Coromandel Beaches - Coastal Hazards:

Review of Primary Development Setback at Selected Beaches

Prepared For:

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focus
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Executive Summary

Background

Coastal erosion hazard on the Coromandel Peninsula is currently managed using two development setbacks defined by Dahm and Munro (2002), the Primary Development Setback (PDS) and the Secondary Development Setback (SDS).

The PDS defines the area currently at risk from erosion with existing coastal processes and sea level for return periods up to 100 years. It is presently used to manage the location of new dwellings under the Building Act, to ensure the houses are safely located and the need for seawalls is avoided. It also informs property owners of the potential risk posed by coastal erosion.

The SDS defines the additional width that may be affected by erosion over the next 100 years given current best estimates of projected sea level rise.

These setbacks are defined without regard to existing human activities (e.g. river entrance and channel dredging) or structures (e.g. seawalls) that influence shoreline position; except where these measures have been specifically designed and consented as long-term solutions to coastal hazards.

This report was commissioned to review the PDS at selected sites, being those coastal settlements where the setback extends sufficiently into private property to affect the location of dwellings. The review takes advantage of improved data and methodologies since development of the present setbacks by Dahm and Munro (2002).

The SDS was not reviewed and the position of this setback is not changed or affected by the review. The only exceptions occur where this study found that erosion resistant materials will preclude any aggravation of erosion by climate change – where the study concludes there is no need for the SDS. It is recommended that any significant review of the SDS at other sites be left until after the next (fifth) IPCC assessment due in 2014.

The primary objective of the review is to ensure that the PDS at each site is robust in respect to existing information and reliably meets statutory standards. In view of the high level of existing subdivision and development, care was also taken to adopt a methodology that avoided unnecessary impacts on the use of existing private property. The review has developed specific hazard setback recommendations for each site that vary between and within sites as appropriate. The review also takes into account any restriction of erosion by site geology (i.e. erosion resistant materials underlying sands) where this could be identified. At all other sites, it has been assumed that erosion is not restricted by site geology – in line with the need for a precautionary approach.

Eastern Coromandel Peninsula

The existing PDS has been revised on a site-specific basis using a consistent technique and the data currently available. The review included assessment of the maximum likely erosion associated with existing sea level and addition of a minimum safety factor – to ensure the least possible restriction on use of private properties while also protecting assets from the worst likely erosion. The revised setback was checked against all available data and with field inspections to ensure it is sufficiently precautionary.

The assessment concluded that the review sites on the eastern Coromandel appear to be in dynamic equilibrium, with no significant long-term trend for erosion or accretion. The erosion assessment therefore focused on the maximum likely erosion associated with dynamic shoreline fluctuations.

The review has reduced the existing PDS at most sites, particularly where there was limited information at the time of the earlier study. Checks of the revised PDS confirm that houses located behind this line would not have been affected by erosion over at least the last 50-60 years. At most sites, the revised PDS appears to be at least 10 m landward of the worst measured erosion. The revised PDS is judged to provide protection against 100-year return period erosion for existing sea level.

The revised PDS is sufficiently reduced at most sites to provide for reasonable use of existing residential sections and thereby to significantly reduce the requirement for site-specific reports.

There are some restricted locations where the setback still extends significantly into private properties. In most cases, there is little to no potential for further seaward adjustment of the PDS without sacrificing critical safety factors. Site specific erosion management strategies will therefore be required to provide for safe use of these properties. These areas include extensive lengths of beach at Whitianga and limited areas (usually <3-4 properties) at Whangamata, Tairua and Hahei.

There may however be some limited areas where the setback is still overly precautionary and could be further reduced by more detailed investigation. Where we believe this could be relevant it has been discussed in more detail in the body of the report (e.g. southern end of Wharekaho Beach).

Plots of the revised PDS are included in Appendix B. The previous PDS is also included on the plots for comparison.

Western Coromandel Peninsula

The existing PDS includes allowance for coastal erosion associated with dynamic shoreline change and for high velocity effects associated with wave overtopping during extreme events.

It is recommended that coastal flooding including wave overtopping is best managed using minimum floor levels rather than setbacks. A minimum floor level of RL3.0 m is recommended to ensure sufficient allowance for extreme sea levels, wave effects, potential sea level rise and freeboard over the next 50 years. In beachfront sections exposed to wave overtopping, the minimum floor level should be the greater of RL3.0 m or 0.3 m above existing ground level.

Coastal erosion along the Thames Coast is associated with dynamic shoreline fluctuations and long-term trends for shoreline change. Estimation of extreme erosion at each of the study sites considered all available information, including historical shoreline mapping, aerial photography and community information.

Analysis of existing data and community information indicates that dynamic shoreline fluctuations typically vary from 5-15 m. Larger fluctuations occur near stream entrances and at other rare locations (e.g. Te Puru School). There is also potential for larger shoreline change where shorelines are held seaward of their natural position by existing seawalls. The revised PDS allows for dynamic shoreline fluctuations of 10-15 m depending on site exposure, with larger site specific provision near stream entrances or where seawalls hold the shoreline seaward of its natural position.

The review has reduced the PDS at most sites. In limited areas however, the PDS still extends deeply within some properties. Sustainable management of coastal hazards in these areas will require site specific coastal hazard management strategies to complement the PDS and minimum floor levels. Existing measures (e.g. seawalls; placement of dredged sediment) provide reasonable interim protection at most of these sites. These limited areas occur at all four sites and are discussed in more detail in the text.

The review has also highlighted that existing raised coastal margins and stopbanks are vulnerable to erosion in many areas. Loss of such areas would markedly increase exposure to coastal flooding. Over time, site specific strategies will also be required to address this risk.

Diagrams showing the revised PDS are included in Appendix B.

Contents

1 Introduction

The Coromandel Peninsula includes a number of coastal settlements with development in close proximity to the shoreline. Much of this development occurred historically in the absence of a full understanding of coastal hazards. Consequently, many existing residential properties and some public infrastructure are located in areas at risk from coastal hazards. In order to better manage this risk, coastal development setbacks were introduced in the early 1980s.

In 2002, Environment Waikato commissioned work to revise the then existing development setbacks. Ideally, development setbacks would provide for avoidance of coastal hazard risk for return periods up to at least 100 years, including the effects of projected sea level rise. However, given existing subdivision and development, setbacks sufficient to provide for this objective would preclude reasonable use of beachfront properties at most existing coastal settlements. Dahm and Munro (2002) therefore followed earlier work and defined two development setbacks; the Primary Development setback (PDS) and the Secondary Development Setback (SDS).

The PDS defines the area currently at risk from erosion with existing coastal processes and is used to manage the location of new dwellings under the Building Act. With current practice, this is applied as a building exclusion zone. The standard of protection provided by this setback therefore has to meet the 2% AEP standard of the Building Act.

The SDS defines the additional width that may be affected by erosion over the next 100 years given current best estimates of projected sea level rise. Current practice recognises the residual risk in this zone and requires new development to be relocatable.

These setback recommendations and their application by the District Council serve a number of purposes, most importantly to:

- ensure that new beachfront houses are safely located in relation to existing risk
- avoid the need for seawalls to protect private property
- take into account residual risk, including that associated with projected sea level rise to 2100
- inform property owners of immediate and long-term risks from coastal erosion.

The Thames Coromandel District Council is currently considering the introduction of policy to further improve the management of coastal development within these setback areas. The current report was commissioned to review the PDS at selected sites to ensure the setback reflects best existing information. This review has a purely technical/scientific focus and provides information about the extent of hazard risk only. This review provides no planning recommendations for the application of the setbacks to long-term management of the coast.

1.1 Objectives

The review has focussed on the following sites, where the PDS impacts on the use of private property:

East Coast

- Whangamata
- Tairua Ocean Beach
- Hahei
- Maramaratotara
- Buffalo Beach
- Wharekaho
- Matapaua Bay
- Opito Bay
- Kuaotunu East
- Rings Beach
- Matarangi
- Whangapoua
- Kennedy Bay
- Port Charles
- Sandy Bay

West Coast

- Tararu
- Te Puru
- Waiomu
- Waikawau

The primary objective of the review is to develop robust setbacks that reliably meet statutory standards, in particular to provide for safe location of coastal development in respect to coastal erosion for return periods up to 1% AEP for existing sea level. The longer term uncertainties associated with projected sea level rise are addressed in the secondary development setback (SDS), which is not part of the current review.

In view of the high level of existing subdivision and development at these sites, care is required to ensure that the statutory standards are met while avoiding unnecessary restrictions on the use of existing private property. This has required careful attention to methodology, as discussed further in Section 3.

The review aims to develop specific hazard setback recommendations for each site, which vary between and within sites, as appropriate. This contrasts with the existing setbacks which are generally generic. For instance, the existing setbacks along the east coast are linked to two separate beach types – with the beaches within each type having the same setbacks. This approach reflects data limitations at the time of the original work, which was primarily undertaken in the late 1990s.

The existing setbacks assume the beach and dunes at most sites are composed of loose erodible sand. It is known however, that a number of sites have erosion resistant materials underlying the existing beach and dune sediments. The review also aims, where practical, to identify such areas where erosion is restricted by site geology.

In order to achieve these objectives, the review takes advantage of improved data and methodologies since development of the present setbacks by Dahm and Munro (2002). In addition, the review was undertaken in consultation with Council and affected property owners to access additional knowledge and information.

1.2 Background

Damage to residential beachfront subdivisions in the late 1970s highlighted issues with coastal hazard management at many sandy beach settlements on the east and west coast of the Coromandel Peninsula. Management agencies recognised the need to define and manage risk to minimise future damage and avoid concentration of development in high risk areas.

Following severe storm damage in late 1978, the "Coromandel Coastal Survey" beach profile network was established at most sandy beaches on the eastern Coromandel Coast (Healy et al., 1981). Monitoring at these sites has continued to the present time, and is a key source of data for this review.

In the early 1980s, Council adopted 30 m and 60 m setbacks along all sandy beaches of the eastern Coromandel. These setbacks were measured from the toe of the frontal dune at the time of the building consent application and therefore varied as the toe of dune changed. The 30 m setback was adopted as a building exclusion area, with new dwellings seaward of the 60m setback required to be relocatable.

A further review of information on coastal hazards was undertaken by Dahm and Munro (2002), with revised setback recommendations given for beaches on both coasts of the Peninsula. This review concluded that shoreline change on the Coromandel Peninsula is dominated by dynamic fluctuations, rather than any long-term trend for erosion or accretion. The revised setbacks were therefore fixed (i.e. no longer changed with movements of the dune toe) to provide a more consistent level of protection than the early 30 m and 60 m setbacks.

Two development setbacks were recommended to provide protection against existing and future coastal erosion hazard:

- Primary Development Setback (PDS): defines the area of coastal land currently at risk from erosion driven by existing coastal processes. This setback is applied through the Building Act. Council generally does not consent new dwellings or extensive renovation seaward of this setback. The only exceptions occur where a site specific review undertaken by a suitably qualified professional concludes the setback can be reduced (i.e. the generic setback for that beach is found to be overly precautionary, and therefore unnecessarily restrictive on property use), or where owners utilise existing use right provisions.

- Secondary Development Setback (SDS): defines the area of coastal land at risk in the long-term from erosion driven by sea level rise. Houses seaward of this setback generally have to be readily relocatable to provide for the longer term risk. This setback also serves an advisory and information role for the long-term planning of coastal settlements has some influence on subdivision.

These setbacks were based on detailed information at some locations, but more limited data at others. Generic setbacks linked to beach type were defined along the eastern Coromandel. Subsequent investigation using site specific data has indicated that the generic setbacks, while reasonable at many sites were overly precautionary at some. This was particularly the case where the 2002 recommendations were primarily based on data from other sites. This has led to significant numbers of owners commissioning site specific reports to review existing setbacks in relation to individual properties. The increasing demand for site specific reports introduces the risk of inconsistencies. The current review utilises available site specific information to review the PDS and so will likely reduce the need for property specific reports.

2 Coastal Hazards

This chapter briefly reviews the coastal hazards relevant to the Primary Development Setback (PDS) and sets the scene for discussion of setback methodology in Chapter 3.

On the eastern Coromandel beaches, the PDS identifies the area at risk from coastal erosion with existing coastal processes. Coastal flooding also poses a threat to existing development in some areas (e.g. Whitianga foreshore, Manaia Road foreshore in Tairua Harbour; low-lying areas around Whangamata Harbour) but these hazards are accepted as an inevitable consequence of coastal living and are often managed separately (e.g. through minimum floor levels and other measures such as stopbanks).

On the western coast, the existing PDS identifies the area at risk from both coastal erosion and high velocity effects in nearshore areas associated with wave overtopping. Coastal flooding is a serious issue at each of the study sites on this coast, but apart from the overtopping zone it is managed separately through minimum floor levels, complemented by other measures (e.g. stopbanks and other raised barriers) at some sites.

2.1 Coastal Erosion on the Eastern Coromandel

Assessment of coastal erosion on beaches of the eastern Coromandel requires consideration of a number of factors, including:

- **Dynamic shoreline fluctuations over timescales of years and decades** – movements in the shoreline associated with storm events and weather patterns, with no long-term trend for accretion or erosion.
- **Long-term trends for shoreline change** – any long-term trends for permanent shoreline advance or retreat within the timeframes relevant to the review (i.e. 50-100 years).
- **Projected sea level rise** and other changes that may accompany predicted global warming
- **Appropriate safety factors**

The influence of projected sea level rise to 2100 is addressed in the Secondary Development Setback (see discussion in Section 1) and is not relevant to this review. The remaining factors are briefly discussed below.

2.1.1 Dynamic Shoreline Fluctuations

Dynamic shoreline fluctuations are the primary cause of shoreline movements on eastern Coromandel beaches over periods of years to several decades (Dahm and Munro, 2002). These shoreline fluctuations occur in response to various factors, but most particularly storm erosion and recovery and tidal entrance dynamics.

2.1.1.1 Storm cut and recovery

During major coastal storms, significant beach and dune erosion can be experienced at eastern Coromandel beaches associated with both offshore and alongshore sediment transfers (Dahm and Munro, 2002). In quieter periods between storms, the sand generally returns onshore resulting in beach and (with appropriately vegetated dunes) dune recovery.

Occasionally (e.g. Whangapoua August 2008), significant erosion occurs during an individual storm event (see section 4.12.3), particularly when a storm has a long duration and is associated with elevated sea levels.

It is more common, however for severe erosion at eastern Coromandel and Bay of Plenty beaches to cumulate gradually over a number of storms (Dahm and Munro, 2002; Eco Nomos, 2003). This is most likely because storms on the Coromandel Coast are usually "duration-limited" so storms do not last long enough for individual events to cause the maximum possible erosion. A sequence of storms is therefore required to cause severe erosion.

The beaches are often characterised by periods of several years in which erosion dominates, followed by lengthy periods of overall shoreline recovery (Dahm and Munro, 2002). The most significant dynamic shoreline fluctuations tend to be associated with these multi-decadal cycles rather than with individual storm events. Full "cycles" from a wide prograded beach and dune state through a period of severe erosion, and back to a fully recovered dune have commonly occurred over periods of 30-40 years (Dahm and Munro, 2002). These multi-decadal "cycles" of erosion and recovery can, however be of variable length.

The reasons for these multi-decadal variations are not yet well known. They are probably related primarily to the influence of climatic cycles and variations (e.g. El Nino and La Nina phases) on storm frequency, intensity and/or duration (de Lange, 2000; Eco Nomos, 2003; Bryan et al, 2008). Periods dominated by erosion may represent higher than normal storm frequency, with a lower than normal frequency during periods dominated by recovery. Other coast-wide and local factors undoubtedly also influence these multi-decadal variations as there is considerable variation in the scale and timing of the changes both within and between individual sites (Dahm and Munro, 2002; see also Chapters 4 and 5 of this report).

In general, available data (Dahm and Munro, 2002; see also Chapter 4) suggests two periods of widespread severe erosion on eastern Coromandel beaches since the 1960s:

- The period from the late 1960s (about 1967/68) to 1978, with dune erosion reaching maximum extent following the July 1978 storm event (Dahm and Munro, 2002). In subsequent years, most (not all) eastern Coromandel beaches went through a period dominated by beach and dune recovery, extending at through to at least the early-mid 1990s at most sites.
- The period from the mid-late 1990s (typically 1995/96) to the early 2000s (approximately 2003). Severe dune erosion cumulated at a number of beaches during this period (e.g. Buffalo, Ohuka, Otahu and Whangapoua Beaches).

These periods of erosion did not affect all beaches but erosion was sufficiently widespread to suggest coast-wide drivers. The beaches severely affected in one erosion period were not always as severely affected in the other, indicating the importance also of local factors (e.g. beach orientation/exposure). For instance, Otahu Beach at Whangamata was severely eroded in the late 1990s and early 2000s, but far less affected by the erosion culminating in July 1978. The converse was true for the main ocean beach at Whangamata.

2.1.1.2 Tidal and river entrance dynamics

Tidal and river entrances along the eastern Coromandel tend to experience larger than normal shoreline fluctuations (Dahm and Munro, 2002), typical of near entrance areas along sandy coasts.

A notable example is the distal end of Matarangi Spit at the entrance to Whangapoua Harbour, which can experience shoreline fluctuations in excess of 200 m. Similarly, maximum shoreline changes measured at the northern end of Pauanui Beach adjacent to the Tairua Harbour entrance are significantly larger than areas further removed from the entrance (Dahm and Munro, 2002; Figure 1).

Complex and active sediment dynamics drive large-scale shoreline changes in areas near estuary entrances. These areas experience high current velocities, large areas of breaking waves, and active sediment transport. Significant transfers of sand occur, often in episodic pulses, between the shorelines and the ebb and flood tidal delta systems that occur seaward and landward of the entrances, respectively.

The larger scale shoreline fluctuations in near entrance areas also tend to be multi-decadal in nature (Dahm and Munro, 2002; see also Chapters 4 and 5 of this report).

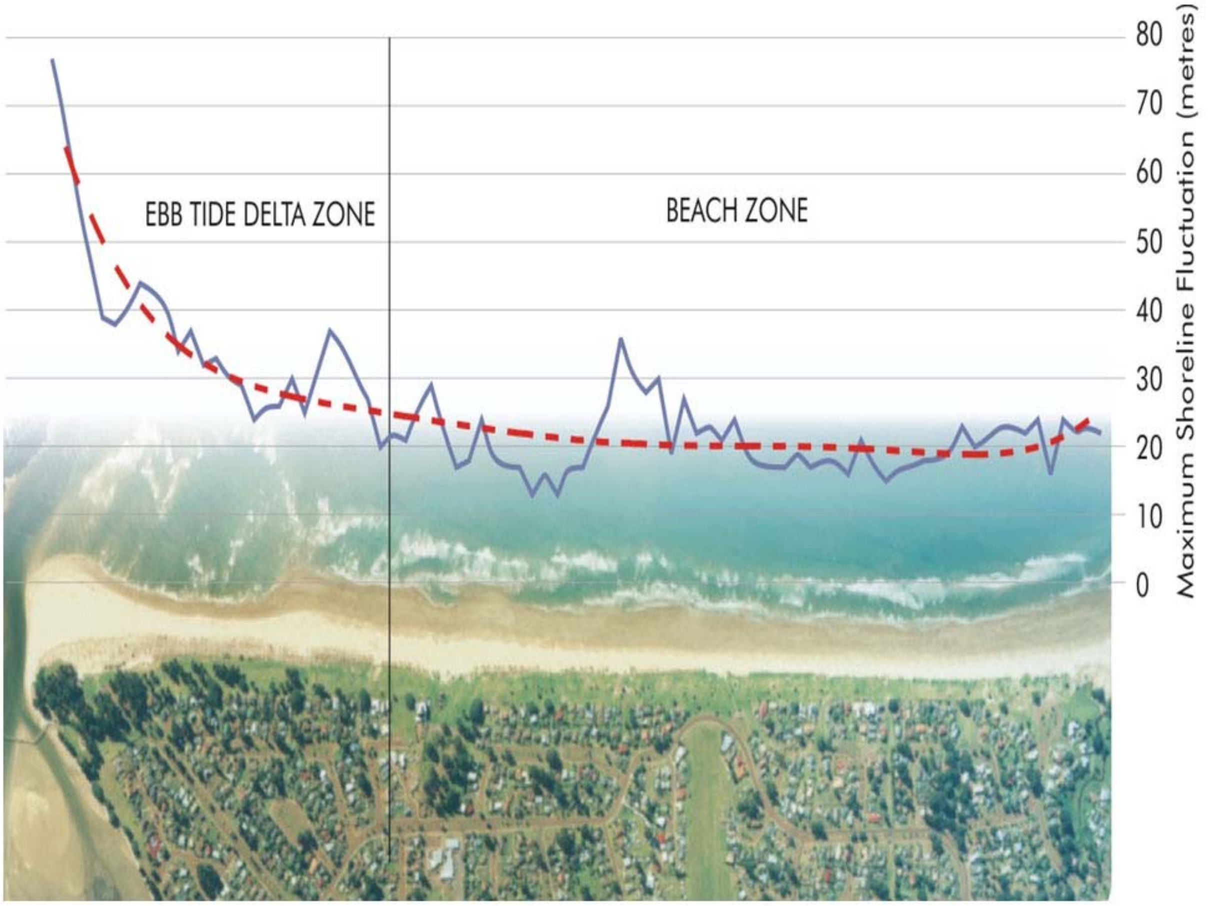

Figure 1: Maximum shoreline changes measured along Pauanui Beach (from Dahm and Munro, 2002).

2.1.2 Long-term trends for shoreline change

Significant rates of shoreline advance occurred at many eastern Coromandel beaches following initial formation of the beaches 6500-7600 years ago (Gibb and Aburn, 1986; Dahm and Munro, 2002). Detailed investigation of this beach advance based on drilling and dating of the barrier systems indicates that the rate of seaward advance has tended to decrease over time. Little to no net shoreline advance (typically <5 m/century) has occurred at most beaches in recent centuries (Dahm and Munro, 2002).

This indicates that beach sands were largely derived from wave reworking and onshore movement of sediments submerged by the recent post-glacial rise in sea level. The rate of shoreline advance decreased as the continental shelf came into equilibrium with prevailing processes and as sediment reserves suitable for beach deposition were depleted (Dahm et al, 1994; Dahm and Munro, 2002). The primacy of offshore sediment supply for the development of eastern Coromandel beaches is also consistent with evidence from detailed investigations of sediments on the nearshore continental shelf along the eastern Coromandel (Bradshaw, 1991; Bradshaw et al., 1994; Bradshaw and Nelson, 2004) and similar sites (Hilton, 1999).

Some net shoreline advance has occurred at a few sites in recent centuries. These isolated examples tend to occur on barrier systems located near the entrance of significant river catchments and probably reflect accelerated runoff from land catchments since early European settlement. Investigations of estuarine sedimentation in Coromandel estuaries indicate considerable (often 10-20 times) acceleration in sedimentation rates since early European settlement (e.g. Hume and Dahm, 1992; Swales and Hume, 1995). For example, there is evidence of some net shoreline advance (possibly 10-15 m) at Pauanui over the last century (Gibb and Aburn, 1986; Dahm and Munro, 2002).

There are also sites with evidence of recent trends for sustained historic erosion. In particular, data from Whiritoa and Kuaotunu West (aka Grays) Beaches indicates some long-term erosion (Dahm and Munro, 2002). These are both sites of historic sand extraction, with significant volumes of sand having been removed from the finite (and largely non-renewable) sand reserves of these beach systems (McLean, 1979; Healy et al., 1981; Dell, 1981; Dahm et al, 1993; Dahm and Munro, 2002). The trends for long-term retreat probably reflect local shoreline adjustment in response to these sediment losses, rather than a widespread trend for net erosion on eastern Coromandel beaches.

Dahm and Munro (2002) argued that available evidence otherwise suggests that most eastern Coromandel beaches are currently in dynamic equilibrium. Shorelines show little or no trend for shoreline advance or retreat over the 50-100 year timeframes relevant to human management. This assumption was reviewed in light of the data at each site. Sites which may not be in dynamic equilibrium are identified and discussed in Section 4. Sites that appear to be in dynamic equilibrium may have low rates of long-term erosion (i.e. <0.05 m/yr) that are not able to be detected with existing data but we have addressed this through inclusion of safety factors in the estimates as discussed in Section 3.2.3.3. Similarly, there may be low rates of continuing long-term advance that cannot be detected. It would not however be consistent with a precautionary approach to assume the presence of such trends. If long term trends for shoreline change (advance or retreat) are confirmed in the future they can be incorporated in the setbacks in future reviews.

2.1.3 Safety factor

There are inevitable uncertainties in any setback estimate, due to limitations with existing data and methodologies. It is therefore common practice to include an appropriate safety factor in hazard setback estimates.

A safety factor can also be applied for management purposes; for instance, to ensure a reasonable dune buffer still remains in the event of the worst estimated erosion. This can be particularly useful where a setback is intended to identify safe locations for new dwellings or infrastructure and/or avoid the need for protection works, as relevant to current use of the PDS. Use of a safety factor in such situations can help ensure that relevant owners are not only safe but feel safe – reducing demand for hard protection structures following severe events.

Safety factors can be cumulative where this is appropriate (e.g. where errors would have serious consequences). However, in this review we have concluded that this would be an overly precautionary approach and so each safety factor we have adopted usually covers 2-3 separate uncertainties.

It is important that safety factors are explicit so their influence on the total setback is clear.

2.2 Coastal Hazards on the Western Coromandel Coast

The review sites along the Thames Coast (Tararu, Te Puru, Waiomu and Waikawau) are settlements located on low-lying deltas formed at the entrances of significant streams discharging from the steep western flanks of the Coromandel Ranges.

The low-lying areas are stream deltas formed by the interaction of stream and wave processes and associated sediment transport (Dravitski, 1988; Dahm and Munro, 2002; Eco Nomos, 2003; 2008). Sediments deposited seaward of the stream entrances during floods are subsequently reworked by waves, with sands and fine gravels moved onshore to form the deltaic lowlands and the mixed sand and gravel beaches which generally front these features (Figure 2) (Eco Nomos, 2003; 2008). The deltas can be subject to overbank deposition during floods and to modification by stream channel changes, coastal processes and human activities. The shoreline dynamics and the gross morphology of the deltas therefore reflect the interaction of a wide range of factors acting over a range of spatial and temporal scales.

Figure 2: Example of the mixed sand and gravel beaches which tend to characterise the foreshore of the Thames Coast deltas

The intertidal and subtidal flats seaward of the beaches are often lagged with large rocks and coarse gravels in areas close to the river entrance (Figure 3). Swash bars are common over these intertidal flats, often shore perpendicular (Figure 3). Sands and fine gravels winnowed by wave action are also commonly evident as low onshore migrating swash bars. Sediment size over the intertidal flats generally decreases with distance from river entrances and the flats can be relatively sandy in some areas.

Figure 3: Rock and shell-lagged intertidal flat at Waikawau, typical of the low intertidal flats seaward of the Thames Coast deltas. This photo taken at mid tide also shows the shore-perpendicular swash bars and intervening swales that often characterise these areas.

The elevation of the subaerial (i.e. above high tide) regions of the deltas is largely determined by waves (i.e. beaches and associated storm ridges) and floods (over-bank deposits on flats, hollows associated with previous channels, etc). The deltas are therefore low-lying, except near the base of adjacent hills where landslip debris results in higher elevations. Survey data for Te Puru indicates that land elevations are often only 2.0-2.5 m above mean sea level (Tararu Datum). The coastal margin tends to be slightly elevated as a consequence of storm wave run-up and human activities (e.g. to reduce wave overtopping), with levels in this area typically ranging from 2.7-3.1 m.

The low-lying nature of the deltas makes them vulnerable to stream flooding.

Dahm and Munro (2002) found that these low-lying deltas are also subject to a number of different coastal hazards, including:

- **Coastal erosion associated with shoreline fluctuations**, with these changes generally most significant in the vicinity of stream entrances.
- **High velocity wave effects** (within 'V' zone in Figure 4) occur in nearshore areas where the coastal margin is overtopped by wave action during rare and severe coastal storms (e.g. Cyclone Drena, January 1997). These effects can transport significant volumes of rock debris where this material exists on the local shoreline (see Figure 68 later in this report).
- **Sea flooding of low-lying areas**, generally arising from wave overtopping of coastal margins and flooding of low-lying areas further inland.
- **Significant morphologic change** occurring over periods of several decades associated with river entrance and channel changes.
- **Projected sea level rise and other climate change effects**

These hazards, summarised schematically in Figure 4, are discussed further below and in Chapter 5.

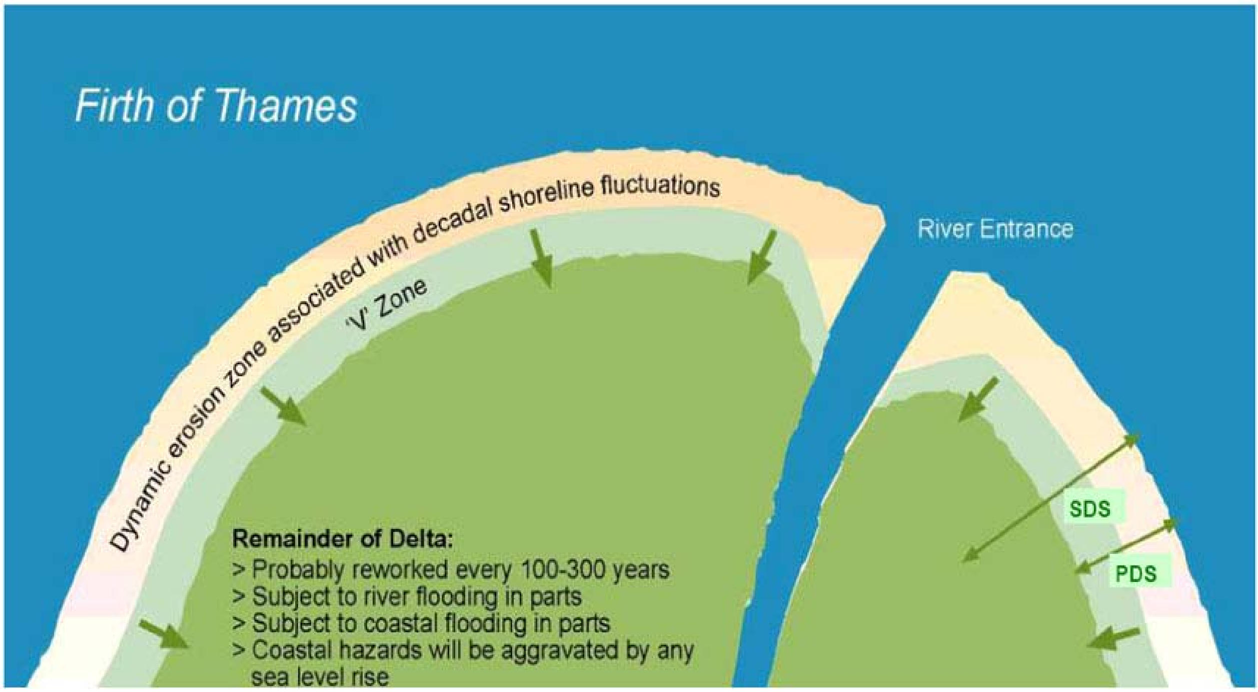

Figure 4: Schematic illustration of a typical Thames Coast delta showing the various coastal hazards the areas are exposed to and the risk factors addressed with the exiting PDS.

The influence of projected sea level rise to 2100 is addressed in the Secondary Development Setback (see discussion in Section 1) and is not relevant to the review of the PDS. The potential impact of sea level rise has however been included in consideration of coastal flooding. The remaining factors are briefly discussed below.

2.2.1 Coastal erosion associated with shoreline fluctuations

Dynamic shoreline fluctuations are common around the deltas of the Thames Coast, tending to be most significant near stream entrances (Dahm and Munro, 2002).

Available evidence suggests the most significant fluctuations tend to be multi-decadal in nature, with the maximum erosion typically cumulating over a number of storm or other (e.g. river flood) events. Subsequent recovery also cumulates over periods of many years (Dahm and Munro, 2002).

For example, the beach in front of Te Puru School progressively eroded landward during a number of storm events in the 1990s, culminating in Cyclone Drena of January 1997 and placement of a backstop seawall. The beach has since gradually recovered and a wide high tide beach now exists seaward of the seawall (Dahm and Munro, 2002; see also further discussion in Section 5.2.2). A similar cycle of erosion and recovery is evident in historic data from Te Puru, with severe erosion in the 1940s followed by a period of recovery (Dahm and Munro, 2002) (see Section 5.2.2). The period between the two successive erosion cycles was in the order of 50 years.

The reasons for these decadal fluctuations are not well understood, but there appear to a number of factors involved, including:

- **"Cycles" of sediment delivery and removal.** Widespread accretion often tends to occur after periods of significant sediment input during major floods (e.g. following the 'Weather Bomb' in June 2002). Similarly, erosion tends to occur when there is less frequent sediment input from floods and sediment losses through net longshore removal tend to dominate (e.g. 1990s).

- **Climatic variations** which may influence the frequency of coastal storms (i.e. erosion tending to occur during periods with a higher frequency of coastal storms and accretion tending to be more marked during periods with a lower frequency).
- **Various local factors** such as cyclic changes around stream entrances, as discussed by Dahm and Munro (2002) in respect to the Te Puru stream entrance, and a range human influences and activities (see discussion in Section 5).

The importance of various local and coast-wide drivers of coastal erosion and shoreline change varies from site to site and even within individual coastal systems. This is also observed along the east coast.

Coastal erosion was quite widespread in the 1990s and coastal accretion over the few years following the 'Weather Bomb', indicating the importance of coast-wide factors. Local factors can also be important. For example, there was extensive accretion around the Tararu entrance after the weather bomb (related to both natural sediment input and disposal of dredged sediment). Shoreline areas further south however continued to experience erosion for some years until the sediments deposited near the stream entrance were redistributed southwards by longshore drift (see discussion in Section 5.2.1).

2.2.2 High velocity wave effects associated with wave overtopping

Wave breaking on the mixed sand and gravel beaches fronting deltas occurs close to the shoreline. Extreme waves tend to break by plunging near the base of the beach face, unlike the wide dissipative surf zones of the eastern Coromandel. Wave energy is therefore dissipated over a narrow beach width. This results in significant wave run-up and overtopping of the low lying coastal margins during periods of extreme waves.

Severe wave run-up and overtopping is infrequent as the Firth of Thames is dominated by fetch-limited wind waves, with heights typically less than 1 m and with wave periods of 2-4 seconds.

The Firth is largely sheltered from significant ocean swell, with the most frequent swell waves being highly refracted and therefore low (typically < 0.2 m) by the time they reach the upper Firth. Extreme swell waves can, however, occur from a northerly quarter (particularly NNW), with swell from this direction running directly into the Firth from the outer Hauraki Gulf. These waves are extensively modified by wave refraction by the time they reach the study sites relevant to this report. Nonetheless, during major storms and periods of extreme sea level, significant wave energy can still penetrate to the upper Firth. The most extreme wave event in recent decades was Cyclone Drena in January 1997. This event, with strong northerly winds, generated large swell in the outer Hauraki Gulf. These waves were significantly reduced by refraction, but heights up to approximately 1 m were observed in the upper Firth. Storm swell has longer wave periods (commonly around 6 seconds) and therefore higher energy than locally-generated wind waves.

Severe wave overtopping during major storm events is accompanied by high velocity wave effects in areas close to the shoreline. During Cyclone Drena, these overtopping velocities were often sufficient to transport significant volumes of rocks, gravel and debris up to 10-15 m inland.

Severe wave overtopping events of this magnitude are relatively infrequent. For instance, a detailed review of historic records undertaken by Dahm and Munro (2002) noted only six major storm events since 1936 in which sea flooding appeared to be of similar or greater magnitude to the events of July 1995 and Cyclone Drena. These events are irregularly distributed over time, with 4 such storms in the 15 year period between March 1936 and March 1951, inclusive; followed by a break of just over 34 years before the next event (July 1995); and then a period of less than 2 years to Cyclone Drena (January 1997).

In addition to the mixed sand and gravel beaches, there are locations with largely sand-dominated beaches. There may have been wind-formed dunes landward of some such beaches in their natural state (e.g. probably at Thornton and Ngarimu Bays), but these features have long since been removed or lowered by human encroachment (e.g. roads, development) making back-beach areas low and vulnerable to wave overtopping.

In general, most beaches and backshores along this coast are vulnerable to wave overtopping during extreme conditions.

2.2.3 Sea flooding of low-lying areas

Serious coastal flooding can be experienced along the Thames Coast – affecting not only the coastal margins of the settlements but often also flowing through and ponding in low-lying areas further inland. Extensive sea flooding affected dwellings at Thames, Moanatairi, Tararu, Te Puru, Waiomu and Waikawau during the most recent sea flood events of July 1995, and Cyclone Drena (January 1997).

The coastal flooding arises from the combined influence of astronomical tides, storm surge and wave effects, particularly wave run-up and overtopping. Astronomical tides and storm surge result in elevated sea levels relative to predicted tides, with this elevated sea level widespread along the coast. Wave run-up and overtopping are more localised effects and vary according to factors such as wave exposure and elevation of the coastal margin. These various factors are reviewed and discussed in Section 5.1.

The relative importance of extreme sea levels (i.e. tides and storm surge) and wave run-up varies with different events. For instance, in the July 1995 sea flood event, wave action was far less severe than during Cyclone Drena but was accompanied by a higher extreme sea level (peaking at RL 2.48 m at the Tararu tide gauge, compared to RL 2.05 m during Cyclone Drena). In both events, the combination of extreme sea levels and wave run-up overtopped coastal margins of RL 2.6-2.8 m. In some places, wave run-up and overtopping exceeded RL 3.0 m, particularly during Cyclone Drena (Dahm and Munro, 2002).

2.2.4 Significant long-term morphologic change

Significant morphologic change occurs over periods of several decades at some sites - associated with river entrance and channel changes (Dahm and Munro, 2002). These changes are most marked in the northernmost deltas, particularly Waikawau and Tapu (Dahm and Munro, 2002). This could reflect the slightly higher wave energy that occurs with distance north, resulting in more active longshore drift and associated stream entrance changes. Human activities, including dredging and the placement of shoreline armouring works also prevent large-scale changes at deltas further south.

3 Data and Methodology

The following sections briefly outline the data and methods adopted to review the Primary Development Setback at the selected sites. Separate approaches have been adopted for the eastern and western Coromandel coasts reflecting the different coastal morphodynamics of these areas.

3.1 Data

The existing setback recommendations described in Dahm and Munro (2002) were based on historical shoreline change information from surveys and photographs, limited beach profile data, field observations, previous work, management agency files and public information. The bulk of the analysis was undertaken in 1999 and involved data available to 1998/99.

This review takes advantage of further information that has become available over the last 10 years. In particular, the beach profile records at most sites now contain considerable additional information – including, for a number of sites, instances of severe erosion.

The various data used for this review is discussed below.

3.1.1 Beach Profile Data

3.1.1.1 Eastern Coromandel Beaches

Beach profile data has been gathered on the East Coast of the Coromandel Peninsula by Environment Waikato and its predecessors since 1979 – with data available for all sites in this review except Matapaua Bay.

This data was not extensively used in the earlier report, as with only a few exceptions the records to that time did not include a period of major coastal erosion – the period from 1979 to the mid 1990s typically being dominated by beach and dune recovery following the erosion culminating in 1978. There was also no common vertical datum between the sites and various issues with some of the data.

Since the mid-late 1990s, severe erosion has been experienced at a number of sites and most beach profile records now contain surveys after periods of storm erosion. This significantly improves the usefulness of this data for the estimation of extreme erosion.

Environment Waikato has now surveyed all sites to a common mean sea level datum, obtained additional data from other sources, and addressed issues and uncertainties with most historic data. This extensive and useful upgrade work, detailed in reports by Stewart (2002; 2006), has considerably improved the value and reliability of this data set.

There are also now improved techniques available to estimate the worst estimated erosion using beach profile data (see discussion in Section 3.2.3).

In view of these factors and the availability of beach profile data for most review sites, this data was used to develop estimates of extreme erosion for this review. The methodology is outlined fully in Section 3.2.3.

The review included detailed analysis of all beach profile data held by Environment Waikato for the key sites listed in Table 1. The review was also able to obtain excursion distance data from the additional beach profile data set surveyed and compiled by Mr. R. Keith Smith, a coastal science consultant based in Hamilton.

The analysis at most sites considered all data available up to September 2007 – the limit of the reduced data available when the analysis was undertaken. Subsequently, major storms in July and August 2008 caused severe erosion in central and southern areas of Whangapoua Beach and, to a lesser extent, some other review sites (Matarangi, Rings Beach and Kuaotunu East). The severity of the erosion at the southern end of Whangapoua Beach was equal to or greater than any erosion at that site for at least 50-60 years. The analysis for these sites was therefore repeated to include profiles surveyed after the July and August 2008 storms. The impact of the storms at other sites was generally negligible.

3.1.1.2 Western Coromandel

In general, there is no beach profile data available for western Coromandel beaches.

The only exception is beach profile monitoring conducted along the foreshore fronting Te Puru School from December 1992, to document a period of severe erosion. The monitoring involved 13 transects covering the full 330-350 m length of the foreshore. The monitoring continued into the subsequent period of beach recovery – with the most recent survey conducted in February 2000. Additional field measurements were conducted during this review to complement the available information.

