COASTAL MANAGEMENT CONSULTANCY LIMITED

REVIEW OF THE 1996 COASTAL HAZARD ZONE BETWEEN AHURIRI ENTRANCE AND ESK RIVER MOUTH

Report prepared for Napier City Council

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EXECUTIVE SUMMARY

OBJECTIVES

On 5 September 2001, Coastal Management Consultancy Limited (CMCL) were commissioned by Napier City Council (NCC) to review the 1996 single line Coastal Hazard Zone (1996 CHZ) between the Ahuriri Entrance and Esk River mouth. The primary objectives of the review were:

i. Review the basis of the 1996 CHZ assessment.

ii. Determine the impact of the current level of beach nourishment of the Westshore nourishment scheme on the 1996 CHZ and whether such nourishment is an appropriate mitigation option of the identified coastal hazards of erosion and flooding from the sea.

iii. Assuming that the Westshore nourishment scheme is discontinued, assess a single line CHZ with respect to the 1995 line of Mean High Water Springs (MHWS) (**Scenario 1**).

iv. Assuming beach nourishment continues at current rates, assess a single line CHZ with respect to the 1995 MHWS (**Scenario 2**).

METHODS

The methods adopted for the review were peer reviewed by Dr Peter J Cowell, an international expert in coastal hazard assessment from the Coastal Studies Unit, University of Sydney. The methods involved:

i. A rigorous analysis of the Westshore nourishment scheme and its effects on the coast during its period of operation between January 1987 and October 2001.

ii. Adopting a planning horizon of 100 years (2001-2100).

iii. Quantifying the rate of erosion both before and after the inception of the Westshore nourishment scheme in January 1987 (Factor **R**).

iv. Quantifying the zone subject to short-term beach profile fluctuations (Factor **S**).

v. Quantifying the potential rate of erosion from local relative sea-level rise (RSLR) (Factor **X**).

vi. Determining a Safety factor that reflects uncertainties in the data for Factors **R**, **S** and **X** (Factor **F**).

vii. Quantifying potential sea flood elevations.

viii. Developing internally consistent ‘best practice’ deterministic methods to assess CHZ widths.

Data utilised for the CHZ review were a combination of existing survey data held by NCC, Hawke's Bay Regional Council (HBRC) and Port of Napier and new survey data gathered by Jones Zorn Surveying Ltd, and CMCL between September and October 2001.

MAIN FACTS FOUND

Coastal Erosion Hazard:

Following the Magnitude 7.8 Hawke's Bay Earthquake of 3 February 1931 and accompanying uplift of the 10km-long barrier beach ridge by 1.8-2.1m, the coastline advanced from accretion from 1931 to about 1962. After 1962, the trend of advance reversed to retreat from erosion at net rates between about 1962 and 2001 of:

-0.06 to -0.79m/year along Westshore;

-0.13 to -0.26m/year along Bay View;

-0.15 to -0.30m/year along Gill Road – Rogers Road; and,

-0.05 to -0.45m/year along Le Quesne Road.

The proximate causes of the post 1931 erosion trend include:

i. Termination of the natural supply of beach gravels to the area transported by the net Northerly longshore drift, by construction of breakwaters at Port Ahuriri in 1876-1879 and Port of Napier in 1887-1890.

ii. Removal Northward of beach gravels by the net Northerly longshore drift at 10,000m^3/year along Southern Westshore and 12,000m^3/year along The Esplanade.

iii. Temporary reversals in the direction of the net Northerly drift during 20-30 year climatic cycles.

iv. Local relative sea-level rise at 1.73-2.30mm/year last century increasing to 2.73-5.1mm/year by 2100.

v. Wave abrasion of beach gravels on the foreshore reducing beach volumes by 10% at Southern Westshore, 15% along The Esplanade and 40% toward Bay View.

vi. Localised southward migration of the Esk River mouth.

Coastal Flood Hazard:

Following the 1931 Earthquake, tsunami have not posed a significant sea flood hazard along the 10km-long barrier ridge compared to storm wave runup (SWRU). Maximum SWRU elevations of the order of 3.5-4.5m above MSL occur at Westshore, 6m at Bay View and 7m at Le Quesne Road. Localised coastal flooding from the Esk River occurs around the mouth. The sea has not overtopped the tectonically uplifted barrier crest since 1931 on which most of the residential development is placed.

Westshore Nourishment Scheme:

Between January 1987 and October 2001, 240,000m^3 of gravel and sand were placed along 3km of Westshore coastline, averaging 12,000m^3 per 20 placement events. The following effects have occurred since 1987:

i. For the 6km of coast between Scarpa Flow and Bay View, the line of the coast has been successfully held in position along the Northern 4.5km against erosion forces, partially held along the 1.2km of Southern Westshore, and not held along about 0.3km of Whakarire Avenue.

ii. The net Northerly longshore drift of 10,000-12,000m^3/year has been the dominant process responsible for spreading the net benefit along the 4.5km of coast as far as the start of Snapper Park Motor Camp, and preventing the net benefit spreading South of Fenwick Street to Scarpa Flow and remaining in situ.

iii. The line of the coast along the 1.2km-long Southern Westshore area has not been held by the scheme but has retreated at –0.27 to –0.95m/year from erosion since nourishment began there in March 1991.

iv. The amenity value of approximately 6km of the 10km-long barrier beach has been maintained and possibly enhanced by the Westshore nourishment scheme.

CHZ REVIEW

The findings of this review are summarised in the following table with respect to CHZ widths for 7 coastal areas along the 10km-long coast assessed for; the 1996 CHZ, the **Scenario 1** CHZ (Westshore nourishment scheme stopped) and the **Scenario 2** CHZ (Westshore nourishment scheme continues at current rates).

	Whakarire Ave	Westshore South	The Esplanade	Beacons–Reserve area	Bay View	Gill Rd–Rogers Rd	Le Quesne Rd
Cumulative Distance (km)	0.28	1.45	3.19	4.70	6.0	7.43	10.0
1996 CHZ (m)	35-70	45-105	55-135	70-95	80-90	75-95	80-210
Scenario 1 CHZ (m)	35-75	50-110	65-130	75-95	100-105	90-105	85-225
Scenario 2 CHZ (m)	-	-	40-65	60-75	80-85	-	-

Comparing the 1996 CHZ with the **Scenario 1** CHZ, the only significant change in widths are increases for **Scenario 1** of 15-20m at Bay View, 10-15km along Gill Road-Rogers Road and 5-15m along Le Quesne Road. The increase has resulted from an increase in values for Factors **R**, **S** and **F** in **Scenario 1** owing to both improved data and refined methods used for this review.

Comparing the **Scenario 1** CHZ with the **Scenario 2** CHZ, there is a significant reduction in CHZ widths for **Scenario 2** of 25-65m along The Esplanade, 15-20m along the Beacons-Reserve area and 20m along Bay View. The reduction has resulted from Factor **R** being reduced to zero owing to the Westshore nourishment scheme mitigating erosion and holding the line of the coast since 1987. The current scheme has not mitigated erosion along Westshore South or Whakarire Avenue.

Although the scheme has mitigated erosion hazard from1987 to 2001 from The Esplanade to Bay View, current nourishment rates make no provision for the effects of rising sea levels or uncertainties in Factors **R**, **X** and **S**. The **Scenario 2** CHZ assessment adopts a precautionary approach thus making provision for these factors for these areas.

Maximum SWRU elevations of 4-7.5m that accommodate sea-level rise and define a Coastal Flood Hazard Zone all lie within the **Scenario 1** CHZ and do not extend landward of it. Hence the hazard zone for both erosion and flooding from the sea is termed the 2001 CHZ in this review.

RECOMMENDATIONS

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

1. **ADOPT** the 2001 Coastal Hazard Zone for Scenario 1 between the Ahuriri Entrance and Esk River mouth to replace the 1996 Coastal Hazard Zone previously adopted and implemented by Council.

2. **REVIEW** the current Westshore nourishment scheme to improve its effectiveness and sustainability during this century, with special reference both to mitigating coastal erosion between Scarpa Flow and Fenwick Street, and ensuring the sustainability of the Pacific Beach supply source and any other potential sources.

3. **INITIATE** steps to guarantee the operation of the Westshore nourishment scheme on a sustainable basis before considering the adoption and implementation of the much-reduced 2001 Coastal Hazard Zone for **Scenario 2** that assumes the continuation of the scheme.

4. **REVIEW** the current coastal monitoring programme of Hawke's Bay Regional Council between Ahuriri Entrance and Esk River mouth to ensure its effectiveness and sustainability at quantifying the effects of both coastal hazards and the Westshore nourishment scheme.

5. **REVIEW** the 2001 CHZ using similar methods every 5-10 years based on monitoring data and the performance of an upgraded Westshore nourishment scheme.

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REVIEW OF THE 1996 COASTAL HAZARD ZONE BETWEEN AHURIRI ENTRANCE AND ESK RIVER MOUTH

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PART I: BACKGROUND

1. INTRODUCTION

On 5 September 2001, Coastal Management Consultancy Limited (CMCL) were commissioned by Napier City Council (NCC) to review the Coastal Hazard Zone (CHZ) assessed for the 10km-long coastline between the Ahuriri Entrance and Esk River Mouth in 1996 by Dr JG Gibb (Director CMCL). The adopted acronyms to be used in this report for the 1996 CHZ assessment are "*1996 CHZ*", and for this review, "*2001 CHZ*". The agreed objectives of the review are:

> i. *"To review the 1996 CHZ assessed between Ahuriri Entrance and Esk River Mouth and the basis of that assessment.*
>
> ii. *To take account of the impact of the current level of beach nourishment on the 1996 CHZ in the review and whether such beach nourishment forms an appropriate mitigation of the identified coastal hazards which could lead to a revision of the 1996 CHZ in line with ongoing beach renourishment in perpetuity."*

In addition, the terms of reference for the review required that:

> i. *"Empirical methods using the same factors to assess the 1996 CHZ will be adopted for the revised 2001 CHZ.*
>
> ii. *The 2001 CHZ will be plotted on fully rectified Orthophotomaps based on the April 1999 Aerial Survey by Air Logistics Ltd which have been incorporated into Council's GIS. The revised 2001 CHZ will be compared with the 1996 CHZ.*
>
> iii. *The 2001 CHZ will identify a single line on the Orthophotomaps in relation to the 1995 position of MHWS (MHWS 1995) used as the reference shoreline for the 1996 CHZ, such line indicating the Coastal Hazard Zone should replenishment be continued at current rates.*

> *iv. The 2001 CHZ will also identify a line on the Orthophotomaps in relation to the same reference shoreline (MHWS 1995), such line indicating the Coastal Hazard Zone should replenishment at current rates be discontinued.*
>
> *v. The 2001 CHZ will accommodate the identified coastal hazards of erosion and flooding from the sea over a planning horizon up to 2100. "*

In this report, the beach replenishment programme and the empirical methods and parameters adopted for the review are described. The parameters underpinning the 2001 CHZ were derived from new field data collections for which data summaries are tabulated and descriptions given in the text. All relevant data collections were carefully vetted by CMCL and incorporated into NCC's Geographic Information System (GIS) along with the 2001 CHZ lines. The incorporation of this information into NCC's GIS is regarded here as an important long-term contribution to informed coastal management by NCC of the 10km-long study area coast and a basis for monitoring.

At NCC's request the methods used in this review to assess the 2001 CHZ were peer reviewed by Dr PJ Cowell, Coastal Studies Unit, University of Sydney. Copies of the briefing paper for Dr Cowell plus his peer review are provided in Appendix I of this report.

1.1. HAZARDS ASSESSMENT TERMINOLOGY AND ACRONYMS USED IN TEXT

Many of the terms and acronyms below are used in the text. The definitions are those that have been generally adopted by Dr Gibb since the 1970s.

Barrier Beach Ridge: A depositional beach ridge of mixed sand and gravel that provides a natural barrier to low-lying coastal hinterland from marine erosion and flooding.

Barrier Crest: A line representing the maximum elevation of the barrier crest above MSL.

Barrier Edge: A line representing the contact point of the active foreshore with the seaward edge of the barrier ridge crest that is generally recognised in the field as the toe of a small erosion scarp and/or the seaward limit of land vegetation.

Closure Depth: A depth contour (isobath) below MSL that represents the seaward toe of the barrier beach ridge at which no measurable or significant change in bottom depth occurs with time.

Coastal Accretion: The product of deposition of material at the shoreline by the action of wind, waves and currents, leading to a gain of land as the shoreline advances seaward.

Coastal Erosion: The process of episodic removal of material at the shoreline by the action of wind, waves and currents, leading to a loss of land as the shoreline retreats landward.

Coastal Hazard Zone (CHZ): A generic term to define areas of coastal hinterland adjacent to the sea where the land is or is likely to be subject to the effects of actual and potential natural coastal hazards over defined planning horizons. In the context of this study the term encompasses both a CEHZ and a CFHZ.

Coastal Erosion Hazard Zone (CEHZ): A precisely defined CHZ where the dominant natural coastal hazard is sea erosion.

Coastal Flooding: Inundation of low-lying coastal hinterland by a storm tide during a severe wave storm or a local or distantly generated tsunami, often enhanced by fresh water run-off during associated prolonged, intensive rainfall.

Coastal Flood Hazard Zone (CFHZ): A precisely defined CHZ where the dominant natural coastal hazard is flooding from the sea sometimes combined with fresh water flooding.

Eustatic Sea Level: Time-dependent uniform change in global sea-level trends around the coastline, regardless of causation.

Foreshore: Area of coast washed by the ebb and flow of the tides and swash-backwash from breaking waves.

Local Relative Sea Level Rise (RSLR): The resultant of the combination of eustatic sea level rise and vertical land displacements at the coast such as tectonic downdrop plus subsidence, leading to a local apparent rise in sea level against the coast.

Longshore Drift: The movement of sand and gravel along the shore in response to the oblique approach of waves to the shore. Momentum (mass times velocity) from the angled breaking wave induces a longshore current by which water together with fine sediments placed in suspension by the breaking wave, moves parallel to the shoreline. In addition, coarser sediments are pushed and rolled along the bottom and across the foreshore as bedload, tracing a sawtooth path in the direction of wave travel.

Mean High Water Springs (MHWS): The average of the levels of each pair of successive high waters, during that period of about 24 hours in each semi-lunation (approximately every 14 days), when the range of the tide is greatest.

Mean Sea Level (MSL): The average level of the sea surface over a long period, (preferably 19 years), for all stages of the tide, or the average level which would exist in the absence of tides.

Natural Hazard: The probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. 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

Reference Shoreline: The identified shoreline both in the field and on Orthophotomaps adopted as the reference line for the assessment of a CHZ on a map, which may include; the line of MHWS, the top seaward edge of seacliffs (clifftop), seaward toe of seacliffs (cliffline), seaward toe of foredune (duneline), seaward edge of barrier ridge crest (barrier edge), and seaward limit of land vegetation (vegetation line).

Storm Surge: During a wave storm a storm surge against the coast is generated by the combination of barometric set-up and wind set-up from the event.

Storm Tide: A storm tide is a generic term used to cover the elevation reached during flooding from the sea resulting from the combinations of storm surge, dynamic wave set-up and run-up, wave overtopping of coastal barriers and seawater ponding in flood basins enhanced by fresh water run-off.

Storm Wave Run-up (SWRU): During a wave storm the combination of the storm surge plus dynamic wave set-up and run-up generated by the event produces SWRU on the coast.

2. METHODS

The following methods were adopted in this review of the 1996 CHZ, including the assessment of the 2001 CHZ.

2.2. WESTSHORE NOURISHMENT SCHEME

Data supplied by Hawke's Bay Regional Council (HBRC) were analysed to determine the effects of the Westshore nourishment scheme since its commencement in January 1987. The data included beach and offshore profile data and information on volumes of sediment placed on the Westshore beach area between January 1987 and November 2001. Figure 1 shows the location of profiles referred to in this study that are monitored by HBRC from time to time.

2.3. 1996 COASTAL HAZARD ZONE ASSESSMENT

The 1996 CHZ incorporated both a Coastal Erosion Hazard Zone (CEHZ) and a Coastal Flood Hazard Zone (CFHZ). The following factors used to assess the 1996 CEHZ by Gibb (1996), were reviewed:

2.3.1. 1996 CEHZ ASSESSMENT

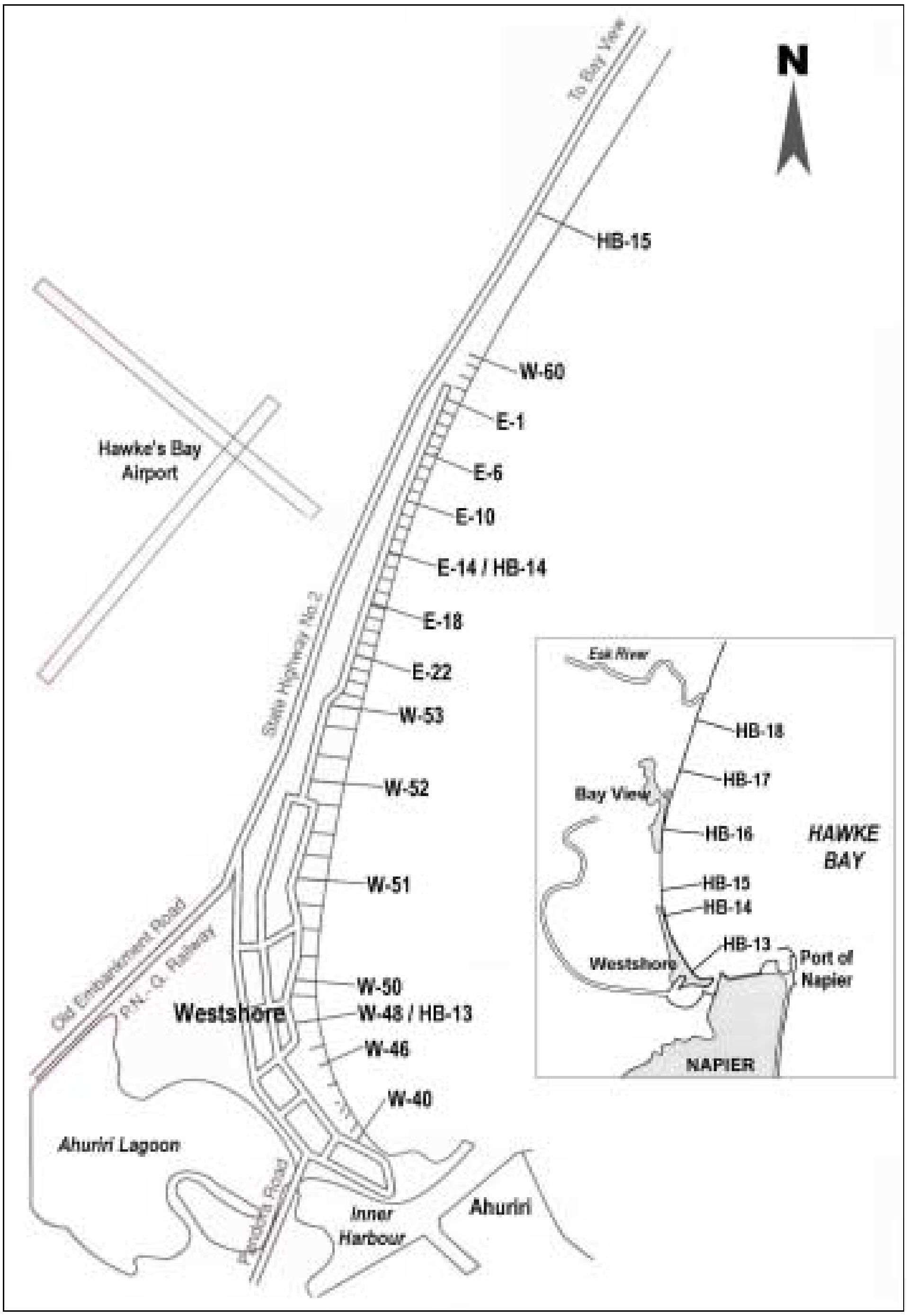
R = Rate of long-term (historic) trend of net shoreline advance, retreat, or dynamic equilibrium in metres per year (m/y).

S = Horizontal distance in metres (m) subject to the maximum observed short-term beach profile fluctuation.

X = Potential rate of long-term shoreline retreat in response to local relative sea-level rise (SLR) this century.

T = Planning horizon of 100 years.

F = Safety factor that reflects uncertainties in the data for parameters **R**, **S** and **X**.



- **Figure 1:** Sketch map showing the beach profile network in the study area monitored by HBRC. Profiles are indicated by lines generally at right angles to the coast. All HB Series are numbered and E and W Series are selectively numbered on the basis of profiles with the most comprehensive record.

2.3.2. EMPIRICAL METHODS

Gibb (1996) adopted the following empirical equations to assess the 1996 CEHZ including factor **X**, where;

$$\mathbf{CEHZ = [(X + R)\ T]\ F + S} \qquad \text{Eqn [1]}$$

Factor **X** was calculated by the Bruun Rule (Bruun 1962, 1983), where:

$$\mathbf{X} = \frac{\mathbf{al}}{\mathbf{d + h}} \qquad \text{Eqn [2]}$$

Where; **a** = Amount of forecast local relative SLR in metres (m) by 2100.
l = Horizontal distance from the barrier beach crest to the closure depth (m).
d = Closure depth of the barrier beach ridge below Mean Sea Level (MSL) Napier Datum.
h = Elevation of the barrier crest above MSL.

