above MSL, deposited about 1,800 years ago when sea-level was close to that of the present-day (Gibb 1986), suggests potential maximum storm surge elevations of the order of 7m above MSL may occur in the study area.

For the study area, Hay et al. (1991) compiled a storm database for the period 1873 to 1990. To qualify as a storm with coastal impacts, onshore wind velocity had to reach or exceed Force 8 on the Beaufort Scale. For the 117-year period, Hay et al. recorded 153 storms of which a Force 7 event (28-33knots) could be expected every 0.71 years, Force 8 (34-40 knots) every 14 years, and Force 9 (41-47 knots) every 30 years. Storm frequency was relatively higher in May and July and lowest in November. Storm duration lasted from 6 to 36 hours with one extreme event lasting 92 hours.

Tsunami data available in New Zealand are sparse and generally only from populated areas. A review of such data by de Lange and Healy (1986) showed that those locally generated are potentially larger than distantly generated tsunami and therefore, pose the greatest inundation hazard. Although most parts of New Zealand were found by de Lange and Healy to have experienced tsunami, the Bay of Plenty-East Coast-Wellington regions were found to be the most sensitive with up to 9 tsunami being recorded in the Bay of Plenty during the period 1840 to 1982. These events, however, have recorded a maximum wave height of less than 1m on the open coast (de Lange and Healy 1982) and may not pose a significant flooding hazard compared to storm wave runup.

**Sea Erosion**

In this study, minor long-term shoreline retreat at the very low rates of -0.02 to -0.13m/year was found to be confined to 4 areas of coastline. These were southeastern
Karewa Parade, Moltit Reserve, Surf Road, and in the centre of Main Mount Beach. For
the remaining study area coastline the long-term trend was found to be advance from
sand accretion.

In contrast, short-term duneline fluctuations of the order of 15 to 50m occur along the
entire 13.9km-long foredune involving some 100 to 250m$^3$ of sand per linear metre of
duneline. Although there has been a short-term trend of widespread accretion of the
foredune since 1981 generally, in response to El Niño conditions the foredune was
trimmed back by up to 6m in the study area by ENE wave storms in 1992, 14 July 1995
and 24 January 1996 (Figure 14 and 15).

The last significant onshore wave storm is thought to have occurred in July 1978 which
eroded the foredune and flooded parts of Papamoa (Kay et al. 1994). Since that time
there have been no equivalent sustained wave storms in the Bay of Plenty and the
duneline has generally advanced 1 to 20m and increased in height in most places in
response to accretion and relatively calmer seas associated with predominant El Niño
conditions.

Erosion Processes

The effects of the sub-tropical cyclonic storm of 23-25 January 1996 were observed by
the writer and wave heights obtained from A-Buoy off the entrance to Tauranga Harbour,
courtesy of the Port of Tauranga Limited (Owen Maynard, Hydrographer, pers. Comm.
1996). At Midnight on 23 January, mean and maximum wave heights of 1.0 and 1.6m
were recorded, respectively. By mid-afternoon on 24 January the mean and maximum
wave heights had increased to 3.0m and 4.5m, respectively. By 0800 hours the next day
(25 January), mean and maximum wave heights had fallen to 1.8m and 2.6m, respectively.
During the short duration of the wave storm the wind was generally light and
offshore on the coast and there was a well developed longshore current to the northwest.
Although there was selected duneline recession of the order of 3 to 6m in the study area
(Figure 15), other areas were unaffected.

Observations to date reveal that duneline retreat from erosion does not occur uniformly
along the study area coastline. The present state of the foredune reveals discrete areas
actively retreating, others advancing, and still others in dynamic equilibrium. Further,
erosion phases do not appear to always occur in the same area. They shift from place to
place over time. An erosion phase like that adjacent to Moltit Road, Papamoa, for
example, starts with the beach being cut down by the sea, exposing the foredune to wave
attack. Under these conditions the greatest sand losses appear to occur at high spring
tides during ENE wave storms, the losses being proportionate to incident wave energy,
storm surge elevation and storm duration.

The short-term trend of duneline retreat only reverses to advance with an increase in
supply of sand to the area. Such an increase occurs offshore firstly with the formation of
an offshore bar. Under favourable sea conditions the bar moves shorewards and widens
on to the beach increasing the elevation and width of the beach. A dry backshore is
created which provides wind blown sand to reconstruct the stressed foredune. A steady
reduction in the long-term natural supply rate of sand to the area would reduce dune
recovery proportionately. The measured long-term trend of accretion however, suggests
the study area coastline is still, on balance, receiving sand.
Figure 14: Short-term duneline erosion adjacent to Motii Road, Papamoa, most of which occurred during a ENE wave storm on 14 July 1995. Photo taken on 30 August 1995.

Figure 15: Short-term duneline erosion adjacent to Surf Road, Omanu, all of which occurred during a moderate wave storm on 24 January 1996 which generated short-duration maximum wave heights of 4.0 to 4.5m. Photo taken on 25 January 1996.
Wind Erosion

As noted above, the entire 13.9km-long foredune complex is extremely susceptible to wind erosion. Aerial photographs taken in 1943 show extensive blowouts of the foredune complex, ranging in width from 35 to 115m inland from the duneline. The blowouts were classified as parabolic transgressive dunes by Gibb (1995b) and were orientated NE-SW indicating that northeasterly winds were primarily responsible for severe wind erosion. Since the study area coastline was residentially developed over the last 3 decades, the area of severe wind erosion has been reduced in many places through planting of dune binding vegetation by many beachfront residents. Areas where active dune blowouts are still occurring today are listed in Table 2.

The Potential Hazard of 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 (Brun 1962, 1983; Hicks 1990). In 1986 the writer commissioned the Geodetic Section of the Department of Lands and Survey to determine historical trends and rates of sea-level rise from automatic tide gauge records collected since 1899 from the ports of Auckland, Wellington, Lyttelton and Dunedin. The results of this analysis were published by Hannah (1990a) and Gibb (1991) and are summarised in Figure 16.

Hannah (1990a) used the observed annual MSLs at each site and by means of a least squares analysis, simultaneously determined values for a datum offset, a linear sea-level trend, local pressure and temperature forcing effects, and the amplitude and phase of the lunar tides with 8.847 and 18.613 year periodicities. The linear MSL trends determined by Hannah were adjusted by Gibb (1991) for local tectonic effects (Table 4) to derive residual rates of sea-level rise for each port area.

Figure 16: Graphs of corrected annual MSLs and net rates of sea-level rise determined by linear regression techniques. Gaps in annual MSLs represent no data (Adapted from Gibb 1991, fig.2).
<table>
<thead>
<tr>
<th>PORT</th>
<th>TIDAL RECORD</th>
<th>CORRECTED NET RATE (mm/yr)</th>
<th>TECTONIC NET RATE (mm/yr)</th>
<th>RESIDUAL RATE (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUCKLAND</td>
<td>1898-1988</td>
<td>1.3±0.1</td>
<td>0.1±0.03</td>
<td>1.2±0.1</td>
</tr>
<tr>
<td>WELLINGTON</td>
<td>1901-1988</td>
<td>1.7±0.3</td>
<td>0.0±0.1</td>
<td>1.7±0.3</td>
</tr>
<tr>
<td>LYTTLETON</td>
<td>1901-1988</td>
<td>2.3±0.1</td>
<td>-0.1±0.03</td>
<td>2.4±0.01</td>
</tr>
<tr>
<td>DUNEDIN</td>
<td>1891-1901</td>
<td>1.4±0.2</td>
<td>0.0±0.1</td>
<td>1.4±0.2</td>
</tr>
<tr>
<td>NET RESIDUAL RATE</td>
<td></td>
<td></td>
<td></td>
<td>1.7±0.2</td>
</tr>
</tbody>
</table>

**TABLE 4:** Residual rates (Column E) of sea-level rise for the period 1899-1988 (Column B). Sea-level trends (Column C) are from Hannah (1990a). Tectonic net rates (Column D) are from Gibb (1986), positive values indicating uplift and negative, downdrop (Adopted from Gibb 1991, table 1).

Table 4 shows that 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. These rates are entirely consistent with the global average rate of 1.8mm/year, ranging from 1 to 2.5mm/year, over the last 100 years (Douglas 1991; Pettier and Tushingham 1991; Wamck et al. in press). Although the relatively higher rate for Lyttelton (Table 4) is consistent with late Quaternary geologic evidence for continuous (aeseismic) regional downwarping (Gibb 1986; Brown and Weeber 1992), the lack of pre-1924 data has weighted the calculation of the net rate (Hannah 1990a).

In addition to the above data, an indicative rate of sea-level rise of 2.3mm/year was tentatively determined for Gisborne for the period 1926 to 1990 from sparse tidal data from the Port of Gisborne (Alan Raddiffe, Deputy Chief Surveyor, Dept of Survey and Land Information, Gisborne, pers. comm. 1993). The tide gauge is sited in an area subject to episodic tectonic uplift during large earthquakes, yet still records a relatively rapid rate of sea-level rise comparable with that in Lyttelton (Table 4).