The erosion phase had been under way for several years when the surveying work commenced and therefore the beach profile record does not record the most seaward shoreline location prior to commencement of the erosion. However, useful quantitative information on this shoreline position was obtained from historic surveys and community information. The beach is currently in an accreted position, so field measurements conducted during this review also provide a useful indication of more accreted shoreline positions.

3.1.2 Shoreline Change Maps

3.1.2.1 Eastern Coromandel

Mapping of historical shoreline changes from rectified aerial photography has been conducted at various eastern Coromandel sites (Dahm and Munro, 2002), including two sites within the scope of this review (Whangamata and Buffalo Beach). The dates of the mapped shorelines range from 1944 to 1993 (Table 1).

The shoreline mapping at both sites included photography purpose-flown in September 1978 to record the impact of the July 1978 storm wave event. The landward extent of erosion following this event was among the most severe noted at many eastern Coromandel sites over the last 65 years.

Table 1: Historic shoreline mapping data available for Whangamata and Whitianga. The work was commissioned by Environment Waikato, who hold copies of the plans.

Location	Years	Plan Numbers	Company
Whangamata	1944; 1959; 1973; 1978; 1993	*3107/1000/A1/793 Sheets 1-7*	Photosurvey Ltd Auckland
Whitianga(Buffalo)	1944; 1967; 1/1978; 9/1978; 1993	*3240/1000/A1/395 Sheets 1-7*	Photosurvey Ltd Auckland

The shoreline mapping at both sites was conducted by Photosurvey Ltd of Auckland (now Precision Aerial) using a stereo-plotter. The seaward toe of foredune was mapped for each of the aerial photographic surveys. The top landward edge of the eroded dune scarp was also mapped from the September 1978 photography to record the extent of erosion during the July 1978 event. A coastal scientist (J Dahm) was present during the mapping to confirm the shoreline features being mapped.

Photosurvey Ltd estimated the accuracy of the mapping as ranging from ± 1.5-2.0 m to ± 4.0 m (the later usually the 1940s imagery) (Letter from Keith Miller of Photosurvey Ltd, dated 7 September 1993).

Healy et al., (1981) also mapped historic shoreline change for most developed beaches of the eastern Coromandel beaches using aerial photography dating the 1940s to September 1978. This mapping was conducted by transposing and overlaying shoreline information using simple manual techniques and unrectified enlargements. Shoreline mapping similarly compiled from unrectified photography is also available for Tairua and Matarangi from other sources (Dahm and Munro, 2002). The use of unrectified imagery lessens the positional accuracy of the plotted shorelines in these data sets, and this data, while useful, was given less emphasis in determining the revised PDS.

The shoreline mapping using unrectified imagery was of limited value to this review, but was occasionally used to confirm dates of severe erosion.

3.1.2.2 Western Coromandel

Historic shoreline change maps were available for Tararu, Te Puru and Waikawau (Table 2). This data was compiled for the review of the setbacks undertaken in the 1990s (Dahm and Munro, 2002). In view of the general absence of beach profile data for the western Coromandel, this shoreline change and other historic information has played a significant role in the present review (see Section 3.2.4)

The Tararu data was commissioned by Environment Waikato in 1998 and included:

- Survey of the toe of bank and the seaward toe of the beach (i.e. where the beach intersects with the low tide platform further seaward) over the full length of the shoreline south of Tararu Creek.
- 28 cross sections over the beach to approximate low tide at 50 m intervals from the Tararu Sailing Club (south end of Tararu) to the mouth of Tararu Creek
- Compilation of available cadastral survey information – limited to an undated MHWM survey (shown as “Old MHWM” on plan) plotted from a 1952 survey plan (SO35852). The actual date of the survey is unknown but is believed to be the early 1900s or earlier.

The Te Puru data commissioned by Environment Waikato in 1995 included:

- Survey of the toe of bank and seaward toe of beach over the full length of the Te Puru shoreline
- 28 cross sections over the beach to approximate low tide over the area south of Te Puru Creek and 16 cross-sections at variable (typically 10-30 m) spacing over the area fronting Te Puru School
- Compilation of available historic cadastral surveys. Each survey generally covers only part of the Te Puru shoreline but there are typically at least three separate surveys (including the 1995 data) for most parts of the shoreline. The earliest surveys in most areas dates from either the 1800s (1868 forward) or the early 1900s.

Shoreline changes in the period from 1968 to 1991 were also mapped by O’Regan and Chalmers (1995) using rectified imagery from 1968, 1983, 1985 and 1991.

The Waikawau data commissioned by Environment Waikato in 1998 included:

- Survey of the toe of bank and seaward toe of beach over the full length of the Te Puru shoreline
- 13 cross sections over the beach to approximate low tide over the area south of Waikawau River
- Compilation of historic cadastral surveys from 1925 and 1939 (plotted with the 1998 survey).

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Table 2: Historic shoreline change information available for Tararu, Te Puru and Waikawau

Location	Years	Plan Numbers	Company
Tararu	"Old MHWM" 1952 1998	1661 Sheets 1-6	FW Millington Ltd Thames
Te Puru	1869/70 1898 1913 1921 1927 1942 1946/47 1955 1995	1344 Sheets 1-13	FW Millington Ltd Thames
Waikawau	1925 1939 1998	1661B Sheets 1-5	FW Millington Ltd Thames

3.1.3 Previous Reports and other Historic Data

Previous reports on coastal hazards at the study sites were reviewed for relevant observations and data. This included work by Carter (1976), Smith (1980), Healy et al. (1981), Dell (1981), Healy and Dell (1982), Dravitski (1988), Bradshaw (1991), Bradshaw et al. (1991; 1994), O'Regan and Chalmers (1993), Tonkin & Taylor (1998; 2003), Dahm (1999a; 1999b), Dahm and Munro (2002), Cooper (2003), Bradshaw and Nelson (2004), Beca et al. (2004) and approximately 30 property-specific reports.

Other historic information included summaries of historic newspaper reports on coastal storms from the extensive storm database compiled by Environment Waikato (Dahm and Munro, 2002) and a search of relevant Council files for information on past storms and coastal hazards.

3.1.4 Community Information and Knowledge

This review involved extensive liaison with affected landowners, with emphasis given to seeking information from the owners in respect to past coastal hazard impacts.

The liaison included:

- A reply-paid questionnaire sent to all beachfront owners seeking information
- 11 public meetings held in coastal communities around the Peninsula during the weekend (eastern Coromandel) and evenings (western Coromandel) to discuss the setback review and obtain feedback and further information from the community. The process by which the setbacks were derived and the preliminary findings were also discussed to seek feedback. Considerable useful information was obtained at the meetings and in follow-up meetings and discussions.
- Several on site meetings with property owners to discuss individual sites or properties, as well as numerous telephone conversations and e-mails.

In addition, a wide range of historic community information was obtained from Council files. These included copies of all submissions relevant to coastal hazards and flooding received by Council during 2007 in response to advertisement of a draft hazards variation for public comment. Approximately 884 submitters responded to the variation with around 112 providing information or comment in respect to coastal hazard or river flooding hazard risk to their properties or area.

3.1.5 Recent and Historic Photography

A large number of recent and historic photographs were viewed during this review to help assess historic shoreline change, including:

- **Copies of the existing setbacks plotted on most recently available (2007/2008) ortho-**

rectified photography with property boundaries marked. This facilitated ready identification of the areas where the existing setbacks most significantly restrict existing use of private properties, identifying key areas requiring particular focus during the review.

- **Historic aerial photography**, including Whites Aviation oblique photography for many sites and historic vertical photography. The Whites Aviation photography and historic aerial photography was accessed through collections held by Environment Waikato and the Alexander Turnbull Library (ATL), including a visit to the latter institution to inspect imagery and also access to the extensive photographic available online through the ATL "Timeframes" site. This photography provided useful qualitative and semi-quantitative information on shoreline position and shoreline change (e.g. using shoreline features still present at the time of this review). At some sites, the available historic photography provided good coverage extending back to the 1940s, providing valuable data on shoreline change over this period. These sites included Tairua, Whitianga, Whangamata and Whangapoua on the east coast, and Tararu and Te Puru on the west coast.
- **Historic photographs** showing duneline position and/or coastal hazard damage from Council files, landowners and the wider community, newspaper reports and our own personal records. These photos often provided a useful cross-check on coastal erosion and flooding hazard estimated using other data. The data included extensive photographs of damage sustained during the July 1995 and January 1997 (Cyclone Drena) coastal flooding events along the western Coromandel, together with a large number of spot levels (maximum flood levels, debris lines, etc) surveyed after this event.

3.1.6 Field Investigations

Field investigations were undertaken at all sites to:

- **Check and ground truth the extreme erosion estimates** developed using available data. The erosion estimates developed for east coast sites using beach profile data were taped out at each beach profile site, with the site and general area checked for any evidence of historic erosion of similar or greater magnitude (old erosion scarps, etc). The field inspections also assessed the representativeness of each beach profile site (e.g. whether there were local factors that may exacerbate or reduce erosion relative to adjacent beach areas).
- **Investigate the presence of subsurface geology** that may limit erosion. These observations included examination of local exposed banks and digging or hand-auguring to depths of up to 1.5 m where such materials were suspected. Discussions with local landowners (many of whom have drilled or excavated their properties for various reasons over time) also helped assess subsurface geology.
- **Observe geomorphic and other features** relevant to understanding shoreline dynamics and historic change at the site.
- **Undertake survey work** (e.g. cross sections) as required to complement existing information. This was particularly important at sea-walled sites (e.g. parts of Buffalo Beach, Tararu and Te Puru), to assess the extent of influence imposed by the structures on foredune position.

3.2 Methodology

3.2.1 Key Assumptions

The following factors and assumptions have shaped the methodologies adopted in this review:

i. **The key objective of the PDS is to identify the area likely to be impacted by coastal erosion with existing coastal processes** for events up to and including the 1% Annual Exceedance Probability (1%AEP). The 100 year return period is standard best practice in coastal hazard assessment.

ii. **The review relates to sites with existing residential development close to the shoreline.** The setbacks must therefore meet the above 1% AEP standard, without being unnecessarily precautionary. Clearly, this assumes that any remaining risk will be managed by other means (e.g. relocatable dwellings). In our opinion, the methodologies used in this report are generally <u>not</u> therefore appropriate for Greenfield sites (i.e. new subdivisions) where total hazard avoidance is generally practical and appropriate.

iii. **The shorelines are composed of loose erodible Holocene sands and are free to erode back to the defined setback,** except where explicitly recognised and provided for**.** Considerable attention has been given to identifying sites where erosion is likely to be constrained by underlying resistant materials and the setback has been modified accordingly at such sites.

iv. **Human activities and structures which mitigate erosion have only been taken into account where these measures have been consented or otherwise accepted as appropriate long-term (i.e. > 50-year) solutions to erosion hazard**. In some areas (particularly parts of Buffalo Beach, Tararu, Te Puru and Waiomu), the revised PDS thus defined extends deeply into private properties. These are areas where the current application of the PDS would preclude reasonable use of properties. Site-specific strategies involving additional measures will be required at these sites. In practice, Council already allows reasonable use of most such properties and so there is a presumption that appropriate hazard mitigation strategies will ultimately be developed.

v. **Coastal flooding will be adequately addressed through means other than setbacks** (e.g. building design; minimum floor levels). The revised PDS defines coastal erosion hazard only - a change from the existing PDS on the western Coromandel Coast. This places further emphasis on the need to ensure appropriate minimum floor levels and design for new dwellings and renovations.

3.2.2 Disclaimer

On the basis of the available data considered in this review, we believe the revised PDS will provide protection for worst estimated erosion within return periods of up to at least 100 years <u>with existing sea level.</u>

We emphasize however that there are considerable uncertainties that relate to potential sea level rise. These uncertainties have been further emphasized with early findings arising from the recent International

Polar Year (2007-08), a major internationally coordinated campaign of research looking at both the Arctic and Antarctica and involving over 50,000 scientists from more than 60 countries. Results published recently (March 2009) suggest that the IPCC 2007 assessment may considerably under-estimate sea level rise over the next century.

Sea level rise therefore inevitably poses some potential risk within the next 50 years that is not adequately accounted for in our calculations. This additional risk is defined by the Secondary Development Setback (SDS) (see Section 1). Residual risk beyond the PDS associated with projected sea level rise must therefore be recognised and managed. Reliance should not be placed on the setbacks alone.

3.2.3 Methodology Used to Review PDS at East Coast Beaches

On the basis of the discussion in Section 2, the review of the PDS at eastern Coromandel beaches requires consideration of:

- The maximum likely erosion associated with dynamic shoreline fluctuations
- An appropriate safety factor

The methodology adopted in this review is outlined below.

3.2.3.1 Estimate of maximum likely erosion

A wide variety of techniques can be used to estimate the maximum likely erosion associated with dynamic shoreline fluctuations (NSW, 1990; ARC, 2000; MfE, 2008). There is no one standard technique that provides reliable estimates; all techniques have particular strengths and weaknesses and all depend heavily on expert judgment (and, sometimes, local knowledge). Available data can also have a significant influence on the choice of technique and the level of uncertainty.

In our opinion, the most reliable results are best obtained by:

- Using a wide variety of approaches and data to cross-check results
- Placing emphasis on the use of observations and measured data.

In this review, estimates of maximum likely erosion were first developed at all sites using available beach profile data (Section 3.1.1). These estimates were then cross-checked using field inspections (Section 3.1.6) and all other data available (Sections 3.1.1 to 3.1.5). This methodology is discussed in more detail below.

3.2.3.2 Initial estimates of extreme erosion using beach profile data

Beach profile data was used to calculate the worst estimated dune erosion as this data was available at all sites except Matapaua and enabled a consistent methodology to be adopted. The beach profile data was typically the best quantitative data available, with most records used for this review covering a period of at least 25-30 years and/or containing periods with at least 1-2 examples of severe erosion.

There are various techniques that can be used to calculate worst estimated erosion from beach profile data.

A widely used technique is that developed by Komar et al. (1997; 1999) and referred to in this review as the “Komar Method”. In essence, the method assumes that erosion is not limited by storm duration and can continue to the maximum limit of wave run-up. If the method is applied to the most deeply eroded storm cut profile in the record, it can provide a useful estimate of the worst possible erosion at that site. This method is therefore overly precautionary where erosion is duration-limited.

Examination of the use of this technique for developed eastern Coromandel beaches indicated that this approach over-estimates erosion. Use of the Komar Method would have placed the PDS near the landward edge of many existing beachfront sections. Checks of these estimates indicated they were well in excess of any erosion evident in available data. This reflects the duration-limited nature of beach erosion along the eastern Coromandel (Section 2.1.1.1).While such extreme erosion is theoretically possible, available evidence suggests it has a return period well in excess of 100 years with existing sea level, if it occurs at all. The assumption of unlimited storm duration central to the Komar Method was therefore judged to be inappropriate in the context of Coromandel beaches and the considerations outlined in Section 3.2.1.

This review uses an alternative method based on the assumption that (over long periods of time) the variation in dune toe position perpendicular to the shore is normally distributed (Dahm, 2006). We believe this is a reasonable proposition on shorelines such as the eastern Coromandel where shoreline variation is dominated by dynamic shoreline fluctuations.

All normally distributed populations follow the Empirical Rule with 68% of observations falling within 1 standard deviation of the mean, 95% within 2 standard deviations and 99.7% (i.e. almost all values) within three standard deviations. Therefore, values 3 standard deviations from the mean generally provide a good measure of extreme values within such populations.

The method uses the following procedure to calculate the most extreme seaward and landward dune toe positions likely to occur:

- Calculate the mean dune toe position using excursion distance data
- Calculate the standard deviation of the dune toe positions
- Estimate the most accreted dune toe position likely to occur (i.e. Mean + 3 standard deviations)
- Estimate the most eroded (i.e. landward) dune toe position likely to occur (mean – 3 standard deviations)

In this review, we modified the method further – calculating weighted means and weighted standard deviations; with the weighting based on the time interval between successive surveys. This helps remove bias that would otherwise occur given the highly variable time interval between successive surveys in the available data sets.

The method has significant advantages for the estimation of erosion where suitable data exists. In particular, it enables the exact position of the estimated erosion to be fixed – since the outcome of the calculations (i.e. most accreted and most eroded dune toe positions) are offset relative to a benchmark of known position (i.e. the beach marker used for the beach profile monitoring). This eliminates the problems that can arise when choosing an appropriate baseline from which to map the setbacks. Significant unacknowledged error can be incorporated into setbacks if inappropriate baselines are used. In our experience, this is relatively common. The most appropriate dune toe elevation for the calculations was selected by careful examination of the survey data at each site, using plots of the entire record. Care was taken to ensure the dune toe elevation used for calculations was always above the maximum high tide beach level in the record. This ensures the excursion distance data reflected dune rather than high tide beach movements. Otherwise, significant error can arise. Where appropriate dune toe elevation was not clear in the beach profile data, field observations and survey data was used.

The estimate of extreme dune erosion also included allowance for collapse of the near vertical dune face scarp typically formed by storm erosion. It was assumed this face would collapse to a slope of 1V:3H – with the slope formed by collapse of the top half of the bank to the base of the bank. In other words, following dune slope collapse, the top edge of the erosion scarp lies landward of the post-storm eroded dune toe by a distance equal to 1.5 times the height of the eroded dune face (Figure 5).

Field observations over several months following the severe erosion at Whangapoua in July-August 2008 suggest this is precautionary; with surveyed sections showing collapsed dune faces were generally steeper than 1V:2H (Eco Nomos, 2008).

3.2.3.3 Safety factor

It is standard practice in coastal hazard assessments to include safety factors where appropriate to provide for uncertainties and data limitations. Unavoidable uncertainties relevant to this study include:

- **Length of data set.** The beach profile data sets are all less than 30 years long, and generally record only 1-2 (rarely 3) separate periods characterised by extreme erosion. Given the importance of multi-decadal variation in extreme erosion at these beaches as discussed in Section 2.1.1, data sets should ideally contain several such cycles to reliably estimate extreme erosion. It is therefore possible (or even likely) that the record does not contain the most severe past erosion. We have attempted to mitigate this limitation through field observations, community information and other data on historic erosion (Section 3.1). Nonetheless, some uncertainty remains.

- **Shoreline trends over period of available records**. Many of the Coromandel data sets appear to be skewed in favour of advanced shoreline positions. The primary reason for this is that the period from 1979 to the early-mid 1990s was dominated by beach and dune recovery at many sites (see Section 2.1.1). This could bias the estimate of mean shoreline position to seaward and may lead to under-estimation of the standard deviation. These sources of error could lead to under-estimates of extreme shoreline erosion.

In light of these data limitations, two separate safety factors were applied as shown in Figure 5.

The first safety factor is included to ensure the worst estimated dune toe erosion is precautionary. The magnitude of the required safety factor was assessed by:

- Plotting constructed erosion profiles for the worst estimated erosion at each site and comparing this to the record of historic change at that site (e.g. Figure 6).

- Checking the estimated dune toe erosion against the worst measured erosion at that elevation.

This found that the estimates often exceeded the worst measured erosion by less than 5 m and commonly by only 1-3 m (e.g. Figure 6). To ensure estimates were adequately precautionary, a safety factor of 5 m was added to all estimates of extreme dune toe erosion. This is equivalent to approximately 20-25% of the average extreme fluctuation. In our judgement, this is a sufficient provision to ensure the estimates are precautionary for return periods of up to 100 years with existing sea level. This safety factor was applied prior to the calculation of dune slope adjustment (Figure 5). We believe this safety factor is adequate and reasonable to provide for uncertainties associated with the data and current knowledge. This safety factor will be more or less precautionary depending on the scale of shoreline fluctuation at the site, being more precautionary where the beach experiences very little shoreline change (e.g. Wharekaho Beach).

A second 5 m safety factor was applied after calculation of the dune slope adjustment to ensure the safe location of new dwellings for periods of at least 50 years. We believe this factor is required to ensure a useful dune buffer is retained following the most severe erosion likely. In essence, this safety factor is intended to ensure that not only are the dwellings safe but owners also feel safe. It also ensures sufficient space for dune restoration work if required (e.g. dune enhancement with beach scraping; planting to encourage dune recovery; etc). We do not believe it is appropriate to have a setback (and therefore potentially a dwelling) located right on the line of the worst estimated erosion. Owners would not feel safe even if they were – probably resulting in increased demand for seawalls following severe erosion. In our judgement, an allowance of 5 m for this factor is the minimum reasonable provision. For instance, following erosion of July and August 2008 at Whangapoua, considerable concern was expressed by landowners with dwellings within 5-7 m of the top of the erosion crest. A safety factor of 10 m would be more ideal to provide for these concerns at many sites but would result in further restriction on property use. However, the lesser 5 m allowance is probably adequate. For instance, the experience at Whangapoua was that landowner concerns were able to be resolved without recourse to seawalls and there was sufficient space for required dune restoration. Nonetheless, the adequacy of the lesser (5 m) safety factor proposed is a matter Council should review in the light of future experience, increasing further if required.

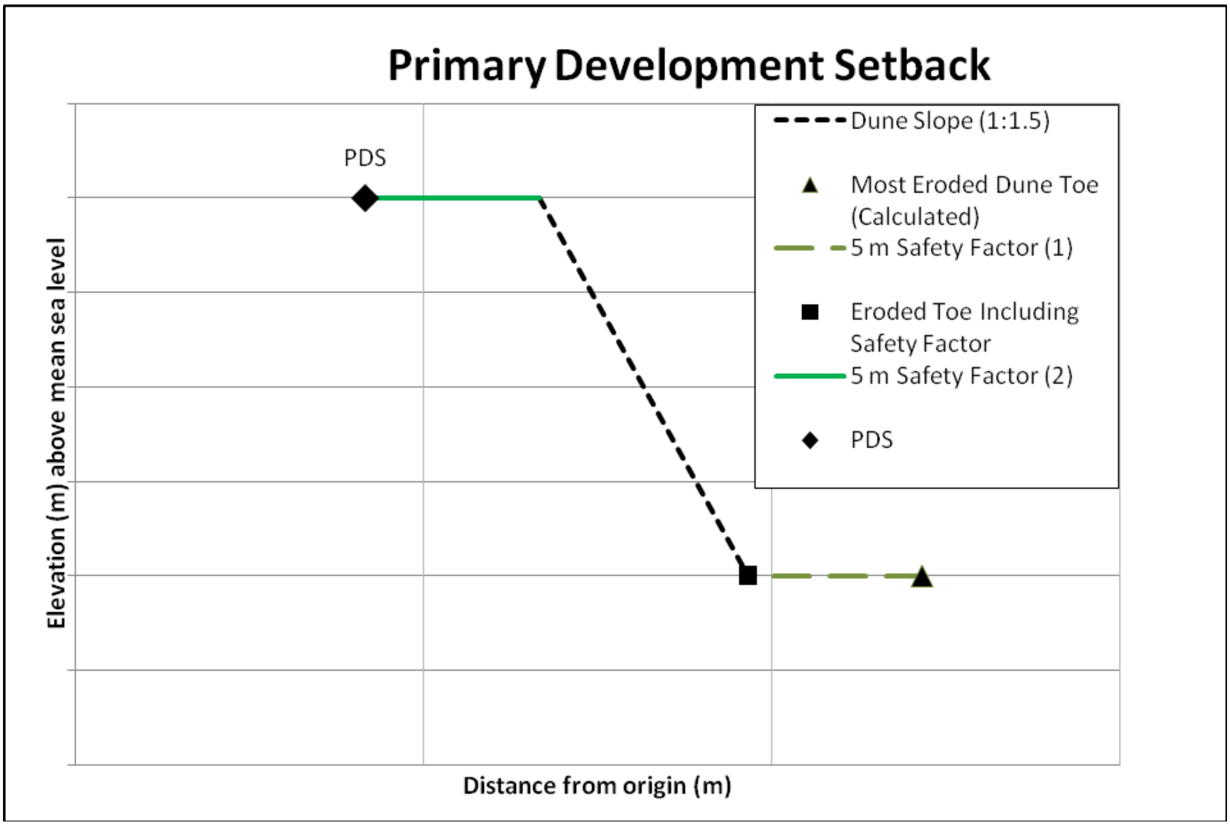

Figure 5: Key parameters including safety factors used to calculate revised PDS (see text for explanation)

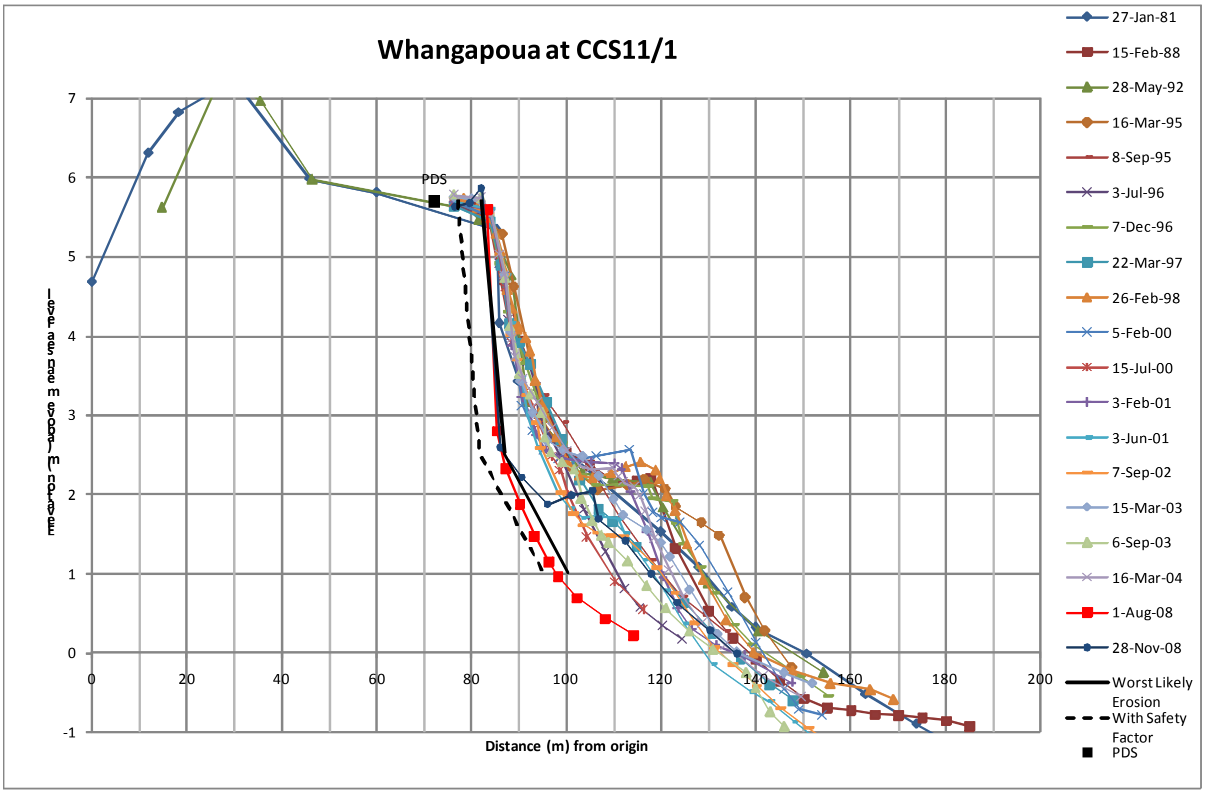

Figure 6: Example showing worst estimated erosion at site CCS11/1, with and without 5 m safety factor.

3.2.3.4 Check of estimates against other data

The worst estimated erosion calculated using the beach profile data were then checked using field inspections and all other available data for each site - including worst measured erosion in the beach profile records, historic shoreline mapping data, community information, previous reports and historic photography (see Section 3.1).

This process included checking both for any evidence of:

- Historic erosion more severe than the estimates
- Erosion resistant materials or other factors which may limit erosion to less than the estimates.

The estimates were found to exceed worst measured erosion from all data sources at all sites.

There were a number of sites identified where lesser erosion is likely to occur due to the presence of erosion resistant materials and, accordingly, setbacks were reduced at these sites. Detailed considerations for each site are discussed in Section 4.

3.2.4 Methodology Used to Review PDS at West Coast Beaches

The existing PDS at West Coast sites incorporates an allowance for high velocity wave effects associated with overtopping as well as coastal erosion associated with dynamic shoreline fluctuations and, where relevant, longer term trends. In this review, the allowance for high velocity effects has been removed from the setback with all coastal flooding effects to be managed by other means (e.g. minimum floor levels) – as discussed in Section 3.2.1. The risk posed by coastal flooding is also reviewed.

The following sections briefly outline the methodology adopted to assess coastal flooding and erosion and to revise the PDS along this coast.

3.2.4.1 Coastal Flooding

Coastal flooding along the Thames Coast arises from the combination of astronomical tides, storm surge and wave effects, particularly wave run-up (Dahm and Munro, 2002). The susceptibility to coastal flooding also varies with the elevation of the coastal margins.

Astronomical tides and storm surge result in an elevated sea level which probably applies fairly widely at all sites in this review. Serious flooding can occur where this extreme sea level exceeds the elevation of coastal margins.

Available information suggests that wave run-up and overtopping is a significant factor in coastal flooding along the Thames Coast. Much of the serious flooding during the July 1995 and Cyclone Drena events would not have occurred in the absence of wave action. This reflects the fact that, in general, the elevation of the coastal margins exceeded the extreme sea level experienced during these events. There were exceptions (e.g. parts of Tararu and Te Puru in July 1995 – though the Tararu areas have since been raised).

Estimation of the extreme sea level likely to be experienced at the review sites from the combination of storm surge and astronomical tides was based both on analysis of the Tararu tide gauge (Goring, 1995, Goring et al. 1997; Bell and Hill, 1997) and on historic information. In time, analysis of data from the Tararu tide gauge will provide the most reliable estimates of extreme sea levels but at present the available data from this site is still of relatively limited length (data collection commenced in May 1990) compared to the frequency of major coastal flooding events. Meanwhile, assessment of extreme sea levels requires consideration of both tide gauge and historic data.

Wave run-up is variable and significantly influenced by factors such as wave exposure. The estimation of extreme wave run-up and overtopping was based on a variety of information including:

- Empirical estimates using the technique developed by Hughes (2003; 2005)
- Flood and debris levels surveyed after the July 1995 and Cyclone Drena sea flood events
- Reports from earlier events (including newspaper reports, community information and information from management agency files).

The empirical analysis provided useful information on maximum potential wave run-up for various extreme sea levels. The field data from actual historic events provided a cross check on the empirical estimates and an indication of the extent to which potential wave run-up was reduced by variations in wave exposure and other factors.

Good information was available on the elevation of coastal margins for Tararu, Te Puru and Waikawau (see Section 3.1.2.2).

3.2.4.2 Coastal Erosion

The maximum likely coastal erosion was estimated using available mapping of historic shoreline change and surveyed cross sections, historic photography, community information, field inspections and various historic reports (newspaper reports after historic storms and information from management agency files) (see detailed discussion of this various data in Section 3.1). The analysis used the available data for each area to assess the scale of historic fluctuations and any evidence of long term trends for erosion or accretion.

The data was generally adequate to provide useful indications on the nature and scale of historic shoreline change at most sites. This was particularly the case at Tararu, Te Puru and Waikawau where available data provided useful indications of shoreline change back to the early 1900s and (for Te Puru) even the mid to late 1800s (see detailed discussion of data in Section 3.1). At Waiomu, the historical shoreline change data available to this study was limited and so the erosion assessment was based primarily on both community information and geomorphic appraisal during field inspections.

In some areas, particularly parts of Tararu and Te Puru, shoreline change was limited by seawalls. Some of these areas have been protected by seawalls for many decades – back to at least the 1930s and probably even earlier in some locations (e.g. Tararu; southern end of Te Puru). Obviously, in these areas, historic information on shoreline change generally does not provide an indication of the maximum likely shoreline change in the absence of seawalls. In these situations, we used surveyed cross sections from earlier mapping (Section 3.1.2.2) and field measurements conducted during this study to estimate potential shoreline erosion. This procedure typically involved comparison of existing cross-sections with the closest areas without seawalls. A number of measurements were conducted for such areas to ensure reasonable estimates. This procedure was also used to estimate natural shoreline positions where seawalls currently hold the shoreline further seaward.

The estimates of erosion at each site have been derived from available data to be precautionary for return periods of 100 years with existing sea level. The final setback assessed for each area includes at least 3-5 m (variable according to site) safety factor.

3.2.5 Secondary Development Setback (SDS)

The SDS was originally defined relative to the PDS, which would result in widespread reduction of this setback in response to this review. However, recent climate change research and sea level rise projections suggest a future review of the SDS would most likely increase this setback. Until reviewed it is therefore recommended that the location of the SDS remains unchanged from that recommended by Dahm and Munro (2002).

4 Primary Development Setbacks – East Coast

4.1 Whangamata

Beach profile data is currently collected at two sites on Whangamata Ocean Beach (CCS55/1 and CCS56) and four sites on Otahu Beach (CCS57, 57/3, 57/2 and 58). Sites CCS56, 57 and 58 contain data from 1978/9 with the other sites dating from the early 1990s. Sites CCS56, 57, and 57/3 were chosen for the setback analysis after initial calculations and field examinations indicated that the data at the other sites was too limited to be useful or reliable. Results of calculations for the chosen sites are summarized in Table 3. Charts showing the calculated erosion profile against the beach profile record are included in Appendix A.

Other key information at this site includes a plot of historic shorelines from 1944, 1959, 1973, 1978, 1987 and 1993, historic aerial photography from 1944, and a range of information provided by the community.

Results from beach profile analysis and the consideration of all additional information is discussed in relation to each beach profile site below. Results and setback recommendations are summarised.

4.1.1 CCS56 (Whangamata Ocean Beach)

Beach profile site CCS56 is adjacent to the Surf Club near the southern end of Ocean Beach at Whangamata. Beach profile data has been collected irregularly since 1979 (more frequently since the 1990s) and indicates dune toe fluctuations of 20 m over this period.

Calculations place the most eroded likely dune toe 9 m landward of the most eroded state in the beach profile record. Dunes in this area have been flattened so it is not possible to compare results with natural dune geomorphology. The worst estimated erosion at CCS56 is however landward of all field evidence of past erosion. For instance, the erosion is on the line with the seaward edge of large pines to the immediate south; these trees are old and have clearly not been disturbed by erosion for several decades (Figure 7). Examination of historic aerial photography (e.g. SN 854 H11 from October 1954) indicates the pines trees were present and already quite large trees. The line of worst estimated erosion also lies within the Esplanade sealed parking area at the south end, which has not been affected by erosion in the last few decades. The worst measured erosion in this area (1978) reached the line of the Esplanade and is at least 5 m further seaward than the predicted erosion. All this evidence suggests a sensible level of conservatism in the erosion estimates.

Historical mapping indicates all recorded shoreline locations are at least 20 m seaward of the worst estimated erosion in the vicinity of the Surf Club and beach profile site CCS56. There is no indication in the historical shoreline mapping data that erosion has been any more severe elsewhere on Whangamata Ocean Beach. Calculations of shoreline fluctuation and worst estimated erosion based on CCS56 data appear therefore to be representative along the length of the beach.

Figure 7: Photo showing approximate location of y-intercept at CCS56, close to the Whangamata Surf Club. Note relatively large trees immediately south of the profile growing on a line seaward of the calculated erosion.

Historic photos indicate that there was serious wind erosion with migrating sand sheet extending some distance inland along much of the beachfront. This issue is now well under control at Whangamata with an active Beachcare dune management programme at the site and a reasonable spinifex cover on most areas of the frontal dune. Migrating sand sheets no longer pose a hazard to dwellings. The Williamson Park stormwater outlet has also caused quite serious local erosion in historic times. This area is now actively managed by Council to prevent damage to adjacent private properties. There is serious beach and dune scour seaward of the outlet during major rainfall events but the management appears adequate to prevent damage to adjacent private properties. The revised PDS therefore includes no allowance for severe erosion similar to that noted historically.

This site also has the longest and most comprehensive beach profile record for Whangamata Beach. Calculations for this site were therefore used as the basis for recommended setbacks along the Ocean Beach, with the worst estimated erosion on Whangamata Ocean beach lying 35 m landward of the most seaward measured duneline.

4.1.2 CCS57 (North Otahu Beach)

Beach profile data has recorded maximum shoreline fluctuations of 11 m since 1979 at the northern end of Otahu Beach (CCS57). Calculations predict a most eroded dune toe 4 m landward of the most landward observed dune toe in the profile record. The worst measured erosion in the beach profile record occurred in 1979. Elsewhere on Otahu beach the worst measured erosion occurred in 2003.

Field observations showed that the worst estimated erosion at ground level is close to the current dune crest (Figure 8). Remnants of the July 1978 dune scarp were noted in field inspections but were seaward of the erosion predictions - confirming that the calculated erosion at ground level exceeds that observed in the last 30 years.

Data for site CCS57 appears to best represent the area of Otahu Beach sheltered by Clark Island (in the vicinity of Pipi Road) and has been used as the basis for setbacks at the northern end of Otahu Beach.

Figure 8: Approximate location of worst estimated erosion at ground level (arrow) at Whangamata beach profile site CCS57.

Review of the historic mapped shorelines indicates that the most landward of these recorded positions are seaward of the worst estimated erosion at CCS57, typically by 5-10 m. Similarly, there is no indication in historic aerial photography that erosion has been any more severe than estimated at the northern end of Otahu Beach. Calculations of shoreline fluctuation and worst estimated erosion based on CCS57 data appear therefore to be sufficiently precautionary for this section of the beach.

4.1.3 CCS57/3 (Central Otahu Beach)

Beach profile site CCS57/3 is located near the centre of Otahu Beach, where profile data has been collected since 1991. The worst observed erosion occurred at this site in 2003. Over the 17 year profile record, the dune toe location has fluctuated by 12 m.

The worst measured erosion cut the frontal dune back to the crest, while the worst estimated erosion is located in the swale approximately 5 m further landward (Figure 9). On the basis of geomorphic considerations, the location of the worst estimated erosion in the swale landward of the frontal dune further suggests the estimate is reasonable.

At the time of the field visit, the beach profile site also lay on the line of the worst recent erosion in this area – with the dune erosion scarp on this line at least 1-2 m landward of adjacent shorelines (Figure 9). The calculations for this site should therefore also be reasonable for adjacent shoreline areas.

Site CCS57/3 appears to best represent central areas of Otahu Beach, with field inspections indicating that the beach profile site lies in the location of the worst erosion along this area in recent decades.

Erosion in 2000 is known to have affected moderate-sized pohutukawa on a Hinemoa Street property south of beach profile site CCS57/3. Analysis of aerial photos shows that these trees lie approximately 10 m seaward of the worst estimated erosion (at dune toe).

Checks of the calculated erosion against mapped historic shorelines indicate all recorded shoreline locations are seaward of the worst estimated erosion at CCS57/3. The predicted most landward dune toe lies 5-10 m landward of any of the historic shorelines. Calculations of shoreline fluctuation and worst estimated erosion based on CCS58 data appear therefore to be precautionary for this section of the beach.

Figure 9: Approximate location of most severe likely erosion (at ground level) as estimated from beach profile data at site 57/3 (arrow). The calculated erosion is in the swale behind the frontal dune and approximately 5 m landward of the dune crest, which is location of the most severe observed erosion at this site (2003). Note large Pohutukawa in background, known to have been threatened by erosion in 2000.

4.1.4 CCS58 (South Otahu Beach)

Profile data has been collected at the southern end of Otahu Beach (CCS58) since December 1978. The profile record contains two periods of erosion, at the beginning of the record in early 1979, and in 1997. This area of the beach was not severely affected by the erosion in 2003. Beach profile site CCS58 appears to best represent the shoreline areas closest to the entrance of Otahu Estuary, and is therefore applied to determine setbacks south of the site.

The erosion estimates based on data from this site are at least 5-10 m landward of any erosion evident in historic mapped shorelines or historic aerial photography and therefore appear to be adequate for this section of beach.

4.1.5 Discussion and Setback Recommendations

The available beach profile data includes profiles surveyed after major erosion events. Surveys undertaken several months after the July 1978 storm confirm this event as one of the most significant erosion events for Whangamata along the main beach and the eastern end of Otahu Beach. Other areas of Otahu Beach were more severely affected by the erosion of the late 1990s and early 2000s; the worst in this area over the last 3-5 decades and well documented in the beach profile surveys.

The estimated worst estimated erosion derived from beach profile data plots landward of historic data including historic mapped shorelines dating from 1944 (which includes various shoreline positions mapped from purpose flown aerial photography a few months after the severe erosion event of July 1978). The estimates are also similar or slightly more precautionary than various property specific estimates conducted over the last 5 years – which did not include safety factors and excluded any consideration of sea level rise effects over the next 50 years. The estimates of worst estimated erosion derived from beach profile analysis therefore appear to be reasonable in the light of all available information.

Data from beach profile site CCS56 is used to calculate an appropriate setback for the entire length of Whangamata Ocean beach, as far south as the northern end of Pipi Road.

Calculations of erosion based on CCS57 data used to derive setbacks north of site CCS57 to the northern end of Pipi Road, and south from the site tapering to CCS57/3. Data from sites CCS57/3 and CCS58 are used to derive setbacks for central and southern areas of Otahu Beach.