2.3.3. 1996 CFHZ ASSESSMENT

For the 1996 Coastal Flood Hazard Zone assessment, Gibb (1996) determined maximum storm wave runup elevations (SWRU) along the 10km-long barrier beach ridge from historical observations. A value allowing for the projected SLR this century was added to the maximum SWRU elevations to estimate a height for a severe wave storm with a recurrence interval of the order of 50 to 100 years.

The estimated height of SWRU was then compared with known elevations of the barrier ridge crest at that time to determine the CFHZ by an appropriate contour above MSL. In this review, the 1996 SWRU elevations, forecasts for SLR this century and elevations of the barrier ridge where reviewed.

2.4. FIELD DATA COLLECTIONS

In September-October 2001, field surveys were conducted by both CMCL and David Zorn of Jones Zorn Surveying Limited, Napier, (under CMCL's direction) to gather relevant data for this review. All surveyed heights and positions by Jones Zorn Surveying Ltd were to centimetre accuracy and were fixed and recorded digitally by a differential Global Positioning System (GPS). A survey report is provided by David Zorn in Appendix I. The following field data were collected.

i. *Beach Profiles*: Table 1 summarises the existing established profile network selectively monitored by HBRC in the study area. Of the 56 profiles, 6 were resurveyed on 4 October 2001 (HB Series), 13 resurveyed on 6 October (E Series), 17 on 17 October 2001 (W Series), and the remainder (20) between 15 July 1997 and 26 July 2000 (Table 1).

- **Table 1:** Beach and offshore profile surveys between Ahuriri and Esk River mouth held by Hawke's Bay Regional Council. General locations of the 56 profile sites are shown on Figure 1. * E-14 same station as HB-14; W-48 same station as HB-13.

PROFILE SURVEYS							
PROFILE	BEACH			OFFSHORE			
SERIES	First Date	Last Date	Total Surveys	First Date	Last Date	Total Surveys	
HB-13	27-Aug-1975 to	4-Oct-2001	63	26-May-1988 to	9-Oct-2001	6	
HB-14	1-Apr-1937 to	4-Oct-2001	48	23-Dec-1996 to	9-Oct-2001	3	
HB-15	1-Jan-1916 to	4-Oct-2001	26	23-Dec-1996 to	9-Oct-2001	2	
HB-16	21-Aug-1974 to	4-Oct-2001	49	12-Nov-1974 to	9-Oct-2001	4	
HB-17	20-Dec-1995 to	4-Oct-2001	9	9-Oct-2001 to	9-Oct-2001	1	
HB-18	5-Dec-1991 to	4-Oct-2001	14	30-Mar-1992 to	9-Oct-2001	3	
E-a	2-Dec-1986 to	6-Oct-2001	19	nil		-	
E-b	2-Dec-1986 to	15-Jul-1997	18	nil		-	
E-c	2-Dec-1986 to	15-Jul-1997	17	nil		-	
E-1	20-Oct-1977 to	20-Jul-2001	26	nil		-	
E-2	20-Oct-1977 to	6-Oct-2001	25	nil		-	
E-3	20-Oct-1977 to	15-Jul-1997	22	nil		-	
E-4	20-Oct-1977 to	6-Oct-2001	26	nil		-	
E-5	20-Oct-1977 to	15-Jul-1997	24	nil		-	
E-6	20-Oct-1977 to	6-Oct-2001	28	nil		-	
E-7	20-Oct-1977 to	15-Jul-1997	23	nil		-	
E-8	20-Oct-1977 to	6-Oct-2001	21	nil		-	
E-9	20-Oct-1977 to	9-Aug-1999	25	nil		-	
E-10	21-Feb-1955 to	6-Oct-2001	26	nil		-	
E-11	20-Oct-1977 to	20-Jul-2001	26	nil		-	
E-12	20-Oct-1977 to	6-Oct-2001	21	nil		-	
E-13	20-Oct-1977 to	15-Jul-1997	22	nil		-	
E-14	1-Apr-1937 to	6-Oct-2001	48	23-Dec-1996 to	9-Oct-2001	3	*
E-15	20-Oct-1977 to	15-Jul-1997	22	nil		-	
E-16	20-Oct-1977 to	6-Oct-2001	24	nil		-	
E-17	20-Oct-1977 to	15-Jul-1997	24	nil		-	
E-18	21-Feb-1955 to	6-Oct-2001	29	nil		-	
E-19	20-Oct-1977 to	15-Jul-1997	23	nil		-	
E-20	20-Oct-1977 to	6-Oct-2001	27	nil		-	
E-21	20-Oct-1977 to	15-Jul-1997	22	nil		-	
E-22	21-Feb-1955 to	6-Oct-2001	30	nil		-	
E-23	3-Mar-1987 to	20-Jul-2001	16	nil		-	
E-24	3-Mar-1987 to	6-Oct-2001	16	nil		-	
E-25	3-Mar-1987 to	15-Jul-1997	14	nil		-	

PROFILE SURVEYS									
PROFILE	BEACH				OFFSHORE				
SERIES	First Date		Last Date	Total Surveys	First Date		Last Date	Total Surveys	
W-39	13-Aug-1998	to	17-Oct-2001	4	nil			-	
W-40	1-Jul-1984	to	17-Oct-2001	15	nil			-	
W-41	1-Jul-1984	to	26-Jul-2000	16	nil			-	
W-42	1-Jul-1984	to	17-Oct-2001	14	nil			-	
W-43	1-Jul-1984	to	13-Aug-1998	13	nil			-	
W-44	1-Jul-1984	to	20-Jul-2001	14	nil			-	
W-45	1-Jul-1984	to	17-Oct-2001	16	nil			-	
W-46	1-Jul-1984	to	17-Oct-2001	17	nil			-	
W-47	1-Jul-1984	to	26-Jul-2000	15	nil			-	
W-48	27-Aug-1975	to	4-Oct-2001	63	26-May-1988	to	9-Oct-2001	6	*
W-49	1-Jul-1984	to	13-Aug-1998	15	nil			-	
W-50	1-Jul-1984	to	17-Oct-2001	17	nil			-	
W-50a	29-Oct-1992	to	17-Oct-2001	9	nil			-	
W-50b	29-Oct-1992	to	26-Jul-2000	9	nil			-	
W-50c	29-Oct-1992	to	17-Oct-2001	11	nil			-	
W-51	1-Jul-1984	to	17-Oct-2001	17	nil			-	
W-51a	29-Oct-1992	to	17-Oct-2001	8	nil			-	
W-51b	29-Oct-1992	to	17-Oct-2001	9	nil			-	
W-51c	29-Oct-1992	to	17-Oct-2001	8	nil			-	
W-52	21-Feb-1955	to	17-Oct-2001	18	nil			-	
W-52a	29-Oct-1992	to	17-Oct-2001	8	nil			-	
W-52b	29-Oct-1992	to	17-Oct-2001	8	nil			-	
W-53	21-Feb-1955	to	17-Oct-2001	27	nil			-	
W-60	21-Feb-1955	to	17-Oct-2001	25	nil			-	

ii. *Offshore Profiles*: All 6 offshore profiles were resurveyed by a Port of Napier inshore survey craft on 9 October 2001 with Jones Zorn Survey Ltd., using an echo sounder to decimetre accuracy (Table 1-HB Series).

iii. *Barrier Crest*: The position and crest elevation of the barrier beach ridge (Plate 1) between the Ahuriri Entrance and Esk River mouth was fixed by survey in October 2001 by a series of cross-sections across the barrier ridge to centimetre accuracy. The crest of the artificial barrier beach ridge along southern Westshore was also fixed by survey. The highest point along each cross-section was captured and joined by line between each cross-section to determine the crest position and elevation.

iv. *Barrier Edge*: The seaward toe of the barrier crest located at the base of a small but noticeable erosion scarp at the top of the active beach was fixed by survey to centimetre accuracy. Jones Zorn Surveying Ltd. conducted this exercise with CMCL on 8 October using a differential GPS and 4WD motorbike between the Ahuriri Entrance and Esk River Mouth (Plate 2).

- **Plate 1:** Photograph taken 28 September 2001 by Dr Gibb looking North from the end of The Esplanade, showing barrier beach ridge crest marked by the track and edge marked by the contact of the active beach with vegetation.

- **Plate 2:** Photograph taken 8 October 2001 by Dr Gibb looking South from near Le Quesne Road, showing David Zorn fixing the position of the barrier edge.

v. *Photographs*: A series of 35mm ground photographs were taken at representative sites by CMCL along the 10km-long barrier ridge between the Ahuriri Entrance and Tangoio in September-October 2001 as part of field observations of the barrier beach ridge.

All digital survey data were quality checked by Jones Zorn Surveying Ltd., and entered by NCC into their Geographic Information System (GIS). The survey data were recorded as an information layer over the coloured backdrop of the fully rectified April 1999 Orthophotomaps. In addition, the GIS layer also included all HBRC profile benchmarks, the 1996 CHZ, the 77 stations used in this study, including the 61 stations used by Gibb (1996) to plot the 1996 CHZ, the 1995 line of MHWS, cadastral surveys of MHWM dating from 1882, and aerial surveys of the barrier edge made in 1936 and 1962. These data provided the basis of the review of the 1996 CHZ and the assessment of the 2001 CHZ.

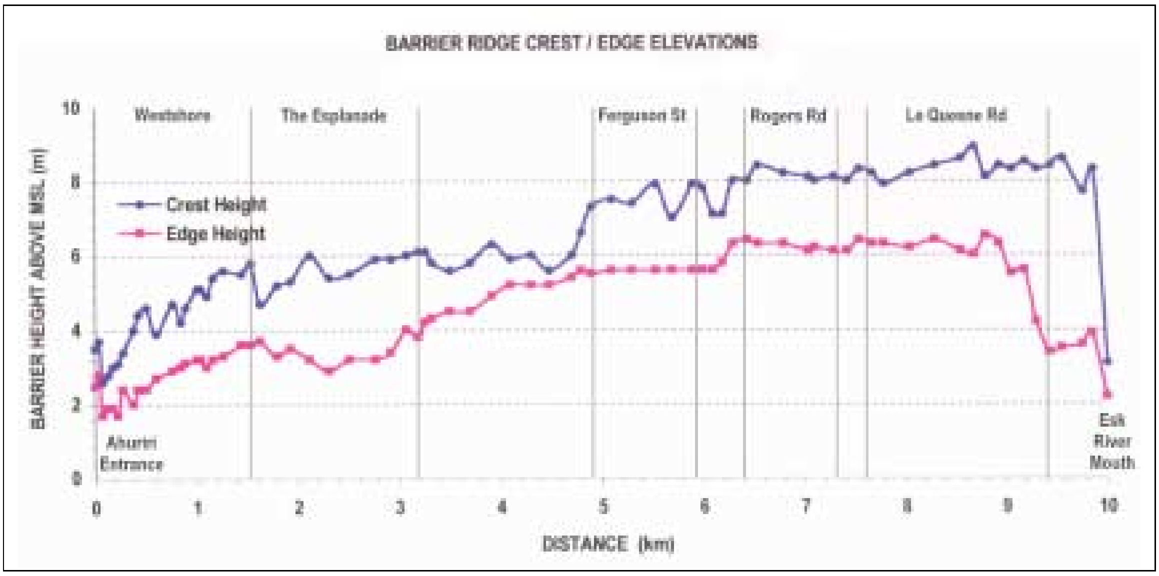
PART II: FACTS FOUND

3. BARRIER BEACH RIDGE

The 10km-long barrier beach ridge between the Ahuriri Entrance and Esk River mouth is a component of a 42.5km-long barrier ridge between Clifton and Tangoio in the North. The barrier has been constructed principally from wave action and is composed of well-rounded greywacke gravels and sand that generally diminish in size North. The continuity of the barrier beach was interrupted about mid-way by the construction of both the East Mole at Ahuriri Entrance in 1879 and the weather breakwater for Napier Harbour between 1887 and 1890 (Gibb 1996). Table 2 summarises some physical attributes of the 10km-long section of barrier ridge that were derived from both Gibb (1996) and survey data collected during this review.

3.1. BARRIER ELEVATION

Table 2 provides elevations of both the crest of the 10-km-long barrier beach ridge and the barrier edge. Figure 2 provides a graphic depiction of alongshore trends in both barrier crest and edge between the Ahuriri Entrance and Esk River mouth. Table 3 provides summaries of elevations for the 7 areas listed in Table 2.



• **Figure 2:** Alongshore trends in elevation with respect to MSL of the barrier beach ridge crest and edge between the Ahuriri Entrance and Esk River mouth. Compiled from data in Table 2.

- **Table 2:** Dynamic attributes of the 10km-long barrier beach ridge between Ahuriri and Esk River mouth. Column [A] - Location of 77 stations of which 16 are new since 1996, for 7 general areas. Column [B] - Distances from the West Ahuriri Mole adopted from Gibb (1996, table 5) and derived from 1:1000 Scale NCC Orthophotomaps based on April 1999 Aerial Survey. Column [C] - Surveys adopted to quantify barrier crest retreat or advance. Column [D] - Net advance (+) or retreat (-) in metres (m) of the seaward edge of the barrier crest during the 39-65 year survey period, and net rates [Column E] in metres per year (m/y). Column [F] - Beach widths for 1986 and 1995 adopted from Gibb (1996, table 5) for 61 stations and widths for 2001 measured from the NCC 1:1000 Scale Orthophotomaps for all 77 stations. Column [G] - Barrier crest and barrier edge elevations derived from field surveys in October 2001. Column [H] - Closure depth and distance from the barrier crest, derived from HBRC profile data and Port of Napier Ltd., hydrographic data. Column [I] - The barrier crest trend over the last 39-65 years and proximate cause derived from rates (Column E) and other information.

	A	B	C	D	E	F			G		H		I
	LOCATION OF STATIONS	**CUMULATIVE DISTANCE NORTH**	**SURVEY INTERVAL**	**BARRIER CREST RETREAT (-) or ADVANCE (+)**	**RATES**	**BEACH WIDTHS**			**BARRIER ELEVATION**		**CLOSURE DEPTH**		**BARRIER CREST TREND**
		(km)	**(y)**	**(m)**	**(m/y)**	**(m)**			**(m)**		**(MSL)**		
						1986	**1995**	**2001**	**Crest Height**	**Edge Height**	**Depth**	**Distance**	
	WESTSHORE SOUTH												
1	**West Mole**	0.00	1962-2001	8.0	0.21	10	10	10	3.5	2.5	-4.7	382	Advance - Reclamation
1a	**Car Park**	0.045	1962-2001	6.0	0.15	-	-	8	3.7	2.8	-4.7	387	Advance - Reclamation
2	**Whakarire St east**	0.08	1962-2001	-8.0	-0.21	15	10	5	2.6	1.7	-4.7	392	Retreat - Sea Erosion
3	**Whakarire St**	0.135	1962-2001	-15.0	-0.39	15	6	4	2.8	1.9	-4.7	416	Retreat - Sea Erosion
4	**Whakarire St west**	0.18	1962-2001	-13.0	-0.33	20	7	7	3.0	1.9	-4.7	448	Retreat - Sea Erosion
4a	**Charles St**	0.23	1962-2001	-3.0	-0.08	-	-	18	3.1	1.7	-4.7	446	Retreat - Sea Erosion
5	**Profile W-39**	0.28	1962-2001	3.0	0.08	20	17	20	3.4	2.4	-4.7	445	Dynamic Equilibrium
5a	**Profile W-40**	0.38	1962-2001	3.0	0.08	-	-	19	4.0	2.0	-4.7	460	Dynamic Equilibrium
6	**James St**	0.43	1962-2001	-2.5	-0.06	20	15	18	4.4	2.4	-4.7	482	Retreat - Sea Erosion
6a	**Profile W-44**	0.51	1962-2001	-5.0	-0.13	-	-	17	4.6	2.4	-4.7	482	Retreat - Sea Erosion
7	**Tareha St**	0.61	1962-2001	-4.0	-0.10	25	25	17	3.9	2.7	-4.7	475	Retreat - Sea Erosion
7a	**Profile W-46**	0.69	1962-2001	-7.0	-0.18	-	-	16	4.3	2.9	-4.7	443	Retreat - Sea Erosion
8	**Nott St**	0.77	1962-2001	-12.5	-0.32	25	25	15	4.7	2.9	-4.7	410	Retreat - Sea Erosion
9	**Profile HB-13**	0.85	1962-2001	-14.0	-0.36	30	25	16	4.2	3.0	-4.7	340	Retreat - Sea Erosion
	WESTSHORE CENTRAL												
10	**Naomi St**	0.90	1962-2001	-16.0	-0.41	30	27	17	4.6	3.1	-4.7	365	Retreat - Sea Erosion
10a	**Profile W-50**	1.01	1962-2001	-20.5	-0.53	-	-	23	5.1	3.2	-4.7	344	Retreat - Sea Erosion
11	**Westshore School**	1.05	1962-2001	-21.0	-0.54	30	25	24	5.1	3.2	-4.7	334	Retreat - Sea Erosion

	A	B	C	D	E	F			G		H		I
	LOCATION OF STATIONS	**CUMULATIVE DISTANCE NORTH**	**SURVEY INTERVAL**	**BARRIER CREST RETREAT (-) or ADVANCE (+)**	**RATES**	**BEACH WIDTHS**			**BARRIER ELEVATION**		**CLOSURE DEPTH**		**BARRIER CREST TREND**
		(km)	**(y)**	**(m)**	**(m/y)**	**(m)**			**(m)**		**(MSL)**		
						1986	**1995**	**2001**	**Crest Height**	**Edge Height**	**Depth**	**Distance**	
12	**Alfred St**	1.11	1962-2001	-19.0	-0.49	30	22	22	4.9	3.0	-4.7	345	Retreat - Sea Erosion
12a	**Profile W-50C**	1.17	1962-2001	-15.5	-0.40	-	-	22	5.4	3.2	-4.7	370	Retreat - Sea Erosion
13	**Gardiner St**	1.27	1962-2001	-21.0	-0.54	40	23	25	5.6	3.3	-4.7	378	Retreat - Sea Erosion
13a	**Profile W-51B**	1.45	1962-2001	-23.0	-0.59	-	-	23	5.5	3.6	-4.7	275	Retreat - Sea Erosion
14	**Fenwick St**	1.54	1962-2001	-22.5	-0.58	40	26	25	5.8	3.6	-4.7	250	Retreat - Sea Erosion
	THE ESPLANADE												
15	**Profile W-52**	1.63	1955-1986	-24.6	-0.79	38	29	28	4.7	3.7	-4.7	235	Retreat - Sea Erosion
16	**Domain St**	1.80	1962-1992	-16.0	-0.67	40	37	36	5.2	3.3	-4.7	230	Retreat - Sea Erosion
17	**Profile W-53**	1.93	1955-1986	-24.3	-0.78	35	37	40	5.3	3.5	-4.7	230	Retreat - Sea Erosion
18	**Profile W-54/E-22**	2.114	1955-1986	-13.8	-0.45	38	20	22	6.0	3.2	-4.7	225	Retreat - Sea Erosion
19	**Profile W-55/E-18**	2.31	1955-1986	-19.4	-0.63	30	16	17	5.4	2.9	-4.7	220	Retreat - Sea Erosion
20	**Profile HB-14/E-14, Air Gap**	2.51	1952-1986	-26.4	-0.78	35	22	20	5.5	3.2	-4.7	219	Retreat - Sea Erosion
21	**The Esplanade**	2.77	1962-1986	-16.0	-0.67	30	20	21	5.9	3.2	-4.7	234	Retreat - Sea Erosion
22	**The Esplanade**	2.92	1962-1986	-16.0	-0.66	30	20	21	5.9	3.4	-4.8	222	Retreat - Sea Erosion
23	**The Esplanade**	3.07	1962-1986	-9.0	-0.38	30	20	20	6.0	4.0	-4.8	222	Retreat - Sea Erosion
24	**The Esplanade**	3.19	1962-1986	-3.0	-0.13	45	25	26	6.1	3.8	-4.8	230	Retreat - Sea Erosion
	BEACONS RESERVE AREA												
24a	**Reserve**	3.26	1962-2001	-5.0	-0.13	-	-	37	6.1	4.2	-4.8	246	Retreat - Sea Erosion
25	**Profile W-60**	3.32	1962-2001	-1.0	-0.03	45	40	41	5.8	4.3	-4.9	246	Retreat - Sea Erosion
26	**Reserve**	3.50	1962-2001	-5.0	-0.12	45	40	43	5.6	4.5	-4.9	250	Retreat - Sea Erosion
27	**Reserve**	3.70	1962-2001	-4.0	-0.10	40	40	36	5.8	4.5	-5.0	248	Retreat - Sea Erosion
28	**Profile HB-15**	3.915	1962-2001	-7.0	-0.18	40	40	39	6.3	4.9	-5.0	247	Retreat - Sea Erosion
29	**The Beacons**	4.10	1962-2001	-8.0	-0.21	30	47	47	5.9	5.2	-5.1	246	Retreat - Sea Erosion
30	**Reserve**	4.30	1962-2001	-10.0	-0.26	30	43	49	6.0	5.2	-5.1	242	Retreat - Sea Erosion
31	**Gun Turret**	4.48	1962-2001	-1.5	-0.04	30	44	48	5.6	5.2	-5.2	232	Retreat - Sea Erosion
32	**Reserve**	4.70	1962-2001	-7.0	-0.18	35	50	61	6.0	5.4	-5.2	231	Retreat - Sea Erosion
	BAY VIEW												
32a	**Reserve**	4.8	1962-2001	-9.0	-0.23	-	-	61	6.6	5.6	-5.3	235	Retreat - Sea Erosion

