Waihi and Pukehina Beaches: Assessment of Storm Cut Dune Erosion

Report prepared for: **Environment Bay of Plenty**

Eco Nomos Ltd
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Cover Photos: Top – Waihi Beach
Bottom – Pukehina Beach

EXECUTIVE SUMMARY

Purpose of Report

Eco Nomos Ltd were engaged by Environment Bay of Plenty to review existing information and assess maximum storm-cut erosion for Waihi and Pukehina beaches, to assist in developing defensible setback distances for storm erosion at these sites.

The particular objectives of the study were to:

- Review available data and make a defensible assessment of the maximum expected 50 and 100-year return period storm cut erosion for Waihi and Pukehina beaches.

- Review the existing 15-metre development setback and the 8-metre development relocation trigger and, if appropriate, provide revised recommendations.

- Review the existing dune instability factor, particularly at Pukehina Beach and provide recommendations that allow for variations in dune height.

- Identify the implications of the revised estimates for existing coastal hazard setbacks at Waihi and Pukehina beaches.

- Identify implications for beach monitoring, including any appropriate recommendations that will assist in improving estimates of coastal erosion.

Methodology

The report:

- Assessed the maximum-recorded storm cut of both sites using a wide variety of data.

- Developed design erosion estimates using the model developed by Komar et al. (1997; 1999) and field data from each of the two sites.

Careful attention was given to data limitations, any apparent survey or datum irregularities, and evidence of long-term trends or other factors besides storm cut that may have influenced recorded duneline changes.

Analysis of Beach Profile Data

The analysis of the beach profiles concluded that:

- Most beach and duneline changes appear to be associated with storm-cut and/or recovery, rather than long-term trends for recession or progradation.

- Maximum-recorded storm cut erosion of the dune toe ranged from 14.5-29 metres at Pukehina and from 6.5-24 metres at Waihi.

- Maximum storm cut duneline erosion cumulated over a period of many years, rather than occurring during either a single storm or a close succession of storms.

- The maximum duneline erosion during individual events or periods of less than a few months ranged from 6.5-12 metres at Pukehina. This short-term erosion typically had only limited impact (<5 metres of erosion) on the seaward face of the main foredune.

- There was a common trend for duneline erosion in the 1970's, duneline recovery from the late 1970's to the early 1990's, and more recently, duneline erosion

- While best-fit regression lines applied to volume change data suggested a trend for net erosion at many sites, these trends were not statistically significant.

Estimates of Extreme Storm Cut using Beach Profile Data

Estimation of the maximum likely storm cut using the procedure of Komar et al. (1997; 1999) and data from severely eroded storm cut profiles, suggests:

- The maximum likely 100-year return period storm cut duneline erosion at both sites is about 30 metres and the 50year return period erosion about 25 metres – as measured from the most seaward toe of the main frontal dune

- These estimates were very consistent, despite using data from different beach profile sites and storm dates.

- In the sea walled areas of Waihi Beach, the estimates were typically 7-10 metres higher – as the seawalls hold the shoreline seaward of the natural duneline and also exacerbate storm cut erosion of the adjacent beach.

Analysis of Other Data on Historical Shoreline Changes

Pukehina Beach
Analysis of other shoreline data for this site concluded that:

- Most shoreline changes over the period from 1902 to 2002 appear to have been associated with duneline fluctuations related to storm cut and recovery.

- The maximum-recorded duneline fluctuations were less than 23 metres, most commonly 10-20 metres, except at the distal end of Pukehina Spit.

Waihi Beach
Analysis, focused on shoreline trends along Shaw Road where serious erosion has been experienced and there is good data available, concluded:

- The duneline along Shaw Road advanced seaward by at least 20 metres between 1902 and 1953 and was eroded landward by up to 25-30 metres between 1954 and late 1968.

- Historical reports that suggest greater duneline erosion (about 50 metres) between 1954 and late 1969 appear to have used the 1951 mean high water mark (MHWM) survey (located well seaward of the duneline) as a baseline and are over-estimates.

- While it is difficult to reliably assess the relative contribution of storm cut and long-term recession to the duneline changes, decadal duneline fluctuations were probably the primary component.

- Maximum duneline erosion of 6-10 metres appears to have occurred during individual storm events, particularly in areas close to Two Mile Creek and during the Wahine storm of April 1968. There are reports of up to 12-metre duneline retreats during individual storms but these were not able to be confirmed using available data.

In the area of Waihi Beach to the south of Island View:

- Duneline fluctuations considerably exceed the scale of changes likely to be associated with storm cut and recovery.

- The larger fluctuations evident probably reflect the additional influence of deep, duneline embayments and (at the southern end of the beach) the Bowentown ebb tide delta.

50 and 100-year Return Period Storm Cut Erosion

The major conclusions arising from the analysis are:

- Extreme storm cut erosion of the duneline generally cumulates over a period of several years at both Pukehina and Waihi beaches, with more limited erosion typically associated with individual events. This probably reflects the duration-limited nature of extreme coastal storms in the Bay of Plenty.

- Estimates of the maximum likely 50 and 100-year return period storm cut erosion of the main foredune average 25 metres and 30 metres respectively, and appear to be reasonably precautionary for Pukehina Beach and areas of Waihi Beach north of Island View, except sea walled areas and locations close to stream entrances.

- In sea walled areas north of Island View, the maximum likely storm cut duneline erosion ranges from 30-35 metres (50-year return period erosion) and 35-40 metres (100-year return period erosion).

- The existing data is not adequate to enable any useful revision of earlier estimates of duneline fluctuations in the area south of Island View.

- The estimates given above are most likely to cumulate over a number of storms and years rather than to occur during any single storm event.

- Rare and extreme storm cut erosion (i.e. >100-year return period) may exceed the above estimates but they appear to be reasonably precautionary for the management of dwellings in areas of existing development. A safety factor of 1.5 should be applied in utilising the figures to estimate setbacks for Greenfields' subdivision.

Dune Stability Factor

The existing dune stability factor at Pukehina is relatively precautionary and there is potential for this factor to be refined, possibly reducing the value by more than 50%.

However, it is recommended that geotechnical investigations be conducted to assess the effect of loading on slope stability before any refinement of the existing values.

Implications for 15-metre Development Setback

This setback is significantly less than the maximum likely storm cut erosion at both beaches and does not provide protection from either the maximum 50 or 100-year return period duneline erosion.

WBOPDC staff note that the 15-metre setback is not intended to provide for hazard avoidance – but rather to mitigate hazard risk.

Nonetheless, an increased setback sufficient to provide protection from the maximum likely 100-year return period storm cut and subsequent dune face instability appears likely to be practical at Pukehina.

However, a lesser standard of protection (50-year return period) may have to be adopted at Waihi to avoid precluding reasonable use of some existing sections. Therefore, development setbacks at this site may need to be complemented by other appropriate measures.

Any revision of the existing setbacks should be undertaken in close liaison with WBOPDC, property owners and the wider community at both sites.

Implications for 8-metre Relocation Trigger

The report concludes that this trigger may not provide adequate protection for dwellings, given a storm of sufficient severity and duration.

Given this uncertainty and difficulties in estimating a more appropriate trigger, it is recommended that hazard mitigation place emphasis on ensuring a reasonable development setback, rather than relying on a relocation trigger.

Where the trigger is used, it should be measured from the upper edge of the dune face erosion scarp, rather than from the toe of the dune.

Any building permits issued on the basis of a relocation trigger should clearly warn property owners that this measure may not provide adequate protection for their dwelling in the event of serious storm erosion.

Implications for Healy Setbacks

The estimates of the 100-year return period storm cut erosion recommended by this review are similar to the figures used by Healy (1993; 2001) in derivation of the hazard setback recommendations at Pukehina and the areas north of Island View at Waihi.

No change in the dune safety factor adopted by Healy (1993; 2001) is recommended until further geotechnical assessment has been completed.

Therefore, the implications for the overall setbacks are minor (changes of less than <5-7 metres) and no revision in the width of the total coastal hazard zone is recommended at this point in time.

This investigation did not review the other elements (long term trends and potential impacts of projected climate change) of Dr Healy's recommended setbacks.

Implications for Beach Monitoring

A 3-monthly frequency for beach profile surveys is recommended as adequate for the definition of maximum duneline retreat associated with storm cut.

It is also recommended that greater focus be given to pre and post-storm surveys to improve estimates of storm cut and that additional profile sites be established along the seaward margin of Waihi and Pukehina townships.

As beach profiles monitor only a limited portion of lengthy beach systems, the maximum duneline changes in any particular period almost certainly occur between, rather than at, the profiles. Therefore, it is recommended that the councils continue to conduct dune toe surveys along the length of the coast.

Consideration could be given to conducting the dune toe surveys at a higher frequency during periods of erosion – particularly in the vicinity of subdivisions like Pukehina and Waihi located relatively close to the coast.

It is recommended that Environment Bay of Plenty and Western Bay of Plenty District Council develop a partnership approach to address the increased monitoring requirements at Waihi and Pukehina Beaches.

CONTENTS

1 Introduction

Eco Nomos Ltd were engaged by Environment Bay of Plenty to review existing information and assess maximum storm-cut erosion for Waihi (Figure 1) and Pukehina (Figure 2) beaches - to provide defensible setback distances for storm erosion at these sites.

1.1 Scope of Work

The particular objectives of the study are to:

a) Review available information and make a defensible assessment of the maximum expected 50 and 100-year return period storm cut erosion for Waihi and Pukehina beaches.

b) Review the existing 15-metre development setback and the 8 metre-development relocation trigger and, if appropriate, provide revised recommendations.

c) Review the existing dune instability factor, particularly at Pukehina Beach and provide an assessment and recommendations for post-storm dune instability that allows for variations in dune height.

d) Identify and outline the implications of the revised estimates for existing coastal hazard setbacks at Waihi and Pukehina beaches.

e) Identify implications for beach monitoring, including any appropriate recommendations that will assist in improving estimates of coastal erosion.

1.2 Report Layout

The report is structured as follows:

Section 2 discusses the factors influencing storm cut erosion.

Section 3 summarises previous work on storm cut at Waihi and Pukehina beaches.

Section 4 outlines the methodology adopted for this study.

Section 5 discusses the available data and limitations of this information.

Section 6 reviews the beach profile data for Waihi and Pukehina beaches.

Section 7 assesses other information on historical shoreline change at the two sites.

Section 8 synthesizes the results to address the report objectives

Section 9 outlines the conclusions and recommendations of the study.

An Executive Summary is also presented at the front of the report.

2 Background

2.1 Importance of Storm Cut in Erosion Hazard Assessment

Assessment of coastal erosion hazard at beaches along the Bay of Plenty coast requires consideration of duneline fluctuations (over short-term and decadal time frames), any long-term trend for net recession or accretion over periods of several decades or longer, and the potential impact of projected climate change (e.g. Healy, 1993; Gibb, 1994).

Duneline fluctuations typically dominate shoreline movements over periods of decades. Storm cut and recovery is usually the primary cause of these fluctuations, though other factors can also be significant influences in localised areas – including estuary entrances and ebb tide deltas, stream entrances (e.g. Two- and Three-Mile creeks at Waihi) and arcuate duneline embayments (e.g. the area of Waihi Beach south of island View). The other factors (long term trends and potential impact of changes likely to accompany projected climate change) are generally only significant over timeframes of 50-100 years or more.

Therefore, over periods of up to several decades, storm cut (including any post-storm adjustment of over steepened dune faces) generally poses the major threat to nearshore development. Consequently, in areas of existing subdivision and development, particular attention has to be given to the magnitude of extreme storm cut to ensure that any hazard to new dwellings is appropriately mitigated.

It is a particularly important consideration in areas such as Waihi and Pukehina beaches, where, historically, much existing subdivision has been placed very close to the sea. Originally, these subdivisions were dominated by low-cost baches. However, in more recent years, the baches have tended to be replaced by relatively large and expensive dwellings, including holiday homes and permanent dwellings.

As shown in Figure 3, the assessment of storm cut hazard usually requires consideration of both:

1. **The most extreme wave erosion of the duneline likely to occur over any given period**,

2. **A "dune stability factor",** this simply being an allowance for potential collapse of the over-steepened dune face erosion scarp that forms during severe storm erosion.

The former is normally, by far, the more important of these two factors. However, the dune stability factor is an important consideration in areas where nearshore subdivision and development is located on relatively high dunes, such as Pukehina Beach.

This section briefly backgrounds the considerations that can influence the magnitude of these two elements of storm cut duneline erosion.

2.2 Factors Affecting Wave Erosion During Coastal Storms

This section briefly discusses the various factors which influence the severity of storm cut erosion, including extreme water levels, waves, storm duration, initial cross-shore profile, and the geomorphologic characteristics of the beach and shoreface (including sediment characteristics) (e.g. Zhang et al., 2001; Morton, 2002).

2.2.1 Extreme Water Levels

While large waves are the agents of beach and dune erosion, the water level at any given time determines the position and elevation at which the waves can attack the beach and dunes (Kriebel and Dean, 1985; Zhang et al., 2001).

Consequently, many authors have argued that, given storm wave conditions, extreme water levels are the single most important factor in the erosion process (e.g. Edelman, 1968, 1972; Vellinga, 1986; Kriebel and Dean, 1985; Balsillie 1986 & 1999; Dean, 1991; Zhang et al., 2001). Extreme water levels are usually the product of several factors, including astronomical tides, storm surge, wave setup, and wave runup.

For instance, Balsille (1986; 1999) found that the peak storm tide elevation was the most important variable contributing to storm-induced erosion along the U.S. East and Gulf Coasts, contributing to about 75% of the erosion volume.

During any particular storm, water level will change over the duration of the event and the duration of maximum water levels may be relatively short. Therefore, the equilibrium beach profile and maximum erosion potential of the peak water level and wave conditions may not be realised during a single event (Kriebel and Dean, 1985). Similarly, the erosion rate will vary over the storm as water level varies, being at a maximum at the time of peak water level.

2.2.2 Waves

The effect of increasing wave height is to increase the surf zone width and thus the amount of sand that must be eroded to achieve equilibrium. In other words, wave characteristics (particularly wave height and steepness) have a significant influence on the shape and scale of the cross-shore erosion profile. The time scale required to achieve an equilibrium profile also increases dramatically with wave height (Kriebel and Dean, 1985). Wave-induced nearshore circulation can also result in longshore variation in storm cut. For instance, erosion is often exacerbated in areas immediately onshore from rips, with notable rip-head embayments occasionally observed.

2.2.3 Storm Duration

The duration of a storm determines the time available for waves to erode the beach and dune. A slow moving, low intensity storm can often cause as much or more erosion than a fast moving, high intensity event (Morton, 2002).

Numerical results from various laboratory tests indicate that the time required for a natural beach to attain the equilibrium erosion profile may be of the order of 10-100 hours, depending on the storm conditions (Kriebel and Dean, 1985). Moreover, the peak erosive combination of extreme water levels and waves typically only occurs for short periods near high tide.

Therefore, in real storm situations, the duration of any single event is often not sufficient for the full equilibrium erosion profile to develop. Consequently, the maximum potential erosion of relatively large waves and high water levels is often only realised through the cumulative erosion of a number of storms. This is most likely to occur in a period with a relatively high frequency of severe storms, when there is limited duneline recovery between successive events. (i.e. In terms of duneline erosion, the next storm tends to pick up where the last one left off – though significant beach recovery can occur between events). This is particularly likely to be the situation on the Bay of Plenty, which is a lee coast, rarely exposed to extreme storms, and where the storms tend to be duration-limited events.

2.2.4 Pre-Existing Topography and Beach Morphology

The erosive impact of a particular storm can be strongly influenced by the antecedent beach and dune state (Wright and Short, 1983).

For instance, the size and morphology of the beach influences its capacity to serve as a buffer against erosion of the dune. The elevation of the berm also influences the extreme water levels required to enable dune erosion – at least up until the beach is eroded and/or reshaped by the prevailing waves. Therefore, for any given storm conditions, more severe duneline erosion will be experienced if the beach and dune buffer has already been diminished by preceding storm events. This is most likely to occur in periods with a higher than normal frequency of storm events, when there may be insufficient time for full beach and dune recovery between storm events.

Natural beach and nearshore characteristics can also influence storm cut. For instance, sediment characteristics, together with waves, largely determine the shape and scale of the erosion profile. Beaches with larger grain sizes have steeper profiles and, therefore, narrower surf zones for any given wave and water level conditions. As a consequence, it has been argued that such beaches require a lesser volume of erosion and shorter periods of time to achieve the equilibrium beach profile for any given storm conditions (Kriebel and Dean, 1985).

Other factors such as geological setting can also influence storm cut through wave and storm exposure.

2.2.5 Other Factors

Of relevance to the southern end of Waihi Beach and the northern end of Pukehina Spit, it is well known that ebb tide deltas can have significant influence on the timing and scale of shoreline erosion on adjacent shorelines. This influence is typically related to bar movements (associated with sediment circulation on the delta and with bypassing) and their influence on marginal flood channels, which often run directly offshore from adjacent shorelines.

Longshore plan shape can also have a significant influence on the storm erosion at particular locations. For instance, storm cut erosion is most severe at the head of embayments in longshore rhythmic features – the very marked arcuate duneline embayments at the southern end of Waihi Beach being a notable example of relevance to this study.

Storm cut erosion can also be markedly aggravated in the vicinity of stream entrances, such as Two- and Three-Mile Creeks at Waihi Beach. This influence is quite evident in longshore planform. There are also useful community observations of the effect of these creeks – including the observations of Sherson (2001) in respect of the Wahine Storm, and the various observations outlined by Slavich (2001). The influence of these creeks is also quite evident from the historical reports of erosion at Waihi Beach noted in various management agency files during this study. The longshore extent of these influences is however a matter of some debate (Healy, 2001; Sherson, 2001; Slavich, 2001).

2.3 Dune Stability Factor

In addition to the setback provided for erosion of the dune toe, there is widespread agreement on the need to provide sufficient allowance for the top seaward edge of an eroded dune scarp to retreat - as a consequence of slumping to attain a stable slope (e.g. Healy, 1993; Gibb, 1994; ARC, 2001; Dahm and Munro, 2002).

This is particularly relevant at Pukehina where the dunes are often quite high. For instance, dune heights shown on the beach profile sites typically range from RL 8-13 metres.

The dune stability factor is usually calculated using the following simple equation (ARC, 2000):

$$D = (H/\tan x^{o})F$$

Where D is the additional setback to allow for dune face collapse

H is the height of the foredune above MSL

x^{o} is the angle of repose of dry sand (typically 30-33^{o})

F is a factor of safety varying from 0.5 to 1, depending on assumptions made about dune face collapse

There is widespread agreement on a stable angle of repose of around 30-33 degrees (Healy, 1993; Gibb, 1994; ARC, 2000). However, sometimes a steeper dune face angle can be appropriate at a particular site. Conversely, influences such as loading at the top of the slope (e.g. due to a house) may require a lesser slope to be adopted.

The factor of safety used varies between different workers and sites.

Appropriate values of the dune stability factor for Pukehina Beach are considered in section 8.2.

2.4 Implications for this Study

The above discussion has important implications for estimation of maximum storm-cut.

Firstly, it is clear that there are a wide variety of factors that can influence the timing and magnitude of storm cut. Therefore, it is very difficult to specify the combinations of storm wave height, extreme water levels, storm duration and antecedent beach state that will give rise to the specified 50 or 100-year dune erosion.

This severely complicates the use of simple numerical models such as SBeach (Larson and Kraus, 1989) - since the "design assumptions" will largely determine the outcome. The use of such models requires reasonable knowledge of the frequency of various combinations of the above factors, information that is not available for the Bay of Plenty coastline.

Secondly, the discussion emphasizes that:

- Individual storms are not independent events; their impact very much depends on the impact of preceding storm events and the level of beach and dune recovery since these preceding events.

- Extreme "storm cut" duneline erosion (i.e. 50 and 100-year return period erosion) may well cumulate over a number of storms and even a number of years.

This has significant implications for methodology.

In particular, it suggests that estimation of maximum duneline erosion requires the careful consideration of cumulative duneline erosion over periods of several storms and probably several years.

Approaches that estimate storm cut by assigning return periods to individual erosion events (or groups of closely spaced events over a period of weeks or months), extrapolating best-fit lines to this data to estimate extreme events (e.g. Smith, 1999), may seriously underestimate 50 or 100-year return period storm cut duneline erosion. The problems with this approach relate not only to extrapolation from a short and inadequately representative record (Brooks and Benson, 1999; Tonkin and Taylor, 2001), but also to a fundamentally flawed conception of the nature of storm cut erosion. The approach treats storm cut as if it were a process that begins and ends with individual events (or closely spaced events over a period of a few weeks to months) – instead of a process that can cumulate over a period of years.

The perception of storm cut as a process relating to discrete storm events and/or a short period of time may in part relate to the term 'storm cut' itself. This terminology tends to focus on individual events and also on only the component of the process that causes erosion. A more appropriate term or phrase is probably decadal duneline fluctuations associated with storm cut and recovery.

In hazard assessment, practitioners often use the term "storm cut" interchangeably with duneline fluctuations, reflecting the dominant role that storm cut and recovery usually plays in such fluctuations. However, care is required as decadal duneline fluctuations can also be influenced by other factors – such as arcuate duneline embayments and other longshore rhythmic features, streams and stream entrances, and estuary entrances and associated ebb tide deltas. In hazard assessment, it is probably best to adopt the term "decadal duneline fluctuations' and then assess the factors responsible for such fluctuations at each site.

Overall, any assessment of 50 or 100-year return period 'storm cut' erosion needs to consider cumulative duneline retreat over a period of years and not just focus on the duneline erosion associated with individual storms. Therefore, the methodology used to assess storm cut also has to distinguish changes associated with decadal shoreline fluctuations from any trends for net long-term recession or progradation – as far as is practicable within the limitations of the available data set.

The approach taken in this study is outlined in section 4.

3 Previous Work

Various previous studies have assessed maximum potential storm-cut and dune stability factors at both Waihi and Pukehina beaches, including:

- Coastal hazard assessments undertaken at both sites by Healy (1993), with further information and an update on this analysis in evidence to a recent Environment Court hearing (Healy, 2001a,b,c).

- An initial assessment of areas sensitive to coastal hazards (ASCH) for selected parts of the Bay of Plenty coast, including Waihi and Pukehina (Gibb, 1994a).

- A recent property-specific report at Pukehina (Abbott, 2003).

Work on coastal dynamics at Waihi Beach by Gibb (1996a) and Gibb and Tonkin & Taylor (1997) also discussed storm-cut and Gibb (2001) provided further estimates of dune stability factors for Waihi Beach.

Gibb (1996b), Smith (1999, 2000), Brookes and Benson (1999, 2001) and Tonkin and Taylor (2001) also provide extensive comment on coastal erosion, including storm-cut, at Papamoa Beach.

In addition, there have been a large number of investigations of coastal processes and erosion at these beaches and/or the general locality. These include Harray (1977), Healy et al., (1977), Healy (1978a, b), Harray and Healy (1978), Smith (1986; 1999), Bradshaw (1991), Bradshaw et al., (1991; 1994), Hume and Hicks (1993), Phizacklea (1993; 1999), Gibb (1994b), Steele (1995), Beamsley (1996), Stephens (1996), Hodges and Deely (1997), Hicks and Hume (1997), Hicks et al., (1999), Stephens et al., (1999), Smith et al., (1997), Pickett et al. (1997), Tonkin and Taylor (1999), and Easton (2002).

There has also been a compilation of past storm events that have affected beaches along the northern Bay of Plenty (Hay, 1991; Hay et al., 1991), usefully refined and extended by Gibb (1996a,b), who included reports of past storm erosion damage at Waihi and along the coast between Mauo and Papamoa.

The following sections briefly review the previous estimates of storm-cut at Waihi and Pukehina beaches.

3.1 Waihi Beach

Previous estimates of maximum storm cut and the dune stability factor at Waihi Beach are summarised in Table 1.

Table 1: Previous estimates of storm cut and dune stability factors at Waihi Beach. Note that the Healy (2001) figure of 60 metres for the northern end of the beach incorporates both storm cut and long-term recession, as Healy noted these factors were difficult to

Location	Storm-cut (S_{max}) (metres)			Dune Stability Factor (D) (metres)		
	Healy 2001	Gibb 1994 (ASCH)	Gibb and Tonkin & Taylor 1997	Healy 2001	Gibb 1994 (ASCH)	Gibb 2001
Northern End	60	25	10m	6	6	6.5-10.5
Shaw Road	seawall	25	25	12	6	
The Loop	seawall	25	25	10	6	
Island View	25	25	25	10	6	
Pios Point to Bowentown	40	45	Not considered	10	8	

Healy (1993) assessed maximum likely storm-cut based on various factors including the Bay of Plenty Coastal Erosion Survey of 1977 (Healy et al., 1977), a maximum storm-cut of 24 metres measured at Bowentown in 1978, storm-cuts observed by Harray (1977) and Gibb (1996a), and interpretations from air photos.

These initial estimates were updated in 2001 (Table 1) on the basis of further information then available – including historical shoreline positions compiled for the northern 3.5kilometres of Waihi Beach (Gibb, 1996a) and an aerial photograph with cadastral lines overlaid (Healy, 2001a,b).

A safety factor of 2x was applied to the estimates because of the limited data available on the magnitude of storm cut (Healy, 1993).

Estimates of storm-cut were not considered appropriate for Shaw Road and The Loop as the seawalls in these areas were heavily exposed (Table 1). The 2001 estimate for the northern end of the beach incorporated both short-term fluctuations and long-term recession, as these components were difficult to reliably separate (Healy, 2001a,b) (Table 1).

In his assessment of factors for the ASCH lines, Gibb (1994) assessed maximum duneline fluctuations of 45 metres for Waihi East (the area south of Island View) and 25 metres for Waihi West (Island View to the north end of the beach).

Gibb and Tonkin & Taylor (1997) assessed maximum duneline fluctuations of ±25 metres for the area south of Waihi Stream, decreasing to ±10 metres north of The Esplanade - based largely on recorded storm-cuts between Shaw Road and Ocean View Road compiled by Gibb (1996a).

It can be seen from Table 1 that the various estimates of storm-cut are relatively consistent – typically about 25 metres for Island View and areas further north, excepting the very northern end where storm-cut of about 10 metres is assessed. South of Island View, the maximum duneline fluctuations increase to about 40-45 metres (Table 1).

The estimates of the dune stability factor are also generally similar (Table 1).

3.2 Pukehina Beach

Healy (1993) and Gibb (1994) both assessed a maximum duneline fluctuation of 30 metres for this site and dune stability factors of 10 metres (Gibb, 1994) and 16 metres (Healy (1994).

Abbott (2003) assessed the 100-year return period storm-cut for a property towards the northern end of Pukehina Township (707 Pukehina Parade) using various procedures and safety factors. His various estimates of dune cut (as scaled from Figure 3 on page 7 of his report) range from about 11-23 metres – the latter estimate involving a safety factor of 50%.

In relation to the dune stability factor, Abbott adopted a 40-degree angle for the toe of the dune (i.e. a dune face slope of about 1:1.2), whereas Healy (1993) and Gibb (1994) adopted a dune face slope of about 1:2.

4 Methodology

This report has sought to adopt reasonable, but precautionary estimates of the 50 and 100-year return period storm cut erosion.

The approach taken has placed an emphasis on the use of existing data to develop the estimates, involving:

- An assessment of maximum-recorded storm cut using beach profile and other data on historical shoreline changes (see section 5).
- Application of the simple design procedure developed by Komar et al. (1997; 1999), using field data for the various parameters required for the calculation.

These steps are briefly outlined below.

4.1 Recorded Storm Cut

The beach profile data and other shoreline change data outlined in section 5 was analysed to identify the maximum-recorded duneline erosion associated with past storm cut.

Essentially, this process involved the following steps:

- **Assessment of data limitations** (outlined in section 5 – though also periodically reinforced elsewhere in the text).

- **Visual check of data for any apparent survey or datum irregularities**.

- **Assessment of any decadal or long-term trends in profile or shoreline change over time.**

- **Identification of maximum-recorded duneline changes attributable to storm cut and/or recovery,** including cumulative changes over time and, where practicable, maximum cut associated with individual storms or over short periods of time.

In the analysis of the beach profile data, the position of the dune toe was assessed from the profile shape, rather than adopting a particular elevation and using excursion distances. Examination of the data indicated that the level of the dune toe varied too much to rely on the excursion distance for any particular elevation.

The storm cut was assessed in terms of duneline changes rather than volumes, as the only useful information on volume change is the relatively short beach profile record. This record does not necessarily record the maximum cut occurring during any particular storm, as there may well have been some beach recovery before the post-storm survey. The surveys also only extend a short distance offshore and frequently do not record the total storm cut occurring during any event.

There are also practical difficulties in translating design storm cut volumes into setbacks. This requires assumptions in regard to both the shape of the beach cut profile and the antecedent beach state – with the estimated duneline retreat very sensitive to these assumptions. A good example of the practical difficulties is evident in Abbott (2003), who applied a design storm cut volume to a site at Pukehina Beach. He obtained a number of different storm cut profiles and setbacks depending on assumptions about antecedent beach conditions (see Figure 3, Abbott, 2003). While the procedure is valid and the assumptions were clearly spelt out, it does illustrate the practical difficulties involved in trying to estimate setbacks from design volumes.

Some authors have attempted to avoid these issues by using the volume of sediment eroded above a particular datum such as MSL (e.g. Gibb, 1996b). However, storm cut beach profiles slope seaward and generally do not extend to MSL at the landward end, particularly for rare and extreme events (i.e. 50 or 100-year return period erosion). Therefore, it is difficult to reliably relate volumes above MSL to storm cut estimates.

Moreover, while beach and dune volumes above a particular datum are useful to monitor changes or trends in beach state, they are not always reliable indicators of dune toe position or changes in dune toe. An extreme example of this issue is shown in Figure 4, beach profile surveys from BOPCES 25 at Pukehina Beach. In the survey of 6 September 1987, the beach profile was severely eroded. The volume above MSL was only 131 cubic metres / metre, the second lowest recorded at this site and less than half the volume above MSL in the survey of 14 February 1991 (280 cubic metres / metre). However, in September 1987, the face of the main foredune was actually further seaward (Figure 4).

Therefore, while more difficult and time-consuming, direct measurements of duneline changes were considered more appropriate for this study – particularly since the outcomes of the study are used to assess various setback distances.