**Historical Sea-Level Trends vs. Atmospheric Temperature**

Figure 17 compares a regional sea-level curve derived by Gibb (1991) for New Zealand for the period 1904-1988, with a surface air temperature curve for the Southern Hemisphere derived by Ghil and Vautard (1991) for the period 1854-1988. The sea-level curve was derived from the MSL trends determined by Hannah (1990a) for the ports of Auckland, Wellington and Lyttelton and tested for evidence of any acceleration in the rate of change of MSL around New Zealand. The data from Dunedin were discarded for this analysis by Gibb because of the likely effects of harbour works (dredging, reclamation, etc.) altering the tidal prism and affecting the secular trend of RSL.
The datasets for Auckland and Wellington were normalised to bring them in terms with the Lyttelton values. The 3 normalised datasets were then combined and a weighted mean calculated for each year. The period 1904-1988 was selected as it had MSL values from at least 2 of the 3 ports for each year. The weighting adopted for each MSL value was based on the standard deviations assigned by Hannah to each annual value. A least squares fit was applied to the composite dataset to derive secular trends over the 85-year period. The analyses were undertaken in 1990 by the Geodetic Section of DOSLI, Wellington, under the writer’s direction (Gibb 1991).

A visual inspection of the composite graph (Figure 16) indicated a possible acceleration in the rate of rise of MSL around New Zealand during the 1930s. To test for this, a year was selected within this decade and least squares fits were applied to the periods before and following the selected year. A constraint applied to the 2 straight lines so calculated was that they intersect at the selected year. The process was repeated by the Geodetic Section by incrementing the selected year by one throughout the dataset interval until the year of change became evident. Finally, the pair of lines were compared with the single line fit for the 85-year period using the F distribution to test the comparison of the 2 line fit with the single line fit (Gibb 1991).

For the Southern Hemisphere air temperature, Figure 17 reveals no significant change from 1890 to 1910, with an increase of 0.5°C from 1910 to 1988. For the New Zealand sea-level curve, Figure 17 reveals no significant change from 1904 to 1931, with an increase of 1.9mm/year from 1931 to 1988. The fact that both trends are on the increase suggests that global atmospheric warming of 0.5°C during the last century has contributed to sea-level rise over that period. A comparison of the curves (Figure 17) suggests that there is a 20 year lag between temperature rise and sea-level response which is in agreement with the findings of Gordon (1988) into possible causes of coastal erosion in New South Wales, Australia, during the past century.

**Recent Local Relative Sea-Level Trends**

Bell and Goring (submitted) analysed records from the open-coast tide gauge at Motunui Island covering a 21-year period (1973-1994), using similar techniques to those employed by Hannah (1990a). They compared the local RSL trend with
trends in sea-surface temperatures (SST) measured at Leigh, north of Auckland, over the same period, and with the El Niño - Southern Oscillation (ENSO) events and barometric-pressure variability.

Over the 21-year period the trend in sea-level at Moturiki was slightly downwards by a net change of -9mm. The downward trend was consistent with allied decreases in SST and the Southern Oscillation Index (SOI) of -0.9°C and -1.4, respectively, over the same period (Figure 18).

Figure 18: Graphs showing comparisons of trends in the Southern Oscillation Index (SOI) with Sea Surface Temperatures (SST) measured at Leigh (top) and with Mean Sea Level (MSL) measured at Moturiki (bottom) over a 21-year period (1973-1994) [Adopted from Bell & Goring (submitted), fig.6]).

Bell and Goring concluded that climatic factors, including sea-surface temperatures, were “masking any eustatic (global) rise in sea-level” at Moturiki. They also noted the similarity in trend over the 21-year period with the nearby tidal record from Auckland (see Figure 16) over the same period. The preponderance of El Niño over La Niña episodes is thought by them to have contributed to the “net downwards trend in SST and to a lesser extent MSL”. Generally, negative MSL and SST values occur during El Niño episodes and positive values during La Niña episodes (Figure 18) in the Bay of Plenty. At ENSO time scales of 4 to 5 years there is an average lag of MSL response behind SOI compared to the response of SST which is generally instantaneous (Bell and Goring, submitted).

Although the sea-level record for the Bay of Plenty is dominated by tides which account for 97.3% of the variance, monthly MSL was found by Bell and Goring (submitted) to fluctuate within an overall range of around 0.23m and interannual variability around 0.14m. The tentative correlation of the Moturiki record (Figure 18) with the Auckland record (Figure 16) suggests that it may be more appropriate to adopt the residual rate of historic sea-level rise of 1.2±0.1mm/year (Table 4) for the Bay of Plenty than the net rate for New Zealand of about 1.7mm/year (Table 4, Figure 17).

Future Sea-Level Rise

In 1990, current scientific knowledge and predictions of Climate Change from an enhanced Greenhouse Effect were formally assessed by both national and
international practising scientific experts in an attempt to achieve a scientific consensus. Their findings were first published by the New Zealand Climate Committee of the Royal Society of New Zealand (NZCC 1990), followed closely by the Intergovernmental Panel on Climate Change (IPCC 1990) to which New Zealand was a major contributor. The IPCC-90 report was compiled by 170 scientists from 25 countries and peer reviewed by a further 200 practising scientists including experts from New Zealand.

Warming of the atmosphere in response to an increased concentration of greenhouse gasses was widely expected to lead to a significant rise in global sea-level. Under the IPCC-90 Business-as-Usual [BaU] scenario global mean temperature was predicted to increase to about 1°C above the present value by 2025 and 3°C before 2100, with an uncertainty range of 0.2-0.5°C per decade. The BaU scenario assumed that the energy supply was coal intensive and on the demand side only modest efficiency increases were achieved. Carbon monoxide controls were modest, deforestation continued until the tropical forests were depleted and agricultural emissions of methane and nitrous oxide were uncontrolled (IPCC 1990).

The NZCC-90 estimated sea-level rises of 0.07 to 0.17m by 2025 A.D. and 0.17 to 0.35m by 2050 A.D. which could be expected in New Zealand (Hannah 1990b). The programme did not make provision for estimates beyond the year 2050 A.D. The IPCC-90 provided “best estimates” of global sea-level rises of 0.18m by 2030 A.D., 0.30m by 2050 A.D., 0.44m by 2070 A.D. and 0.66m by 2100 A.D. (Warlick and Oerlemans 1990). The IPCC-90 “best estimate” of 0.3m by 2050 A.D. was in reasonable agreement with the estimate by NZCC-90 for New Zealand for 2050 A.D. owing to similar information being utilised.

More recently, research by internationally acclaimed scientists has revealed that even if humanity could stabilise greenhouse gas emissions by the year 2030 A.D., “substantial increases in sea-level are likely to continue for centuries into the future” (Wigley and Raper 1993). For thermal expansion of the oceans from atmospheric warming, for example, Wigley and Raper noted that the ocean lags behind the immediate response of the less dense atmosphere, as indicated in Figure 17. Only 16% of the final value of sea-level rise from this factor is seen by 2030 A.D.. 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 has just revised its 1990 estimates for global climate change and sea-level rise for the period 1990 to 2100 A.D.. Their findings indicate that the basic understanding of climate-sea-level relationships has not changed fundamentally since IPCC-90. The concurrent rise in global temperature and sea-level during the last 100 years suggests a causal link (see Figure 17). Preliminary estimates of global sea-level rise by IPCC-95 for the next 100 years are lower than those of IPCC-90, owing to significantly lower estimates of global temperature change which drive projections of sea-level rise (Warrick et al., in press).

Allowing for the effects of either including increasing aerosol levels in the atmosphere, or constant 1990 aerosol levels continuing throughout next century, preliminary estimates of global temperature are for atmospheric warming of about 2
to 2.4°C by 2100 A.D., respectively. Aerosols provide a cooling effect, offsetting atmospheric warming associated with accumulating greenhouse gasses such as carbon dioxide (Associate Professor R.A. Warrick, University of Waikato, pers. comm. 1995).

![Figure 19: The current Low, Best Estimate and High projections of global sea-level rise by the IPCC for the period 1990-2100 for Scenario IS92A which includes aerosols (from Warrick et al. in press).](image)

Adopting the IPCC-95 scenario of increasing aerosol levels, preliminary best estimates of global sea-levels associated with a 2°C warming are for rises above present sea-level of 0.20m by 2050 A.D., and 0.49m by 2100 A.D. with uncertainties of 0.08 to 0.39m and 0.20 to 0.86m respectively (Figure 19). Taking into account both forcing scenarios and model uncertainties the extreme range of projections by IPCC-95, is 0.13 to 1.11m above present sea-level by 2100 A.D. (Warrick et al., in press). The current best estimates of 0.20m by 2050 A.D., and 0.49m by 2100 A.D. of IPCC-95 are significantly lower than the IPCC-90 BAU best estimates of 0.30m and 0.66m, respectively. As noted above the difference is due to a lower temperature prediction and the inclusion of aerosols.

**Potential Physical Coastal Impacts**

Hicks (1990) attempted the daunting task for the New Zealand Climate Change Programme of forecasting the physical coastal impacts likely to occur around the New Zealand coasts in response to Climate Change and sea-level rise from an enhanced Greenhouse Effect. Two Climate Change scenarios were adopted for the forecasts for 2050 A.D. The “Most Likely” Scenario 1 allowed for a rise in local relative sea-level of 0.2 to 0.4m above present level and the “Alternative Warm” Scenario 2 allowed for a rise of 0.3 to 0.6m above present level over the next 55 years. Scenario 1 generally accords with the preliminary revised sea-level
projections of IPCC-95 of 0.08 to 0.39m above present level for 2050 A.D.. For the Bay of Plenty, Hicks forecast the following changes:

I. "Sandy beaches from Waihi to Opape would erode by about 20-40m for Scenario 1 and 40-60m for Scenario 2".

II. "Dramatic decrease in westerlies and the increasing importance of north-easterlies and extratropical depressions and cyclones".