	A	B	C	D	E	F			G		H		I
	LOCATION OF STATIONS	**CUMULATIVE DISTANCE NORTH**	**SURVEY INTERVAL**	**BARRIER CREST RETREAT (-) or ADVANCE (+)**	**RATES**	**BEACH WIDTHS**			**BARRIER ELEVATION**		**CLOSURE DEPTH**		**BARRIER CREST TREND**
		(km)	**(y)**	**(m)**	**(m/y)**	**(m)**			**(m)**		**(MSL)**		
						1986	**1995**	**2001**	**Crest Height**	**Edge Height**	**Depth**	**Distance**	
33	**Ferguson St South**	4.9	1962-2001	-6.5	-0.17	45	52	60	7.3	5.5	-5.3	230	Retreat - Sea Erosion
34	**Ferguson St South,**	5.1	1962-2001	-8.0	-0.21	50	53	65	7.5	5.6	-5.3	220	Retreat - Sea Erosion
35	**Ferguson St South**	5.3	1962-2001	-9.0	-0.23	50	47	62	7.4	5.6	-5.3	208	Retreat - Sea Erosion
36	**Profile HB-16, Fannin St**	5.535	1962-2001	-5.0	-0.13	55	58	61	7.9	5.6	-5.3	203	Retreat - Sea Erosion
37	**Ferguson St North**	5.7	1962-2001	-10.0	-0.26	55	50	62	7.0	5.6	-5.3	197	Retreat - Sea Erosion
38	**Ferguson St North**	5.9	1962-2001	-9.0	-0.23	55	50	58	7.9	5.6	-5.3	206	Retreat - Sea Erosion
38a	**Snapper Park Motor Camp**	6.0	1962-2001	-8.0	-0.21	-	-	57	7.8	5.6	-5.3	200	Retreat - Sea Erosion
	GILL RD/ROGERS RD AREA												
39	**Snapper Park Motor Camp**	6.1	1962-2001	-8.0	-0.21	55	46	52	7.1	5.6	-5.3	185	Retreat - Sea Erosion
40	**Gill Rd South**	6.20	1962-2001	-11.0	-0.28	45	43	45	7.1	5.8	-5.3	170	Retreat - Sea Erosion
41	**Gill Rd North**	6.30	1962-2001	-12.0	-0.30	35	42	47	8.0	6.3	-5.3	180	Retreat - Sea Erosion
42	**Mer Place**	6.44	1962-2001	-12.0	-0.30	40	47	45	8.0	6.4	-5.3	180	Retreat - Sea Erosion
43	**Rogers Rd**	6.55	1962-2001	-12.0	-0.30	40	41	43	8.4	6.3	-5.3	175	Retreat - Sea Erosion
44	**Reserve**	6.80	1962-2001	-12.5	-0.32	45	47	42	8.2	6.3	-5.3	175	Retreat - Sea Erosion
45	**Reserve**	7.05	1962-2001	-14.0	-0.36	40	52	50	8.1	6.1	-5.3	180	Retreat - Sea Erosion
45a	**Profile HB-17**	7.11	1962-2001	-14.0	-0.36	-	-	49	8.0	6.2	-5.3	177	Retreat - Sea Erosion
46	**Reserve**	7.30	1936-2001	-10.0	-0.15	50	54	54	8.1	6.1	-5.3	185	Retreat - Sea Erosion
47	**Reserve**	7.43	1936-2001	-7.0	-0.11	50	55	56	8.0	6.1	-5.3	167	Retreat - Sea Erosion
	LE QUESNE RD AREA												
48	**Pig Styes**	7.55	1936-2001	-3.0	-0.05	55	55	46	8.3	6.4	-5.3	170	Retreat - Sea Erosion
48a	**Le Quesne Rd**	7.68	1936-2001	0.0	0.00	-	-	57	8.2	6.3	-5.3	177	Dynamic Equilibrium
49	**Le Quesne Rd**	7.80	1936-2001	4.0	0.06	55	55	55	7.9	6.3	-5.3	160	Dynamic Equilibrium
50	**Le Quesne Rd**	8.05	1936-2001	1.5	0.02	50	50	48	8.2	6.2	-5.3	165	Dynamic Equilibrium
51	**Le Quesne Rd**	8.30	1936-2001	0.0	0.00	50	50	47	8.4	6.4	-5.3	147	Dynamic Equilibrium
52	**Le Quesne Rd**	8.55	1936-2001	11.0	0.17	50	48	46	8.6	6.1	-5.3	154	Dynamic Equilibrium
52a	**Profile HB-18**	8.68	1936-2001	13.0	0.20	-	-	46	8.9	6.0	-5.3	161	Dynamic Equilibrium
53	**Anthony Place**	8.80	1936-2001	24.0	0.37	50	50	46	8.1	6.5	-5.3	180	Dynamic Equilibrium
53a	**Le Quesne Rd**	8.93	1936-2001	5.0	0.08	-	-	56	8.4	6.3	-5.3	180	Dynamic Equilibrium

	A	B	C	D	E	F			G		H		I
	LOCATION OF STATIONS	**CUMULATIVE DISTANCE NORTH**	**SURVEY INTERVAL**	**BARRIER CREST RETREAT (-) or ADVANCE (+)**	**RATES**	**BEACH WIDTHS**			**BARRIER ELEVATION**		**CLOSURE DEPTH**		**BARRIER CREST TREND**
		(km)	**(y)**	**(m)**	**(m/y)**	**(m)**			**(m)**		**(MSL)**		
						1986	**1995**	**2001**	**Crest Height**	**Edge Height**	**Depth**	**Distance**	
54	**Thurley Place**	9.05	1936-2001	-9.0	-0.14	65	67	72	8.3	5.5	-5.3	180	Retreat - River Erosion
55	**Le Quesne Rd**	9.18	1936-2001	-7.0	-0.11	70	68	72	8.5	5.6	-5.3	190	Retreat - River Erosion
56	**Le Quesne Rd**	9.30	1936-2001	-12.0	-0.19	80	78	83	8.3	4.2	-5.3	202	Retreat - River Erosion
57	**Le Quesne Rd**	9.43	1936-2001	-29.0	-0.45	95	100	100	8.4	3.4	-5.3	195	Retreat - River Erosion
58	**Barrier North**	9.55	1936-2001	-21.0	-0.32	85	85	90	8.6	3.5	-5.3	180	Retreat - River Erosion
58a	**Barrier North**	9.65	1936-2001	-47.0	-0.72	-	-	104	8.1	3.5	-5.3	195	Retreat - River Erosion
59	**Barrier North**	9.75	1936-2001	-51.0	-0.79	120	120	120	7.7	3.6	-5.3	210	Retreat - River Erosion
60	**Barrier North**	9.85	1936-2001	-29.0	-0.45	100	100	110	8.3	3.9	-5.3	195	Retreat - River Erosion
61	**Esk River mouth**	10.00	1936-2001	-13.5	-0.21	85	85	90	3.1	2.2	-5.3	180	Retreat - River Erosion

- **Table 3:** Average heights and range (brackets) of the barrier beach crest and edge in metres above MSL along the study area, summarised from data in Table 2.

	Westshore South	Westshore Central	The Esplanade	Beacons Reserve Area	Bay View	Rogers Road	Le Quesne Road
Coastline length (km)	0.85	0.69	1.65	1.51	1.2	1.53	2.57
Barrier crest (m)	3.6	5.3	5.6	5.9	7.4	7.9	8.4
	(2.6-4.7)	(4.6-5.8)	(4.7-6.1)	(5.6-6.3)	(6.6-7.9)	(7.1-8.4)	(7.9-8.9)
Barrier Edge (m)	2.3	3.3	3.4	4.8	5.6	6.1	6.3
	(1.7-3.0)	3.0-3.6)	(2.9-4.0)	(4.2-5.4)	(5.5-5.6)	(5.6-6.4)	(6.0-6.5)
Average Difference (m)	**1.3**	**2.0**	**2.2**	**1.1**	**1.8**	**1.8**	**2.1**

Figure 2 and Table 3 reveal that the barrier crest elevation progressively increases Northwards from an average of 3.6m above MSL at Westshore South to an average of 8.4m at Le Quesne Road. CMCL is of the opinion that the primary cause of the increase in elevations Northwards is progressive exposure to increasing wave energy away from the sheltering effects of Scinde Island and the Port of Napier. This would suggest that the predominant wave direction responsible for barrier construction is from the East-Southeast quadrant. The actual elevations of the barrier crest were increased by 1.8 to 2.1m by tectonic uplift accompanying the 3 February 1931 Hawke's Bay Earthquake (Gibb 1996).

The barrier edge elevation increases Northwards as well from an average of 2.3m above MSL at Westshore South to 6.3m at le Quesne Road. The barrier edge elevation generally represents the average elevation reached by maximum SWRU since the effects of the February 1931 earthquake. The differences in elevation between the barrier crest and barrier edge (Table 3) are interpreted here as representing the amount of uplift that occurred during the 1931 earthquake. The height differences range from 1.1 to 2.2m, averaging 1.8m, which is in good agreement with the known uplift values of 1.8-2.1m (Gibb 1996).

There are some anomalies in both the barrier crest and elevations (Figure 2) that need to be explained. There is a pronounced dip in the crest heights between The Esplanade and Ferguson Street and near the Esk River mouth (Figure 2). From field observations, the former appears to have resulted from lowering of the crest by earthmoving machines in the recent past. The latter is clearly the result of breaching and erosion of the barrier ridge by the migrating Esk River mouth prior to 1936. Localised dips in crest heights (Figure 2) are mostly the result of human modifications to individual properties.

There is also a pronounced dip in the barrier edge heights adjacent to The Esplanade and from Le Quesne Road to the Esk River mouth (Figure 2). Field observations revealed that the method of beach nourishment along The Esplanade has truncated the beach profile thus lowering its height and the height of the barrier edge. For the latter the barrier edge was lowered by river erosion following the Southward migration of the Esk River over some 1.2km between 1936 and the 1960s.

3.1.1. INFERRED MAXIMUM SWRU ELEVATIONS

The barrier edge is clearly shown in Plates 1 and 2 and often has wave washed flotsam at the base indicating that wave swash has reached this position during severe wave storms. The fact that there is an erosion scarp along the barrier edge indicates that maximum storm wave runup (SWRU) elevations have exceeded the barrier edge elevations in Figure 2 by perhaps 0.5m after 1931 during severe wave storms over the last 70 years. This would suggest maximum (SWRU) elevations of the order of 3.5-4.5m above MSL along Westshore, 6m at Bay View and 7m at Le Quesne Road. The area of greatest exposure to storm waves extends North from about Gill Road to the Esk River mouth (Figure 2).

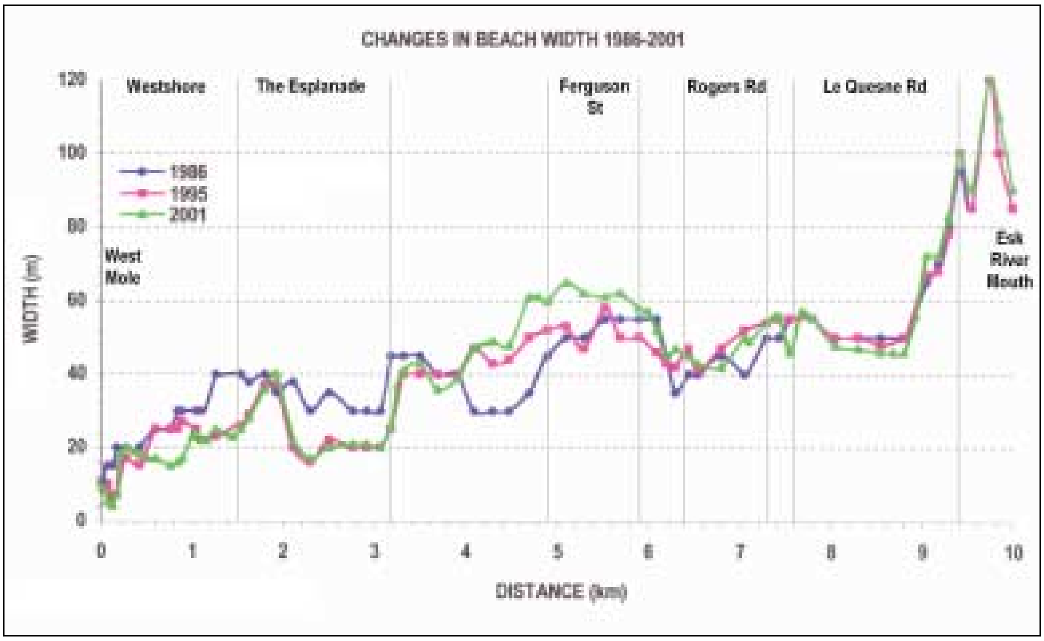
3.2. BARRIER BEACH WIDTH

Figure 3 shows alongshore trends in barrier beach widths over 10km for the years 1986, 1995 and 2001 and is derived from data in Table 2. All beach widths were determined between MHWS and the barrier edge. Although the 1995 beach widths were fixed by survey to an accuracy of the order of ±2m, the beach widths for 1986 and 2001 are not as accurate as the position of the line of MHWS was estimated. An order of accuracy of ±6m is assumed here for both the 1986 and 2001 beach widths. Table 4 provides summaries of beach widths for the 7 areas listed in Table 2.

- **Table 4:** Average barrier beach widths in metres (m) between MHWS and the barrier edge along the study area, summarised from data in Table 2. Uncertainty limits are given in brackets.

		Westshore South	Westshore Central	The Esplanade	Beacons Reserve Area	Bay View	Rogers Road	Le Quesne Road
	Coastline length (km)	0.85	0.69	1.65	1.51	1.2	1.53	2.57
Average Barrier Beach Width (m)	**1986 (±6m)**	20	34	35	37	52	44	72
	1995 (±2m)	16	25	25	43	52	47	72
	2001(±6m)	13	23	25	45	61	49	70
	1986-95 (±8m)	-4	-9	-10	6	0	3	0
	1995-2001 (±8m)	-3	-2	0	2	9	2	-2
	1986-2001 (±12m)	-7	-11	-10	8	9	5	-2

Figure 3 and Table 4 reveal the following trends. Average beach widths increase Northwards from less than 20m at Westshore South to more than 40m between Bay View and Le Quesne Road to more than 60m North of Le Quesne Road. Within the bounds of uncertainty there has been a general reduction in beach widths since 1986 along the Westshore area, a concomitant increase in beach widths North of The Esplanade up to Bay View, and no significant change North of Bay View. Most of the reduction in width at Westshore occurred between 1986 and 1995 whereas most of the increase in width at Bay View occurred between 1995 and 2001.



• **Figure 3:** Alongshore trends in barrier beach widths.

Trends in beach width are an indicator of sediment supply and the sensitivity of the barrier crest to erosion. A trend of reducing beach width is generally indicative of a deficit in sediment supply thereby increasing the potential for erosion of the barrier ridge crest. Conversely, a trend of increasing beach width is generally indicative of a local surplus in sediment supply thereby mitigating potential erosion. No significant change in beach width with time indicates a system in dynamic equilibrium where sediment supply balances losses from processes such as wave swash abrasion of beach gravels.

Along the Westshore area the reduction in beach widths since 1986 (Table 4) is clearly indicative of a sediment deficit. The stabilising of beach widths along the central to northern part of Westshore since 1995 has probably resulted from the Westshore nourishment scheme that commenced after 1986, offsetting the sediment deficit in this area.

The increase in beach widths in the Bay View area since 1986 is clearly indicative of a localised sediment surplus. As there is a well-established net Northerly longshore drift in the area (Gibb 1996), the localised sediment surplus is probably the result of the combined effects of erosion and beach nourishment along Westshore since 1986. North of Bay View no significant changes in beach widths are evident owing to the large uncertainties in the measurements.

The very wide beach widths up to 120m North of Le Quesne Road are the result of localised erosion of the tectonically uplifted barrier crest by the Southward migration of the Esk River prior to 1986. the barrier edge has locally retreated landward as a consequence and the erosion embayment infilled by wave-transported barrier sediments, increasing beach widths between the barrier edge and MHWS to 72-120m (Table 2).

3.3. CLOSURE DEPTH

The closure depth (see definition Section 1.1) represents the approximate seaward toe of the dynamic barrier beach ridge. Table 2 provides depths and distances for the closure depth for the 75 stations. The closure depth was determined from repeat offshore profiles by HBRC at the 6 HB-Series sites (Figure 1, Table 1). Table 1 shows that the number of surveys per profile range from one to 6 so that the extent of the survey data is limited.

The closure depth was identified on profiles HB-13 (Westshore South) and HB-16 (Bay View) as –4.7m and –5.3m below MSL, respectively. At these depths, repetitive survey profiles recorded changes in seabed elevation not exceeding ±0.10m, corresponding to the level of accuracy of the echo sounder and survey conditions. Landward of the closure depth, fluctuations in elevation of the seabed of the order of ±1.0m were recorded by repeat profiling indicating this area to be part of the dynamic barrier beach.

On profiles HB-14, HB-15, HB-17 and HB-18, closure depths were inferred mostly on the basis of changes in gradient of the nearshore seabed. The gradient changes were interpreted here as indicating a change from the Very Fine Sand comprising the very flat nearshore seabed seaward of the closure depth, to the relatively coarser sands and gravels of the relatively steeper barrier beach shoreface.

Distances from the closure depth to the barrier crest were either measured directly from all the HB-Series offshore profiles or from the barrier crest line to the appropriate isobath. Port of Napier sounding Chart 4444/3 at 1:5000 Scale was used for this purpose along Westshore. The soundings were from a survey conducted by Port of Napier on 20 December 2000 and were normalised from Chart Datum to MSL in this study by applying a correction factor of 0.92m. Table 5 provides summaries of closure depths and distances for the 7 areas listed in Table 2.

- **Table 5:** Average closure depths (CD) in metres below MSL and distances in metres from the barrier crest to closure depth along the study area, summarised from data in Table 2

	Westshore South	Westshore Central	The Esplanade	Beacons Reserve Area	Bay View	Rogers Road	Le Quesne Road
Average Closure Depth below MSL	-4.7	-4.7	-4.7	-5.0	-5.3	-5.3	-5.3
Average Distance (m)	428	333	227	243	214	180	178

Table 5 shows that there is a small increase in closure depth Northwards from –4.7m at Westshore to –5.3m below MSL at Bay View to Le Quesne Road. Although closure depth deepens northwards the distance offshore decreases from an average of 428m at Westshore to 178m at Le Quesne Road (Table 5). There is relatively deeper water inshore to the North which also promotes exposure of this area to greater incident wave energy compared to Westshore resulting in a proportionate increase in the height of the barrier ridge crest North (see Figure 2).

4. SHORELINE TRENDS AND VARIABILITY

Detecting and quantifying a shoreline trend of advance, retreat, or dynamic equilibrium in the study area is a complex task because of the significant impacts the 10km-long barrier has been subject to over the last 200 years or so.

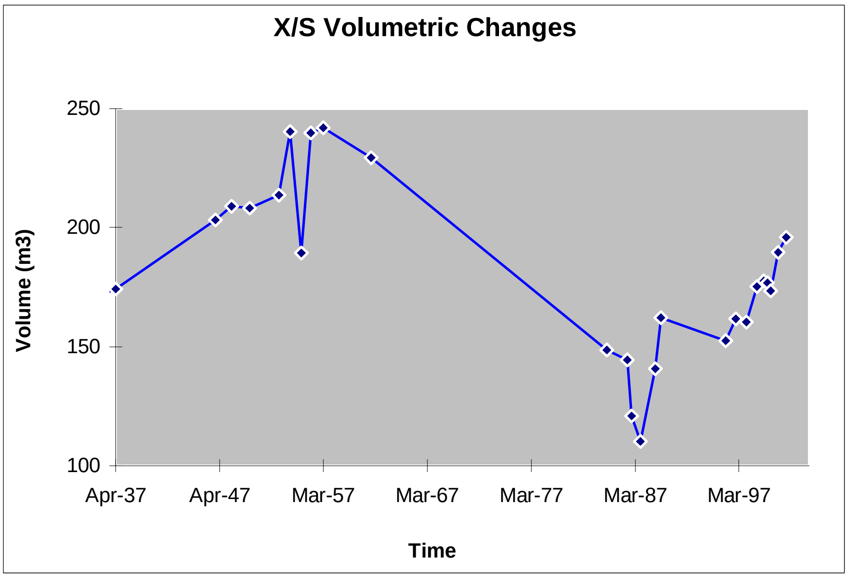
4.4. TREND

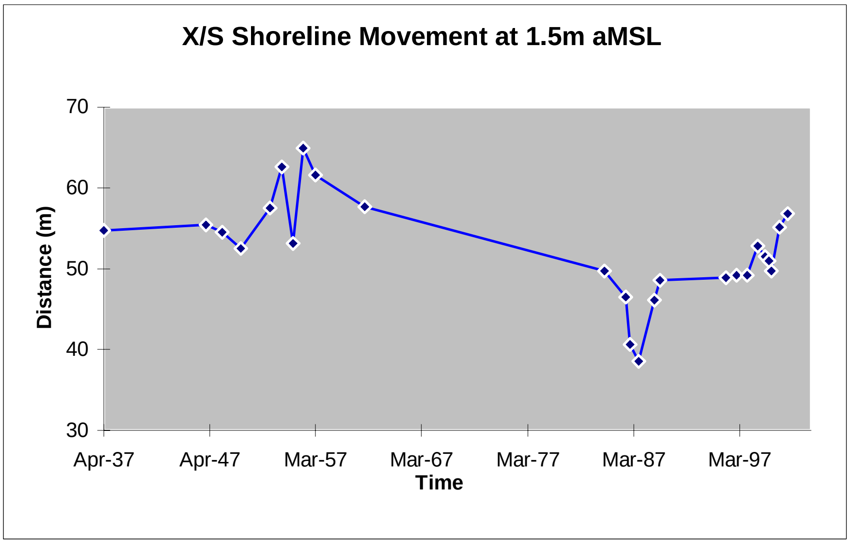
The long-term stability of the 10km-long barrier beach ridge was significantly disturbed by both human activities over approximately the last 230 years and the 3 February 1931 Magnitude 7.8 Hawke's Bay Earthquake (Gibb 1996).