Recommended PDS distances at Whangamata Ocean Beach are presented in Table 3and Table 4 as a distance relative to the most seaward measured dune toe at each site. Setback distances are fixed at the location of CCS56, CCS57, CCS57/3 and CCS58 beach markers and grade in distance between.

These setbacks are summarized from north to south below:

- Whangamata Ocean Beach: **45 m**
- Northern Otahu Beach (at CCS57): **30 m**, graded to;
- Central Otahu Beach (at CCS57/3): **29 m**, graded to;
- Southern Otahu Beach (at CCS58): **32 m**

The revised setback at Whangamata Ocean Beach is just 1 m seaward of the setback recommended by Dahm and Munro (2002). At Otahu Beach, the revised setbacks represent 5 m seaward relaxation at the northern end of the beach and little change in the central and southern areas.

Table 3: Summary of beach profile data analysis at Whangamata. All figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 56 (north)	20 m	29 m	35 m	45 m
CCS 57	11 m	15 m	20 m	30 m
CCS 57/3	12 m	17 m	19 m	29 m
CCS58 (south)	10 m	16 m	22 m	32 m

4.1.6 Implications for Management

As is currently the case, the PDS at Whangamata and Otahu Beaches intercepts private beachfront properties in many areas along the beach, particularly central areas of Ocean Beach and much of Otahu Beach. In most cases, the setback is well forward on the properties and will not preclude reasonable use. There are however two properties on Otahu Beach adjacent to Hinemoa Street where the setback extends well landward into the properties. In the event of renovation or replacement of existing dwellings, these properties will probably require site specific management strategies to provide for reasonable use.

4.2 Tairua Ocean Beach

Beach profile data is collected at four sites on Tairua Ocean Beach.

Original beach profile sites CCS36 and CCS37 have surveys dating from January1979 and are the most representative sites for the areas of nearshore subdivision at the southern and northern ends respectively. Therefore, this data was primarily used for the setback calculations.

Data collection at CCS36/1 (central beach) commenced in 1992 and the record is therefore much shorter. This site also lies at a location on the beach where there is a wide dune reserve and no risk to private property. Examination of this data indicated large fluctuations due to changes in an incipient dune feature at the seaward toe of the main dune, a feature not evident at sites CCS36 and CCS37. The pattern of shoreline change tended to follow the trends at CCS37 at the northern end of the beach. The data was not directly used in setback calculations but provided a useful check on calculated changes at CCS37.

Site 36/2 provides only a short record and was not used for this study.

Other key information at this site includes site specific hazard investigations for properties at the southern end of the beach, historic photographs dating from 1944, and information provided by the community.

The available data and the results for each site are discussed in detail below. Charts showing the calculated erosion profiles against the beach profile records are shown in Appendix A. Setback recommendations are summarised in Section 3.2.4.

4.2.1 CCS36 (South Tairua Beach)

Beach profile data has been collected irregularly at the southern end of the beach (CCS36) since 1979, and more frequently since the 1990s. The records show a period of erosion immediately prior to the first survey in January1979, with further erosion in 1990 and (most severely) 2003/4. The periods between erosion are typically characterised by beach and dune recovery.

The calculated "most eroded dune toe" is just over 1 m landward of the most landward measured dune toe (Table 4, see also graph in Appendix A). The worst estimated erosion at ground level is shown in Figure 10 (April 2008) and is near the top seaward face of the frontal dune (Figure 10). This predicted erosion is landward of the most recent (2003) erosion scarp evident at the site.

Figure 10: Calculated worst estimated erosion at ground level (arrow) at CCS36.

A number of historical vertical and oblique aerial photos were available as detailed in Section 3.1.5. Additional insight into beach behaviour has also been provided by images and research associated with the NIWA Cam-Era project. Historical aerial photography and Cam-Era data periodically show a rip embayment formed at the southern end of the beach (from Hemi Place towards the Surf Club). This rip embayment often extends landward of the general trend of the shoreline further north. This rip embayment typically lies south of the CCS36 beach profile site, so will not have been observed fully in the beach profile data and associated analysis. However, detailed site specific investigations have been conducted in regard to the erosion risk to properties adjacent to the worst areas of the rip embayments (Eco Nomos 2003; 2008). The effect of the embayment on shoreline erosion has been considered as part of the setback recommendations in this area (section 3.2.4).

4.2.2 CCS37 (North Tairua Beach)

Beach profile data has been collected irregularly at the northern end of the beach (CCS37) since 1979, and more frequently since the 1990s. The most marked erosion recorded occurred in the late 1990s, with significant beach and dune recovery then occurring through the period to 2004. The central and northern areas of the beach were not affected by the severe erosion which occurred at the southern end of the beach in 2003.

The calculated "most eroded dune toe" is only 2 m landward of the most landward measured dune toe, indicating (as at the southern end) that the calculations, while precautionary, are not overly so. The worst estimated erosion at ground level coincides closely with the crest of the main frontal dune.

There is no field evidence at this site of any past erosion landward of the above predictions or any evidence of such erosion in extensive historic aerial photography dating from 1944 to the present.

4.2.3 Discussion and Setback Recommendations

The various available data reveals marked differences in patterns of erosion and accretion along the beach, with erosion at one end often coinciding with accretion at the other – suggesting considerable redistribution of material along the beach and variations in wave exposure from one end of the beach to the other. Therefore, while the observed and calculated maximum shoreline fluctuations are similar at both ends (see Table 4); the timing of such erosion is usually quite different. These effects were marked in 2003 when erosion severely affected the southern end of the beach while the northern end was relatively unaffected.

It also has a significant effect on the revised PDS relative to the existing setback. The existing PDS was mapped relative to a 1995/96 baseline when the Coromandel beaches were generally in an accreted condition and adopted then as the best estimate of the most seaward toe of dune. At Tairua, however, the northern end of the beach was in a far more accreted state than the southern. Therefore, the revised PDS (mapped relative to the most seaward measured dune toe at both ends) lies landward of the existing PDS at the northern end and seaward at the southern – even though the maximum duneline fluctuation is similar at both beach profile sites analysed.

These setback recommendations are summarized below:

- Northern portion of beach: **35 m**
- Southern portion of beach north of CCS36: **36 m**
- Southern portion of beach south of CCS36: **41 m**

Table 4: Summary of beach profile data analysis and recommended PDS at Tairua Ocean Beach. All figures are presented relative to the most seaward (accreted) measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 37 (north)	11 m	13 m	25 m	35 m
CCS 36 (south)	16 m	17 m	26 m	36-41 m

The beach profile analysis is not suitable for estimation of the position of the PDS at the very southern end of the beach due to the added influence of the severe rip embayments which occur in this area, which influence is less significant at the closest beach profile site (i.e. the beach profile data may under-estimate erosion). We have therefore used data from the detailed analysis by Eco Nomos (2003; 2008) for this area. These earlier analyses involved estimation of extreme erosion using both the method used in this report and the Komar Method (briefly discussed in Section 3.2.3.1 of this review). The calculations used cross sections surveyed across the southernmost properties following the extreme erosion of 2003 with results cross-checked the results of a detailed analysis of all available aerial photography dating from 1944 to 1979, beach profile data from 1979 to the present, and 6 separate cores located from the seaward edge of the properties to the landward and extending to underlying rock. Eco Nomos (2008) adopted the more precautionary estimates obtained using the Komar Method and we have followed those recommendations in this report – given the added complexity imposed by the significant rip embayments that can develop at this end of the beach. Eco Nomos (2008) noted that that available data indicated the Komar Method calculations appeared from available evidence to be suitably precautionary as:

- The estimated extreme erosion is at least 6-8 m landward of any observed erosion over the last 65-70 years and probably longer. This includes what appears to be the remains of a large rip-head embayment evident (landward of the dune toe) in the 1944 aerial photography; which Eco Nomos (2008) suggested could relate to the severe coastal storm of March 1936 – the most severe erosional event at many east coast sites over the last century. The defined hazard area extends >10 m further landward than the severe erosion of 2003, which appears from all available evidence to be the most severe erosion since at least 1944 (Eco Nomos, 2008).
- Evidence from cores (e.g. orange stained sands) and excavation (uncovering of a body estimated by archaeologists to be >200 years old) within the defined hazard area (Eco Nomos, 2003; 2008).

4.2.4 Management Implications

The PDS extends well within properties towards the southern end of the beach, even though it is reduced relative to the existing PDS. Eco Nomos (2003; 2008) developed site specific strategies to enable reasonable use of two of these properties. These strategies consist of a number of measures including design of both houses to withstand the severe erosion estimated using the Komar Method – with the houses designed to be founded on rock underlying the dunes. Similar considerations are likely to be relevant to other properties very close to the southern end, notwithstanding the precautionary nature of the hazard zone relative to historic events. This reflects the uncertainty associated with potential rip-head erosion and the potential for erosion to be aggravated in the future with climate change.

The PDS at the northern end of the beach extends further landward than the existing PDS, reflecting the more accurate definition of the baseline discussed above.

4.3 Hahei

Beach profile data is collected at two sites at Hahei Beach (CCS32 and CCS33). Both monitoring sites have been in place since 1978/9, but were surveyed only irregularly until the mid 1990s. Results of the beach profile analysis from both sites are summarized in Table 5 below.

Other key information at this site included site specific studies at the southern end (Eco Nomos 2002; 2005) and information provided by locals (including useful photographs taken following the erosion of July 1978).

Results from beach profile analysis and the additional information is discussed in relation to each beach profile site below. Results and setback recommendations are discussed in section 3.3.3.

4.3.1 CCS32 (North Hahei Beach)

Beach profile data has recorded only relatively small fluctuations (7 m) in dune toe position since the beginning of the beach profile record in 1979. The most severe erosion at CCS32 occurred during the late 1980s. Ten years later, the dune toe had recovered by approximately 7 m. There has some minor erosion since.

Calculations suggest the most severe dune toe erosion likely may be only one metre landward of the most severe observed erosion – with the erosion unlikely to even extend landward to the car park in this area (Figure 11).

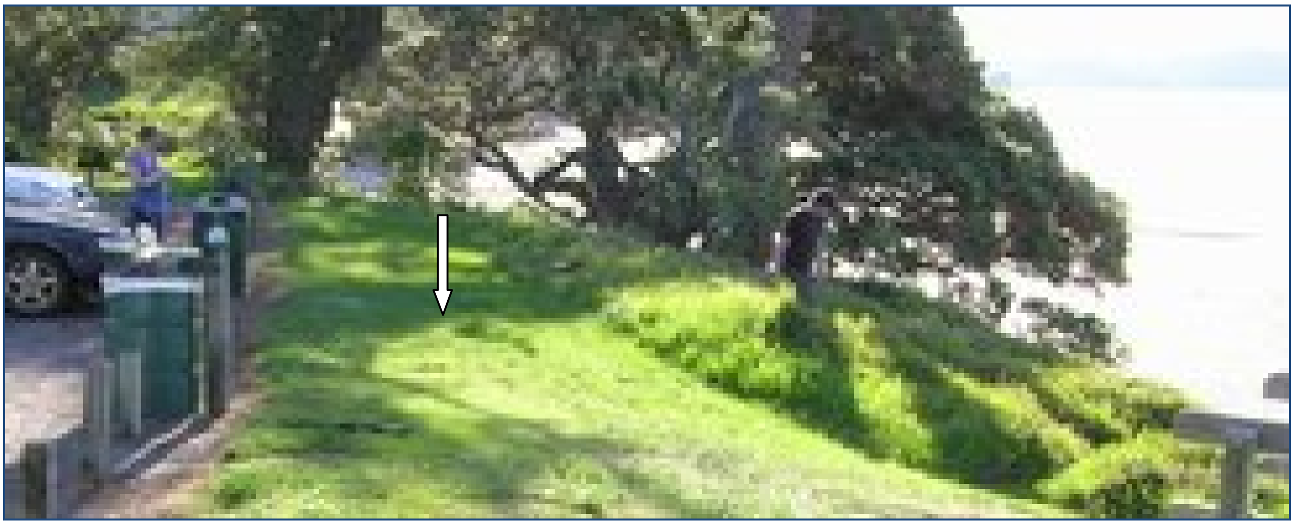

Figure 11: Approximate location of worst estimated erosion at ground level (arrow) at beach profile site CCS32, northern end of Hahei Beach. Note large pohutukawa to immediate north, founded on hard materials, well seaward of predicted erosion.

Figure 12: Old pohutukawa tree rooted in consolidated materials (arrow) at the base of the current dune, immediately north of beach profile site CCS32. This and other trees lie on a line seaward of erosion estimates from beach profile analysis.

Field inspections confirmed the potential for limited erosion - indicating relatively erosion resistant materials underlie the dune and extend close to the present dune toe. For instance, a large and apparently relatively old pohutukawa is present at the existing dune toe (Figure 12), with pre-Holocene consolidated materials, relatively resistant to erosion, exposed among the roots of this tree at the back of the beach. Auguring at the top edge of the dune, seaward of the car park, found that the veneer of Holocene sands is often only about 1 m deep. CCS33 (South Hahei Beach)

Beach profile data shows relatively small fluctuations (8 m) in the dune toe position over the last 30 years. Data from CCS33 shows two periods of relatively severe erosion in the early 1990s and in 2003. Only a small amount of accretion has occurred since.

Calculations suggest the most severe likely erosion may be only 2 m landward of the most severe observed erosion. The worst estimated erosion at ground level lies 15 m landward of the most seaward dune toe position, just landward of the top edge of an old erosion scarp (Figure 12).

Other data indicates that erosion at this end of the beach is also constrained by relative erosion resistant materials underlying the dune – with photographs from 1978 indicating that these erosion resistant materials probably prevented undermining and loss of several beachfront houses.

Site specific investigations indicate that the seaward edge of the underlying erosion resistant materials varies and work to date has required drilling to confirm the seaward edge and the top elevation of the erosion resistant materials (Eco Nomos, 2002; 2005).

Figure 13: Worst estimated erosion at ground level at the south end of Hahei Beach (CCS33).

4.3.2 Discussion and Setback Recommendations

The investigations indicate that erosion resistant materials constrain erosion along most of the length of this beach.

These materials are exposed along the back of the beach in places at the northern end and this has allowed the PDS in this area to be reliably and significantly reduced – confirmed also by the presence of large and old trees seaward of the reduced PDS. The revised PDS is based largely on the beach profile calculations but without the inclusion of safety factors to fit with field observations of erosion resistant materials. Mapping of the setback immediately south of the small stream north of Hahei Beach Road was based on field investigations as the location of erosion resistant materials varied.

The situation is more complex at the southern end, as the erosion materials are deeply buried and the location of these materials appears to vary. Drilling work beyond the scope of this review would be required to confirm the presence, seaward edge and top elevation of these erosion resistant materials (the relevant factors required for accurate erosion assessment). This information is presently only available for two properties.

We have therefore adopted a precautionary approach for the southern end and mapped the setbacks using our standard approach (using CCS 33 data). Results from these calculations and from previous work (Eco Nomos, 2002; 2005) indicate that the existing PDS is appropriate for properties where underlying materials limit erosion – with only a slight increase (about 1 m). In other areas further south, the existence of underlying erosion resistant materials is unknown and the data from CCS33 (where erosion is limited by resistant materials) may not adequately estimate erosion. The presence of the Wigmore Stream may also aggravate erosion of the southernmost properties. We have therefore added a safety factor to allow for additional erosion and stream effects in this area. This safety factor decreases from 6 m adjacent to the stream to 3 m approximately 90 m further north. This increases the existing setback more significantly in close proximity to the stream.

Table 5: Summary of beach profile data analysis at Hahei Beach. All figures are relative to the most seaward measured dune toe. The PDS at the three southernmost properties also includes an additional safety factor as discussed above.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 32 (north)	7 m	8 m	15 m	15 m
CCS 33 (south)	8 m	10 m	19 m	29 m

4.3.3 Management Implications

The revised PDS is substantially reduced at the northern end of the beach but slightly increased at the southern end, particularly the most southern properties close to Wigmore Stream. We believe the PDS at the southern end may be slightly over-precautionary for most properties but any reduction of this setback or mitigation of the hazard would require more detailed work similar to the site specific studies already conducted.

Site specific studies, such as Eco Nomos (2002; 2005), which involve detailed property-specific investigations and site-specific design of dwellings to mitigate hazard risk (including use of piling and retaining walls to manage dune face slope adjustment well above beach level), provide for appropriate management of any hazard risk including any revision of the PDS in this report.

4.4 Maramaratotara Beach

Maramaratotara Beach lies on the southern side of Mercury Bay towards the head of the bay, fronting the peninsula on the seaward side of Whitianga Harbour entrance.

Beach profile data is collected at one site (CCS28) at this beach, with data collected (irregularly) since 1979.

4.4.1 CCS 28

The data from this beach profile site indicates the duneline has been subject to only minor dynamic fluctuations – approximately only 2 m at RL 5 m (Figure 14). The worst measured erosion occurred in the early 2000s (survey of September 2002), rather than the storm of July 1978. Interestingly, this ties in broadly with the worst measured at Buffalo Beach (which varied alongshore from the late 1990s to the early 2000s).

Field inspections indicated that the reason for the limited duneline fluctuations relates to erosion-resistant materials along the back of the beach. These consolidated materials were observed at the base of the current bank at the beach profile site (Figure 15) and exposed at the base of a large Pohutukawa to the south of the site. Field inspection also confirmed that the relatively high "dune" at the southern end of the beach consists of thin veneer of Holocene sands over more erosion resistant materials. The presence of large pohutukawa rooted on the bank all the way along the back of the beach further confirms the presence of erosion resistant materials.

The erosion resistant materials outcrop in the beach within the bed of the second small creek south of the site (Figure 16) and several holes dug in the beach also found the materials underlying the beach sands. These outcrops relate to a shore platform formed by cliff erosion – probably before the Holocene sands were emplaced; though rare and severe storms do also expose the underlying materials at the back of the beach and may result in ongoing (very slow) retreat of the bank (probably at rates of less than 1 m per century given the rarity of such erosion events at this site).

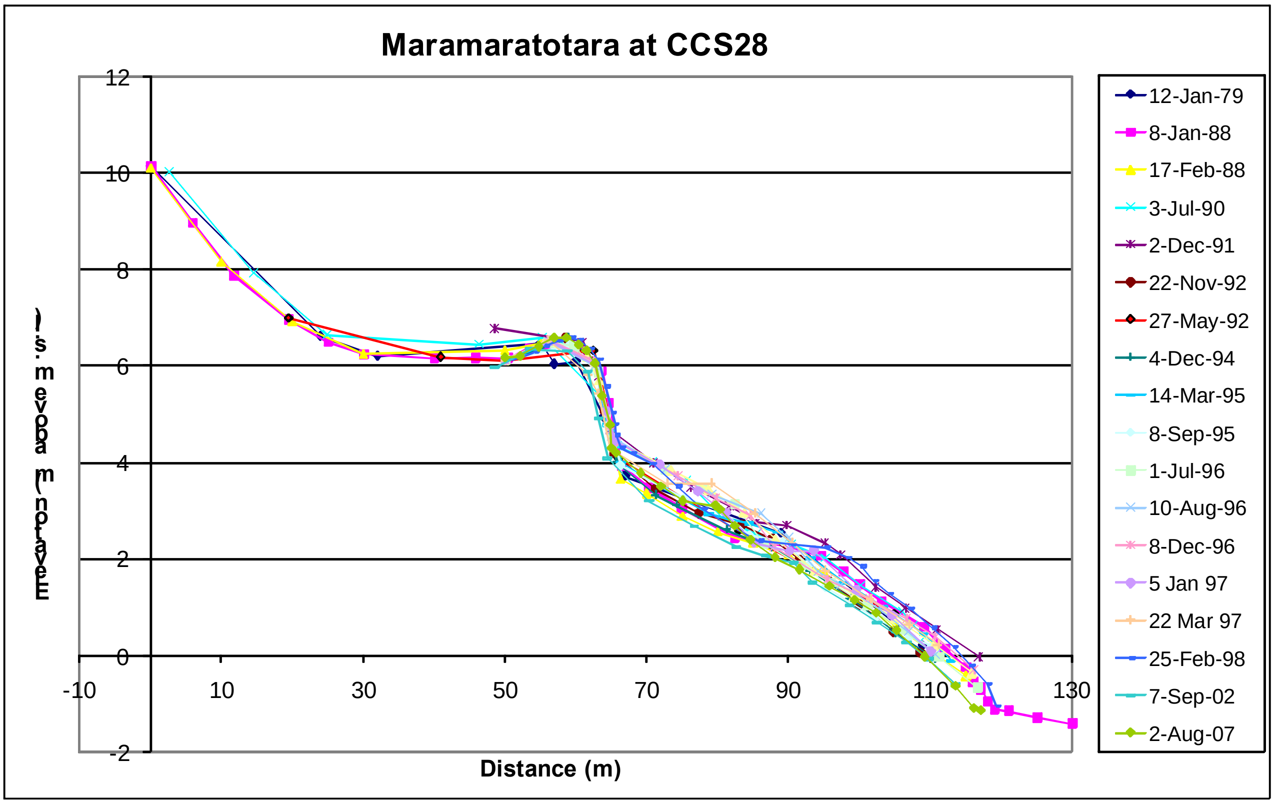

Figure 14: Duneline change recorded at CCS 28

Figure 15: Erosion resistant material exposed in bank behind beach in the vicinity of profile site CCS28.

Figure 16: This creek bed at the southern end of Maramaratotara Beach contains erosion resistant materials under a thin layer of sand.

4.4.2 Discussion and Setback Recommendations

The presence of erosion-resistant materials along the back of the beach limits erosion at this site and the revised PDS has been placed slightly landward of the approximate seaward edge of these erosion resistant materials – based on field observations. The revised PDS does not affect any properties along this beach. In common with all sites where erosion is similarly restricted, there is no need for a Secondary Development Setback to reflect accelerated erosion by sea level rise. Council require a setback of new dwellings approximately 7.5 m from front boundaries for reasons related to natural character, beach amenity and other purposes. This setback will be more than adequate at this site to ensure all dwellings lie seaward of any future erosion.

4.4.3 Management Implications

The removal of hazard setbacks from the properties due to the presence of erosion resistant materials removes any associated restrictions on property use.

4.5 Buffalo Beach

This beach probably has the most lengthy and complete data set of all eastern Coromandel beaches. There are a number of beach profile sites at Buffalo Beach, though many have only limited data sets and some are also located where they are influenced by stream entrances and other local influences. Data from only three of these sites were suitable for the purposes of this review – CCS 25, CCS 25/1 and CC 27. These sites are from representative locations along the beach and have lengthy data sets. Results of the beach profile analysis from these four sites are summarized in Table 6, and charts showing the calculated erosion profile against the beach profile record are included for all sites in Appendix A.

Other key information available for the review at this site included a plot of historic shorelines (Table 1), historic photography (including vertical and oblique photography extending back to 1944 and ground photography dating back to the late 1800s), previous reports and local history materials, and information provided by the community. The available information provides a reasonably detailed and quantified/semi-quantified view of shoreline change since the 1940s and useful indications of shoreline position in various localities back to the late 1800s.

Results from beach profile analysis and the consideration of all additional information is discussed in relation to each beach profile site below.

4.5.1 CCS25 (North Buffalo Beach)

It is clear from field observations that shoreline change at beach profile site CCS25 is influenced by stream effects, end effects, armouring structures and fill placed following a period of erosion in July 2000 (Figure 17).

Figure 17: View in vicinity of CCS 25 (line of profile is approximately indicated by the tape measure evident centre-left). Tarapatiki Stream is evident in the middle background. The shoreline behind the photographer consists of a rock and concrete mass block seawall extending approximately 350 m alongshore (fronting private beachfront properties). The wall holds the shoreline seaward of the natural shoreline position with a high tide beach only rarely occurring. There are significant end

effects at both ends of the wall during storms.

Data from the site was not therefore used to calculate a development setback, but provided a useful record of changes in beach elevation and beach movement in the vicinity of the Tarapatiki stream and the eastern end of the beachfront properties. This information helped revise the PDS in the area.

4.5.2 CCS25/1 (Central/North Buffalo Beach)

Beach profile site CCS25/1 lies south of the beachfront development on northern Buffalo Beach, in an area of wide vegetated reserve. The site provides the most representative data for estimation of extreme erosion at the northern end of the beach, as it is away from both stream and seawall end-effects influences. Data has only been collected since January 1991 but includes surveys conducted after the worst erosion in this area for several decades (see discussion further below).

The beach profile data measurements in 1991 commenced when the shoreline was towards its most accreted position in recent decades, with the most advanced duneline position in the record surveyed in March 1995. The shoreline subsequently entered a period of severe erosion with approximately 19 m duneline retreat to mid 2007. The erosion cumulated over a period of years and storm events but primarily occurred between 1997 and 2005. Field inspections during this review indicated significant vegetation recovering on the seaward dune face and a moderate width of high tide beach, suggesting the shoreline may be in or near the next multi-decadal period of shoreline recovery. (Note that storm erosion does occur during periods of multi-decadal periods of shoreline recovery – these recovery periods being marked by an overall trend for beach advance over a period of years rather than the absence of storm erosion within this period).

Calculations based on the beach profile analysis predict a most eroded likely dune toe 28 m from the most seaward (accreted) observed dune toe position. At ground level, this represents an erosion line on the landward side of the frontal dune (Figure 18). This appears from field observations and geomorphic considerations to be a reasonable estimate. At the time of the field visit (April 2008), the most eroded dune line in the vicinity of CCS25/1 lay further to the north, being approximately 3.5 m landward of the dune line at the beach profile site. The worst estimated erosion does however also extend well landward of the current (2008) duneline in that location.

Examination of the various other sources of data noted above indicates that the worst estimated erosion lies well landward of shoreline positions evident. The various sources of data indicate that the most significant erosion in this area (and along Buffalo Beach in general) is associated with multi-decadal shoreline fluctuations. The most severe of the recent erosion cycles occurred in the mid to late 1950s and the late 1990s to early 2000s – with erosion during the most recent cycle the most significant.

Collectively, the various sources of data suggest the revised PDS in this area is at least 5-10 m landward of any erosion recorded in the last 60 years and probably much longer. The setback is therefore judged to be precautionary for return periods up to 100 years with existing sea level.

Figure 18: Photo taken at Buffalo Beach profile site CCS25/1. Person (and arrow) at the approximate location where the worst estimated erosion intercepts ground level.

4.5.3 CCS26 (Central Buffalo Beach)

Data has been collected at this site since January 1979. The site lies south of the Taputapuatea Stream, which discharges in the middle of Buffalo Beach. Field inspection, historic aerial photographs and the beach profile data indicate that the profile changes at this site have been affected by stream entrance effects and human activities (extensive sand placement for dune restoration in the early 1990s). The data from the site is therefore not representative of the wider beach further south and has only been used for setback estimates in the vicinity of the Taputapuatea Stream.

Interestingly, although duneline fluctuations were impacted by stream migration, the width of beach level fluctuations further seaward is similar to that observed at CCS25/1 and CCS27 (about 30-35 m at all sites).

4.5.4 CCS27 (South Buffalo Beach)

Beach profile data has been collected irregularly at CCS27 since January 1979, and more frequently since the 1990s. The profile data has recorded dune toe fluctuations of about 13-14 m over this period. The data indicates a multidecadal period of overall beach advance in the period from 1979 to March 1995, followed by a period of erosion extending over approximately 6-7 years, with the most severe erosion noted in mid 2001.

The beach level has recovered since this time, with the widest high tide beach in the record occurring in September 2006 - but the duneline has undergone little to no recovery. The slow dune recovery appears to reflect at least in part the lack of native dune building grasses on the seaward face of the dunes along the back of Buffalo Beach. This reinforces the need for improved dune management along this foreshore. The development of a wide dune during periods of beach recovery is important in helping mitigate the severity of dune erosion with future storm events.

Calculations based on beach profile analysis indicate that the most severe duneline erosion likely lies approximately 10 m landward of the worst measured dune erosion – suggesting it is sufficiently precautionary. Field checks indicate that the worst estimated erosion lies close to the swale behind the frontal dune. Medium sized Norfolk Pines and a pohutukawa lie on a line approximately 2.0 m landward of benchmark (1-2 m seaward of the worst estimated erosion) suggesting that erosion has not proceeded further landward in the last 3-4 decades. The worst estimated erosion also plots landward of historical mapped shorelines dating back to 1944. It also lies further landward than shorelines evident on aerial photographs dating back to 1944, with quite closely spaced photos available for the period from 1944 to the start of the beach profile monitoring (including images from 1944, 1948, 1950, 1953, 1955, 1959, 1962, 1965, 1970, 1971, 1972, and 1979).

At the southern end of Buffalo Beach, the rock seawall holds the shoreline seaward of where it would naturally lie. Profile extrapolation, field measurements and aerial photographs were used to estimate the position of the shoreline were the seawall were not present. This indicated potential for variable shoreline adjustment, up to 10 m in places. A figure of 10 m was therefore added to the erosion estimates.

The setback in this area, while reduced, still extends reasonably deeply into some properties reinforcing the need for an appropriate long term strategy for the management of coastal erosion in this area. The long-term management strategy for the land behind the seawall has not yet been confirmed, though an initial assessment of options suggest it is likely to include holding the shoreline using artificial means, possibly alongside allowance for some landward readjustment (Beca et al., 2004).

Figure 19: Approximate location of the worst estimated erosion at ground level (arrow), at the southern end of Buffalo Beach (CCS27).

4.5.5 Discussion and Setback Recommendations

The four beach profile sites provide reasonably good data on which to base setbacks in this area, and the erosion estimates based on this data appear to be adequate as discussed above. The profile data has recorded maximum dune toe fluctuations of 13-30 m over the last 30 years.

Data collected at beach profile site CCS25/1 was used for the design of the setback fronting development at the north end of the beach. Data collected at beach profile site CCS27 was used to establish the PDS for the southern end of the beach. Results of the beach profile analysis are shown in Table 6.

Table 6: Summary of beach profile data analysis at Buffalo Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 25	27 m	30 m	32 m	
CCS 25/1	19 m	28 m	31 m	41 m
CCS 26	30 m	33 m	35 m	
CCS 27	13 m	17 m	20 m	30 m Plus 10 m adjustment for effect of seawall

The revised PDS represents no change in setback for development at the northern end of the beach. However, the PDS has been reduced at the southern end, where beach profile data has revealed a less dynamic shoreline.

4.5.6 Management Implications

The PDS at northern Buffalo beach still includes a significant proportion of the private residential sections in this area. Reasonable use of the properties is likely to require a strategy that involves limiting the worst estimated erosion. The existing seawall has only been consented as a short term solution and a longer term strategy will be required. Council is likely to commence work on defining an appropriate long-term solution in concert with landowners and the wider community later in 2009. Initial investigations suggest a back-stop seawall located further landward than the existing structure may be an appropriate longer term solution (Beca et al., 2004) but details of this or other possible options have yet to be confirmed. In the interim, the setbacks will continue to apply and property specific strategies will continue to be required for any new development to ensure it does not compromise potential longer term solutions.

The updated information and analysis suggests the erosion hazard issues at the southern end behind the rock wall may not be quite as serious earlier thought – with the PDS in this area reduced. Nonetheless, the revised PDS indicates that erosion could eliminate the road and affect properties to landward in the absence of protection. The revised setback therefore reinforces the need to develop an appropriate long-term strategy for the management of coastal erosion in this area – particularly given the scale of coastal development now being consented. In short, while the setback has been reduced, reasonable and sustainable use of this area will require a coherent long term hazard management strategy.

4.6 Wharekaho Beach (Simpson's Beach)

Beach profile data is collected at three sites on Wharekaho Beach. Two sites (CCS22 and CCS23) were established in 1978/9 as part of the original network, while CCS 22/1 at the northern end of the beach has been in place since 1991. Charts showing the calculated erosion profile against the beach profile record are included for all sites in Appendix A; though erosion is limited in some areas by underlying materials that are resistant to erosion (see further discussion below).

Other information available for this site includes limited historic photography and community information at this site includes a plot of historic shorelines from 1944, 1959, 1973, 1978, 1987 and 1993, Whites Aviation oblique photographs; and information provided by the community.

Results from beach profile analysis and the consideration of all additional information is discussed in relation to each beach profile site below.

4.6.1 CCS22/1 (North Wharekaho)

This beach profile site is located at the north end of Wharekaho Beach. The area is characterised by a steeply sloping high frontal dune vegetated backed by land covenanted with QEII National Trust and therefore not likely to ever be developed. It is over 50 m from the top edge of the dune face to the nearest farm house.

In addition, beach profile data shows only small fluctuations in shoreline position since 1991, with up to 2m fluctuations at the dune toe and virtually no change to other regions of the steep seaward dune face.

Foredune stability is also indicated by the presence of large old trees located on or just above the seaward dune face, some of which appear to be at least 50-70 years old (Figure 20). These trees are not undermined by erosion, but the roots are exposed, which suggests some past erosion of the dune face. The top seaward edge of the dune face appears from field evidence to represent the most landward erosion over at least the last 50-70 years. At one location, there is a large tree only 2-3 m from the existing dune toe, further indicating the limited dune erosion.

The steep and faceted nature of the frontal dune (Figure 20) could be interpreted to suggest a (very slow) trend for long-term erosion. This could also be reflected in the darker sand in this area which reflects concentration of heavy minerals through selective removal of the lighter coloured felsic (quartz, feldspar, etc) component. However, we believe that a trend for long-term erosion is an unlikely interpretation. The beach profile data complemented by field inspections indicates no scarping of the dune face has occurred over the last 18 years. The beach levels in front of the dune also appear to be simply fluctuating up and down and there is no evidence of a trend for progressive lowering or narrowing of the beach since records commenced.

The perseverance of past erosion scarps and the steeply sloping dune face is more likely to reflect the fact that the seaward face is vegetated with low exotic grasses which are not effective at sand trapping and natural dune repair.

Figure 20: Approximate location of estimated most eroded toe of dune at CCS22/1 (top photo). Note large old pines indicating shoreline has not been landward of the present dune crest for many

decades.

4.6.2 CCS22 (Central Wharekaho Beach)

Beach profile site CCS22 has been surveyed irregularly since 1979, and more frequently since the 1990s. The site lies just south of Winiata St, in an area backed closely by residential development. The beach profile data shows little shoreline change in this area. Dune toe fluctuations of just 4 m have been recorded during this time.

Calculations suggest the worst estimated erosion to be only 4 m landward of the current (April 2008) dune toe.

Field inspections indicate that the limited erosion in this area reflects erosion resistant materials underlying the dune, which is generally just a relatively thin veneer of Holocene sands. A clay bank is visible approximately 16 m landward of the current toe of dune adjacent to the toilet block to the immediate north of the profile site (Figure 21). An old concrete structure also lies approximately 9 m landward of the current toe of dune, several metres landward of the worst estimated erosion (Figure 22). Previous property specific reports also indicate that erosion in this general area is limited by erosion resistant materials.

We have mapped the revised PDS in this area on the basis of precautionary estimates of the seaward edge of these erosion resistant materials, though the actual seaward edge may well be further seaward.

Figure 21: Toilet block at Wharekaho beach profile site CCS22. A clay bank is evident immediately landward of this structure.

Figure 22: Concrete structure at beach profile site CCS22.

4.6.3 CCS23 (South Wharekaho Beach)

Beach profile site CCS23 has been surveyed irregularly since 1979, and more frequently since the 1990s. The site lies at the end of Josephs Road, just south of the beachfront development, in an area with a high frontal dune and wide dune reserve (Figure 23). The beach profile data shows overall shoreline (dune toe) fluctuations of 11 m during the last 30 years of record, considerably greater than the 4 m seen further north at CCS22.

Field inspections indicate that the beach is backed by a much greater width of Holocene dune sands in this area – with no erosion resistant materials noted. Drilling beyond the scope of this study would be required to determine the presence and seaward edge of any erosion resistant materials underlying the dunes. We have therefore assumed the dunes are erodible over the full width of the revised PDS.

The worst estimated erosion at ground level (Figure 23) lies approximately on the line of an old erosion scarp immediately south. There is no field evidence of past erosion extending further landward. In fact, the historic dune scarp is cut in a relatively high (and therefore probably quite old) high dune suggesting erosion probably has not extended landward of the fence (Figure 23) in recent decades.

Field observations indicate that stream effects influence erosion further south. This area is however undeveloped and not relevant to the present review.

Figure 23: Most severe calculated erosion at ground level (arrow) at Wharekaho CCS23 (excluding safety factors).

4.6.4 Discussion and Setback Recommendations

The revised PDS in the areas of beach represented by CCS 22/1 and CCS 22 have been fixed on the basis of a precautionary assessment of the seaward edge of the line defined by the underlying erosion resistant materials. In many areas, the seaward edge of these materials is probably located further seaward.

In the more southern areas where there is a greater width of erodible dune sands, we have assessed the revised PDS using the calculations for site CCS 23. This includes all properties south of Joseph Road. There may well be underlying materials at depth which restrict erosion seaward of the revised PDS but fixing this line would require further investigation. The revised PDS in this area is typically 10-15 m landward of the top seaward edge of the existing steep dune face.

Table 7: Summary of beach profile data analysis for CCS 23 at Wharekaho Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 23	11	14	20	30

4.6.5 Management Implications

The setbacks represent a considerable relaxation of the previous primary development setback, and will impose little restriction on the use of private property to the north of Joseph Road.

South of Joseph Road, the setback, though reduced, continues to extend a significant distance into properties. Geomorphic observations suggest that more detailed work may enable the setback in this area to be adjusted seaward, but such reduction was not possible on the basis of information available to this study. It is possible that landowners in this area have further information on subsurface geology (e.g. from past excavations) though no such information was submitted during this review. Otherwise, drilling and other work will be required.

4.7 Matapaua Bay

Matapaua Bay is located just south of Opito Bay on the southern side of the Kuaotunu Peninsula. The beach is relatively sheltered, though can be subject to ocean swell a southerly quarter (SSE to SE), though waves from this direction are fetch-limited by East Cape except waves from the southeast. Refracted swell waves from the east can also impact the bay. The beach is backed by coastal development along much of its length (Figure 24).

Figure 24: Matapaua Bay

No beach profile monitoring is conducted at the site and review of the PDS at this site is based primarily on field inspection.

Field inspection indicates that large pohutukawa occur close to the back of the beach both to the east and the west of the small stream discharging in the middle of the beach – suggesting limited erosion of this bank. This reflects the occurrence of erosion resistant materials.

Figure 25: Large pohutukawa located close to the back of the beach at Matapaua, east (top) and west (bottom) of the small un-named stream which discharges into the centre of the bay

A dune occurs along the back beach to the east of the stream (see top photo in Figure 25), though field inspection and auguring indicated erosion resistant materials underlying these sands a short distance back from the beach. The resistant materials are also directly exposed towards the eastern end of the beach where large rocks have been placed to manage previous slow erosion of this clay bank.

The area to the west of the stream is elevated and fronted by steep vegetated banks composed of weathered volcanic (andesitic) materials - either directly exposed along the back of the beach or buried under a relatively thin veneer of sand. The weathered volcanic materials composing the banks appear to erode only very slowly (toe erosion rates probably <1m per century).

A revised PDS has been mapped along the full length of the beach based on field observations of erosion resistant materials. This setback lies within public reserve east of Matapaua Bay Road but does extend slightly within private properties to the west; though it will not significantly affect the location of new dwellings on these properties. The setback does not provide for slope failure which might be relevant for properties to the west of Matapaua Bay Road. Any future dwellings close to the steep coastal banks on these properties will need to obtain advice on this aspect from appropriately experienced geotechnical specialists.

4.8 Opito Bay

Beach profile data is collected at six sites at Opito Bay. Four sites (CCS47, CCS48, CCS48/1 and CCS49) were established in 1978/9 as part of the original network, or soon after in 1981. Profile sites CCS 47/1 (which has replaced CCS47) and CCS49/1 have been in place since 1996. Profile site 48/1 lies well north of existing residential development and is therefore not relevant to this review.

Results of beach profile analysis are summarized in Table 8, and charts showing the calculated erosion profile against the beach profile record are included for all sites in Appendix A. Results from beach profile analysis and the consideration of all additional information is discussed in relation to each beach profile site below.

4.8.1 CCS49 (North Opito Bay)

Beach profile site CCS49 (Skippers Road) lies at the northern end of current development at Opito Bay, in an area where there is currently a wide dune reserve seaward of residential properties (Figure 26). The Waitaha Stream exits across the beach immediately south of this development and influences shoreline change in the area.

Beach profile analysis shows maximum observed dune toe fluctuations of 100 m, in part driven by stream migration. The most significant period of erosion in the record occurred just prior to the beginning of the profile record. Local long-term residents at Opito Bay confirm that this historic erosion was caused by alongshore migration of the Waitaha Stream at this time (Figure 27). The stream was subsequently straightened by human activities and the dune reinstated. A wide dune presently exists seaward of the (still visible) historic erosion scarp. This scarp is now approximately 50 m landward of the current dune toe. The calculated worst estimated erosion is 15-20 m landward of this historical scarp.

Dune vegetation seaward of this scarp is dominated by spinifex, while more mature vegetation exists to landward (e.g. arctotis, ice plant, and yucca).

In this area, the sand dune appears to extend landward of the residential properties, with no evidence of hard or erosion resistant material that may limit erosion.