III. "Northeast facing coasts, particularly around the North Island, would become stormier".

IV. "The width of the 'storm erosion hazard zone' might increase as the size of erosion 'bites' increased".

V. "Low-lying coastal land would be subject to flooding from the sea (by rising sea and storm wave levels) and from rivers (arriving on a higher base level)".

VI. "Backshore farmland would suffer flooding and saline intrusion. Estuary margins would flood, and their mouths would become unstable".

VII."With increased flooding, erosion, and wave energy, coastal structures and facilities would be at greater risk of damage".

VIII."With more north-east winds, an increasingly predominant south-east littoral drift would accentuate erosion on the south (downdrift)side of headlands (Mount Maunganui to Omapu)".

IX. "A stronger onshore wind regime would cause dunefield instability and sand losses inland".

The conditions associated with these long-range forecasts are similar to those that occur during a predominance of La Niña episodes. Such forecasts suggest the need for a precautionary approach to coastal management in the study area and the inclusion of a Safety Factor in any Coastal Hazard Zone assessment, as the historical past cannot simply be projected into the future.

**Summary**

1. The identified coastal hazards along the 13.9km-long study area coastline include localised sea and wind erosion and flooding from storm wave runup.

2. The entire 13.9km-long sand dune is subject to wind erosion and maximum short-term, episodic duneline fluctuations involving some 100 to 250m³ of dunesand per metre length of duneline.

3. Although there is a general trend of historic duneline advance, minor long-term retreat at the very low rates of -0.02 to -0.13m/year has occurred over the last 50 to 100 years along southeastern Karewa Parade, Motiti Reserve, Surf Road and at central Main Mount Beach. The proximate cause of the erosion is most probably a localised reduction in long-term sand supply.

4. Maximum storm wave runup levels of the order of 5 to 7m above MSL have occurred in the past and can be expected to occur over the next 100 years along the entire open-exposed coastline during severe onshore wave storms coupled with high spring
tides. Tsunami wave runup levels of the order of 1m above MSL have not posed a flood hazard along the coast in historical times and are unlikely to over the next 100 years.

5. Where the crest of the foredune is generally less than 5m above MSL, there is a high probability that low-lying coastal hinterland will be adversely affected by temporary saltwater inundation from storm wave runup coupled with high spring tides.

6. Climate Change from an enhanced Greenhouse Effect is forecast to cause a predominance of La Niña type conditions and an acceleration in the rate of historic sea-level rise from 1.2mm/year to 3.6mm/year by 2050 A.D., and 4.7mm/year by 2100 A.D.

7. An increase in wave storminess and the rate of sea-level rise next century is likely to increase the frequency and magnitude of short-term duneline fluctuations and cause a reversal in some areas of the long-term duneline trend from very slow advance and dynamic equilibrium, to long-term duneline retreat.

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).

Coastal Erosion Hazard Zone (CEHZ)

In accordance with the requirements of Environment BOP and the Methods stated in Part II 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 15 years (BPA 1984; 1989; Gibb 1981; 1983; 1987; 1991;1994a-d; 1995c; Gibb and Aburn 1986; AICE 1991), where:

\[
R = \text{Rate of long-term (historic) trend of net shoreline advance, retreat or dynamic equilibrium (m/year).}
\]
\[
S = \text{Area subject to maximum potential short-term duneline fluctuation (m).}
\]
\[
F = \text{Safety factor that is expressed on a scale from 1.0 (0%) to 2.0 (100%).}
\]
\[
T = \text{Planning horizon (years).}
\]
\[
X = \text{Rate of shore retreat (m/year) from local relative sea-level rise calculated by the Bruun Rule (Bruun 1962; 1983).}
\]

Where:

\[
X = \frac{la}{h + d} \quad \text{Eqn [1]}
\]

Where:

\[
a = \text{Rate of local relative sea-level rise (m/year).}
\]
\[
d = \text{Average closure depth below MSL (m).}
\]
\[
h = \text{Height of foredune above MSL (m).}
\]
\[
l = \text{Horizontal distance from the crest of the foredune to the contour representing the closure depth or seaward limit of beach sediment transport (m).}
\]
\[
D = \text{Horizontal distance of retreat of the top seaward edge of the dune erosion scarp (m), from collapse of unstable dunesand, calculated by:}
\]
\[ D = \left[ \frac{h}{\tan \theta} \right]^{0.5} \]  

Eqn [2]

Where:

\[ h \quad = \quad \text{Height of the foredune complex above MSL.} \]

\[ \tan \theta \quad = \quad \text{Angle of repose of dry loose dunesand.} \]

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:

\[ \text{CEHZ} = \left[ (X + R) T + S + D \right] F \]  

Eqn [3]

**Factor R**

For \( R \), long-term rates of erosion or accretion were calculated from the MWD Survey Plans of the area at 1:2,000 Scale and entered into the GIS model. Rates determined at every change point along the 13.9km-long coastline on baselines at 1:10,000 Scale were digitised by UniServices. An example is shown in Figure 20 along Main Mount Beach.

**Factor S**

For \( S \), the maximum potential short-term duneline fluctuations were determined from the combination of field and anecdotal observations, previous work, the MWD 1:2,000 Scale plans and observations of storm cuts during the events of 14 July 1995 and 24 January 1996. In particular, volumes of dunesand were measured along profiles seaward of old erosion scarps evident in the foredune complex in undeveloped areas. From these information sources, volumes were calculated by either ground surveys or with Council’s DTM and GIS.

The landward limit beyond which such duneline fluctuations were unlikely to penetrate was determined here to be the relatively high secondary dune about 60 to 75m inland from the present duneline. The secondary dune formed about 600 years ago and is clad in many places by shell middens indicating the preservation of evidence of Maori occupation over the last several centuries from erosion processes. No middens were observed on the foredune complex seaward of the 600-year dune, suggesting its potential sensitivity to large duneline fluctuations of the order of 100 to 250m³/m-length of beach.

From such evidence the volumes adopted in this study were 140m³/m length of duneline at Papamoa Township, 150m³ for Papamoa Domain, 175m³ from Te Ara Place to just south of Mussell Rocks, 150m³ from Mussell Rocks to the lee of Moturiki Island, grading to 100m³ and 125m³ northwestward along Main Mount Beach.
Figure 20: An example of digitised long-term shoreline erosion/accretion rates along baselines along Main Mount Beach. Data were incorporated into the GIS model. Positive values are accretion and negative, erosion.
The variation in volumes is indicative of the relative exposure and concomitant response of lengths of coastline to incident wave energy. For example, Motiti Island provides partial protection of Papamoa Township. Motuotau and Moturiki Islands and associated reefs provide similar protection at southeastern Main Mount Beach. The adopted volumes were entered into the GIS model and tested with respect to the dune topography shown on the April 1992 Aerial Photographic base in the GIS.

**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 2B). The following parameters for the Bruun Rule were entered into the GIS model.

For Equation [1], an average closure depth of -8.5m was adopted for factor $d$ based on the September 1995 hydrographic survey (Table 2) and work elsewhere within the Bay of Plenty. For factor $h$ (Eqn 1), the crest heights of the foredune were determined from Council’s DTM. For factor $l$ (Eqn 1), distances were determined from the crestline of the foredune to the -8.5m isobath by the GIS model.

For factor $a$ (Eqn 1), rates of sea-level rise of 3.6 and 4.7mm/year were determined from the IPCC-95 best estimates of 0.20m by 2050 A.D. and 0.49m by 2100 A.D., respectively. No adjustments were required for vertical displacement of the coastline from tectonic effects as the area is regarded as relatively stable (Kay et al. 1994).

**Factor T**

For $T$, periods of 55 years (1995-2050) and 105 years (1995-2100) 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 one-in-100year onshore wave storm and accompanying flooding from storm wave runup, 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° was determined directly by field measurement in the study area. This value was entered into the GIS 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. For Queensland, the Beach Protection Authority adopted a Safety Factor of 1.4 to calculate Buffer Zone widths (BPA 1984; 1989). Gibb (1995c&d) adopted a Safety Factor for 1.3 for assessment of CHZs in Central Hawke Bay and Gisborne.

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 Abum 1986), Hokitika (Gibb 1987), the Bay of Plenty (Gibb 1994a-d), Gisborne (Gibb 1995c), and Hawke’s Bay (Gibb 1995d), 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 2). As one might expect, relative risk over the next century diminishes landward from Extreme next to the coast, to Moderate inland. Although the above zones were determined for the 13.9km-long study area by the GIS model, Table 5 demonstrates the methodology and provides calculations for 14 representative sites. The CEHZs determined for the study area are shown on maps in Appendix V.

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 and has a high probability of being adversely affected at any point in time. The EREZ on the GIS plots ranges in width from 30 to 50 along Papamoa Township, 28 to 43m along Papamoa Beach Road, 33 to 47m along Oceanbeach Road, and 21 to 53m along Marine Parade (Appendix V).

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. The HREZ encompasses the period from 1995 to 2050 A.D., and has a high probability of being adversely affected at any time over the next 55 years. The HREZ ranges in width from 0 to 13m along Papamoa Township, 0 to 7m along Papamoa Beach Road, 0 to 14m along Oceanbeach Road, and 0 to 15m along Marine Parade (Appendix V).
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. The **MREZ** encompasses the period from 2050 to 2100 A.D., and ranges in width from 0 to 22m along Papamoa Township, 0 to 13m along Papamoa Beach Road, 0 to 17m along Oceanbeach Road, and 0 to 18m along Marine Parade (Appendix V).