In terms of hazard assessment, the most meaningful trends have occurred since the 1931 Hawke's Bay Earthquake. The combined effects of 1.8-2.1m tectonic uplift accompanying this event plus the onshore supply of sediment from erosion of the destabilised nearshore seabed resulted in shoreline advance up to 0.5 to 2.54m/year along Bay View and Westshore, respectively. The trend of accretion persisted from 1931 to about 1962 during which time (31 years) sediments accumulated along the seaward edge of the crest of the barrier ridge (barrier edge). The changing trends are well illustrated in Figure 4 by repeat beach profiles at Profile HB-15 since 1 April 1937.

After about 1962, the 31-year accretion trend reversed to retreat from erosion. It is likely that the shoreface and nearshore seabed had reached a new equilibrium by the early 1960s so that no more sediment was being supplied from this source area to the barrier by onshore wave transport. Compounding the post 1962 erosion reversal was the fact that the supply of beach gravels to the area by the net Northerly longshore drift had been terminated by the construction of harbour works at Port Ahuriri from 1876 to 1879 and Port of Napier from 1887 to 1890 (Gibb 1996). The post 1962 trend of erosion of the barrier edge was effectively irreversible without some form of human intervention or indeed, tectonic uplift from a similar magnitude earthquake to the 1931 event.

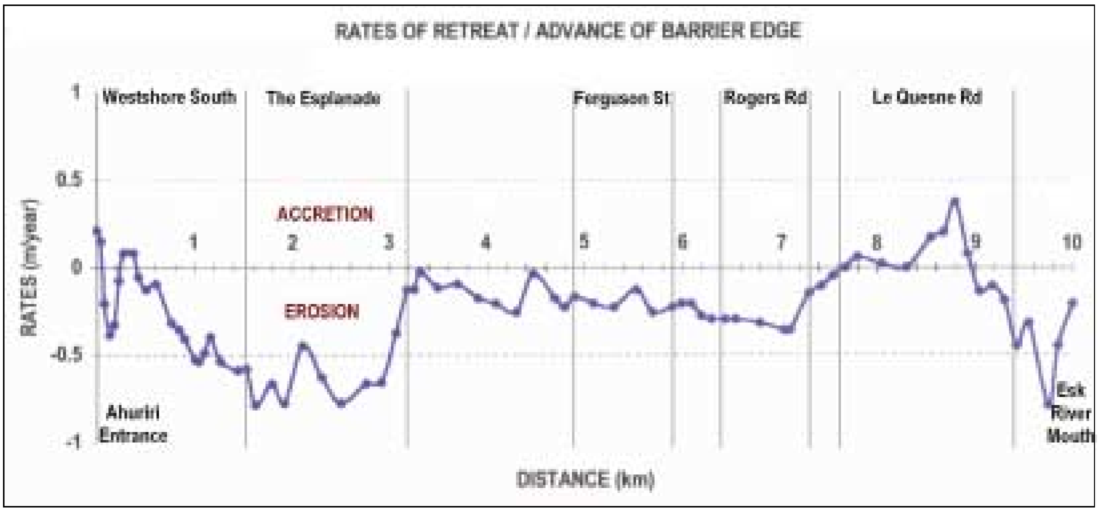
Rates of retreat of the barrier edge were quantified for the 77 stations by comparing the 1962 barrier edge position generally with the 2001 position as far as the start of Le Quesne Road. The 1962 aerial survey did not extend North of this point so rates were quantified for the Le Quesne Road area by comparing the 1936 barrier edge position with the 2001 position. Because of the effects of beach replenishment since January 1987 along The Esplanade, the 1962 barrier edge position was compared with the 1986 position. CMCL is of the view that the accuracy of defining the barrier edge in the field and from aerial photographs ranged from ±1m (2001), ±2m (1986), ±3m (1962), to ±5m (1936). Figure 5, based on data in Table 2, shows the alongshore trend in rates between the Ahuriri Entrance and Esk River mouth.





- **Figure 4:** HBRC Profile HB-15 showing both trends and variability between 1937 and 2001.

Figure 5 shows a general trend of barrier edge erosion along most of the 10km-long barrier with the exception of some minor accretion along Southern Westshore and Le Quesne Road. Maximum erosion rates up to –0.79m/year occurred along both The Esplanade and near the Esk River mouth. Between The Esplanade and Le Quesne Road, rates do not exceed –0.36m/year. The minor accretion along Southern Westshore is largely the result of reclamations and hard engineering structures. Accretion up to 0.37m/year along Le Quesne Road is likely to be a residual from the effects of the 1931 Earthquake as the 1936 survey was used in this area to quantify rates. For this area the rates should be treated with caution, as post-1962 changes are not known.



- **Figure 5:** Rates of erosion/accretion between the Ahuriri Entrance and Esk River mouth of the barrier edge. With the exception of The Esplanade and Le Quesne Road area North of 7.3km rates were calculated for the period 1962-2001. For the Esplanade rates are for 1962-1986 and for Le Quesne Road, 1936-2001.

4.5. VARIABILITY

HBRC beach profiles provide a measure of shoreline variability, revealing as one might expect that the barrier beach profile moves in and out about the trend of long-term retreat. All 56 profiles in the study area were analysed by HBRC in terms of both volumetric changes above either MSL (HB Series) or 1m above MSL (E & W Series), and excursion distances at 1.5m above MSL (HB, E & W Series). Figure 4 provides an example of the results of the standardised method of analysis.

Maximum fluctuations of the 1.5m reference line of; 9.1-10.5m were recorded at Profiles W-47 and W-44 respectively at Westshore; 11.6-17.9m along The Esplanade at Profiles E-9 and HB-14, respectively; 7.3-11.8m along the Beacons Reserve area at profiles W-60 and HB-15; 15.1m at Bay View at Profile HB-16 and 5.1 to 5.9m between Bay View and Esk River mouth at Profiles HB-17 and HB-18. All the fluctuations recorded appear to be confined to the foreshore area seaward of the barrier edge.

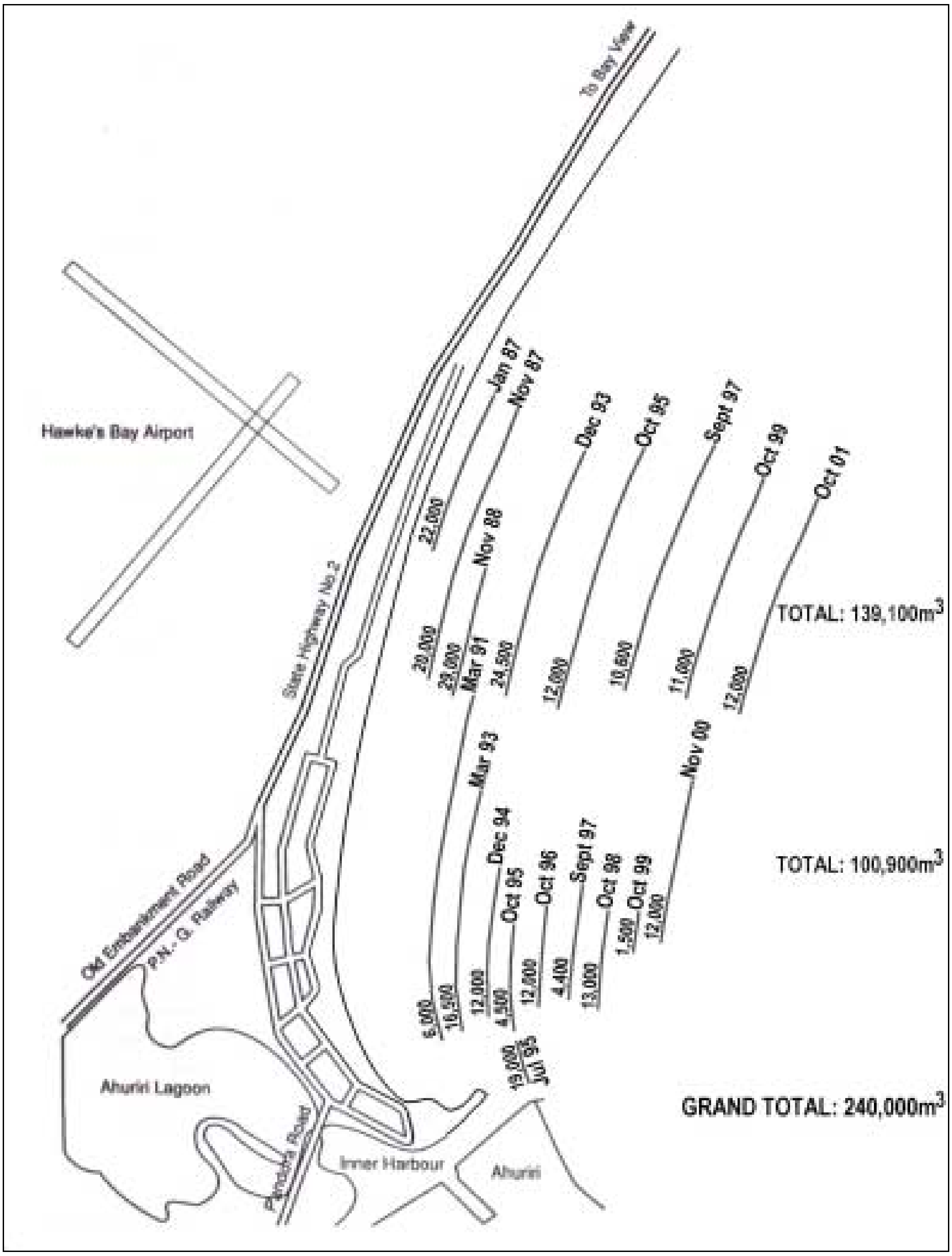
Whilst a maximum '*shoreline'* variability of 15-18m was recorded such a fluctuation is regarded here as a minimum. Although profiling commenced as early as 1916 (HB-15) and 1937 (HB-14) the data are very limited by survey frequency which varies randomly from months to decades. Therefore, it is possible that the maximum shoreline variability has not been recorded by survey.

5. WESTSHORE NOURISHMENT SCHEME

Table 6 and Figure 6 summarise the continuing Westshore nourishment scheme since its inception in January 1987. The purpose of the scheme is to primarily mitigate coastal erosion whilst ensuring that the significant amenity values of Westshore to the Hawke's Bay region are maintained and enhanced. Plate 3 shows the renourished Westshore Beach and its obvious amenity value.

LOCATION	DATE	VOLUME (m^3)	SOURCE AREA	SEDIMENT GRADE	PLACEMENT AREA FORESHORE	PLACEMENT AREA BACK BARRIER
The Esplanade North (E1-E15)	January 1987	22,000	Wildlife Ponds	Mixed Fine Gravel, Silt and Sands	50%	50%
The Esplanade (E1-E25)	November 1987	20,000	Wildlife Ponds	Mixed Fine Gravel, Silt and Sands	50%	50%
The Esplanade South (E15-W53)	November 1988	27,000	Wildlife Ponds	Mixed Fine Gravel, Silt and Sand	50%	50%
Charles St to The Esplanade (W40-W53)	March 1991	6,000	Wildlife Ponds	Mixed Fine Gravel, Silt and Sand	100%	
Charles St to Fenwick St (W40-W51C)	March 1993	16,500	Pacific Beach	Medium Size Gravel	20%	80%
The Esplanade (E3-E25)	December 1993	24,500	Pacific Beach	Fine Gravel	80%	20%
Charles St to Gardiner St (W40-W51)	November 1994	12,000	Pacific Beach	Fine Gravel	50%	50%
Whakarire Ave	July 1995	19,000	Ahuriri Entrance	Fine to Very Fine Sand	100%	-
Whakarire Ave	October 1995	4,500	Pacific Beach	Fine Gravel	100%	-
The Esplanade (E1-E25)	October 1995	12,000	Pacific Beach	Fine Gravel	80%	20%
Whakarire Ave to Alfred St (W40-W50C)	October 1996	8,500	Pacific Beach	Fine Gravel	60%	40%
Whakarire Ave	October 1996	3,500	Pacific Beach	Fine Gravel	100%	-
Whakarire Ave to Tareha St (W40-W44)	September 1997	2,600	Pacific Beach	Fine Gravel	100%	-
Ferguson Ave (W50A-W51)	September 1997	1,800	Pacific Beach	Fine Gravel	80%	20%
The Esplanade (EB-E21)	September 1997	10,600	Pacific Beach	Fine Gravel	70%	30%
Whakarire Ave to Alfred St (W39-W50C)	October 1998	13,000	Pacific Beach	Fine Gravel	80%	20%
Ferguson Ave (W50A-W50C)	October 1999	1,500	Spirit of Napier Statue	Fine Gravel	100%	-
The Esplanade (EA-E20)	October 1999	11,000	Spirit of Napier Statue	Fine Gravel	80%	20%
James St to The Esplanade (W41-W52A)	November 2000	12,000	Pacific Beach	Fine Gravel	70%	30%
The Esplanade (EA-E20)	October 2001	12,000	Pacific Beach	Fine Gravel	80%	20%
TOTALS:		**240,000m^3**			**161,300m^3**	**78,700m^3**

- **Table 6:** Westshore Beach nourishment scheme. Data adopted from Gibb (1996, table 1) and from information supplied by Hawke's Bay Regional Council (Kamen Ganev, Design Engineer, HBRC pers. comm. Dec. 2001).



• **Figure 6:** The Westshore nourishment scheme including dates and places of nourishment events. Data from Table 6.

- **Plate 3:** Photograph taken 28 September 2001 by Dr Gibb looking North along Westshore Beach close to low tide, showing the resultant beach from the Westshore nourishment scheme since 1987.

Between January 1987 and October 2001, a total of 240, 000m^3 of sediments were placed along the Westshore coastline. Of the 240,000m^3, 139,100m^3 were placed adjacent to The Esplanade and 100,900m^3 were placed between The Esplanade and Whakarire Avenue (Figure 6). Of the total of 240,000m^3, about 161,300m^3 were placed on the foreshore and 78,700m^3 were used to create the crest of the artificial barrier beach ridge mostly beyond the reach of the waves. Plates 4 and 5 show the effects of beach replenishment along the Westshore area.

The sediments used in the Westshore nourishment scheme (Table 6) are in CMCL's opinion, generally compatible with those that naturally occur along the 10km-long barrier ridge. Between January 1987 and March 1991, the sediments were extracted from the back of the barrier beach ridge behind Westshore to form the present wildlife ponds. The fine gravels and sands contained silt, which has acted to partially bind the artificial embankment at Westshore into a relatively steep erosion resistant feature (see Plate 5) that has partially truncated the local beach profile.

• **Plate 4:** Photograph taken 28 September 2001 by Dr Gibb looing North along the artificial barrier ridge constructed and maintained along Southern Westshore since March 1993 of fine gravels and sand.

• **Plate 5:** Photograph taken 28 September 2001 by Dr Gibb looking North along the artificial embankment constructed and maintained along The Esplanade since January 1987.

The fine gravels extracted from Pacific Beach since March 1993 (Table 6) just South of the Port of Napier weather breakwater, are those that would have naturally bypassed Scinde Island prior to the construction of the weather breakwater in 1887-1890 and the Port Ahuriri training moles in 1876-1879. These sediments are not bound by silt and as a consequence are more mobile so that they have relatively quickly established the present beach profile (see Plate 3). The Fine to Very Fine Sand pumped on to the lower foreshore by Whakarire Avenue from the Ahuriri Entrance (Table 6) is in CMCL's opinion, generally compatible with the fine sediments on the lower shoreface in this area.

5.1. PERFORMANCE OF THE SCHEME

The performance of the Westshore nourishment scheme was investigated by CMCL from the standpoint of erosion mitigation and just how far North of the 3km-long replenishment area potential mitigation effects might extend. A rigorous analysis of HBRC beach profile data was undertaken, focussing mainly on the effects of the scheme since its commencement in January 1987. The results of this analysis are summarised in Table 7 and Figures 7 and 11. Before the profile data were analysed in this study, it was necessary to remove many inconsistencies in the HBRC data.

5.1.1. GENERAL TREND

Figure 7 reveals that since the Westshore nourishment scheme commenced in January 1987, the 1.2km-long coastline along Southern Westshore (Stations W-40 to W-51c) has continued to lose sediment from erosion. In contrast, the 1.7km-long coastline along The Esplanade (Stations W-53 to EA) and 2.4km-long coastline North of The Esplanade (Stations EA to HB-16) has advanced from deposition of sediment. The nourishment scheme has been executed over about 3km of coastline along Southern Westshore-The Esplanade. As will be demonstrated below, the scheme has provided a net benefit to about 4.5km of coast and a partial benefit to about 1.2km of coast, and no benefit to about 0.3km of coast largely as a result of both abrasion losses and the net Northerly longshore drift dispersing sediment. The 3 coastal areas in Table 7 are now considered in detail below.

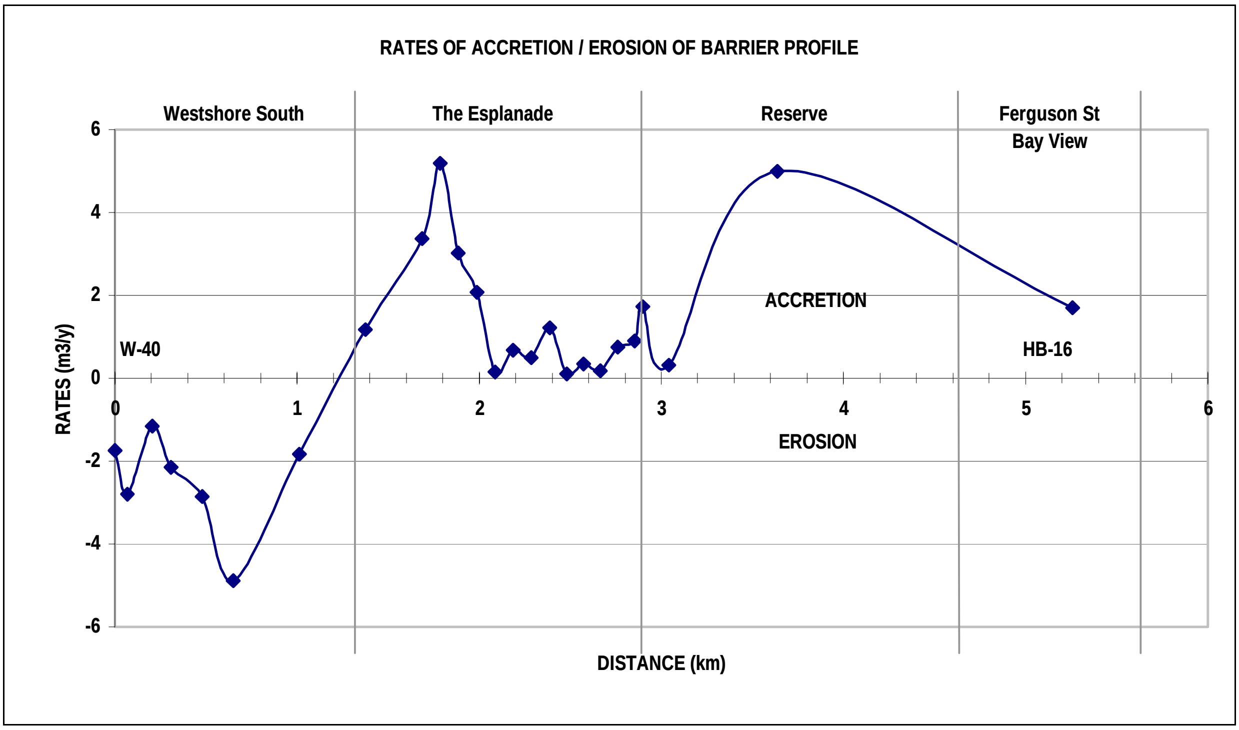
- **Table 7:** Rates of gains (+) or losses (-) to the beach profile above MSL since the Westshore nourishment scheme began in January-November 1987 along The Esplanade (Stations W-52 to E-A) and in March 1991-1993 along Ferguson Avenue-Charles Street (Stations W-40 to W-51). Column (A) are HBRC profiles and street names; Column (B) are horizontal distances between profile bench marks North of profile W-40; Column (C) survey interval covering nourishment period; Column (D) net advance or retreat of barrier edge in metres (m); Column (E) rate of advance or retreat in metres per years (m/y); Column (F) net accretion or erosion of foreshore above MSL in cubic metres per metre length of beach (m^3/m); Column (G) rate of accretion (+) or erosion (-) in cubic metres per year ($m^3/m/y$). Column (H) net volume change to beach between Stations (m^3); Column (I) cumulative net volume change for Southern Westshore, The Esplanade, Reserve-Bay View, and total coast (m^3).