4.2 Numerical Estimates of Duneline Erosion

The shoreline record used to assess maximum-recorded storm cut duneline erosion, while spanning a period of nearly 100 years at both sites, is relatively sparse (section 5). Therefore, it probably does not include either the most eroded or prograded shoreline positions over that time. Consequently, relying entirely on recorded storm cut erosion may underestimate extreme storm cut such as the 50 or 100-year return period erosion. Therefore, it is important to have some crosscheck on these maxima.

Komar et al. (1997; 1999) describe a simple geometric model that can be used to estimate the maximum extent of foredune retreat. The model translates the existing beach/dune form landward in response to elevated storm water levels according to the following relationship:

$$S_{dune} = \frac{(WL - Hj) + \Delta BL}{\tan\beta}$$

Where:

- S_{dune} is the maximum extent of foredune retreat due to storm erosion;
- WL is the total water level during the storm event;
- Hj is the elevation of the toe of dune at the start of the storm;
- ΔBL is a vertical shift in the beach profile that can result from the presence of a rip current, in effect a safety factor;
- $\tan\beta$ is the beach slope.

Values for the total water level are a combination of astronomical tides, storm surge and wave effects, including runup.

The model assumes that the extreme storm event is of sufficient duration for the eroded beach/dune system to reach a steady state. Therefore, the procedure is useful for estimating the maximum potential storm-cut erosion that may arise for any given storm conditions.

This procedure was used to develop estimates of 50 or 100-year return period duneline erosion – to supplement the recorded maxima.

The extreme water level is a critical value in this procedure and has a significant influence on the estimates of storm cut obtained.

The procedure developed by Komar is often used to calculate the most extreme storm cut theoretically possible (i.e. given a storm of infinite duration). Obviously, for this purpose, the value adopted for the extreme water level is the most extreme water level likely to occur (summing the relative contributions of astronomical tides, storm surge and wave effects such as wave setup and wave runup). On the Bay of Plenty coast extreme wave runup levels have on occasions exceeded RL 5 metres (Healy, 1993; Gibb, 1994a).

However, in my judgement, while the development of an extreme storm cut profile to this elevation is theoretically possible (given a storm of infinite duration), such erosion would be a very rare and extreme occurrence – probably having a return period of 500-1000 years or more, if it occurs at all.

The purpose of this report is to estimate the maximum likely storm cut erosion with return periods of 50100 years – rather than the largest storm cut erosion that might occur.

The deepest and most severe storm cut profiles evident in the available beach profile records generally extend no higher than RL 3 metres (e.g. RL 2.9 metres in the February 1999 profile at site 49 – see Figure 26). However, there are more superficial storm cut erosion profiles that occasionally scarp the dune toe to elevations of RL 3.5-4 metres (e.g. Survey of 14 February 1991 at BOPCES 25 – see Figure 4) –

suggesting storm wave runup to these elevations is reasonably common during significant storm events.

Therefore, it seems reasonable to assume that fully developed, extreme storm cut profiles extending to RL 3.5-4 metres can and do probably occur – given either a single storm of sufficient duration or (more probable) a period with a relatively high frequency of coastal storms. Therefore, for the purposes of this study it has been assumed that a 50-year return period storm cut profile would extend to RL 3.5 metres and a fully developed 100-year storm cut erosion profile to RL 4 metres.

Obviously, these are judgements but they appear to be reasonable and precautionary based on the available information.

Other values required for the calculations were taken from storm cut erosion profiles recorded at the various beach profile sites. The calculations used only the most deeply eroded beach profiles in the records, assuming these to be representative of severe wave conditions. The estimates used 3-6 different storm cut profiles for the calculations at each beach, with the profiles taken from at least 3 separate sites. This enabled a crosscheck on the consistency of the estimates.

The extreme storm cut profiles used for the calculations generally had dune toe elevations of RL 2-2.5 metres or less (e.g. Survey of 6 September 1987 at BOPCES 25 – see Figure 4). The calculations effectively assume storm cut of sufficient duration to extend these eroded beach profiles landward to elevations of RL 3.5 metres and RL 4 metres. Therefore, they should provide reasonably precautionary for estimates of 50 and 100-year return period storm cut erosion.

A further element of precaution in the estimates is that the procedure takes no account of dune height. This is likely to introduce further conservatism into the estimates at Pukehina, where the dune heights are often in excess of 6-8 metres at the landward limit of the estimated erosion. High dunes typically reduce storm cut for any given conditions.

Given the reasonable precaution inherent in the estimates, no additional allowance has been made for rips or similar features (i.e. in all estimates in this report it has been assumed that $\Delta \underline{BL} = 0$).

5 Data

The primary sources of information used in this report were:

a) Previous work (see section 3)

b) Beach profile data from both beaches

c) Information on historical shoreline changes

The details of the available data, including limitations, are discussed below. The analysis undertaken on each data set is discussed at the beginning of each chapter.

5.1 Beach Profile Data

5.1.1 Available Data

There are 5 beach profile sites available for both Pukehina Beach (BOPCES 25 to 29 inclusive - extending from Rodgers Road to Pukehina Spit, respectively) and Waihi Beach (BOPCES sites 47 to 51, from the southern end of Waihi Beach to the northern). There are also some additional sites at Waihi (BOPCES 52-54) but these have a very limited database and were not used in this study.

Volume and profile data for the above sites were supplied by Environment Bay of Plenty. Further survey data held by NIWA was not available for this study.

The sites were established in 1977 and 1978 (Healy et al, 1977; Healy 1978a,b) and available surveys date from 1977 or 1978 – except for sites 26 and 49 (from March 1990) and site 48 (from May 1992).

However, even at those sites with data from the late 1970's, there are generally only 1-3 surveys for the period 1977-79 and then a gap to either the mid to late 1980's (for Pukehina sites) or 1990 (Waihi sites). The only exception is BOPCES 27, which has several surveys in the period 1977-79, before a gap to 1988. Therefore, the main body of data generally dates from 1985-1990, according to site, typically with 1-4 surveys per year over this period.

The profiles are generally surveyed using the Emery Pole method (less commonly, with an automatic level or total station), which has been evaluated by Environment Bay of Plenty and found to be adequate (Hodges and Deely, 1997).

5.1.2 Data Limitations

The beach profile data provides useful information on duneline erosion and/or recovery over a period of 10-25 years. However, the data is also subject to the following limitations in terms of use for estimating 50 and 100-year return period storm cut erosion:

- The record is relatively short and caution has to be applied in extrapolating from this record – particularly in terms of estimating rare and extreme events.

- There are some significant gaps in the record, particularly for the early 1980's, and spacing of the surveys is often lengthy.

- There is some question about the representativeness of the period in which most of the data has been gathered – with this period appearing to be characterised by less frequent and/or less severe storms than earlier periods such as 1960-1976 (Brooks and Benson, 1999; de Lange and Gibb, 2000; Tonkin and Taylor, 2001).

- The surveys typically extend seaward only to low water level or higher and do not monitor changes over the full width of the active beach system, which typically extends to depths of 5-8 metres below MSL (Hume and Hicks, 1993; Healy, 1993; Gibb, 1994) or further (e.g. the outer closure depth of Healy, 1993).

- The changes between the surveys do not necessarily represent the maximum storm-cut in that period – in many cases there is some beach recovery before the first post-storm survey.

- The profiles monitor changes at individual points along lengthy beach systems and, in any given period, the maximum changes may well occur at points between the profiles.

Collectively, these factors suggest that the maximum changes noted in the beach profile record may be less than occurs during rare and extreme (i.e. 50 and 100-year return period) storm cut erosion.

5.2 Compilations of Historical Shoreline Positions

Previous workers have compiled maps of historic shoreline changes for both Pukehina and Waihi beaches.

This data provides a number of "snapshots" of shoreline position over a period of 90-100 years. In addition, many of the shoreline surveys cover considerable lengths of the beaches. The additional temporal and spatial coverage provides a useful complement to the beach profile data.

The available data and associated limitations are briefly outlined below.

5.2.1 Pukehina Beach

Maps were obtained from Environment Bay of Plenty showing historic shoreline positions at Pukehina in 1912, 1943, 1949, 1970, 1981 and 1994 (Job 2/398/5, Code 3204, Sheets 23-27 inclusive).

The Hamilton District Office of the Ministry of Works and Development (MWD) compiled the shoreline positions from early cadastral and vertical aerial photographic surveys in the early 1980's, under the supervision of Chief Surveyor, Mr John H Aburn (Gibb, 1996b). A GPS fix of the toe of the foredune was added in 1994 (van der Vlugt, 1994). The compilation process is discussed by Gibb (1994; 1996b) and van der Vlugt (1994).

The shoreline positions from 1912, 1949 and 1970 are survey fixes of mean high water mark (MHWM), while the 1943, 1981 and 1994 shorelines show the position of the toe of dune as fixed from aerial photography (1943, 1981) and a GPS survey (1994).

The fix used for the MHWM surveys is unknown, though work by McBride (1995) conducted on surveys from the period 1888-1974 in the area from Papamoa to Mount Maunganui, noted (p5) that: *It is our opinion that, for the surveys for which there is no recorded method, ... the fix would have been of a line which lies somewhere between the established wet line on the beach, determined by direct observation of the height any particular tide reached, and the flotsam line."* Therefore, the MHWM lines may well be fixes of positions that, at the time of the respective surveys, lay seaward of the dune toe. Given the description by McBride and the typical beach widths observed in field inspections and beach profile data, it is estimated that the surveyed lines may lie up to 10 metres seaward of the duneline. More information on each of these historical surveys (e.g. old field books) would have to be obtained and inspected to improve these estimates.

No information is available on the accuracy of the duneline fixes from aerial photographs, though the 1981 fix was based on a controlled aerial survey of the coast undertaken as part of the original compilation (Gibb, 1996b) and probably has an accuracy of $\pm$5 metres or better. The same accuracy has been assumed for the other duneline work from aerial photos, but errors may be greater depending on how this work was conducted.

The 1994 GPS fix of the foredune was estimated to have an accuracy of $\pm$1.8 metres (van der Vlugt, 1994).

In order to provide some updated information, the toe of dune was fixed at 37 locations (approximately every 200 metres) along the front of Pukehina Township in December 2002 by measuring from adjacent property boundaries. These shoreline positions were then scaled onto the shoreline change sheets. This data has an estimated accuracy of $\pm$2 metres and was only compared with previous shoreline positions in the vicinity of each measurement.

The surveys generally cover the full length of Pukehina Township – except for the surveys of 1943 and 1970 (which start at the southern end of the township) and the spot measurements of 2002.

The major limitations of the data set are:

- The shoreline positions do not necessarily record either the most eroded or the most prograded positions of the Pukehina shoreline over the last 100-120 years. As such, the data may underestimate maximum duneline changes over the period of the record (1912-2002).
- The MHWM and duneline positions are not directly comparable and changes between these measurements may both over and understate actual duneline changes. For instance, erosion between a MHWM position and a subsequent duneline measurement will over-estimate actual dune erosion, possibly by several metres.

- The accuracy of the 1943 duneline fix is unknown.

5.2.2 Waihi Beach

Two sets of shoreline change maps were available for Waihi Beach:

- Dune toe fixes from 1943 and 1994 along the full length of the beach, compiled by Environment Bay of Plenty in 1994 (Gibb, 1994; van der Vlugt, 1994).

  The 1943 shoreline has an estimated accuracy of ±20 metres, while the 1994 duneline was a GPS fix with an estimated accuracy of ±1.8 metres (van der Vlugt, 1994).

- Duneline and MHWM fixes compiled for the northern end of Waihi Beach (from Island View north) by Harrison Grierson Ltd of Tauranga (Collie, 1996; Gibb, 1996a).

  Dunelines were fixed from photography in November 1942 (±5 metres) and March 1964 (±15 metres) and a "duneline" survey conducted in June 1996 (Gibb, 1996a). A fix of "*approximate H.W.M.*" from October 1902 is also plotted.

The data sets, while providing useful information, also have a number of limitations that have to be taken into account in the interpretation of derived shoreline changes:

- Significant errors were involved in fixing some of the lines (i.e. ±15-20 metres).

- There is uncertainty in regard to the position fixed in 1902 – it may have been near the duneline (Gibb, 1996a) or a position some distance further seaward (Collie, 2001). The upshot of this is that the duneline in 1902 may have been located some distance landward of line fixed by this survey. Without further information on the survey, it is not possible to accurately assess the potential error. However, McBride (1995) noted that historical surveys often fixed a point between the high-tide wet line and a flotsam line. Field observations suggest that such a line could well be 10 metres or more seaward of the actual duneline position. For the purposes of this report, it has been assumed that the 1902 survey represents either the duneline or a line up to 10 metres further seaward.

- In some northern areas of Waihi Beach, the shoreline is held seaward of its natural position by sea wall structures, largely installed since 1968 (Gibb, 1996a). Therefore, in these areas, "duneline" surveys that post-date the sea walls (e.g. 1994 and 1996 duneline surveys) may not show the natural duneline position. Had the walls not been present, the duneline may have been located further landward. Therefore, surveys post-dating the seawalls have not been used for this study.

- The surveys are simply "snapshots" in time and probably do not show either the most eroded or prograded positions of the shoreline over the period (1902-1996). As such, the maximum shoreline changes that occurred over this period may not be evident in the data.

- The data south of Island View is of limited value for shoreline comparisons, as there are only two shoreline fixes for this area and one of these (1944) has an accuracy of only ±20 metres (van der Vlugt, 1994).

5.3 Other Information

Other information on storm-cut and shoreline changes was also obtained from:

- **A personal collection of information on historical storm impacts**. As part of work conducted for Environment Waikato, I oversaw the compilation of several hundred pages of newspaper reports on historic coastal storms along the eastern Coromandel and Bay of Plenty, dating from August 1868 to June 1997. This work involved searching various available newspaper archives, including the New Zealand Herald and various past and present Thames Valley papers relevant to the Waihi area (e.g. Waihi Gazette, Ohinemuri Gazette, Paeroa Gazette, Hauraki Plains Gazette). The storm dates and the newspapers searched are detailed in Appendix C of Dahm and Munro (2002). The newspaper archives are held by Environment Waikato. However, I have made extensive notes from the archives over time, including any references to impacts on Waihi Beach. The data contains no information on storm impacts at Pukehina Beach, as local papers relevant to that area were not searched as part of the previous work.

- **Community information** from Council files, previous reports (e.g. Gibb, 1996a,b; Abbott, 2003), newspaper reports, and evidence to Environment Court hearings (e.g. Land, 2001; Sherson, 2001; Slavich, 2001). Unfortunately, the scope of this work precluded visiting and interviewing past and present residents and property owners.

- **Historical aerial photographs**, particularly the Whites Aviation collection held by Air Logistics. This database has little information on Pukehina Beach but a large number of photos of Waihi Beach dating from 1950.

- **Council and other agency files**. Files held by Western Bay of Plenty and Environment Bay of Plenty were inspected and relevant information copied. In addition, two days were spent in Archives New Zealand in Mount Wellington, viewing various past Ministry of Works files – which contained considerable information on erosion at Waihi Beach, including photographs and survey plans dating back to the late 1950's and early 1960's.

- **Field observations**, particularly of old erosion scarps.

6 Analysis of Beach Profile Data

6.1 Pukehina Beach

6.1.1 Datum Irregularities

The only notable datum irregularities observed in the Pukehina dataset occur at BOPCES 29. The elevation datum used for the three 1977/78 surveys originates from a benchmark varying in elevation from RL 9.65-10 metres, whereas the remaining data originates from a benchmark of RL 8.03-8.32 metres. The lesser datum irregularities noted in the other data (i.e. varying benchmark elevations from RL 8.03-8.32 metres) should also be corrected. The datum irregularities did not affect the envelope of storm cut duneline changes calculated for this study and even the 1977/78 surveys lay within the duneline envelope defined by the remainder of the dataset.

6.1.2 Shoreline Trends

Changes in beach profile volumes above MSL at each site are shown in Figures 6-10.

Best-fit regression lines applied to the volume change data suggest a background trend for net erosion at all sites except BOPCES 28. However, the linear regression explains only a small proportion of the variance, with low R^2 values (Figures 6-10), and no firm conclusions can be drawn in respect of long-term trends.

Each site shows evidence of short-term fluctuations in beach and dune volumes, over periods from days to several months (Figures 6 to 10).

More detailed examination of the volume changes and of profile characteristics also suggests the following background trends:

- Most sites experienced erosion in the 1970’s and had a faceted dune face at the time of the earliest dune surveys in 1977, though also with evidence of early dune recovery (Healy et al., 1977).

- A general trend for beach and dune recovery is evident from the late 1970’s to the early 1990’s. An exception is BOPCES 25, where severe erosion occurred in the mid 1980’s (especially 1987). However, even at that site, the largest beach and dune volumes were recorded in 1991 (Figure 6).

- A general trend for erosion has been evident at many sites since the early 1990’s, particularly severe at BOPCES 27 (Figure 8). The only notable exception is BOPCES 28, where the site appears to have remained in dynamic equilibrium from the 1990’s to the present (Figure 9).

These are similar to trends generally reported for the east coast beaches of the Bay of Plenty, Coromandel, Auckland and Northland - i.e. severe and sustained duneline erosion in the 1960’s and 1970’s, giving way to a period of duneline recovery in the 1980’s and early 1990’s, with a trend for renewed duneline erosion observed in the mid-late 1990’s (e.g. Brooks and Benson, 1999; Dahm and Munro, 2002).

The reasons for such decadal duneline fluctuations have not yet been conclusively demonstrated, though de Lange (2001) suggests that they may relate to the influence of the Inter-decadal Pacific Oscillation (IPO) on the frequency and intensity of El Nino Southern Oscillation (ENSO) extremes. This explanation suggests that a La Nina dominated phase of the IPO may have a higher frequency of severe storms and therefore be characterised by duneline erosion. Conversely, periods dominated by El Nino extremes may well have a lower frequency of severe storms and therefore be characterised by a general trend for beach and duneline recovery.

Therefore, while far more detailed work and information would be required to adequately assess any long-term trends, it does appear that most of the beach and duneline changes evident in the beach profile record can be attributed to duneline fluctuations rather than long-term trends for recession or progradation. This interpretation has been adopted for the purposes of this report and is consistent with a precautionary approach to the estimate of storm cut and recovery. It ensures that recorded duneline fluctuations associated with storm cut and recovery will be over-estimated, rather than underestimated.

6.1.3 Maximum Duneline Changes

Envelopes of maximum duneline change at each site are shown in Figures 12 to 16 and Table 2 records the maximum duneline changes noted at each site.

All measurements recorded in Table 2 are with respect to the most seaward-recorded position of the dune toe – whether the toe of the main foredune or the toe of an incipient dune seaward of the main frontal dune (Figure 11). All duneline profiles discussed in Table 2 are also shown in Figures 12-16.

Table 2: Maximum duneline fluctuations noted at BOPCES 25 to 29 (Pukehina Beach).

BOPCES Site	Maximum volumetric change above MSL (m3/m)	Maximum duneline fluctuation (m)	Comment on duneline fluctuation
25	157	21	Total cumulative erosion between March 1985 (toe of incipient dune) and August/September 1987
26	123	16	Total cumulative duneline retreat between April 1993 and September 2000
27	101	29	Total cumulative erosion between February 1977 (toe of incipient dune) and December 2002
28	117	14-15.5	Total cumulative progradation between February 1978 (toe of main foredune) and May 1992/March 2002 (both toe of incipient dune)
29	153	17-19	Total cumulative erosion between April 1993 and March 1998

It can be seen that the maximum-recorded duneline fluctuations range from 14.5-29 metres, typically being in the range of 15-22 metres (Table 2).

The period between the most prograded and eroded duneline states is generally several years, sometimes 1-2 decades (Table 2). The shortest period of significant duneline retreat occurred at BOPCES 25, where erosion between March 1985 and August/September 1987 removed an incipient dune about 15 metres wide. However, the seaward face of the main foredune suffered only 3-5 metres of erosion over this period. More significant erosion of the foredune occurred in the period between the surveys of February 1978 and September 1987 (Figure 12).

Therefore, as anticipated from theoretical considerations (section 2), the most significant storm cut duneline erosion cumulated over a period of many years, rather than occurring during either a single storm or a succession of storms within a few months.

The maximum duneline erosion most commonly occurred in the late 1990's or early 2000's, except at BOPCES 25, and the maximum prograded state was generally recorded in the late 1970's or the early 1990's (Table 2) – reflecting the underlying trends discussed earlier.

6.1.4 Shorter Term Duneline Changes

The maximum short-term duneline erosion recorded at the various sites ranges from 6.5-12 metres, occurring over periods from 2 days (6.5 metres) to 6 months (12 metres) (Table 3).

Table 3: Maximum short-term duneline erosion noted at BOPCES 25-29 (Pukehina Beach)

BOPCES Site	Maximum Recorded Short Term Duneline Erosion (m)	Period over which change was observed
25	8	1.5 months - between surveys of 24 June 1987 and 8 August 1987
25	11	4 months - between surveys of 4 February 1991 and 10 June 1991
27	12	6 months - between surveys of 25 March 1978 and 7 September 1978
29	6.5	2 days - between surveys of 20 April 1993 and 22 April 1993
29	9	7 months - between surveys of 3 Feb 1978 and 28 September 1978

It can be seen that the short-term duneline retreat can be significant. However, it should also be noted that this short-term erosion largely affected lower dune areas and resulted in only minimal erosion (always <5 metres) of the seaward face of the main frontal dune. This is well illustrated in Figures 17 and 18, which show the maximum short-term duneline erosion events recorded.

Overall, this shorter-term duneline erosion is relatively minor compared to the maximum-recorded storm-cut duneline erosion at each site (Figures 12 to 16).

6.1.5 Estimates of Maximum Likely Storm Cut

Estimates of the maximum likely storm cut at Pukehina Beach using the procedure outlined in section 4.2 are summarised in Tables 4 and 5). The estimates in Table 4 are measured with respect to the most seaward duneline (often an incipient dune), while those in Table 5 are measured from the most seaward-recorded toe of the main frontal dune (i.e. ignoring any incipient dune further seaward) (see Figure 11). The equivalent maximum-recorded duneline erosion is also included (in brackets) in each table.

Table 4: Estimates (bold) of maximum 50 and 100-year return period storm cut duneline erosion for Pukehina Beach. The maximum-recorded fluctuations at each site are also shown (in brackets) for comparison.

Beach Profile Site	**50-year Return Period Duneline Erosion (m)**	**100-year Return Period Duneline Erosion (m)**	**Date of Storm Cut Profile used for Calculations**
BOPCES 25	**31** (21)	**34** (21)	6 September 1987
BOPCES 27	**31.5** (29)	**37.5** (29)	7 September 1998
BOPCES 29	**26.6** (19)	**31.6** (19)	25 March 1998

It can be seen that the estimates are higher than the maximum-recorded duneline erosion at each site (Tables 4 and 5).

It is notable that the estimates show a high level of consistency, despite using profiles from different sites and different dates for the calculations. However, the consistency of the estimates improves even further when measured from the most seaward position of the main frontal dune (Figure 11) – averaging 25 metres for the 50-year return period storm cut erosion and 30 metres for the 100-year (Table 5). This appears to be a more consistent and stable baseline than the toe of incipient dunes – as would be expected.

Table 5: Estimates of maximum 50 or 100-year return period storm cut duneline erosion for Pukehina Beach – measured from most seaward-recorded position of main frontal dune. Equivalent maximum-recorded duneline erosion is shown in brackets.

Beach Profile Site	50-year Return Period Duneline Erosion (m)	100-year Return Period Duneline Erosion (m)	Date of Storm Cut Profile used for Calculations
BOPCES 25	25 (15)	28 (15)	6 September 1987
BOPCES 27	24 (21.5)	30 (21.5)	7 September 1998
BOPCES 29	25.6 (17-19)	30.6 (17-19)	25 March 1998

6.1.6 Dune Stability Factor

The dune stability factor (section 2.3) is an important consideration with severe storm cut at Pukehina, given the considerable height of the frontal dune on which development is located. For instance, dune heights shown on the beach profile sites typically range from RL 8-13 metres.

As discussed in section 2.3, the dune stability factor is usually calculated using the following simple equation:

$$D = (H/\tan x^o)F$$

Where D is the additional setback to allow for dune face collapse

H is the height of the foredune (usually measured wrt MSL)

x^o is the angle of repose of dry sand (typically 30-33^o)

F is a factor of safety.

Healy (1993) adopted a stable angle of repose of 1V:2H (i.e. about around 30 degrees) at Pukehina, an average height of 8 metres and (implicitly) a value of F=1.

Therefore, with the approach adopted by Healy, the above equation essentially reduces to:

$$F = 2H \quad \text{(with H=8)},$$

providing a dune stability factor of 16 metres.

A simple means of providing for variation in dune height at this site would be to adopt the approach of Healy (1993) but leave dune height variable. I.e.

$$F = 2H \quad \text{(with H variable)}$$

However, there are various other refinements that can also be considered:

1. A common refinement is to assume that only the top half of the dune face will need to collapse to form the desired angle of repose – setting F at 0.5 (ARC, 2001). This approach assumes that collapse occurs after the erosion has ceased, with the debris collecting at the base of the dune.

   This would reduce the dune safety factor to:

   $$F = H$$

   An examination of the adjustment of storm scarps at Pukehina, using the beach profile data, indicates that this approach is probably adequately precautionary for Pukehina – depending on the effect of loading (see discussion below).

2. The approach of Healy (1993) has adopted the dune height as the height above MSL. However, in practice, the relevant height is the height of the erosion scarp above the dune toe. After severe storm erosion, this elevation is normally well above MSL, typically RL 2-3 metres in the beach profile data.

   For instance, in the 50-year or 100-year design conditions, the elevation of the eroded dune toe may well be as high as RL 3.5-4 metres (see discussion in section 4.2).

Taking these two factors into account may result in the dune safety factor being reduced by more than 50%. Such refinement can be useful in reducing unnecessary constraints on the use of private property.

However, before adopting any such refinements, it is important that appropriate geotechnical investigations be undertaken to investigate the influence of loading (i.e. a house) on the top of the eroded dune face – to ensure that an adequate factor of safety is retained in any refinements. Until this work is completed, the precautionary approach adopted by Healy (1993; 2001) should be retained.

6.2 Waihi Beach

6.2.1 Datum Irregularities

The only significant datum irregularities noted at sites BOPCES 47-51 were the January 1978 survey at BOPCES 47 (benchmark elevation of RL 10 metres, compared to RL 6.45 at most other sites), the 5 February 1993 survey at the same site (benchmark elevation of RL 7.82 metres) and the January and September 1978 data at BOPCES 51 (benchmark elevations of RL 9-10 metres, compared to RL 4.48 metres for other sites).

Checks indicated that correction of these differences would result in each of the profiles plotting within the envelope formed by the other data at these sites. Therefore, the datum issues did not have any influence on this study. However, the January 1978 data at BOPCES 47 was one of the two most prograded profiles in the record at that site.

There was also one profile incorrectly labelled (profile 1020315 at BOPCES 48).

6.2.2 Shoreline Trends

The Waihi profiles show considerable evidence of short-term dynamic fluctuations, over periods ranging from several weeks to 2-3 years (Figures 19 to 23). At site 47, the dynamic fluctuations are very marked, reflecting the influence of the adjacent ebb tide delta (e.g. Hicks et al., 1999) as well as storm erosion and recovery.

Best-fit regression lines applied to the volume data supplied by Environment Bay of Plenty suggested that sites 47 and 48 at the southern end of the beach are relatively stable (Figures 19 and 20) and that sites 49-51 are experiencing a trend for net recession (Figures 21-23). However, as at Pukehina, the trends for recession are not statistically significant and appear to be an over-simplification of the actual background trends.

It is difficult to identify background trends with any confidence at Waihi, given the short length of the record at most sites, the influence of seawalls at some sites (particularly BOPCES 50), and the influence of the adjacent ebb tide delta.

However, examination of trends in volume and profile characteristics suggests that sites 49 and 51 both experienced a general background trend for duneline recovery and accretion to the early 1990’s, with erosion thereafter - similar to the background trends observed at Pukehina Beach over this period.

Site 50, backed by a seawall that generally truncates the profile, also experienced an overall trend for progradation and duneline advance to the early 1990’s, followed by a period of severe erosion. However, at this site, there is also some evidence of a background trend for recovery between mid 1997 and 2000 (Figure 22). Site 48 appears largely to have fluctuated backwards and forward over the short period of the available record.

Therefore, the primary changes evident appear to be related to duneline fluctuations. While there may also be a long-term trend for erosion at this site (Healy, 1993; 2001), it is difficult to confidently discern any evidence of such trends from the available beach profile data. This is also to be expected, as any long-term trends are likely to be low (e.g. 0.1 metres / yr) and to have resulted in shoreline changes of less than 1-2 metres over the relatively short period of the beach profile record. It would be extremely difficult to discern such trends given the much larger short-term duneline fluctuations.

6.2.3 Maximum Duneline Fluctuations

Duneline envelopes for each site are shown in Figures 24 to 28 and the maximum duneline erosion (or fluctuations – site 47) associated with these envelopes is tabulated in Table 6. The baseline for the measurements in Table 6 is the most

seaward recorded position of the dune toe – often an incipient dune feature (Figure 11) seaward of the dune toe (see Figures 24-28).
It can be seen that the maximum prograded states generally occurred in the early 1990's and the maximum eroded states are typically more recent (late 1990's, early 2000's) – consistent with the general trends noted at Pukehina.

The recent erosion at both Pukehina and Waihi may indicate that these beaches are presently in the early stages of a new erosive phase similar to that of the 1960's and 1970's – though it is too early to be conclusive in this respect.

Table 6: Maximum duneline fluctuations recorded at BOPCES 47-51, Waihi Beach

BOPCES Site	Maximum volumetric change above MSL (m3/m)	Maximum duneline erosion or fluctuation (m)	Comment on duneline fluctuation
47	142	19	Site strongly influenced by ebb tide delta and subject to regular fluctuations. This measurement is duneline *progradation* between September 1978 and April 1994
48	79	6.5	Total duneline erosion between March 2000 and March 2001
49	80	11.5	Cumulative erosion measured from toe of dune in February 1993 to toe of main foredune in February 1999.
50	40	7	Duneline erosion limited by seawall
51	101	7	Total duneline retreat between toe of incipient dune in February 1991 and toe of main dune in June 2002. Slightly higher (about 9 metres) if measured relative to wider, flatter dune toe of February 1993 (see Figure 28)

The maximum-recorded duneline erosion ranges from 6.5-19 metres (Table 6). However, the largest duneline change shown in Table 6 is measured at site 47 and this area is not representative of the wider beach system, being significantly influenced by the Bowentown ebb tidal delta (Hicks et al., 1999). At other sites the maximum erosion of the main dune face was only 11.5 metres and generally less than 10 metres (Table 6 and Figures 24-28).