Beach profile data at CCS49 (Skippers Road) provides a record of the influence of the Waitaha Stream on the adjacent shoreline. Results from the analysis of this data are therefore used to establish recommended setbacks both north and south of the stream entrance, where along shore stream migration influences shoreline change. However, the analysis relies heavily on geomorphic considerations as well since the extent of stream erosion likely does vary in this area.

Figure 26: Photo looking south at CCS 49. Arrow indicates approximate location of worst measured erosion (old erosion scarp), largely relating to past stream changes.

Figure 27: Photo provided by local property owners showing erosion caused by movement of the Waitaha Stream at the northern end of Opito Bay in 1981. Photo also shows works being undertaken by locals to relocate the path of the stream and plant the dunes.

4.8.2 CCS49/1 (Central Opito Bay)

Beach profile data has been collected at this site opposite Calder Place since 1996. The beach was in its most eroded (recorded) state at the beginning of the record, and has recovered a small amount since, with minor erosion in 2003. Dune toe fluctuations of just 4 m have occurred since 1996.

A large frontal dune exists at the site and the area seaward of the road appears to be erodible sand, though there may be erosion resistant materials at depth. Field inspections indicate large trees (Figure 28) and midden deposits with soft and old shell on the dunes seaward of the road, suggesting that there has been no erosion extending back near the road in recent centuries. This is also consistent with geomorphic evidence.

Figure 28: Opito Bay beach at CCS49/1. Note large frontal dune and mature vegetation. Arrow shows approximate landward limit of calculated likely erosion. Midden deposits occur seaward of this position in places suggesting the estimate is precautionary.

4.8.3 CCS47/1 (Central Opito Bay)

Beach profile data at CCS47/1 near the centre of the beach showed dune toe fluctuations of just 2 m since 1996. The site is characterised by a steep vegetated bank (Figure 29).

Field observations at this site confirm the presence of consolidated and relatively erosion resistant Pleistocene sediments slightly (0.3-0.4 m) below the surface of the beach and underlying dune sands along the back of the beach (exposed directly behind the beach in places – including an approximately 40 m to the east of the beach profile site). Auguring confirms these materials extend to elevations near the top of the dune and will preclude any significant erosion of the dunes in this area. The Pleistocene sediments appear to be beach or dune sediments and probably formed at the time of the last interglacial period when sea level was at or about present sea level (c 120,000 years ago).

Figure 29: Beach profile CCS47/1 near the centre of Opito Bay. The steep bank at this site has experienced little movement over the beach profile record. Hard material is exposed further south on the beach and can be felt at a shallow depth at this site.

4.8.4 CCS48 (Southern Opito Bay)

Field inspections confirm erosion resistant Pleistocene sediments also underlie the beach and dune in this area. The consolidated material are sometimes exposed directly behind the beach (e.g. from Stewart Stream entrance in the north to the southern extent of residential development) (Figure 30). In other places they underlie a shallow veneer of dune sands. These consolidated materials prevent any significant erosion of the dune face – reflected in the fact that maximum observed duneline fluctuations at CCS 48 are less than 1 m. The erosion resistant materials were noted close to the existing shoreline in all areas to the east except for the property immediately east of the volcanic promontory. Erosion resistant materials may also exist in this area at greater depth under the dune (our site inspections did not excavate beyond 1 m depth in most areas). However, as a precaution the setback has assumed erodible sands and is therefore slightly wider in front of this property – though still reduced relative to the existing PDS. The setback in this area also allows for aggravation of erosion in areas close to the stream.

Figure 30: Erosion resistant Pleistocene sediments exposed along the back of the beach in southeastern areas of Opito Bay (photo near CCS48). This material has prevented significant shoreline erosion over the last 30 years. Arrow marks approximate elevation of top of hard material.

4.8.5 Discussion and Setback Recommendations

Two Opito Bay sites CCS49 and CCS49/1 provide good data on which to base setbacks in the northern portion of the Bay where there are no geological controls evident (though these may occur in places).

The data from CCS49 was used along with geomorphic considerations to fix the setback in the vicinity of the Waitaha Stream. CCS 49/1 was used to develop the revised PDS south to Stewart Stream; this setback grading northwards to the setback at Waitaha Stream entrance.

East of Stewart Stream, the revised PDS is located just a few metres landward of the seaward edge of the erosion resistant materials.

Table 8: Summary of beach profile data analysis for CCS49 and CCS49/1at Opito Bay Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 49	55	77	79	89
CCS 49/1	4	5	10	20

The revised setback at the northern extent of the current development is the same as the existing PDS and has little to no influence on the use of private property. Revised setbacks further south and east represent a significant (approximately 10 m) relaxation of the current PDS, with private property no longer affected. The revised PDS east of the Stewart Stream is particularly narrow given the geological restraints on coastal erosion in this area, except for the one property noted in Section 4.8.4. The SDS can also be eliminated in such areas where erosion is limited by geological controls. In places the setback intercepts the road. However, this reflects the precautionary nature of the setback and we do not believe the road is currently exposed to any immediate threat.

It is important to note that these recommendations are for currently developed areas and do not consider wider values that would be important in the establishment of development setbacks for undeveloped areas to both the east and west of the current residential development.

4.9 Kuaotunu East

The beaches from Kuaotunu East to Rings Beach are oriented east-west and therefore directly exposed to waves from a northerly quarter (NW to NE); whereas most other eastern Coromandel beaches are more exposed to waves from an easterly quarter. Kuaotunu and Rings beaches are partially sheltered from easterly swell by the Mercury Islands as well as beach orientation.

Reasonably lengthy beach profile records are available at Kuaotunu East beach at CCS20 (since 1988), CCS21 (1981) and CCS20/2 (1981). Data from CCS21 was not used due to stream influences at the site.

Two transects were surveyed at the beach during the field visit to confirm dune toe elevations for beach profile analysis, as this was not clear from the profile data alone. Both surveys confirmed the dune toe elevation at approximately RL 3.0 m, and this figure was used for the profile analysis.

4.9.1 CCS20/2

Beach profile site CCS20/2 is located in the centre of the beach and is well removed from any influence of local streams. This site provides the most accurate and appropriate data on which to base setbacks for developed areas. Significant erosion occurred at this site during the review and provided a useful cross-check on calculations of worst estimated erosion. Locals indicated that the wave effects and erosion were the most severe in several decades – supported by field evidence as noted below.

The data from CCS20/2 prior to the storm erosion of July and August 2008 indicated dune toe fluctuations of about 11 m since 1988. The worst estimated erosion calculated from the beach profile data is shown in Figure 31 (top photo) compared to a second shot in this area after the mid 2008 erosion. The calculated erosion lay 6 m landward of the dune toe before the storms of 2008 and about 3 m landward after the storm. However, the relatively low nature of the dune at the point of worst estimated erosion suggests to us that this area has been eroded in recent decades (prior to the beach profile data). We therefore believe the estimate is probably not precautionary.

Field inspection indicated mature trees growing on the frontal dune close to the sea to both the east and west of the profile site. These trees included a large macrocarpa located approximately 5 m seaward of the estimated most eroded dune toe (Figure 32). This tree appears to be relatively old (probably >50 years). The erosion of 2008 outflanked this tree and eroded about 1m landward (Figure 32). This erosion is seaward of our estimate and clearly the worst for several decades in that location. However, a rip-head embayment further south of the tree extended a further 3-4 m landward – probably close to our erosion estimate. Therefore, once again the post-storm data suggests the estimate is not precautionary.

Before and after shots from other sections also suggest the 2008 erosion is not the worst possible – with low dune areas further landward that were not affected such as evident in Figure 33.

Figure 31: Approximate line of worst estimated erosion at ground level (top photo arrow) at CCS20/2 at the southern end of Kuaotunu East Beach. Bottom photo shows same area (just beyond the people in the top photo) after the mid 2008 erosion.

Figure 32: Large macrocarpa near top edge of dune face north of beach profile site CCS20/2 – before (top) and after (bottom) severe erosion of July/August 2008).

Figure 33: View along part of Kuaotunu East beach before and after mid 2008 erosion. The low dune areas landward of the 2008 erosion suggest this erosion is exceeded on occasions - probably extending back to the higher dune area behind.

4.9.2 Discussion and Setback Recommendations

Overall, despite the fact that the 2008 erosion was relatively rare and that the estimate of worst estimated erosion is equal or greater than this erosion, we believe the erosion estimate is not adequately precautionary. The limited conservatism in the calculations probably reflects the fact that there were no significant erosion events evident in this beach profile record.

With the total 10 m safety factor adopted in calculations (Table 9), the revised PDS lies at least 12-14 m landward of the recent erosion. There are also several large and old trees (pine and macrocarpa) up to 5-7 m seaward of the revised PDS. The PDS also generally lies on higher dune areas. The line of the revised PDS therefore appears not to have been affected by erosion in the last 60-80 years and (judging by dune topography) probably much longer. Therefore, with the 10 m safety factor, we believe the revised PDS is adequately precautionary.

Table 9: Summary of beach profile data analysis at Kuaotunu East Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 20/2	11	8	11	21

The setback at the eastern end of the beach around the Kuaotunu River mouth is based largely on geomorphic considerations from aerial photographs and field observations. This area is affected by lateral stream movements which in recent years have cut the duneline back by more than 65-70 m in places. Historically, lateral stream movements have eroded back to the seaward toe of the sloping bank seaward of the 6 developed properties (i.e. 185-195 State Highway 25). Geomorphic evidence suggests that past erosion has extended up to 70-110 m inland (varying with distance from river entrance).

The low dune occurring in this area as a result of periodic lateral stream movements also makes the area vulnerable to wave overtopping. In the storm events of July and August 2008, significant wave overtopping occurred over the entire area and washed high onto the dune face to landward (Figure 34). This wave overtopping did not however extend to elevations sufficient to threatened existing dwellings.

4.9.3 Management Implications

The revised setback represents a relaxation of the current setback recommendations and no longer has any significant impact on use of private properties along the back of the beach.

Figure 34: Eastern end of Kuaotunu Beach near Kuaotunu River mouth following storms of July and August 2008 showing areas subject to wave overtopping and run-up.

4.10 Rings Beach

Rings Beach is backed by a dune reserve with most subdivision and development located landward of Bluff Road behind the reserve (Figure 35). There are a few properties at the extreme eastern end of the beach on the seaward side of Bluff Road but the nearest dwelling in this area is approximately 40 m landward of the dune toe.

Beach profile data is collected at just one site at Rings Beach (CCS18), located near the centre of the beach and representative of the main beach areas away from the small stream entrances at either end. This site has been monitored since January 1979.

4.10.1 CCS 18

The data from this site shows only minor (4 m) duneline fluctuations, as summarized in Table 10 below.

A recent storm in August 2008 caused some beach lowering and toe erosion towards the northern end of the beach, with slightly more significant erosion occurring around the small stream entrance at the extreme northern end of the beach. The central and southern areas of the beach were relatively unaffected though wave run-up extended half way up the beach face in some places.

Figure 35: View of Rings Beach from eastern end.

Figure 36: Minor dune toe erosion at north end of Rings Beach following storms of July and August 2008

Figure 37: Dune toe erosion at very north end of Rings Beach following storms of July and August 2008

Estimates of the likely extreme erosion are summarised in Table 10. Field measurements place the worst estimated erosion (at ground level) a small distance landward of the frontal dune crest (Figure 38), about 8-10 m landward of the top seaward edge of the moderately steeply sloping dune face

Field observations and community information indicate that the estimate is precautionary for existing coastal processes, being well landward of any evidence of erosion over the last 50-100 years.

Figure 38: Worst estimated erosion as estimated for Rings Beach

4.10.2 Discussion and Setback Recommendations

A constant of 21 m from the most seaward measured dune toe is recommended at Rings Beach based on calculations using the data from CCS 18 (Table 10). This setback incorporates the most likely extent of erosion and a 10 m safety factor. The revised represents a relaxation in the existing hazard setback (a generic value based on data from other sites) of over 20 m.

Table 10: Summary of beach profile data analysis at Rings Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 18	4 m	4 m	11 m	21 m

4.10.3 Management Implications

Private use of residential property will not be affected by the revised PDS at Rings Beach. The setback intercepts the road in places but geomorphic evidence suggests any risk to the road is low.

4.11 Matarangi

Matarangi Beach fronts a 4.2 km sand spit enclosing Whangapoua Harbour (Figure 39). Coastal development is set back 100 m along most of the length of the ocean shoreline apart from the southernmost length (about 1 km) fronting Kenwood Drive. The latter area is the only section relevant to this review.

Beach profile data is collected at five sites along Matarangi Beach. Profile site CCS13 is the only site fronting the development at the southern end relevant to this review and was the data used for the setback review at this site. Field inspections confirmed the site is representative. However, data from the other sites (except those close enough to the entrance to be affected by entrance effects) were also analysed and inspected in the field as a cross check on the method. The estimates at each of these sites exceeded the worst measured erosion at each. Charts showing the calculated erosion profile against the beach profile record are included for all sites analysed (Appendix A.).

4.11.1 CCS13

Monitoring at this site commenced in January 1979, approximately 6 months after the severe storm of July 1978. The eroded dune toe surveyed at that time is still the most severe erosion evident in the beach profile record – indicating that the July 1978 event was one of the more severe events at this site as with various other eastern Coromandel sites noted in this report – though slightly more severe erosion may have occurred earlier as noted below.

The main frontal dune along the back of the beach in this area is generally fronted by a low spinifex dune typically up to 15-20 m wide (Figure 40). The July 1978 storm eroded this incipient dune and scarped the face of the 3-4 m high dune to landward. Observations of aerial photographs suggest the erosion may even have occurred earlier – with a Whites Aviation photo from August 1972 (WA 70519) showing this high dune faceted along most of the length of the beach The recent storms of July and August 2008 also caused severe erosion of the low incipient dune and in places cut back to the high dune further landward – though the erosion was slightly less significant than that evident in the 1979 beach profile survey and the 1972 imagery noted above. While the exact date of the severe erosion evident in the 1970s is not clear, there appears to be 30-40 years between this and the more recent period of extreme erosion, further reflecting the multi-decadal nature of extreme erosion along this coast. The observed period is similar to erosion cycles noted at many other sites in this review.

At beach profile site CCS13, the most landward (estimated) dune toe is close to the top of the 1970s erosion scarp (Figure 42). Field evidence indicates no evidence of more serious erosion over the last few decades and sands on this higher dune often indicate a slightly weathered appearance in contrast to the fresh white sands to seaward, suggesting the high dune landward of the scarped face is not regularly disturbed by erosion. This is also consistent with geomorphic considerations given the dune topography.

The revised PDS is at least 10-12 m landward of the worst measured erosion for at least 40-50 years.

Figure 39: Matarangi Spit.

Figure 40: View of dune fronting the southern end of Matarangi Beach (seaward of Kenwood Drive) taken in April 2008. Note the low incipient dune to seaward that typically characterises this area. The 1978 storm scarp is still evident in the dune to landward (see text).

Figure 41: View looking south along the seaward edge of Kenwood Drive following the storms of July and August 2008

Figure 42: Location of worst estimated erosion (ground intercept excluding safety factors) at CCS 13. The estimate is close to (but landward of) historic erosion scarps but field evidence suggests the revised PDS (with the 10 m safety factor) is adequate.

4.11.2 Discussion and Setback Recommendations

The revised PDS at Matarangi is based on data from CCS 13 summarised in Table 11 and is generally at least 10-12 m landward of the worst measured erosion over the last 50 years. The setback in the vicinity of the stream at the south end of the beach was adjusted based on field inspections and geomorphic evidence.

Table 11: Summary of beach profile data analysis at Matarangi Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 13	23 m	25 m	30 m	40 m

4.11.3 Management Implications

The revised PDS is largely unchanged, except at the south end of the beach where it has been reduced. The setback extends within a number of private residential properties, but not sufficiently to impose any restriction on the location of dwellings – given the existing beachfront yard setback requirement.

4.12 Whangapoua

Whangapoua is a medium to coarse grained beach located to the east of the Whangapoua Harbour entrance. The beach, approximately 1.6 km long, is exposed to waves from the Northwest to east (though partially sheltered from easterly waves by the Mercury Islands) and is backed by beachfront development along most of its length (Figure 43).

Figure 43: Whangapoua Beach

Beach profile data is collected at three sites along the beach. All sites have nearly 30 years of data and are reasonably representative of adjacent beach areas. The sites have therefore all been used to establish recommended setbacks as part of this review. Data from CCS11 and CCS12 dates from January 1979, while surveys at site at CCS11/1 were started in January 1981. Charts showing the calculated erosion profiles against the beach profile record are included for all sites in Appendix A.

Other information available at this site including information from long-standing property owners (some owners dating back to the early 1960's) and limited historic photography (the earliest aerial photographs dating from 1944). There are also a number of property specific reports relating to properties at the northern, central and southern ends of the beach.

4.12.1 CCS12

Beach profile site CCS12 provides a record of beach change at the northern end of Whangapoua Beach, with the transect line in the lee of the small island immediately offshore (Figure 43). Field observations confirm that the shoreline at the profile site is influenced by a salient formed behind the island, with the dune line curving inland to the south. This salient effect could be one of the reasons for the greater fluctuations in dune toe observed at this site when compared with other profile sites at Whangapoua Beach.

The most landward erosion profiles in the record were surveyed in 1997 and 1998, with the eroded dune toe position about 22 m landward of the most seaward dune toe. Interestingly, the profile surveyed in January 1979, approximately 6 months after the July 1978 storm, is one of the more accreted dunelines in the record with the most accreted duneline surveyed 2 years later in 1981. Therefore, this storm did not cause significant erosion at the northern end of the beach, with the more severe erosion experienced during the late 1990s – a period also noted for erosion at some other eastern Coromandel sites as discussed earlier (e.g. Buffalo Beach).

The local Beachcare group has actively planted the eroded dune face since the early 2000s and the dune in this area was in early stages of recovery at the time of our initial field inspection in April 2008 (Figure 44.

Figure 44: View south from CCS 12 in April 2008 showing early stages of dune recovery

The predicted worst estimated erosion extends approximately 10-11 m landward of the worst measured erosion and is located in the swale behind the frontal dune. All available evidence for the site suggests the estimate is reasonable and approximately 8-11 m landward of any erosion recorded over at least the last 50 years.

Figure 45: Location of worst estimated erosion in swale behind frontal dune.

4.12.2 CCS11

Beach profile site CCS11 lies near the centre of the beach. The most serious dune erosion at this site occurred in the late 1990s and early 2000s, with the most eroded dune toe about 10 m landward of the most prograded (the latter surveyed in the mid 1980's). The January 1979 dune profile lies about midway between the most eroded and most accreted dune profiles, indicating that the erosion accompanying the July 1978 storm was not as serious in this area. The dune in this area was eroded again in the storms of July and August 2008, but not as severely as the dunes further south (see discussion in next section).

The worst estimated erosion intercepts ground level about 8-10 m landward of the worst measured erosion (see graph for CCS 11 in Appendix A). Field inspections (Figure 46) and available community information indicate that this is well landward of any erosion observed since at least the early 1960s and probably earlier.

Data collected at CCS11 is representative of the central area of the beach and accordingly has been used to revise setback recommendations in this area – though grading to CC 11/1 for areas to the south.

Figure 46: Worst estimated erosion at ground level at Whangapoua Beach, profile site CCS11.

4.12.3 CCS11/1

Beach profile site CCS11/1 lies near the southern end of Whangapoua Beach.

The most severe erosion in the profile record occurred in the storms of July and August 2008, with the eroded dune toe (at RL 3.5 m) nearly 5 m landward of the previous worst measured erosion surveyed in 1981. However, the latter profile was surveyed over 2.5 years after the storm of July 1978 when the beach and dune were recovering. Photographs of the 1978 erosion held by property owners indicate the 1978 erosion was as severe in some areas towards the southern end of the beach as the recent (August 2008) erosion. The earlier erosion was not as widespread along the beach and in places the August 2008 erosion was more severe. Erosion protection works placed in the 1970s (permeable fences with little to no effect on erosion) were located close to the recently eroded dune face at the more southern end of the beach. Further north on the beach, August 2008 erosion extended landward of these works.

The erosion of July and August 2008 was extensive, with severe erosion extending 750 m northward from the southern end of the beach (Figure 47) and lesser erosion for at least a further 250 m. In places, the erosion severely threatened houses (Figure 48). Erosion mitigation works (dune reinstatement using beach scraping) were subsequently designed (Eco Nomos, 2008) and implemented.

Figure 47: View looking south from centre of beach before (top, June 2007) and after (bottom, November 2008) erosion of July and August 2008

Figure 48: View of erosion scarp in central-southern beach following storms of July and August 2008 (Photo: Meg Graeme – taken August 2008).

The of worst estimated erosion calculated using the data from CCS 11/1 intercepts ground level about 8 m landward of the top edge of the erosion scarp measured following the July and August 2008 storms (the worst erosion since at least the early 1960s). There is no field evidence of more severe erosion. We believe the estimate is sufficiently precautionary to use to revise the PDS in this area of the beach.

Trend analysis of the variation in dune toe at this site raised the question whether or not the southern end of the beach is experiencing a long-term trend for erosion (Environment Waikato, pers. comm.) . Planning maps also show a 16 m wide reserve fronting development. At present, little width of reserve land remains in many areas. Community photographs we viewed dating from the 1960s (held by the Goldsmith family, long-term property owners at Whangapoua) also seem to show the duneline at the southern end of the beach further seaward than has been observed since.

Historically, sand was extracted from the ebb tide delta at the entrance to Whangapoua Harbour and the sand grade removed was similar to that on Whangapoua Beach. Other eastern Coromandel beaches subject to sand extraction often show evidence of some long-term erosional response (see discussion in Section 2.1.2). We analysed trends evident in the beach profile data at CCS 11/1; inserting a data point for the July 1978 erosion based on the position of shoreline armouring works placed at that time. The variation over time is shown in Figure 49. With insertion of data for the 1978 erosion, the figure tends to suggest that shoreline change from 1978 to the present was dominated by a multidecadal shoreline fluctuations – with a period of 30 years for the 'cycle' from severe erosion in 1978 through a period of sustained shoreline recovery/advance and back to severe erosion in July 2008. No significant long-term trend can be reliably assessed from the data. The similarity of the 1978 and 2008 erosion suggests there is either no ongoing long-term trend for erosion or that any trend is slow (e.g. less than 5 m per century).

While there is no conclusive evidence for long-term trends since July 1978, it is possible that some adjustment to the earlier sand extraction occurred before or up to this time. Accurate analysis of shoreline change using rectified historic photographs and any available historic surveys would be required to more reliably assess this. However, regardless of any such adjustment, we believe that no additional allowance for ongoing long-term erosion can be justified on the basis of existing data.

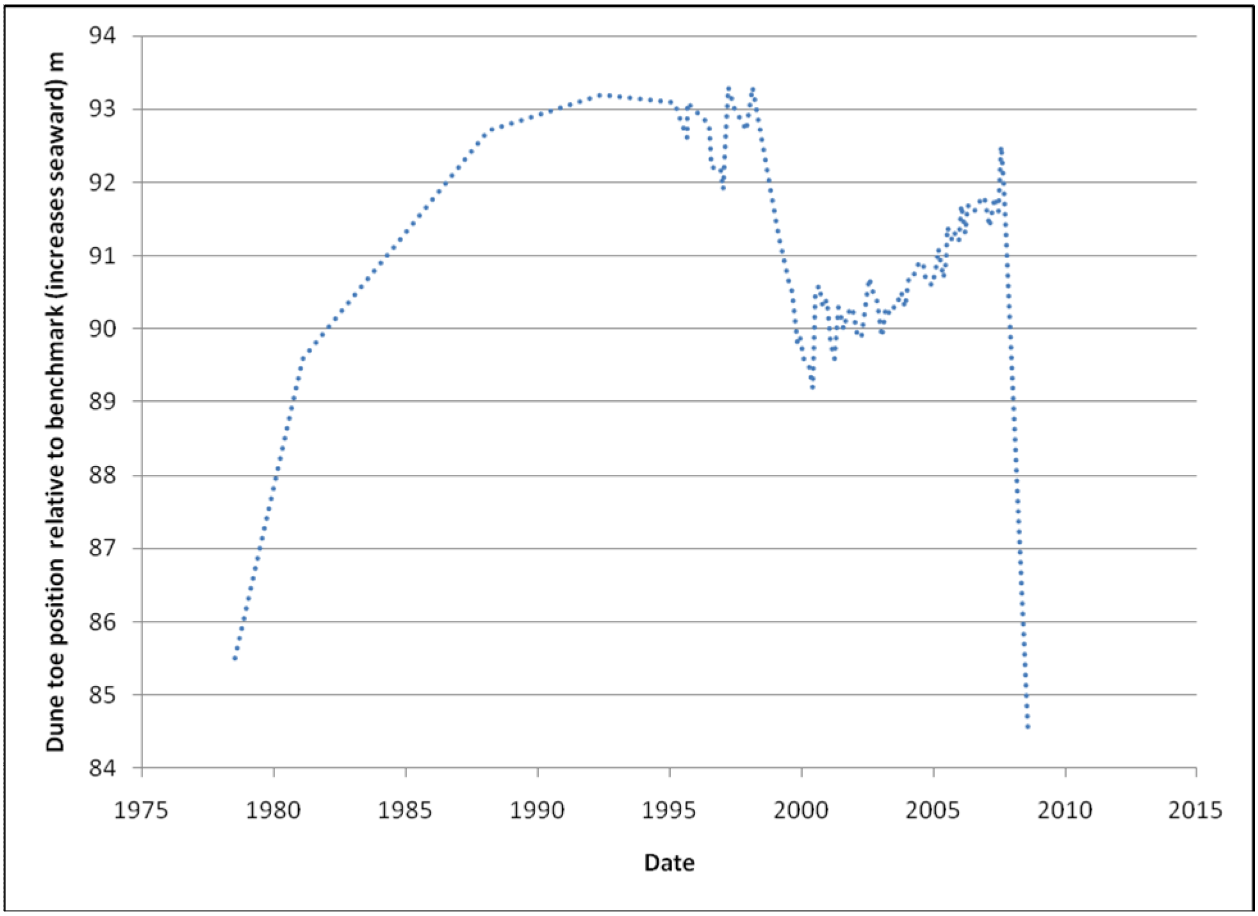

Figure 49: Trends in duneline (RL 3.5 m) position from 1978 to 2008 at CCS 11-1.

4.12.4 Discussion and Setback Recommendations

Primary development setbacks at Whangapoua Beach are based on beach profile data and include a 10 m safety factor. Setback distances are fixed at the location of CCS11, CCS11/1 and CCS12 beach markers and grade between as summarized below:

- From CCS12 (Fire Station) to the north extent of development: **34 m**
- At CCS11: **27 m**
- From CCS11/1 (southern accessway) to southern extent of development: **21 m**
- Distances graded between CCS11 and CCS11/1, and between CCS11/1 and CCS12.

Table 12: Summary of beach profile data analysis at Whangapoua Beach. Figures are relative to the most seaward measured dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level (“y-intercept”)	Recommended PDS
CCS 12 (north)	15 m	21 m	24 m	34 m
CCS 11 (central)	9 m	10 m	17 m	27 m
CCS 11/1 (south)	9 m	6 m	11 m	21 m

This revised setback represents a moderate relaxation of the current PDS – varying from 8-14 m along the beach.

4.12.5 Management Implications

The current review has reduced the width of PDS recommendations for most areas of Whangapoua Beach. The revised hazard line does however continue to extend some distance into some properties – particularly at the southern end of the beach. The setbacks will therefore continue to exert some influence on dwelling location, though less was previously the case.

4.13 Kennedy Bay

The existing PDS at Kennedy Bay applies only to the developed area in the centre of the beach, immediately south of Beach Road.

The areas to the north of Beach Road and to the south of Pakori Stream are relatively undeveloped. The spit area towards the entrance is also known to have been breached historically, approximately 1 km south of the present estuary entrance. The potential for changes of this nature could be severely complicated by projected sea level rise. Dahm and Munro (2002) recommended that site-specific setbacks be determined for such areas that provide not only for existing and potential coastal hazards, but also for the wide range of other coastal management objectives that are relevant to such areas (e.g. Sections 5-7 of the RMA and the provisions of the NZCPS). In the absence of site-specific determinations, a single, minimum setback of 100 m was proposed as a general rule.

This review is therefore limited to the area of the existing development immediately south of Beach Road. The closest beach profile site in this vicinity is CCS 10, located at the seaward end of Beach Road at the immediate northern end of the development. Field inspection suggests the site is representative of the area of the development.

The only other beach profile site at Kennedy Bay, CCS 10/1, is located 150-175 m to the south of Pakori Stream. Field inspection suggests this site is less representative than CCS 10 and may also be affected by proximity to the stream entrance. Preliminary analysis of the data was however conducted for comparison and indicated that less significant fluctuations and erosion have occurred at this site and that estimates of potential shoreline fluctuations and erosion were also less than obtained using data from CS 10. Use of this data would not therefore be consistent with a precautionary approach – particularly given the closer proximity of CCS 10 to the developed area and the fact that it is more representative of conditions in that area.

Therefore, the data from CCS 10 was used to revise the PDS at this site.

4.13.1 CCS10

Available information at this site dates from January 1979. Beach profile data records dynamic shoreline fluctuations of up to 16 m, with the most eroded duneline position measured in the surveys of January 1979, indicating that the July 1978 storm appears to have been the most severe event in this area of the beach in recent decades.

The calculations suggest potential for duneline fluctuations of up to nearly 30 m, with the most landward erosion likely estimated at approximately 8 m landward of the most eroded dune toe position so far recorded at the site.

Field inspections and beach profile data indicate that recorded erosion at the site has largely affected a wide and low spinifex vegetated dune seaward of the main frontal dune. The 1978 erosion extended to the landward edge of the wide low spinifex dune, faceting the seaward face of the higher dune to landward. The estimated erosion intercepts the ground surface in the swale behind this higher and main frontal dune. Field inspections suggest that there has probably been no erosion this far landward over the last several decades – probably not even in the last 50-100 years. This is also consistent with expectations from geomorphic data, which tend to suggest that dynamic fluctuations are typically limited to the lower dune area to seaward.

The limited other data available for this site, including past community information, also suggests the estimated erosion is precautionary.

4.13.2 Discussion and Setback Recommendation

The various considerations noted above suggest the calculations for this site (Table 13) are relatively precautionary and the revised PDS recommended probably exceeds any erosion over the last 50-100 years by at least 10-15 m. In most areas there is a slight reduction in the existing PDS except for the vicinity of the stream entrance where the revised PDS is mapped on the basis of geomorphic considerations and there is a small increase.

Table 13: Summary of beach profile data analysis at Kennedy Bay. All figures are landward of the most seaward observed dune toe.

	Most Eroded Dune Toe Observed	Most Eroded Dune Toe Calculated	Worst Estimated Erosion at Ground Level ("y-intercept")	Recommended PDS
CCS 10	16 m	24 m	28 m	38 m

4.14 Port Charles

Port Charles is a deep embayment on the east coast exposed to ocean swell from a northerly quarter (especially the NW) but sheltered from more easterly wave directions. The embayment is approximately 2.7 km deep and narrows from 1.5 km wide at the seaward end to 50-550 m at the head. Depths at the entrance to the embayment are typically 10-15 m but the beaches at the head of the embayment are fronted by wide shallow flats extending seaward approximately 800 m above Chart Datum.

There are 2 beaches in Port Charles relevant to this review and these lie at the head of the embayment, separated by a small peninsula (Figure 50).

The main port Charles beach at the head of the embayment is backed by a public reserve and Carey Road, with Tangiaro Stream discharging at the western end of this beach (Figure 50). There are two beach profile sites at this beach, CCS 6 about 80 m east of the stream entrance and CCS 6/2 approximately 175 m east of the entrance. Field inspections suggest that CCS 6/2 is probably the more representative site and less subject to river entrance influence. However, site CCS 6 does provide useful information on the potentially more dynamic area close to the stream entrance.

The second of the 2 beaches lies further east in a small embayment associated with the Parakete Stream which discharges at the northern end of the beach (Figure 50). There is a single beach profile site at this beach, located just south of the centre of the beach, about 165 m from the Parakete Stream entrance.

Figure 50: View at head of Port Charles embayment showing the two beaches relevant to this review.

4.14.1 CCS 6 and CCS 6/2

The data at CCS 6 dates from January 1979 while Site CCS 6/2 covers a lesser period, dating from 1996. Therefore, while CCS 6/2 is more representative of the bay as a whole the data from both sites was used for analysis.

Examination of the data from both sites suggests the shoreline is dynamically stable over time and subject to only relatively minor dynamic fluctuations. Dynamic fluctuations at CCS 6 are typically in the order of 4-5 m, though the January 1979 survey indicates an eroded shoreline position approximately 10-12 m landward of the most seaward toe of bank measured. This erosion probably reflects the effect of the July 1978 storm and suggests that this event was the most significant erosion event at this site in recent decades. The data from CCS 6/2, more removed from the stream entrance, indicates a relatively stable shoreline with dynamic fluctuations typically less than 2-3 m.

The larger scale fluctuations close to the river entrance are consistent with expectations from geomorphic considerations and with field evidence. Field evidence indicates that the site at CCS 6 is subject to erosion associated with lateral stream movements. Onshore migrating swash bars are also evident offshore from this site.

Field inspections and community information also confirm that the shoreline is relatively stable. Long-term residents indicate that the road landward of the reserve has never been threatened by erosion. This is consistent also with field evidence, including geomorphic evidence and the presence of relatively mature trees on the reserve seaward of the road (Figure 51).

Figure 51: Large Norfolk Pines on public reserve seaward of road.

4.14.2 CCS 6/1

The data available at this site extends back to January 1981. The data indicates a trend for continued net erosion of the beach and low vegetated bank to landward, with approximately 9 m retreat over the period from January 1981 to July 2007 (Figure 52). This represents an average rate of shoreline retreat of approximately 0.3 m/yr when averaged over long periods of time, though the erosion probably occurs episodically during major storms when retreat may well significantly exceed the average rate.

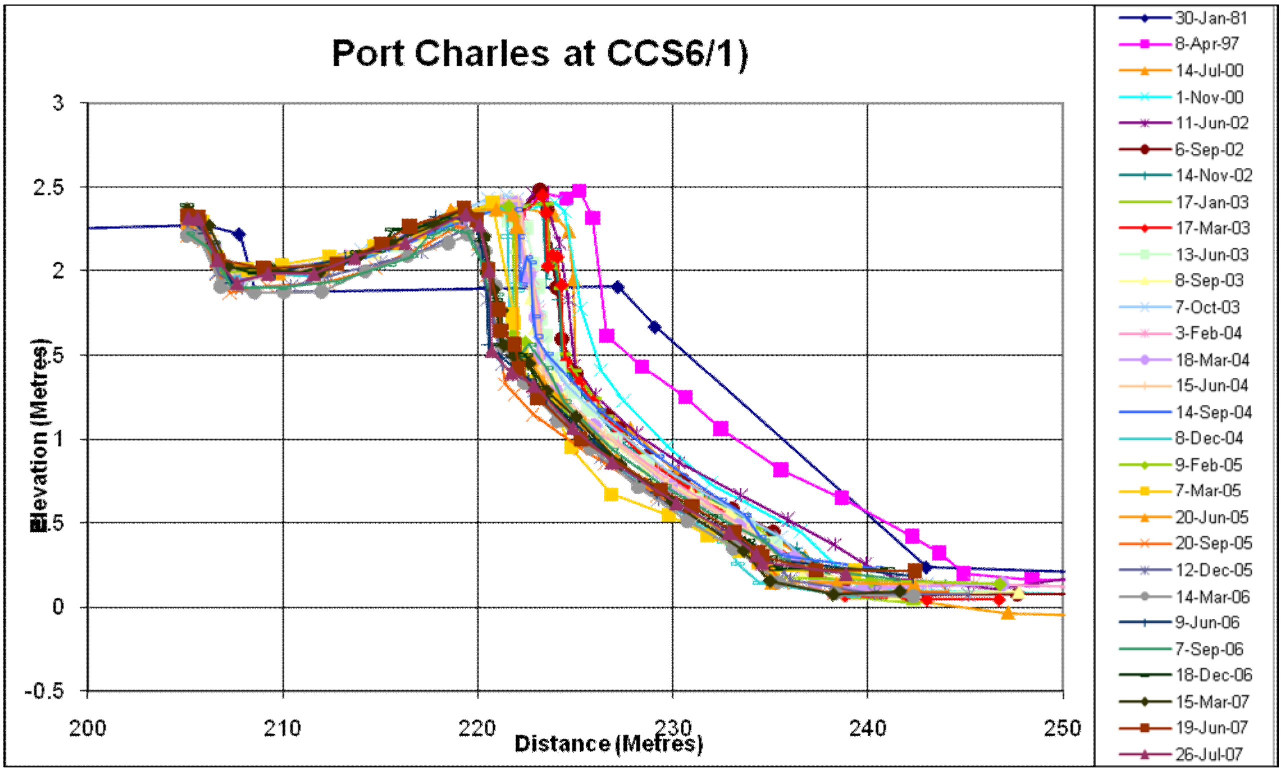

Figure 52: Shoreline changes since 1981 at CCS 6/1 - indicating an ongoing trend for net shoreline retreat

Field inspections and discussions with local landowners confirm the ongoing trend of erosion. The available data at the time of our analysis extended to July 2007 and local landowners advise that further significant erosion has occurred since that time, particularly associated with the severe storms of mid 2008 – possibly up to 1 m. This would increase the time-averaged rate to over 0.35 m/yr.

The reasons for the net erosion are unclear, though sand trapped behind make-shift groynes on the beach indicate net eastwards transport of sediment into the Parakete Estuary (Figure 53). Field inspections and aerial photographs indicate evidence of net shoreline advance at the eastern end of the beach adjacent to the stream entrance suggesting some deposition of eroded sand in this area. The remaining sand has probably been deposited in the estuary and carried out into the bay by tides and stream flows (probably most significantly during freshes and floods).

A variety of ad hoc protection works have been placed on and along the back of the beach by locals in an attempt to mitigate erosion, though these works appear to be having only limited effect (Figure 53). A site specific erosion strategy is likely to be required at this site to more appropriately manage ongoing erosion.

Figure 53: View of erosion at Port Charles east of CCS 6/1

4.14.3 Discussion and Setback Recommendation

The beach at the head of the embayment adjacent to Tangiaro Stream is subject to relative minor dynamic fluctuations, increasing towards the stream entrance. The beach appears to be relatively stable and not experiencing any long-term retreat. The revised PDS at this site is therefore adopted as the seaward edge of the road. Field evidence and calculations using beach profile data suggest this is a precautionary estimate for this site – probably exceeding the worst measured erosion in recent decades by 5-10m in areas close to the stream and by >15 m along most of the length of the beach.

The ongoing trend for net erosion at the more eastern beach adjacent to Parakete Stream is more significant. The revised PDS for this site has, for the sake of precaution, assumed that the present erosion will continue indefinitely – though this may not be the case. An ongoing rate of erosion of 0.5 m/yr has been assumed for the next 50 years to allow for potential aggravation of existing erosion – providing a revised PDS of 25 m for this site. The existing rate of erosion appears to average 0.3-0.35 m/yr as noted above – suggesting the revised PDS is probably precautionary by 7.5-10 m for this site. We believe this is adequate precaution for this site.

4.14.4 Management Implications

There are no major management implications for private property with the revised PDS recommended for the beach at the head of the Port Charles embayment, as the PDS is well seaward of private property. Erosion is also unlikely to serious threaten Carey Road in the absence of projected sea level rise. The more significant erosion evident near the stream entrance (CCS 6) following the July 1978 event suggest there may be some limited risk to the road with the combination of major floods and wave storms – though the risk is low and would be relatively simple to address if problems arose.

The revised PDS for the eastern beach adjacent to Parakete Stream does extend into private properties. Existing houses are typically setback at least 20-25 m from the eroding shoreline suggesting reasonable protection from erosion in the near future – probably for at least 50 years unless the existing rate of erosion is aggravated by climate change or other factors. The sections at this beach are also relatively deep, some extending more than 80-90 m landward from the shoreline. This provides opportunity for landward relocation if required in the future providing additional security for the dwellings. In addition, the nature of the site is such that appropriate mitigation of erosion may be practical, though shoreline armouring structures are unlikely to be an appropriate solution. If existing erosion needs to be managed in the short to medium term, an appropriate hazard mitigation strategy will need to be developed.

The relatively low banks backing the beach at both sites suggest the potential for coastal flooding to become a more significant issue with projected sea level rise. Advice from long-standing residents suggests sea flooding is presently not a significant issue. Nonetheless, thought should be given to adopting minimum floor level recommendations for nearshore dwellings at these sites to provide security against projected sea level rise. .

4.15 Sandy Bay

Sandy Bay (Figure 54) is an embayed beach located on the eastern side of the entrance to the Port Charles embayment. The beach is directly exposed to ocean waves from a northerly quarter (especially N and NW) but also impacted by easterly waves refracted around the Peninsula on the eastern side of the Port Charles embayment. The beach is primarily sand but gravel content increases significantly towards the eastern end where Okahutahi Stream flows onto the beach (Figure 54)

Figure 54: Sandy Bay

4.15.1 CCS 5

There is only one beach profile site at Sandy Bay (CCS5). Surveys have been conducted at this site since January 1979, though only a limited number of surveys were undertaken in the 1980s and 1990s. The site has been surveyed moderately frequently since 2002. CCS5 lies in the centre of the beach and is considered to be representative of shoreline behaviour at Sandy Bay.