A		B	C	D	E	F	G	H	I
STATION		DISTANCE	SURVEY INTERVAL	RETREAT (-) ADVANCE (+)	RATE	EROSION (-) ACCRETION (+)	RATE	VOLUME CHANGE	CUMULATIVE NET VOLUME
		(m)		(m)	(m/y)	(m^3/m)	($m^3/m/y$)	(m^3)	(m^3)
W-40	**Charles St**	0	1990-2001	-7.5	-0.68	-19.3	-1.75		
W-42	**Charles St**	67.55	1990-2001	-10.5	-0.95	-30.7	-2.79	-1688.75	
W-45	**Charles St**	206.33	1990-2001	-7.0	-0.64	-12.8	-1.16	-3018.5	
W-46	**Charles St**	305.71	1990-2001	-3.5	-0.32	-23.7	-2.15	-1813.7	
W-48 / HB-13	**North Tce**	479.34	1990-2001	-5.0	-0.45	-31.3	-2.85	-4774.8	
W-50	**Ferguson Ave**	649.13	1990-2001	-9.0	-0.82	-53.8	-4.89	-7224.6	
W-51	**Ferguson Ave**	1011.24	1990-2001	-3.0	-0.27	-20.1	-1.83	-13380.0	
								-1820.2	-33720.6
W-52	**The Esplanade**	1373.47	1986-2001	8.5	0.57	17.6	1.17	1593.8	
W-53	**The Esplanade**	1686.33	1986-2001	5.0	0.33	50.6	3.37	10668.5	
E-24	**The Esplanade**	1786.33	1987-2001	9.0	0.64	72.7	5.19	6165.0	
E-22	**The Esplanade**	1886.33	1986-2001	10.5	0.70	45.3	3.02	5900.0	
E-20	**The Esplanade**	1986.33	1986-2001	7.0	0.47	31.2	2.08	3825.0	
E-18	**The Esplanade**	2086.33	1986-2001	4.0	0.27	2.3	0.15	1675.0	
E-16	**The Esplanade**	2186.33	1986-2001	5.5	0.37	10.0	0.67	615.0	
E-14 / HB-14	**The Esplanade**	2286.33	1986-2001	5.0	0.33	7.3	0.49	865.0	
E-12	**The Esplanade**	2386.33	1986-2001	7.0	0.47	18.3	1.22	1280.0	
E-10	**The Esplanade**	2481.33	1986-2001	1.5	0.10	1.7	0.11	950.0	
E-8	**The Esplanade**	2573.83	1986-2001	3.5	0.23	5.3	0.35	323.8	
E-6	**The Esplanade**	2666.33	1986-2001	2.5	0.17	2.7	0.18	370.0	
E-4	**The Esplanade**	2760.33	1986-2001	3.5	0.23	11.3	0.75	658.0	
E-2	**The Esplanade**	2853.33	1986-2001	4.0	0.27	13.5	0.90	1153.2	
E-A	**The Esplanade**	2898.33	1986-2001	8.5	0.57	25.9	1.73	886.5	36928.8
W-60	**Reserve**	3041.33	1986-2001	2.0	0.13	4.8	0.32	2195.1	
HB-15	**Reserve**	3636.33	1986-2001	23.5	1.57	75.0	5.00	4899.7	
HB-16	**Ferguson St**	5256.33	1986-2001	0.0	0.00	25.5	1.70	81405.0	88499.8
					TOTAL CUMULATIVE NET BEACH VOLUME CHANGE SINCE BEACH NOURISHMENT:				**91707.2**

5.1.2. GENERAL TREND

Figure 7 reveals that since the Westshore nourishment scheme commenced in January 1987, the 1.2km-long coastline along Southern Westshore (Stations W-40 to W-51c) has continued to lose sediment from erosion. In contrast, the 1.7km-long coastline along The Esplanade (Stations W-53 to EA) and 2.4km-long coastline North of The Esplanade (Stations EA to HB-16) has advanced from deposition of sediment. The nourishment scheme has been executed over about 3km of coastline along Southern Westshore-The

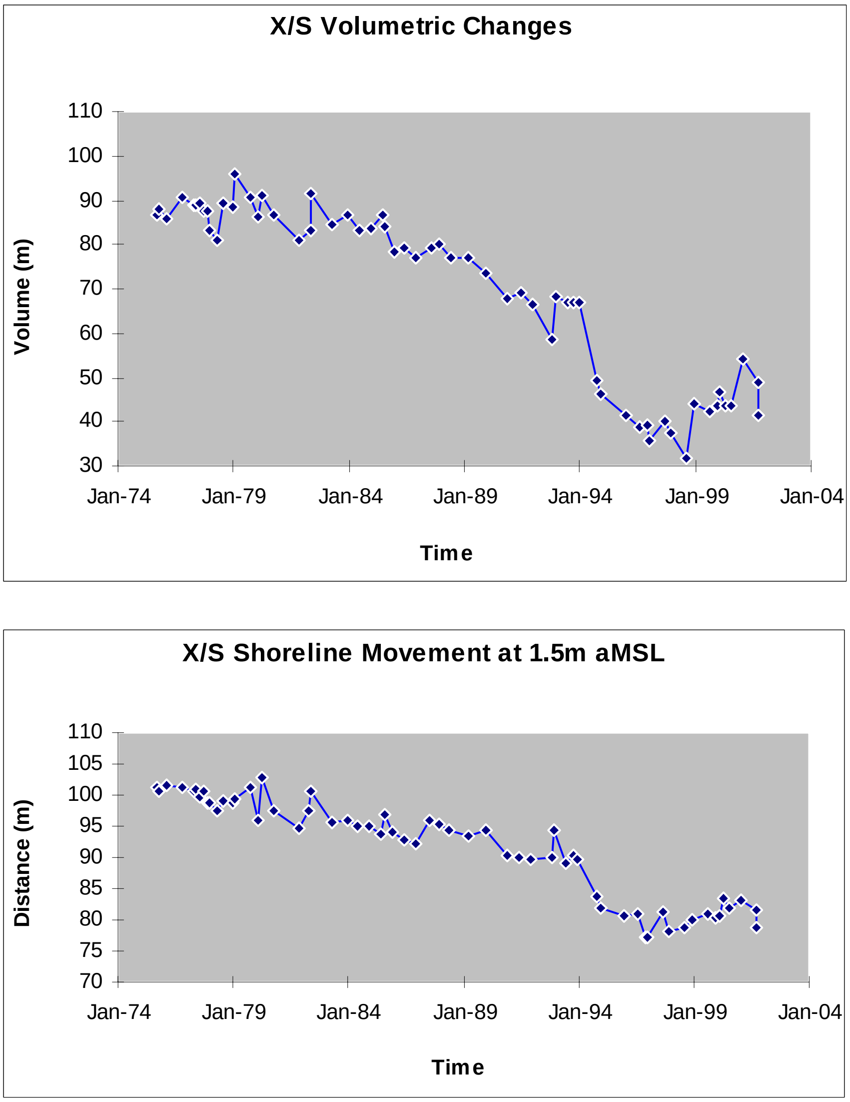
Esplanade. As will be demonstrated below, the scheme has provided a net benefit to about 4.5km of coast and a partial benefit to about 1.2km of coast, and no benefit to about 0.3km of coast largely as a result of both abrasion losses and the net Northerly longshore drift dispersing sediment. The 3 coastal areas in Table 7 are now considered in detail below.



- **Figure 7:** Rates of retreat (-) and advance (+) of the barrier profile since the Westshore nourishment scheme began in January 1987. Data from Table 7.

5.1.3. SOUTHERN WESTSHORE

Along Southern Westshore, the longest time series of beach profile surveys is provided by Profile HB-13 dating from 27 August 1975 (located Figure 1). Repeat surveys record a trend of shoreline retreat of 20.7m at -1.04m/year between 1975 and 1995 (Figure 8). From 1995 to 2001, only 1.8m of retreat occurred at -0.30m/year. Although beach replenishment commenced along Southern Westshore in March 1991 (Figure 6), it wasn't until after 1994 that the rate of shoreline retreat was reduced at HB-13 (Figure 8). In total, Table 7 records a net loss of 31.3m^3 of sediment from the beach profile from 1990 to 2001 at –2.85m^3/m/year. These trends (Figure 8) clearly indicate that the Westshore nourishment scheme has partially arrested the long-term trend of shoreline retreat in this area.



• **Figure 8:** HBRC Profile HB-13 showing both trends and variability between 1975 and 2001.

Figure 6 shows that between March 1991 and November 2000, 100,900m^3 of sediment was placed along the 1.2km-long coastline in this area. From Table 6, we calculate that of this volume, about 71,700m^3 was placed on the beach and 29,200m^3 was used to construct the artificial beach ridge (Plate 4). The 29,200m^3 was effectively placed in storage beyond wave action, whereas the 71,700m^3 of sediment placed on the beach has not remained in situ but has been removed by the action of waves and currents.

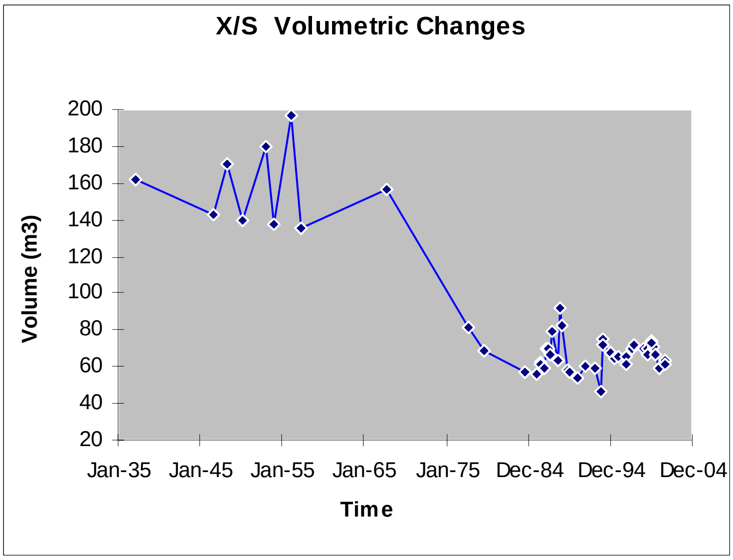
Since beach nourishment commenced along Southern Westshore in March 1991, there has been a net loss of 33,721m^3 of sediment from the beach profile above MSL between 1990 and 2001 (Table 7). During the 11-year period, the edge of the artificial barrier ridge has retreated at –0.27 to –0.95m/year, averaging about –0.6m/year (Table 7). The total loss of sediment over the last 10 years from the 1.2km-long beach can be determined by adding the 71,700m^3 placed on the beach to the measured loss from retreat of 33,721m^3. The total loss between 1990 and 2001 therefore, is determined here as 105,421m^3 at a rate of 9,584m^3/year.

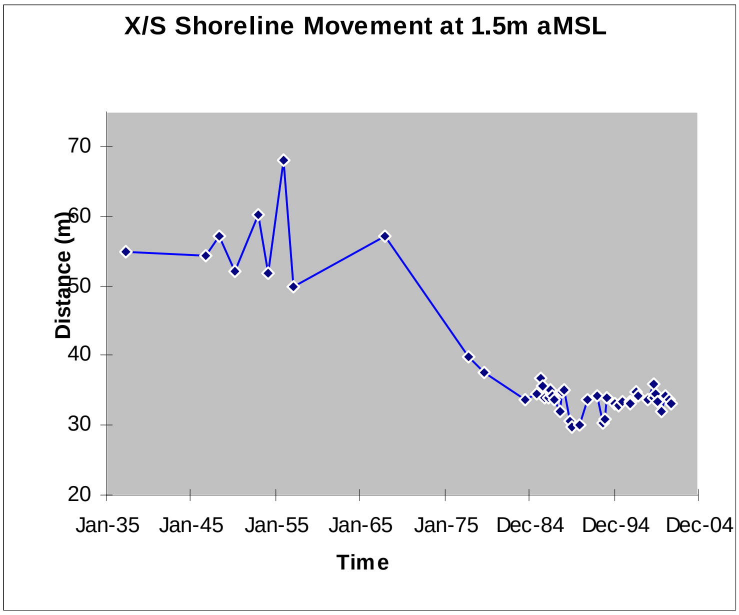
For the 1.2km-long coastline of Southern Westshore, the line of the coast in 1990 has not been held in position but has continued to retreat. The rate of loss of sediment at about 10,000m^3/year exceeds the rate of beach nourishment at about 7,000m^3/year by about 3,000m^3/year. The artificial beach ridge in this area constructed from about 29,200m^3 of nourishment sediment at about 3,000m^3/year is presently absorbing the continuing trend of retreat. The 10,000m^3/year lost from Southern Westshore is being transferred to The Esplanade by the net Northerly longshore drift.

5.1.4. THE ESPLANADE

Along The Esplanade, the longest profile time series is provided by HB-14 dating from 1 April 1937 (located Figure 1). Repeat surveys record a trend of a shoreline in dynamic equilibrium from 1937 to 1967 with fluctuations up to 18m, followed by a trend of shoreline retreat of 23.4m at –1.38m/year between 1967 and 1984 (Figure 9). From 1984 to 2001, the amount of shoreline retreat at HB-14 was effectively reduced to a very minor 0.5m at -0.03m/year, mostly as a consequence of beach replenishment that commenced along The Esplanade in January 1987 (Figure 6). In total, Table 7 records a small net gain of sediment on the beach profile of 7.3m^3 from 1986 to 2001 at 0.49m^3/m/year. These trends clearly indicate that the Westshore nourishment scheme has mitigated the long-term trend of shoreline retreat in this area.

Figure 6 shows that between January 1987 and October 2001, 139,100m^3 of sediment was placed along the 1.7km-long coastline in this area. From Table 6 we calculate that of this volume, about 49,600m^3 was placed to form an artificial embankment beyond the effects of wave action and 89,500m^3 was placed on the beach at about 6,000m^3/year. Table 7 reveals that since beach nourishment commenced along The Esplanade in January 1987, there has been a net deposition of 36,929m^3 of sediment on the beach profile between 1986 and 2001 at a rate of 2,462m^3/year. During the 15-year period, the edge of the artificial barrier ridge has also advanced at 0.10 to 0.70m/year, averaging about 0.4m/year (Table 7).





• **Figure 9:** HBRC Profile HB-14 showing both trends and variability between 1937 and 2001.

The reversal from a long-term trend of retreat to shoreline advance since 1986 can be explained by the positive effects of the Westshore nourishment scheme combined with the net Northerly longshore drift. The 1.7km-long coastline has benefited from the combination of 6,000m^3/year of beach replenishment supplemented with about 10,000m^3/year of sediment transported to the area by the net Northerly drift. The line of the coast along The Esplanade since 1986 has been effectively held against the effects of erosion by these processes.

5.1.5. FURTHER NORTH

Table 7 reveals that since beach nourishment began in January 1987, there has been a net deposition of 88,500m^3 of sediment on the 2.4km-long beach between The Esplanade and Fannin Street, Bay View, from 1986 to 2001 at a rate of 5,900m^3/year. Because of the well-established net Northerly longshore drift, the Westshore nourishment scheme has extended its benefits North of The Esplanade since 1987.

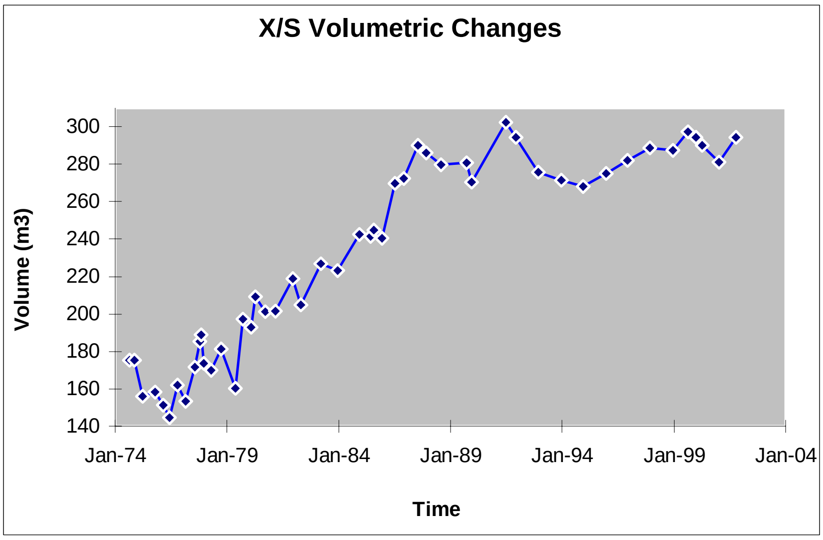
Profile W-60 is located about 150m North of the replenishment area along The Esplanade and records a minor but consistent shoreline advance at 0.13m/year and beach profile volumetric increase at 0.32m^3/year since 1986 (Table 7). Clearly, replenishment is holding the line of the coast since 1986 up to this point.

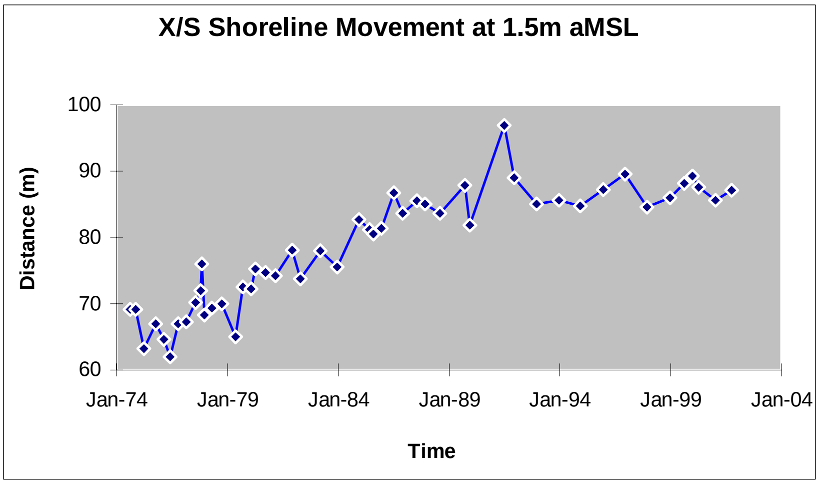
The longest beach profile time series North of W-60 is provided by Profiles HB-15 and HB-16 dating from 1 January 1916 and 21 August 1974, respectively. Profile HB-15 is located in the Reserve area about 740m North of The Esplanade and Profile HB-16 is located at Fannin Street, Bay View, about 2,360m North of The Esplanade (Figure 1). Figure 4 shows shoreline trends at HB-15 and Figure 10 shows trends at HB-16.

For Profile HB-15, Figure 4 shows a trend of minor shoreline advance of 3.5m at 0.15m/year from 1937 to 1961 with short-term shoreline fluctuations up to about 12m. From 1961 to 1986 a reversal to a trend of shoreline retreat of 17.1m at –0.68m/year occurred. From 1986 to 2001 the trend reversed again to shoreline advance of 23.5m at 1.57m/year equating to an increase in profile volume of 5.0m^3/m/year (Table 7). The reversal from shoreline retreat to advance after about 1986 is coincidental with the start of the replenishment programme early in 1987 and is interpreted here as being largely the result of the combined effects of the Westshore nourishment scheme plus the net Northerly longshore drift at a rate of 10,000-12,000m^3/year.

For Profile HB-16, Figure 10 shows a trend of shoreline advance of 14.5m at 1.2m/year from 1974 to 1986 equating to a profile volume increase at 8.1m^3/m/year. From 1986 to 2001 the volumetric increase slowed to 1.7m^3/m/year (Table 7). The significant accretion from 1974 to 1986 is matched by equally significant erosion at Profiles HB-13 to HB-15 (Figures 8, 9 & 4). CMCL is of the opinion that the pre-nourishment accretion at HB-16 is the result of the net Northerly longshore drift transporting and stockpiling beach sediments in the Bay View area eroded from the barrier beach South of Bay View. The fact that accretion has still persisted since 1986, albeit at a reduced rate, suggests that the effects of the Westshore nourishment scheme have extended as far North as Bay View.

North of Bay View data are too sparse to form an opinion about the probable effects of the nourishment scheme. Compared to Bay View where beach widths are of the order of 60-65m, beach widths reduce North of the Snapper Park Motor Camp to 42-56m South of Le Quesne Road. HBRC Profiles HB-17 and HB-18 established on 20 December 1995 and 5 December 1991 (Figure 1), respectively, both record a trend of shoreline retreat and reduction in beach volume since establishment. The survey period is too short at this stage to make a sound evaluation except to note the trend of retreat here compared to advance to the South.





• **Figure 10:** HBRC Profile HB-16 showing both trends and variability between 1974 and 2001.

On the basis of all the data available for this study, CMCL is of the opinion that the benefits of the Westshore nourishment scheme extend as far North as the South end of Snapper Park Motor Camp (Bay View) but no further as a result of wave abrasion constantly reducing the volume of beach gravels (Figure 11). The distance involved is about 6km North of the West Mole at the Ahuriri Entrance or 2.8km North of The Esplanade beach nourishment source area.

Of the 6km of coast, North of the West Mole, the Westshore nourishment scheme has provided a net benefit to about 4.5km, a partial benefit to 1.2km and no benefit to the remainder. The dominant process responsible for the distribution of the net benefit has been the net Northerly longshore drift. Constant abrasion of gravels by wave action on the foreshore is the most likely erosion process preventing the effects of beach nourishment extending North of Bay View as far as the Esk River mouth.