The **Safety Buffer Zone (SBZ)** encompasses the area determined by the Safety Factor ($F$). 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 10 to 20m along Papamoa Township, 9 to 15m along Papamoa Beach Road, 10 to 20m along Oceanbeach Road, and 7 to 17m along Marine Parade (Appendix V).

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. However, should sea-level rise exceed the 1995 best estimates of the IPCC, then the rate of shoreline retreat has a high probability of accelerating proportionately. Equally, if the rise is less than the best estimate values of the IPCC, then the extent and rate of retreat has a high probability of being proportionately less.

**Sensitivity Test**

The methods adopted in this study and incorporated into the GIS computer model are sensitive to variations in the parameters which collectively determine the width of the CEHZ and associated Risk Zones and Safety Buffer Zone. To demonstrate the sensitivity, three Scenarios were adopted in Table 6 for three representative sites within the study area.

The **Medium Scenario** (Table 6) adopts the values used in this study to assess the CEHZ (Table 5). The **Low Scenario** (Table 6) assumes the IPCC 'Low' projections of global sea-level rise for next century (see Figure 19) of 0.08 and 0.20m by 2050 and 2100 A.D., respectively; the inner closure depth of -6.4m, averaging 434m offshore (see Table 3); a long-term accretion rate of 0.20m/year from a positive sand budget; a 20% decrease in the maximum potential short-term duneline fluctuation from the values given for the Medium Scenario; an angle of repose of dry, loose dunesand of 350; and, a safety factor of 1.2 (20%) (Table 6).

The **High Scenario** (Table 6) assumes the IPCC 'High' projections of global sea-level rise for next century (see Figure 19) of 0.39 and 0.86m by 2050 and 2100 A.D. respectively; a maximum closure depth of -23m, averaging about 2,000m offshore based on a significant change in gradient and sediment facies; a long-term erosion rate of -0.20m/year from a negative sand budget; a 20% increase in the maximum potential short-term duneline fluctuation from the values given for the Medium
### TABLE 6: Sensitivity tests for CEHZ calcula... using Equations [1], [2] & [3] for 3 representative sites. Papamoa Township (57 Motti Road), Papamoa Domain (500 Papamoa Beach Road) and Omana (3 Surf Road). Data for the Medium Scenario are from Table 5 and were adopted in this study for the CEHZ assessment for the 3 sites. Data for the High and Low Scenarios were adopted to demonstrate the sensitivity of the method to changes in the values for each factor.

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<th>3 Surf Road</th>
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<td>5.19</td>
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<tr>
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Scenario; an angle of repose of dry loose dunesand of 20\(^\circ\); and, a safety factor of 1.4 (40\%) consistent with that used by the Queensland Beach Protection Authority, Australia (Table 6).

Table 6 shows that changing the values for the factors used in Equations [1], [2] and [3] can have quite dramatic results when determining CEHZ widths for the 3 sites. For a planning horizon of 55 years (1995-2050 A.D.), CEHZ widths increase to 109 to 147m under a High Scenario relative to Medium Scenario widths of 41 to 68m (Table 6). Under a Low Scenario, CEHZ widths decrease to 32 to 38m for the same planning horizon (Table 6).

For a planning horizon of 105 years (1995-2100 A.D.), CEHZ widths increase to 164 to 181m under a High Scenario relative to Medium Scenario widths of 45 to 90m (Table 6). Under a Low Scenario, CEHZ widths decrease to 32 to 38m for the same planning horizon (Table 6).

The significant increases in CEHZ widths under a High Scenario (Table 6) are due mostly to significantly higher rates of erosion from sea-level rise, a negative sand budget enhancing these rates, and a higher safety factor of 1.4. Higher rates of erosion from sea-level rise occur from the combined effects of the ‘High’ projected rates of rise by IPCC-95 combined with a deeper closure depth further offshore.

In contrast, the significant decrease in CEHZ widths under a Low Scenario (Table 6) are mostly due to significantly lower rates of erosion from sea-level rise, a positive sand budget overwhelming these effects, and a lower safety factor of 1.2. Lower rates of erosion from sea-level rise occur from the combined effects of the ‘Low’ projected rates of rise by IPCC-95 combined with a shallower closure depth closer inshore.

The sensitivity test used here (Table 6) highlights the importance of reviewing the parameters used in the GIS computer model from time to time. Such a review should only take place if new high quality information becomes available. Such information will only become available if Council adopts an adequate ongoing monitoring programme of research and survey for the study area. The sensitivity test also highlights the fact that the CEHZ widths recommended in this study are mid-range or conservative.

**Coastal Flood Hazard Zone (CFHZ)**

The CFHZ is the area of land that “is subject to, and is likely to be subject to” episodic, temporary inundation by the sea. Such inundation would be caused by storm wave runup overtopping the crest of the foredune during high tide. For next century, the CFHZ should allow for both rising sea-levels of 0.20 and 0.50m above the present by 2050 and 2100 A.D., respectively, and the maximum probable storm wave runup elevations of 5 to 7m above MSL Moturiki Datum.

Using a similar framework to the Risk Zones adopted above for sea erosion hazard, High and Moderate Risk Flooding Zones are proposed here for the study area. Based on the above observations and projections, storm wave runup levels of 5.0 and 6.5m above MSL are adopted for the High and Moderate Risk Flooding Zones, respectively. Storm wave runup levels reaching and exceeding 5m are assumed to
occur during a 1-in-30 to 1-in-50 year wave storm. Runup levels reaching and exceeding 6.5m are assumed to occur during events of the order of 1-in-100 years.

The GIS model incorporating the DTM indicates both the area of coastal hinterland below 5.0m elevation included in the High Risk Flooding Zone and the area below 6.5m elevation included in the Moderate Risk Flooding Zone. These areas are associated with foredune elevations of similar or lesser heights, as the crest height will control the level of saltwater ponding behind.

**Summary**

1. The Coastal Hazard Zone (CHZ) assessed in this study incorporates both a Coastal Erosion Hazard Zone (CEHZ) and a Coastal Flood Hazard Zone (CFHZ) along the 13.9km-long study area coastline.

2. The Coastal Erosion Hazard Zone (CEHZ) ranges in width from about 40 to 100m and comprises an Extreme Risk Erosion Zone (EREZ) of 21 to 53m width, a High Risk Erosion Zone (HREZ) of 0 to 15m width, a Moderate Risk Erosion Zone (MREZ) of 0 to 22m width, and a Safety Buffer Zone (SBZ) of 9 to 20m width.

3. Although the EREZ and SBZ exist along the entire coast, both the HREZ and MREZ are discontinuous and exist only in areas where the predicted erosion rates from projected rises of sea-level of 0.20m by 2050 A.D. and 0.49m by 2100 A.D. exceed the long-term historical accretion rates.

4. Adopting higher or lower parameters for the GIS computer model significantly increases or decreases CEHZ widths respectively. CEHZ widths recommended in this study are regarded as conservative.

5. The CFHZ comprises a High Risk Flooding Zone (HRFZ) delineated by the 5m contour above MSL Moturiki Datum and a Moderate Risk Flooding Zone (MRFZ) delineated by the 6.5m contour.

6. The CFHZ is discontinuous along the entire coast and does not exist where the crest of the foredune equals or exceeds 6.5m above MSL.

**DISCUSSION**

The coastal hazard assessments made here are based on the highest quality scientific information available at this point in time (1995), much of which agrees with and quantifies the observations of long-standing residents. This study has revealed a general trend of long-term duneline advance over the last 600 years at the very low rates of 0.07
to 0.17m/year, from sand supplied predominantly from the nearshore seabed. The trend of duneline advance has generally persisted over the last 50 to 100 years, punctuated by areas of localised very slow long-term erosion at Papamoa Township, Surf Road and Main Mount Beach compared to dynamic equilibrium elsewhere. Much of the accretion has occurred since 1980 from sand supplied to the beach-dune system from the nearshore seabed out to about -8.5m water depth. These observations suggest a slightly positive sand budget in the study area which could become negative in the future with reduced supplies of sand into the area.

During the last 21 years (1973-1994), a predominance of El Niño conditions have contributed to ideal conditions for accretion through a local relative fall in sea-level and a lack of severe onshore wave storms. With the expected reversal to La Niña dominant conditions, local relative sea-level in the Bay of Plenty is likely to rise in accordance with both global and New Zealand regional sea-level rise, and there is likely to be an increase in severe onshore wave storms as tropical cyclones track down on to New Zealand.

La Niña conditions would promote a general reversal from accretion to erosion. Furthermore, a global sea-level rise of 0.20m above the present level by 2050 A.D. is likely to produce potential long-term erosion rates of -0.10 to -0.15m/year, which will increase to -0.13 to -0.19m/year from a sea-level rise of 0.49m by 2100 A.D. (Table 5).

Where the coastline already has an historic trend of long-term retreat, sea-level rise will enhance the existing erosion rates (Table 5). In contrast, where the historic long-term trend is advance, rates of accretion will either reduce or eliminate completely the potential erosion arising from sea-level rise.

These observations highlight the importance of maintaining a positive sand budget at all times to nourish the beach-dune system. They also highlight the importance of retaining sand in the foredune complex at times of accretion through effective Dune Care programmes.