The maximum-recorded duneline erosion has generally cumulated over periods of several years, typically from the early 1990's to the late 1990's or early 2000's (Table 6). Therefore, as observed at Pukehina, it appears that maximum storm cut duneline erosion at Waihi is in general not the product of a single extreme event (or a series of successive events over a period of weeks or months), but rather of cumulative erosion over a period of several years.

6.2.4 Maximum Likely Storm Cut

The estimates of maximum storm cut for Waihi Beach are shown in Table 7 with respect to the most seaward-recorded position of the main frontal dune (i.e. ignoring any incipient dune features further seaward). The equivalent maximum-recorded fluctuations at each site are also included (in brackets) for comparison. The estimates for BOPCES 50 (sea-walled site) are of the erosion that would occur if the wall were not present.

As at Pukehina, the estimates are relatively consistent when measured from the most seaward-recorded position of the main frontal (Table 7).

The estimates show a high degree of consistency despite the use of different beach profile sites and survey dates. Interestingly, the maximum estimated erosion is also very similar to Pukehina Beach (i.e. 100-year return period erosion of about 30 metres and 50-year return period about 25 metres), despite the coarser sands and steeper storm erosion profiles at Pukehina (e.g. storm cut beach slopes of about 0.1, compared to values of about 0.06-0.065 at Waihi).

Table 7: Estimates of maximum 50 or 100-year return period storm cut duneline erosion for Waihi Beach, measured with respect to most seaward-recorded position of main foredune. The maximum-recorded duneline changes measured from the same baseline are shown in brackets for comparison.

Beach Profile Site	50-year Return Period Duneline Erosion (m)	100-year Return Period Duneline Erosion (m)	Date of Severe Storm Cut Profile(s) used for Calculations
BOPCES 48	24 (6.5)	31.5 (6.5)	24 February 1999 7 March 2001
BOPCES 49	25.5 (11.5)	33 (11.5)	25 September 1996
BOPCES 50 (Seawall)	33-36 (seawall)	39-42 (seawall)	3 January 1996 25 September 1996
BOPCES 51	21 (7)	27 (7)	20 June 2002

The only major difference occurs at BOPCES 50 where the estimates were typically 7-10 metres higher (Table 7). This probably reflects the fact that the seawall (the datum from which the cut was measured) lies several metres seaward of where the natural duneline would otherwise lie. In addition, the extreme storm cut profiles observed at
this site may have been accentuated by the presence of the wall – which would be expected to aggravate scour of the beach area directly seaward. As noted in section 4.2, any aggravation of beach scour by such effects (or rips) will tend to flatten the slope of the storm cut beach profile, leading to increased estimates of erosion.

The estimates are generally much higher than the maximum duneline erosion so far recorded at these beach profile sites (Table 7). This could suggest the estimates are too conservative. However, there is evidence from other lines of data that significant storm cut duneline erosion does occur at this site (discussed further in section 7). Therefore, the limited changes so far noted at the beach profile sites are probably a reflection of the short record and the dominance of a period of duneline recovery until relatively recently.

7 Historical Shoreline Changes

7.1 Pukehina Beach

The maps of historical shoreline positions dating from 1902 (discussed section 5.2) were analysed by drawing shore perpendicular transects every 40 metres along the full length of Pukehina Beach to about 1500 metres south of the township (adjacent to the Urupa) - a total shoreline length of approximately 7.2kilometres (See Figures in Appendix A). At each transect, distances were measured from a shore parallel baseline to each of the historical shoreline positions. This data was then analysed to investigate the nature and magnitude of shoreline changes between the various surveys.

7.1.1 Trends in Shoreline Change

The change in spatially averaged shoreline position along the full length of Pukehina township (transects 11-143) is shown in Figure 29, and for the 1500 metres to the immediate south of the township in Figure 30. As the variation in shoreline position between these surveys is unknown, each date ("snapshot") is shown as an isolated point – rather than linked by a line.

Error bars shown were assessed according to the nature of each shoreline survey. The MHWM surveys were assessed at being up to 10 metres seaward of the duneline, while dunelines from shoreline surveys and aerial photographs are shown as ±5 metres (Figures 29 and 30). Errors may exceed these estimates in some cases but cannot be more adequately assessed from available information (see discussion in section 5.2).

It can be seen that the spatially-averaged shoreline position was relatively consistent at the time of the 1912 and 1949 surveys (Figure 29) – though the duneline may have been located up to 10 metres further landward at the time of either or both of these MHWM surveys.

A similar trend is evident over the approximately 1500 metres shoreline length to the immediate south of the township, with a relatively consistent, spatially-averaged shoreline position being evident in the surveys of 1912, 1943 and 1970 (Figure 30).

However, both shoreline areas show evidence of significant duneline erosion in the period to 1981 – averaging about 12 metres along the entire 5.3kilometres length fronting Pukehina and about 18.5 metres over the area to the immediate south (Figures 29 and 30).

It appears that most of the erosion evident in the period to 1981 occurred since 1970 (Figure 30).

Both areas also show evidence of duneline recovery in the period between 1981 and 1994, with some erosion being evident subsequent to that time along the front of the township - though the scale of the latter change is uncertain as the 2002 data is not continuous along the foreshore (Section 5.2).

The above trends are subject to some uncertainty, as evident in the error bars. However, the trends since the 1970's are consistent with other lines of evidence.
For instance, the severe erosion in the 1970's is consistent with Healy et al. (1977), who noted that the dunes in this area were faceted. It is also consistent with experience at many other east coast sites in the 1970's.

Similarly, the duneline recovery noted to 1994 is consistent with the beach profile data discussed in section 6, and with the resident observations of significant dune building during the last two decades reported by Abbott (2003). However, the interpretation of Abbott (2003) that this dune building is indicative of a long-term trend for accretion is not supported by the data (Figures 29 and 30). Rather, the data suggests the dune building relates to ongoing duneline recovery following the erosion of the 1970's. It has been widely noted that, after periods of significant erosion, dune recovery can require a decade or more (e.g. Morton *et al.,* 1994; Galgano *et al.,* 1998; Douglas *et al.,* 1998).

The apparent significance of the erosion over the last 30 years and the apparent lack of full duneline recovery (Figures 29 and 30) could be taken to suggest that there is also a trend for some net recession superimposed on the duneline fluctuations over this period. However, the uncertainties associated with the data are such that no definitive comment can be made on long-term trends from this information. Nonetheless, the sudden nature of the 1970's erosion (Figure 30) and the evidence of subsequent dune building and recovery tend to suggest the changes are primarily associated with decadal shoreline fluctuations.

Therefore, overall, it appears a reasonable assumption to ignore any contribution from long-term recession and assume that the observed shoreline changes primarily relate to duneline fluctuations associated with storm cut and recovery. This approach also ensures precautionary estimates of the storm cut that occurred between the surveys.

7.1.2 Maximum Duneline Fluctuations

Figure 31 shows the maximum duneline fluctuations recorded at each of the transects along Pukehina Beach. The changes are assumed to relate entirely to storm cut or recovery.

It can be seen that the fluctuations are generally less than about 25-30 metres.

However, larger fluctuations occur in the area nearest the tip of the spit (transect 1), adjacent to the entrance to Waihi Estuary. Like most estuary entrance spits, this area is subject to significant shoreline variation.

The other two locations where fluctuations exceed 25-30 metres (transect 70 and transects 143-149 inclusive – see Figure 31) appear to relate to errors in the plotting of the 1981 duneline. There was some wind erosion damage to the dunes at Pukehina in 1981 and it appears that the mapped shoreline occasionally followed the landward edge of dune blowouts and wind erosion, rather than the toe of the dune. As such, the line in many areas appears to lie landward of the actual dune toe. This procedure was probably adopted to highlight the hazard from wind erosion as well as coastal erosion. However, it complicates accurate assessment of duneline changes due to coastal erosion alone. Ideally, mapping of dunelines for the assessment of coastal erosion should focus on mapping the toe of the dune.

Detailed checking of the data suggests that most duneline changes in excess of about 23 metres relate to problems with the plotting of the 1981 duneline. Therefore, apart from the distal end of the spit, the maximum duneline fluctuations observed between the various surveys were probably less than 23 metres.

Interestingly, the maximum fluctuations recorded at the northern end of Pukehina Beach (i.e. transects 5-50) were generally less than 10-12, much less than those typically observed in other areas (Figure 31). However, further investigations and data would be required to confirm that this is generally the case and not just a function of this limited dataset.

Figure 32 presents a histogram showing the frequency of different magnitude duneline fluctuations. The erroneous data in excess of 25 metres was removed before preparation of the histogram. It can be seen that the most common shoreline fluctuations were in the range of 10-20 metres, with almost 50% of all duneline changes between the various surveys of this magnitude. Nonetheless, shoreline fluctuations of 20-23 metres were also relatively common, making up just fewer than 20% of all observed changes.

7.2 Waihi Beach

The available data on shoreline change at Waihi Beach (discussed in section 5.2) is complicated by various factors including uncertainties and inaccuracies associated with maps of historical shoreline changes, the influence of sea walls that constrain duneline erosion in the northern areas of the beach, the influence of stream entrances (particularly Two and Three-Mile Creeks) and the longshore extent of such influences.

Different authors have also questioned the meaning and reliability of much of the available data and past interpretations of this data have been the subject of debate (e.g. Healy, 1997, 2001a,b,c,d; Gibb, 2001).

Therefore, care is required in using and interpreting this information.

The approach adopted in this report has been to:

- Focus the analysis of trends along Shaw Road, which is an area where serious erosion has been experienced and there is good data available. The changes in this area are also less complicated by the influence of creek entrances, except for the southernmost 150-200 metres just north of Two Mile Creek. Further data would be required to assess trends in The Loop and Island View, though they appear broadly similar in areas removed from the influence of Two- and Three-Mile Creeks.

- Assess the nature and scale of shoreline changes over the last 100 years, placing emphasis on the least ambiguous elements of the existing database and attempting to crosscheck among the different lines of data available.

- Evaluate the relative role of shoreline fluctuations and long-term trends in these changes.

- On the basis of this analysis, assess the maximum-recorded storm-cut duneline erosion.

Where available data was adequately verifiable, the maximum-recorded storm-cut duneline erosion during individual storms or relatively short periods was also noted.

Initially, an analysis of changes along shore perpendicular transects was attempted (using data from Gibb, 1996). However, difficulties with the 1964 and subsequent dunelines (discussed in section 5.2.2) severely limited the usefulness of this analysis. More accurate mapping of historical duneline positions from available aerial photography would be required for this approach.

7.2.1 Shoreline Changes over Time

The earliest useful information on shoreline positions is the 1902 shoreline, this being either the duneline or a position further seaward (Collie, 2001). This shoreline was generally located only 2-3 metres seaward of the present day properties along Shaw Road, and lies slightly landward of present property boundaries at the northern end near Coronation Park (Drawings 10170-103&104; Harrison Grierson Ltd, Tauranga).

Over subsequent decades to 1951, the shoreline maps prepared by Collie (1996) suggest a general trend for duneline advance. This information is confirmed by available aerial photography. For instance, by early 1953, there was a frontal dune seaward of the properties along the full length of Shaw Road (Whites Aviation Photographs 31990 and 31993, January 1953) (Figure 33). This feature was typically 18-22 metres wide, though narrower (about 10-15 metres) over the southernmost 150 metres near Two Mile Creek entrance.

The seaward face of the frontal dune in these photographs is well vegetated and gently sloping, suggesting the previous few years had generally been characterised by dune building and advance rather than erosion.

Therefore, over the period from 1902 to 1953, there appears to have been a total duneline advance along Shaw Road of at least 20 metres – possibly 25-30 metres if the 1902 shoreline fix was seaward of the duneline at that time.

However, from about March 1954, the shoreline experienced a period of significant duneline erosion. By December 1955, only a narrow width (about 5-8 metres) of foredune remained at the southern end of Shaw Road (Whites Aviation Photo 40388). By early 1958, erosion had eliminated this feature and was impacting residential sections in southern and central areas of Shaw Road, with a variety of makeshift protection works already in place (Whites Aviation Photo 45536, April 1958). Therefore, there appears to have been at least 10metres of duneline retreat between January 1953 and December 1955 and a total of about 20 metres by April 1958.
The situation was slightly less severe further north on Shaw Road, where a narrow width of frontal dune still remained in April 1958 (Photo 45535). The Coronation Park duneline appeared largely unaffected.

The erosion appears to have been part of a general trend along east coast beaches - as a letter from the Minister of Marine to OCC (dated 3 October 1956) reported that there had been general erosion on the eastern coast beaches of the Coromandel and North Auckland Peninsulas "over the last year or so."

Further erosion was reported at various periods through to 1969, including a reported 8 metres of duneline retreat in a single storm in early June 1962, this erosion extending over a length of 160 metres to the immediate north of Two Mile Creek (Report from OCC County Engineer, dated to November 16, 1962).

In the Wahine Storm (Cyclone Giselle) of April 1968, various photographic evidence and reports indicate that the duneline was eroded by up to a further 5-9 metres along Shaw Road – affecting properties and some houses.

For instance, the Waihi Gazette of 18 April 1968 presents photographs of the erosion. At one house, located about 250 metres north of Two Mile Creek, the sea eroded back to the front edge of the house, undermining and destroying the chimney on the seaward side but not undermining the house. The paper also presents a photograph of the same house, looking alongshore after the May 1956 storm. At that time, the shoreline was about 6-8 metres seaward of the house. The house was also able to be identified in Whites Aviation photography from 1955, 1958 and 1962, and lay up to about 5-7 metres landward of the front property boundary at these dates.

Interestingly, in the 1962 photograph (Whites Aviation Photo 57185, April 1962), this house and others significantly affected during the Wahine storm appear to be located on a seaward protuberance of the shoreline, with part of this area protected by relatively light seawalls (e.g. Whites Aviation Photo 45536, April 1958). This protuberance appears to have been the area most severely eroded in the Wahine event.

The most serious erosion during the Wahine Storm occurred along the north side of a brick house protected by boulders. A photo of this house and associated damage reports in the Waihi Gazette of 18 April 1968 show erosion of at least 8-10 metres on the northern side of this house – leaving the house on a "peninsula" protected by rock according to the Waihi Gazette reports. It is probable that "end effects" associated with the rock wall exacerbated this erosion.

In other areas, the various available photographs and reports indicate that the maximum erosion in the Wahine storm appears to have extended up to 6-8 metres landward of the front property boundaries – indicating a total duneline retreat of up to 26-28 metres over the 15 year period from 1953 to 1968.

The Shaw Road areas eroded by the Wahine event were subsequently reinstated and protected by a seawall – this feature being extended to Coronation Park in 1969. The seawall has occasionally been damaged but has largely prevented further duneline erosion in central and southern areas of Shaw Road.

Overall, by the end of the Wahine Storm in April 1968, the worst affected properties (southern areas of Shaw Road) had experienced up to 25-30 metres of duneline retreat.

Various reports suggest much larger erosion. For instance, a letter from the OCC to the Ministry of Works dated 24 June 1968 notes: "*Where, previously, there was more than 150 feet of land between the sections and the sea this has almost totally disappeared and in many cases the erosion is right into the sections and undermining the houses.*" Similarly, a letter from the OCC County Engineer to a local property owner, dated 1 February 1972, noted that there was approximately "*2.5 chains* (about 50 metres) *of dune between the section boundaries and mean high water mark*" when this area of Shaw Road was subdivided in 1951. However, this is not consistent with the above-noted photographic data, which indicates that the duneline was, at most, about 18-22 metres seaward of the property boundaries prior to the erosion.

However, these early reports used the 1951 MHWM survey as a baseline to estimate the erosion. This line generally lies 45-55 metres seaward of the property boundaries along Shaw Road (Drawings 10170-103&104; Harrison Grierson Ltd, Tauranga). However, it is clear from the photographic evidence noted above that the duneline was only 18-20 metres seaward of the properties in the early 1950's. The 1951 MHWM fix appears to have been a position some 25-35 metres further seaward. Therefore, while the MHWM along Shaw Road may well have retreated by 50-60 metres between 1951 and 1968, the duneline retreat appears to have been of the order of 25-30 metres.

In summary, it appears that the duneline along Shaw Road advanced seaward by at least 20 metres between 1902 and 1953 and was eroded landward by up to 25-30 metres between 1954 and late 1968. Further erosion might also have occurred subsequent to 1968 had the area not been fixed by seawalls – though it is not possible to estimate the extent of this erosion. Estimating such erosion is also complicated by the fact that the seawalls were placed well seaward, being used to reclaim at least 5-10 metres of shoreline lost to erosion.

7.2.2 Implications for Storm Cut

It is difficult to reliably assess the relative contribution of storm cut and long-term recession to the duneline changes noted at Waihi Beach given the uncertainties associated with the available information on historic shorelines and the various factors complicating shoreline change at this site (e.g. creek outlets, seawalls).

Past assessments of long-term trends have been conducted, but there are significant questions in respect of the procedures and data used for this work. For instance, end point analysis (widely used in past work) is unlikely to yield reliable assessments of long-term trends at this site.

However, despite the difficulties with existing data, there are indications that decadal duneline fluctuations played a significant role in the changes noted between 1902 and 1969. In particular, the duneline erosion of 25-30 metres since 1954 appears to approximately balance progradation of at least 20 metres between 1902 and 1954.

In addition, the recorded shoreline positions may not show the maximum duneline changes that occurred. For instance, the 1902 "snapshot" may not have been the most landward duneline position in the late 1800's or early 1900's. Moreover, as noted in section 5.2, the duneline in 1902 may also have been landward of the line fixed by the 1902 survey. Therefore the duneline advance to 1953 may have exceeded 20 metres.

Similarly, additional duneline erosion may have occurred, if not for the seawalls placed along Shaw Road from 1962-1969.

There may also be a component of long-term recession in the historical changes since 1902. In other words, these changes may not be entirely attributable to shoreline fluctuations associated with storm cut and recovery. For instance, the fact that the duneline has not recovered to the positions observed in the early 1950's may indicate a contribution from long-term recession. This matter cannot be definitively resolved from the available data and would require more detailed work well beyond the scope of this study.

However, overall, the data tends to suggest that duneline fluctuations of 25-30 metres can occur over long periods of time, similar to the magnitude of extreme storm cut estimated in section 6.

7.2.3 Maximum Storm Cut During Individual Storm Events

There are historical reports of 6-12 metres of erosion during individual storm events in various OCC and MWD files and reports (e.g. see compilation of historical reports in Gibb, 1996a).

In most cases, it was difficult to check these estimates during the preparation of this report.

However, comparison of aerial photographs from December 1955 and April 1958 (Whites Aviation Photos 40388 and 45536) show evidence of severe erosion at the south end of Shaw Road between these photos, removing at least 8-10 metres and leading to landward relocation of several houses. This is consistent with the estimate of 8.5-10 metres of erosion in the May 1956 storm – reported by Gibb (1996a). However, storm cut in this area was almost certainly exacerbated by the influence of Two Mile Creek, as the affected area lies immediately north of the creek entrance. Moreover, at the time of the April 1958 photograph, the creek alignment discharged northwards towards these properties. There was also further erosion in this area in 1962, leading to installation of a 160 metres length of seawall (Report from OCC County Engineer, dated November 16 1962).

Other reports of up to 12 metres along Shaw Road in October 1958 storm (Gibb, 1996a) and loss of 12 metres from the frontage of southern Shaw Road properties during "one night" in 1961 (Mr Malcolm, OCC County Clerk, Report dated 16 July 1969) were not able to be confirmed by comparison of photos from 1958 and April 1962. However, the erosion may have been reinstated by the time of the 1962 photograph.

Overall, it appears that individual storm events eroded up to 10 metres in southern areas of Shaw Road, where Two Mile Creek exacerbated erosion. In other areas, the maximum duneline erosion able to be confirmed was the (up to) 6-8 metres noted during the Wahine event – though the worst affected area appears to have been a seaward protuberance before the storm.

7.2.4 Maximum Duneline Fluctuations: Island View to South End

Estimates of maximum decadal duneline fluctuations in this area are difficult as there is very little data on historic shoreline change.

However, analysis of the limited shoreline change maps available (Plan M697, Sheets 3 and 4, Bay of Plenty Regional Council) suggests very significant duneline erosion occurred between the surveys of 1944 and 1994 – commonly 30-50 metres and up to 62 (Figure 34). Unfortunately, the accuracy of the 1943 duneline is assessed at only ±20 metres (van der Vlugt, 1994) and therefore the changes are subject to some uncertainty. Further and more accurate mapping of historical shoreline positions is required to better assess shoreline changes. Nonetheless, even allowing for the uncertainties in plotting shoreline position, it is clear that very significant shoreline changes occur in this area.

The shoreline maps show the (undated) cadastral boundary as being very close to the surveyed duneline of 1994. This tends to suggest that the erosion between 1944 and 1994 returned the shoreline to a similar historic position. Therefore, decadal shoreline fluctuations may have played a significant role in the observed change – though the relative contribution of duneline fluctuations and long-term recession cannot be reliably assessed from the available data.

If duneline fluctuations of 40-60 metres do occur in this area, the shoreline movements clearly exceed the maximum storm cut estimates for this part of the beach (i.e. BOPCES 48 and 49 - Tables 7 and 8). This would not be surprising as the deep arcuate duneline embayments in this area (Harray, 1977; Stephens, 1996) would be expected to exacerbate shoreline changes associated with storm cut and recovery.

At the southern end of the beach, the ebb tide delta is also an additional factor influencing the magnitude of shoreline fluctuations.

Given the limited available data and associated uncertainties, this study is not able to usefully refine the maximum shoreline fluctuations estimated for this area by Healy (1993; 2001) and Gibb (1994) (Table 1).

8 Discussion

This section uses the results from the preceding chapters to consider the various questions in the brief.

8.1 50 and 100-year Return Period Storm Cut Erosion

It is evident from the preceding analysis that extreme storm cut erosion of the duneline generally cumulates over a period of several years; with much more limited erosion tending to occur during individual events – reflecting the duration-limited nature of extreme coastal storms in the Bay of Plenty.

There is also some evidence that the most extreme storm cut erosion occurs during periods with a higher frequency of severe storm events. Periods with a lower frequency of severe storms appear to be generally characterised by duneline recovery. The historical periods in which duneline erosion has dominated at Waihi and Pukehina and the periods characterised by a trend for duneline recovery appear to broadly coincide with La Nina and El Nino dominated periods of the IPO, respectively, as postulated by de Lange (2001).

In some places, decadal duneline fluctuations also appear to be significantly influenced by factors in addition to storm cut and recovery, including duneline embayments, stream entrances and ebb tide deltas.

8.1.1 Pukehina Beach

Estimates of the maximum likely 50-year and 100-year return period storm cut erosion of the main foredune average 25 metres and 30 metres, respectively. The estimates obtained were very consistent, despite using beach profile data from different sites and different extreme erosion profiles.

The estimates appear to be reasonably precautionary as they exceed the largest storm cut erosion of the main foredune noted at any of the beach profile sites (i.e. 21.5 metres) and the maximum changes (<23 metres) observed between various historical shoreline surveys dating from 1912.

They are also consistent with previous estimates by Healy (1993) and Gibb (1994) (see section 3).

8.1.2 Waihi Beach

The assessment of storm cut at Waihi Beach is considerably complicated by a lack of accurate and reliable historical data (particularly in central and southern areas of the beach), significant data uncertainties, and the influence of existing seawalls, creek entrances, arcuate duneline embayments and (at the southern end of the beach) the adjacent ebb tide delta.

However, estimates of the maximum likely storm cut were able to be made using a simple storm cut model and beach profile data, cross-checked against recorded shoreline changes from various sources. These estimates suggest a maximum likely storm cut duneline erosion of 25 metres (50-year return period) and 30 metres (100-

year return period), except in those areas where the shoreline is held several metres seaward of the natural duneline position by seawalls (e.g. Shaw Road, The Loop). In these latter areas, estimates of the maximum likely storm cut range from 30-35 metres for the 50-year return period erosion and 35-40 metres for the 100-year return period event.

In the beach areas south of Island View, the estimated 100-year return period and 50-year storm cuts are considerably less than historical shoreline changes in this area. This probably reflects the influence of factors in addition to storm cut and recovery – including arcuate duneline embayments and, at the southern end of the beach, the ebb tide delta. There may also be a long-term trend for duneline recession in this area (Healy, 1993). The existing data is not adequate to enable any useful revision of earlier estimates of duneline fluctuations in this area.

At the northern end of the beach, in areas removed from the influence of the various stream entrances, the estimates of the 100-year return period and 50 year storm cut exceed the maximum-recorded shoreline erosion and appear to be reasonably precautionary estimates.

8.1.3 Summary

The available data suggests that 25 metres and 30 metres respectively are reasonable but precautionary estimates of the maximum likely 100-year return period and 50-year storm cut duneline erosion at Pukehina Beach and the areas of Waihi Beach north of Island View.

However, the warning given by Healy (1999c) is relevant in considering maximum storm cut "… it is not possible to predict … the precise storm cut of a given storm or how frequently severe storms will occur, and their effects".

I concur with this view and note that storm cut erosion more severe than the above estimates may occur. For instance, during very rare and severe events (>100-year return period) or where storm cut is locally aggravated by features such as rips, stream entrances, or ebb tide deltas.

Therefore, while the above estimates are appropriate for the management of development in the existing subdivisions, a factor of safety of 1.5 should be applied to estimate storm cut for any Greenfields' subdivisions.

The implications of the storm cut estimates for development setbacks at these locations are discussed in section 8.3 below.

8.2 Dune Stability Factor

The considerations outlined in section 6.1.6 suggest that the present dune stability factor for Pukehina Beach can probably be further refined and may ultimately be able to be reduced by about 50%.

However, geotechnical investigations are first required to investigate the potential impact of loading (i.e. due to a house) on this factor. The existing precautionary estimates should be retained until this work has been completed.

8.3 Implications for 15-metre Development Setback

8.3.1 Comment on the Setback

At present, new or proposed development within the Primary Protection Zone of the District Plan at Waihi and Pukehina beaches is required to be set back at least 15 metres from the toe of dune.

The review of existing information in this report suggests that this setback is significantly less than the maximum likely storm cut erosion at both sites.

WBOPDC staff advise that this measure is not intended to provide for hazard avoidance. Nonetheless, there is a risk that continued application of the 15-metre setback will necessitate the relocation of dwellings within their expected design life, or lead to property owner pressure for the placement of shoreline armouring or other works to protect them. Existing armouring works have significant adverse environmental effects (Gibb, 1996a) and actions that may lead to pressure for further such works are not compatible with either the New Zealand Coastal Policy Statement or the Regional Coastal Plan for the Bay of Plenty.

8.3.2 Options for Improved Development Setbacks

Ideally, a development setback applied to existing subdivisions, such as those at Waihi and Pukehina Beaches, will provide appropriate protection from potential storm cut erosion and associated dune face instability, while also enabling reasonable use of existing private property.

For instance, the Primary Development Setback adopted for the coast of the Eastern Coromandel (Dahm and Munro, 2002) is designed to protect dwellings from the maximum erosion likely to be associated with existing coastal processes. A Secondary Setback zone defines the additional area that may be impacted to 2100 with changes likely to accompany projected climate change.

Further work would be required to properly refine the existing development setbacks for Waihi and Pukehina. For instance, further geotechnical work is required before the dune safety factor can be refined. Similarly, additional and more accurate mapping of historical shorelines and other complementary work would be required to better estimate any existing long-term trends for recession at both sites (or to confirm that no such trends currently exist).

Nonetheless, the scale of the development setbacks likely to be required to provide protection from storm cut erosion and dune instability can be broadly estimated and are briefly discussed in the following sections.

Pukehina Beach

At Pukehina, a minimum setback sufficient to provide protection from the maximum likely 100-year return period storm cut and subsequent dune face instability is likely to be of the order of 35-40 metres, depending on dune height and the degree to which the dune safety factor is able to be further refined.

Further work would be required to adequately define the most appropriate baseline for this setback. However, approximate plotting of this setback, using an aerial photo enlargement provided by Environment Bay of Plenty with historical shorelines superimposed, suggests the setback would generally extend about 12-15 metres into existing properties. In general, this would leave at least 25-30 metres section-depth further landward – providing adequate space for reasonably substantial dwellings.

Given the very contentious nature of such setbacks, it is strongly advised that any revision of the existing 15-metre measure be developed and refined in close discussion with property owners. This will not avoid controversy but, in my experience, it offers the best opportunity to achieve a satisfactory outcome without expensive litigation. It also provides useful opportunity for the community to have input into decisions that will significantly affect their property and interests, and ensures that their knowledge and experience (often extending over several decades) can be utilised in formulating a more appropriate setback.

Waihi Beach

At Waihi, the situation is more complicated.

It is possible that the existing armouring works will be maintained and upgraded to provide improved hazard mitigation – lessening the need for reliance on an adequate development setback. However, the existing works have severe adverse environmental effects (Gibb, 1996) and an appropriate long-term solution has not yet been developed and consented for this area. Therefore, at this point in time, it is probably inappropriate to assume that shoreline armouring works will always be present – requiring more emphasis to be placed on development setbacks for hazard mitigation. However, given the development that has already been consented in these areas, user expectations have probably been encouraged that will lead to significant opposition to any increase in setback.

In Shaw Road, the minimum setback required to provide for 100-year return period storm cut and dune instability will probably be of the order of 35-40 metres, possibly higher within 100-150 metres of Two Mile Creek. Similar requirements would probably apply for The Loop and Island View.

Setbacks of this magnitude, as measured from the existing seawalls, may not be practicable as they may preclude reasonable use of existing properties – given the close proximity of these properties to the sea.

On the basis of existing development, the maximum setback likely to be practicable may only be of the order of 25-30 metres – as measured from the existing seawalls. A setback of this magnitude, while not providing full protection, would however provide reasonable protection for erosion up to and including the 50-year return period storm cut in most areas.