- **Figure 11:** GIS map showing the Westshore nourishment area and area of net benefit.

6. SWASH-BACKWASH ABRASION

In this study, an attempt was made to quantify volumetric losses from abrasion. Based on a sediment budget analysis, gravel losses of the beach sediment budget of 10% were inferred for Southern Westshore (-0.92m^3/m/year), 15% for The Esplanade (-1.21m^3/m/year), and 40% up to Bay View (-1.94m^3/m/year). The losses increase North as a result of increased exposure of the beach to greater wave energy. These estimates are regarded here as being more reliable than the estimate of –7.5m^3/m/year adopted by Gibb (1996) for the study area from the published work of Gibb and Adams (1982) relating to the South Island east coast.

7. LONGSHORE DRIFT

HBRC beach profile data provide compelling evidence of a net Northerly longshore drift between the Ahuriri Entrance and Bay View both prior to and after the start of the Westshore Nourishment scheme in 1987. Between Bay View and the Ahuriri Entrance there was a steady trend of reduction in barrier beach volume with time (Figures 4, 8, 9) prior to 1987. In contrast, from 1974 to 1987 beach gravels accumulated at Bay View (Figure 10).

Following the initiation of the Westshore nourishment scheme, there was a significant accumulation of beach gravels between The Esplanade and Bay View (Figures 4 & 10). Although the line of the coast has been held along The Esplanade, the coast has continued to retreat along Southern Westshore since 1987. Furthermore, since profiling began along Southern Westshore in August 1975 (Figure 8) beach gravels have never accumulated between the West Mole and Ferguson Avenue. CMCL is of the opinion that the coastline here is out of equilibrium.

These observations are consistent with a significant wave generated net Northerly longshore drift. Assuming that the barrier beach ridge North of Bay View has reached an equilibrium planform orientation to the predominant waves over the last 7,000 years, a predominant wave approach from the East-Southeast quadrant is inferred for this period.

The volume of the net Northerly longshore drift is directly proportional to the angle of incidence of waves to the shore, incident wave energy and the amount of sediment available for transport. Where there is a deficit in the availability of sediment for longshore transport, coastal erosion is likely to occur. The loss of approximately 10,000m^3/year along Southern Westshore over the last 10 years is indicative of the potential volume of net Northerly drift passing along this area. No beach gravels are bypassing the breakwaters of either the Ahuriri Entrance or Port of Napier, hence the sediment deficit along Southern Westshore North of the West Mole.

On 27 January 1999, Survey Services Hawke's Bay Ltd, took a set of coloured vertical aerial photographs of the Southern Hawke Bay coastline, including the study area. Wind, tide and pressure data recorded at the Port of Napier from 22 to 28 January 1999, recorded predominant winds from 120-130^0 (East-Southeast) of about 14 to 28 knots. Wave effects in the harbour did not show up until 26 February at which time a significant oscillation was recorded on the tide gauge (Peter Frizzell, Engineer, Port of Napier, pers. comm. 2002). Examples of the aerial photographs are given in Plates 6 (Westshore) and 7 (Bay View).

- **Plate 6:** Vertical aerial photograph taken 27 January 1999 between 1030 and 1230 hours of predominant waves approaching from the East-Southeast quadrant producing a high angle of incidence to the North along Southern Westshore (Photograph supplied courtesy of Mark Dunnett, Survey Manager, Survey Services HB Ltd.).

- **Plate 7:** Vertical aerial photograph taken 27 January 1999 of East-Southeast waves approaching Bay View South. The angle of incidence to the North is reduced to almost zero along the residential area of Bay View (Photograph supplied courtesy of Mark Dunnett, Survey Manager, Survey Services HB Ltd.).

The January 1999 aerial survey reveals that the angle of incidence of predominant waves to the shore is pronounced along Southern Westshore but decreases to the North, becoming generally parallel to the shore at Bay View. Along Le Quesne Road there is a slight angle of incidence of the approaching waves to the South. Under these conditions, CMCL is of the view that there is a pronounced net Northerly longshore drift of about 10,000m^3/year along Southern Westshore, increasing to about 12,000m^3/year along The Esplanade which progressively decreases towards Bay View as the approaching waves start to parallel the shore. North of Bay View, there would be a counter Southerly longshore drift. The result could be a net accumulation of beach gravels at Bay View from both directions during predominant deep water wave approach from the East-Southeast quadrant.

Although the aerial photographs are a snapshot in time they do help explain the sustained build-up of beach gravels at Bay View since 1976. It is possible that the accretion over the last 25 years has resulted mostly from the net Northerly longshore drift with some enhancement from a counter Southerly drift under predominantly East-Southeasterly approaching waves. Should there be an increase in the approach of wave storms from the East-Northeast quadrant, then a counter longshore drift to the South toward The Esplanade would occur which would affect the pattern of beach accretion since 1976.

7.2. DRIFT REVERSALS

The analysis of shoreline trends from 1962 to 2001 records 5-10m retreat of the barrier edge at Bay View at a net rate of –0.13 to –0.26m/year over the 39-year period (Table 2). Most of this retreat would have occurred during the period 1962-1976. It was during this period that the sea threatened beachfront property resulting in some owners constructing walls to mitigate property losses. These walls are still evident today.

Following 1976, the beach has built out some 26-30m thus protecting the barrier edge from further retreat from erosion and stranding the old seawalls. CMCL is of the opinion that the reversal from beach erosion to accretion after 1976 at Bay View was largely because of the effects of a predominant net Northerly longshore drift supplemented after 1987 by the Westshore nourishment scheme.

Clearly, if the net Northerly longshore drift had persisted for most of last century, Bay View would not have suffered coastal erosion prior to 1976. The predominant wave approach from the East-Southeast quadrant would have persisted. A small but significant shift in wave approach to the East-Northeast quadrant would be sufficient to produce a counter longshore drift to the South. Such a shift, if prolonged for some years, would reduce beach volumes at Bay View to the extent that the uplifted residentially developed barrier crest was exposed to the pre-1976 wave erosion.

CMCL is of the opinion that the best possible explanation for the pre-1976 erosion at Bay View was a short-term drift reversal to the South. Figure 9 shows that prior to about 1967 beach volumes along The Esplanade were in a state of dynamic equilibrium. The fact that this state was sustained through to 1967 and perhaps even longer in a known area with a sediment deficit, suggests that beach volumes were being sustained from another source. Supply of gravel from the beach area North of The Esplanade by a counter Southerly longshore drift is a possible explanation.

It is now known that beaches and coasts are influenced by a 20-30 year-climate cycle known as the Interdecadal Pacific Oscillation (IPO). The IPO is thought to have been in a positive phase in 1922-1944 and 1976-1998, and a negative phase in 1890-1922 and 1944-1976. In 1998, the IPO switched to a negative phase (Gibb 2001). The different phases affect coastal processes such as erosion-accretion cycles and longshore drift directions.

A positive IPO in New Zealand is known to temporarily inhibit sea-level rise (SLR), reduce storm surge frequency and magnitude and to have prevailing winds and waves from the Southwest quadrant. A negative IPO may promote or even enhance SLR, increase storm surge frequency and magnitude and to have prevailing winds and waves from the Northeast quadrant. A negative IPO therefore, would produce the climate conditions conducive to generating a temporary counter longshore drift to the South, thus enhancing coastal erosion at Bay View and further North up to Tangoio.

Barrier edge trends at Bay View may reflect the 20-30year IPO climate cycle. Available evidence indicates an erosion trend prior to 1976 during the 1944-1976 negative IPO. This was followed by an accretion trend after 1976 during the 1976-1998 positive IPO. CMCL is therefore, of the opinion that there is a high probability of erosion resuming at Bay View during the current negative IPO that switched in 1998. Conversely, as a result of the temporary drift reversal associated with the negative IPO, the coastline between Bay View and The Esplanade may well receive the potential benefits from a counter Southerly longshore drift over the next 20-30 years. Such a possibility at this stage should be treated with caution but carefully monitored.

8. LOCAL RELATIVE SEA-LEVEL RISE

Sea-level rise (SLR) is a recognised contributory cause of shoreline retreat. Local relative SLR (RSLR) is particularly important to any coastal area when considering its effect on shoreline retreat. Local RSLR is made up of the combination of eustatic (global) SLR and localised subsidence or emergence of the coast. This factor is usually established on a site-specific basis from automatic tide gauge records that span the last 50-100 years with respect to a 'stable' bench mark that has not moved vertically during the period of record with respect to '*sea-level'*.

Although an automatic tide gauge exists at the Port of Napier the records as yet have not been rigorously analysed to produce a sea-level trend (Peter Frizzell, pers. comm. 2002). The most relevant trend for Hawke Bay therefore, is the regional sea-level trend established for New Zealand from a rigorous analysis of automatic tide gauge records from last century from the Ports of Auckland, Wellington, Lyttelton and Dunedin (Hannah 1990). These records combined indicate a net rate of regional SLR at 1.7mm/year.

Although the 1931 Hawke's Bay Earthquake resulted in an instantaneous uplift of 1.8-2.1m in the study area, available geologic evidence is consistent with tectonic downdrop over the last 7,000 years at rates somewhere between 1 and 5m/1,000 years (1-5mm/year) (Gibb 1996). To investigate any evidence of historical subsidence the results of precise re-levelling of benchmarks in the study area by Mark Dunnett, Survey Manager, Survey Services Hawke's Bay Ltd, were examined.

Mr Dunnett carried out high accuracy levelling in 1999 using a precise level with parallel plate and a 3m staff with an invar steel graduated strip. Precise levels achieved in 1999 for a number of benchmarks between Westshore and Bay View were compared by Mr Dunnett with the original precise levels obtained by the Department of Lands and Survey in 1959.

Over the 40-year survey interval the land was found to have subsided –24mm (-0.6mm/year) at Napier Airport, -6mm (-0.15mm/year) at The Beacons and 0mm at Southern Westshore and Bay View, which is generally consistent with the geologic evidence. The 1999 precise levels were to an accuracy of ±1.0mm (0.03mm/year). No levels were obtained North of Bay View. Table 8 provides estimated local RSLR values for the study area based on the combination of historic regional SLR and land subsidence.

Table 8 provides estimated rates of local RSLR against the barrier beach ridge ranging from 1.73mm/year to 2.30mm/year. Of the 10km-long study area coastline, about 6.84km has been subject to local RSLR of 1.73mm/year, 1.51km to local RSLR of 1.85mm/year

(Beacons Reserve Area) and 1.65km to local RSLR of 2.30mm/year (The Esplanade). CMCL is of the opinion that the rates of local RSLR amongst other factors, have contributed to the widespread trend of barrier retreat over the last 39 to 65 years.

- **Table 8:** Rates of local relative sea-level rise (RSLR), estimated for the study area between Ahuriri Entrance and Esk River mouth from the sum of regional SLR and land subsidence. For zero subsidence areas a rate of 0.03mm/year is adopted from survey uncertainty. Distances are in kilometres (km) and all rates are in millimetres per year (mm/y).

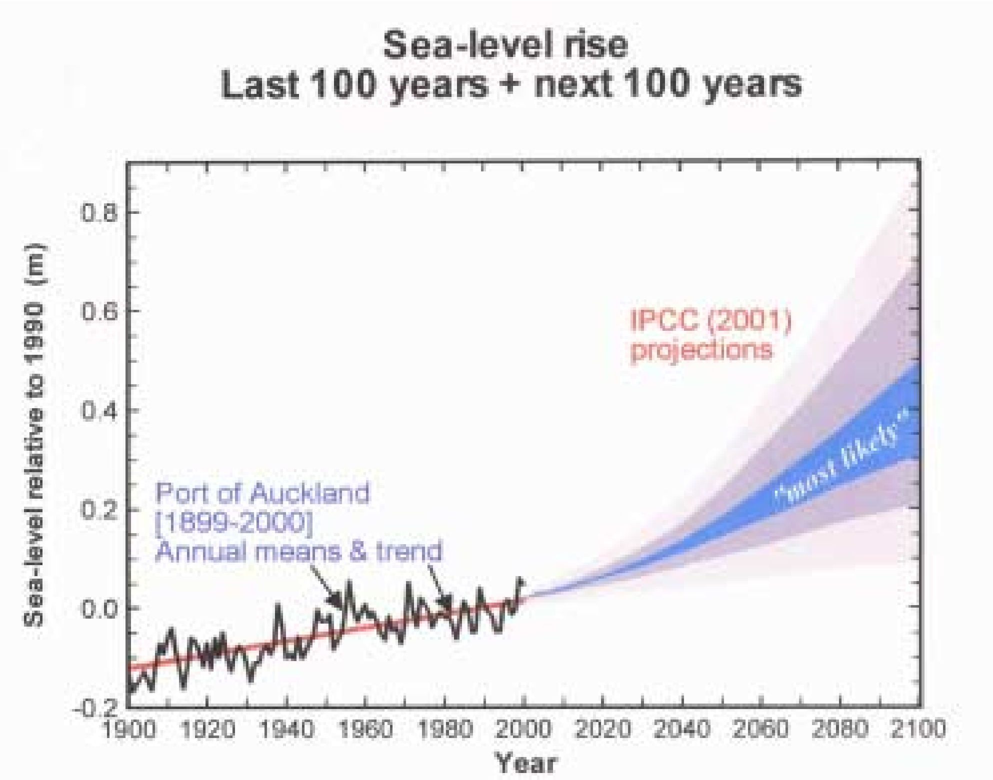
	Whakarire Avenue	Westshore South	The Esplanade	Beacons Reserve Area	Bay View	Rogers Road	Le Quesne Road
Coastline Length	0.28	1.26	1.65	1.51	1.2	1.53	2.57
Stations	1-5	5a-14	15-24	24a-32	32a-38a	39-45a	46-61
Regional SLR	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Land Subsidence	0.03	0.03	0.60	0.15	0.03	0.03	0.03
Local RSLR	1.73	1.73	2.30	1.85	1.73	1.73	1.73

8.3. CLIMATE CHANGE AND GLOBAL SLR

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

Figure 12 shows the range of SLR projections up to 2100 by the IPCC (2001a) with respect to the Auckland trend since 1899 as an example. In response to a projected increase in global surface air temperature of 1.4 to 5.8^{0}C by 2100, global MSL is projected to rise 90 to 880mm between 1990 and 2100. The "*most likely*" mid-range projections are 140-180mm above 1990 levels by 2050, and 310-490mm by 2100 (IPCC 2001a). Figure 12 indicates an average "*most likely*" forecast acceleration in SLR around New Zealand from 1.7mm/year (1899-1990) to about 3.6±0.9mm/year (1990-2100) in response to global warming this century from an enhanced Greenhouse Effect.

Apart from sea-level rise there are other impacts forecast by the IPCC (2001a, 2001b) that could adversely affect the coastlines of New Zealand including the 10km-long barrier beach ridge. The extent and severity of storm impacts, including storm-surge floods and storm-induced erosion will increase as a result of climate change. There is likely to be an increase in both tropical cyclone and mid-latitude storm peak wind and precipitation intensities and concomitant wave heights. Higher maximum temperatures and intensified droughts and floods associated with *El Niño* events are likely as the climate changes to a more *El Niño*-like average state (IPCC 2001b). Forecast Climate change effects strongly suggest a precautionary approach should be adopted for CHZ assessments through the inclusion of a Safety Factor to allow for the many uncertainties.



- **Figure 12:** IPCC-2001 projections of global SLR with respect to the historic Auckland trend since 1899. The "*most likely*" range of SLR contrasts with the least likely estimates shown as light coloured zones (Adopted from Bell et al. 2001, fig.10).

9. SUMMARY

1. The progressive increase Northwards in the elevation of the crest of the barrier ridge crest from an average of 3.6m above MSL at Westshore South to 8.4m at Le Quesne Road is directly the result of both tectonic uplift of 1.8-2.1m during the 3 February 1931 Hawke's Bay Earthquake and increasing exposure of the barrier to wave energy Northwards.

2. The net Northerly longshore drift of beach sediments increases from about 10,000m^3/year along Southern Westshore to 12,000m^3/year along The Esplanade. Zero drift of gravel passes the Ahuriri entrance, resulting in a net deficit of about 10,000m^3/year along Southern Westshore which is compensated for by coastal erosion.

3. Since the 1970s the net Northerly drift has been primarily responsible for the erosion, transport and deposition of beach sediments between Westshore and Bay View, with most of the deposition occurring between The Esplanade and Bay View.

4. Since 1986, barrier beach widths have reduced along Westshore and The Esplanade and increased North of The Esplanade particularly at Bay View as a result of the net Northerly longshore drift eroding sediment from the former area and depositing sediment along the latter.

5. Estimated maximum storm wave runup elevations increase Northwards from 3.5-4.5m above MSL along Westshore, to 6m at Bay View and 7m at Le Quesne Road and are unlikely to have overtopped the tectonically uplift barrier beach ridge crest since February 1931.

6. Closure depths of the barrier ridge increase Northwards from –4.7m below MSL and an average distance of 428m offshore at Westshore to –5.3m at Le Quesne Road and 178m offshore, the closure depth equating to the approximate offshore toe of the dynamic barrier ridge subject to sediment exchanges between the foreshore and nearshore seabed.

7. Following the Hawke's Bay Earthquake the barrier ridge advanced from accretion of sediments supplied from the seabed between 1931 and 1962 at rates of 0.5 to 2.54m/year after which time there was a trend reversal to retreat from erosion at rates of –0.10 to –0.79m/year between 1962 and 2001.

8. Along with the termination of the natural supply of beach sediments by the net Northerly longshore drift to the area by the construction of breakwaters at Port Ahuriri in 1876-1879 and Port of Napier 1887-1890, local relative sea-level rise at 1.73-2.30mm/year has contributed to the trend of coastal erosion since 1962. A projected acceleration in the rate of sea-level rise from 1.7mm/year to about 4mm/year this century will enhance current erosion rates.

9. Swash-backwash abrasion on the barrier foreshore is resulting in an annual reduction of beach volumes by 10% along Southern Westshore, 15% along The Esplanade and 40% along Bay View, thereby contributing to long-term erosion.

10. The 20-30 year climate cycle of the Interdecadal Pacific Oscillation is likely to cause a temporary reversal in the direction of the Northerly longshore drift during its negative phase which commenced in 1998. A reversal would once again expose the Bay View area to erosion that last occurred during the previous negative IPO phase in 1944-1976. The positive IPO phase that occurred in 1976-1998 appears to enhance the net Northerly longshore drift thereby increasing erosion at Westshore whilst providing a temporary reprieve at Bay View by beach accretion.

11. Maximum beach profile fluctuations of the order of 10-20m recorded by repeat surveys have occurred on the foreshore seaward of the barrier edge in response to periods of storminess and fluctuations in the direction and amount of longshore drift.

12. The Westshore nourishment scheme commenced in January 1987 resulting in the placement of 161,300m^3 of fine gravels and sand on the foreshore and 78,700m^3 on the crest of an artificial barrier ridge beyond the effects of everyday wave action.

13. The nourishment scheme has positively stabilised the erosion trend between Fenwick Street and the South end of Snapper Park Motor Camp and generally held the line of the coast in its current position since about 1987 as a result of net Northerly longshore drift dispersing placed sediments Northwards. The apparent benefits of the scheme do not extend further North than Snapper Park Motor Camp.

14. Along Southern Westshore the Westshore nourishment scheme has partially stabilised the erosion trend by offsetting about 70% of the annual losses of beach sediments from erosion processes in this area that are transported away by the net Northerly longshore drift to benefit The Esplanade.

15. Whilst the current levels of beach nourishment have proved adequate as an appropriate mitigation option for coastal erosion between Fenwick Street and the Snapper Park Motor Camp the erosion rate is likely to accelerate in response to accelerating global sea level rise outpacing the effects of current levels of beach nourishment. Nourishment levels would need to be progressively increased with time as a result to hold the present line of the coast.

16. In general, the Westshore nourishment scheme between 1987 and 2001 has been successful but needs to be reviewed to improve both its effectiveness and sustainability at mitigating erosion hazard whilst continuing to maintain and enhance the amenity of the beach.

PART III - CHZ REVIEW

10. 2001 CHZ

The Contract between CMCL and NCC requires that the following broad methods are followed by CMCL for the review of the 1996 CHZ to produce the 2001 CHZ:

i. The 2001 CHZs are to be plotted on a fully rectified coloured Orthophotomap base derived from an April 1999 controlled vertical aerial survey. The Orthophotomaps are incorporated into NCC's computer based GIS which will also incorporate the 2001 CHZs for planning and management applications by NCC.

ii. **Reference Shoreline**. The 2001 CHZ is to be established with respect to the line of MHWS accurately defined by ground survey in 1995 along the 10km-long barrier and incorporated into NCC's GIS. The 2001 CHZ will therefore, include the active foreshore above MHWS plus coastal hinterland subject or likely to be subject to the effects of coastal hazards this century.

iii. The 2001 CHZs are to be identified by a single line for 2 Scenarios with respect to MHWS 1995.

Scenario 1 – Assess a single line CHZ (CHZ_1) based on the assumption that the current Westshore nourishment scheme will be discontinued.

Scenario 2 – Assess a single line CHZ (CHZ_2) based on the assumption that the Westshore nourishment scheme will continue at current rates (c.12,000m^3/year).

iv. The same factors used to assess the 1996 CHZ are to be adopted for the revised 2001 CHZ using empirical methods. The factors are:

Factor R: Actual rate of long-term (historic) shoreline trend quantified by comparing historical aerial and beach profile surveys of the study area coast with the 2001 position of the coast.