The beach profile data indicates that the worst measured erosion in the record occurred at the time of the January 1979 survey – indicating that erosion during the July 1978 storm is the worst in recent decades at this site. Over the following 30 years, the bank profile has gradually advanced seaward – with the 1979 erosion scarp approximately 5m landward of the most prograded position at the same elevation (RL 2.5 m). Dynamic fluctuations following dune face recovery have been less than 3m.

Field examinations indicate the recovered dune face is typically vegetated with exotic stoloniferous grasses though it does contain patches of native vegetation (especially knobby clubrush) (Figure 55).

Figure 55: View of Sandy Bay beach and reserve from western end

4.15.2 Discussion and Setback Recommendation

The calculations using beach profile data suggests the worst estimated erosion would extend no more than 1-2 m landward of the July 1978 erosion scarp. Therefore, the worst estimated erosion lies well seaward of private property and in fact well seaward of the foreshore road (Port Charles Road).

With the inclusion of the safety factors discussed in Section 29, the revised PDS lies just seaward of Port Charles Road; this position is generally 10-12 m landward of the worst measured (July 1978) erosion. In our opinion, erosion is unlikely to extend this far landward unless seriously exacerbated by climate change.

4.15.3 Management Implications

The existing PDS extends onto private property in places on the landward side of the road. However the revised PDS indicates that erosion is unlikely to affect even the road in the absence of projected sea level rise.

5 Primary Development Setbacks – West Coast

The existing along the Thames Coast provides for both coastal erosion and high velocity wave effects associated with wave overtopping (see earlier discussion in Section 2.2). The setback is also complemented by a minimum floor level requirement to provide protection from both river and coastal flooding.

The following sections review the hazard posed by coastal flooding and erosion and discuss implications for review of the Primary Development Setback at the review sites.

5.1 Coastal Flooding

Storm-induced sea flooding along the Thames Coast results primarily from the combination of extreme sea levels and wave run-up overtopping low-lying coastal margins (Dahm and Munro, 2002). Water overtopping can flood extensive low-lying areas some distance inland.

There have only been two significant coastal flooding events in the last 50 years, in July 1995 and January 1997 (Cyclone Drena). However, as there have been at least 6 significant events since 1930 (occurring in 1936, 1938, 1947, 1951, 1995 and 1997), the annual probability of these events is probably slightly higher than the record of the last 50 years would suggest. In any given year, the probability of a coastal flooding event is probably about 5-7% (Dahm and Munro, 2002).

The following sections review information on extreme sea levels and wave run-up for the southern Firth of Thames, where the review sites are located. All reduced levels (RL) quoted are with respect to the Tararu mean sea level datum.

5.1.1 Extreme Sea Levels

Extreme sea levels in the Firth of Thames arise largely from the combination of astronomical tides and storm surge. Storm surge refers to the elevation of sea level above predicted tides by onshore winds, lowered barometric pressure and other effects that occur during major storms. Analysis of the sea level record from the tide gauge at Tararu (records since May 15, 1990) indicates that 80% of the variation of sea level from predicted tidal elevations can be explained by barometric pressure variations (Goring, 1995). However, reports from past storms (e.g. May 1938) suggest that strong onshore winds from a northerly quarter may result in wind set-up in southernmost areas of the Firth (e.g. adjacent to Thames and Tararu).

Analysis of the Tararu tide gauge records provides good information on the range of elevations experienced from astronomical tides alone. The highest astronomical tide level in the absence of storm surge has been assessed at RL 1.917 m (relative to the Tararu mean sea level datum), with tides of this elevation occurring once every 18.6 years (Bell and Hill, 1997).

Estimates of extreme sea levels arising from the combination of tides and storm surge are more complex - due to the relatively short record available from the Tararu tide gauge. An analysis of extreme sea levels commissioned by Environment Waikato in 1997 assessed the 1% AEP (annual exceedance probability) sea flood level at RL 2.32 m; the 0.5% AEP (i.e. 500 year return period) at RL 2.39 m; and the 0.1% AEP at 2.54 m (Goring, 1997). The record at that time included two extreme sea flood events – being those of July 1995 and January 1997. These are the two most serious sea flood events since at least 1951 and probably earlier (Dahm and Munro, 2002). However, the author noted that the sea level record from the tide gauge was relatively short and the statistics were likely to change once further data was available.

The highest extreme sea level measured to date occurred in July 1995; when an extreme sea level of RL 2.48 m was recorded at the Tararu tide gauge site. This event appears to have been extremely unusual - as the peak of the storm surge coincided precisely with an extremely high and rare perigean tide level (RL 1.895 m), one of the highest predicted tides for that year (Goring, 1997).

A flood level of RL 3.0 m was also measured following the major sea flood event of May 1938. This event breached foreshore stop-banks fronting the Hauraki Plains in 15 different areas and caused extensive flooding on the eastern Hauraki Plains and also affected parts of Thames and other areas (Dahm and Munro, 2002). It has been generally assumed that this RL 3.0 m elevation was a widely pervasive static sea level arising from the combination of tides and storm surge. For instance, the elevation is currently adopted locally as the best estimate of the 1% AEP extreme sea flood elevation. However, a review of the available data on this event by Dahm and Munro (2002) raises questions in regard to this assumption. For instance, hindcast tidal elevations for the evening of May 4 1938 (when the flooding occurred), commissioned by Environment Waikato, indicate a predicted high tide of RL 1.67 m. Therefore, storm surge of at least 1.3m would have been required to attain a static sea level of RL 3.0 m. This is well in excess of both historic storm surge measurements (typically much less than 0.8 m) and the maximum storm surge amplitudes (<1.0 m) presently believed to be possible around the New Zealand coast. Newspaper reports also indicate the flooding was accompanied by gale force winds from the north to northwest, as with Cyclone Drena, which suggests that significant wave action is likely to have accompanied the event.

Searches of historic management agency files held by Archives NZ were made during this review in an attempt to locate further information on the extreme sea level measurements made after the event. We managed to locate two reports on the flood events prepared by then Public Works Department (PWD). These reports note two flood levels taken after the event – one at Pipiroa "*on the coast*" and the other at Thames Aerodrome "*in a sheltered location*" – both recording similar elevations of approximately 3 m. The Thames Aerodrome is located on the coast. We are therefore inclined to suspect that both of these elevations were affected by wave effects (e.g. wave set-up and wave run-up) as well as tides and storm surge. However, as Dahm and Munro (2002) note, the event is significant in that it has been adopted as the local design level for several decades. Accordingly, we believe the flooding elevations that occurred warrant further more detailed investigation.

Therefore, while available information suggests that RL 2.5 m is probably an adequate precautionary estimate of the 1% AEP extreme sea level (excluding sea level rise and wave effects), we believe some caution is required in the interim.

5.1.2 Wave Run-up

5.1.2.1 Historical data

Dahm and Munro (2002) reviewed all available data on sea flood events around the southern Firth of Thames. This work included a review of information in an extensive storm data base collated in the early 1990s. This database was compiled by searching newspaper reports for all known coastal storms back to 1868 – including all storms identified by Hay (1991) and a large number of events noted from other sources (e.g. Council files, cross-references in newspaper reports; community information obtained during extensive community consultation following the July 1995 and January 1997 coastal storms). Compilation of the data base involved searching of all available newspaper archives – both for major dailies in the Waikato and Auckland area, and historic local papers in the Hauraki, Thames and Coromandel areas. All reports on the storm events were copied and placed in the dossiers, with storms grouped chronologically.

Dahm and Munro (2002) identified from this data six major events since 1935 which appeared to have caused severe coastal flooding in the area. A number of lesser events were also identified. In the period prior to the 1930s, available newspaper records were generally less informative on damage in the Thames and Thames Coast area; focusing on damage reports from larger settlements. There were occasional references to sea flooding in Thames in some of these reports. For instance, the New Zealand Herald of 12 March 1883 (page 5) reported "*considerable damage on shore, flooding one or two shops to .. about two feet*". However, in most cases, damage levels in Thames are difficult to assess from the earlier records.

Dahm and Munro (2002) concluded from the various newspaper and eye witness reports that wave run-up and overtopping was a major factor in all of the serious historic sea flood events identified – particularly wave run-up associated with longer period swell from a northerly quarter which can penetrate into the southern Firth of Thames during extreme storm events.

They noted that strand lines surveyed following the July 1995 and Cyclone Drena events indicated that wave run-up commonly reached elevations of RL 2.6-2.8 m during these events and in places (particularly during Cyclone Drena) exceeded RL 3.0 m. Surveyed elevations are not available for the Thames Coast for the earlier events between 1936 and 1951. Various reports do note the extreme sea levels recorded at the Auckland tide gauge during these storms; but these elevations cannot be easily transferred to the southern Firth of Thames as tidal amplitudes in this area are significantly higher than Auckland. Nonetheless, available information (newspaper reports, community information from older residents and historic photos) suggests similar wave run-up and flooding levels to those experienced in Cyclone Drena. The information also suggests that higher levels of wave run-up may have been experienced during at least two of the storms – the events of 27 March 1936 and 1 March 1951. For instance, the Thames Star of Friday March 27 1936 reported "*considerable damage between Tararu and Thornton's Bay ... some portions of the highway being deeply undermined and in places half the roadway washed out ... the whole length of this eight-mile stretch boulders, driftwood and other debris was washed onto the road, and in some places across and into adjoining paddocks*." The debris on the state highway between Tararu and Thornton Bay is more extensive than that noted during Cyclone Drena, though comparative road elevations at that time are not known.

5.1.2.2 Calculation of wave run-up

In order to assess the potential wave run-up and overtopping that might occur with various combinations of extreme sea levels and waves, calculations were conducted using the procedure developed by Hughes (2003) for smooth impermeable slopes (as later modified in Hughes, 2005). This procedure assumes waves plunge and break at the base of the beach slope and is more representative of the conditions that apply on the mixed sand-gravel beaches of the Firth of Thames than procedures developed for surf beaches on open coasts.

The procedure estimates the wave run-up parameter $Ru_{2\%}$ - defined as the vertical distance between the still-water level and the elevation exceeded by 2 percent of the run-up values in the distribution. In other words, for every 100 waves running up a slope, two waves would have a run-up elevation exceeding the level estimated as $Ru_{2\%}$ (Hughes, 2003).

Calculations were conducted for various combinations of extreme sea levels and waves. In view of the present uncertainties in respect to extreme sea levels (discussed in Section 5.1.1), the calculations adopted figures ranging from RL 2.0 m (lower order and likely to be commonly exceeded) to RL 3.0 m (upper order and rarely if ever equalled). The calculations also assumed highly refracted swell waves penetrating into the Firth from a northerly quarter. These are the highest energy waves experienced in the Firth of Thames and information on past events indicates that the most serious coastal flooding tends to be associated with such waves - rather than the shorter period, fetch-limited waves associated with winds from other directions. Observations during extreme events suggest maximum likely swell wave heights of around 1 m for the review sites. However, to be precautionary, the calculations adopted wave heights ranging from 0.5 m (lower order, likely to be common during major events) to 1.5 m (upper order and maximum likely wave heights). A wave period of 6 seconds was adopted, typical of local storm-generated swell around the Coromandel.

Physical parameters required for the calculations (e.g. beach slope, depth at beach toe) were derived from the cross section data available for Tararu, Te Puru and Waikawau. These cross-sections suggest a common beach slope of about 1V:10H at all sites. However, the depth at the dune toe varied – typically ranging from RL 0.3 to 0.8 m at Tararu (rare values in excess of RL 1.0 m) and from RL -0.36 to -1.41m RL (common values -0.6 to -0.8m) at Waikawau seaward of the trams (the key location at this site in respect to the Primary Development Setback). Therefore, this range of depths was also adopted in the calculations – though this variation had only a minor influence on results. Results are shown in Figure 56

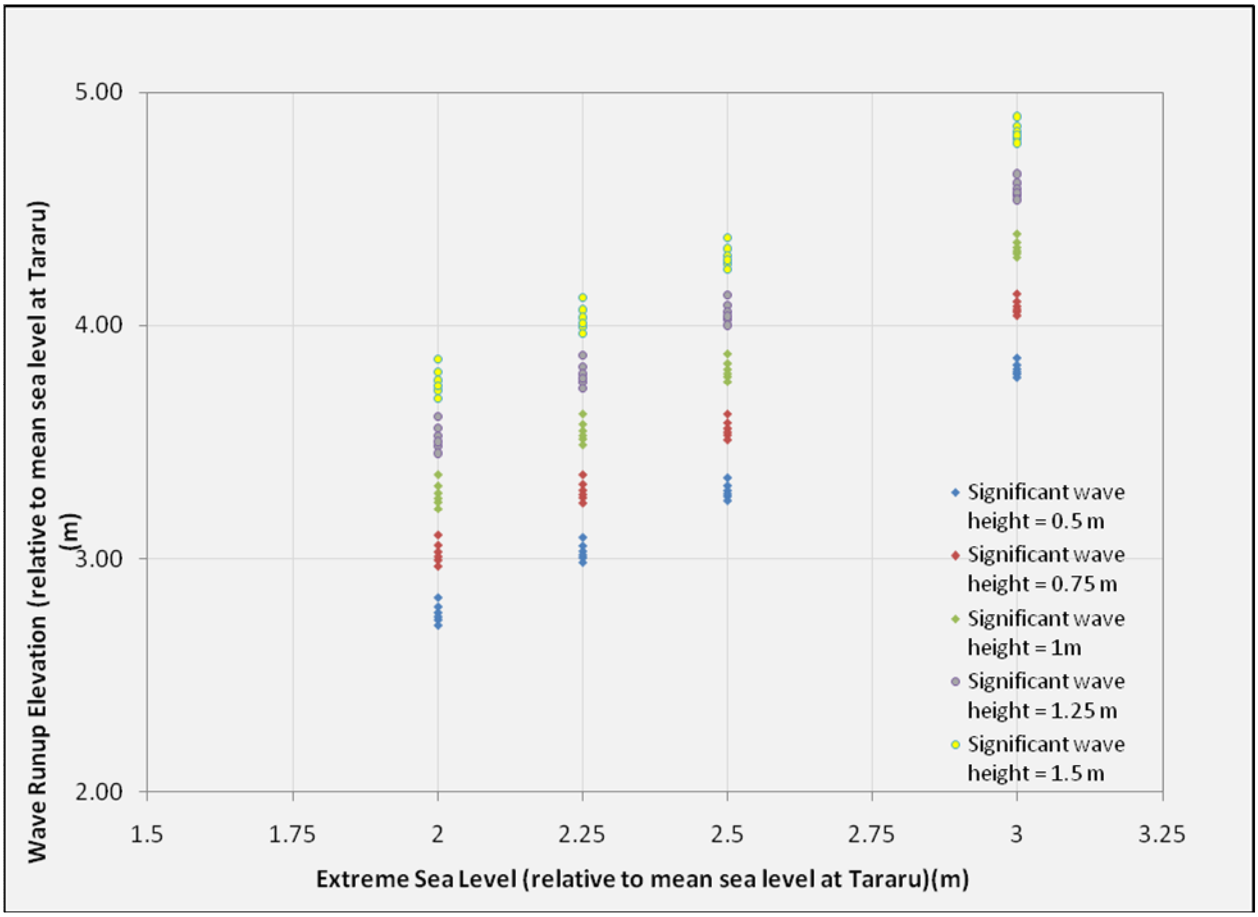

Figure 56: Maximum likely wave run-up elevations for various combinations of extreme sea level and wave height – as estimated using empirical procedures (see text for more detail).

The calculations suggest maximum likely wave run-up elevations of RL 3-4 m for the most likely combinations (i.e. extreme sea levels from RL 2-2.5m with waves of 0.5-1m). Survey data for the review sites suggest that coastal margin elevations are most commonly in the range of RL 2.5-3.25 m. Therefore, there is potential for significant wave run-up and overtopping, particularly in exposed areas.

The highest wave run-up elevations surveyed after Cyclone Drena were RL 3.0-3.5 m, and occurred in the areas most directly exposed to northerly storm swell. The calculated wave run-up is therefore consistent with field observations in exposed areas. In many areas, measured wave run-up has been less than 3.0 m, including (e.g. wave run-up surveyed after Cyclone Drena (extreme sea level RL 2.1m; waves 0.75-1.0 m). Calculations suggest values of RL 3.0-3.5 m might have been expected. The reduced extreme run-up measured relative to calculations is to be expected. Many parts of the coast are oblique (and sometimes almost perpendicular) to incoming swell wave crests; some areas are partially sheltered; and banks and erosion scarps behind beaches introduce roughness elements that reduce run-up.

The calculations also suggest that high rates of overtopping may be experienced in areas with elevations significantly less than RL 3.0 m. This is consistent with Cyclone Drena. For instance, significant wave overtopping occurred between Sarjants Road and Tatahi Street along the margins of the Te Puru delta; an area where maximum elevations commonly range from RL 2.3-2.8 m. Similarly, the significant wave overtopping seaward of the trams at Waikawau involved coastal margins with maximum elevations of RL 2.5-2.7 m.

5.1.3 Summary and Recommendation

Inundation by extreme sea levels arising from storm surge and astronomical tides alone (i.e. without wave effects) appears unlikely for elevations above RL 2.5 m. However, further investigation of flooding levels experienced during the May 1938 event is warranted.

The review suggests however that combinations of extreme sea levels and wave run-up likely to be experienced on the Thames Coast can theoretically overtop elevations of RL 3 m to 4 m, even though run-up beyond RL 3.0 m is probably geographically limited and uncommon. Historic experience suggests the potential for serious wave overtopping where coastal elevations are below RL 2.7 - 2.8 m.

The highest risk of wave overtopping occurs during storm events accompanied by northerly storm swell. There is much less risk of severe flooding with waves from the west or southwest as fetch limitations result in much lower energy waves.

Coastal flooding in areas of existing development is most effectively managed with minimum floor levels rather than setbacks.

In view of the remaining uncertainties discussed further above and projected sea level rise of at least 0.5 m to 2100, it is recommended the existing minimum floor level of RL 3.0 m continues to be adopted. In areas close to the shoreline, which could be impacted by wave overtopping, the minimum floor level should be the greater of RL 3.0 m or 0.3 m above natural ground level.

5.2 Coastal Erosion

5.2.1 Tararu

5.2.1.1 Description

The Tararu Stream delta (Figure 57) has an area of approximately 250,000 m^2, extends seaward about 300 m at its widest point, and has a total shoreline length of approximately 1420 m (Dahm and Munro, 2002). The Tararu Stream presently discharges towards to the northern end of the delta (Figure 57). There is limited information on historic changes near the entrance. However, historic photos dating back to the 1940s show the entrance in the same area, as well as the undated "old MHWM" survey discussed in Section 3.1.2.2. Therefore, the stream entrance appears to have been in the same location for at least the last 60-100 years.

Sediments discharged from the stream are reworked landwards, with sands and fine gravels forming the natural beaches which surround the delta. Coarser materials are concentrated as a lag on the intertidal platform further to seaward. Beach sediments undergo slow net southwards transport; though waves from westerly and north-westerly directions also transport sand and finer gravel to the beach northeast of the river entrance (see more detailed discussion in Section 2.2).

The stream channel and entrance are now regularly dredged to maintain desired channel and bed level dimensions for flood release. Dredged sediments are required to be returned to the coastal system to prevent long-term erosion problems. These sediments are normally returned to shoreline areas either side of the stream entrance. The return of the dredged sediments can result in significant artificial seaward advance of the shorelines in these areas until the materials are naturally dispersed alongshore. This temporary human-induced shoreline advance near entrance areas is also complemented by natural onshore movement of sands and fine gravels to these areas following floods.

Historically, the beaches surrounding the delta have been modified in places by deposition of coarse debris dredged from the stream after floods. The most notable example to date is when large volumes of coarse debris were placed on the foreshore to the north of Wilson Street following the "weather bomb" of 2002.

These materials were landscaped to form the present flood protection embankment and coastal footpath in this area (Figure 58).

The beach to the northeast of the river entrance has also been advanced by about 20 m in recent years by ongoing placement of dredged sediments. The resource consent for the dredging now requires placement of "like on like" so that deposition of coarser gravels and rocks on the sand and fine gravel beaches is precluded. In the future, these coarser sediment mixtures will probably be deposited seaward of the beaches, similar to the practice recommended for Waikawau (Eco Nomos, 2003; 2008). This practice results in beach-suitable sediments being sorted and moved onshore by waves, mimicking the natural process which occurs following floods; ensuring retention of sediments in the total beach system while avoiding the significant modification of the natural beaches that occurred following the "weather bomb".

In many areas, the beaches surrounding the delta have also been modified by sea-walls – as discussed in more detail further below.

The following sections discuss shoreline change around various areas of the delta.

5.2.1.2 South end of Tararu delta north to Prices Avenue

Historic survey and photographic data, together with observations from long-term residents, suggest the high tide beach in this area has generally been characterised by dynamic fluctuations of up to 10 m over periods of decades, with similar though slightly lesser erosion of the vegetated shoreline. Field measurements and inspections over the past 12-15 years indicate that the more seaward edge of the high tide beach observed is typically similar in location to the position shown on the "old MHWM" survey, suggesting little trend for net erosion over the past 60-100 years.

The available evidence suggests the dynamic shoreline fluctuations are decadal in nature, with periods of erosion interspersed with shoreline recovery. For instance, shoreline armouring structures apparent in oblique aerial photography from May 1946 suggest a period of shoreline erosion. These works were subsequently removed and the shoreline remained unprotected for over 50 years. A period of erosion starting from about 2004 threatened a flood embankment located close to the shoreline (Figure 59). The erosion was later aggravated and embankment over-topped by a relatively minor storm event (18-19 September, 2005) leading to placement of rock protection in the most severely threatened area (Figure 60). Measurements conducted at the time of the September 2005 storm indicated that the vegetated shoreline had eroded by up to 3-4 m since a survey of 1996. Extrapolation of surveyed sections indicated that the bank could have been eroded by a further 2-3 m (sufficient to breach the embankment in places) had erosion protection not been placed. Over the past 12-18 months (i.e. 2008-09), sediments deposited near the stream entrance following the "weather bomb" have moved alongshore and the shoreline is presently undergoing a period of beach advance - with a high tide beach up to 20 m wide seaward of the rock wall.

It is interesting that the beach eroded in 2004-05 as other areas of Tararu further north (near the stream entrance) were undergoing shoreline advance at this time – due to large stream sediment inputs during the 2002 'weather bomb' (and the placement of dredged sediments on some of these beaches). It took 6-7 years for large volumes of stream sediment bought down during the weather bomb of 2002 to have been reworked onshore and then alongshore into to this area – with rapid and significant seaward advance in 2008 and 2009 once the sediment arrived. I.e. The benefits of the flood sediment input took some years to be realised in this area. In due course, the 'pulse' of sediment from the 2002 event will be moved further alongshore and a period of erosion will be experienced – unless there is further sediment input.

As in many other areas of this coast, significant shoreline fluctuations appear to relate to variations in sediment input. Significant shoreline erosion occurs during lengthy periods when net southwards longshore sediment removal is not balanced by alongshore inputs. In contrast, significant shoreline recovery and advance occurs when 'pulses' of sediment supply from stream floods are eventually moved alongshore into the area. Over long periods of time, the supply and removal appear to be balanced. This balance reinforces the need to return dredged sediment to the active coastal system – removal off-site could tilt the balance in the direction of net erosion over longer periods of time.

Figure 57: Tararu Stream delta showing locations referred to in text

Figure 58: Flood protection embankment and footpath constructed north of Wilson Street

Figure 59: Erosion threatening flood protection embankment in July 2005

Figure 60: Overtopping and erosion September 2005, leading to placement of rock to protect flood embankment

5.2.1.3 Prices Avenue to 150m north of Wilson Street

An old concrete sea-wall of unknown age existed over the full length of this area from at least the date of the earliest historic photography available (May 1944). The reason for the sea-wall is unknown as the May 1944 photography indicates that it preceded any nearshore subdivision and development in this area.

The seawall holds the shoreline well seaward of its natural position, particularly from approximately 100 m south of Robert Street through to Wilson Street. Photographs from the 1940s and 1950s also show that the seawall then was seaward of the natural shoreline position. This indicates there has not been a trend of permanent shoreline retreat in the last 5-6 decades.

The reasons for the original placement of the seawall so far seaward are unknown. It is possible that the original seawall was placed in an attempt to fix the shoreline towards the most seaward position experienced during natural shoreline fluctuations. This is further suggested by the fact that the “old MHWM” survey lies seaward of the wall alignment in some places. Over the last 12-18 months, alongshore dispersal of sands from the Tararu Stream entrance has occasionally resulted in a narrow sand beach over most of the length of this shoreline; including a minimal (generally <1 m) width of high tide beach in some places under favourable circumstances (e.g. neap high tides with limited wave action), further suggesting that the wall is in places on the alignment of the natural accreted shoreline

The shoreline is still largely sea-walled, though the structure north of Wilson Street was largely undermined and destroyed in the 1990s and was removed (or buried) during placement of coarse river gravels in this area following the “weather bomb” in 2002. In the area from about 100 m south of Robert Street through to Wilson Street (a distance of approximately 220 m), the old sea-wall has generally been either replaced or reinforced by a variety of subsequent sea-walls and (in limited areas) short groynes.

Field measurements conducted during this study and analysis using surveyed cross sections from 1996 (Section 3.1.2.2) indicates the shoreline would probably erode up to at least 5-7m landward in some areas if the sea-wall was removed or destroyed – with the most serious erosion likely from about 50m south of Robert Street through to Wilson Street.

The coarse gravels placed north of Wilson Street following the "weather bomb" also extend well seaward of the natural shoreline position in places – with potential for landward erosion of at least 4-7 m in places during erosion periods accompanying multi-decadal shoreline fluctuations. However, observations during 2005 (a period when erosion was being experienced) indicated that coarse rocks in the original sediment had been concentrated and formed a rock-lagged beach that limited active erosion. Erosion may nonetheless occur during rare and severe wave storms such as Cyclone Drena - when longer-period and much higher energy swell waves can occur that may break up this lagged surface.

It is difficult to accurately assess the scale of dynamic shoreline fluctuations that would have occurred in the absence of the seawall, though it is probably in the order of 5-10 m. The revised PDS also has to allow for landward adjustment of the shoreline were the seawall ever to be replaced – though that is not a likely scenario in the medium term future.

5.2.1.4 150m north of Wilson Street through to Tararu Creek

Historic photos dating from May 1944 indicate a variety of seawalls (including wooden, stone and concrete walls) have been placed along parts of the shoreline from time to time to protect adjacent properties. These are most notable in the area from about 25 m south of Rennie Street through to the creek entrance. Field inspections indicate that some of these structures (now largely buried) are still in place (e.g. at the seaward end and immediately north) of Rennie Street.

Discussions with the owners of the two properties closest to the creek (102 and 104 Rennie Street, both east of the street) indicate that the seawalls have been adequate to protect these properties over the time they have lived there (being 26 years at 104 Rennie and just over 60 years at 102). These observations are supported by old Pohutukawa and Puriri trees with large diameter trunks located close to the shoreline near the boundary between these properties. Some of these trees were evident and already large trees at the time of the earliest vertical aerial photography in 1944. The "old MHWM" survey also plots seaward of both properties. These properties have been in place since the early 1900s, with owners noting that the existing houses on both properties date from c. 1910. The owners also confirm that neither house has been flooded from the sea in the time they have lived there – though river floods from bank overflow further upstream have flowed under the dwelling at 104 Rennie Street.

Analysis of historic photography suggest that the properties would probably have been eroded by at least 5-7 m on occasions but for the various sea-walls placed over time.

A wide prograded shoreline has developed in recent years in this area due to the disposal of dredged sediment and (to a lesser degree) natural onshore reworking and movement of sediment deposited during the 2002 "weather bomb" event. Placement of dredged sediment on the northern side of the stream entrance, extending this shoreline forward, has also provided increased shelter from wave action (Figure 1, Figure 57). At present prograded shoreline provides adjacent properties a high level of protection from coastal erosion, though this level of protection is temporary. Ongoing placement of dredged material in these areas is likely to maintain reasonable protection from coastal erosion as long as the dredging works are continued. The stream entrance has the potential to erode adjacent properties (especially 104 Rennie Street) without these works. . The existing sea-walls are also likely to be maintained by owners whenever and if ever required again.

5.2.1.5 North of Tararu Creek

This area is characterised by a low-lying reserve, which was significantly over-topped by wave action during Cyclone Drena. Historic photographs dating from the 1940s indicate minor fluctuations of the vegetated shoreline, though these generally appear to be less than 5-7 m.

The reserve has been widened by at least 12-15 m in recent years with the placement of sediment dredged from the river and entrance areas. Much of this sediment placement involved coarse river gravels with large rocks and these materials are likely to be concentrated on the beach during erosion events to form a rock-lagged surface, as is common on the Thames Coast. The formation of rock-lagged surfaces limits erosion under local fetch-limited waves, though rare and severe events such as Cyclone Drena are capable of breaking up such surfaces.

In order to be precautionary, this review has assumed potential for the shoreline to be eroded back to historic positions in the longer term future. Severe erosion of this nature is however extremely unlikely while existing dredging and sediment disposal practices are maintained.

The sediment placement has also apparently elevated the reserve according to adjacent owners, suggesting that the severe wave overtopping experienced during Cyclone Drena may be slightly reduced during future events. However, given the exposure of the site and the potential for significant wave run-up at such sites (see discussion in Section 5.1.2), significant wave overtopping may still occur during rare and exceptional events. Minimum floor levels should therefore continue to be adopted.

5.2.1.6 Summary and Setback Recommendation

The revised PDS assumes dynamic shoreline fluctuations varying from 10-15 m (lowest values in the more sheltered southern areas), with additional allowance for shoreline adjustment in sea walled areas. We believe the proposed setback provides adequate allowance for severe erosion and is precautionary by at least 3-5m in all areas.

The revised setback is reduced relative to the original setback along the entire length of the coast, but nonetheless indicates potential for severe erosion of some properties. The erosion hazard is particularly severe in the vicinity of Robert and Wilson Streets, where there would be significant landward adjustment without existing seawalls. The revised setback, though reduced, lies along or towards the landward edge of four beachfront properties in this area. Additional measures will therefore need to be identified to provide for appropriate long-term (i.e. at least 50-year) management and use of these properties. Seawall structures currently provide interim erosion protection.

The revised PDS also indicates the potential for natural shoreline movements to erode important flood protection embankments and elevated coastal margins in some areas – which would significantly increase the risk of sea flooding. As discussed above, rock protection has already been required in places.

The revised setback and minimum floor levels will therefore not be adequate in isolation to successfully manage coastal hazards along much of this shoreline. These measures will considerably assist hazard mitigation in the medium to longer term and help build community resilience; but will need to be complemented by a hazard mitigation strategy to identify additional appropriate measures to provide for coastal hazard mitigation in the short-medium term. The strategy could also consider measures likely to be required in the longer term to adapt to climate change.

5.2.2 Te Puru

5.2.2.1 Description

The Te Puru delta (Figure 61), the largest on the Thames Coast; has a total area of about 422,000 m^2, a total shoreline length of about 1760 m and extends about 400 m seaward at maximum width (Dahm and Munro, 2002).

The present stream entrance discharges near the northern end of the delta. Historic surveys back to the 1880's indicate that the main entrance has been in much the same location over the last 120-130 years. Historic photographs and surveys do however show two secondary entrances (discussed further below) suggesting considerable stream channel and entrance instability over periods of centuries.

The existing stream channel and entrance are now held relatively stable by shoreline armouring structures, flood embankments and regular entrance and channel dredging for flood protection. Dredged sediments are returned to the coastal system, generally in shoreline areas close to the stream entrance. The following sections discuss shoreline change around the delta.

Figure 61: Te Puru delta

5.2.2.2 South End to Sarjants Road

The southernmost beachfront properties have boundaries that extend seaward onto the beach, variously 3-7 m seaward of the sea-walls fronting these properties. This appears to relate to the nature of the initial shoreline surveys rather than any trend for long-term erosion. The properties were initially surveyed in 1913 and 1921, with the shoreline fixes identified as "mean high water" and "high water mark", respectively. This suggests the surveys fixed a position near the high water line, towards the seaward edge of the high tide beach. Field measurements and historic photographs indicate that the high tide beach can often lie 5-10 m seaward of the seawalls, suggesting little to no net change since the original surveys.

Available data does provide evidence of dynamic shoreline fluctuations over long periods of time. For instance, an 1898 "high water mark" survey lies up to 20 m inland of the 1913 MHWM and up to 10 m landward of the 1995 seaward edge of vegetation (usually sea-wall location). The most significant historic erosion inland of present property boundaries is evident towards the southern extremity of this area, probably part influenced by the small stream entrance. Information from local owners indicates that seawalls were commonly installed from at least the 1930s and probably earlier. While existing historic shoreline change data from earlier periods suggests the potential for property erosion is most marked towards the southern end, reliance on historic data to estimate shoreline change is complicated by the long-standing presence of seawalls.

Information from owners has however enabled some estimate of extreme erosion using profile extrapolation, based on the depth of beach lowering observed in front of existing seawalls. One such profile surveyed at 411 Main Road (which the present family has owned since 1922) suggests rare and severe erosion could at worst extend 10-12 m further inland were the sea-walls not present.

The revised PDS is reduced along this shoreline but does still extend significantly within the frontages of the southernmost properties (particularly 401- 405 Main Road), affecting the use of these properties. The PDS is consistent with historic data showing potential for severe erosion of these properties. The properties are presently reasonably well protected by seawalls though these structures are not taken into account in the revised PDS as they are not presently consented as a long-term solution to the hazard risk. We believe there is potential for a hazard management strategy to be developed that will provide for some mitigation of erosion in this area. Development of such a strategy is beyond the scope of this report but initial discussion with various owners suggests they are generally supportive of pursuing such an approach.

5.2.2.3 Sarjants Road to Tatahi Street (9 Sarjants Road to boat ramp)

The properties in this area are generally fronted by grassed reserve (excepting the large lot at 441-443 Thames Coast Road which retains riparian title). The width of the grassed reserve generally increases to the north, varying from 3-5 m along property frontages off the southern end of Sarjants Road (e.g. Lots 13 and 14, DPS 1664) to 30-40 m in the area between Aputa Avenue and Tatahi Street.

Historic high water mark surveys from 1898, 1913, 1921, 1927 and 1955 suggest the shoreline during this period was characterised by dynamic fluctuations of 10-15 m and occasionally 18-20 m. A 1944 aerial photo indicates that properties at the end of Aputa Ave were then subject to coastal erosion, though both properties appear subsequently to have become public reserve. The shoreline advanced by up to 20 m in the period since the late 1950s, creating a local bulge in the shoreline centred on Aputa Avenue and Tatahi Street.

The reason for the shoreline advance since the 1950s is unclear, though the area is located immediately south of a former secondary stream entrance located near Tatahi Street; which appears from historic photos to have carried both water and sediments during flood flows. The 1944 aerial photograph shows a large shallow swash bar located immediately offshore, possibly derived from sediments discharged during flood flows. This swash bar may subsequently have attached to the shoreline creating the localised accretion. The secondary creek channel near Tatahi Street has since been cut off from the main stream during normal flows. It now only carries water during extreme flood events and no longer carries any significant sand and gravel load.

It is not clear whether the accretionary bulge is a permanent feature or whether the shoreline will eventually erode landward to historic positions. There is no present evidence of severe erosion. A precautionary approach has therefore been adopted in regard to the PDS in this area assuming potential for significant erosion of the bulge over periods of many decades.

5.2.2.4 Seaview Avenue (Boat Club to reserve opposite West Crescent)

Historic surveys of limited length dating from 1868, 1869, 1947 and 1996 suggest this shoreline area is subject to dynamic fluctuations; the shoreline in 1868 (ML1409) being in much the same location as that surveyed in 1996, with a 1947 MHWM survey up to 15 m further seaward. The few historic shoreline surveys available all show the shoreline seaward of the toe of bank surveyed in 1995. Historic photographs do however show some erosion of the vegetated bank. These photographs suggest the shoreline fluctuations could be related to the alongshore migration of shore perpendicular swash bars. The shoreline tends to be accreting where these features are attached, and to be eroding in swale areas between these bars (***Figure 62***).

Figure 62: Te Puru foreshore fronting Seaview Avenue in May 1956. Note accretion at the landward end of swash bars, with erosion tending to occur in the swales between these bars (Whites Aviation Photo 40854).

Field inspections and discussions with owners also suggest there may be a recent (since early 1990s) trend for slow long-term erosion superimposed on the dynamic fluctuations. For instance, prior to placement of dredged gravels over the eroding edge, old shell midden deposits were exposed in the eroding bank. This suggests erosion beyond the landward limit of normal multi-decadal shoreline fluctuations. It may be partly related to dredging and sediment disposal activities in the vicinity of the stream entrance, which appear to have reduced longshore sediment movement to sites further west (see discussion in next section).

5.2.2.5 Te Puru Stream Entrance

Historic surveys and aerial photographs indicate larger scale shoreline changes in this area associated with the stream entrance rotating eastwards and westwards over time. The spit on the eastern side of the stream entrance occasionally elongates, tending to cause the stream entrance to rotate westwards. On other occasions the spit is eroded and the entrance tends to rotate eastwards. Movements of this nature are common at stream entrances.

These entrance changes have the potential to seriously erode sections along the western side of the stream entrance in the absence of human intervention. For instance, an historic survey from 1868 (ML1409) indicates that the shoreline at that time was located 15-25 m within the properties that now exist along the western side of the entrance (1- 6 Seaview Road). The erosion appears to be caused by occasional westward extension of the spit on the eastern side of the stream entrance. A HWM survey from 1870 indicates the spit at that time extended significantly eastward with the tip of the spit lying within 18-20 m of what are now the front boundaries of these properties. Similar changes are evident in photographs dating from the 1950s when properties on the western side again experienced erosion. On this occasion, rock protection was placed to protect the properties (Figure 63).

Photographs subsequent to the period of erosion in the 1950s show onshore movement of a large swash bar – sands and gravels bought down by floods being reworked and moved landward. Significant shoreline advance occurred on the western side of the entrance in the 1980s after the bar welded to the shoreline.

In the period since the 1990s, the stream entrance has been regularly dredged for flood protection purposes, largely preventing significant changes in entrance position. The spit on the eastern side is dredged whenever it extends across the stream channel. Dredged sediment from most sources has also tended to be placed on the immediate western side of the entrance channel, building a wide and high reserve seaward of the properties in this area. Limited volumes of sands and fine gravels (e.g. from excavation of the spit) has also been placed fronting Te Puru School and assisted with the natural recovery of this area since the erosion of the 1990s (discussed below). The dredging and disposal has tended to trap larger quantities of sediment in the vicinity of the stream entrance area and may have reduced sediment supply to areas further west – with evidence of slow long-term erosion appearing in this area as noted in Section 5.2.2.4. In recent times (2009), dredged sediments have been placed offshore from the beaches further west to allow wave sorting and onshore sediment supply to the beaches and help to rectify this situation. Advice from adjacent owners indicates that a small sand and fine gravel beach formed very soon after this placement.

Direct placement on the beaches also occurred earlier but was inappropriate as the sediment mixtures contain large rock which tends to concentrate as a lagged surface on the beach during periods of erosion, diminishing amenity values of the beach.

The 1868 survey suggests the potential for severe erosion in the absence of human activities. Despite this, the existing dredging is likely to be maintained for the forseeable future and is part of a consented strategy for hazard management in this area. There is a reasonably substantial rock wall (now buried) seaward of these properties, mostly dating from at the 1950s or earlier (Figure 63) which was apparently constructed by council and is considered part of the total flood protection and river works in this area. The engineering standard of the wall is unknown though it was sufficiently well constructed to protect the properties in the 1950s.