However, as the setback does not provide full protection, it would have to be complemented by other measures. It is beyond the scope of this project to define the details the details of such a strategy - though there are a number of options that may be practical.

8.4 Implications for 8-metre Relocation Trigger

At present, many building consents require a dwelling to be relocated if erosion reaches within 8 metres of the structure. The rationale for this trigger is unknown but is presumably to ensure the house is relocated before it can be undermined and damaged. If so, it is important that the setback provides reasonable protection from the maximum erosion that may occur during a single storm event.

At Pukehina, the maximum erosion of the dune toe noted over periods of up to 4-6 months ranged from 6-12 metres. However, this erosion largely affected incipient dune features (Figure 11) and usually involved the seaward face of the main frontal dune (on which houses are located), which generally experienced less than 5 metres of retreat (see Figures 17 and 18). At Waihi, the duneline erosion associated with individual storm events also appears to have been less than 8 metres, except in areas close to stream entrances (see discussion in section 7.2).

Therefore, the data considered in this report suggests that the trigger should provide sufficient buffer for the erosion likely to occur during many single storm erosion events.

However, there is considerable uncertainty associated with the measure.

For instance, there are unconfirmed reports of up to 12 metres of duneline erosion at Waihi during individual events (Gibb, 1996a). There is also potential for severe erosion in excess of 8 metres to occur at both sites given a storm of sufficient severity and duration. For instance, numerical modelling of 2% AEP storm cut at Papamoa noted the potential for duneline cut of up to 12-15 metres at some sites (e.g. Figure 30, Tonkin and Taylor, 2001).

Problems may also be experienced with the trigger at sites with high dunes, due to a combination of storm erosion and subsequent dune face collapse (Figure 3). For instance, the dune face collapse alone may be sufficient to threaten a house on sites with dune heights in excess of 8 metres. There are also localised circumstances where the buffer may prove to be inadequate, such as areas in close vicinity to stream or estuary entrances or rip-head embayments.

Unfortunately, given the relatively short length of the beach profile record and questions about the representativeness of the existing data (section 5), it is not possible to reliably estimate the maximum storm cut (i.e. 50 or 100-year return period) erosion likely to occur with individual storm events.

Dangers of extrapolating from a relatively short and non-representative period are well illustrated by the 100-year storm cut estimates developed at Papamoa - for both individual storm events and multiple-storm events over periods of 3-4 months (Smith, 1999). These estimates (6-metre and 8-metre retreats at RL 3.5 metres, respectively) were exceeded by the short-term changes noted at Pukehina during this study (Table 3, section 6). Nonetheless, the procedure that Smith (1999) pioneered may provide a useful approach for estimating the maximum storm cut associated with individual events once improved data is available.

In summary, while the 8-metre trigger probably provides sufficient buffer to accommodate duneline retreat during many individual storm events, there is potential for erosion to exceed this buffer in a single event. As such, there are considerable uncertainties associated with the measure. In other words, the trigger may prove inadequate to protect dwellings in some situations.

Given these uncertainties and the difficulties in estimating a more appropriate trigger, hazard mitigation should place emphasis on ensuring a reasonable development setback, rather than relying on a relocation trigger.

It is also recommended that:

- Where a trigger is used, it should be measured from the upper edge of the dune face erosion scarp and not from the dune toe. This will provide a measure of additional security.

- Building permits issued on the basis of a relocation trigger should clearly warn property owners that this measure may not provide adequate warning or protection for their dwelling in the event of serious storm erosion.

8.5 Implications for Existing Setbacks

The estimates of the 100-year return period storm cut erosion recommended by this review are the same as those used by Healy (1993) in derivation of the hazard setback recommendations at Pukehina and slightly higher than used at Waihi.

It has also been recommended that the precautionary estimates of the dune safety factor recommended by Healy (1993; 2001) not be further refined until appropriate geotechnical investigations have been completed.

This investigation did not review the other elements of the setback – such as long-term recession rates and the potential impact of projected sea level rise.

Overall, the implications of this study for the existing setbacks defined by Healy (1993) are minor and no revision in the width of the overall hazard zone is recommended. However, such revision may (or may not) be warranted by any future review of the other elements of the hazard zone not considered in this study.

However, as discussed in section 8.3, revision of the development setback is appropriate.

8.6 Implications for Beach Monitoring

It is strongly recommended that increased emphasis be given to pre and post-storm surveys - to improve estimates of the beach and dune erosion associated with storm cut events. This data will ultimately prove extremely valuable in refining estimates of storm cut.

If necessary, these pre and post-storm surveys could be restricted to a few key sites to meet cost and resourcing constraints. These sites should be focused in key management areas – such as Waihi, Papamoa, Pukehina and Ohope.

Given the potential for several days warning prior to major cyclonic events, consideration should also be given to conducting pre-storm surveys "on spec" – particularly for large cyclones. The post-storm surveys should be conducted as soon as practicable after major storms – preferably within 1-2 days so that good resolution of the post-storm beach cut profile is obtained. If there is too much delay in conducting the post-storm surveys, beach recovery will occur and the value of the survey will be diminished.

Opportunities for obtaining pre and post-storm measurements are rare, particularly in respect of major events, and every effort should be made to monitor the impact of such events. It is clear from this study that storm cut poses by far the most immediate erosion threat to sites such as Waihi and Pukehina. Improved information on this aspect is critical to the design of effective and appropriate solutions for erosion hazard. Good information is also critical to ensure that setbacks can be defined with increasing accuracy, avoiding unnecessary restrictions on the use of private property.

In terms of the frequency of other surveys, a 3-monthly spacing is probably adequate for the definition of duneline changes – as relatively little dune recovery is likely within such periods. It is recognised that cost constraints will preclude this frequency of surveys for most sites, but ideally this frequency should be achieved for important management sites such as Waihi and Pukehina.

It is also recommended that further beach profile sites be established along the seaward margins of Waihi and Pukehina townships to improve understanding of storm cut in these areas. More detail is required in these areas. At Waihi, it is recommended that there should be at least 3-4 sites along Shaw Road; including one site relatively close to Two Mile Creek to better quantify the influence of the creek on storm cut. Similarly, two further sites should be established along the Loop – probably midway between site 50 and Two- and Three-Mile Creeks. Two sites should also be established at Island View – one relatively close to three Mile Creek and the other further removed. This increased density would greatly assist in improving understanding of the complex storm cut changes in this high priority management area. It is also recommended that at least 3 further sites be introduced along the frontage of Pukehina Township – to increase the density of sites in this area.

As beach profiles monitor only a limited portion of lengthy beach systems, the maximum duneline changes in any particular period almost certainly occur between, rather than at, the profiles. Therefore, it is strongly recommended that Environment Bay of Plenty continue to conduct dune toe surveys along the length of the coast until other technologies that provide more comprehensive information (e.g. LIDAR) are more readily available and cost-effective.

In periods with widespread duneline erosion, serious consideration should be given to conducting these duneline surveys on a more frequent basis – perhaps once every two years. If resourcing constraints are an issue, the more frequent surveys could be limited to those shorelines fronting existing settlements and the dynamic area of Waihi Beach from Island View to the southern end.

The recommended changes to the monitoring programme are relatively significant and costly. However, the changes will considerably improve the understanding of storm cut at these sites and significantly assist in the development and implementation of more effective hazard management measures. In view of the importance of this data to more effective management of hazard risk at Waihi and Pukehina, it is recommended that Environment Bay of Plenty and Western Bay of Plenty District Council develop a partnership approach to the coastal monitoring so that the increased level of monitoring will be practicable.

9 Conclusions and Recommendations

9.1 Purpose and Objectives of Report

Eco Nomos Ltd were engaged by Environment Bay of Plenty to review existing information and assess maximum storm-cut erosion for Waihi and Pukehina beaches, to assist in developing defensible setback distances for storm erosion at these sites.
The particular objectives of the study included:

- Review available data and make a defensible assessment of the maximum expected 50-year and 100-year return period storm cut erosion for Waihi and Pukehina beaches.
- Review the existing 15-metre development setback and the 8m-development relocation trigger and, if appropriate, provide revised recommendations.
- Review the existing dune instability factor, particularly at Pukehina Beach and provide recommendations that allow for variations in dune height.
- Identify the implications of the revised estimates for existing coastal hazard setbacks at Waihi and Pukehina beaches.
- Identify implications for beach monitoring, including any appropriate recommendations that will assist in improving estimates of coastal erosion.

9.2 Methodology and Data

The report uses the following two procedures to develop reasonable, but precautionary estimates of the 50 and 100-year return period storm cut duneline erosion:

- Assessment of the maximum-recorded storm cut evident in available data at both sites.
- Application of the simple geometrical model developed by Komar et al. (1997; 1999) to develop the 50 and 100-year design estimates - using field data from each of the beaches for the various parameters required.

The methodology involved careful attention to data limitations, any apparent survey or datum irregularities, and any evidence of long-term trends or other factors besides storm cut that may have influenced the recorded duneline changes.

Information used included beach profile data, maps of historical shoreline positions, reports on historical storms from management agency files and newspapers, community observations, historical photographs and field inspections.

The data provides detailed information on beach profile changes over the last 10-15 years at both sites, reasonable information on duneline changes at Waihi Beach since 1954, and snapshots of shoreline changes at both sites dating back 90-100 years.

9.3 Results – Analysis of Beach Profile Data

9.3.1 Recorded Duneline Erosion

The analysis of the beach profiles concluded that:

- There were a small number of generally minor datum irregularities in the beach profile data. These did not affect the usefulness of the information for this study (see section 6 for more detailed discussion) but the archived data should be corrected.

- Most of the beach and duneline changes appear to be associated with storm-cut and/or recovery, rather than long-term trends for recession or progradation.

- While best-fit regression lines applied to volume change data suggest a trend for net erosion at many sites, these trends are not statistically significant.

- The data shows a common trend for duneline erosion in the 1970's, duneline recovery from the late 1970's to the early 1990's, and more recently, duneline erosion.

- Maximum-recorded storm cut erosion of the dune toe ranged from 14.5-29 metres at Pukehina and from 6.5-24 metres at Waihi. However, maximum erosion of the seaward face of the main frontal dune was typically less than 10 metres.

- Maximum storm cut duneline erosion cumulated over a period of many years, rather than occurring during either a single storm or a close succession of storms.

- The maximum duneline erosion during individual events or periods of less than a few months ranged from 6.5-12 metres at Pukehina. This short-term erosion typically had only limited impact (<5 metres of erosion) on the seaward face of the main foredune.

9.3.2 Estimates of Extreme Storm Cut using Beach Profile Data

Estimation of the maximum likely storm cut, conducted using the procedure of Komar et al. (1997; 1999) and data from severely eroded storm cut profiles, concluded:

- The maximum likely 100-year return period storm cut duneline erosion at both sites is about 30 metres and the 50-year return period erosion about 25 metres, with reference to the seaward toe of the main frontal dune. These estimates were very consistent, despite using data from different beach profile sites and storm dates.
- The only notable exception occurred at sea walled areas of Waihi Beach, where the estimates were typically 7-10 metres higher - reflecting the seawalls holding the shoreline seaward of the natural duneline and/or exacerbating storm cut erosion of the adjacent beach.

- Estimates of storm cut measured with respect to the most seaward recorded position of the dune toe (often the toe of an incipient dune seaward of the main dune) showed less consistency than distances measured from the most seaward toe of the main frontal dune – suggesting the latter is a more useful baseline.

9.4 Analysis of Other Data on Historical Shoreline Changes

9.4.1 Pukehina Beach

Analysis of data for this site concluded that:

- Most shoreline changes over the period from 1902 to 2002 appear to have been associated with duneline fluctuations related to storm cut and recovery.

- Further, more accurate mapping of historical shoreline changes would be required to definitively assess if there is also a trend for long-term duneline recession.

- The maximum-recorded duneline fluctuations were less than 23 metres, most commonly 10-20 metres, except at the distal end of Pukehina Spit.

9.4.2 Waihi Beach

The analysis of historical changes, which focused on shoreline trends along Shaw Road where serious erosion has been experienced and there is good data available, concluded that:

- The duneline along Shaw Road advanced seaward by at least 20 metres between 1902 and 1953 and was eroded landward by up to 25-30 metres between 1954 and late 1968.

- Historical reports that suggest greater duneline erosion (about 50 metres) over the period between 1954 and late 1969 appear to have used the 1951 MHWM survey (located well seaward of the duneline) as a baseline – resulting in over-estimates of duneline erosion.

- It is difficult to reliably assess the relative contribution of storm cut and long-term recession to the duneline changes. However, there are indications that decadal duneline fluctuations were probably the primary component.

- Maximum duneline erosion of 6-10 metres appears to have occurred during individual storm events, particularly in areas close to Two Mile Creek and during the Wahine storm of April 1968. There are reports of up to 12 metre-duneline retreats during individual storms but these were not able to be confirmed using available data.

In the area of Waihi Beach to the south of Island View, available data is limited and subject to significant uncertainties but suggests that:

- Duneline fluctuations considerably exceed the scale of changes likely to be associated with storm cut and recovery.

- The larger fluctuations evident in this area probably reflect the additional influence of deep, arcuate duneline embayments and (at the southern end of the beach) the adjacent Bowentown ebb tide delta.

9.5 50 and 100-year Return Period Storm Cut Erosion

The major conclusions arising from the analysis are:

- The accurate assessment of any long-term trends for recession at both sites requires more accurate mapping of historical duneline changes.

- Nonetheless, over periods of up to 50 years, storm cut appears to pose the major threat to existing property and development at both Waihi and Pukehina beaches.

- The severity of storm cut erosion at these beaches is determined by many factors, including extreme water levels, storm wave characteristics, storm duration, antecedent beach condition, sediment characteristics and local factors such as stream entrances and ebb tide deltas.

- In some places, decadal duneline fluctuations are significantly influenced by factors in addition to storm cut and recovery; including arcuate duneline embayments, stream entrances and ebb tide deltas.

- Extreme storm cut erosion of the duneline generally cumulates over a period of several years at both Pukehina and Waihi beaches, with more limited erosion typically associated with individual events. This probably reflects the duration-limited nature of extreme coastal storms in the Bay of Plenty.

- Estimates of the maximum likely 50 and 100-year return period storm cut erosion (with respect to the most seaward toe of the main frontal dune) average 25 metres and 30 metres, respectively. These estimates appear to be reasonably precautionary storm cut estimates for Pukehina Beach and for areas of Waihi Beach north of Island View, except sea walled areas and locations close to stream entrances.

- In sea walled areas of Waihi Beach to the north of Island View, the maximum likely storm cut duneline erosion ranges from 30-35 metres (50-year return period erosion) and 35-40 metres (10-year return period erosion) – measured with respect to the existing seawalls.

- The existing data is not adequate to enable any useful revision of earlier estimates of duneline fluctuations in the area south of Island View.

- Rare and extreme storm cut erosion (i.e. >100-year return period) may exceed the above estimates but they appear to be reasonably precautionary for the management of dwellings in areas of existing development. A safety factor of 1.5 should be applied in utilising the figures to estimate setbacks for Greenfields' subdivision.

9.6 Dune Stability Factor

The existing dune stability factor at Pukehina is relatively precautionary and there is potential for this factor to be refined, possibly reducing the value by more than 50%. Opportunities to refine the parameter are outlined in the text.

However, it is recommended that geotechnical investigations first be conducted to assess the effect of loading on slope stability before the existing precautionary assessment is refined and reduced - to ensure that an adequate factor of safety is retained in any future refinement. Existing values should be retained in the interim.

9.7 Implications for the 15-metre Development Setback

The report concludes that this setback is significantly less than the maximum likely storm cut erosion at both beaches and does not provide adequate protection from either the maximum likely 50-year or 100-year return period duneline erosion. WBOPDC staff advise that the setback is not intended to provide for hazard avoidance.

An increased setback sufficient to provide protection from the maximum likely 100-year return period storm cut and subsequent dune face instability appears likely to be practical at Pukehina.

A lesser standard of protection (50-year) may have to be adopted at Waihi to avoid precluding reasonable use of existing sections. Therefore, development setbacks at this site will need to be complemented by other appropriate measures.

It is strongly advised that any revision of the existing 15-metre setback be developed and refined in close liaison with WBOPDC, property owners and the wider community at both sites.

9.8 Implications for the 8-metre Relocation Trigger

The rationale behind the 8m-relocation trigger is unknown, but it is presumed that the measure is intended to provide a sufficient buffer to protect dwellings from the maximum erosion likely to occur with individual storm events: i.e. to ensure that dwellings are relocated before being exposed to risk of serious damage.

If so, the measure has to allow for the maximum storm cut and dune face adjustment likely to occur with individual events.

The analysis concludes that there are significant uncertainties in regard to this measure and it may not provide adequate protection from erosion during severe, long-duration storm events.

Given these uncertainties and the difficulties in estimating a more appropriate trigger, it is suggested that hazard mitigation should place emphasis on ensuring a reasonable development setback, rather than relying on a relocation trigger.

Where the trigger is used, it should be measured from the upper edge of the dune face erosion scarp and not from the dune toe. Any building permits issued on the basis of a relocation trigger should also clearly warn property owners that this measure may not be adequate to protect their dwelling in the event of serious storm erosion.

9.9 Implications for Healy Setbacks

The estimates of the 100-year return period storm cut erosion recommended by this review are similar to the figures used by Healy (1993; 2001) in derivation of the hazard setback recommendations at Pukehina and the areas north of Island View at Waihi. Moreover, the dune safety factor adopted in those studies is retained until further geotechnical assessment has been completed.

Therefore, the implications for the overall setbacks are minor (changes of less than < 5-7 metres) and no revision in the width of the total coastal hazard zone is recommended at this point in time.

This investigation did not review the other elements (long term trends and potential impacts of projected climate change) of Dr Healy's recommended setbacks.

9.10 Implications for Beach Monitoring

It is recommended that a 3-monthly frequency for beach profile surveys is adequate for the definition of maximum duneline retreat associated with storm cut.

However, it is recommended that greater focus be given to pre and post-storm surveys to improve estimates of storm cut erosion, and that additional sites be established along the font of existing settlements – particularly the sea-walled area of Waihi Beach.

As beach profiles monitor only a limited portion of lengthy beach systems, the maximum duneline changes in any particular period almost certainly occur between, rather than at, the profiles. Therefore, it is recommended that dune toe surveys along the length of the coast be continued and that consideration be given to conducting these surveys at a higher frequency during periods of erosion – particularly in the vicinity of subdivisions like Pukehina and Waihi.

It is recommended that Environment Bay of Plenty and Western Bay of Plenty develop a joint partnership approach to address monitoring requirements as improved information on storm cut is critical to the management of coastal subdivision at both Pukehina and Waihi.

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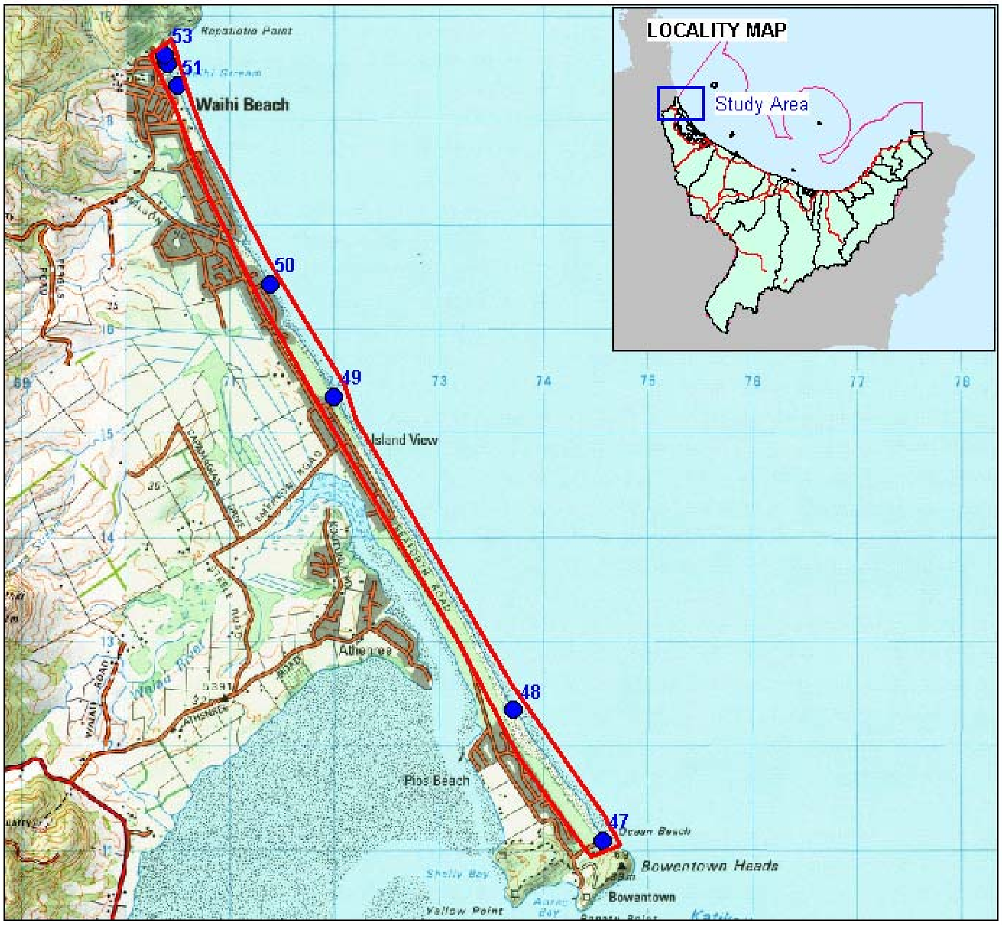
List of Figures

Location of Waihi Beach storm cut dune erosion study area



Disclaimer

This map shows the approximate location of bores and consents within the selected area. Bore data is supplied to Environment Bay of Plenty by third parties and therefore Environment Bay of Plenty takes no responsibility for the accuracy of this informat

Legend

- Study Area
- EBOP Coastal Profile Site

Environment Bay of Plenty REGIONAL COUNCIL

Figure 1: Location of Waihi Beach and Environment Bay of Plenty coastal profile monitoring sites.

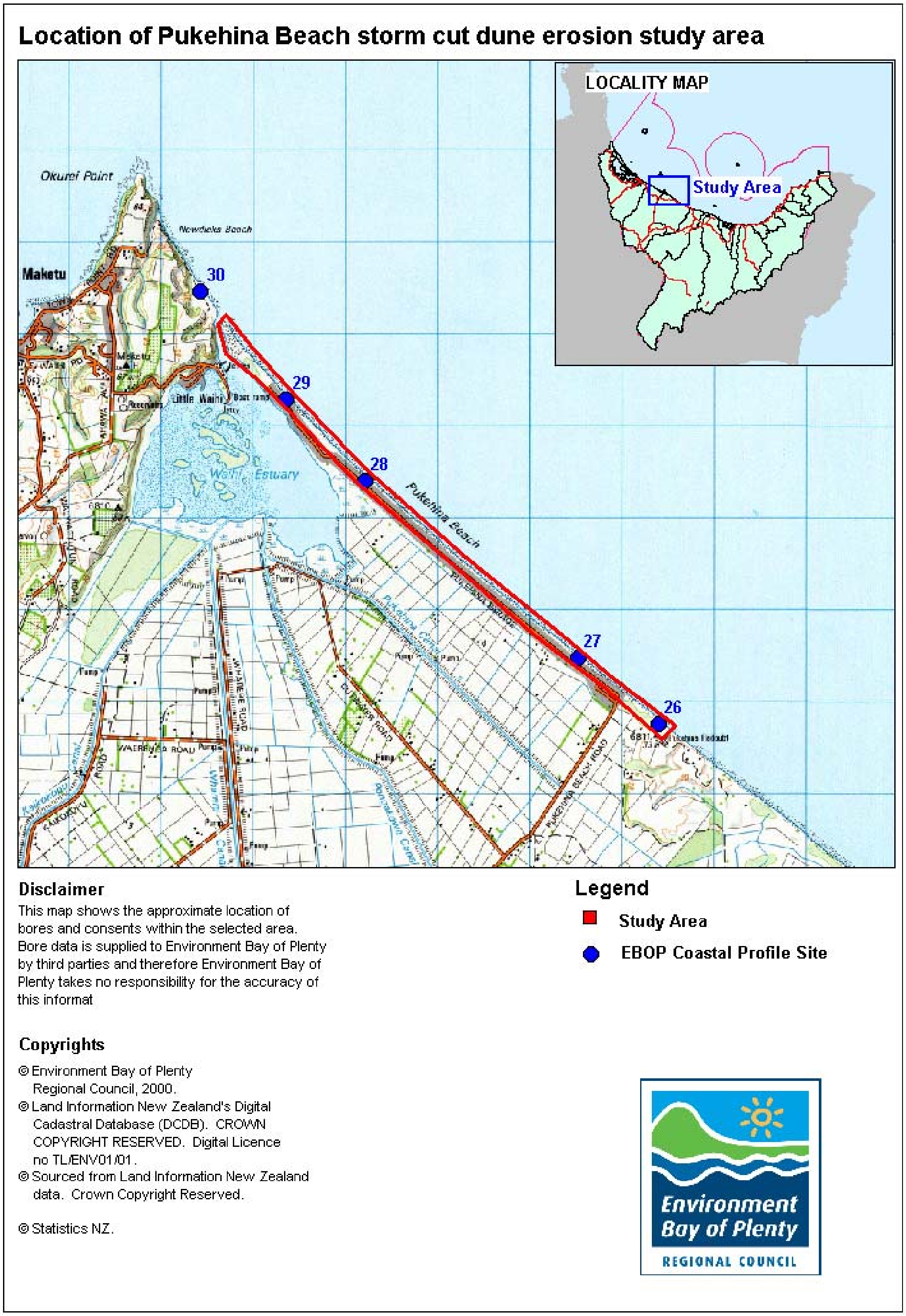


Figure 2: Location of Pukehina Beach and Environment Bay of Plenty coastal profile monitoring sites.