The CEHZ widths assessed in this study are regarded as mid-range or conservative. For the 13.9km-long study area coastline, Table 5 indicates that conservative CEHZ widths for the period 1995-2100 A.D., may range from 45 to 90m inland from the seaward toe of the foredune. Relatively higher CEHZ widths (Table 5) are associated with areas with a modified relatively lower foredune complex and a history of long-term retreat enhanced by erosion from sea-level rise. In contrast, relatively lower CEHZ widths (Table 5) are associated with a long-term trend of accretion offsetting the effects of sea-level rise, and a natural relatively higher foredune complex.

Where the crest of the foredune is generally less than 5m above MSL, low-lying coastal hinterland has a high probability of being adversely affected by temporary inundation from the sea over the next 55 years from a one-in-30 to a one-in-50 year wave storm. Where the crest is generally less than 6.5m, low-lying hinterland has a high probability of being temporarily inundated by the sea over the next 55 to 105 years from a wave storm of the order of one-in-100 years.

Where the foredune complex is under moderate to extreme stress, horizontal duneline fluctuations extend further inland in proportion to the reduced sand volumes. In contrast, where the foredune is accreting naturally and under low stress, duneline fluctuations extend a relatively lesser distance inland. This is particularly well illustrated along the coastline between Te Ara Place and Mussell Rocks where the GIS model indicates horizontal duneline fluctuations of 30 to 53m for a constant volume of 175m³ of sand per metre length of duneline.
This study highlights amongst other matters, the importance of Council undertaking a Coastal Management Strategy soon that enables the permanent restoration, maintenance and enhancement of the foredune complex, where appropriate, between Mauao and Papamoa Township. This important landform is the first line of defence between the land and the mighty forces of the sea. Allowed to function naturally the foredune will adequately absorb the forces of the sea, provide sand to the beach at times of erosion, act as a repository for that sand at times of beach accretion, and protect property and assets inland.

RECOMMENDATIONS

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

RECEIVE and adopt the findings of this report.

ADOPT the conservative Coastal Erosion Hazard Zones, inclusive of the Extreme, High and Moderate Risk Erosion Zones and Safety Buffer Zone for the 13.9km-long study area coastline between Mauao and Papamoa Township east, assessed by the GIS computer model in this study.

ADOPT storm wave runup elevations for the study area coastline of 5m above MSL to define a High Risk Flooding Zone, and 6.5m above MSL to define a Moderate Risk Flooding Zone to delineate a Coastal Flood Hazard Zone between Mauao and Papamoa Township, on Council’s Digital Terrain Model of the dunes.

INCORPORATE the Coastal Hazard Information as appropriate into both Council’s District Plan and Land and Property Information Memoranda, to both control use, subdivision and development in the CEHZ and to advise the public of both long-term and short-term risks to beachfront property from natural hazards.

ESTABLISH and maintain an ongoing Physical Coastal Monitoring Programme between Mauao and Papamoa Township (see S.35, Resource Management Act 1991) in conjunction with Environment BOP, to provide the necessary information to revise, as appropriate, the parameters incorporated into the GIS computer model.

PROMOTE a research programme aimed at reliably quantifying the active sediment budget in the Nearshore Transport Zone including the processes responsible for sediment transport between the Kaituna River mouth and the Tauranga Harbour Entrance.

REASSESS the Coastal Hazard Zones defined by the GIS model every 10 years using the same factors used in this assessment, OR after the occurrence of significant natural phenomena (e.g. large wave storms, tsunami, etc.), OR after significant new information becomes available (e.g. Climate Change and sea-level rise, monitoring programme, etc.), OR after significant improvements in the state of the foredune (e.g. dune conservation and restoration, beach replenishment, Dune Care Programme, etc.),

ADOPT appropriate policies and rules in the District Plan to promote land uses compatible with the identified coastal hazards within the Coastal Hazard Zone to avoid and mitigate damage to assets and the coastal environment from such hazards, and to restore and maintain the integrity of the protective foredune.

COMMISSION the establishment of an integrated holistic Coastal Management Strategy for the long-term sustainable management of the open-exposed physical coastal system
between Mauao and the Kaituna River mouth, including its nationally significant amenity and conservation values.

CONCLUSIONS

1. Observations and anecdotal information held by 24 long-standing local residents that were interviewed is in general, in excellent agreement with the scientific evidence analysed in this study.

2. Levelling of the foredune complex at Main Mount Beach, along parts of Marine Parade, at Papamoa Domain and Papamoa Township between the 1950s and 1970s has increased the sensitivity of these areas to adverse effects from natural hazards.

3. In other areas, local residents have stabilized sand dunes under extreme stress by judicious planting of dune binding vegetation thus reducing the sensitivity of these areas to adverse effects from natural hazards.

4. Over the last 1,800 years the duneline in the centre of the study area has advanced 86m from accretion at a very low net rate of 0.05m/year. Over approximately the last 600 years the duneline between Sunbrae Grove and Papamoa has advanced at 0.07 to 0.17m/year indicating a slightly positive sand budget.

5. Over the last 51 to 106 years, the 13.9km-long study area duneline has generally advanced from sand accretion at rates of 0.03 to 0.51m/year, punctuated by localised areas of long-term retreat at -0.08 to -0.13m/year at Papamoa Township east, Moltii Reserve, Surf Road, and the centre of Main Mount Beach indicating the persistence of a positive sand budget in the northwestern study area and a reversal to a negative sand budget in the southeastern study area.

6. The entire 13.9km-long coastline is subject to short-term episodic duneline fluctuations involving volumes of dunesand of the order of 100 to 175m$^2$ of sand per linear metre of duneline, and wind erosion. The higher volumes occur along more exposed parts of the coast.

7. Of the 13.9km-long foredune complex in the study area, 12% is presently under extreme stress, 43% is under high stress, 38% is under moderate stress and 7% is under low stress. A desirable outcome is that the entire foredune complex be under low stress.

8. The Nearshore Sand Transport System extends 460 to 795m offshore out to the -8.5m depth contour below MSL Moturiki Datum and is composed of medium to fine volcanic-derived sand and an irregular dynamic longshore bar-trough system involved in onshore-offshore exchanges of sand with the beach.

9. The identified coastal hazards that may provide an actual and potential threat to beachfront property and assets include sea and wind erosion and flooding from the sea.

10. A forecast increase in both sea-level rise next century from the historic rate of 1.2mm/year to 4.7mm/year by 2100 A.D. and wave storminess as a consequence of Climate Change from an enhanced Greenhouse Effect, is likely to result in an increase in the magnitude and frequency of short-term duneline fluctuations, and cause a reversal from a long-term trend of very slow advance and dynamic equilibrium, to long-term retreat.
11. The Coastal Erosion Hazard Zone (CEHZ) ranges in width from about 40 to 100m inland from the duneline and comprises an Extreme Risk Erosion Zone (EREZ) of 21 to 53m width, a High Risk Erosion Zone (HREZ) of 0 to 15m width, a Moderate Risk Erosion Zone (MREZ) of 0 to about 22m, and a Safety Buffer Zone (SBZ) of 9 to 20m width. The CEHZ is regarded here as a mid-range or conservative assessment.

12. The Coastal Flood Hazard Zone (CFHZ) comprises a High Risk Flooding Zone (HRFZ) delineated by the 5m contour above MSL Moturiki Datum and a Moderate Risk Flooding Zone (MRFZ) delineated by the 6.5m contour. Flooding from the sea is likely to occur from storm-wave runup during the passage of deep cyclonic depressions, and not from tsunami.

ACKNOWLEDGEMENTS

The following people contributed to this study in various ways and are gratefully acknowledged.

**Tauranga District Council:** Craig Batchelor, Acting Director - Planning and Environment; Colin Mills, GIS Analyst Programmer; Peter Watson, Area Reserves Office;

**Environment BOP:** Christopher Turbott, Coastal Planner;

**Department of Conservation, Bay of Plenty Conservancy:** David Phizacklea, Coastal Conservation Officer;

**Port of Tauranga:** Owen Maynard - Hydrographer;

**University of Waikato:** Associate Professor Richard Warrick of CEARS;

**NIWA:** Dr Robert G Bell, Coastal Oceanographer;

**Uniservices:** Harley Prowse, GIS Consultant;

**The Jones Partnership:** Harold Jones, Director;

**Shrimpton & Lipinski Ltd:** Tim McBride and Ron Lipinski - Surveyors;

**Local Residents:** Edward Murray, Bruce Cunningham, Mary Dillon, Fred H Skipworth, Winston Cox, Blair Dickie, Malcolm Taylor, Marjorie Whiteside, Neil Hansen, Jock Fahy, D N Pirrit, Jenny Blade, Mrs Wilson, Ken Musgrove, Curtis Moxham, Ian Boyce, Taffie Davies, Ron Lipinski, Don Kiddie, Bruce Eaddy, Gordon Crosby, Bruce Crosby, Stuart Crosby and Brian Shrimpton.

Dr Peter Cowell, Senior Lecturer, Coastal Studies Unit, Marine Studies Centre, Department of Geography, The University of Sydney, NSW Australia, peer reviewed the manuscript and hazard maps.
11. The Coastal Erosion Hazard Zone (CEHZ) ranges in width from about 40 to 100m inland from the duneline and comprises an Extreme Risk Erosion Zone (EREZ) of 21 to 53m width, a High Risk Erosion Zone (HREZ) of 0 to 15m width, a Moderate Risk Erosion Zone (MREZ) of 0 to about 22m, and a Safety Buffer Zone (SBZ) of 9 to 20m width. The CEHZ is regarded here as a mid-range or conservative assessment.