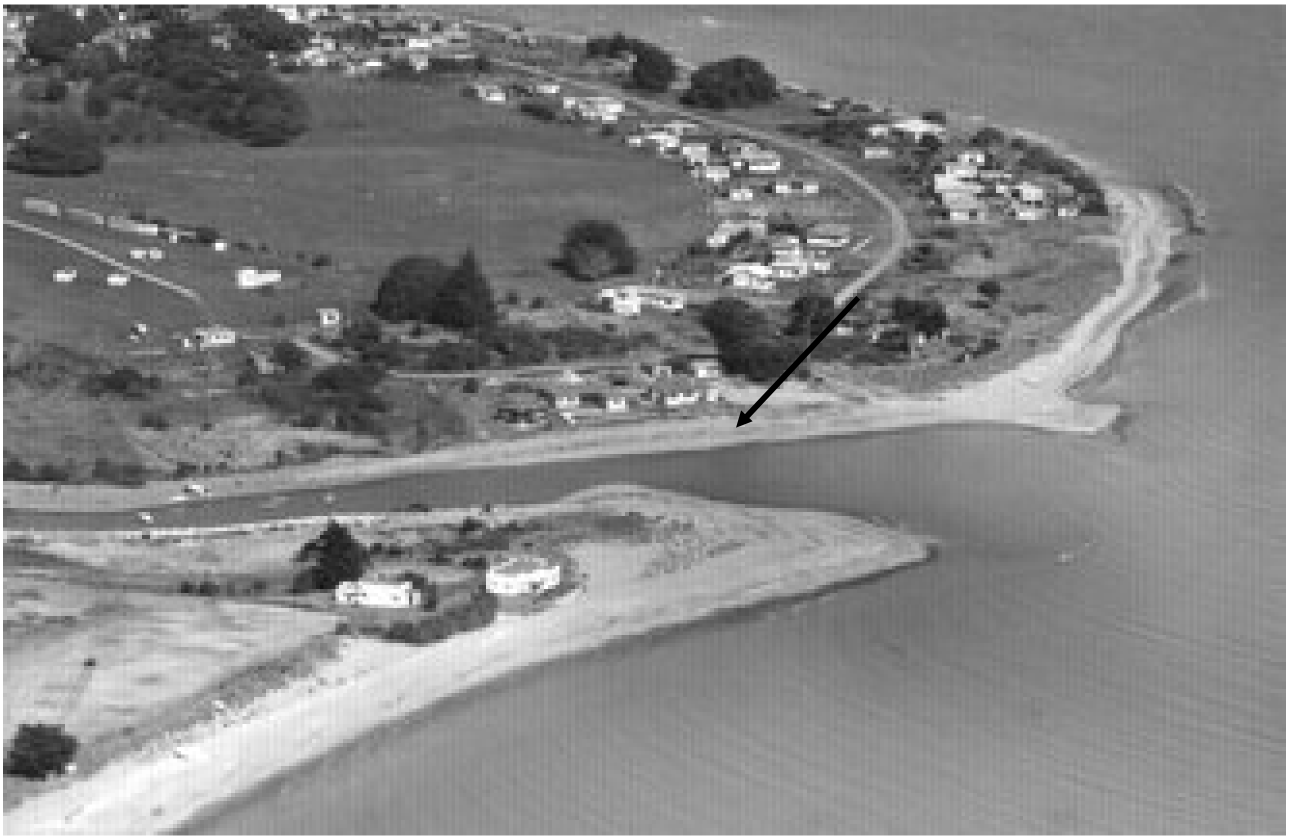

Figure 63: Te Puru stream entrance in March 1956 (Whites Aviation Photo 40852). Rock armouring is arrowed.

5.2.2.6 East of Te Puru Stream

This area of shoreline fronts Te Puru School and two private properties located to the immediate west. The shoreline experiences multi-decadal shoreline fluctuations, with periods of severe erosion cumulating over periods of several years, followed by periods of beach recovery.

A MHW survey from 1947 shows the shoreline well landward indicating a period of erosion around this time. Photos from 1956 show the shoreline in early stages of recovery, though still relatively close to the seaward edge of school buildings. The westernmost property was at this time protected by a seawall located seaward of the natural shoreline (Figure 63). The house on this site would probably have been lost to erosion in the absence of the seawall. This property and dwelling were subsequently replaced further landward and the seawall was buried by shoreline advance. The shoreline recovery appears to have continued until the mid to late 1980s; with a MHWM survey from 1984 (SO 56 123) located nearly 15 m seaward of the similar survey from 1942.

Another period of erosion started in the late 1980s and continued up to Cyclone Drena in January 1997. Beach profile monitoring commenced in front of the school in 1992, with the vegetated bank eroding by 7-8 m over the period to Cyclone Drena (Figure 64). Advice from locals in the early 1990s indicated approximately 3-4 m erosion of the vegetated bank before the beach profile monitoring commenced; suggesting total erosion in the order of 10-12 m. Erosion up to Cyclone Drena occurred primarily under the action of local wind-generated waves and was a relatively slow process. During Cyclone Drena however, the longer period and higher energy ocean swell waves (estimated at about 1 m high) caused rapid and severe erosion (Figure 64). The concrete seawall evident in front of the westernmost private property in 1956 (Figure 63) was again exposed by erosion in the early 1990s and largely destroyed during Cyclone Drena. The shoreline position following Cyclone Drena was virtually identical to the MHW survey dating from 1942.

Extrapolation of beach profiles surveyed after Cyclone Drena indicates that a storm of sufficient duration could have generated further erosion of up to 10 m. A backstop seawall constructed following Cyclone Drena now acts to limit future erosion. The location of the structure towards the landward edge of the dynamic envelop means that it will be buried and out of sight (as at present) during most stages of multi-decadal shoreline fluctuations, exposed only during the most severe periods of erosion.

Since the late 1990s, the shoreline has progressively recovered and accreted by approximately 15 m, burying the seawall and building a wide high tide beach in front of the school (Figure 65).

The line defined by the structure is located as far landward as practical given existing school buildings and playground requirements. The structure was designed by engineers and constructed with engineering supervision and consented as a long-term solution. Given the location and the engineering design, and assuming appropriate maintenance, the wall is likely to withstand future periods of severe erosion similar to those experienced during the 1940s and Cyclone Drena. This is particularly so as the structure will only be exposed and subject to wave forces for short periods of time.

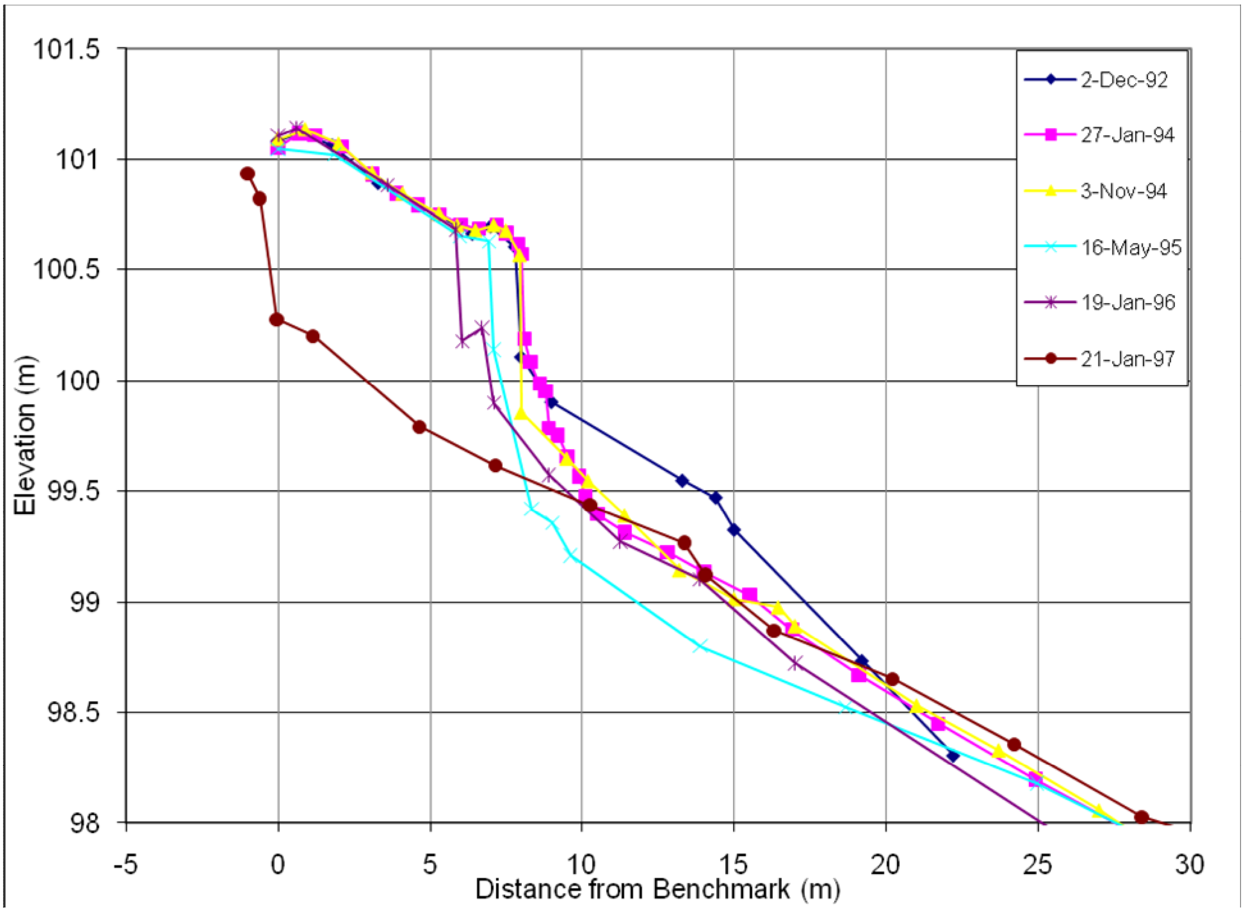

Figure 64: Erosion in front of Te Puru School from 1992 to January 1997 (Cyclone Drena).

Figure 65: Wide high tide beach fronting Te Puru School (February 2009). The seawall is located immediately in front of the grassed area behind the wooden step structures.

5.2.2.7 Summary and Setback Recommendation

The revised PDS assumes dynamic shoreline fluctuations varying from 15-25 m (lowest values in the Seaview Avenue to West Crescent area and highest near the stream entrance), with additional allowance for some shoreline adjustment in sea-walled areas (particularly towards the southern end of the delta).

We believe the proposed setback provides adequate allowance for rare and severe erosion and is precautionary by at least 3-5m in most areas. The only exceptions occur along the front of Te Puru School and on the immediate western side of the stream entrance. In these areas the setback includes allowance for mitigation of hazard risk by consented human activities – being the seawall in front of Te Puru School and dredging and sediment disposal activities on the western side of the entrance. This seawall does not extend to the most western property and therefore the setback for that property is larger.

The revised setback is reduced relative to the existing PDS along the entire length of the coast. In most cases it will no longer exert any significant influence on location of new dwellings, being less than the existing yard setback. There are some exceptions particularly (though not exclusively) south of Aputa Avenue. The revised setback provides for reasonable use of most of these sections, though constraints on the two most southern properties remain severe. It is probable that an appropriate hazard mitigation strategy will need to be developed to complement the PDS towards the southern end of the delta to relax constraints on property use in this area.

There are also other locations where potential shoreline movements could erode elevated reserve margins and increase risk from coastal flooding. Historically, there has also been significant sea flooding around parts of the coastal margin and extending inland through adjacent low-lying areas. In addition, the erosion could also eliminate remaining areas of grassed reserve seaward of properties in some of these areas and thereby impact on public access. Any local hazard mitigation strategies developed to complement the PDS will probably need to address these areas also.

5.2.3 Waiomu

5.2.3.1 Description

Waiomu Township has two small stream deltas along the coastal margin. The larger and southernmost of these is the Waiomu Stream delta which extends approximately 650 m alongshore and up to about 125 m seaward of SH 25. A much smaller delta associated with the Pohue Stream occurs further north, extending approximately 300 m alongshore and up to 30-35 m seaward of SH 25 (Figure 66). The streams discharge towards the northern end of both deltas, as typical along this coast, with the bulk of both features lying to the south of the streams (Figure 66), reflecting the net southwards littoral drift that prevails along the Thames Coast.

5.2.3.2 Pohue Stream Delta

The Pohue Stream delta has two beachfront properties; both located south of the stream; the more southern property being a motel. Discussions with the present owners suggest the properties date from the 1950s, with the motel having operated since the 1960s.

The northern property is affected by minor stream entrance changes over periods of decades but the owners advise that there has been no serious erosion of the property to their knowledge. This is consistent with field observations which suggest the bank in this area may even have accreted in recent years. The bridge immediately upstream of the property tends to help fix the location of the entrance. Geomorphic evidence from aerial photographs and field inspections does however suggest potential for the stream entrance to rotate significantly southwards.

The motel to the south is fronted by a seawall constructed in 1996 (Figure 67). Measurements conducted in the field and aerial photographs suggest the seawall fixes the property margin up to 3-5 m seaward of where the natural coastal margin would otherwise lie, with the most significant encroachment towards the northern end of the property. The toe of the former narrow beach can be seen extending seaward from the base of the seawall (Figure 67). This encroachment onto the active beach appears to have occurred at the time the property was originally developed and owners advise that the property has not experienced serious erosion in recent decades even prior to seawall construction. This probably reflects the fact that the site is moderately sheltered from rare higher energy northerly storm swell. Observations at this site during Cyclone Drena indicated that the swell waves broke oblique to the wall in this area.

5.2.3.3 Waiomu Stream Delta

Settlement on the Waiomu Stream delta is limited to several properties immediately south of the streams, with the remainder of the delta being public reserve (Figure 66).

Currently, the upstream alignment tends to direct flow against the northern bank of the stream, so the southern bank of the stream has advanced in recent decades. The shoreline on the southern stream bank is, however known to be vulnerable to erosion with southward rotation of the stream channel and entrance. The stream has been dredged for flood protection purposes but the entrance position is not as actively managed as at Te Puru and Tararu. The shoreline further south of the entrance is relatively exposed and properties in this area experienced significant wave overtopping during Cyclone Drena with large volumes of gravel carried onto front lawns **(**Figure 68**)**

Field evidence, aerial photographs and community information indicates that the shoreline is subject to dynamic shoreline fluctuations of up to 8 m, though erosion of the vegetated shoreline over the last 10-15 years has generally been less than 3-5 m.

The vulnerability of this shoreline to wave overtopping **(**Figure 68**)** means that most coastal margins in the area have been elevated by property owners. These raised coastal margins provide important mitigation of coastal flooding, though probably not complete protection (as discussed in Section 5.1). The elevated areas tend to be located as far seaward as practical by owners to avoid encroaching too far into properties.

Figure 66: Waiomu Township, showing Waiomu and Pohue Streams and associated deltas

Figure 67: Seawall fronting motel south of Pohue Stream

Figure 68: Rocks and other debris deposited on front of Waiomu property (603 Thames Coast Road) during Cyclone Drena

The embankments are vulnerable to erosion, and action is generally taken by owners to protect them from even minor erosion. These works often degrade the values of the shoreline. By way of example, rock protection has been placed along part of the reserve shoreline. Local property owners also advise that dredged stream sediments including large rocks were placed on the beach in the 1990s to help mitigate erosion. This placement subsequently eroded leaving large rocks over the beach and contrasting markedly with natural beach conditions (Figure 69 and Figure 70). This practice has now fortunately ceased, as resource consents for dredging and sediment disposal now require placement of "like on like".

5.2.3.4 Summary and Setback Recommendation

The revised PDS is significantly reduced with respect to the existing PDS. The revised setback will still impact on any building work proposed for the Seaview Motel on the southern side of the Pohue Stream. Further revision of the PDS in this area would require a detailed site specific study and/or a site specific hazard mitigation strategy.

Erosion could eliminate elevated coastal margins along the edge of the Waiomu delta, aggravating existing coastal flood hazard. A site specific hazard mitigation strategy would be required to mitigate this risk, though there is no immediate need for such action.

Figure 69: Shoreline fronting Waiomu Stream delta. Photo shows natural beach lagged with boulders and large rocks remnant from dredged sediment disposal (see text for discussion).

Figure 70: Natural shoreline fronting Waiomu Stream delta.

5.2.4 Waikawau

5.2.4.1 Description

The Waikawau River delta extends approximately 1150 m alongshore (including the beach in the embayment immediately south, which is part of the total delta) and is up to 230 m wide. The delta is primarily public reserve though the southern area is occupied by a small bach settlement (former Auckland trams converted to holiday homes) operated by Waikawau Properties Ltd (Figure 71). The river is also the site of the most popular boat ramp along the Thames Coast (located just downstream of SH 25 bridge) and is now regularly dredged to maintain a navigable channel. Dredged sediment is placed on the rock-lagged intertidal flat fronting the beach (Eco Nomos, 2003; 2008).

5.2.4.2 Shoreline Change

The Waikawau River delta has undergone large-scale morphologic change over the past century (Dahm and Munro, 2002) and has been far more dynamic over that time than other large Thames Coast deltas.

In particular, the portion of the delta south of the river has progressively enlarged over the past few decades and the area to the north has significantly eroded (Dahm and Munro, 2002).

These changes may have been associated with natural river entrance and channel changes, with the river channel having progressively rotated northwards over time. These changes, while large scale, have however occurred progressively and slowly. Over periods of centuries, it is probable the river channel fluctuates backwards and forwards over this area and much of the delta area is probably reworked by natural processes.

The delta was also the site of historic gravel extraction and the large-scale changes may in part relate to the impact, or recovery from the impact of these operations. Available information suggests the extraction operated from the 1920s to the 1950s. Information from Winstone's archives indicates the area was bought for gravel extraction in 1925 and was described in the annual report (page 1) of the company for 1925 as "*... undoubtedly the best beach for concrete shingle in the vicinity of Auckland*". This suggests the area was quite an important source. However, Winstone's files indicate that when extraction was consented by the local county council there was liability related to maintaining the adjacent roadway which limited royalties able to be derived from the site. Therefore, the extraction appears to have been limited at times by various factors. There was also significant seaward expansion of the delta areas during the sand extraction period which suggest the large scale change cannot be entirely explained by the extraction. For instance, changes between the surveys of 1925 and 1939 indicate that the delta expanded up to 85 m northwards and up to 60-75 m. Further and more detailed work would be required to better ascertain the role of natural changes and the sand extraction.

The river entrance is now controlled by dredging in association with maintenance of navigational access for the local boat ramp, which is the main ramp used on the Thames Coast. This should help to limit further large scale coastal change which appears to have been in part related to natural river channel changes.

Sand and gravel extraction ceased in the 1950s. The current resource consent for navigational dredging requires sediment to be returned to the coastal system, meaning the dredging is unlikely to exacerbate erosion. Under the present design, the dredged sediment is placed in the active coastal system where it can be sorted by waves and provide material for local beaches (Eco Nomos, 2007).

In spite of the increased stability of the main entrance and the return of dredged sediments to the coastal system, the potential for future large scale shoreline instability cannot be ruled out until the factors driving the historic change are better understood.

In addition to the large scale changes observed over the past century the shoreline is also subject to dynamic fluctuations – typically less than 5-7 m.

In spite of the general trend for seaward advance of the shoreline south of the river entrance, the shoreline fronting the trams has slowly retreated by 10-20 m since the earliest survey of 1925. This equates to an average rate of retreat of 0.15-0.25 m/yr. The rate has however been much slower in the period from 1939 to 1998 (typically averaging about 0.07 m/yr), which is probably more relevant to presently ongoing trends. This latter figure has been increased to 0.1 m/yr to ensure conservatism for the purposes of determining setback distances. We believe this figure is adequate in view of advice from long-term tram owners that little net loss of shoreline has been observed over the last 3-5 decades.

The area is also subject to erosion associated with dynamic shoreline fluctuations, estimated at 5 m. This appears to be precautionary given the limited erosion noted by long-term tram owners – though a low wooden seawall was placed in some areas in the past to limit erosion. The shoreline fronting the trams is currently showing signs of erosion in central to northern areas though it is not clear whether this erosion relates to dynamic fluctuations or long-term retreat.

Figure 71: Waikawau River delta. Note bach settlement (known locally as "the tram cars") in centre of photo.

5.2.4.3 Coastal Flooding

The foreshore fronting the trams is elevated, with typical maximum ground elevations ranging from RL 2.5-2.7 m (higher in some places). The area is significantly overtopped by waves during major storms such as Cyclone Drena (see discussion in Section 5.1). The trams are located in a low area (probably a former river channel) further landward, with low elevations (RL 1.4 - 1.7 m - below spring high tide elevations) in places. River floods and wave overtopping tend to pond in this area and so the trams are every vulnerable to flooding. Flood levels surveyed after Cyclone Drena suggest flood elevations in the ponding area were in the order of RL 2.4 m. Higher levels may have been experienced during the July 1995 event given the static sea level of just under RL 2.5 m recorded at the Tararu tide gauge (see section 5.1.1). In the absence of detailed investigations, we would recommend minimum floor levels of RL 3 m to provide reasonable protection against flooding.

5.2.4.4 Summary and Setback Recommendation

The revised PDS is based on a long-term trend for erosion of 0.1 m/yr and dynamic fluctuations of up to 5 m. This yields a revised PDS of 15 m width along the shoreline. We believe the revised PDS is adequately conservative based on the shoreline changes noted over the last 30-50 years. However, we emphasize the uncertainty associated with large scale shoreline change at this site and therefore the need for ongoing monitoring and review. The revised setback is slightly increased relative to the existing setback at the southern end of the trams.

Given the susceptibility of the trams to coastal flooding, the elevated area to seaward is important to mitigate this risk. Therefore, any trend for serious erosion would probably require a site specific hazard mitigation strategy to protect the raised area. The vulnerability of the trams to coastal flooding would increase markedly if this higher area to seaward was significantly eroded – given the low-lying nature of the area occupied by the trams. There is some erosion occurring along the foreshore at present and this should be closely monitored.

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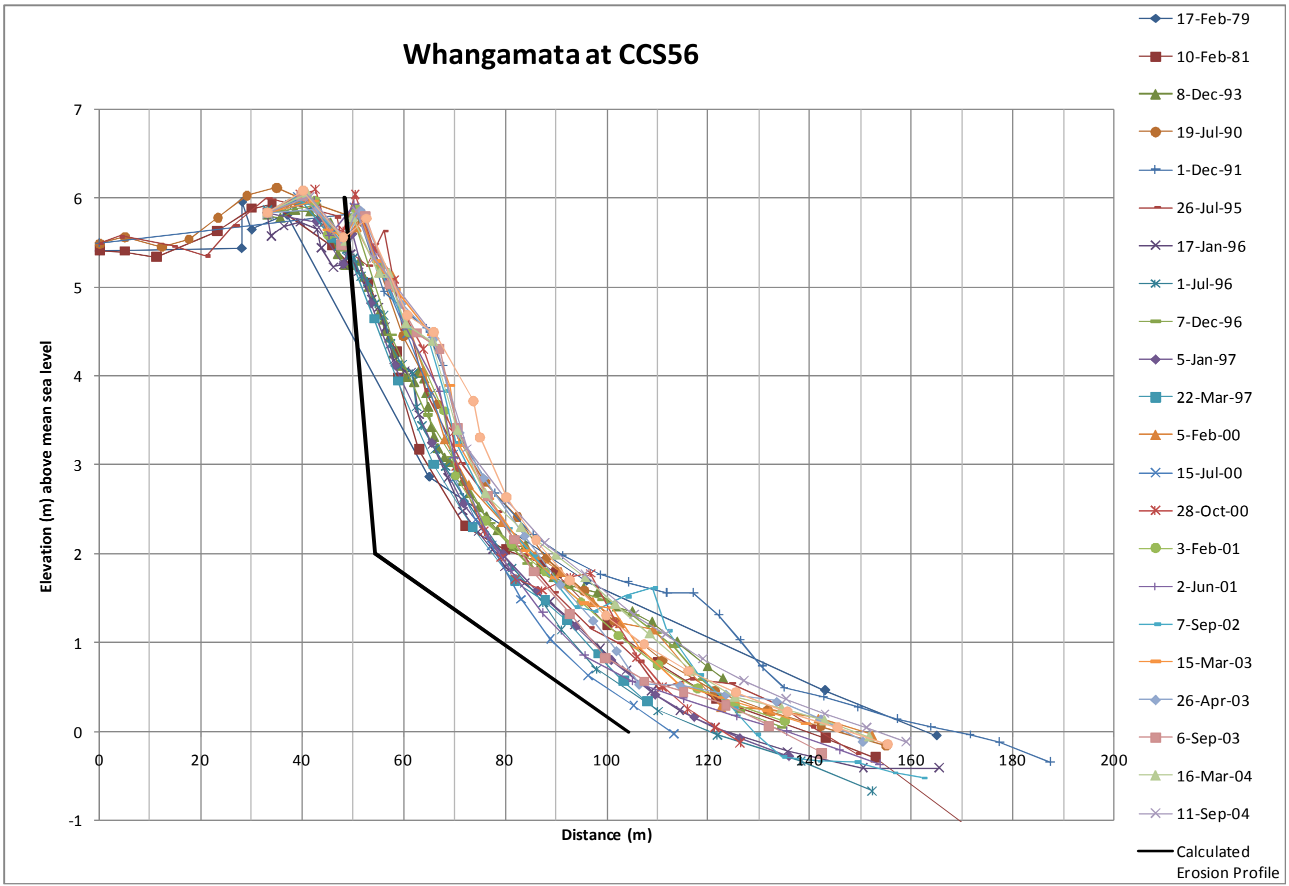
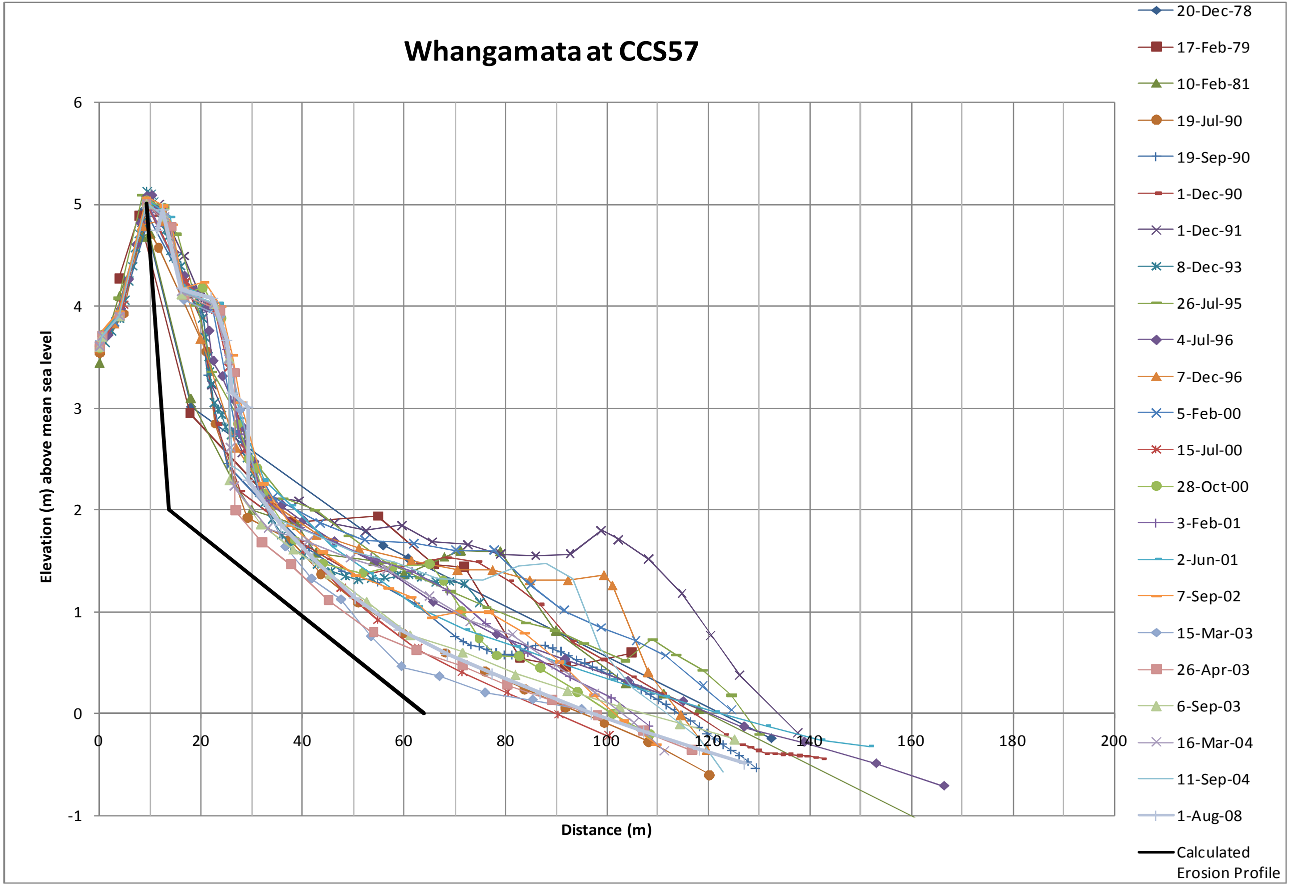
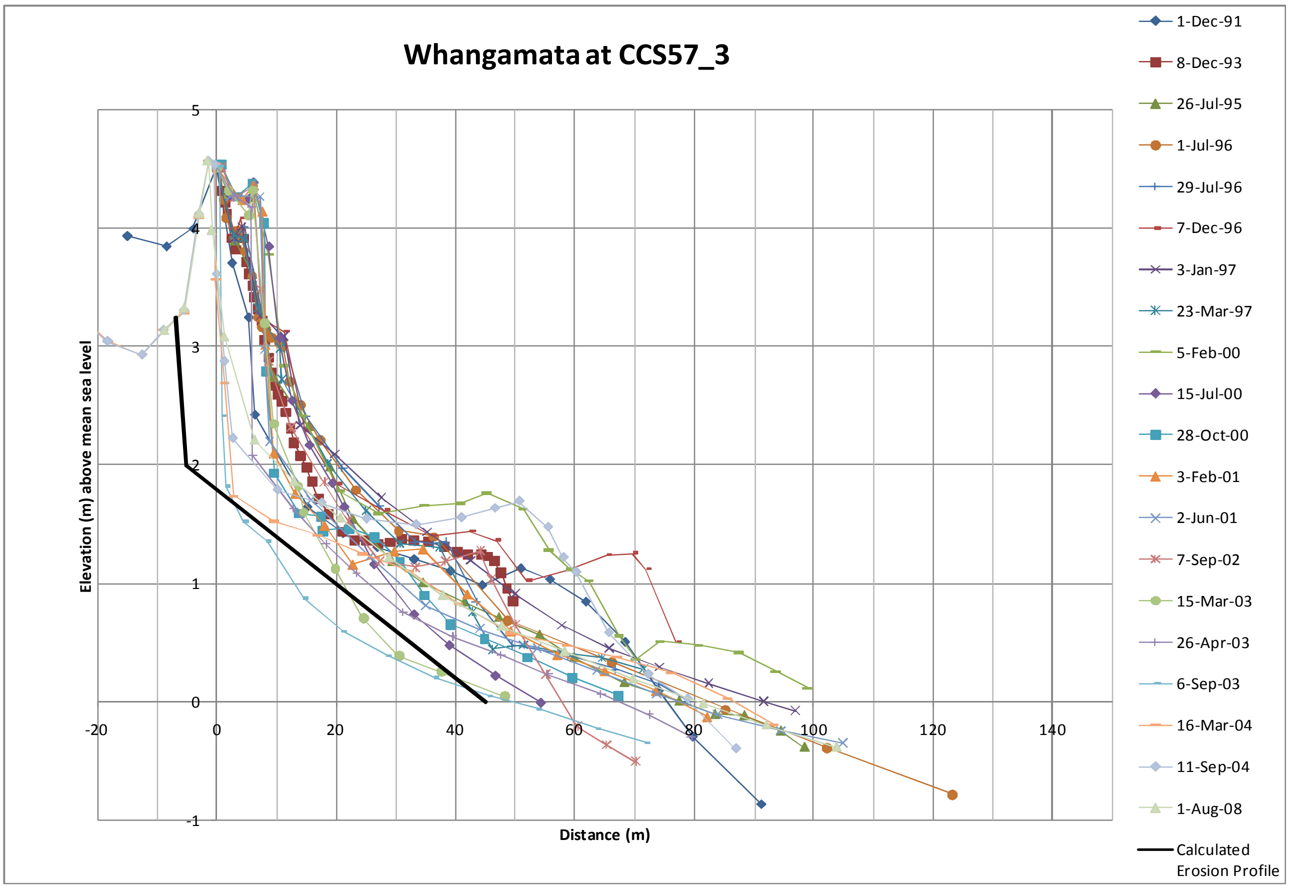
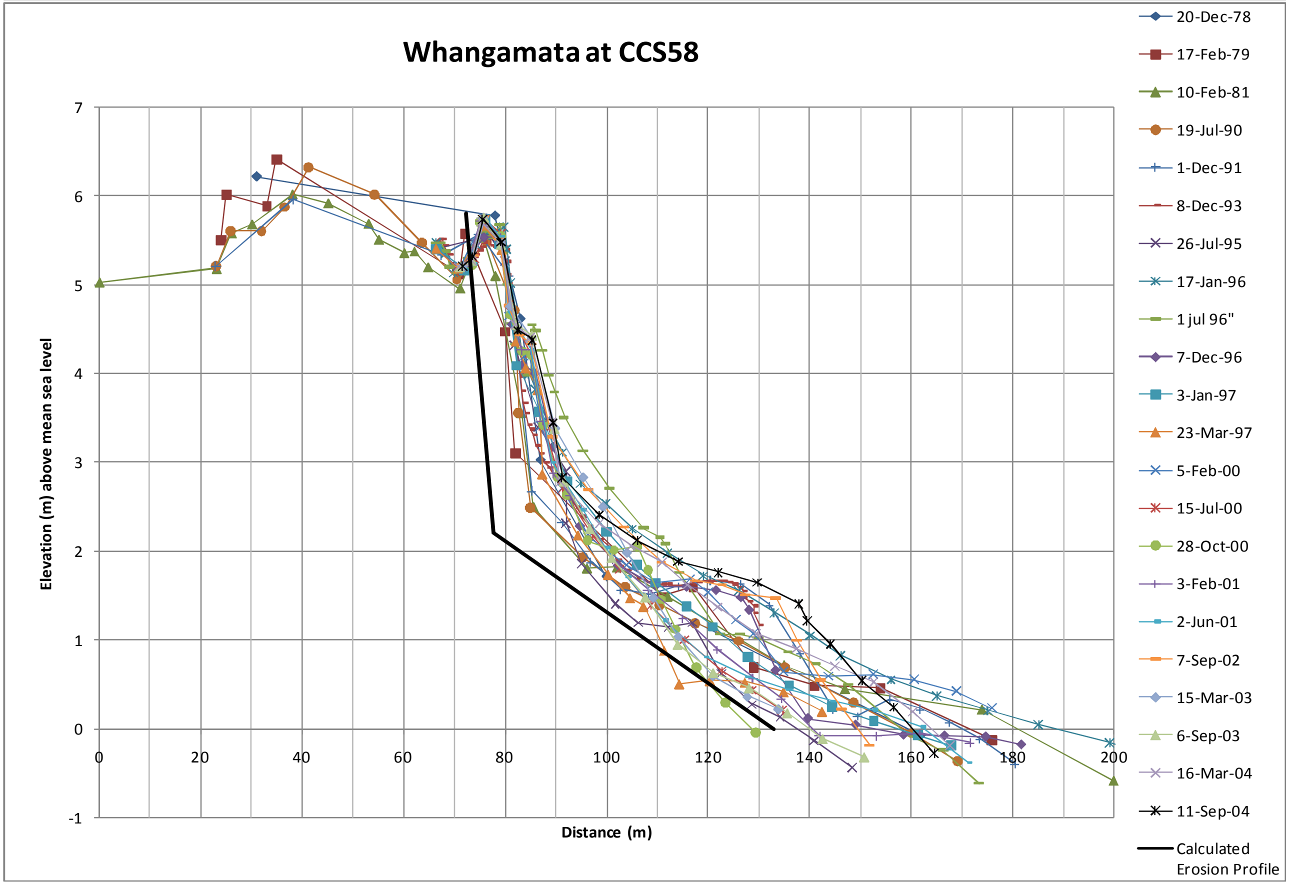
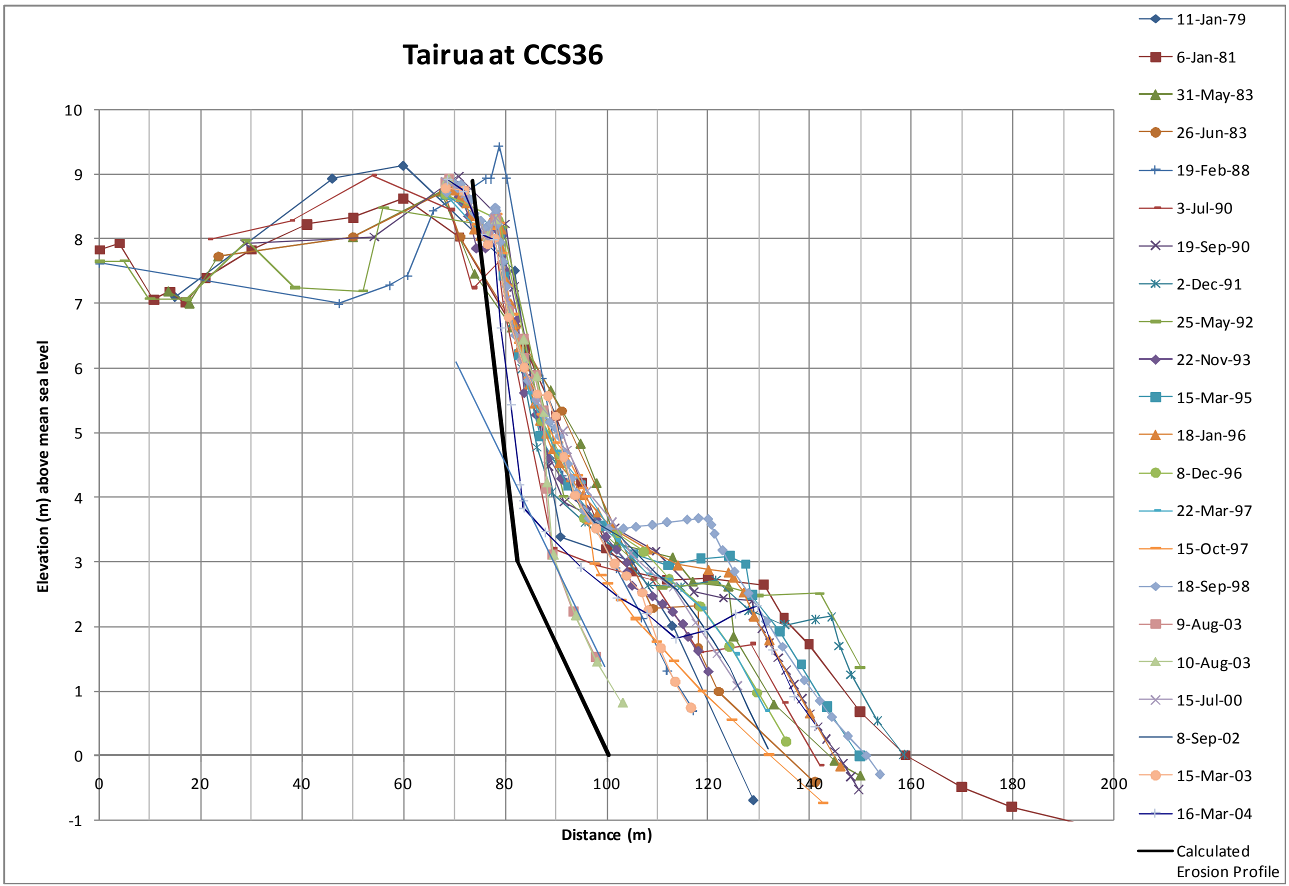
Appendix I: Storm Profile Graphs for East Coast Sites

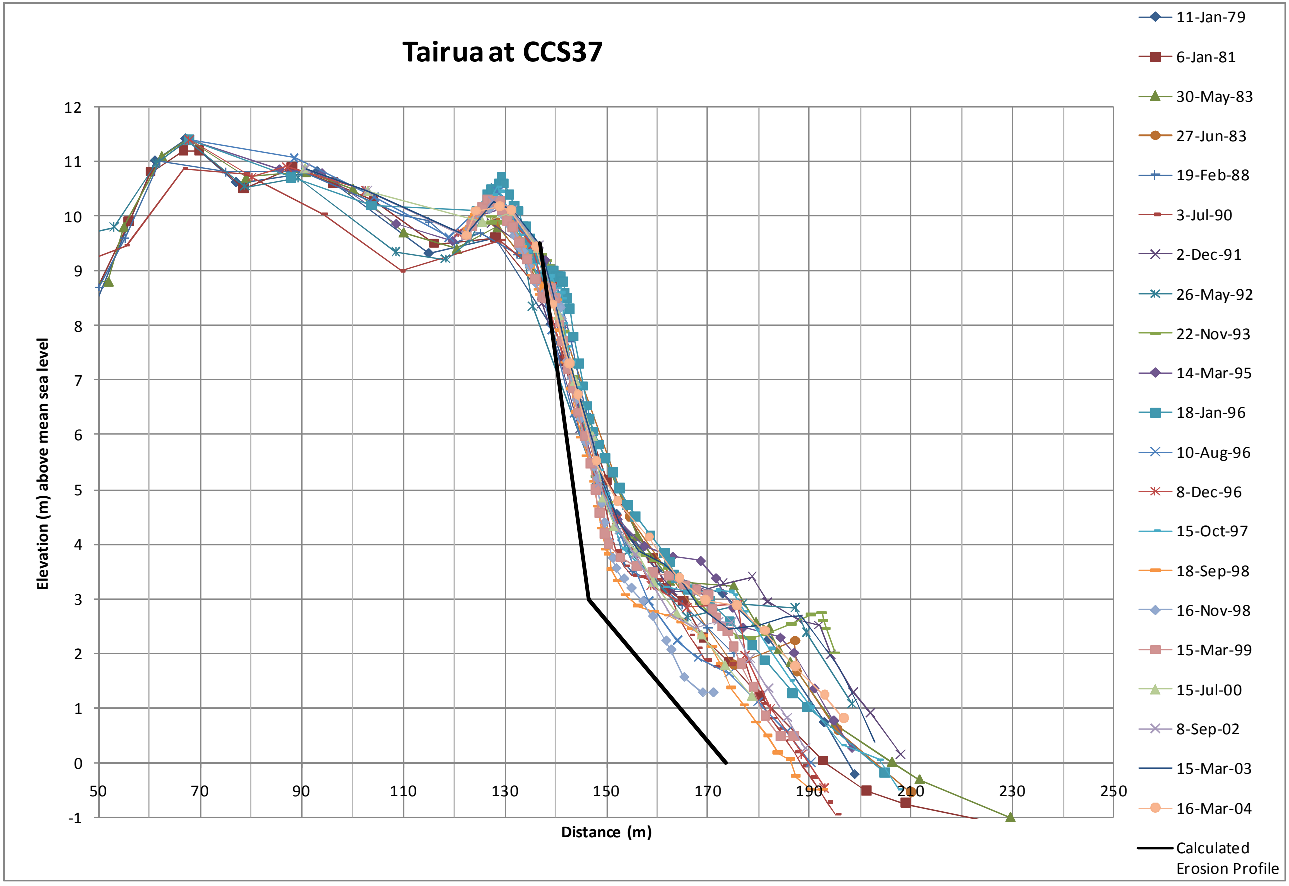

Whangamata at CCS56
Elevation (m) above mean sea level
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
17-Feb-79
10-Feb-81
8-Dec-93
19-Jul-90
1-Dec-91
26-Jul-95
17-Jan-96
1-Jul-96
7-Dec-96
5-Jan-97
22-Mar-97
5-Feb-00
15-Jul-00
28-Oct-00
3-Feb-01
2-Jun-01
7-Sep-02
15-Mar-03
26-Apr-03
6-Sep-03
16-Mar-04
11-Sep-04
Calculated Erosion Profile