Factor S: Maximum potential short-term shoreline fluctuation likely to occur this century quantified from both geologic and survey evidence including beach profile surveys.

Factor X: Potential rate of shoreline retreat in response to local relative sea-level rise (RSLR) this century based on the "*most likely*" projections of the Intergovernmental Panel on Climate Change in 2001.

Factor T: Hazard assessment period of approximately 100 years (2001-2100).

Factor F: Safety factor, which reflects uncertainties in the derivation of Factors **R**, **X** and **S**.

10.1. METHODS

The 2001 CHZ makes provision for the hazards of both erosion and flooding from the sea by including a Coastal Erosion Hazard Zone (CEHZ) and Coastal Flood Hazard Zone (CFHZ).

10.1.1. 2001 CEHZ METHODS

For the 75 stations, parameters were derived for the above factors to derive a CEHZ as follows:

Factor R: The long-term trend of the top seaward edge of the barrier ridge crest (*barrier edge*) was derived from Column E, Table 2, for each of the 75 stations for Scenario 1. for Scenario 2, trends were separately assessed from HBRC profile data post the start of the Westshore nourishment scheme.

Factor S: The zone covered by Factor S was measured at each of the 75 Stations on the NCC Orthophotomaps at 1:1000 Scale. Factor **S** was determined to be the horizontal distance between the 2001 barrier edge and 1995 line of MHWS plotted on the Orthophotomaps for both Scenarios 1 and 2.

Factor X: The "*Bruun Rule*" (Equation 2) used by Gibb (1996) was used to estimate potential erosion from local relative sea-level rise (RSLR) for Scenarios 1 and 2, where:

$$\mathbf{X} = \frac{\mathbf{al}}{\mathbf{h + d}} \qquad \text{Eqn [2]}$$

Where; **a =** Residual rates of SLR up to 2100 as derived in Table 9 for the 75 stations. Rates were rounded to the nearest 0.5mm/year to allow for uncertainties in deriving rates of residual SLR for this century.

- **Table 9:** "*Most likely*" rates of residual SLR derived for Factor **a** by subtracting historic local RSLR (Table 7) from the average "*most likely*" global SLR projections for 2100 by IPCC (2001a) of 400mm above 1990 sea-levels (3.64mm/y). All rates are in millimetres per year (mm/y) and are rounded to the nearest 0.5mm/y for CHZ assessment in Table 11.

STATIONS	1-14	15-24	24a-32	32a-61
IPCC-2001 SLR	3.64	3.64	3.64	3.64
Local RSLR	1.73	2.30	1.85	1.73
Residual SLR	1.91	1.34	1.79	1.91
Rounded (mm/y)	2.0	1.5	2.0	2.0

Factor **R** used in the CHZ assessment automatically incorporates the effects of historic local RSLR over the period of projection of **R** (2001-2100). Subtracting historic local RSLR from the average IPCC-2001 "*most likely*" projection to derive Factor **a** avoids double counting the effects of SLR in the CHZ assessment. Only the rounded residual SLR rate is significant for this purpose (Table 8).

d = The closure depth below MSL was derived from Column H, Table 2, for the 75 stations.

h = The crest heights of the tectonically uplifted barrier ridge above MSL was derived from Column G, Table 2, for the 75 stations.

l = Distance from the barrier ridge crest (**h**) to closure depth (**d**) was derived from Column H, Table 2, for the 75 stations.

Factor T: The hazard assessment period for both Scenario 1 & 2 was 100 years.

Factor F: The Safety Factor (**F**) was determined from root-sum-square (RSS) uncertainty values for Factors **R**, **X** and **S**, for each of the 75 stations using Equation [3] for both Scenarios 1 and 2, where;

$$\mathbf{F = \sqrt{(R)^2 + (X)^2 + (S)^2}} \qquad \text{Eqn [3]}$$

For **R**, uncertainty values were determined from the sum of the uncertainties (given in brackets) in defining the precise position of the barrier edge from the 1936 (±5m), 1962 (±3m), 1986 (±2m) and 2001 (±1m) surveys. These values allow for a potential increase in **R** this century.

e.g. 1936 – 2001 = 5 + 1 = ±6m

1962 – 2001 = 3 + 1 = ±4m

For **X**, uncertainty values were defined using The Bruun Rule and Factor **a**. For Factor **a**, historic local RSLR (Table 7) was subtracted from a "*least likely*" projection of 700mm by IPCC-2001 for 2100 above 1990 sea-levels (6.36mm/y). Table 10 provides rounded residual SLR rates.

- **Table 10:** "*Least likely*" residual rates of SLR derived to calculate uncertainty values for Factor **X** by subtracting historic local RSLR rates (Table 7) from a "least likely" global SLR for 2100 of 700mm above 1990 sea-levels (6.36mm/year), as projected by IPCC (2001a). All SLR rates are in millimetres per year (mm/y) and are rounded to the nearest 0.5mm/y for CHZ assessment in Table 11.

STATIONS	1-14	15-24	24a-32	32a-61
IPCC-2001 SLR	6.36	6.36	6.36	6.36
Local RSLR	1.73	2.30	1.85	1.73
Residual SLR	4.63	4.06	4.51	4.63
Rounded (mm/y)	4.5	4.0	4.5	4.5

There are inadequate data to develop uncertainty scenarios for potential closure depth variability (Factor **d**) such as information on the sand content of the barrier and seasonal changes in sediment composition of the shoreface out to the closure depth hence this possibility was not pursued. Including a greater rate of SLR, allows for a potential increase in erosion from SLR (Factor **X**) this century.

For **S**, maximum uncertainty values of 10m, 15m and 18m were adopted from the longest time-series HBRC profiles and greatest fluctuations for the 75 stations. The value of 10m was adopted for Stations 1-14, 15m for Stations 32-43, and 18m for Stations 15-31 and 44-61. These distances are assumed to extend landward of the barrier edge this century.

For **Scenario 1**, which assumes that replenishment at current rates is discontinued, Equation [4] is used to calculate $CEHZ_1$ widths along the 10km-long study area, where;

$$\mathbf{CEHZ_1 = (R + X)\,T + S + F} \qquad \text{Eqn [4]}$$

Where survey evidence shows that the replenished coastline has continued to retreat during the nourishment period, Equation [4] will also be applied [whilst assuming that present rates of nourishment will continue].

For **Scenario 2**, providing there is compelling survey evidence to demonstrate that current levels of beach nourishment have held the line of the coast in its present position against the trend of historical retreat, Factor **R** is assumed to be zero over the 100 year planning horizon (Factor **T**).

Where the line of the coast has been successfully held in position since the start of the scheme, Factors **R** and **X** have effectively been set to zero during the period 1987-2001. At current nourishment volumes, however, Factor **X** is likely to cause a reversal to erosion this century in response to an acceleration in SLR. Therefore, provision is made for **Scenario 2** in Equation [5] for the effects of increased erosion from sea-level rise, assuming no change in current nourishment volumes and **R** set to zero.

$$\mathbf{CEHZ_2 = X.T + S + F} \qquad \text{Eqn [5]}$$

10.1.2. 2001 CFHZ METHODS

The same methods were adopted for this review as those used by Gibb (1996) to assess a CFHZ. That is, historic SWRU elevations post 1931 were inferred from field evidence and added to a value for local RSLR this century.

10.2. 2001 CEHZ ASSESSMENT

Table 11 provides CEHZ assessments for **Scenarios 1** and **2** to determine 2001 CHZ widths. For a planning horizon of approximately 100 years (2001-2100), Table 11 shows $CEHZ_1$ widths ranging from; 35 to 75m from MHWS 1995 along Whakarire Avenue, 50 to 110m along Southern Westshore, 65 to 130m along The Esplanade, 75 to 95m along the

Beacons Reserve area, 100 to 105m along Bay View, 90 to 105m along the Gill Road-Rogers Road area, and 85 to 225m along the Le Quesne Road area. The $CEHZ_1$ widths were calculated on the assumption that the current Westshore nourishment scheme will be discontinued by the Local Authorities at some time during this century (**Scenario 1**) and the historic erosion trend will continue.

Should the Westshore nourishment scheme continue this century at current rates (c.12,000m^3/y) (**Scenario 2**), then Table 11 shows that $CEHZ_2$ would be significantly reduced in width to; 40 to 65m along The Esplanade, 60 to 85m along the Beacons Reserve area, and 80 to 85m along Bay View. The Westshore nourishment scheme has not arrested the erosion trend along Westshore South of Fenwick Street. The full effects of the scheme as an erosion mitigation measure extend from Fenwick Street to the start of the Snapper Park Motor Camp, but apparently no further.

At current nourishment rates, the Westshore nourishment scheme makes no provision for the effects of rising sea-levels nor uncertainties in Factors **R**, **X** and **S**. For this review, a precautionary approach is adopted which makes provision for these factors in the assessment of $CEHZ_2$ widths using Equation [5]. It is stressed that the implicit assumption for **Scenario 2** is that the Westshore nourishment scheme will continue at current rates in perpetuity.

10.3. 2001 CFHZ ASSESSMENT

The "*most likely*" projection in global sea-level above 1990 levels of 310-490mm by 2100 (IPCC 2001a) will progressively lift the potential maximum SWRU elevations on the barrier beach ridge with time. Therefore, the assessment of potential maximum SWRU elevations must include local RSLR. For this study a value of 0.5m by 2100 is considered reasonable to adopt for local RSLR, as it makes allowances for both subsidence and regional SLR. Flooding of low-lying land behind both the artificial and natural beach ridge crests will only occur if SWRU significantly overtops the crest.

Adopting the historic maximum SWRU elevations from Section 3.1.1 of this report provides potential maximum SWRU elevations this century of the order of; 4.0-5.0m above MSL along Westshore increasing toward the 5.0m level along The Esplanade, 6.5m at Bay View and 7.5m at Le Quesne Road. Apart from the Reserve area behind the artificial beach ridge along Southern Westshore, most of the barrier ridge crest is above these estimated levels (Table 2) as a result of tectonic uplift in 1931. Therefore, the CFHZ is mostly encompassed by the 2001 CHZ. Flooding from the sea should not pose a serious hazard to most beachfront properties in the study area that are above the levels estimated in this study.

Table 11: Coastal Erosion Hazard Zone (CEHZ) widths in metres (m) calculated for 77 stations between the Ahuriri Entrance and Esk River mouth for a planning horizon (Factor **T**) of 100 years (2000-2100). CEHZs were assessed without beach nourishment (**$CEHZ_1$**), using Equation [4], where: **$CEHZ_1 = (X + R) T + S + F$**; and with beach nourishment (**$CEHZ_2$**), using Equation [5], above: **$CEHZ_2 = X.T + S + F$**. Average erosion rates (**R**) for Stations 47-55 and 1996 CEHZ widths in table were adopted from Gibb (1996, appendix II) otherwise data for **X**, **R** and **S** were adopted from Table 2. **(X + R) T** is zero at Stations 1 & 1a because of a rock revetment mitigating erosion. CEHZ widths were rounded to the nearest 5m, plotted for each of the 77 stations on the 1999 NCC Orthophomaps at 1:1000 Scale of the study area, and incorporated into NCC's GIS.

	WHAKARIRE AVENUE						
							W-39
STATION	**1**	**1a**	**2**	**3**	**4**	**4a**	**5**
a	0.002	0.002	0.002	0.002	0.002	0.002	0.002
l	382	387	392	416	448	446	445
h	3.5	3.7	2.6	2.8	3.0	2.1	3.4
d	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
X	-0.09	-0.09	-0.11	-0.11	-0.12	-0.13	-0.11
R	0.21	0.15	-0.21	-0.39	-0.33	-0.08	0.08
R average	0.21	0.15	-0.31	-0.31	-0.31	-0.08	0.08
(X+R)T	0	0	42	42	43	21	3
S	25	8	5	4	7	18	20
F	27	27	27	27	27	27	27
$CEHZ_1$	**52**	**35**	**74**	**73**	**77**	**66**	**50**
2001 $CEHZ_1$	**50**	**35**	**75**	**75**	**75**	**65**	**50**
1996 CEHZ	35	-	70	65	65	-	45
	WITH CURRENT BEACH REPLENISHMENT RATES **R = 8 - 31m** **X = 11 - 13m**						
X.T							
S							
F							
$CEHZ_2$	**NOT APPLICABLE AS R > 0**						
2001 $CEHZ_2$							

	WESTSHORE SOUTH													
	W-40		**W-44**				**HB-13**		**W-50**			**W-50C**		**W-51B**
STATION	**5a**	**6**	**6a**	**7**	**7a**	**8**	**9**	**10**	**10a**	**11**	**12**	**12a**	**13**	**13a**
a	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
l	460	482	482	475	443	410	340	365	344	334	345	370	378	275
h	4.0	4.4	4.6	3.9	4.3	4.7	4.2	4.6	5.1	5.1	4.9	5.4	5.6	5.5
d	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
X	-0.11	-0.11	-0.11	-0.11	-0.1	-0.09	-0.08	-0.08	-0.07	-0.07	-0.07	-0.07	-0.07	-0.05
R	0.08	-0.06	-0.13	-0.10	-0.18	-0.32	-0.36	-0.41	-0.53	-0.54	-0.49	-0.40	-0.54	-0.59
R average	0.08	-0.10	-0.10	-0.10	-0.18	-0.44	-0.44	-0.44	-0.44	-0.44	-0.44	-0.44	-0.57	-0.57
(X+R)T	3	21	21	21	28	53	52	52	51	51	51	51	64	62
S	19	18	17	17	16	15	16	17	23	24	22	22	25	23
F	27	27	27	27	25	19	19	19	19	19	19	19	19	19
$CEHZ_1$	**49**	**66**	**65**	**65**	**69**	**87**	**87**	**88**	**93**	**94**	**92**	**92**	**108**	**104**
2001 $CEHZ_1$	**50**	**65**	**65**	**65**	**70**	**85**	**85**	**90**	**95**	**95**	**90**	**90**	**110**	**105**
1996 CEHZ	-	45	-	70	-	105	105	105	-	105	100	-	105	-
	WITH CURRENT BEACH REPLENISHMENT RATES **R = 6 - 54m** **X = 5 - 11m**													
X.T														
S														
F														
$CEHZ_2$	**NOT APPLICABLE AS R > 0**													
2001 $CEHZ_2$														

	THE ESPLANADE						
		W-52		**W-53**	**E-22**	**E-18**	**HB-14**
STATION	**14**	**15**	**16**	**17**	**18**	**19**	**20**
a	0.002	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
l	250	235	230	230	225	220	219
h	5.8	4.7	5.2	5.3	6.0	5.4	5.5
d	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
X	-0.05	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03
R	-0.58	-0.70	-0.67	-0.78	-0.45	-0.63	-0.78
R average	-0.57	-0.67	-0.67	-0.67	-0.67	-0.67	-0.67
(X+R)T	62	72	71	71	70	70	70
S	25	28	36	40	22	17	20
F	19	20	20	20	20	20	20
$CEHZ_1$	**106**	**120**	**127**	**131**	**112**	**107**	**110**
2001 $CEHZ_1$	**105**	**120**	**125**	**130**	**110**	**105**	**110**
1996 CEHZ	125	125	135	135	115	115	120
	WITH CURRENT BEACH REPLENISHMENT RATES **R = 0** **X = 3 - 5m**						
X.T	5	4	4	4	3	3	3
S	25	28	36	40	22	17	20
F	19	20	20	20	20	20	20
$CEHZ_2$	**49**	**52**	**60**	**64**	**45**	**40**	**43**
2001 $CEHZ_2$	**50**	**50**	**60**	**65**	**45**	**40**	**45**

Table 11:

					BEACONS RESERVE AREA									**BAY VIEW**								**GILL ROAD-ROGERS ROAD AREA**						
						W-60			**HB-15**									**HB-16**										**HB-17**
STATION	**21**	**22**	**23**	**24**	**24a**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**32a**	**33**	**34**	**35**	**36**	**37**	**38**	**38a**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**45a**
a	0.0015	0.0015	0.0015	0.0015	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
l	234	222	222	230	246	246	250	248	247	246	242	232	231	235	230	220	208	203	197	206	200	185	170	180	180	175	175	180	177
h	5.9	5.9	6.0	6.1	6.1	5.8	5.6	5.8	6.3	5.9	6.0	5.6	6.0	6.6	7.3	7.5	7.4	7.9	7.0	7.9	7.8	7.1	7.1	8.0	8.0	8.4	8.2	8.1	8.0
d	-4.7	-4.8	-4.8	-4.8	-4.8	-4.9	-4.9	-5.0	-5.0	-5.1	-5.1	-5.2	-5.2	5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3
X	-0.03	-0.03	-0.03	-0.03	-0.05	-0.05	-0.05	-0.05	-0.04	-0.05	-0.04	-0.04	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
R	-0.67	-0.66	-0.38	-0.13	-0.13	-0.03	-0.12	-0.10	-0.18	-0.21	-0.26	-0.04	-0.18	-0.23	-0.17	-0.21	-0.23	-0.13	-0.26	-0.23	-0.21	-0.21	-0.28	-0.30	-0.30	-0.30	-0.32	-0.36	-0.36
R average	-0.67	-0.67	-0.38	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.21	-0.21	-0.21	-0.21	-0.21	-0.21	-0.21	-0.21	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30
(X+R)T	70	70	41	17	19	19	19	19	18	19	19	18	18	25	25	24	24	24	24	24	24	33	33	33	33	33	33	33	33
S	21	21	20	26	37	41	43	36	39	47	49	48	61	61	60	65	62	61	62	58	57	52	45	47	45	43	42	50	49
F	20	20	20	20	21	21	21	21	21	21	21	21	18	18	18	18	18	18	18	18	18	17	17	17	17	17	20	20	20
$CEHZ_1$	**111**	**111**	**81**	**63**	**77**	**81**	**83**	**76**	**78**	**87**	**89**	**87**	**97**	**104**	**103**	**107**	**104**	**103**	**104**	**100**	**99**	**102**	**95**	**97**	**95**	**93**	**95**	**103**	**102**
2001 $CEHZ_1$	**110**	**110**	**80**	**65**	**75**	**80**	**85**	**75**	**80**	**85**	**90**	**85**	**95**	**105**	**105**	**105**	**105**	**105**	**105**	**100**	**100**	**100**	**95**	**95**	**95**	**95**	**95**	**105**	**100**
1996 CEHZ	115	115	80	55	-	70	70	85	85	95	90	90	80	-	85	85	80	90	80	80	-	75	85	85	90	85	90	95	-
					WITH CURRENT BEACH REPLENISHMENT RATES SOUTH OF STATION 24a **R = 0** **X = 4 - 5m**									**WITH BEACH REPLENISHMENT RATES SOUTH OF STATION 24a** **R = 0** **X = 3 - 4m**								**NO EVIDENCE OF BEACH REPLENISHMENT EFFECTS NORTH OF STATION 38a** **R = 11 - 36m** **X = 3m**							
X.T	3	3	3	3	5	5	5	5	4	5	4	4	4	4	4	3	3	3	3	3	3								
S	21	21	20	26	37	41	43	36	39	47	49	48	61	61	60	65	62	61	62	58	57								
F	20	20	20	20	21	21	21	21	21	21	21	21	18	18	18	18	18	18	18	18	18								
$CEHZ_2$	**44**	**44**	**43**	**49**	**63**	**67**	**69**	**62**	**64**	**73**	**74**	**73**	**83**	**83**	**82**	**86**	**83**	**82**	**83**	**79**	**78**	**NOT APPLICABLE AS R > 0**							
2001 $CEHZ_2$	**45**	**45**	**45**	**50**	**65**	**65**	**70**	**60**	**65**	**75**	**75**	**75**	**85**	**85**	**80**	**85**	**85**	**80**	**85**	**80**	**80**								

Table 11:

			LE QUESNE ROAD AREA																	
									HB-18											
STATION	**46**	**47**	**48**	**48a**	**49**	**50**	**51**	**52**	**52a**	**53**	**53a**	**54**	**55**	**56**	**57**	**58**	**58a**	**59**	**60**	**61**
a	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
l	185	167	170	177	160	165	147	154	161	180	180	180	190	202	195	180	195	210	195	180
h	8.1	8.0	8.3	8.2	7.9	8.2	8.4	8.6	8.9	8.1	8.4	8.3	8.5	8.3	8.4	8.6	8.1	7.7	8.3	3.1
d	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3
X	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04
R	-0.15	-0.11	-0.08	0.00	0.06	0.02	0.00	0.17	0.20	0.37	0.08	-0.14	-0.11	-0.19	-0.45	-0.32	-0.72	-0.79	-0.45	-0.21
R average	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.19	-0.45	-0.32	-0.72	-0.79	-0.45	-0.21
(X+R)T	18	18	18	18	18	17	17	17	17	18	18	18	18	21	48	35	75	82	48	25
S	54	56	56	57	55	48	47	46	46	46	56	72	72	83	100	90	104	123	110	90
F	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	21
$CEHZ_1$	**92**	**94**	**94**	**95**	**93**	**85**	**84**	**83**	**83**	**84**	**94**	**110**	**110**	**124**	**168**	**145**	**199**	**225**	**178**	**136**
2001 $CEHZ_1$	**90**	**95**	**95**	**95**	**95**	**85**	**85**	**85**	**85**	**85**	**95**	**110**	**110**	**125**	**170**	**145**	**200**	**225**	**180**	**135**
1996 CEHZ	95	85	85	-	85	80	80	80	-	80	-	95	100	110	175	130	-	210	165	130
			NO EVIDENCE OF BEACH REPLENISHMENT EFFECTS NORTH OF STATION 38a																	
			R = 15 - 79m																	
			X = 2 - 4m																	
X.T																				
S																				
F																				
$CEHZ_2$			**NOT APPLICABLE AS R > 0**																	
2001 $CEHZ_2$																				

11. 2001 CHZ COMPARED WITH 1996 CHZ

Table 11 provides widths for both the 2001 $CEHZ_1$ and 1996 CEHZ. With respect to 1996 CEHZ widths, the 2001 CEHZ widths are generally increased along; Bay View by 15-20m, the Gill Road-Rogers Road area by 10-15m, and Le Quesne Road by 5-15m. For the remaining areas there is little change (Table 11).