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Dr Peter Cowell, Senior Lecturer, Coastal Studies Unit, Marine Studies Centre, Department of Geography, The University of Sydney, NSW Australia, peer reviewed the manuscript and hazard maps.
REFERENCES


BPA 1981: Coastal dune management. Beach Protection Authority of Queensland.


APPENDICES

APPENDIX I
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Rates of Coastal Erosion and Accretion and List of Cadastral Survey Plans of the study area

APPENDIX IV
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APPENDIX I

A Geographic Information System Model for Coastal Hazard Risk Assessment.

by

Harley Prowse
A Geographic Information System Model for Coastal Hazard Risk Assessment

Report prepared for Tauranga District Council
by
Harley Prowse - GIS Consultant
Geographic Technologies Unit - Auckland UniServices Ltd.

Introduction

In September 1995 the Geographic Technologies Unit (GTU) of Auckland UniServices Ltd. was commissioned by Tauranga District Council (TDC) to provide technical Geographic Information Systems (GIS) support for the Coastal Hazard Risk Assessment Project. The role of the GTU was to liaise with the Coastal Management Consultant (Dr. Gibb) and the Tauranga District Council (Colin Mills) in order to design, test and standardise a flexible model using the Arc/Info Geographic Information System to predict zones of coastal hazard within the study areas (Gibb 1995). This work was to build upon the initial development undertaken by Colin Mills for Tauranga District Council under the guidance of Dr. Gibb.

This report is written as a supplement to the main report prepared by Dr. J. Gibb (Gibb 1995) and makes significant reference to that report avoiding the need to repeat aspects of the work that have been described already.

Data Requirements

A number of key data describing the physical coast are needed to develop and run the model. This data is described in this section of the report.

Digital Cadastral Database Coastline

The digital coastline was supplied by the Department of Survey and Land Information and was already in the TDC GIS as part of the Digital Cadastral Database. It was used to construct the baselines which are a series of straight lines that described the shape of the coast. These baselines were then used by the GIS to generate the perpendicular profile lines at 4m intervals along the baselines (Figure 1).

Digital Terrain Model

The Digital Terrain Model (DTM) was acquired by the TDC in 1992 from digital aerial photography (flown in 1992) and provides elevation data with a horizontal resolution of 8m and a vertical accuracy of ±0.5m. The DTM is an excellent existing data set that is used to provide the spot heights along the profile lines down to 0.0m Mean Sea Level (MSL) (Moturiki Datum 1953) providing similar data to that which would be acquired from conventionally surveyed profile lines. The lower accuracy of the DTM in comparison to conventionally surveyed spot heights, is traded off against the fact that over such a large amount of coastline the cost and practicality of conventionally surveying profile lines at a 4m interval is prohibitive.
Figure 1. Diagram illustrating how the computer model uses baselines to derive the profile lines which are kept perpendicular to the general shape of the coastline.

Dune Toe and Dune Crest Lines

Digital lines representing the dune toe and the crest were captured from maps prepared by Dr. Gibb based on field investigation and contour data (from the TDC GIS). These lines were then digitally captured by the GTU for inclusion in the GIS model.

The Closure Depth Line

The closure depth line describes the position and depth of the seaward limit of the nearshore transport zone and was determined accurately by Dr. Gibb from hydrographic survey work and from previous work in the Bay of Plenty (Gibb 1995). The closure depth is an essential component of the Bruun Rule method (see Figure 2 in Gibb 1995) which estimates the amount of erosion due to sea level rise.

Long Term Erosion/Accretion Rates

Long term erosion or accretion rates were measured by Dr. Gibb by comparing historical surveys of the coastline spanning the last 50 to 106 years (Gibb 1995). These rates were determined in detail along the coast and assigned to the closest profile line by the GIS system. The erosion rate data was then used for the hazard zone assessment.
Short Term Duneline Fluctuation Volume

The maximum potential short term fluctuation volumes (due to 'normal' coastal conditions and processes) of the dune line within the three study areas were determined by Dr. Gibb. These represent the maximum potential short term duneline fluctuations in response to periods of storminess followed by periods of relatively calm seas (Gibb 1995). These volumes vary along the coast and reflected the differing nature of the coast in terms of its exposure to the dominant wave attack and whether there are offshore features providing a wave intercept and therefore potentially decreased wave energy at the coast (such as around the Mount beach area).

Method

The GIS model combines an understanding of coastal geomorphic process with digital data describing the coastal environment to produce a predictive model of coastal hazard risk zones along the coast. The model, based on a knowledge of coastal processes, was developed by Dr. Gibb. The method for putting the model onto the GIS was developed by the author and Colin Mills (of TDC).

Essentially the model aims to predict the maximum amount of foreshore that could be eroded given a severe storm event now and after 55 and 105 years of sea level rise. These three scenarios are labelled the Extreme Risk Erosion Zone, the High Risk Erosion Zone and the Moderate Risk Erosion Zone respectively (Gibb, 1995). In addition, there is a Safety Buffer Zone which allows for uncertainties in the data and is 30% of the total risk zone width.

Profiles are constructed perpendicular to the coast at parallel 4m intervals running in a shoreward direction. The generally parallel profiles are kept perpendicular to the coast by making use of the straight baselines which follow the general shape of the coast (Figure 1). The model calculates the volume of sand beneath the profile line at 1m intervals starting at the dune toe and continuing inland until the short term fluctuation volume is reached (Figure 2). MSL Moturiki Datum (1953) is taken as the baseline (elevation of zero) for the volume calculations.

The initial start volume (Figure 2) is calculated by assessing the height of the dune toe by querying the DTM and projecting a line back seaward at the stable angle of repose (AOR) of dry, loose dune sand which has been measured as 33° for this study. The area of the triangle formed is taken as the initial volume (a on Figure 2). The GIS then moves 1m inland along the profile line and calculates the area indicated by $V_I$ on Figure 2. $V_I$ is added to $a$ and the model continues until the short term fluctuation volume is reached. To further refine the location of where the volume is reached ($E_i$ in Figure 2), when the model gets near the volume it changes from 1m intervals to 0.25m intervals for the area calculations. As a beach face is not vertical the AOR is used to assess the final landward position of the Extreme Risk Erosion Zone ($E$ in Figure 2).

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 profile line which, when joined with all the others, creates a line down 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 dune toe) is calculated (Figure 3) using the Bruun Rule, a detailed
description of which is given in Gibb (1995, Figure 2). This new starting point is the estimated location of the dune toe 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 dune toe and moves it inland a distance calculated by the Bruun Rule plus the long-term erosion trend (x in Figure 3).

The GIS uses the closure depth line and the dune crest line along with other parameters such as sea level rise, elevation and long term erosion trends to calculate erosion from sea-level rise using the Bruun Rule for each profile and provides the new starting location for the model. Thus the model is run twice using the Bruun Rule for a planning horizon of 55 years of sea level change (estimates conditions in 2050) and 105 years of sea level change (estimates conditions in 2100) to determine High and Moderate Risk Erosion Zones respectively (Figure 4).

If potential sea level rise is countered by long term accretion, then the Bruun Rule value is set to zero and, in the model, the dune toe 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.

**Figure 2.** Diagram illustrating the volume calculation method used in the computer model to calculate the Zone of Extreme Risk.

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**Extreme Risk Erosion Zone**

- **E** = initial volume assuming an angle of repose of 33°
- **v, v₁, v₂, v₃ =** next volumes to be calculated and cumulatively totaled, interval of 1m
- **E₁ =** the point where the short term dune line fluctuation volume is reached
- **E₂ =** the point of the inland extent of the Zone of Extreme Risk given an angle of repose of 33°
- **[ ] =** maximum potential short term dune line fluctuation volume

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Once the three zones have been determined, a fourth zone, the Safety Buffer Zone, is calculated (Figure 4). This zone is 30% of the total risk zone width and allows for uncertainty in the various components used to calculate the coastal hazard risk zones.

**Model Testing**

The model has been tested during development in terms of ensuring the calculations are correct and the results are sensible. This has been done by way of manual calculations and double checking of the results against manual calculations from previous work. The model has also been built from the ground up, in that it was started with a simple case (one profile and volume
calculation) and complexity has been gradually added as the model developed to the point where it automatically calculates the Coastal Hazard Risk Zones for the entire study area.

**Figure 3.** 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.

- **High Risk Erosion Zone**
- **Extreme Risk Erosion Zone**
- New start point
- Foredune
- Dune line (initial start point)
- Beach
- Mean Sea Level
- Predicted dune line at 2050 AD
- a = initial volume assuming an angle of repose of 33°
- x = beach set back to new start point due to sea level rise and erosion (Bruun Rule calculations)
- v, v₁ = next volumes to be calculated and cumulatively totalled, interval of 1m
- H₁ = the point where the short term dune line fluctuation volume is reached
- H = the point of the inland extent of the High Risk Erosion Zone given an angle of repose of 33° with respect to H
- □ = maximum potential short term dune line fluctuation volume
- ■ = additional area potentially eroded - added to the Extreme Risk Erosion Zone to give the High Risk Erosion Zone

**Figure 4.** 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.

- **Safety Buffer Zone**
- **Moderate Risk Erosion Zone**
- **High Risk Erosion Zone**
- **Extreme Risk Erosion Zone**
- Foredune
- Original dune line
- Predicted dune line at 2100 AD
- Predicted dune line at 2050 AD
- Beach
- Mean Sea Level

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APPENDIX II

Report on an investigation into the determination of Mean High Water Mark for land title purposes along the coastal strip between Mount Maunganui and Papamoa East 1888-1974

by

T A McBride
A further level of testing is field verification of the computer results. In conjunction with Dr. Gibb, model results were verified in the field by examining a number of representative test areas and calculating the Hazard Zones manually for comparison with the computerised results. The process of verification provided the final step in achieving internal consistency in the model for all parts of Tauranga District's open exposed coastline.