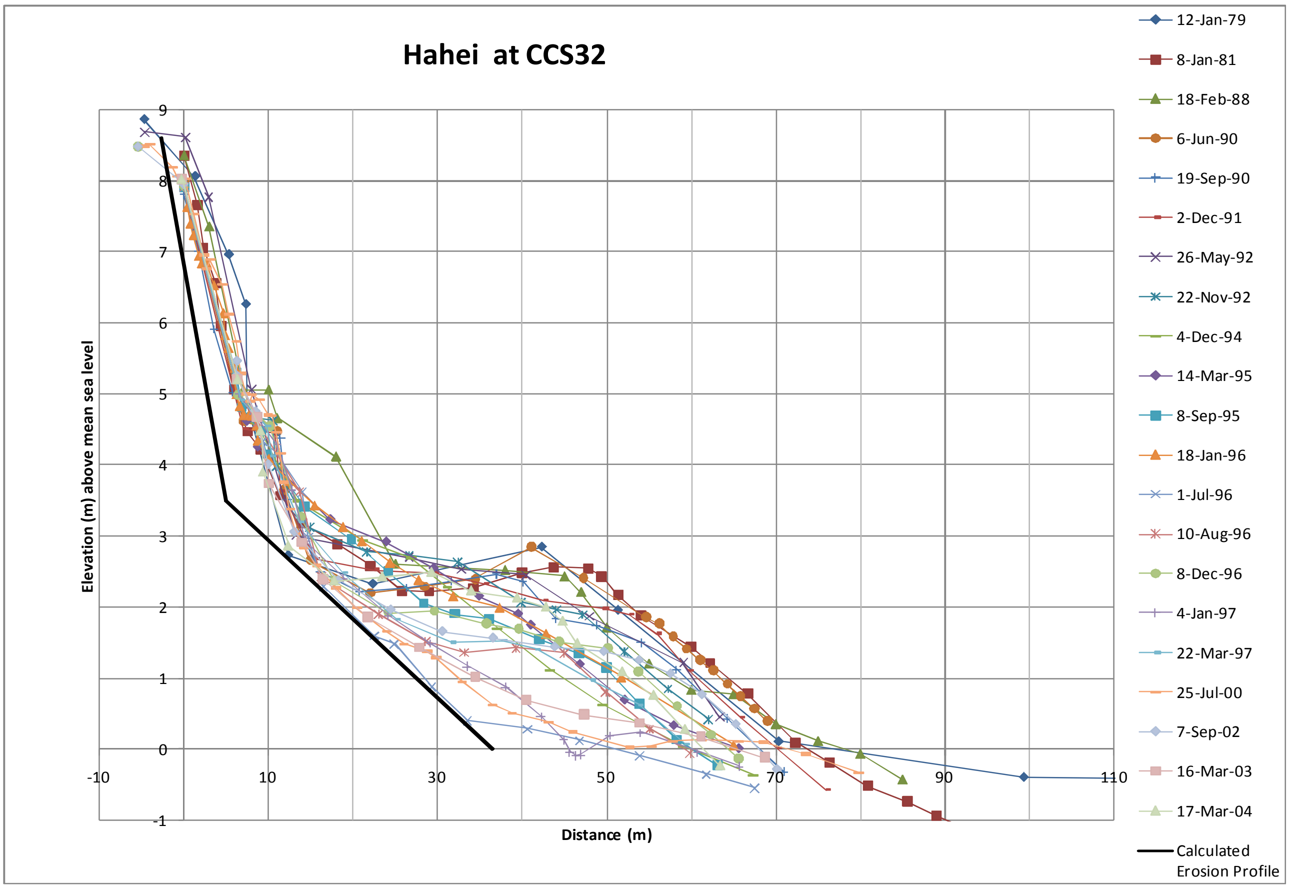

Whangamata at CCS57
Elevation (m) above mean sea level
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
20-Dec-78
17-Feb-79
10-Feb-81
19-Jul-90
19-Sep-90
1-Dec-90
1-Dec-91
8-Dec-93
26-Jul-95
4-Jul-96
7-Dec-96
5-Feb-00
15-Jul-00
28-Oct-00
3-Feb-01
2-Jun-01
7-Sep-02
15-Mar-03
26-Apr-03
6-Sep-03
16-Mar-04
11-Sep-04
1-Aug-08
Calculated Erosion Profile

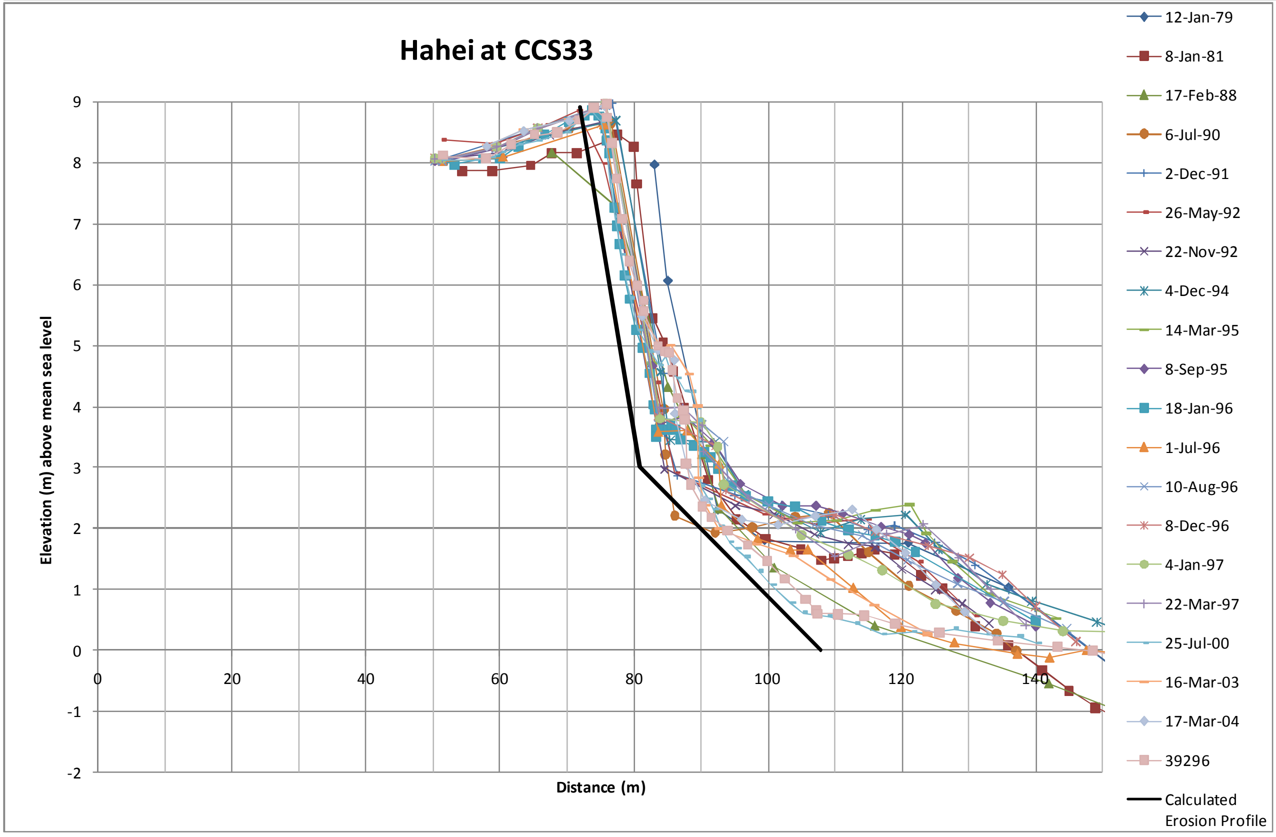

Whangamata at CCS57_3
Elevation (m) above mean sea level
Distance (m)
5
4
3
2
1
0
-1
-20
0
20
40
60
80
100
120
140
1-Dec-91
8-Dec-93
26-Jul-95
1-Jul-96
29-Jul-96
7-Dec-96
3-Jan-97
23-Mar-97
5-Feb-00
15-Jul-00
28-Oct-00
3-Feb-01
2-Jun-01
7-Sep-02
15-Mar-03
26-Apr-03
6-Sep-03
16-Mar-04
11-Sep-04
1-Aug-08
Calculated Erosion Profile

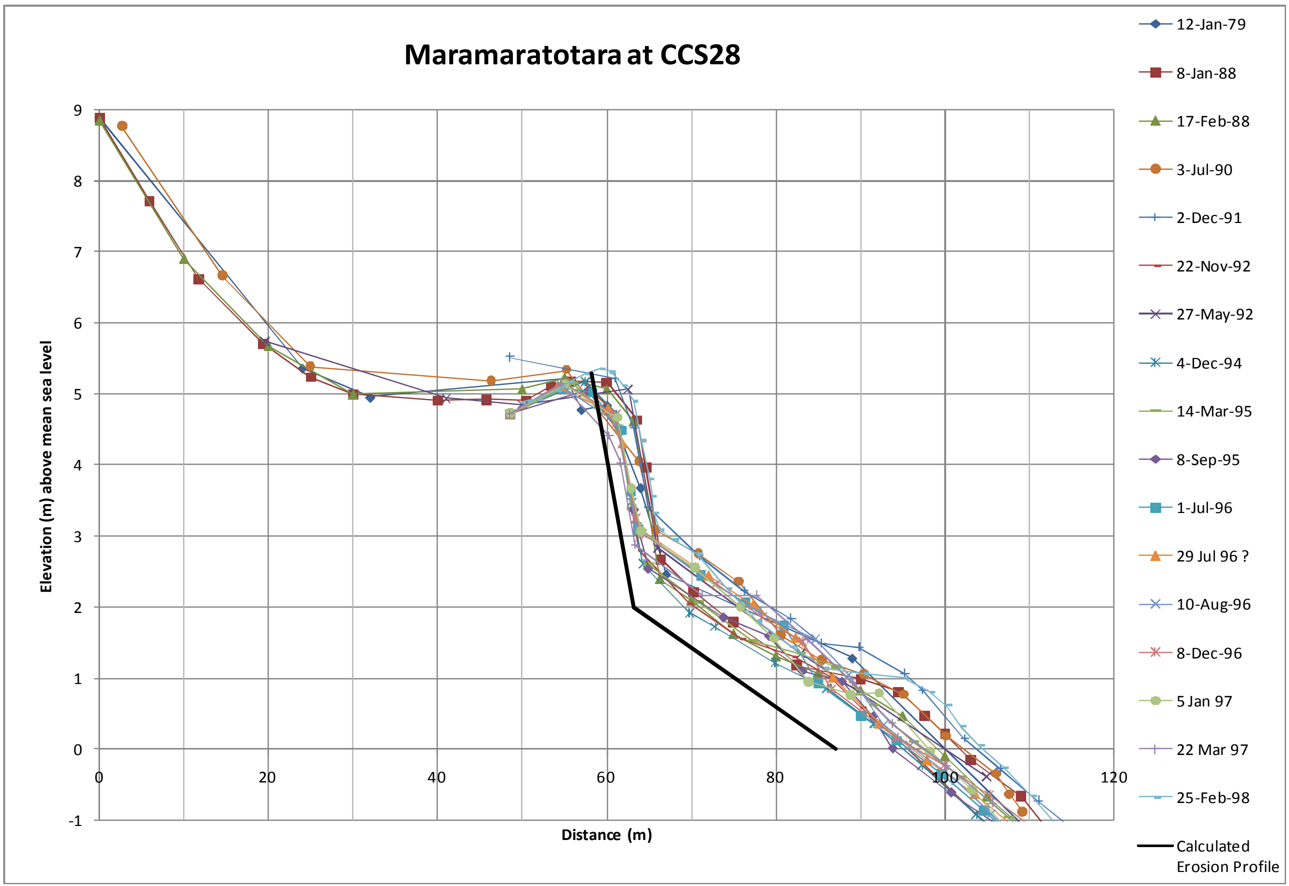

Whangamata at CCS58
Elevation (m) above mean sea level
Distance (m)
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
20-Dec-78
17-Feb-79
10-Feb-81
19-Jul-90
1-Dec-91
8-Dec-93
26-Jul-95
17-Jan-96
1 jul 96"
7-Dec-96
3-Jan-97
23-Mar-97
5-Feb-00
15-Jul-00
28-Oct-00
3-Feb-01
2-Jun-01
7-Sep-02
15-Mar-03
6-Sep-03
16-Mar-04
11-Sep-04
Calculated Erosion Profile

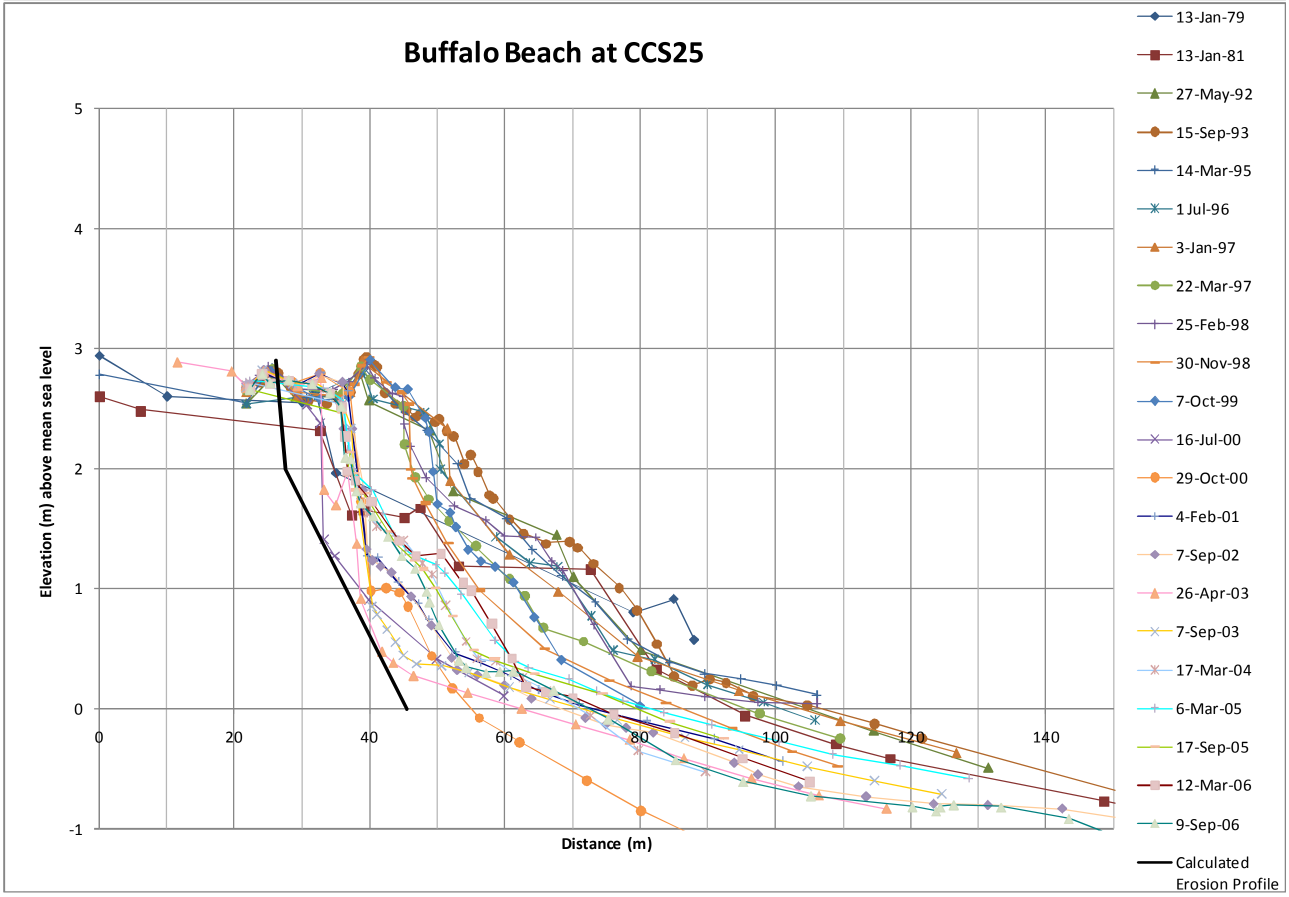

Tairua at CCS36
Elevation (m) above mean sea level
Distance (m)
10
9
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
11-Jan-79
6-Jan-81
31-May-83
26-Jun-83
19-Feb-88
3-Jul-90
19-Sep-90
2-Dec-91
25-May-92
22-Nov-93
15-Mar-95
18-Jan-96
8-Dec-96
22-Mar-97
15-Oct-97
18-Sep-98
9-Aug-03
10-Aug-03
15-Jul-00
8-Sep-02
15-Mar-03
16-Mar-04
Calculated Erosion Profile

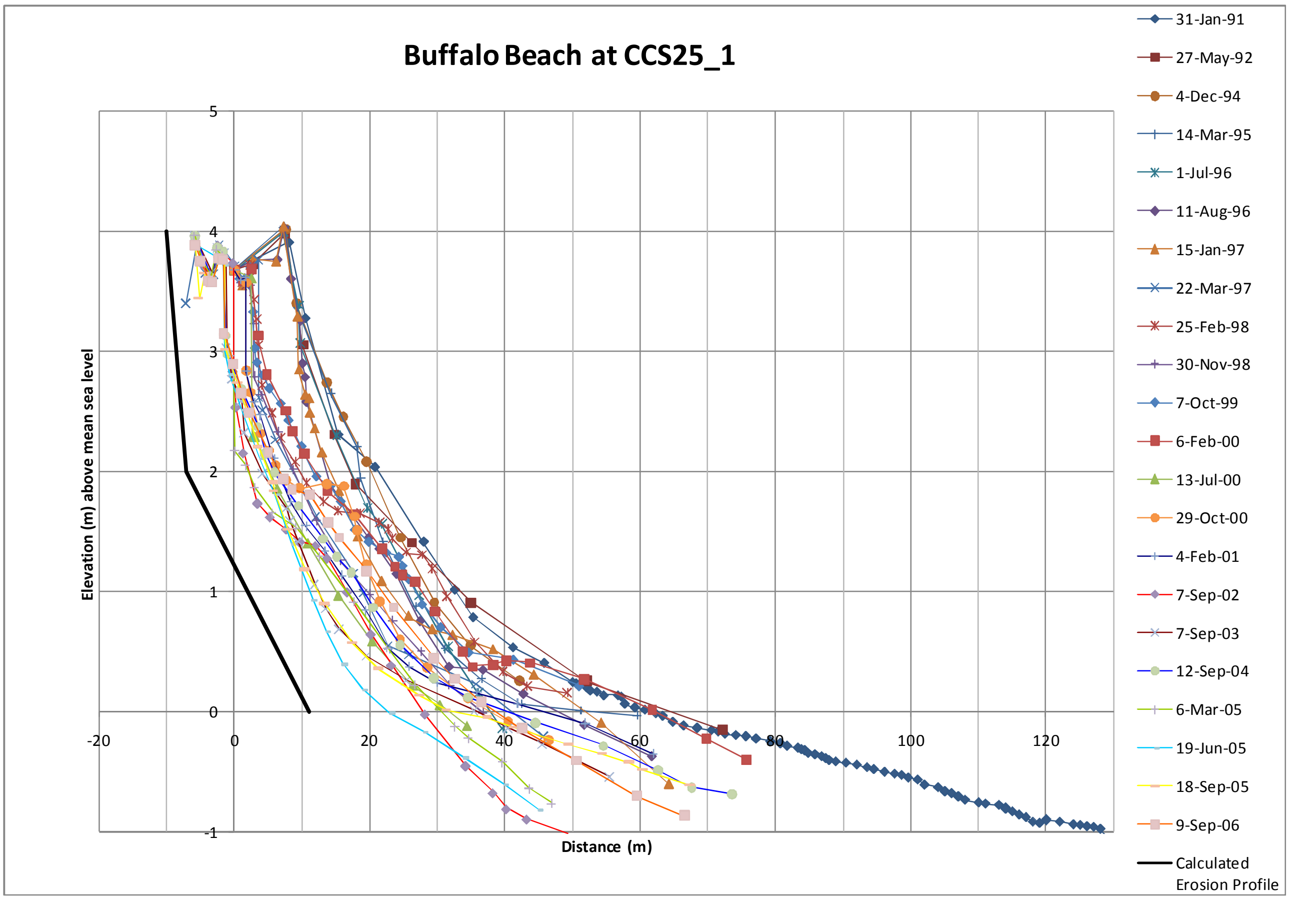

Tairua at CCS37
Elevation (m) above mean sea level
Distance (m)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
50
70
90
110
130
150
170
190
210
230
250
11-Jan-79
6-Jan-81
30-May-83
27-Jun-83
19-Feb-88
3-Jul-90
2-Dec-91
26-May-92
22-Nov-93
14-Mar-95
18-Jan-96
10-Aug-96
8-Dec-96
15-Oct-97
18-Sep-98
16-Nov-98
15-Mar-99
15-Jul-00
8-Sep-02
15-Mar-03
16-Mar-04
Calculated Erosion Profile

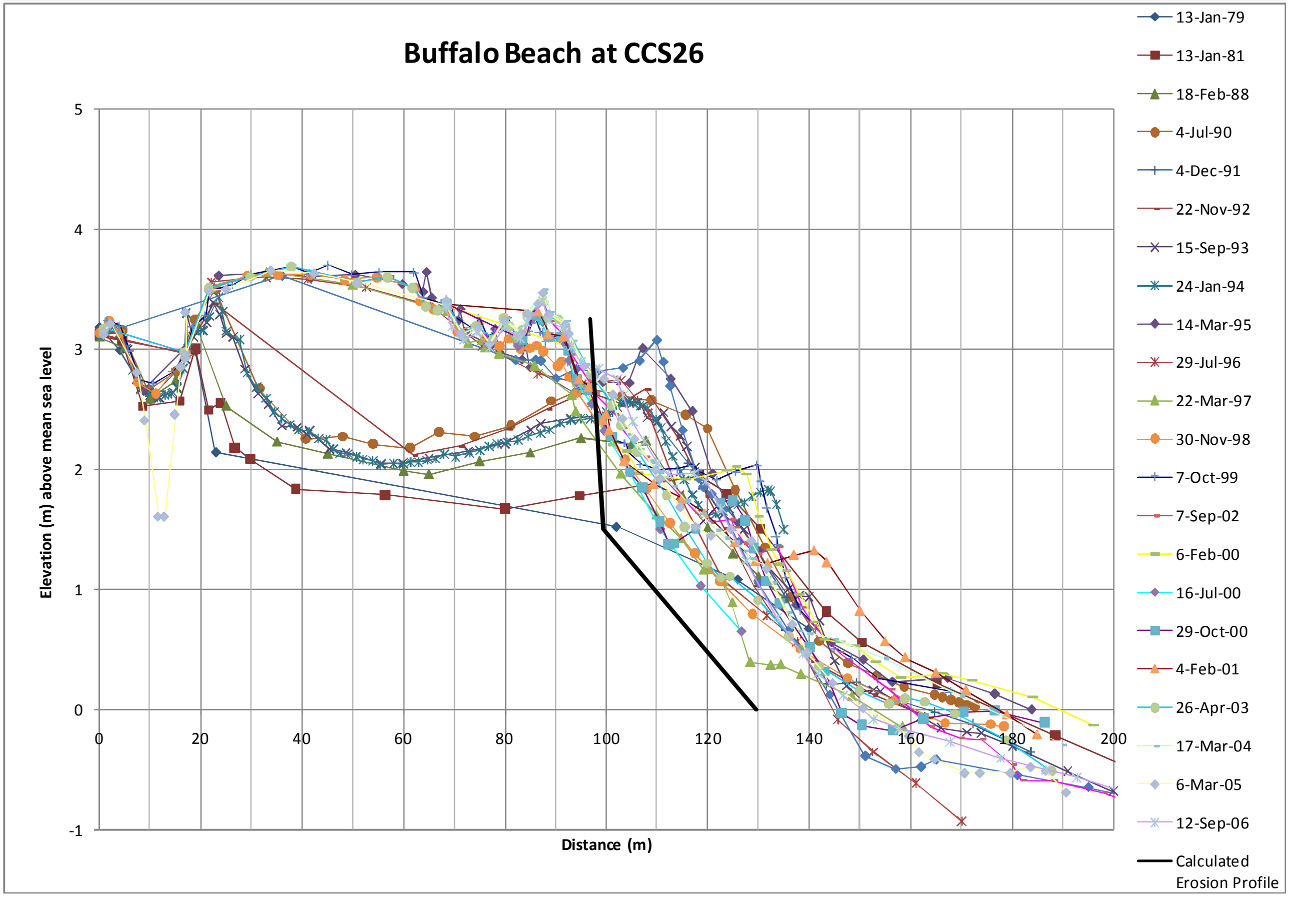

Hahei at CCS32
Elevation (m) above mean sea level
Distance (m)
9
8
7
6
5
4
3
2
1
0
-1
-10
10
30
50
70
90
110
12-Jan-79
8-Jan-81
18-Feb-88
6-Jun-90
19-Sep-90
2-Dec-91
26-May-92
22-Nov-92
4-Dec-94
14-Mar-95
8-Sep-95
18-Jan-96
1-Jul-96
10-Aug-96
8-Dec-96
4-Jan-97
22-Mar-97
25-Jul-00
7-Sep-02
16-Mar-03
17-Mar-04
Calculated Erosion Profile

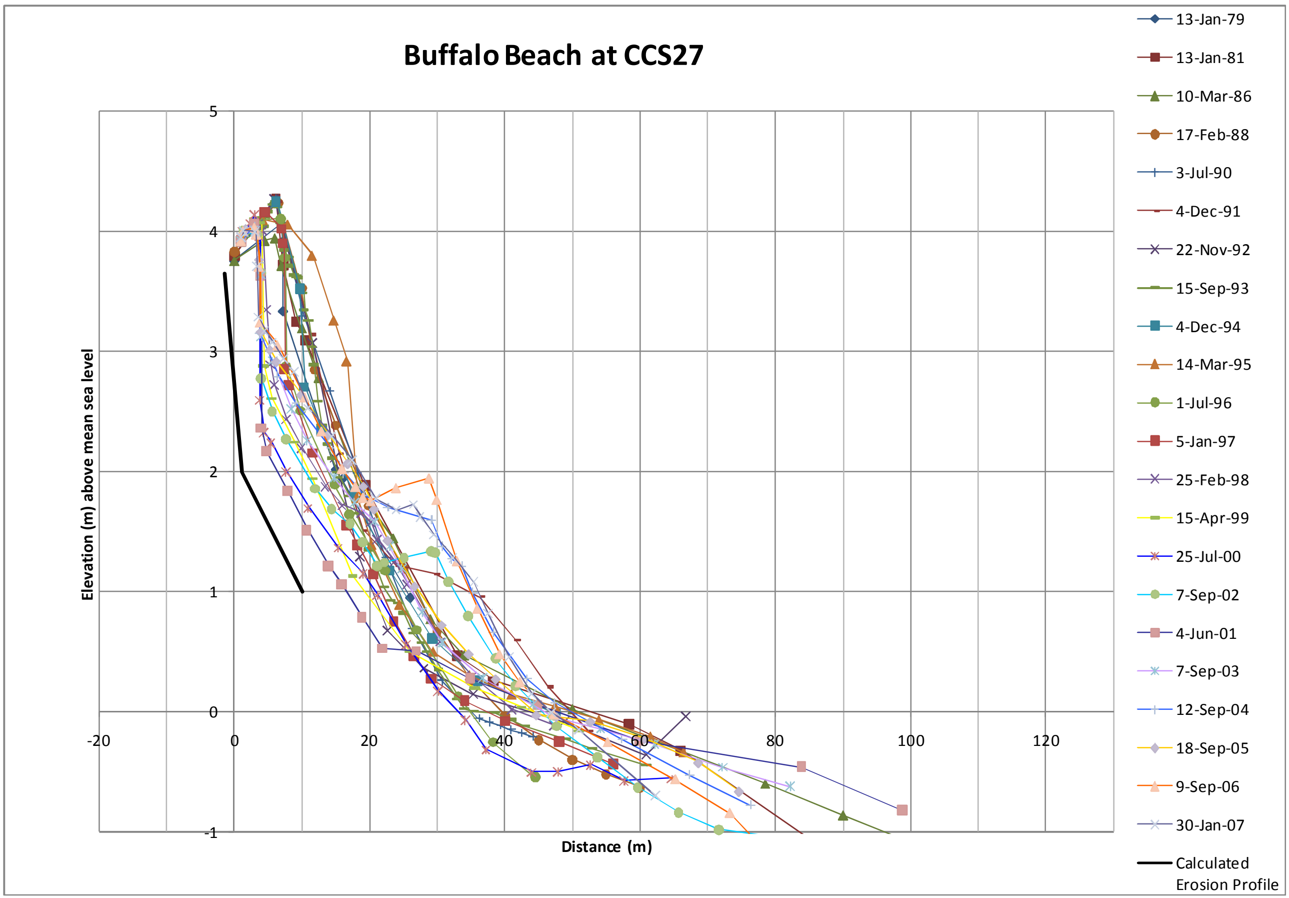

Hahei at CCS33
Elevation (m) above mean sea level
Distance (m)
9
8
7
6
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
12-Jan-79
8-Jan-81
17-Feb-88
6-Jul-90
2-Dec-91
26-May-92
22-Nov-92
4-Dec-94
14-Mar-95
8-Sep-95
18-Jan-96
1-Jul-96
10-Aug-96
8-Dec-96
4-Jan-97
22-Mar-97
25-Jul-00
16-Mar-03
17-Mar-04
39296
Calculated Erosion Profile

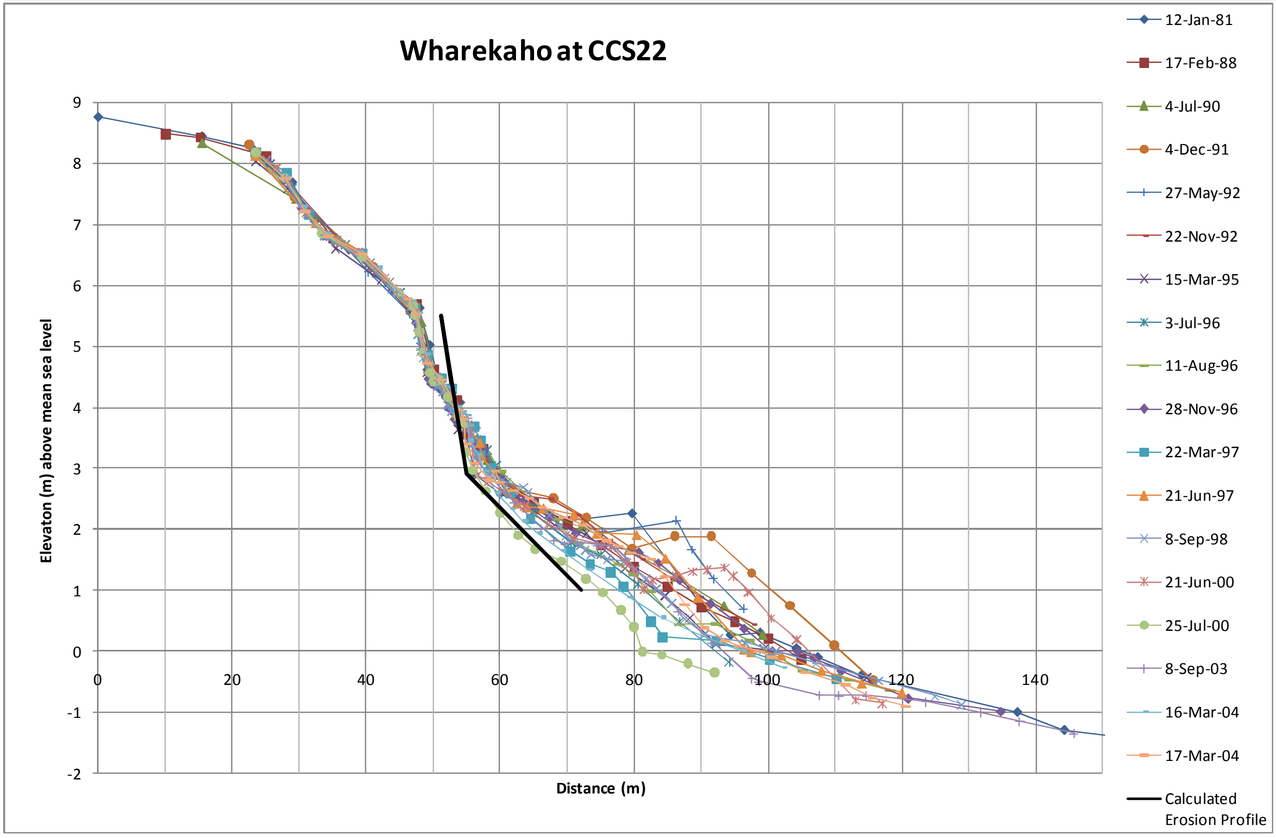

Maramaratotara at CCS28
Elevation (m) above mean sea level
9
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
Distance (m)
12-Jan-79
8-Jan-88
17-Feb-88
3-Jul-90
2-Dec-91
22-Nov-92
27-May-92
4-Dec-94
14-Mar-95
8-Sep-95
1-Jul-96
29 Jul 96 ?
10-Aug-96
8-Dec-96
5 Jan 97
22 Mar 97
25-Feb-98
Calculated Erosion Profile

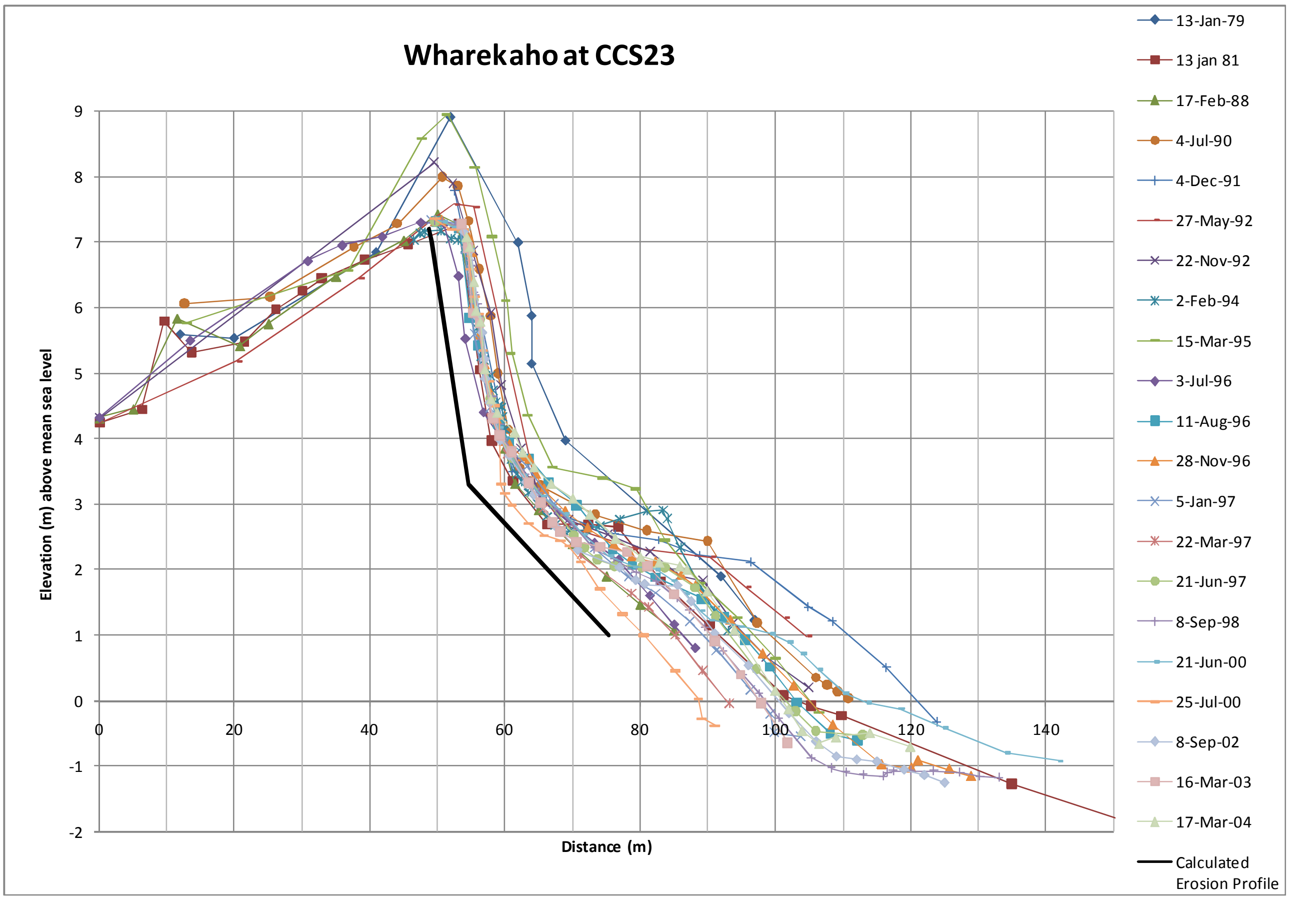

Buffalo Beach at CCS25
Elevation (m) above mean sea level
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
Distance (m)
13-Jan-79
13-Jan-81
27-May-92
15-Sep-93
14-Mar-95
1 Jul-96
3-Jan-97
22-Mar-97
25-Feb-98
30-Nov-98
7-Oct-99
16-Jul-00
29-Oct-00
4-Feb-01
7-Sep-02
26-Apr-03
7-Sep-03
17-Mar-04
6-Mar-05
17-Sep-05
12-Mar-06
9-Sep-06
Calculated Erosion Profile

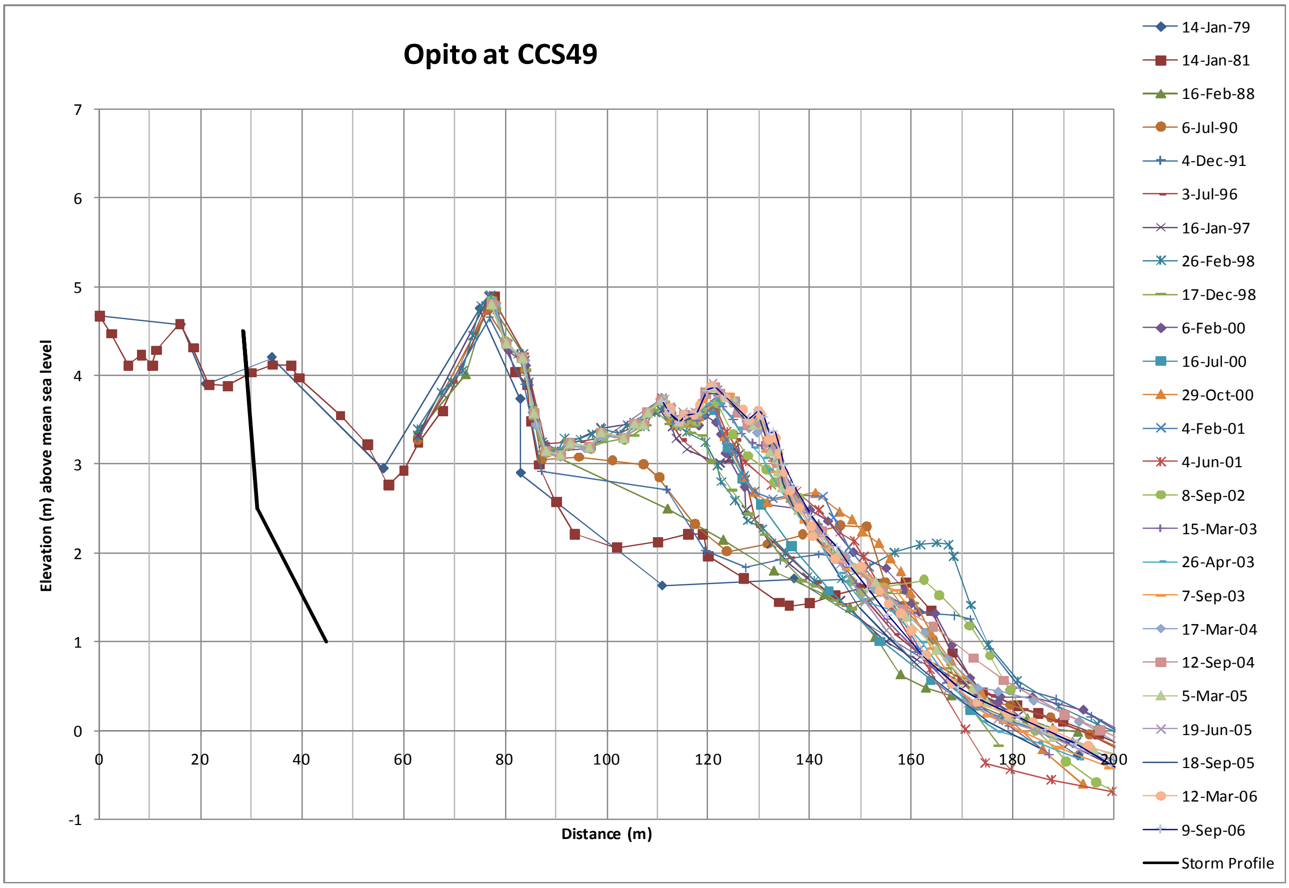

Buffalo Beach at CCS25_1
Elevation (m) above mean sea level
5
4
3
2
1
0
-1
-20
0
20
40
60
80
100
120
Distance (m)
31-Jan-91
27-May-92
4-Dec-94
14-Mar-95
1-Jul-96
11-Aug-96
15-Jan-97
22-Mar-97
25-Feb-98
30-Nov-98
7-Oct-99
6-Feb-00
13-Jul-00
29-Oct-00
4-Feb-01
7-Sep-02
7-Sep-03
12-Sep-04
6-Mar-05
19-Jun-05
18-Sep-05
9-Sep-06
Calculated Erosion Profile