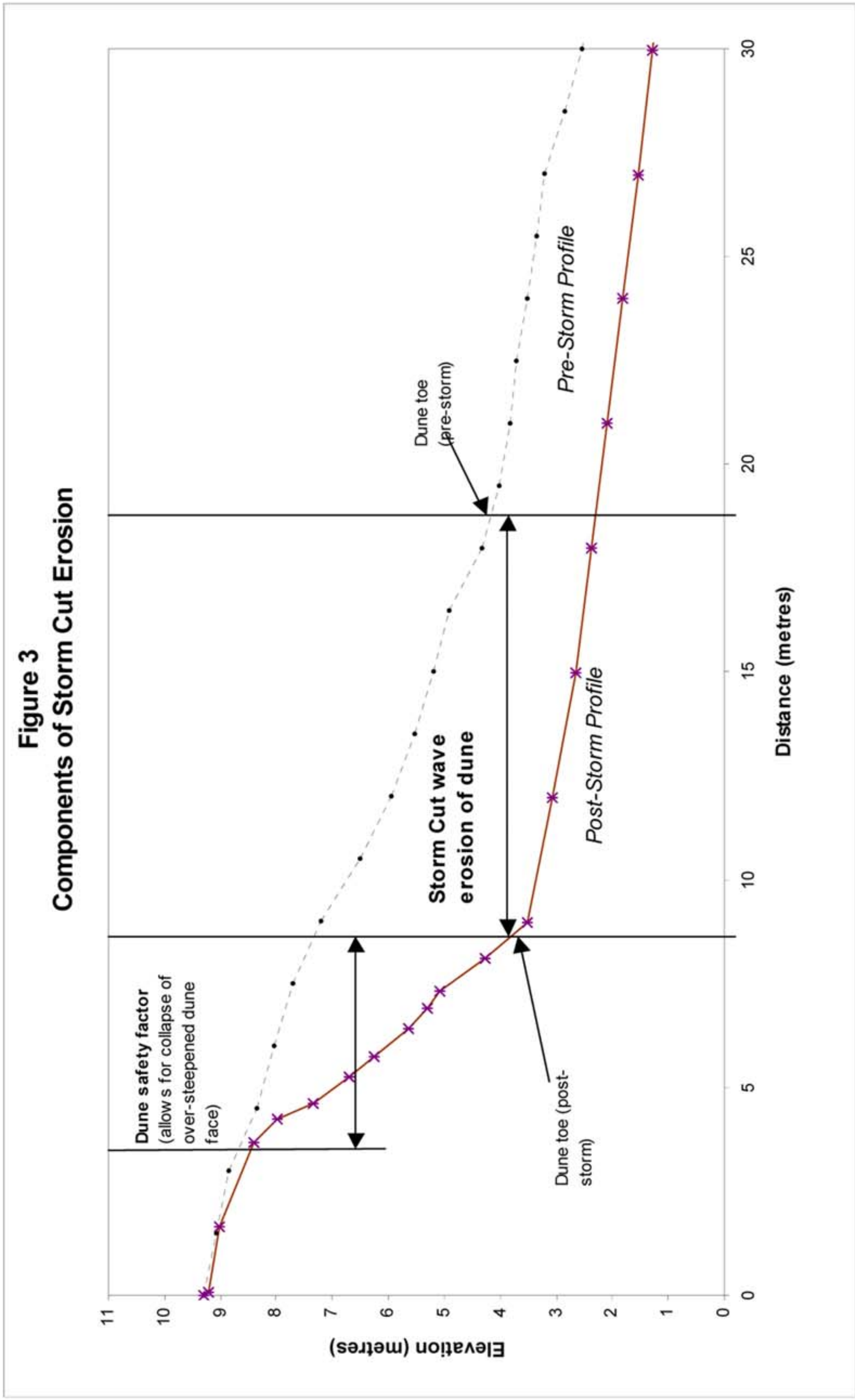


Figure 3
Components of Storm Cut Erosion
Elevation (metres)
Distance (metres)
0
1
2
3
4
5
6
7
8
9
10
11
0
5
10
15
20
25
30
Dune safety factor
(allow s for collapse of
over-steepened dune
face)
Storm Cut wave
e rosion of dune
Dune toe
(pre-storm)
Dune toe (post-
storm)
Pre-Storm Profile
Post-Storm Profile

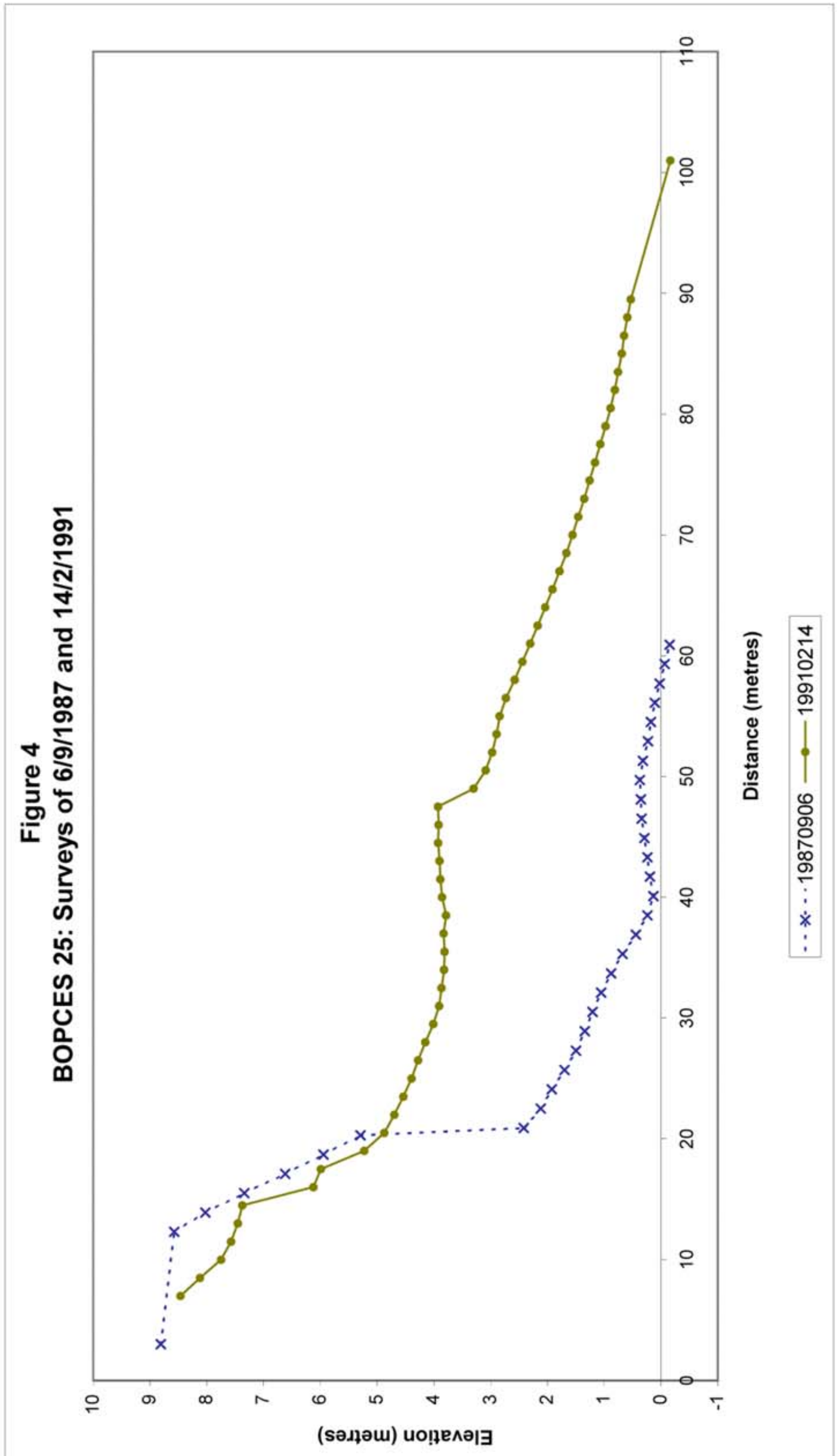


Figure 4
BOPCES 25: Surveys of 6/9/1987 and 14/2/1991
Elevation (metres)
10
9
8
7
6
5
4
3
2
1
0
-1
Distance (metres)
0
10
20
30
40
50
60
70
80
90
100
110
19870906
19910214

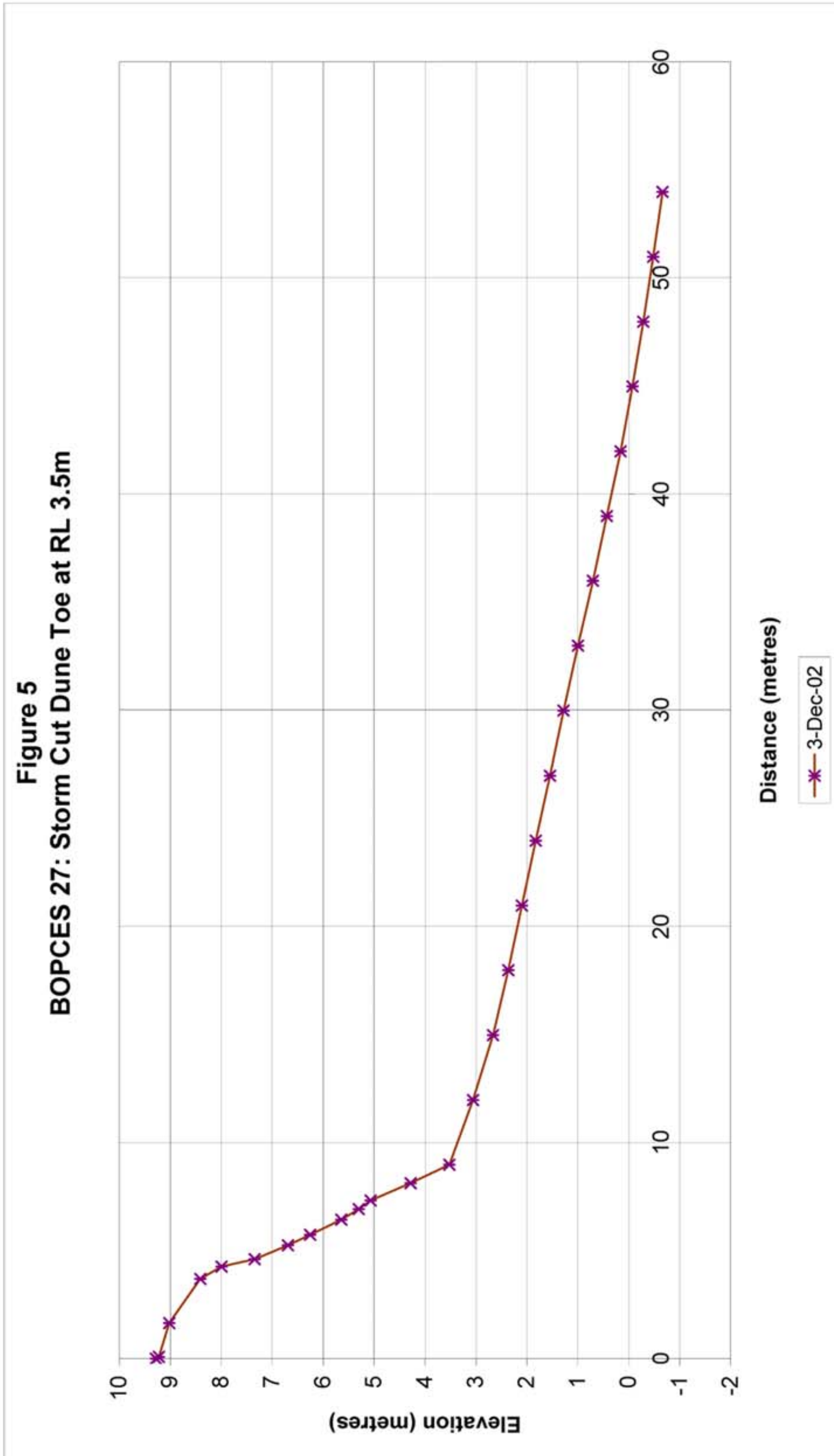


Figure 5
BOPCES 27: Storm Cut Dune Toe at RL 3.5m
Elevation (metres)
Distance (metres)
3-Dec-02
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60

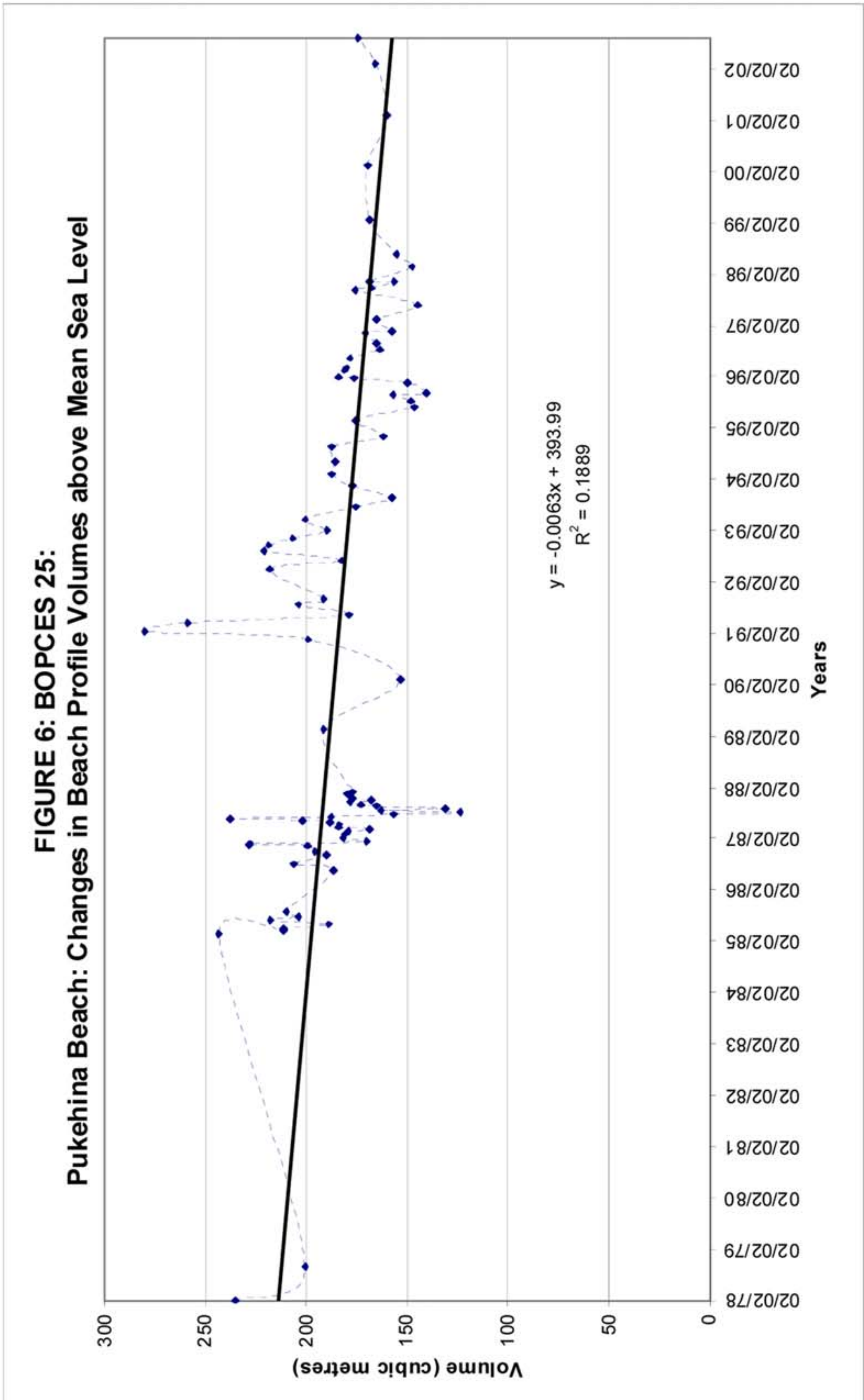


FIGURE 6: BOPCES 25:
Pukehina Beach: Changes in Beach Profile Volumes above Mean Sea Level
Volume (cubic metres)
Years
y = -0.0063x + 393.99
R2 = 0.1889
0
50
100
150
200
250
300
02/02/78
02/02/79
02/02/80
02/02/81
02/02/82
02/02/83
02/02/84
02/02/85
02/02/86
02/02/87
02/02/88
02/02/89
02/02/90
02/02/91
02/02/92
02/02/93
02/02/94
02/02/95
02/02/96
02/02/97
02/02/98
02/02/99
02/02/00
02/02/01
02/02/02

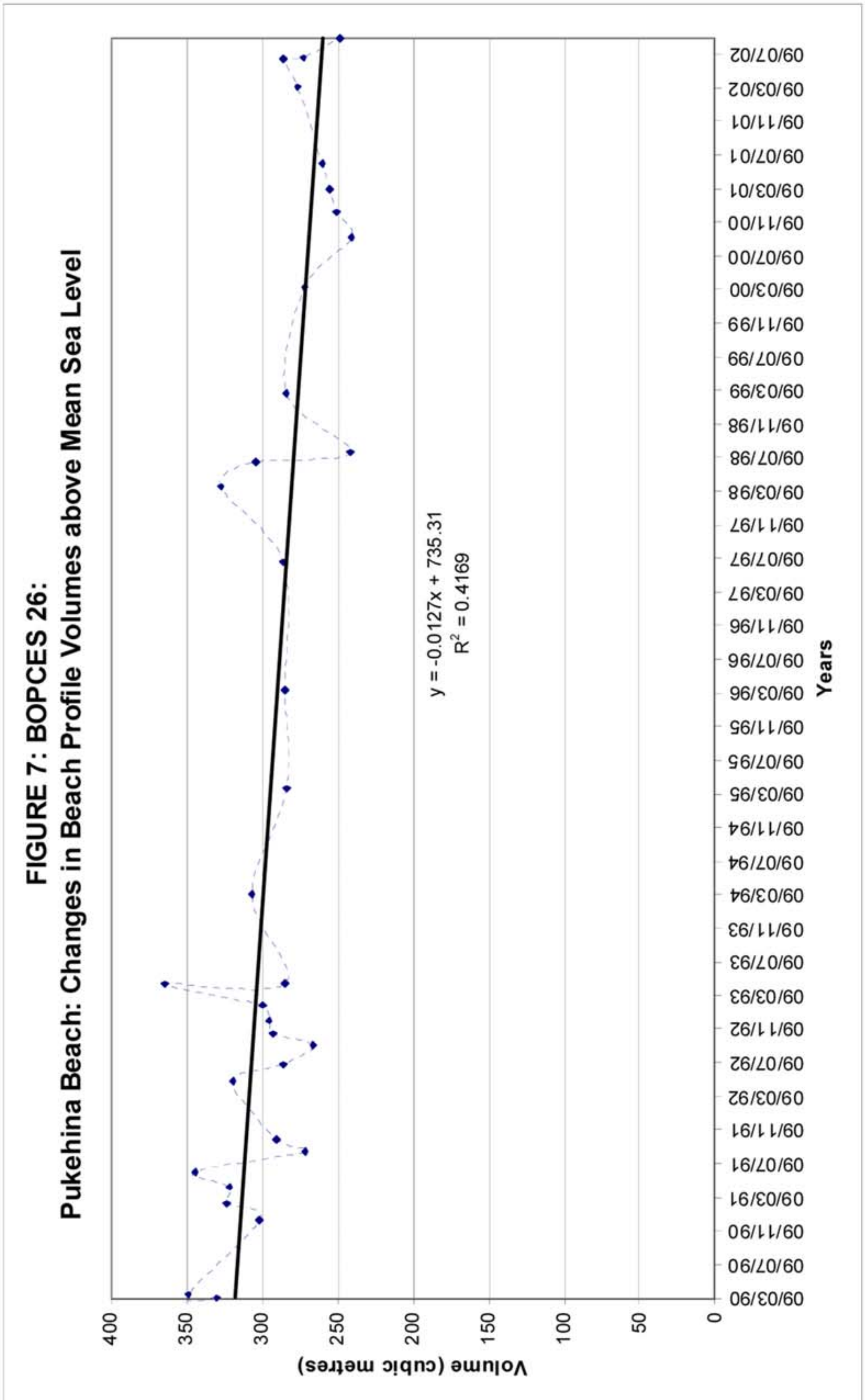


FIGURE 7: BOPCES 26:
Pukehina Beach: Changes in Beach Profile Volumes above Mean Sea Level

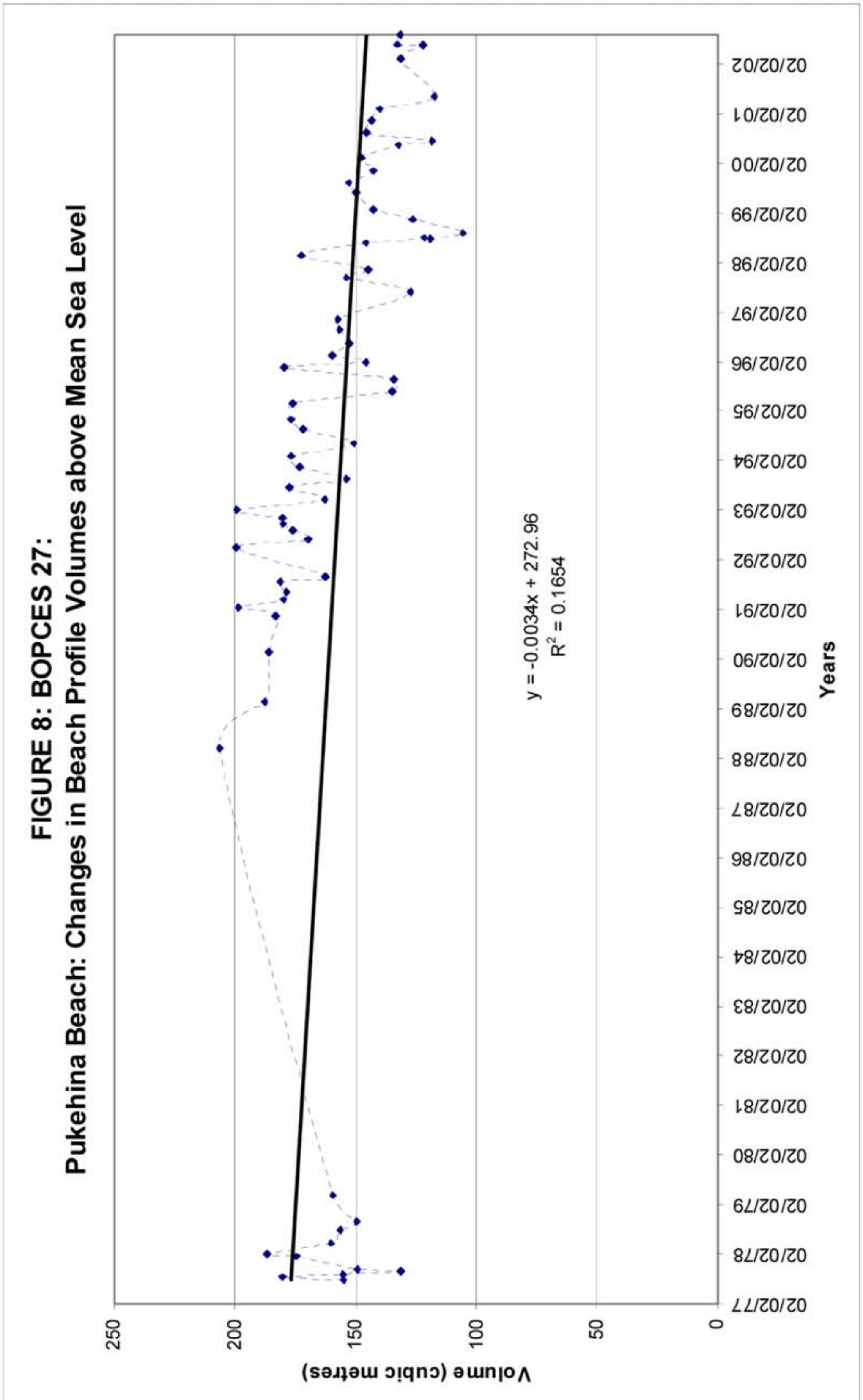


FIGURE 8: BOPCES 27:
Pukehina Beach: Changes in Beach Profile Volumes above Mean Sea Level
Volume (cubic metres)
250
200
150
100
50
0
02/02/77
02/02/78
02/02/79
02/02/80
02/02/81
02/02/82
02/02/83
02/02/84
02/02/85
02/02/86
02/02/87
02/02/88
02/02/89
02/02/90
02/02/91
02/02/92
02/02/93
02/02/94
02/02/95
02/02/96
02/02/97
02/02/98
02/02/99
02/02/00
02/02/01
02/02/02
Years
y = -0.0034x + 272.96
R^2 = 0.1654

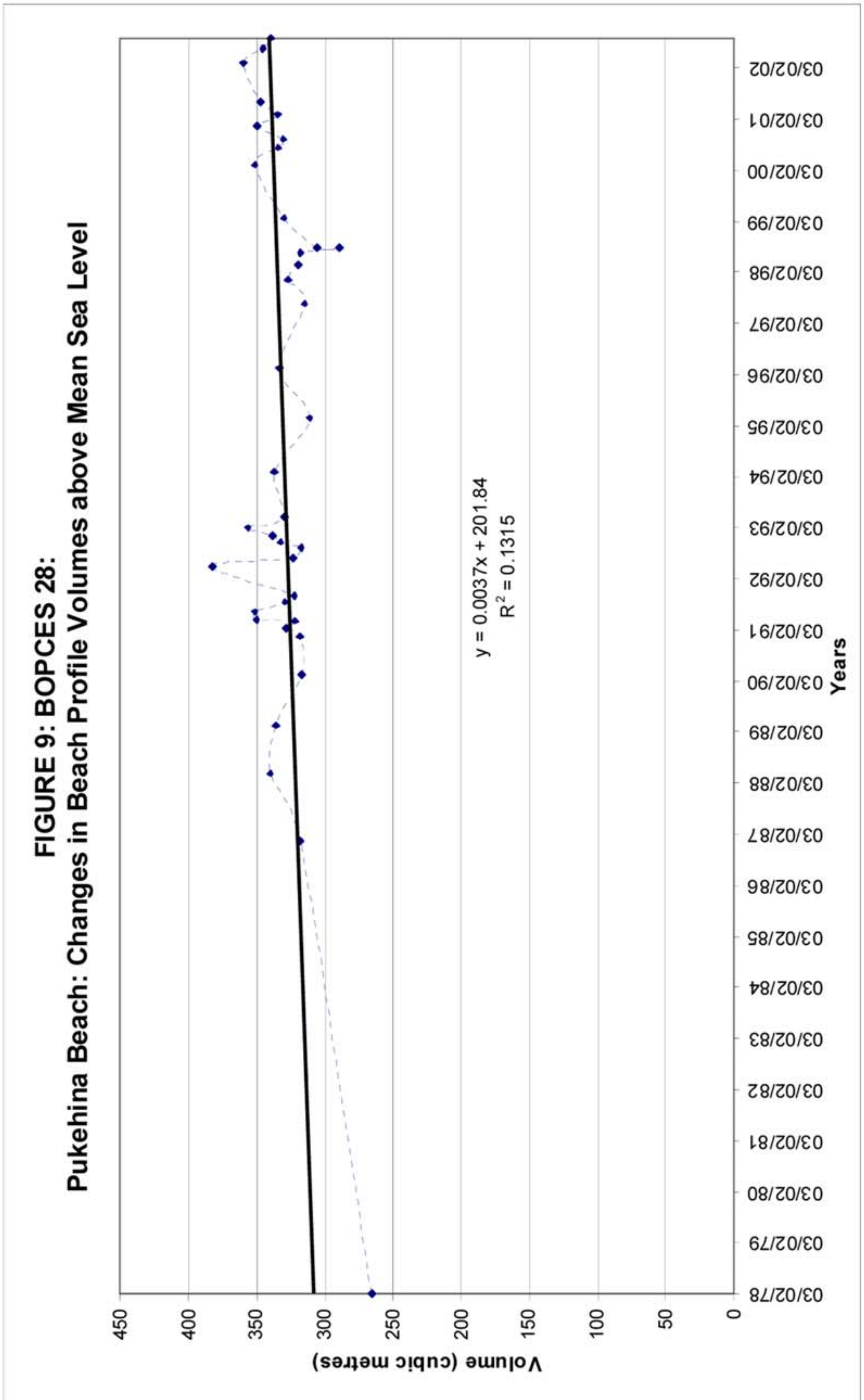


FIGURE 9: BOPCES 28:
Pukehina Beach: Changes in Beach Profile Volumes above Mean Sea Level
Volume (cubic metres)
450
400
350
300
250
200
150
100
50
0
03/02/78
03/02/79
03/02/80
03/02/81
03/02/82
03/02/83
03/02/84
03/02/85
03/02/86
03/02/87
03/02/88
03/02/89
03/02/90
03/02/91
03/02/92
03/02/93
03/02/94
03/02/95
03/02/96
03/02/97
03/02/98
03/02/99
03/02/00
03/02/01
03/02/02
Years
y = 0.0037x + 201.84
R2 = 0.1315

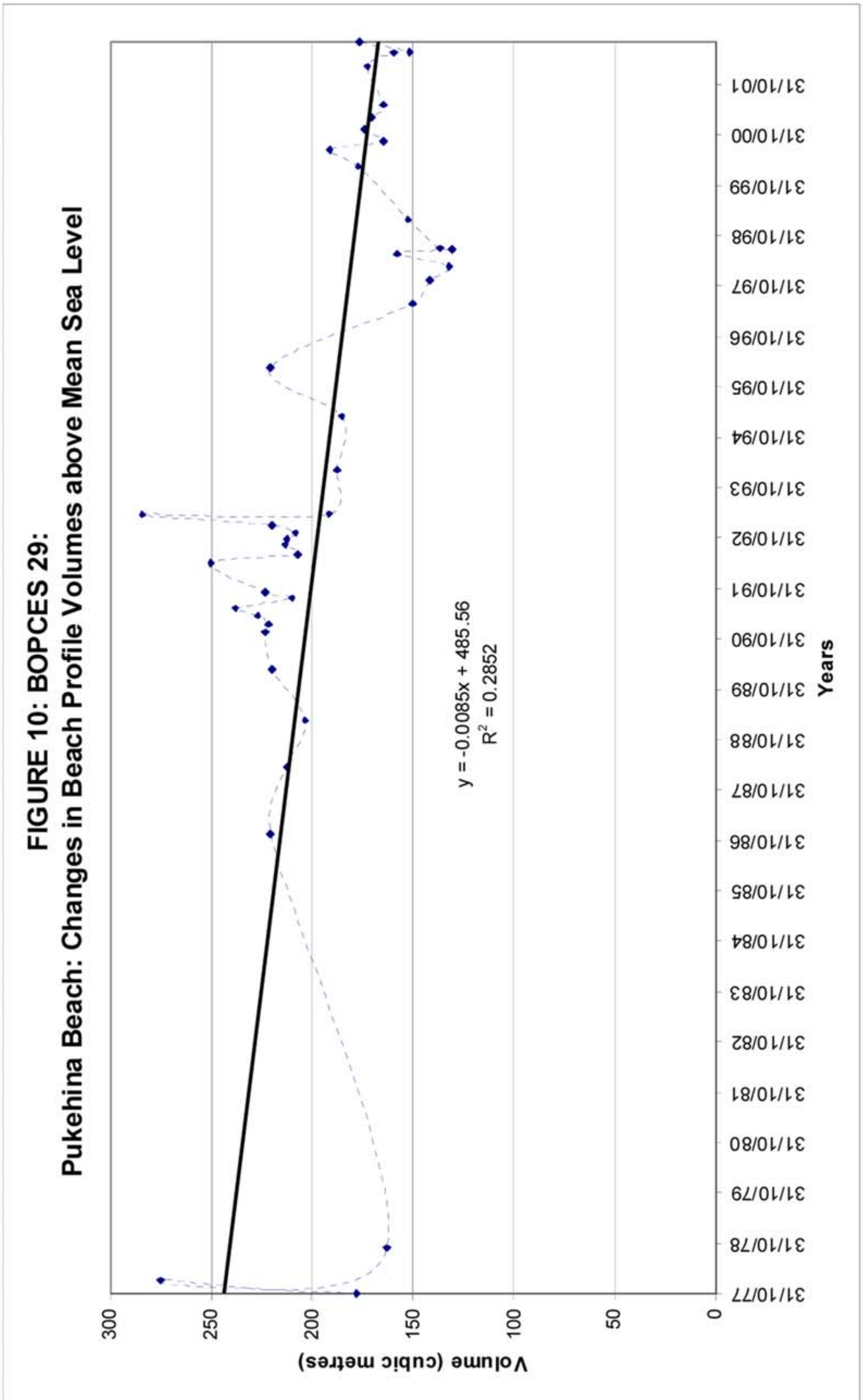


FIGURE 10: BOPCES 29:
Pukehina Beach: Changes in Beach Profile Volumes above Mean Sea Level
y = -0.0085x + 485.56
R2 = 0.2852
Volume (cubic metres)
Years
300
250
200
150
100
50
0
31/10/77
31/10/78
31/10/79
31/10/80
31/10/81
31/10/82
31/10/83
31/10/84
31/10/85
31/10/86
31/10/87
31/10/88
31/10/89
31/10/90
31/10/91
31/10/92
31/10/93
31/10/94
31/10/95
31/10/96
31/10/97
31/10/98
31/10/99
31/10/00
31/10/01