References

REPORT ON AN INVESTIGATION INTO THE
DETERMINATION OF MEAN HIGH WATER MARK FOR LAND
TITLE PURPOSES ALONG THE COASTAL STRIP BETWEEN
MOUNT MAUNGANUI AND PAPAMOA EAST 1888-1974

PURPOSE

The purpose of this investigation was to obtain first hand information regarding the evidence
gathered and methods used by land surveyors to determine the mean high water mark along the
Mount Maunganui/Papamoa coastline during the course of carrying out Land Transfer and Survey
Office surveys in the period 1888-1974.

IDENTIFICATION OF SURVEYS TO BE INVESTIGATED

Dunewatch identified those Land Transfer and Survey Office plans which it required investigated.

METHOD

The method used to investigate the identified plans was as follows:
(1) from the plans identify the surveyors who carried out or supervised the surveys
(2) locate and interview those surveyors still in the district regarding:
   (i) the particular survey/surveys they carried out
   (ii) the methods used by their colleagues
(3) For those surveys carried out by surveyors who are now deceased, or unable to be located,
   and for which no reliable information was available from surviving surveyors, as to the
   methods used by those surveyors, a search of the Department of Survey and Land
   Information (DOSLI) plan files was made for boundary reports. The hope was that the
   boundary reports would provide information on the physical evidence used by the surveyors
   to determine M.H.W.M.

RESULTS

The results of the Investigation are as follows:
MARINE PARADE/OCEANBEACH ROAD AREAS

SO 4802  Surveyor - E C Goldsmith (deceased)
DOSLI were unable to locate a plan file for this survey. The plan gives no indication
as to how the M.H.W.M was fixed. I suspect that the M.H.W.M fix has been taken
from an earlier fix, either contained in a field book or from an earlier plan.

DP 25168 & DP 24561  Surveyor - R T Goulding (deceased) - No information located.
From our examination of the plan, this determination would have been a very rough
and ready fix. The purpose of fixing M.H.W.M would have been merely to illustrate
that Marine Parade (earlier known as Oceanbeach Road) was in excess of 100 lks
wide M.H.W.M was most likely determined by pacing to the wet line on the beach
on the day. An accurate fix was not required as no areas needed to be calculated
using the M.H.W.M line.

DP 30237  Surveyor - J E Benham (interviewed)
Mr Benham was trained by Mr R T Goulding and the methods used by Mr Goulding
were adopted by Mr Benham. It can be safely assumed that the method used by Mr
Benham for fixing the M.H.W.M applies also to surveys carried out by Mr Goulding.

Mr Benham described their method of fixing M.H.W.M as follows:
The wave action was observed over the top of the tides and the extent of the wet line
up the beach noted. This was compared with the flotsom line and a mean position
between the two lines determined as M.H.W.M. Mr Benham does not recall this
position ever reaching as high up the beach as the toe of the foredune.

This method of determining M.H.W.M also applies to the following plans surveyed
by Messrs Goulding and Benham.

DP 32044  Surveyor - R T Goulding

DP 32961  Surveyor - R T Goulding

DP 34334  Surveyor - R T Goulding and J E Benham.

DP 34214  Surveyor - J E Benham
It is interesting to note that the survey marks placed on M.H.W.M by DP 30237 in
1939 and SO 31914 in 1942 were found by this survey and agreed with this plans fix
of M.H.W.M.

SO 31914  Surveyor - A M Linton (deceased)
DOSLI advise the plan file has been destroyed.
It is of interest, that where this plan joins DP 34334, that the M.H.W.M on DP
34334 is approximately 10 metres seaward, five years later, when that survey was
carried out.
ML 7136-40  Surveyor - J Baber (deceased)
DOSLI advise that there is no plan file for this survey and no information was found
from surviving surveyors.

PAPAMOA BEACH ROAD/DOMAIN ROAD AREA

ML 4868  Surveyor - J Baber (deceased)
DOSLI advise that there is no plan file for this survey and no information was found
from surviving surveyors.

ML 18324  Surveyor - L L Elder (interviewed)
Mr Elder’s recollection of the method used on this survey is as follows.
(1) Prior to carrying out a M.H.W.M survey obtain from the Tauranga Harbour
Board the days on which tides approximating mean high water were
predicted.
(2) on a calm day around these predicted tides carry out the survey by fixing the
position of the upper limit of the wave action which became the definition of
M.H.W.M.

SO 22128  Surveyor - H R Atkinson (deceased)
No plan report is available for this plan. Copies of the field notes and plan
enlargement are enclosed. They are of interest as a High Water Springline is also
shown. Enquires with DOC, who DOSLI believe may have the plan file, yielded
nothing. DOC staff did search their files but could not locate the plan report.

SO 27082  Surveyor - N Clay (deceased)
DOSLI advise that the plan file was sent to DOC in 1987 and not returned. DOC
staff were unable to find it. No information was available on the determination of
M.H.W.M.

SO 48303-SO 48304  Surveyor - T A Keefe (interviewed)
Mr Keefe recalled this survey. At the time of this survey Mr Keefe worked for the
Department of Lands and Survey at the Rotorua District office.

M.H.W.M on this survey was determined by fixing the line of flotsom which from
Mr Keefe’s recollection was 5-10m seaward of the toe of the dune. As the surveyor
commuted daily from Rotorua he was unable to reference M.H.W.M directly to
wave action on the beach.

PAPAMOA AND PAPAMOA EAST AREA

DP 10096  Surveyor - O R Farrer (deceased)
DOSLI have no plan report for this survey. Contact was made with present and past
employees of Thomson and Farrer in Hamilton. Mr E Stirling who worked with
Mr Thomson and is now retired was interviewed but had no knowledge of Mr Farrer’s or Mr Thomson’s method of determining M.H.W.M on ocean beaches.

**DPS 3396, DPS 4383 & DPS 4384**  
Surveyors - B A Shrimpton (interviewed)  
- T A Kenny (deceased)

These surveys were carried out jointly by Messrs Shrimpton and Kenny. Mr Shrimpton’s recollection of the surveys was that Mr Kenny did the peripheral survey and M.H.W.M definition while he carried out the laying out of the lots and road alignments.

The plan report for DPS 3396 records that M.H.W.M was determined by levelling from a Lands and Survey Department Bench Mark which was in terms of Moturiki Datum 1953. The report states that the Lands and Survey Department advised the Surveyor that M.H.W.M was 2.3 feet above the height of that bench mark.

The plan reports for DPS 4383 and 4384 record that M.H.W.M was determined by the same method used in the determination of M.H.W.M on DPS 3396. Mr Shrimpton’s recollection is that M.H.W.M for these surveys was in that area of the beach covered by the daily tidal movement.

**DPS 4699**  
Surveyor - T A Kenny (deceased)  
DOSLI has no plan report on file in their records. Examination of the plan indicates that the M.H.W.M has been taken from earlier plans and not fixed by this survey (- possibly taken from DPS 1188).

**DPS 6210 & 6211**  
Surveyor - M C Williams (deceased)

We have spoken to Mr F W Millington a surveyor based at Thames who was a cadet of Mr Williams. Mr Millington recalled Mr William’s practice was to observe a series of tides and then take the average position of the high water mark. The plan report for these plans record, that the high tide was observed over four days and the mean position taken.

**ML 11056**  
Surveyor - Thomson (deceased)

DOSLI hold a plan file for this survey, however, the Surveyor’s plan report does not state how M.H.W.M was fixed. Mr Stirling had no knowledge as to how Mr Thomson would have fixed the M.H.W.M.

**CONCLUSION**

Definitive statements from surviving surveyors as to the methods used either on their own surveys or those of their colleagues have been obtained for thirteen of the surveys.

Two surveys DP 25168 and DP 24561 would be very approximate in location from examination of the plans.
Two plans DPS 4699 and SO 4802 at year to have adopted the position of M.H.W.M from earlier surveys or field records.

No information was found by way of recollections or plan files for eight of the plans.

For those surveys on which no specific detail has been found it is our opinion that the methods used would have been similar to those used on surveys for which specific information is available. The plans which have used a level to determine M.H.W.M are the exception. Levels were used for those plans as substantial earthworks was to be carried out for residential development. The height of the dunes above M.H.W.M was of great significance in ensuring the proposed lots would be safe from inundation.

All the above surveyors were trained under a cadet system and the methods of the master surveyors were invariably adopted by the cadets. It is our opinion that, for the surveys for which there is no recorded method, that the fix would have been of a line which lies somewhere between the established wet line on the beach, determined by direct observation of the height any particular tide reached, and the flotsam line.

T A McBride
Registered Surveyor

16 November 1995

Appendix

Plan Reports - 3 covering 5 surveys

Field notes - Plan enlargement for SO 22128
APPENDIX III:

Rates of advance seaward or retreat landward of Mean High Water Mark (MHWM) and the seaward toe of the foredune (Duneline) between Papamoa Township and Mauao over a total length of coastline of 13.89km for 44 representative Sites.