The differences may be explained as follows. Although the same factors were used to assess both the 1996 CHZ and 2001 CHZ, different parameters were used for some of the factors along with different empirical techniques. For the 2001 CHZ assessment, there was a vast improvement in the data to quantify both the long-term trend (Factor **R**) and potential erosion from sea-level rise (Factor **X**).

For example, Factor **R** was increased along all 3 areas by 6-20m as a result. In contrast, Factor **X** was reduced by 2-9m for all 3 areas. Much more refined techniques were used to assess the Safety Factor (**F**) in 2001 compared to those in 1996 (see Equation [3]). As a result the Safety Factor, which allowed for uncertainties in Factors **X**, **R** and **S**, was increased by 10-13m along all 3 areas.

Perhaps the most significant differences are found when comparing 2001 $CEHZ_1$ widths (without beach nourishment) with the 2001 $CEHZ_2$ widths (with nourishment). With respect to 2001 $CEHZ_1$ widths, the 2001 $CEHZ_2$ widths are generally reduced by 25-65m along The Esplanade, 15-20m along the Beacons-Reserve area, and 20m along Bay View. The reduction is mostly caused by the Westshore nourishment scheme reducing the long-term erosion trend (Factor **R**) to zero.

In terms of sea flood hazard, storm wave runup levels are increased by about 1m along Westshore–The Esplanade whilst being reduced by about 0.5m along Bay View–Le Quesne Road in the 2001 CHZ assessment. The changes are mostly due to better survey data on barrier ridge elevations and SWRU levels in 2001, compared to 1996.

12. CONCLUSIONS

1. The 10km-long barrier beach ridge between the Ahuriri Entrance and Esk River mouth is and is likely to be subject to the hazard of erosion from the sea. Flooding from the sea is unlikely to pose a significant hazard on the tectonically uplifted barrier crest.

2. Climate Change effects this century from an enhanced Greenhouse Effect including accelerated sea-level rise and likely increase in the ferocity of wave storms will enhance sea erosion hazard particularly along Southern Westshore.

3. The Westshore nourishment scheme, initiated in January 1987, has mitigated erosion hazard between Fenwick Street and the start of Snapper Park Motor Camp between 1987 and 2001 mostly, as a result of the net Northerly longshore drift dispersing nourished gravels as far North as Bay View.

4. The scheme has only partially mitigated the erosion hazard along Southern Westshore but has maintained and enhanced the amenity of the entire beach

between Charles Street and Bay View for easy public access, use and enjoyment.

5. The Westshore nourishment scheme has proven itself as an appropriate mitigation option for erosion but could be significantly improved in terms of its potential effectiveness and sustainability this century along the entire Westshore area.

6. At current nourishment levels, the scheme makes no provision for the effects of increasing sea levels this century, and uncertainties relating to the assessment of Factors **R**, **X** and **S**.

7. Data and techniques used to assess the 2001 CHZ compared to the 1996 CHZ assessment were far more robust and refined providing a greater degree of certainty in the 2001 CHZ assessment. On this basis the 2001 CHZ should replace the 1996 CHZ as a planning and management tool for Napier City Council.

13. RECOMMENDATIONS

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

1. **ADOPT** the 2001 Coastal Hazard Zone for Scenario 1 between the Ahuriri Entrance and Esk River mouth to replace the 1996 Coastal Hazard Zone previously adopted and implemented by Council.

2. **REVIEW** the current Westshore nourishment scheme to improve its effectiveness and sustainability during this century, with special reference both to mitigating coastal erosion between Scarpa Flow and Fenwick Street, and ensuring the sustainability of the Pacific Beach supply source and any other potential sources.

3. **INITIATE** steps to guarantee the operation of the Westshore nourishment scheme on a sustainable basis before considering the adoption and implementation of the much-reduced 2001 Coastal Hazard Zone for **Scenario 2** that assumes the continuation of the scheme.

4. **REVIEW** the current coastal monitoring programme of Hawke's Bay Regional Council between Ahuriri Entrance and Esk River mouth to ensure its effectiveness and sustainability at quantifying the effects of both coastal hazards and the Westshore nourishment scheme.

5. **REVIEW** the 2001 CHZ using similar method, every 5-10 years based on monitoring data and the performance of an upgraded Westshore nourishment scheme.

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APPENDIX I

Brief and Peer Review of Dr Peter J Cowell, Senior Lecturer, University of Sydney, New South Wales, Australia.

Survey Report by David Zorn of Jones Zorn Surveying Ltd., Napier.

JONES ZORN

Surveying Ltd

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27 January, 2002

Jeremy G Gibb,
Coastal Management Consultancy Ltd,
555 Esdaile Rd,
RD 6,
TAURANGA.

Dear Jeremy,

Re: Napier City Council Beach Profile Survey - Westshore to Esk River

This GPS survey has been carried out for the Napier City Council to determine the beach crest and barrier edge positions and elevations. Cross sections at historical locations were also surveyed to determine volumetric and excursion distance changes.

Data was collected using the Sokkia GSR2300 GPS System. The survey method was RTK (Real-Time Kinematic). The GPS base receiver was set over OIT RI DP6211 (SO9310). All field data, including horizontal and vertical control, was collected using the roving receiver with data captured in the SDR33 data recorder. This data was downloaded and processed in SDR Map v6.5 where horizontal and vertical transformations were performed to produce final coordinates and heights. Final data was e-mailed to Napier City Council in the form of a CGP XYZ ascii data file, in NZMG, to be loaded into their GIS system. From this final data, cross sections were also created and loaded into Xsect for analysis and volumetric calculations.

The survey was carried out in the following areas on the dates shown:

20/9/01	All HBRC E, W and HB Series plus NCC benchmarks
	X/S at approximately 100m intervals from the Esplanade - Fannin St.
26/9/01	X/S at approximately 100m intervals from Fannin St - Franklin Rd
28/9/01	X/S at approximately 100m intervals from Franklin Rd - Esk River
5/10/01	Coastal X/S - Esplanade to Scarpa Flow
8/10/01	Barrier edge survey with J Gibb, Scarpa Flow - Esk River Mouth

GPS receivers are dual frequency, 12 channel receivers with full wavelength carrier phase on L1 and L2. Expected precision, as provided by the manufactures for Real-Time Kinematic - static (RMS) is:

Horizontal - 1cm
Vertical - 1.7cm.

Hawkes Bay Regional Council made available HB, E and W series cross section databases and spreadsheets. The spreadsheets containing all historical cross section data were checked and minor alterations were made to correct transposed figures, and anomalies in volume calculations. The spreadsheets were then updated to include the latest cross section data, as requested by J Gibb.

Yours sincerely

David Zorn

Harley Jones (025) 326101 **David Zorn (025) 776101**

20 November 2001

Dr P.J. Cowell
(Senior Lecturer)
Coastal Studies Unit
Institute of Marine & Ocean Sciences
School of Geosciences
University of Sydney
NSW 2006
AUSTRALIA

P.Cowell@csu.usyd.edu.au

Dear Dr Cowell

RE: BRIEF FOR PEER REVIEW OF METHODS FOR REVIEW OF THE 1996 AHURIRI TO ESK COASTAL HAZARD ZONE

1. INTRODUCTION

On 5 September 2001, Napier City Council (NCC) commissioned Coastal Management Consultancy Ltd (CMCL to undertake a review of the Coastal Hazard Zone (1996 CHZ) assessed by Dr Gibb (Director, CMCL) between Ahuriri Entrance and the Esk River mouth in 1996, and the basis of that assessment. An important component of the review is to take account of the impact of current levels of beach nourishment on the 1996 CHZ and whether such nourishment forms an appropriate mitigation of the identified hazards. The revised 1996 CHZ will be termed the 2001 CHZ.

NCC requires that a peer review of the methods to be employed in the review be undertaken at the earliest convenience. Dr Peter J. Cowell, Senior Lecturer, Coastal Studies Unit, Institute of Marine & Ocean Sciences, School of Geosciences, University of Sydney, was nominated. On 14 November 2001, Dr Cowell agreed to undertake the peer review and report back as soon as practicable. The purpose of this paper is to brief Dr Cowell on the study area and the proposed methods for the review. Following the peer review process the methods to assess the 2001 CHZ will be finalised.

2. GEOLOGICAL SUMMARY

The 10km-long study area coast is a section of a continuous 42.5km open-exposed barrier beach ridge that has evolved over the past 7.0-7.5ka (thousand years) from the supply of greywacke gravel and sand. Sediment supplied to the coast has been distributed alongshore by a net Northerly longshore drift. Until 1931 the barrier was in quasi-equilibrium with the long-term wave climate coupled with tectonic submergence at 1-5m/ka. On 3 February 1931, a Magnitude 7.8 earthquake reversed the long-term submergence trend producing 1.8-2.1m instantaneous tectonic uplift of the barrier ridge in the study area.

Between about 1770 and 1890 the net Northerly longshore drift supply of predominantly gravel to the study area was significantly affected by both Maori and European activities. The most significant impacts were from the construction of substantial shore-normal breakwaters between 1876 and 1890 at the Ports of Ahuriri and Napier that totally blocked the supply of beach gravel and deflected the supply of sand to the Northern Barrier inclusive of the study area. The lack of an adequate supply of sediment contributed to a post-1890 trend of coastal retreat that suddenly reversed in February 1931 with tectonic uplift. Between 1931 and about 1960±5 years the shoreline advanced some 20 to 66m from these effects. After 1955-1965, the trend reverted back to erosion again.

The onset of erosion started to threaten beachfront assets in the study area at Westshore, and to a lesser extent at the settlements of Bay View and Le Quesne Road to the North. In response, the Local Authorities commenced a programme of beach replenishment as a mitigation measure at Westshore in 1987 using compatible beach gravel and sand. Between January 1987 and November 2001, a total of 240,000m^3 of sediments were placed on the beach and primary beach ridge on 20 occasions at an average of 12,000m^3 per placement. According to the Local Authorities responsible, the primary objective of the programme is to mitigate shoreline retreat by holding the shoreline in its present position whilst maintaining the amenity of the beach.

Increasing wave exposure Northwards has resulted in both a progressive increase in elevation of the barrier ridge crest and steepening of beach profile Northwards. The tectonically uplifted crest increases in elevation Northwards from 3-5m above MSL at Westshore to 8-9m along the Northern part of the study area. The beach profile (±2m 0.0m MSL) increases in gradient Northwards from about 1-in-24 at Westshore to 1-in-10 at Le Quesne Road. There is noticeably more sand on the lower beach profile at Westshore compared to further North which contributes to the relatively flatter gradient. The seaward toe of the barrier is recognisable by a significant change in gradient where the Very Fine Sand of the nearshore seabed meets the coarser sediments of the barrier and is relatively close to the shore compared to sand beach systems.

The following sequence of photographs taken in September 2001 from South to North shows the study area coast. The map outlines the study area coast and beach profile-monitoring network between Ahuriri and Esk Rivers.

3. PROPOSED METHODS

3.1. CONTRACT BRIEF

The Contract between CMCL and NCC requires that the following broad methods are followed by CMCL:

1. The 2001 CHZs are to be plotted on a fully rectified coloured Orthophotomap base derived from an April 1999 controlled vertical aerial survey. The Orthophotomaps are incorporated into NCC's computer based GIS which will also incorporate the 2001 CHZs for planning and management applications by NCC.

2. The 2001 CHZs are to be identified by a single line for 2 Scenarios.

   Scenario 1 – Assess a single line CHZ (CHZ_1) based on the assumption that the beach replenishment programme will be discontinued.

   Scenario 2 – Assess a single line CHZ (CHZ_2) based on the assumption that the beach replenishment programme will continue at current rates (c. 12,000m^3/year).

3. **Reference Shoreline**. The CHZ will be established with respect to the line of MHWS accurately defined by ground survey in 1995 along the 10km-long barrier and incorporated into NCC's GIS. The CHZ will therefore, include most of the active foreshore plus coastal hinterland subject or likely to be subject to the effects of coastal hazards this century. Note that the jurisdictional boundary of the line of MHWS was a snapshot in time in 1995 and will vary typically by 5-10m in position according to beach profile fluctuations.

4. Empirical methods using the same factors used to assess the 1996 CHZ are to be adopted for the revised 2001 CHZ. The factors are:

   Factor R: Actual rate of long-term (historic) shoreline trend quantified by comparing historical aerial and beach profile surveys of the study area coast with the 2001 position of the coast.

   Factor S: Maximum potential short-term shoreline fluctuation likely to occur this century quantified from both geologic and survey evidence including beach profile surveys.

   Factor X: Potential rate of shoreline retreat in response to local relative sea-level rise (RSLR) this century based on the "*most likely*" projections of the Intergovernmental Panel on Climate Change in 2001.

   Factor T: Hazard assessment period of approximately 100 years (2001-2100).

   Factor F: Safety factor, which reflects uncertainties in the derivation of Factors **R**, **X** and **S**.

5. Parameters for each of the above factors will be reviewed by CMCL in the light of new data collected during the review.

3.2. PROPOSED APPROACH

For the 10km-long study area barrier, 75 Stations were established for which parameters were derived for the above factors to derive a CHZ, as follows:

Factor R: The long-term trend of the top seaward edge of the barrier ridge crest (*barrier edge*) will be quantified from both aerial and ground surveys and beach profile surveys for both Scenarios 1 & 2. The barrier edge was reliably fixed by both aerial surveys in 1936, 1962 and 1986 and by ground survey in October 2001.There are 56 beach profile sites (see map) currently being monitored by the Hawke's Bay Regional Council (HBRC). HBRC have undertaken a time-series analysis of both volume and excursion distance changes at each profile to reveal trend and variability. Many of the profiles directly quantify the effects of beach replenishment and will be used for this purpose.

Because of the effects of the 1931 Hawke's Bay Earthquake, the 1962 aerial survey and beach profile surveys dating from the 1950s were generally adopted as the earliest, most reliable surveys to quantify contemporary erosion trends. The only exception was the Northern 2.7km of the 10km-long barrier which was not covered by either the 1962 aerial survey or early beach profile surveys. For this area, the earliest most reliable survey adopted was the 1936 aerial survey.

The early surveys were generally compared with the 2001 barrier edge position to establish rates at each of the 75 stations. The only exception was the 1.56km-long stretch of barrier along The Esplanade where the barrier edge has been artificially advanced by beach nourishment since 1987. For this area, the 1962 barrier edge position was compared with the 1986 position fixed by aerial survey. The effects of beach replenishment on the "*long-term trend*" were investigated by analysis of HBRC beach profile data post 1986.

The predominant factors determining Factor R, are sediment supply and vertical tectonic deformation of the coast. Long-term trends have occurred for example, during a period of net regional sea-level rise (SLR) at 1.7mm/year since 1900 and local differential ground subsidence at 0.02 to 0.57mm/year since 1959.

Factor S: The maximum potential profile fluctuation is the zone covered by the dynamic swept prism above the artificial 1995 line of MHWS. Factor **S** will be quantified from both the HBRC beach profile surveys and from the April 1999 Orthophotomaps at 1:1000 Scale. HBRC have provided excursion distances with time at 1.5m above MSL plus volumetric changes with time of the entire beach profile and barrier crest. These data will be used to quantify Factor **S** in section. The 1999 Orthophotomaps will be used to quantify **S** in plan with respect to the beach profile locations plotted on the Orthophotomaps.

Factor **S** is recognised as the resultant of the interaction of many influences such as fluctuating sediment supply, climate cycles such as the El Niño - Southern Oscillation (ENSO 2-7 years) and the Interdecadal Pacific Oscillation (IPO 20-30 years), and their potential influences on both likely convergences or divergences in longshore drift directions and cross-shore sediment transport both above and below sea-level.

Factor X: The Bruun Rule (Equation 1) will be used to estimate potential erosion from local relative sea-level rise (RSLR), where:

$$\mathbf{X} = \frac{\mathbf{al}}{\mathbf{h + d}} \qquad \text{Eqn [1]}$$

Where;

a = Rate of local RSLR will be derived from the "*most likely*" projections of the IPCC-2001 up to 2100 *minus* the rate of local RSLR derived from measurements of local subsidence and regional SLR last century around New Zealand.

Factor **R** used in the CHZ assessment automatically incorporates the effects of historic local RSLR over the period of projection of **R** (2001-2100). Subtracting historic local RSLR from the IPCC-2001 "*most likely*" projections to derive Factor **a** avoids double counting the effects of SLR in the CHZ assessment.

d = The closure depth below MSL represents the seaward toe of the barrier ridge at which no measurable or significant change (±0.15m) in bottom depth occurs with time (Gorman *et al.* 1998). It defines the potential limit of cross-shore transport and will be derived from rather sparse HBRC repeat offshore profile data plus equally sparse sediment data. Adequate wave climate data do not exist for Hawke Bay to theoretically define likely closure depths using Hallermeier (1981). The seaward toe of the barrier ridge is reasonably well defined by a significant change in gradient as a result of changes in sediment texture. Survey data indicate a sharp change in gradient at the contact of gravel with Very Fine Sand of the nearshore seabed and an observable change in gradient at the contact of coarser sands mantling the gravel toe with the nearshore fine sediments. The contact point along with the results of repeat offshore surveys will be assumed to indicate the closure depth.

h = The crestline of the tectonically uplifted barrier ridge above MSL has been accurately defined from precise levelling in October 2001 and recorded on the April 1999 Orthophotomaps. The crestline will be used to provide heights for each of the 75 stations.

l = Distance from the barrier ridge crest (**h**) to closure depth (**d**) will be accurately measured from both HBRC profile data, Port of Napier high resolution sounding surveys, and ground surveys made in October 2001 for this review.

Factor T: The hazard assessment period for both Scenario 1 & 2 will be 100 years (2001-2100) in accordance with standards established in New Zealand in 1981 by the National Water and Soil Conservation Organisation for CHZ assessment and the current requirements of NCC for this review.

Factor F: The Safety Factor (**F**) will be determined from root-sum-square (RSS) uncertainty values for Factors **R**, **X** and **S**, using Equation 2, where;

$$\mathbf{F} = \sqrt{(R)^2 + (X)^2 + (S)^2} \qquad \text{Eqn [2]}$$

For **R**, uncertainty values will be determined from the sum of the uncertainties in defining the precise position of the barrier edge from the 1936, 1962, 1986 and 2001 surveys.

For **X**, uncertainty values will be defined using The Bruun Rule and Factor **a**. For Factor **a**, historic local RSLR will be subtracted from a "*least likely*" projection of 700mm by IPCC-2001 for 2100. There are inadequate data to develop uncertainty scenarios for closure depth variability (Factor **d**).

For **S**, maximum uncertainty values will be adopted from the longest time-series HBRC profiles and greatest fluctuations. The effects of both negative and positive IPO including drift reversals exposing the raised barrier crest to fluctuations will be taken into account.

3.3. CHZ ASSESSMENT

Empirical Equations: For **Scenario 1**, which assumes that replenishment at current rates is discontinued, Equation [3] will be used to calculate $CEHZ_1$ (Coastal Erosion Hazard Zone) widths along the 10km-long study area, where;

$$\mathbf{CEHZ_1 = (R + X)\,T + S + F} \qquad \text{Eqn [3]}$$

Where survey evidence shows that the replenished coastline has continued to retreat during the nourishment period, Equation [3] will also be applied [whilst assuming that present rates of nourishment will continue].

For **Scenario 2**, providing there is compelling survey evidence to demonstrate that current levels of beach nourishment have held the line of the coast in its present position against the trend of historical retreat, Factor **R** will be assumed to be zero over the 100 year planning horizon (Factor **T**).

Where the line of the coast has been successfully held in position since the start of the scheme, Factors **R** and **X** have effectively been set to zero during the period 1987-2001. At current nourishment volumes, however, Factor **X** is likely to cause a reversal to erosion this century in response to an acceleration in SLR. Therefore, provision is made for **Scenario 2** in Equation [4] for the effects of increased erosion from sea-level rise, assuming no change in current nourishment volumes and **R** set to zero.

$$\mathbf{CEHZ_2 = X.T + S + F} \qquad \text{Eqn [4]}$$

4. PEER REVIEW

The peer review should focus on the methods outlined above in terms of whether they meet the requirements of "*best practice*" on a professional basis for CHZ assessment according to the quality of available information for the assessment. If they do, then this should be qualified in terms of approaches used internationally (if possible) and certainly throughout Australasia. It is suggested that the review initially focus on the 4 equations adopted for the review, followed by the parameters used in the equations and the methods used to quantify the parameters. Please address your peer review to John O'Shaughnessy of Napier City Council at the address supplied.

5. REFERENCES

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Sincerely,

Jeremy G Gibb
Director
COASTAL MANAGEMENT CONSULTANCY LTD

Encl