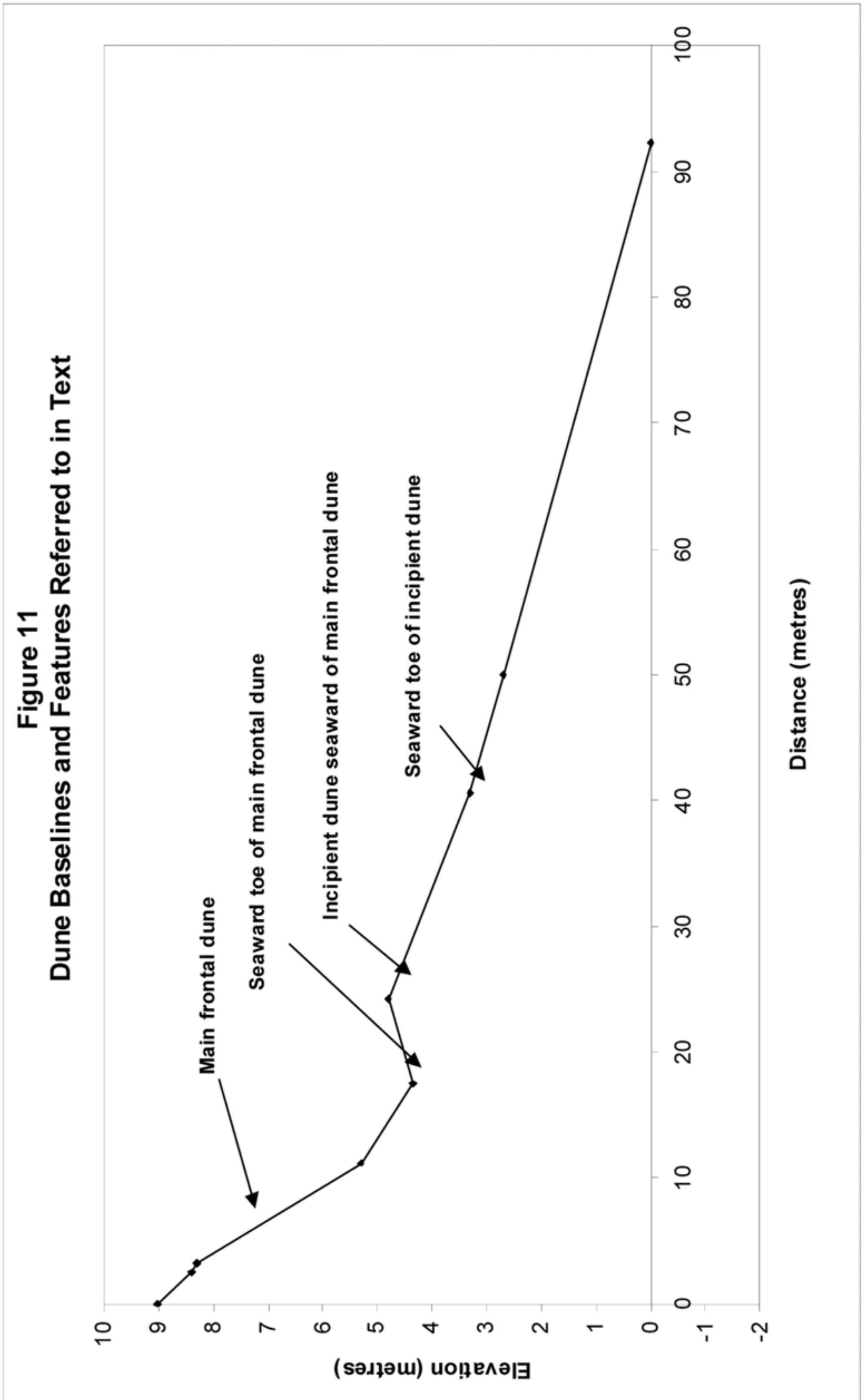


Figure 11
Dune Baselines and Features Referred to in Text

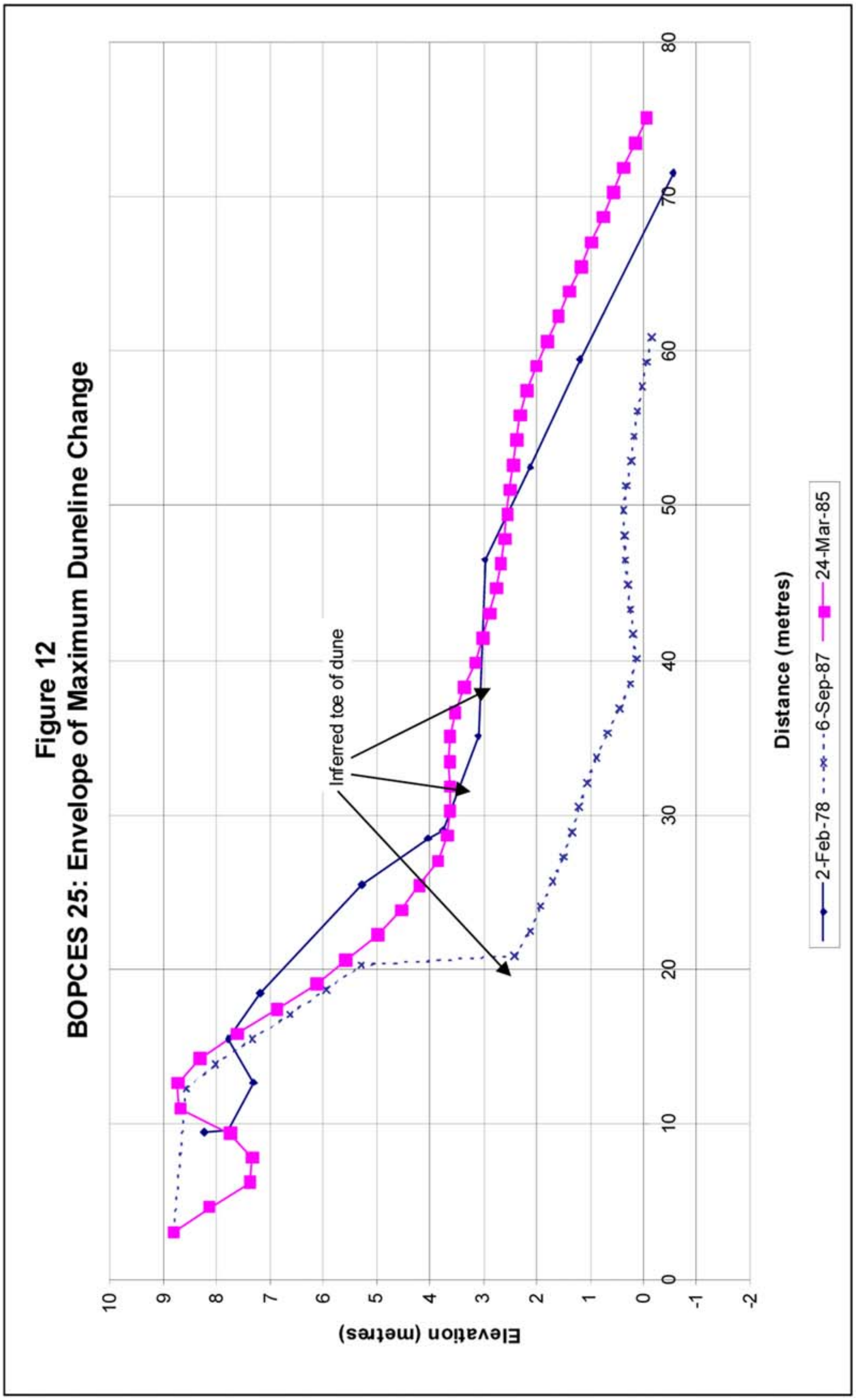


Figure 12
BOPCES 25: Envelope of Maximum Duneline Change
Inferred toe of dune
Elevation (metres)
Distance (metres)
2-Feb-78
6-Sep-87
24-Mar-85

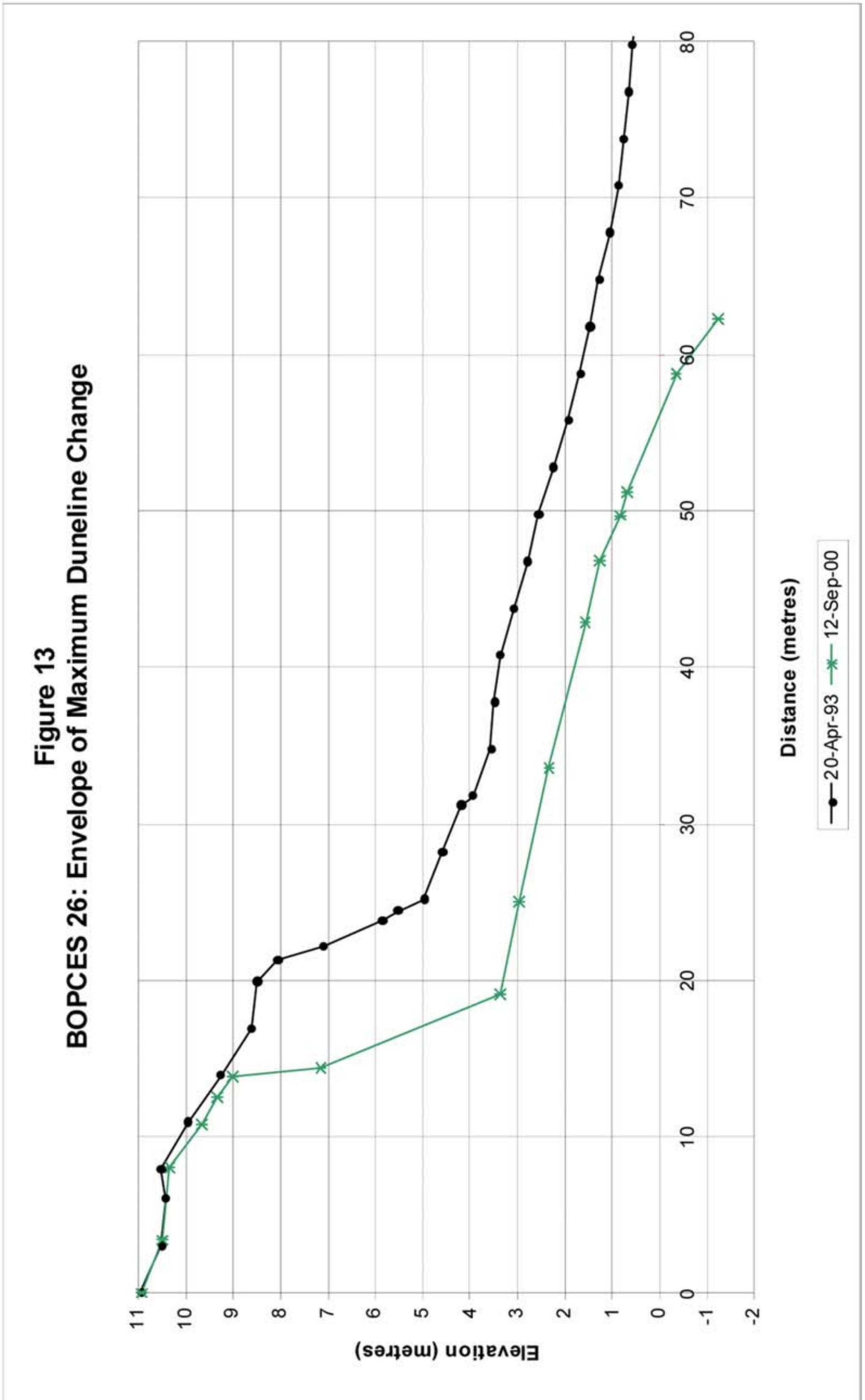


Figure 13
BOPCES 26: Envelope of Maximum Duneline Change
Elevation (metres)
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
Distance (metres)
20-Apr-93
12-Sep-00

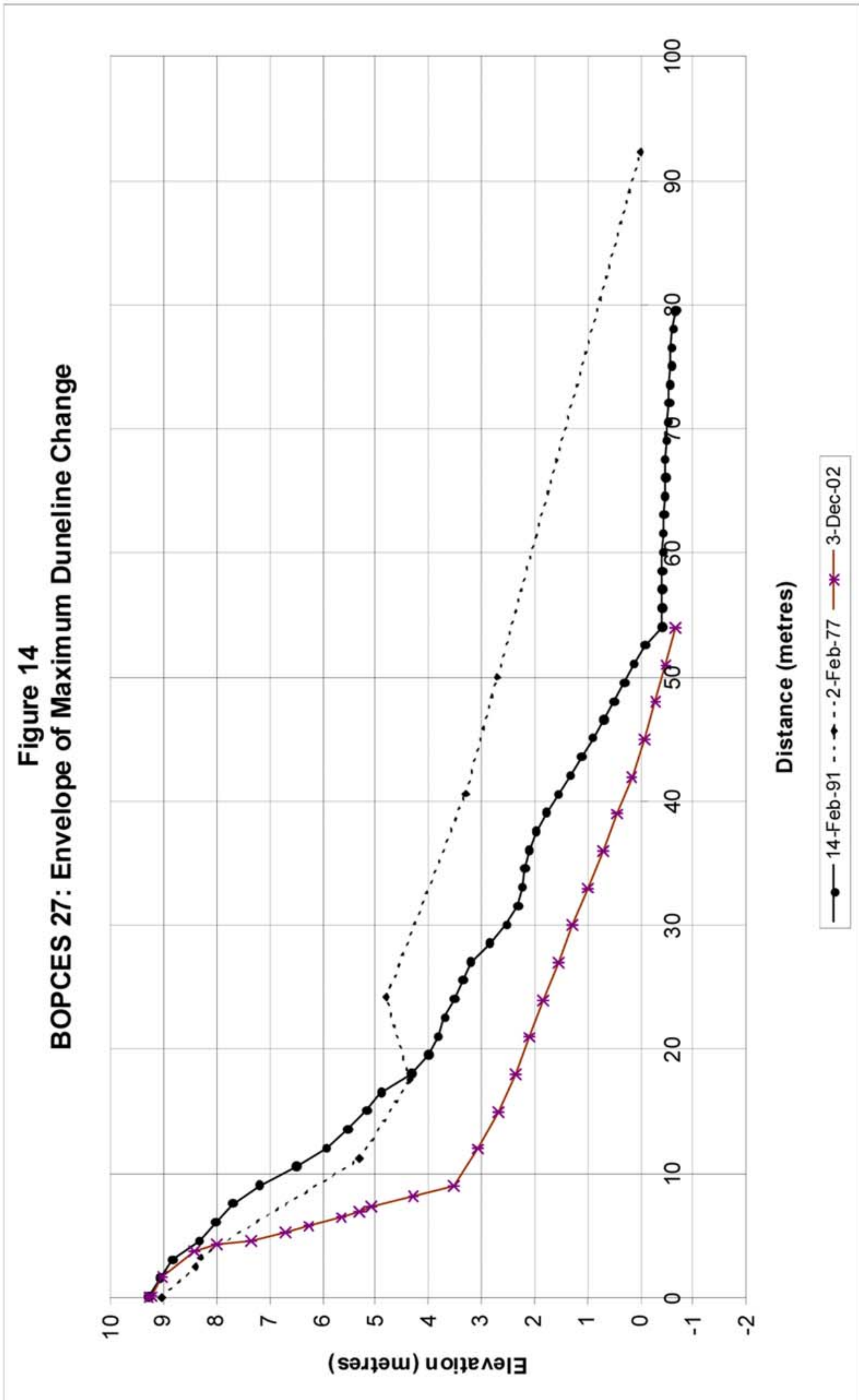


Figure 14
BOPCES 27: Envelope of Maximum Duneline Change
Elevation (metres)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
Distance (metres)
0
10
20
30
40
50
60
70
80
90
100
14-Feb-91
2-Feb-77
3-Dec-02

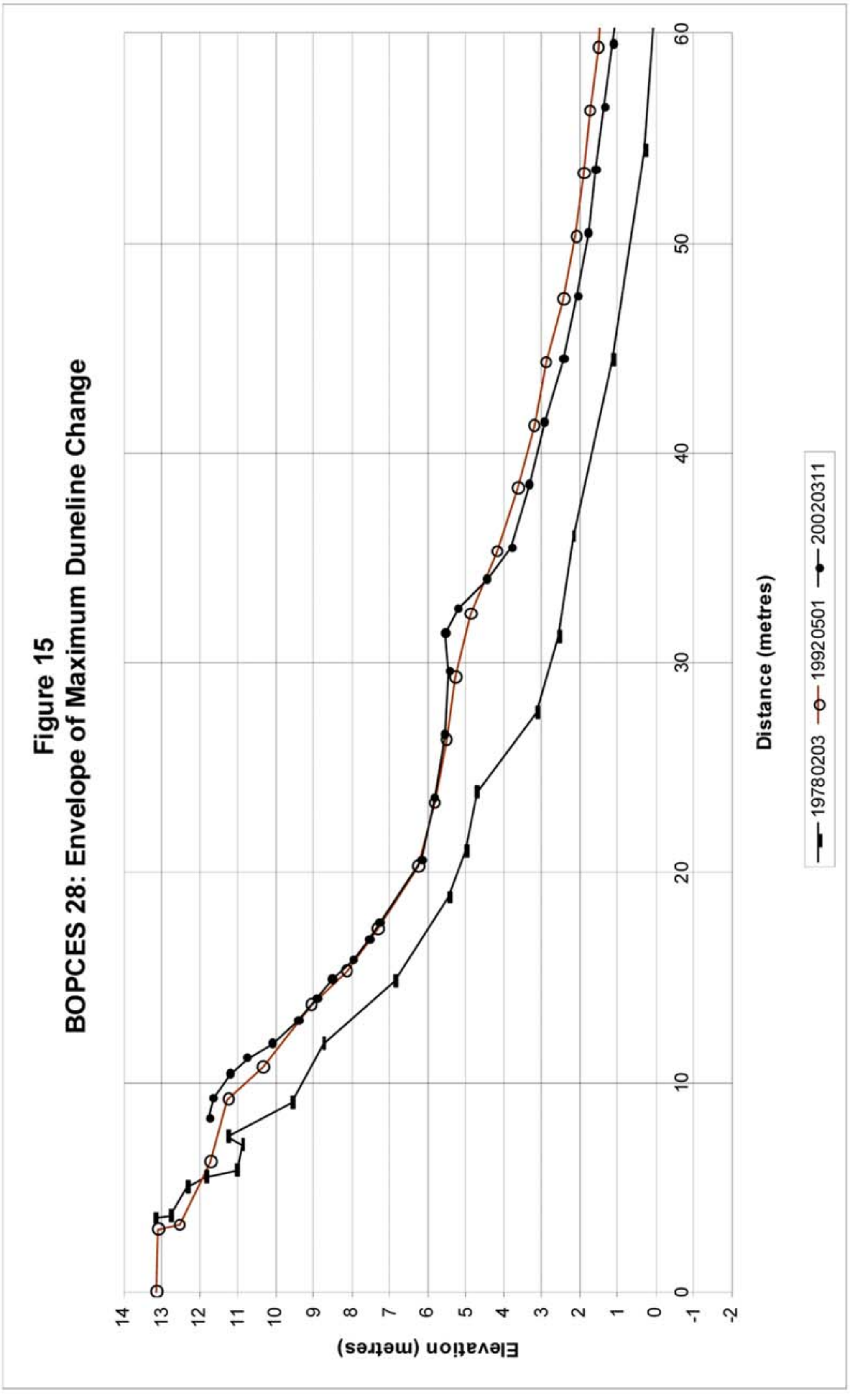


Figure 15
BOPCES 28: Envelope of Maximum Duneline Change

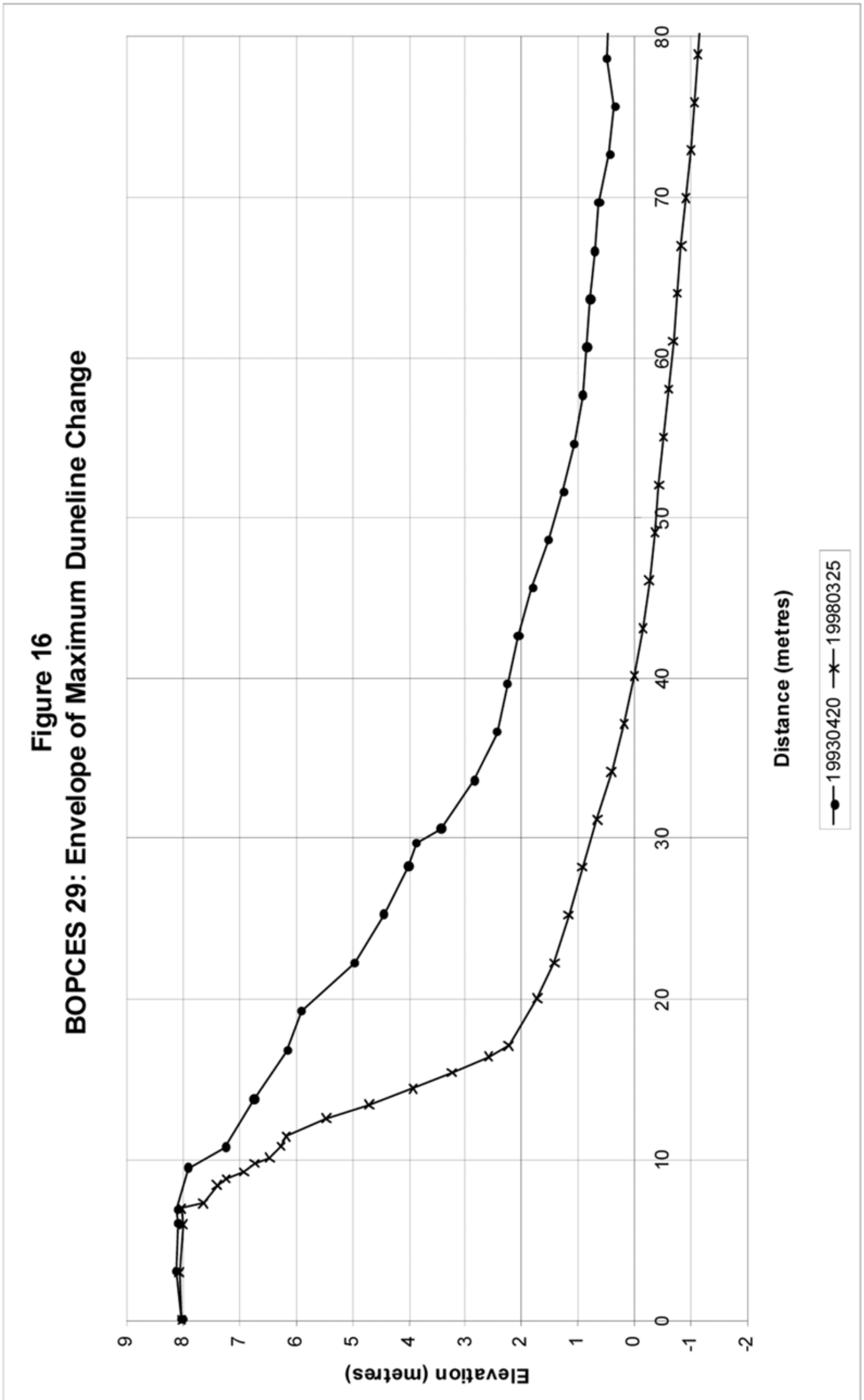


Figure 16
BOPCES 29: Envelope of Maximum Duneline Change
Elevation (metres)
Distance (metres)
19930420
19980325
9
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80

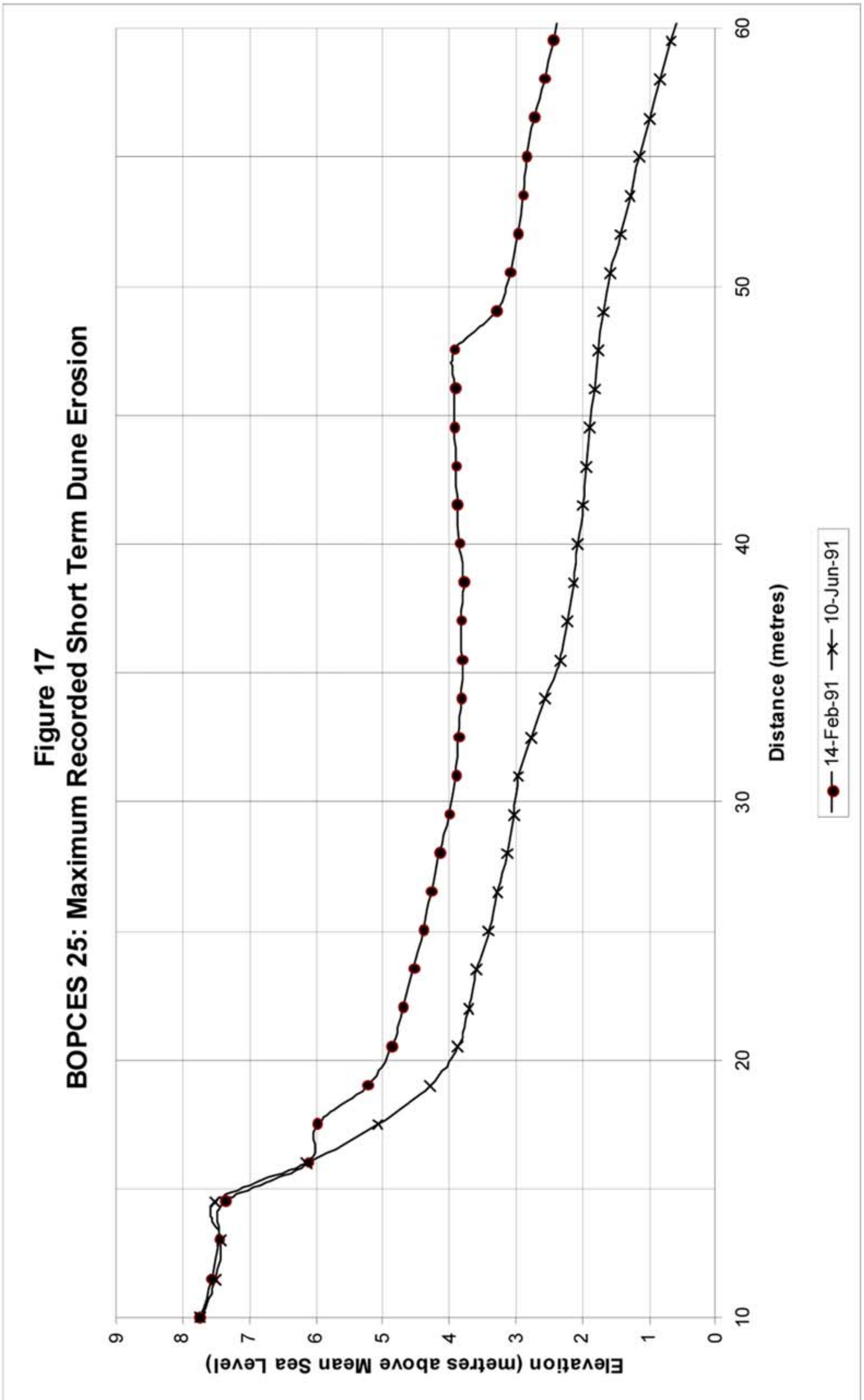


Figure 17
BOPCES 25: Maximum Recorded Short Term Dune Erosion
Elevation (metres above Mean Sea Level)
0
1
2
3
4
5
6
7
8
9
Distance (metres)
10
20
30
40
50
60
14-Feb-91
10-Jun-91

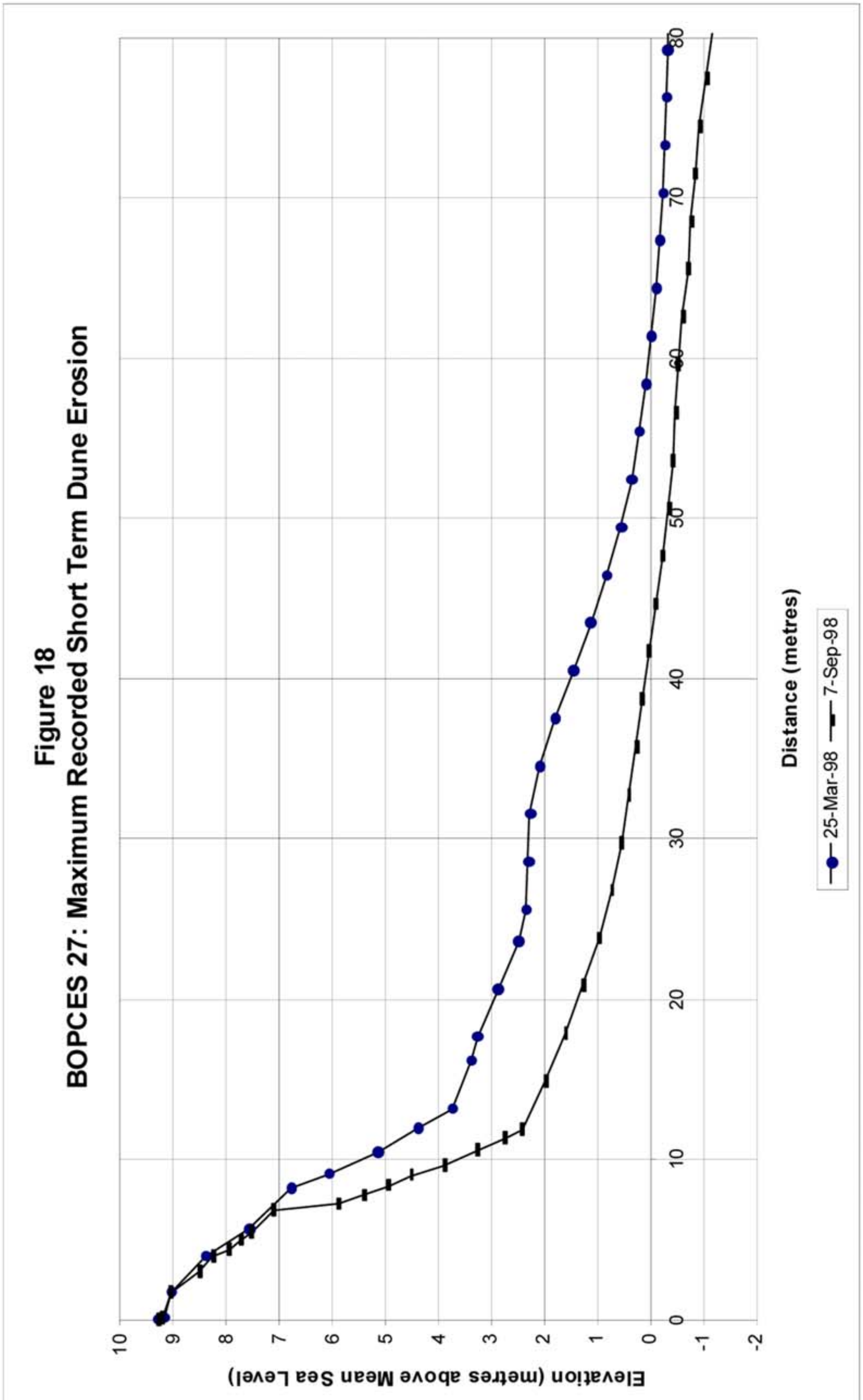


Figure 18
BOPCES 27: Maximum Recorded Short Term Dune Erosion
Elevation (metres above Mean Sea Level)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
Distance (metres)
25-Mar-98
7-Sep-98