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
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<tbody>
<tr>
<td>(A)</td>
<td>Site location by street address;</td>
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<tr>
<td>(B)</td>
<td>cumulative distance of Stations measured from maps at 1:2,000 Scale;</td>
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<td>(C)</td>
<td>texture of beach sands from Healy et al. (1977, fig.9.1);</td>
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<td>(D)</td>
<td>survey years from MWD Sheets 1982 (revised 1994);</td>
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<td>(E)</td>
<td>reference shorelines from MWD Sheets and report by T.A. McBride (Appendix II);</td>
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<td>(F)</td>
<td>dune gained from accretion (+) or lost from erosion (-) tabulated as a horizontal distance in metres for each site;</td>
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<td>(G)</td>
<td>rates of advance/retreat of MHWM or duneline in metres per year (m/y) for each survey interval;</td>
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<td>(H)</td>
<td>net rates (m/y) for entire survey periods for MHWM and the duneline;</td>
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<tr>
<td>(I)</td>
<td>data sources from which direct measurement were made.</td>
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Table of Cadastral Plans used to assist with derivation of rates of shoreline movements.
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<th>SURVEY INTERVAL (y)</th>
<th>REFERENCE SHORELINE</th>
<th>RETREAT (+) or ADVANCE (-) (m)</th>
<th>RATES (m/y)</th>
<th>NET RATES (m/y)</th>
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<td>B CUMULATIVE DISTANCE (km)</td>
<td>C BEACH TEXTURE</td>
<td>D SURVEY INTERVAL (y)</td>
<td>E REFERENCE SHORELINE</td>
<td>F RETREAT (-) or ADVANCE (+) (m)</td>
<td>G RATES (m/y)</td>
<td>H NET RATES (m/y)</td>
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# Cadastral Plans Covering Selected Parts of the Tauranga District Coastline Between Mount Maunganui and Papamoa

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<th>Surveyed Shoreline</th>
<th>Inferred Duneline Position</th>
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<td>Papamoa east</td>
<td>April 1918</td>
<td>HWM</td>
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**Notes:**

(i) Plans with inferred duneline (seaward toe of foredune) positions were used to quantify directions and rates of shoreline movements.

(ii) Duneline positions were inferred on the basis of the Shrimpton and Lipinski report (Appendix II), the plotted position of the surveyed shorelines on the MWD Plans Sheets 1 to 14 at 1:2,000 Scale, and the relative width of the beach shown on TDC Photomaps 1982 at 1:2,000 Scale.

(iii) Survey dates and surveyed shorelines are from the cadastral plans.
APPENDIX IV

Peer Review of this study
The University of Sydney

Coastal Studies Unit
(Department of Geography)
Marine Studies Centre

Chief Executive
Tauranga District Council
Private Bag 12022
Tauranga, Bay of Plenty,
New Zealand

Attn: Craig Batchelor (Acting Director - Planning)

Dear Sir,


I have read the report as requested by Dr Gibb. I concentrated on the general principles rather than site specific aspects, since I have no direct knowledge of the study area. In respect of the general principles however, I am well qualified to comment. I am presently engaged in the development of an expert system for assessing the coastal impacts of climate change, together with Professor B.G. Thom (Vice Chancellor, University of New England and Chair of the New South Wales Coastal Committee), funded by the Federal Government's National Greenhouse Advisory Committee, and the science of long-term coastal change is central to my expertise in research. The main points emerging from my review of the Dune Watch report are as follows:

- The study is based on techniques in coastal-hazard assessment used elsewhere by established specialists, such as the Coastal Branch of the NSW Department of Public Works.
- The assessment incorporates use of a GIS model that represents a major advance on the techniques available anywhere in the international arena at present.
- The GIS model allows integration of the data, and more importantly, provides the capability of undertaking sensitivity analysis for dealing with uncertainty stemming from limitations to scientific knowledge and from the non-linear nature of the coastal processes themselves.
- Consideration should be given to providing additional funds to take full advantage of the GIS model through a extensive sensitivity analysis in respect of the important parameters. Such an analysis would deal with the uncertainty in more comprehensively, and allow hazard extremities can be determined with more confidence.

More specifically, the Dune Watch report is based upon established and accepted principles that are applied widely by experienced coastal management practitioners for estimation of existing geomorphic hazard levels on the coast, together with projections of these hazards that take into account forecasts concerning climate change. In particular, the report follows an approach that is similar to that used by the Coastal Branch of NSW Department of Public Works (now Dept. of Land and Water Conservation) in undertaking coastal hazard assessments for local government. The PWD have 20 years experience in this field and have state-wide statutory responsibility to provide expert advice of this kind. Consistent with the approach used by the NSW PWD, the Dune Watch study provides detailed analyses and cross checking, using various lines of evidence, have been followed in the study to help deal with the uncertainty surrounding the processes involved, as well as the predictions and recommendations upon which they are based. The results of the analyses lead directly to the basic recommendations. However, the results have the additional purpose of providing the estimates for parameter values used in a GIS model that was

Dr Peter J Cowell

April 10, 1996
developed in conjunction with project to map risk levels along the coast. This parametric GIS model is a new and very worthwhile methodological development. The model allows the results of the analyses to be tailored to meet the variations in local conditions throughout the study region. The model therefore provides a valuable tool for use by local-government decision makers. Its value as a coastal management tool is further enhanced because the model allows for revision of hazard assessments when new information becomes available, warranting changes to parameter values in the model.

It must be stressed that the basic derivation of parameter values follows well-accepted procedures. However, it must be stressed just as strongly that hazard assessment is fraught with uncertainty, for reasons elucidated by de Vriend (1991, Proc. Coastal Sediments '91, ASCE, p. 356) and Cowell and Thom (1994, in Coastal Evolution, Cambridge Univ. Press.) and that the uncertainty becomes severe when the projected coastal impacts of climate change are included in any assessment. It is with regard to this uncertainty that I raise the following cautionary points concerning the analyses from which parameter values were derived for use in the GIS model. These points follow from the results of rather new work and ideas stemming from it, although I hasten to add that the work has passed the test of peer review and it has been published recently in international journals (eg Cowell et al, 1995, Mar. Geol., 126, p. 45). These cautionary points are as follows:

1. The closure depth may be too shallow in relation to the time scales over which climate-induced sea-level rise is anticipated. The report derives estimates based upon a range of criteria, but the focus seems to be on annual closure depths (p.25). Cross-shore sand transfers that are too small to cause measurable morphological change on an annual basis may well prove important over periods extending to 50 years and beyond, particularly if sea-level rise is involved. Offshore patterns in the grain size of surface sediment, similar to those reported for the study region, are known to occur off many coasts world-wide, including south-east Australia. Coarser sands at depth on the Atlantic coast of the USA are invoked as evidence of offshore losses beyond the shoreface (eg Niederoda and Swift, 1991, in Handbook of Coastal and Ocean Eng., v.2, Gulf Pub.). In south-eastern Australia we invoke an explanation for the coarse sand zone offshore that is similar to the explanation offered for the NZ study region; ie, winnowing of fines onshore. However, we remain uncomfortable with the idea that this indicates that there can be no loss of fines offshore, especially in response to high magnitude storms or, over the long term as a Bruun-type response to sea-level rise. Recommendation: Make additional funds available to re-run the GIS model for larger closure depths, possibly to depths of 25 m, to assess the sensitivity of the hazard-zone mapping to closure-depth uncertainty in relation to Greenhouse-induced sea-level rise over the long term.

2. Diminishing rates of coastal progradation in parts of the study region are interpreted in the report as being attributable to the tendency for the coast to be adjusting toward a dynamic equilibrium, as a lagged response to previous changes in environmental conditions such as the onset of sea-level still stand. Other possibilities should be considered perhaps, such as there being a progressive change in sediment budgets simply related to depletion of sediment sources. If this were so, the sediment budget may reach a balance temporarily, followed by reversal to a new regime dominated by a negative sediment budget, causing coastal recession. The central coast of The Netherlands is a good example of such an occurrence over the long term (Beets et al., 1992, Mar. Geol., 423). Recommendation: Make additional funds available to undertake a sensitivity analysis of coastal change in relation to an arbitrary (though realistic) range of gains and losses in the littoral sand budget. (This can be done crudely using manual methods, or by application of profile-response models such as our Shoreface Translation Model or Kraus and Hansen's Genesis or S-Beach models.)

3. Very recently we have come to appreciate that coastal recession is much more sensitive to a local deficit in the littoral sand-transport budget than to the effects of sea level rise (Cowell et al., 1995). Estimates for the littoral sediment fluxes are rarely accurate, so estimation of the residuals, upon which coastal recession/advance depends, is even more difficult to gauge. Given the additional uncertainty alluded to under Point 2, I place considerable importance on the Recommendation given under Point 2.

4. The repose angle for dry sand (33°) is used in determining extent of the coastal-erosion hazard
zone (CEHZ). The horizontal width of the CEHZ becomes progressively more sensitive to the slope angle as dune height increases. This issue is of considerable practical relevance if the hazard-zones are to be used as the basis for building set-back limits. Geotechnical considerations, to do with lateral forces on inclined surfaces due to foundation loadings, result in slope-stability criteria that involve angles much less than 33°. Engineering studies by Poulos (c.1992) apply these principles to coastal frontal dunes. (I do not have the reference at my finger tips at present, but I can dig it up if necessary.) The effect of lowering the stability angle for slopes is to widen the CEHZ by an amount that increases with dune height. Recommendation: Decide whether geotechnical loadings are of administrative importance in relation to the CEHZ, and consider whether relevant parameters should be adjusted in the GIS model.

Yours sincerely,

Dr P.J. Cowell
Senior Lecturer
APPENDIX V

Coastal Erosion Hazard Maps for the 13.9km-long study area.