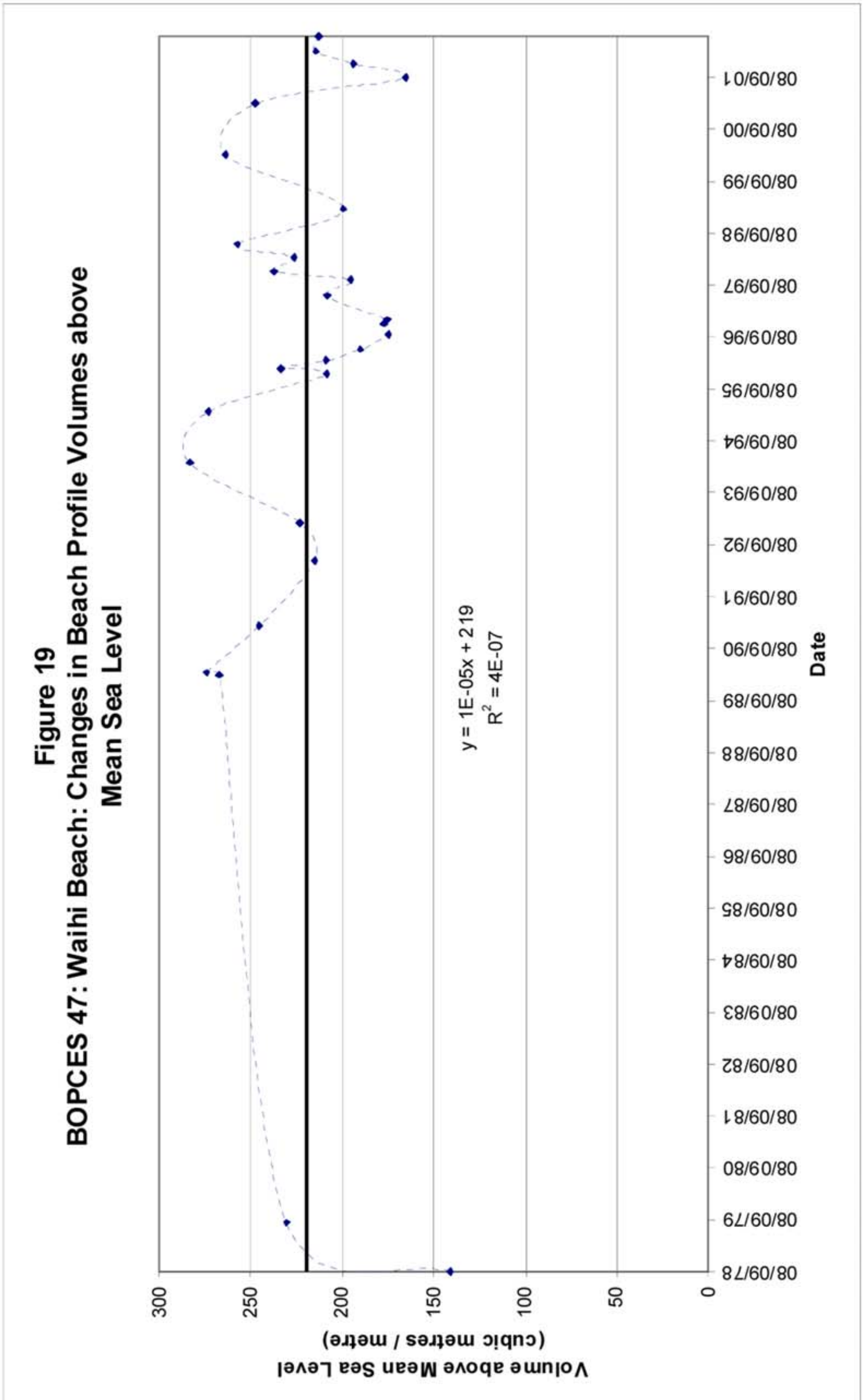


Figure 19
BOPCES 47: Waihi Beach: Changes in Beach Profile Volumes above Mean Sea Level
Volume above Mean Sea Level (cubic metres / metre)
300
250
200
150
100
50
0
y = 1E-05x + 219
R2 = 4E-07
08/09/78
08/09/79
08/09/80
08/09/81
08/09/82
08/09/83
08/09/84
08/09/85
08/09/86
08/09/87
08/09/88
08/09/89
08/09/90
08/09/91
08/09/92
08/09/93
08/09/94
08/09/95
08/09/96
08/09/97
08/09/98
08/09/99
08/09/00
08/09/01
Date

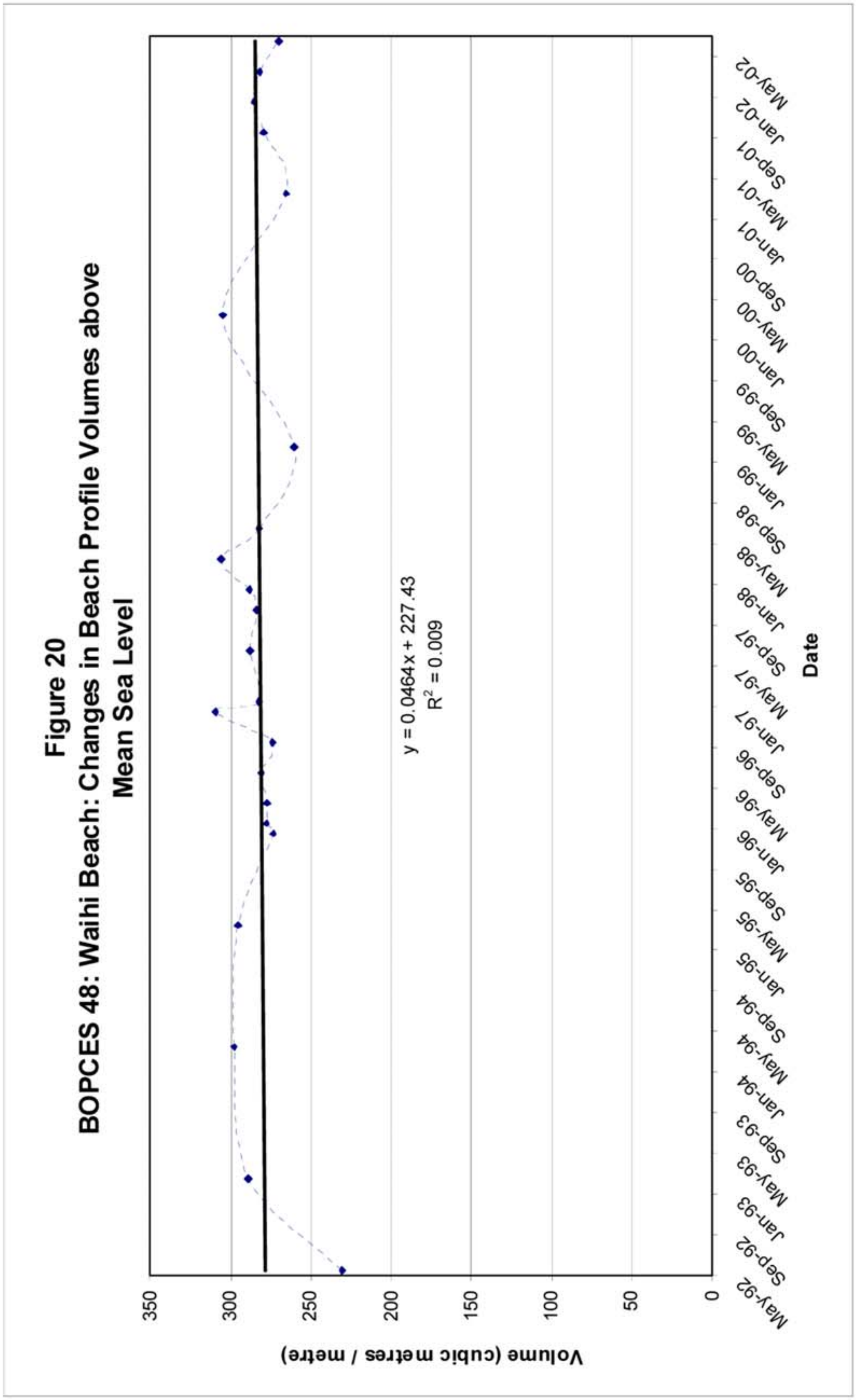


Figure 20
BOPCES 48: Waihi Beach: Changes in Beach Profile Volumes above Mean Sea Level

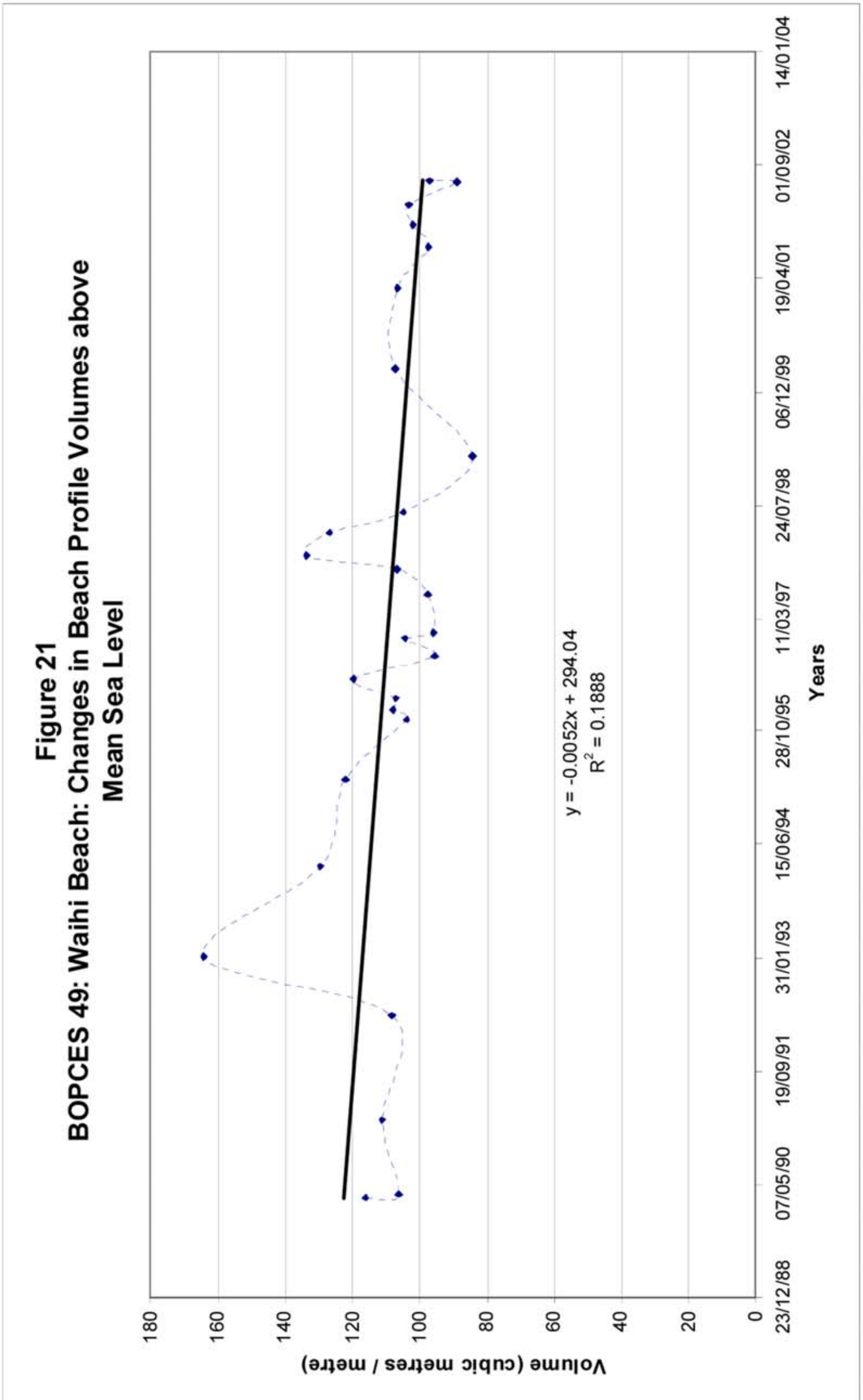


Figure 21
BOPCES 49: Waihi Beach: Changes in Beach Profile Volumes above Mean Sea Level
y = -0.0052x + 294.04
R2 = 0.1888
Volume (cubic metres / metre)
Years
0
20
40
60
80
100
120
140
160
180
23/12/88
07/05/90
19/09/91
31/01/93
15/06/94
28/10/95
11/03/97
24/07/98
06/12/99
19/04/01
01/09/02
14/01/04

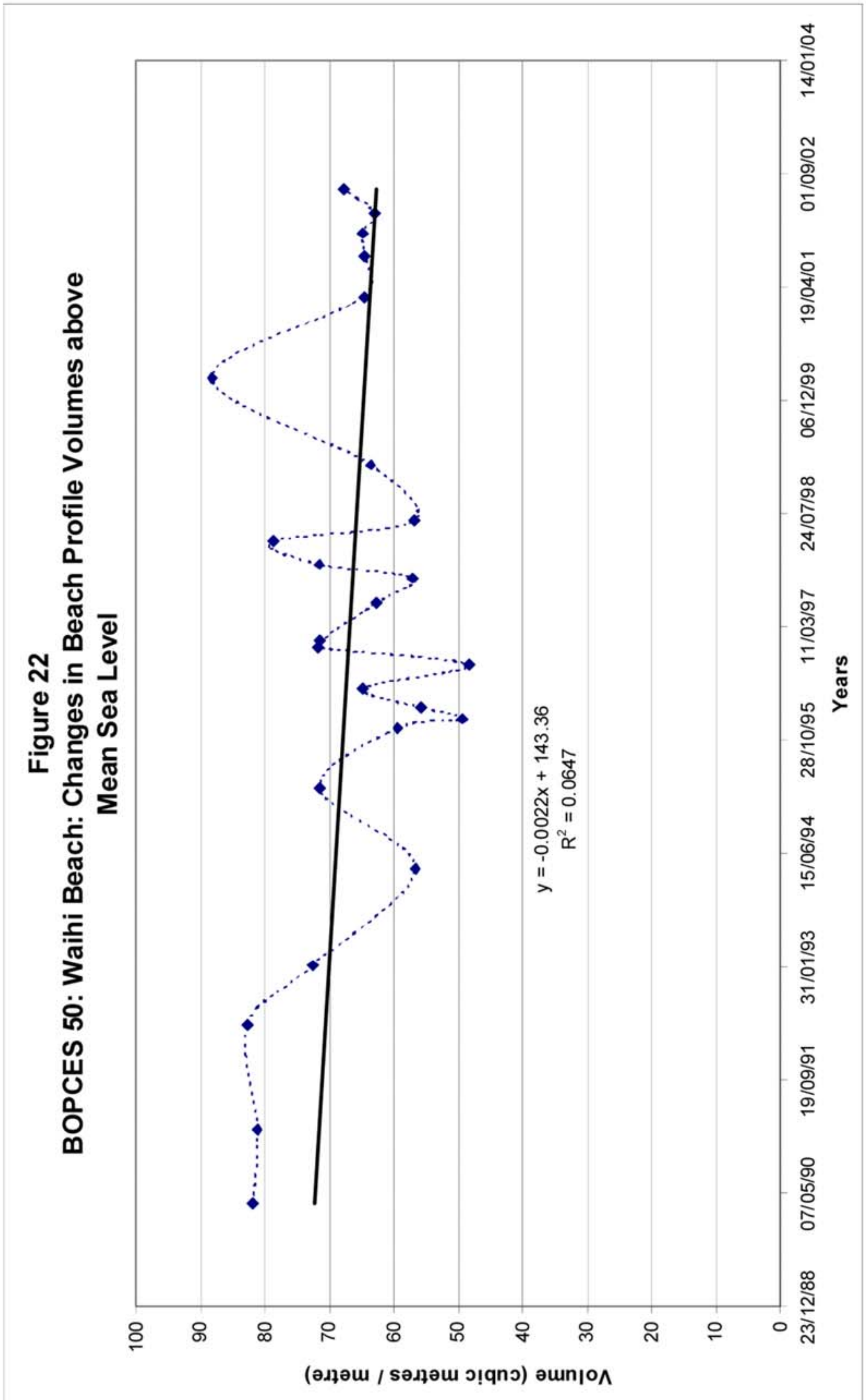


Figure 22
BOPCES 50: Waihi Beach: Changes in Beach Profile Volumes above Mean Sea Level
y = -0.0022x + 143.36
R2 = 0.0647
Volume (cubic metres / metre)
Years
100
90
80
70
60
50
40
30
20
10
0
23/12/88
07/05/90
19/09/91
31/01/93
15/06/94
28/10/95
11/03/97
24/07/98
06/12/99
19/04/01
01/09/02
14/01/04

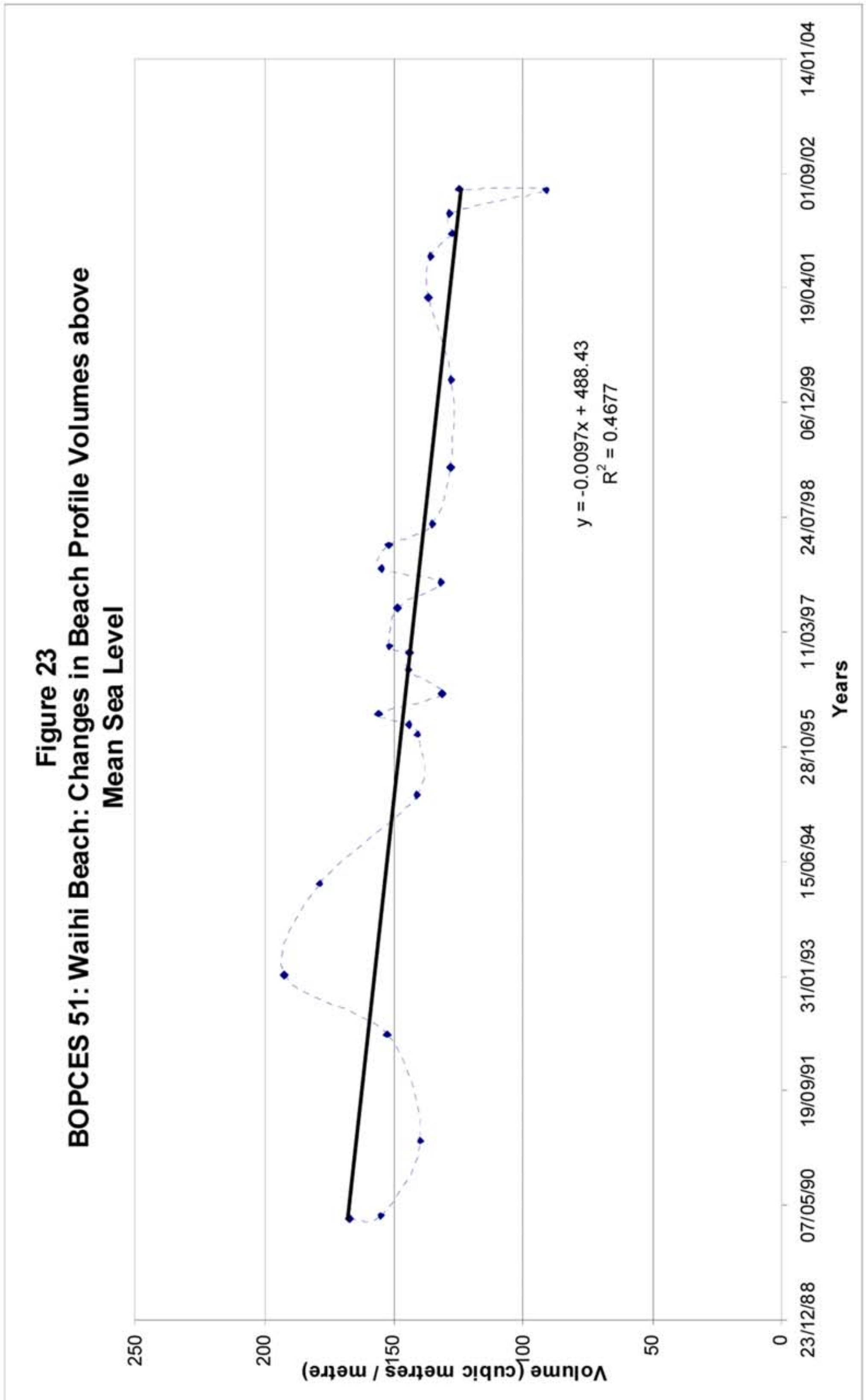


Figure 23
BOPCES 51: Waihi Beach: Changes in Beach Profile Volumes above Mean Sea Level

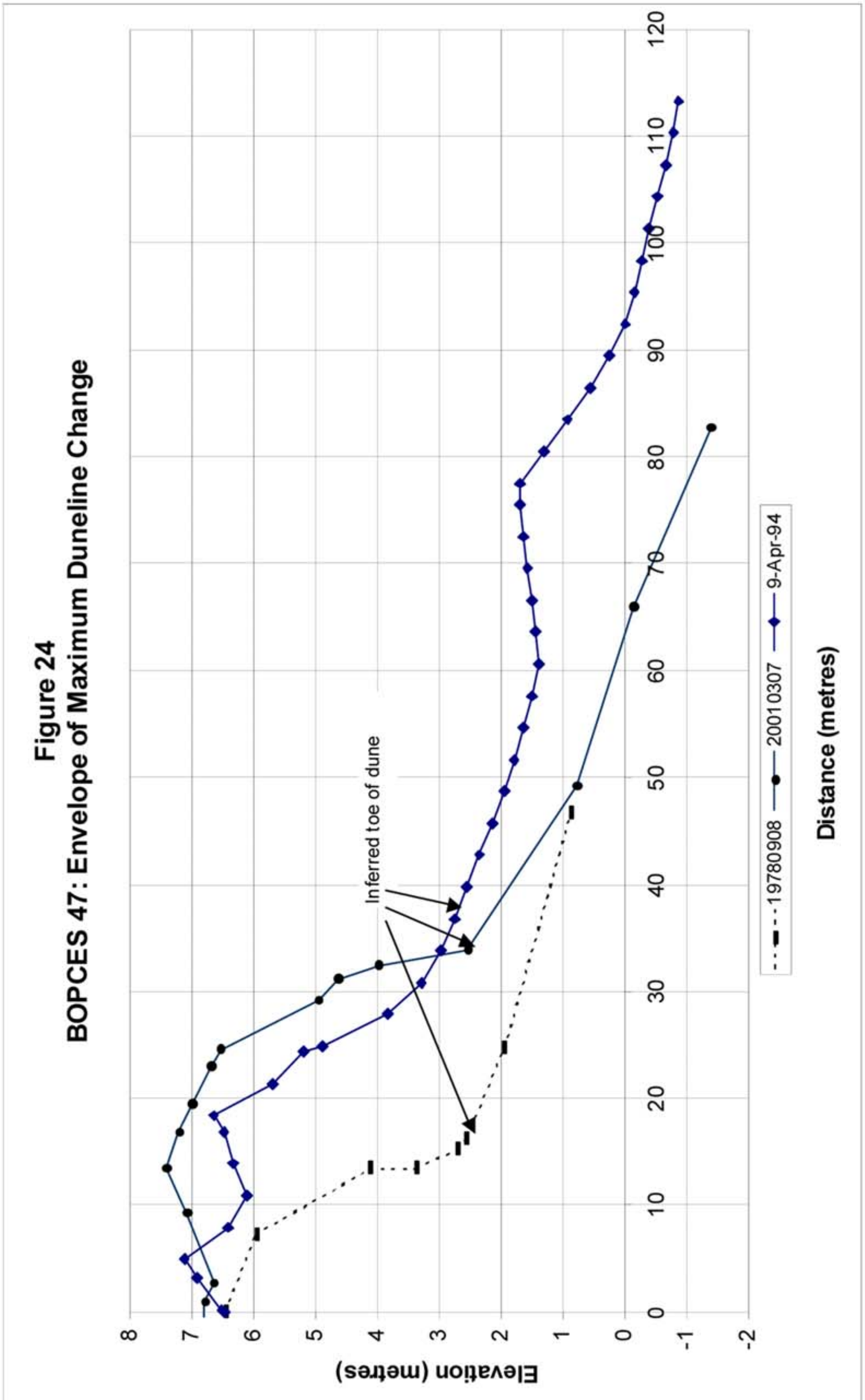


Figure 24
BOPCES 47: Envelope of Maximum Duneline Change
Elevation (metres)
Distance (metres)
Inferred toe of dune
19780908
20010307
9-Apr-94
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
90
100
110
120

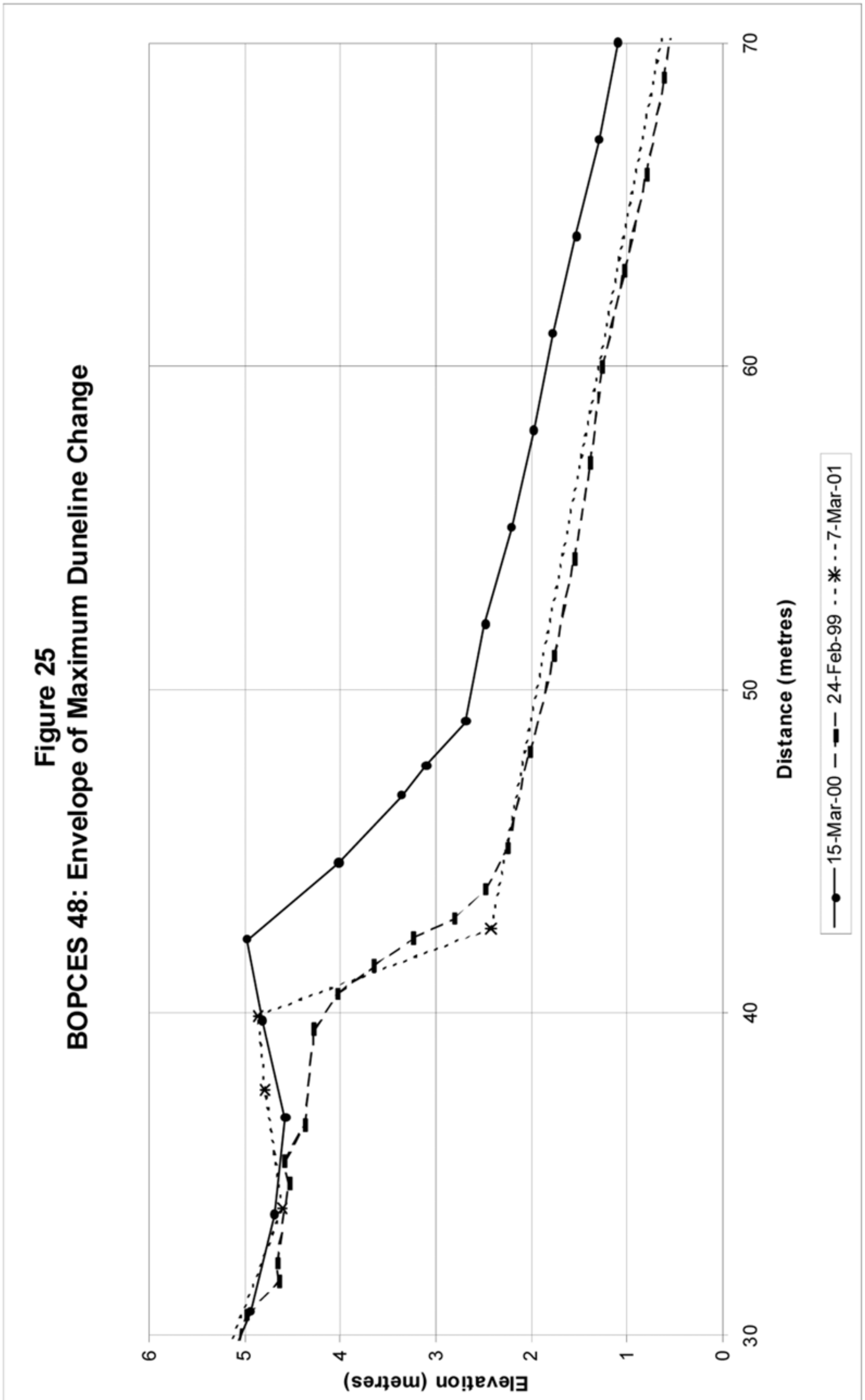


Figure 25
BOPCES 48: Envelope of Maximum Duneline Change
Elevation (metres)
6
5
4
3
2
1
0
30
40
50
60
70
Distance (metres)
15-Mar-00
24-Feb-99
7-Mar-01

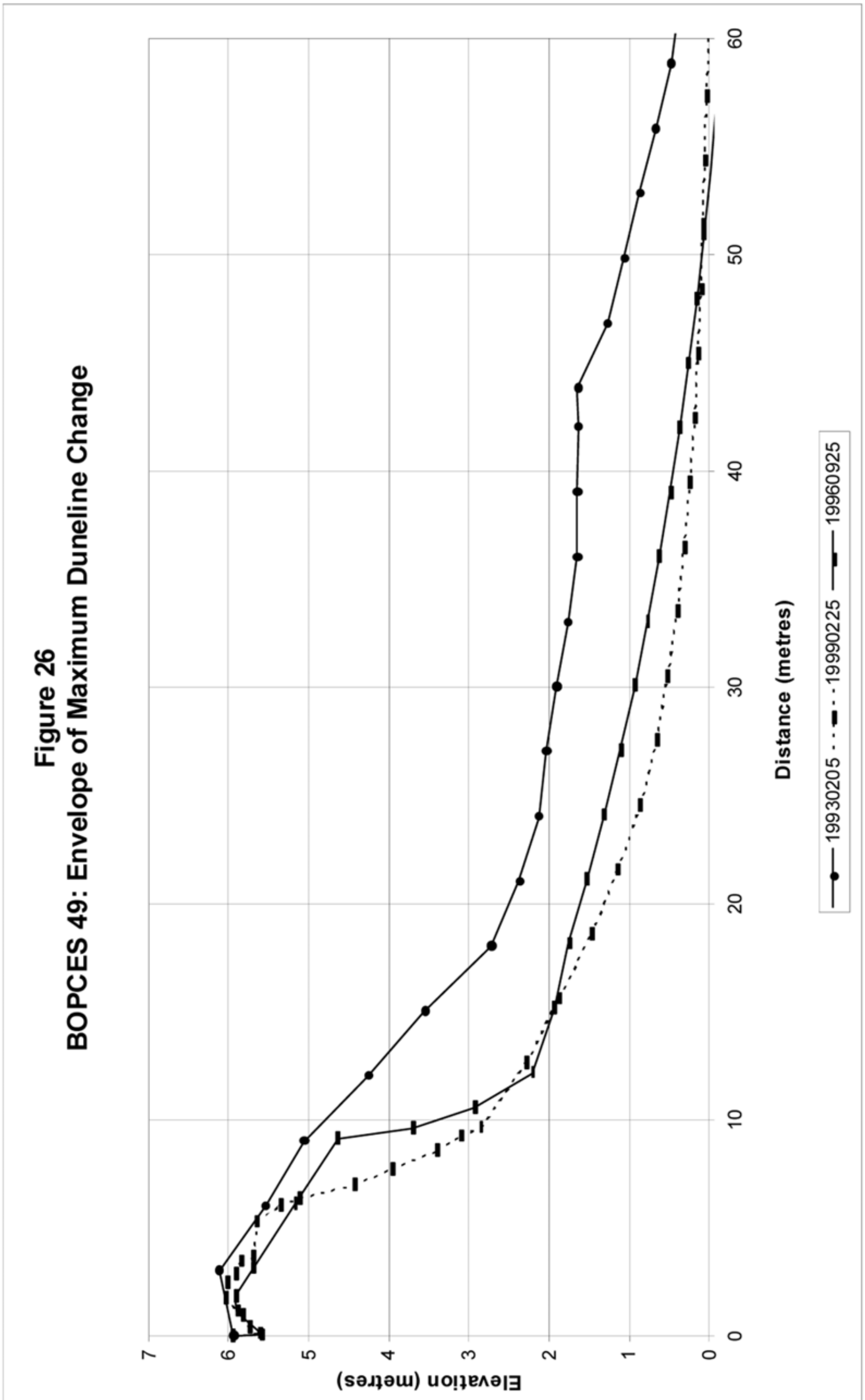


Figure 26
BOPCES 49: Envelope of Maximum Duneline Change
Elevation (metres)
Distance (metres)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
19930205
19990225
19960925

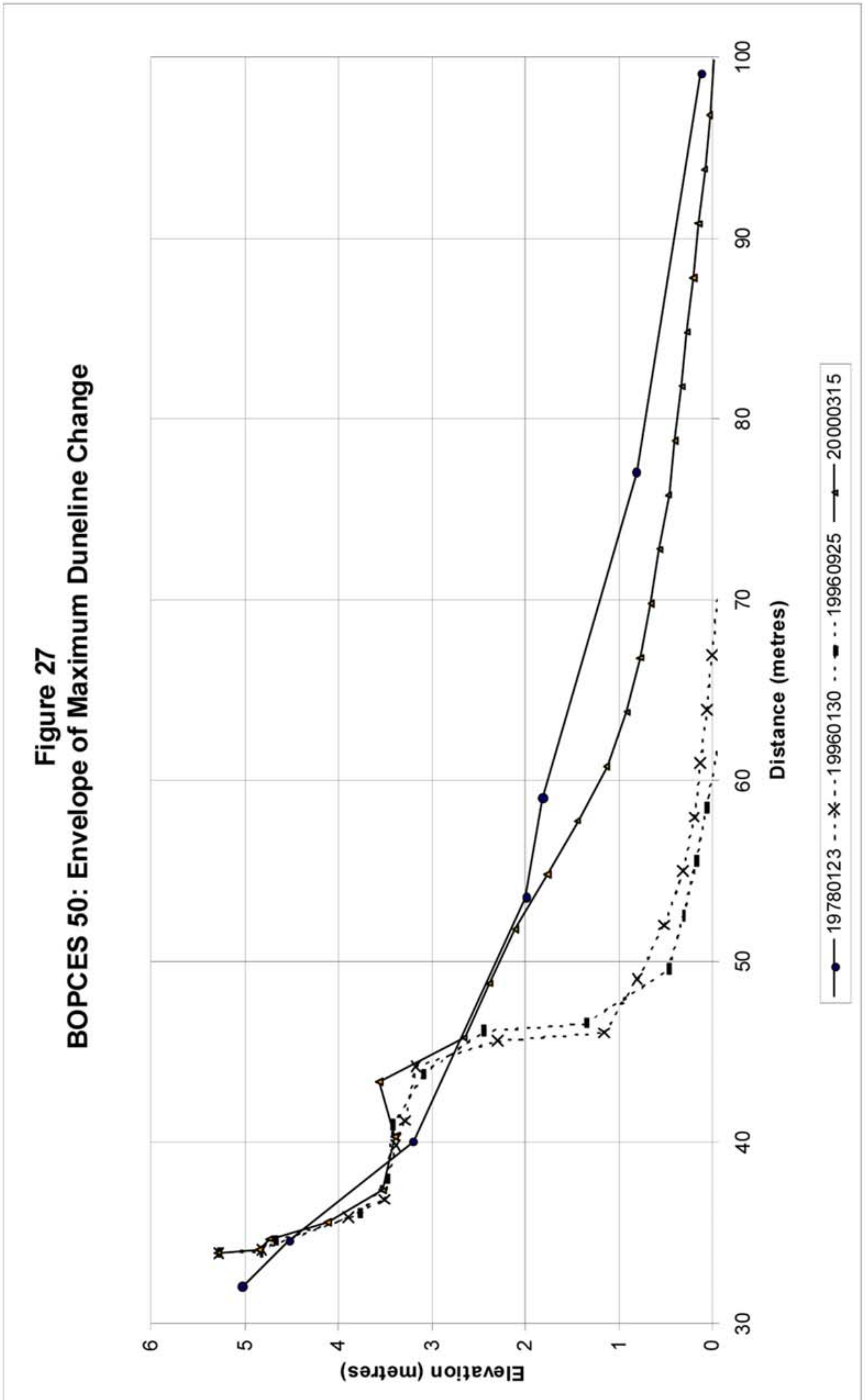


Figure 27
BOPCES 50: Envelope of Maximum Duneline Change
Elevation (metres)
Distance (metres)
19780123
19960130
19960925
20000315
0
1
2
3
4
5
6
30
40
50
60
70
80
90
100

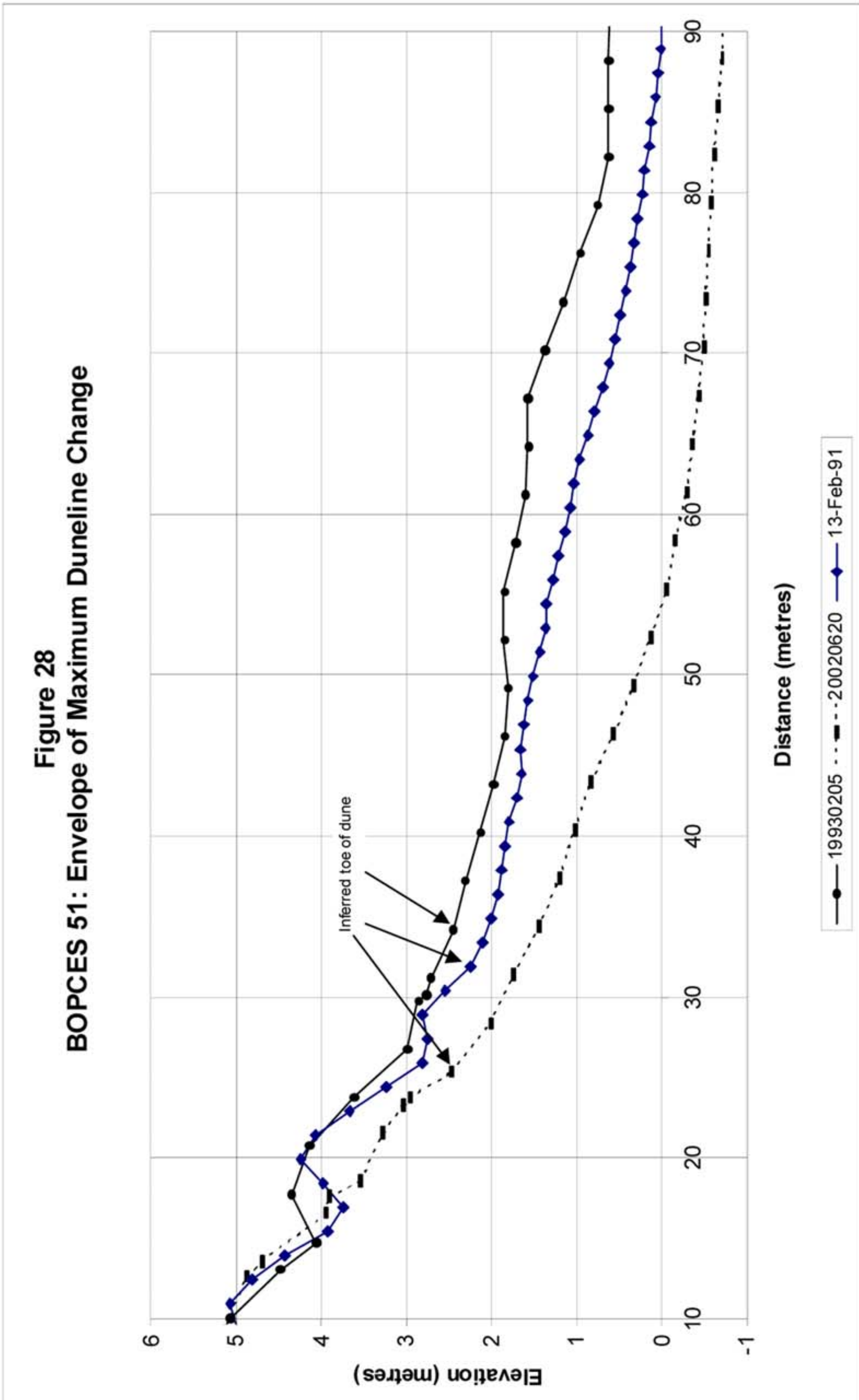


Figure 28
BOPCES 51: Envelope of Maximum Duneline Change
Inferred toe of dune
Elevation (metres)
Distance (metres)
19930205
20020620
13-Feb-91
6
5
4
3
2
1
0
-1
10
20
30
40
50
60
70
80
90

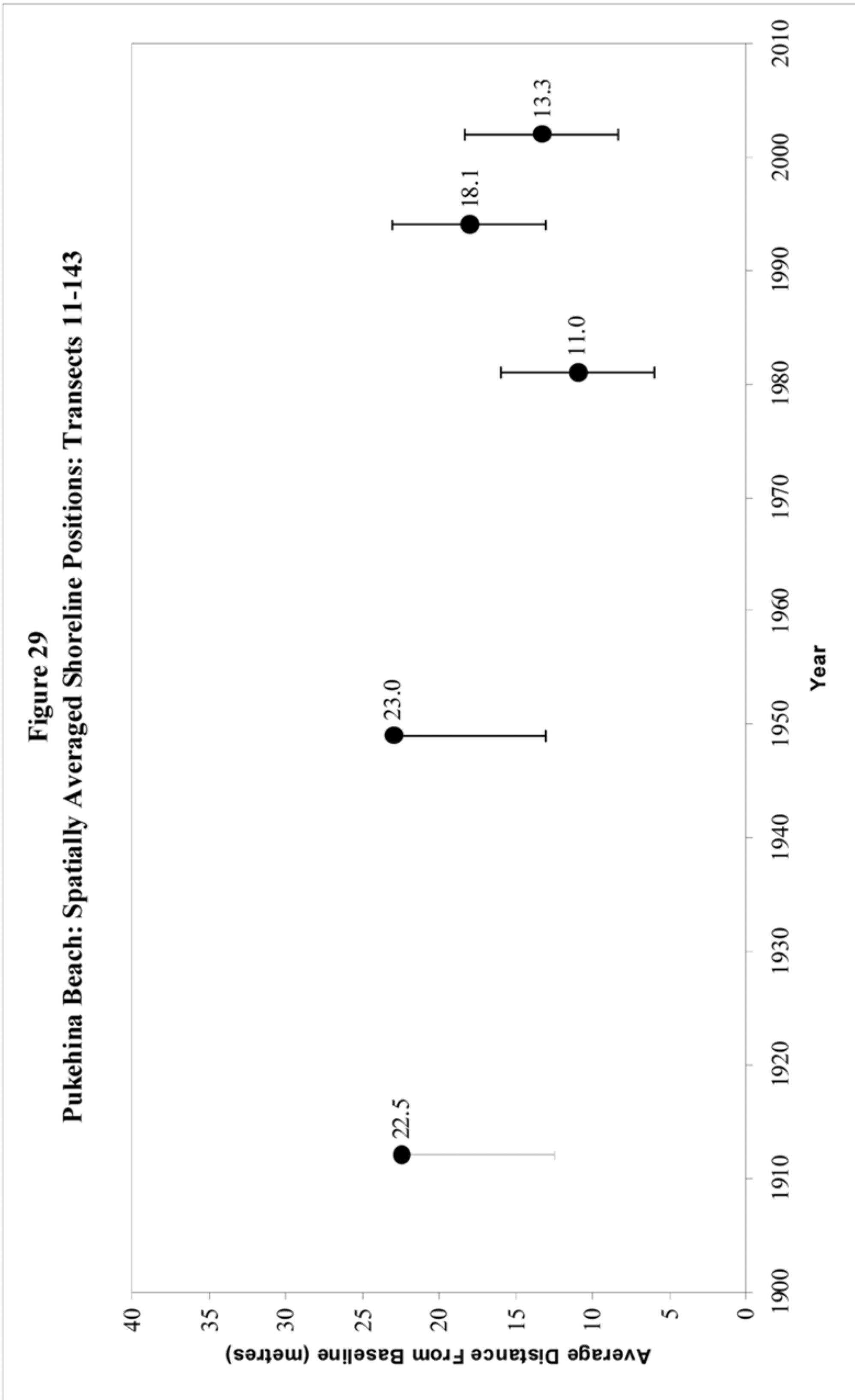


Figure 29
Pukehina Beach: Spatially Averaged Shoreline Positions: Transects 11-143

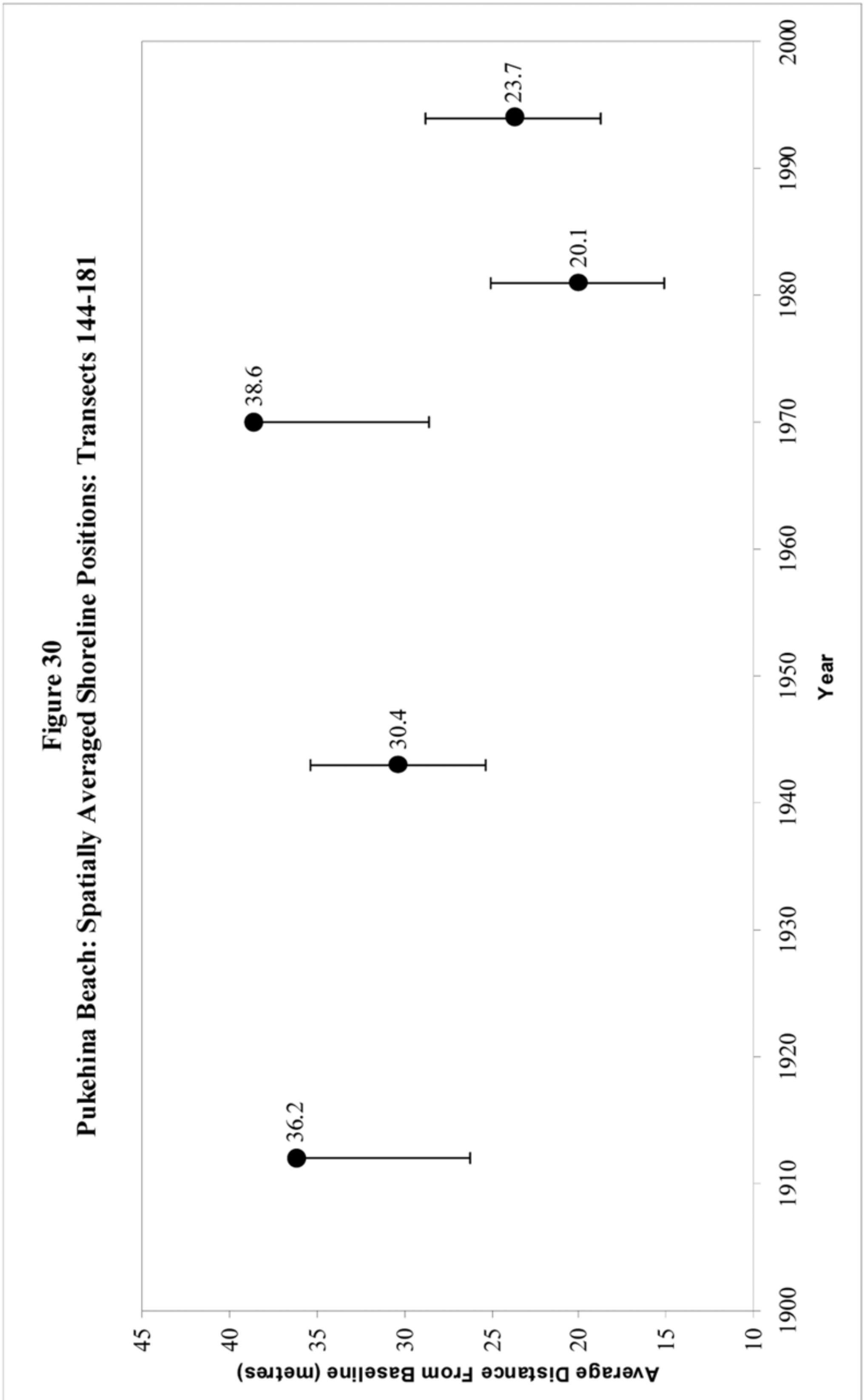


Figure 30
Pukehina Beach: Spatially Averaged Shoreline Positions: Transects 144-181
Average Distance From Baseline (metres)
Year
45
40
35
30
25
20
15
10
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
36.2
30.4
38.6
20.1
23.7

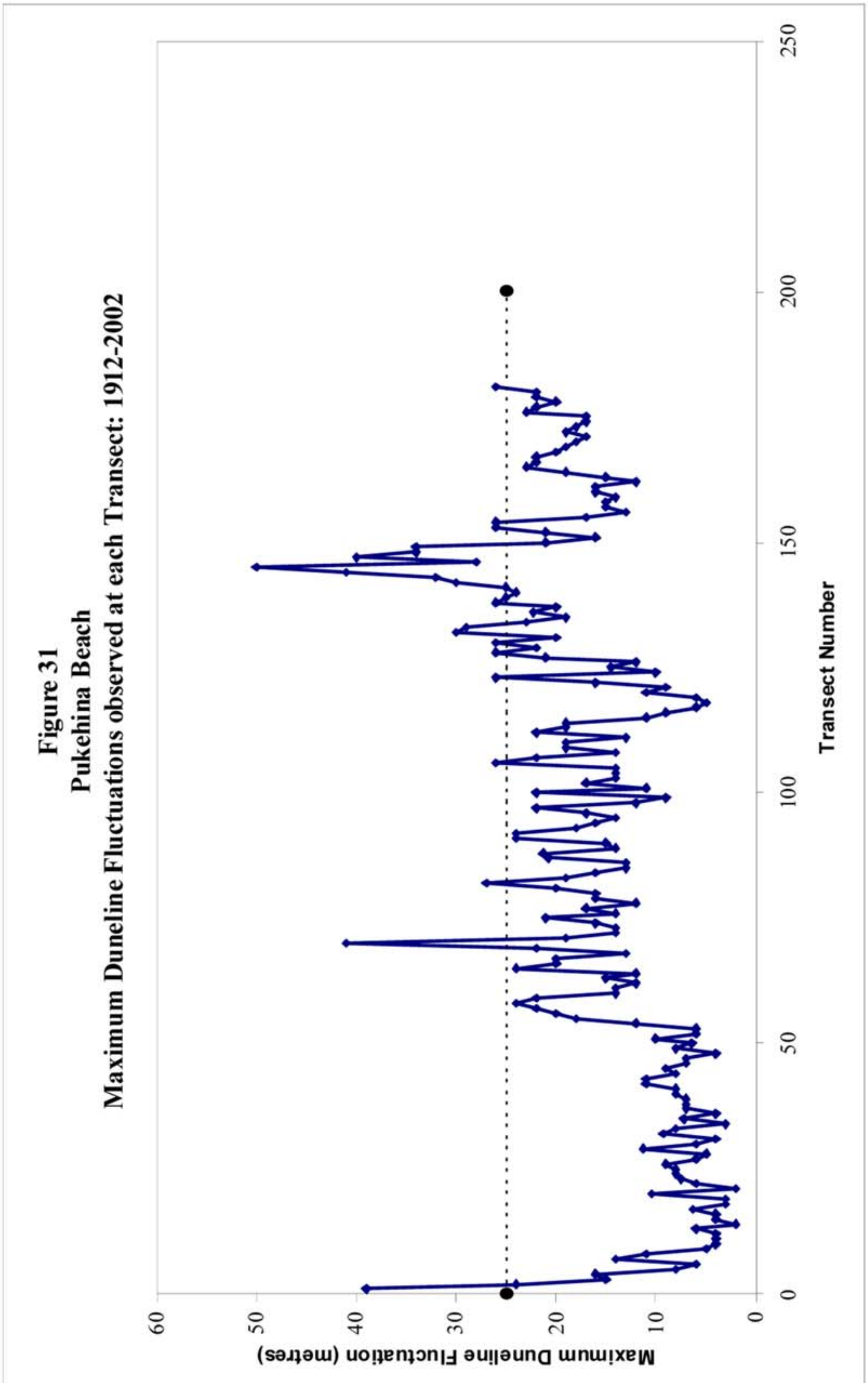


Figure 31
Pukehina Beach
Maximum Duneline Fluctuations observed at each Transect: 1912-2002
Maximum Duneline Fluctuation (metres)
Transect Number
0
10
20
30
40
50
60
0
50
100
150
200
250

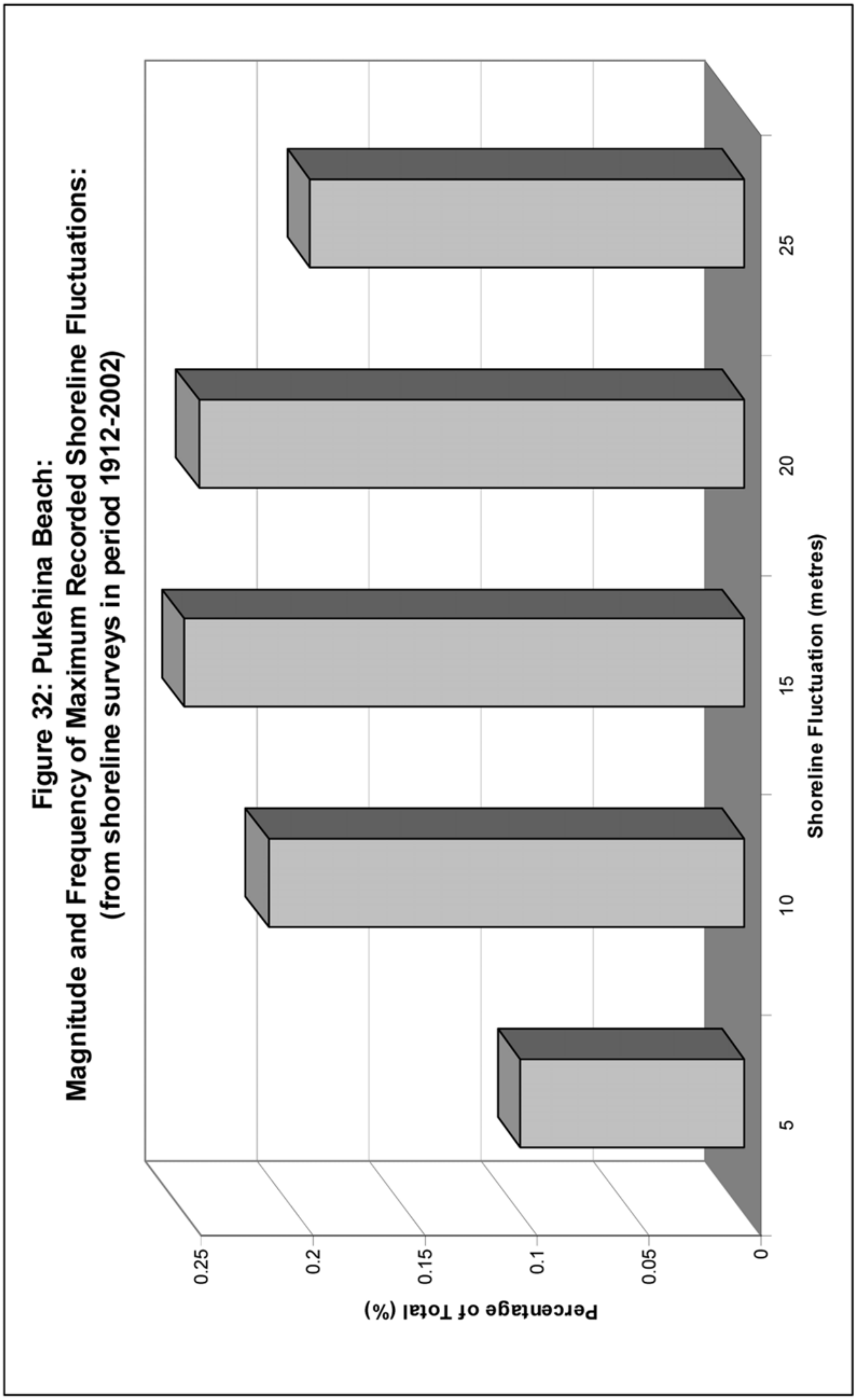


Figure 32: Pukehina Beach:
Magnitude and Frequency of Maximum Recorded Shoreline Fluctuations:
(from shoreline surveys in period 1912-2002)

Figure 33 Waihi Beach fronting Shaw Road, January 1953 (Whites Aviation Photo No.1990, Air Logistics Ltd Auckland).

Note well-vegetated foredune along seaward face of properties with gently sloping seaward face - with no evidence of recent erosion**.**

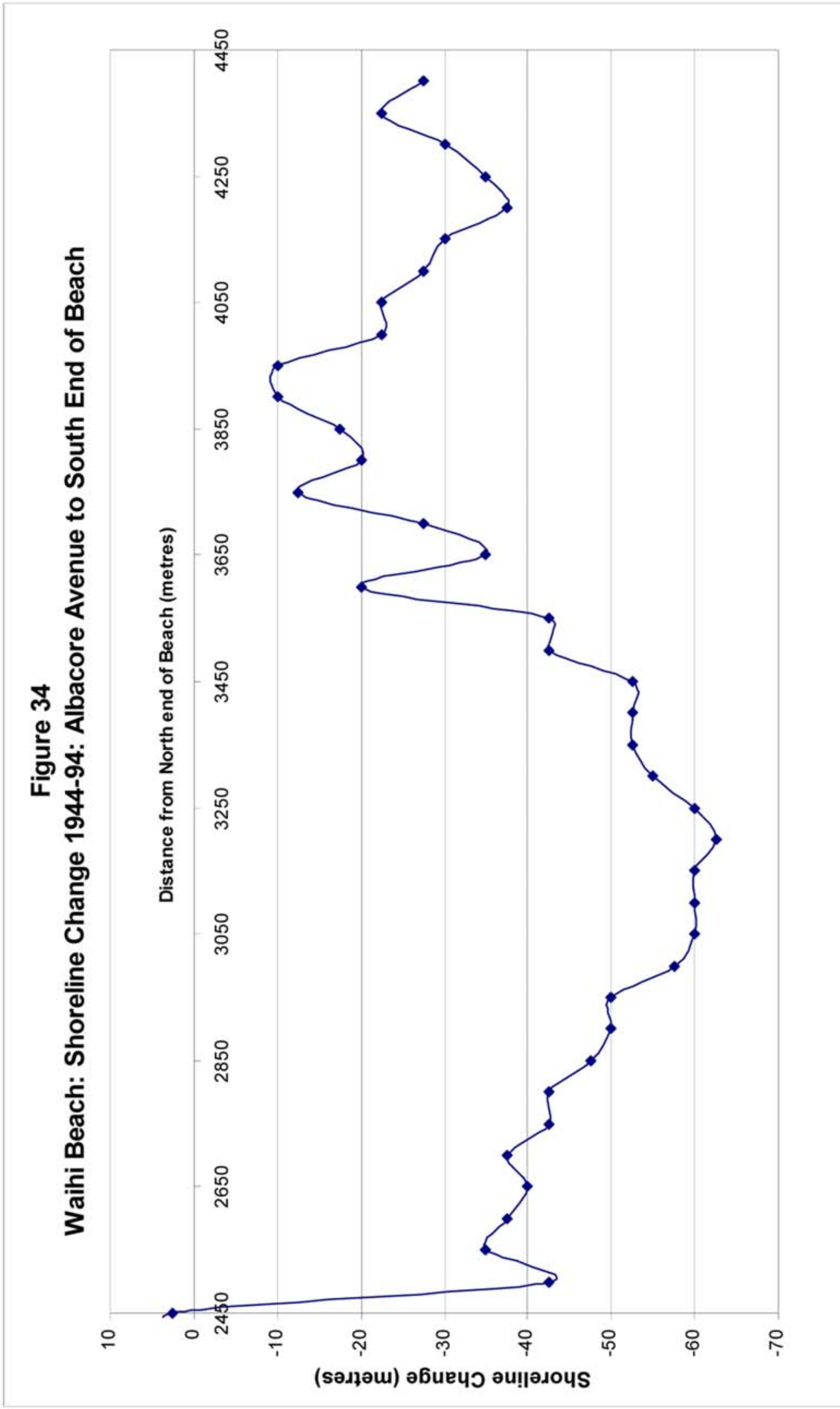


Figure 34
Waihi Beach: Shoreline Change 1944-94: Albacore Avenue to South End of Beach
Distance from North end of Beach (metres)
Shoreline Change (metres)
2450
2650
2850
3050
3250
3450
3650
3850
4050
4250
4450
10
0
-10
-20
-30
-40
-50
-60
-70