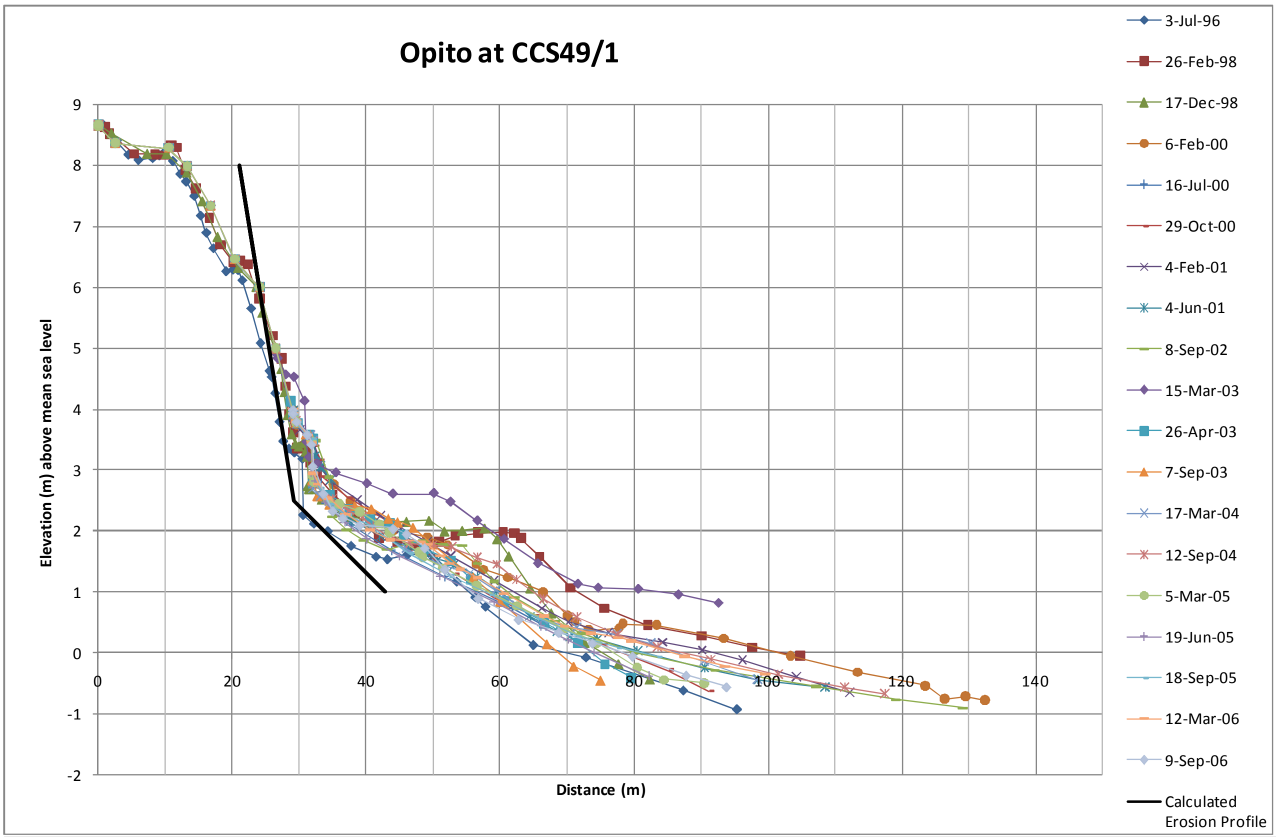

Buffalo Beach at CCS26
Elevation (m) above mean sea level
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
13-Jan-79
13-Jan-81
18-Feb-88
4-Jul-90
4-Dec-91
22-Nov-92
15-Sep-93
24-Jan-94
14-Mar-95
29-Jul-96
22-Mar-97
30-Nov-98
7-Oct-99
7-Sep-02
6-Feb-00
16-Jul-00
29-Oct-00
4-Feb-01
26-Apr-03
17-Mar-04
6-Mar-05
12-Sep-06
Calculated Erosion Profile

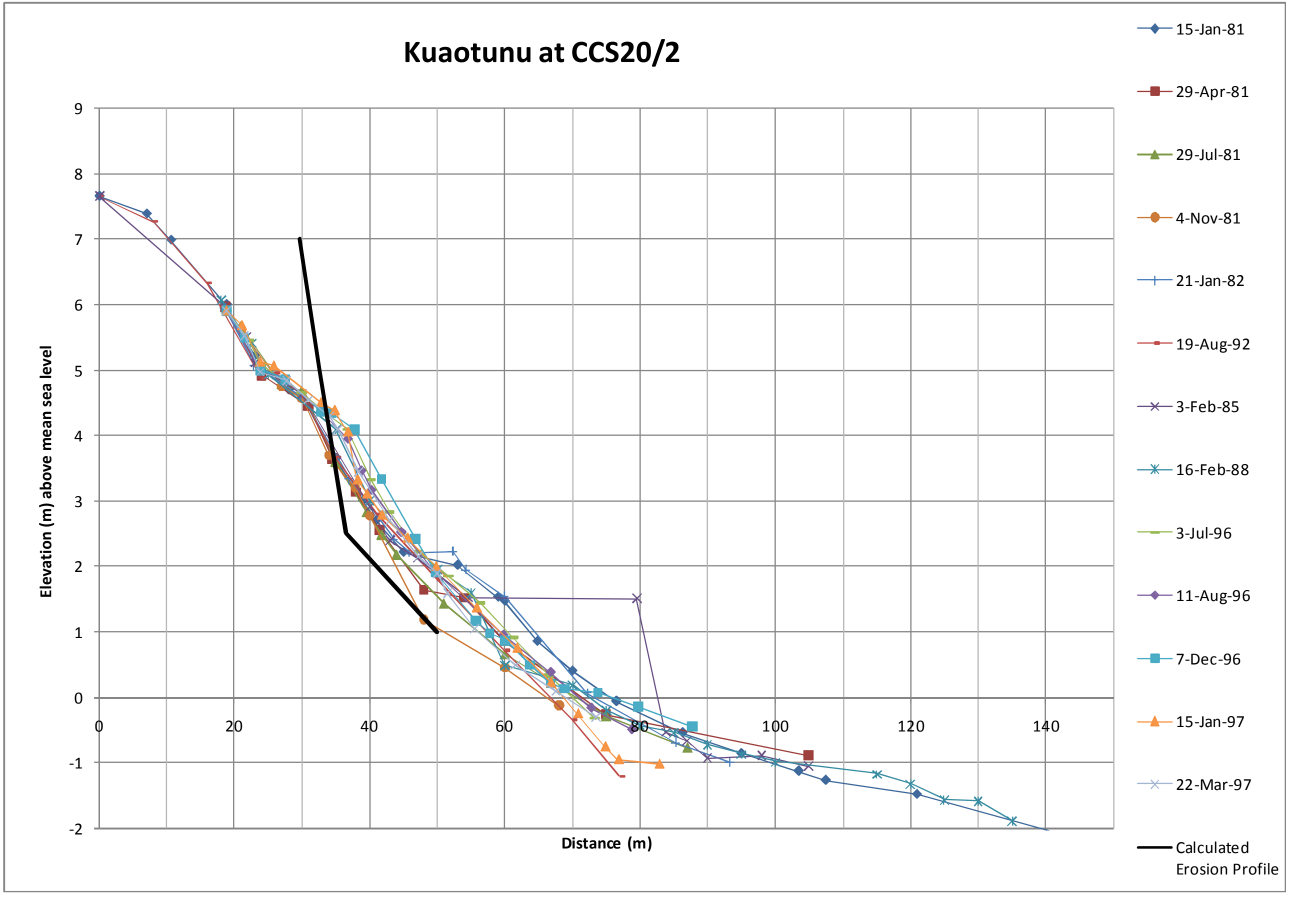

Buffalo Beach at CCS27
Elevation (m) above mean sea level
Distance (m)
5
4
3
2
1
0
-1
-20
0
20
40
60
80
100
120
13-Jan-79
13-Jan-81
10-Mar-86
17-Feb-88
3-Jul-90
4-Dec-91
22-Nov-92
15-Sep-93
4-Dec-94
14-Mar-95
1-Jul-96
5-Jan-97
25-Feb-98
15-Apr-99
25-Jul-00
7-Sep-02
4-Jun-01
7-Sep-03
12-Sep-04
18-Sep-05
9-Sep-06
30-Jan-07
Calculated Erosion Profile

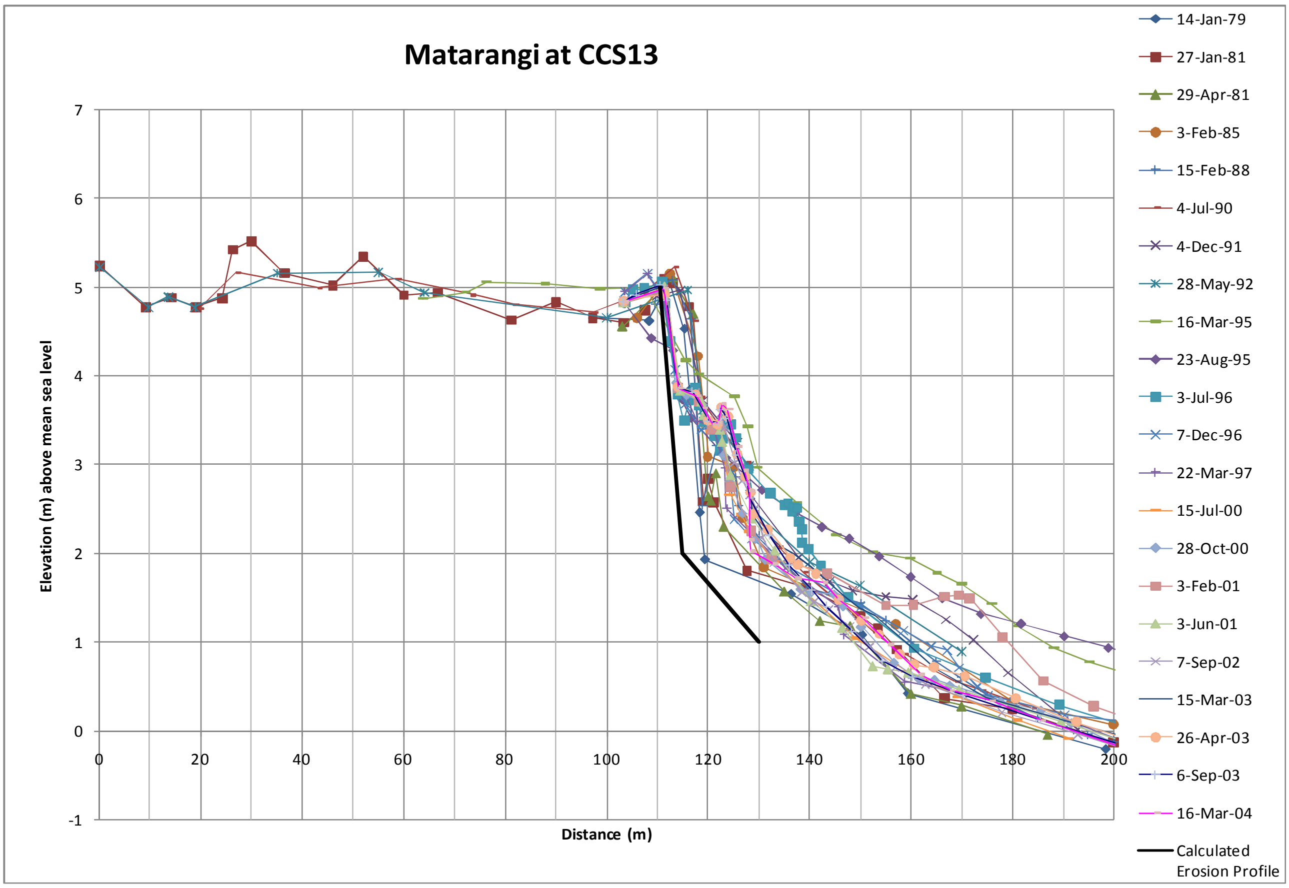

Wharekaho at CCS22
Elevaton (m) above mean sea level
Distance (m)
9
8
7
6
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
12-Jan-81
17-Feb-88
4-Jul-90
4-Dec-91
27-May-92
22-Nov-92
15-Mar-95
3-Jul-96
11-Aug-96
28-Nov-96
22-Mar-97
21-Jun-97
8-Sep-98
21-Jun-00
25-Jul-00
8-Sep-03
16-Mar-04
17-Mar-04
Calculated Erosion Profile

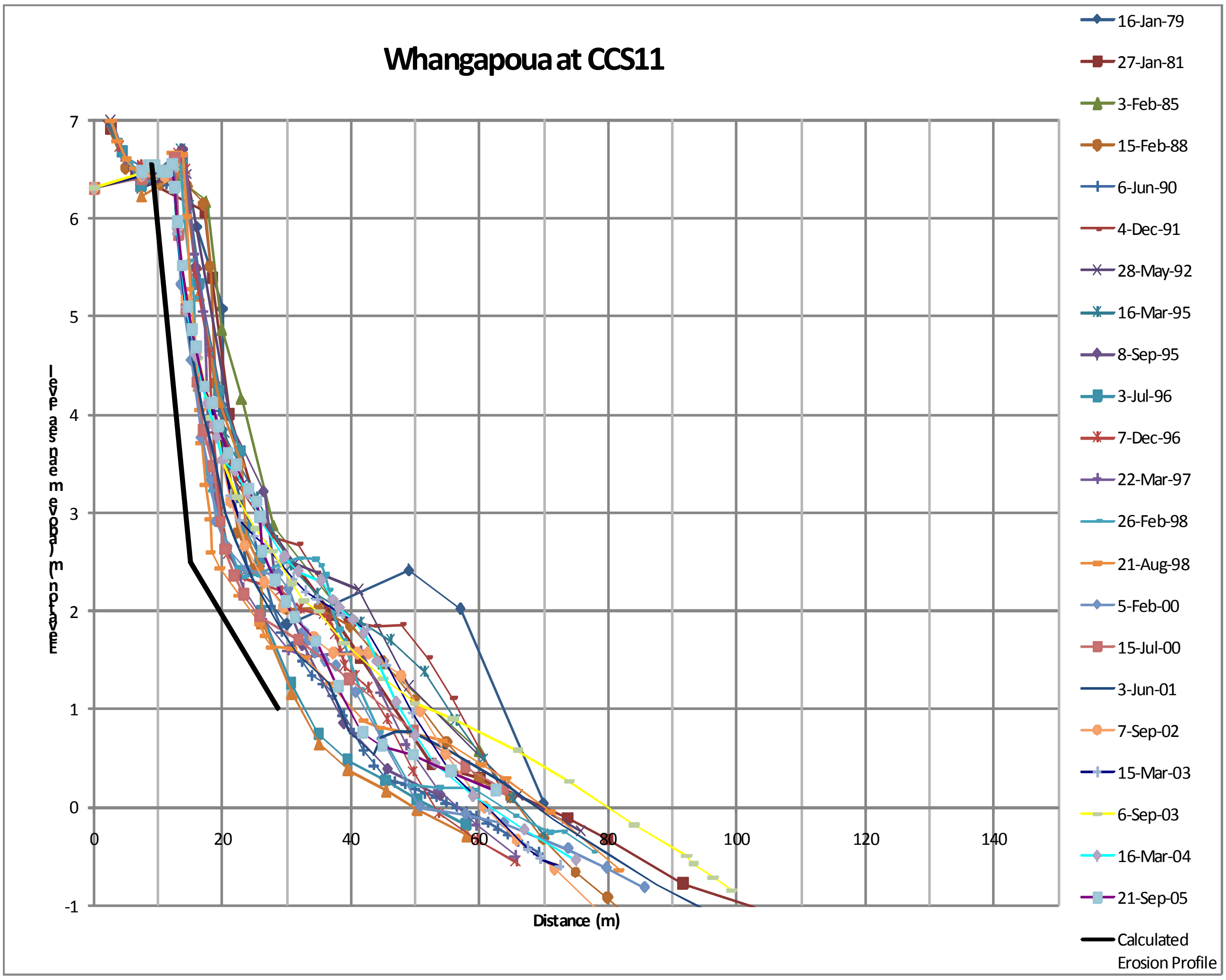

Wharekaho at CCS23
Elevation (m) above mean sea level
9
8
7
6
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
Distance (m)
13-Jan-79
13 jan 81
17-Feb-88
4-Jul-90
4-Dec-91
27-May-92
22-Nov-92
2-Feb-94
15-Mar-95
3-Jul-96
11-Aug-96
28-Nov-96
5-Jan-97
22-Mar-97
21-Jun-97
8-Sep-98
21-Jun-00
25-Jul-00
8-Sep-02
16-Mar-03
17-Mar-04
Calculated Erosion Profile

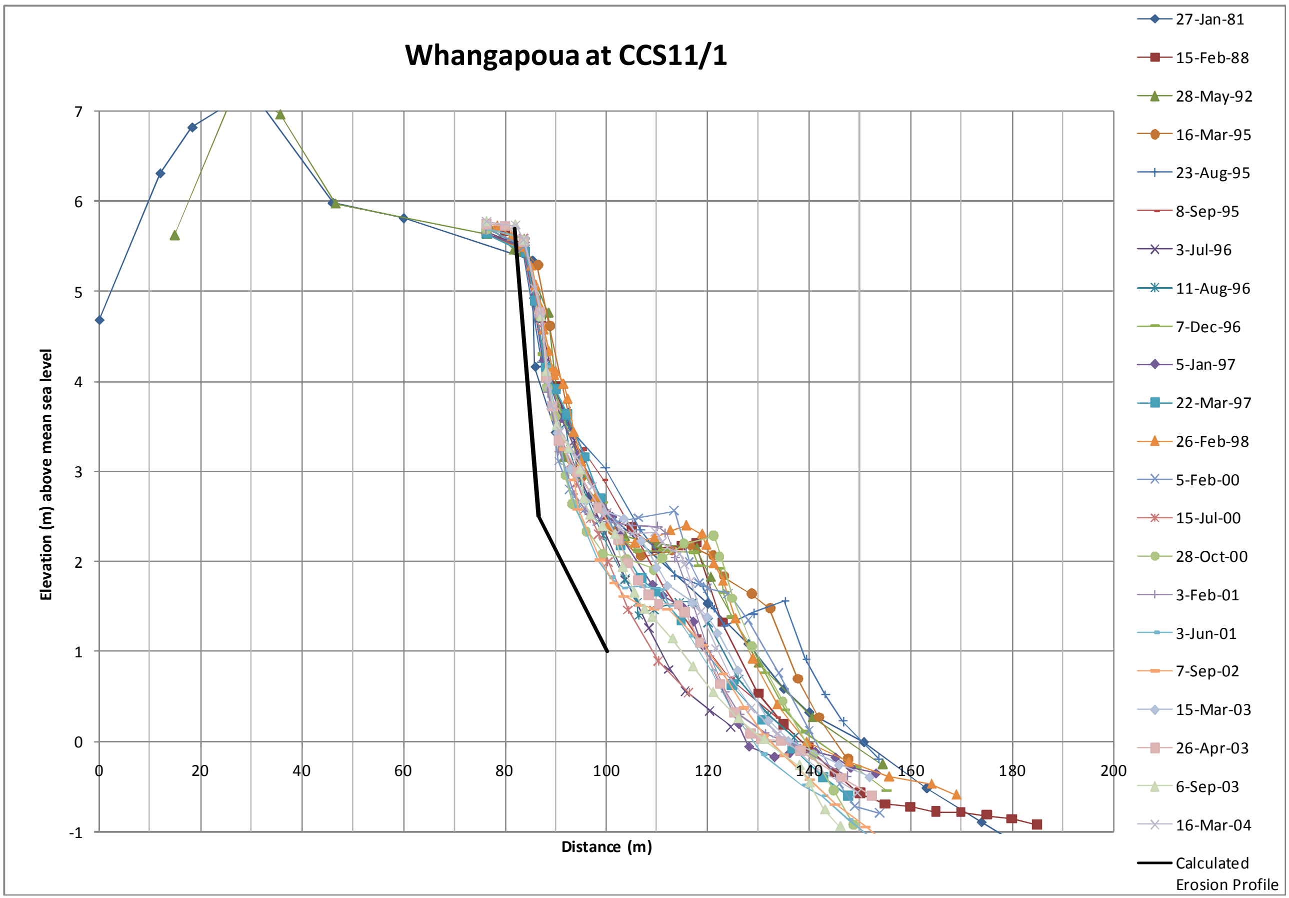

Opito at CCS49
Elevation (m) above mean sea level
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
14-Jan-79
14-Jan-81
16-Feb-88
6-Jul-90
4-Dec-91
3-Jul-96
16-Jan-97
26-Feb-98
17-Dec-98
6-Feb-00
16-Jul-00
29-Oct-00
4-Feb-01
4-Jun-01
8-Sep-02
15-Mar-03
26-Apr-03
7-Sep-03
17-Mar-04
12-Sep-04
5-Mar-05
19-Jun-05
18-Sep-05
12-Mar-06
9-Sep-06
Storm Profile

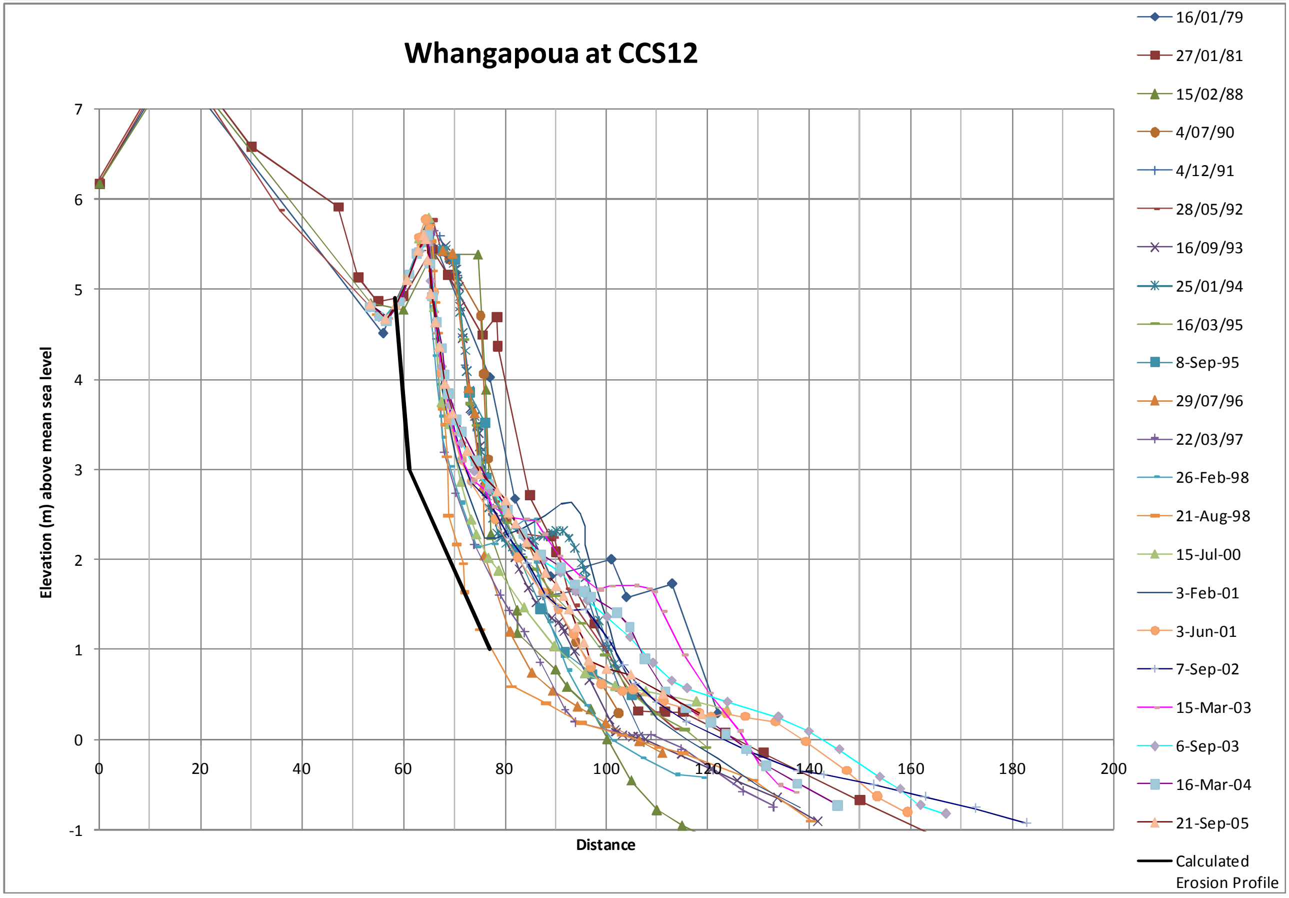

Opito at CCS49/1
Elevation (m) above mean sea level
Distance (m)
9
8
7
6
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
3-Jul-96
26-Feb-98
17-Dec-98
6-Feb-00
16-Jul-00
29-Oct-00
4-Feb-01
4-Jun-01
8-Sep-02
15-Mar-03
26-Apr-03
7-Sep-03
17-Mar-04
12-Sep-04
5-Mar-05
19-Jun-05
18-Sep-05
12-Mar-06
9-Sep-06
Calculated Erosion Profile

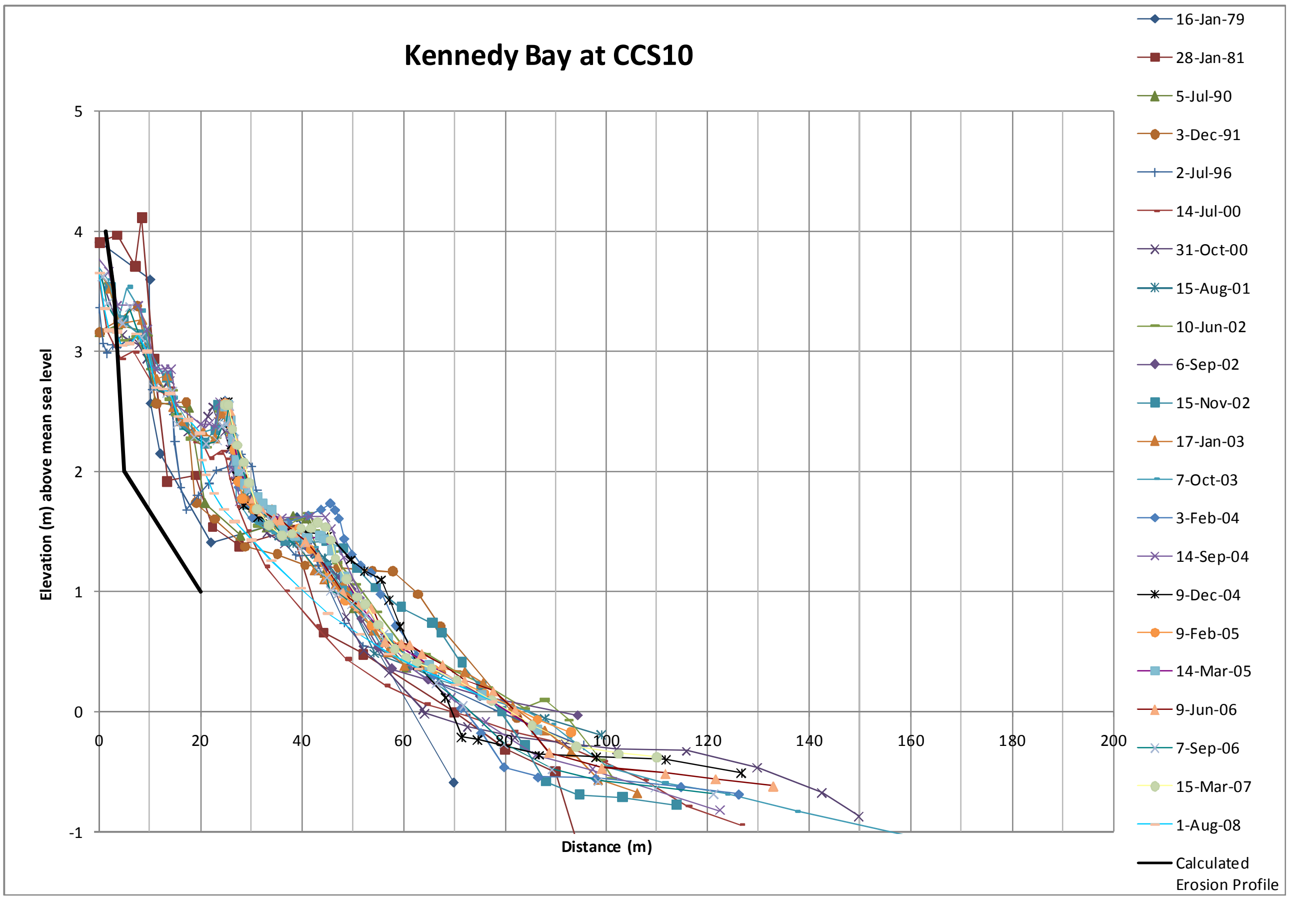

Kuaotunu at CCS20/2
Elevation (m) above mean sea level
Distance (m)
9
8
7
6
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
15-Jan-81
29-Apr-81
29-Jul-81
4-Nov-81
21-Jan-82
19-Aug-92
3-Feb-85
16-Feb-88
3-Jul-96
11-Aug-96
7-Dec-96
15-Jan-97
22-Mar-97
Calculated Erosion Profile

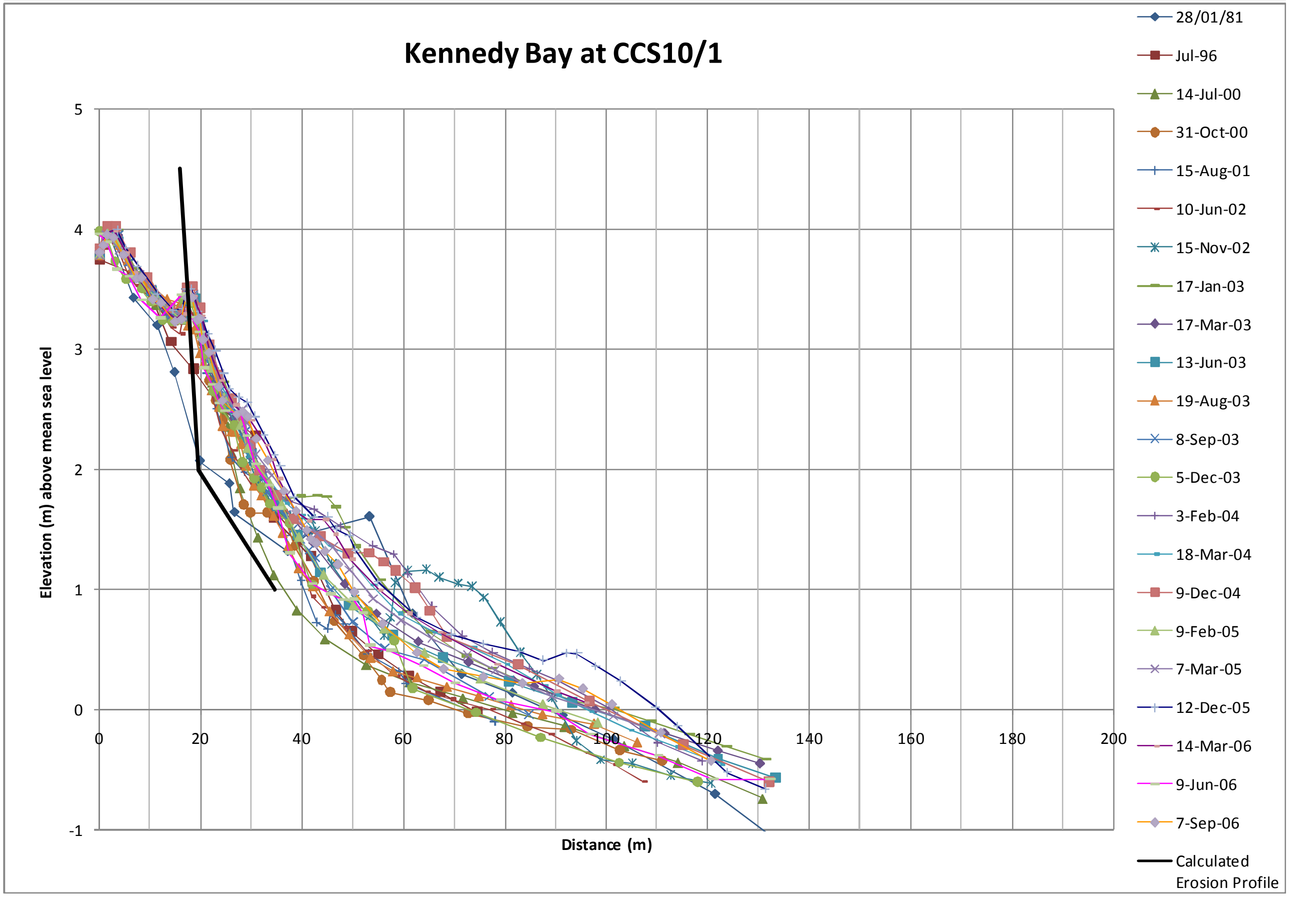

Matarangi at CCS13
Elevation (m) above mean sea level
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
14-Jan-79
27-Jan-81
29-Apr-81
3-Feb-85
15-Feb-88
4-Jul-90
4-Dec-91
28-May-92
16-Mar-95
23-Aug-95
3-Jul-96
7-Dec-96
22-Mar-97
15-Jul-00
28-Oct-00
3-Feb-01
3-Jun-01
7-Sep-02
15-Mar-03
26-Apr-03
6-Sep-03
16-Mar-04
Calculated Erosion Profile

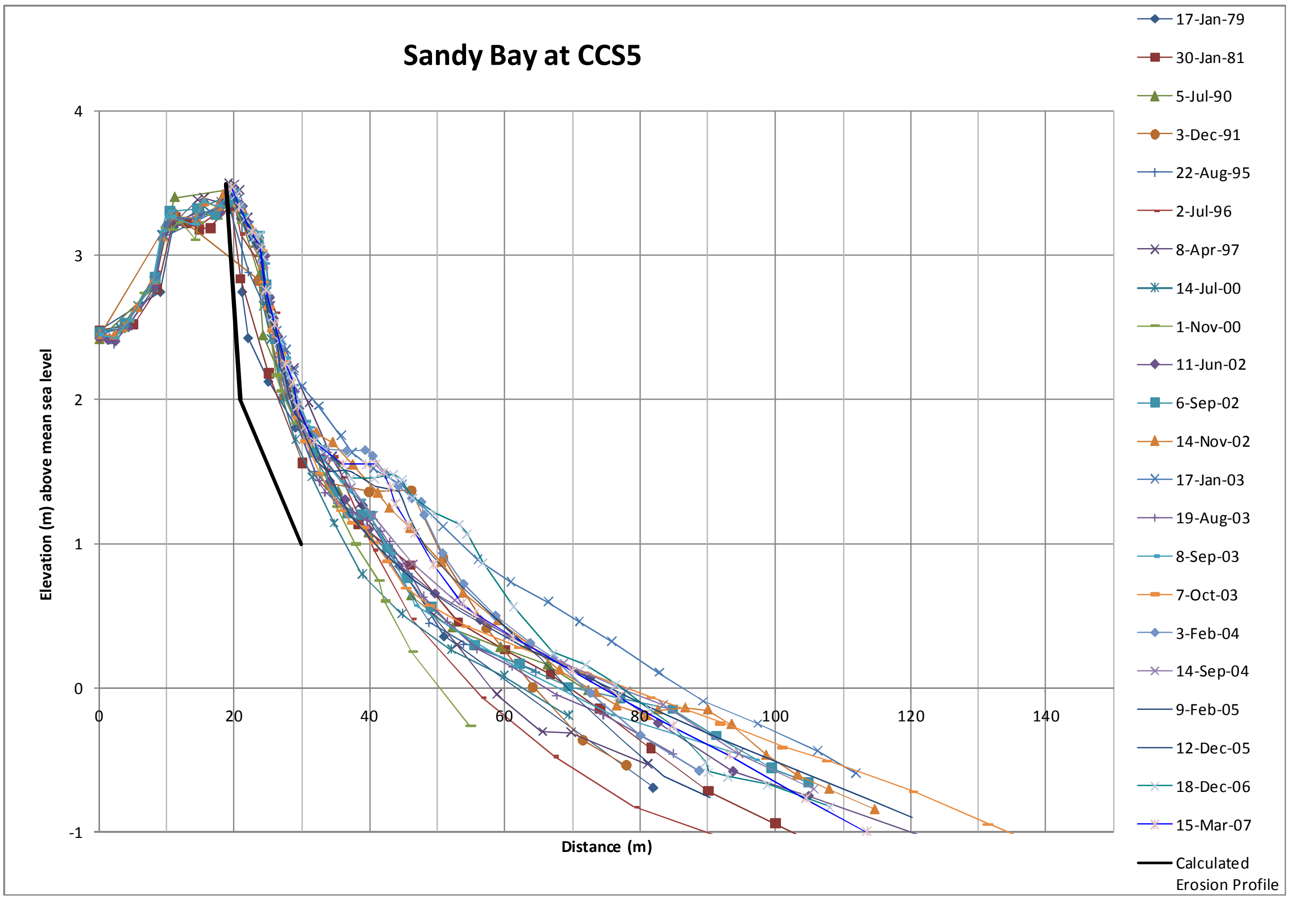

Whangapoua at CCS11
Elevation (m above mean sea level)
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
Distance (m)
16-Jan-79
27-Jan-81
3-Feb-85
15-Feb-88
6-Jun-90
4-Dec-91
28-May-92
16-Mar-95
8-Sep-95
3-Jul-96
7-Dec-96
22-Mar-97
26-Feb-98
21-Aug-98
5-Feb-00
15-Jul-00
3-Jun-01
7-Sep-02
15-Mar-03
6-Sep-03
16-Mar-04
21-Sep-05
Calculated Erosion Profile


Whangapoua at CCS11/1
Elevation (m) above mean sea level
Distance (m)
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
27-Jan-81
15-Feb-88
28-May-92
16-Mar-95
23-Aug-95
8-Sep-95
3-Jul-96
11-Aug-96
7-Dec-96
5-Jan-97
22-Mar-97
26-Feb-98
5-Feb-00
15-Jul-00
28-Oct-00
3-Feb-01
3-Jun-01
7-Sep-02
15-Mar-03
26-Apr-03
6-Sep-03
16-Mar-04
Calculated Erosion Profile


Whangapoua at CCS12
Elevation (m) above mean sea level
Distance
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
16/01/79
27/01/81
15/02/88
4/07/90
4/12/91
28/05/92
16/09/93
25/01/94
16/03/95
8-Sep-95
29/07/96
22/03/97
26-Feb-98
21-Aug-98
15-Jul-00
3-Feb-01
3-Jun-01
7-Sep-02
15-Mar-03
6-Sep-03
16-Mar-04
21-Sep-05
Calculated Erosion Profile


Kennedy Bay at CCS10
Elevation (m) above mean sea level
Distance (m)
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
16-Jan-79
28-Jan-81
5-Jul-90
3-Dec-91
2-Jul-96
14-Jul-00
31-Oct-00
15-Aug-01
10-Jun-02
6-Sep-02
15-Nov-02
17-Jan-03
7-Oct-03
3-Feb-04
14-Sep-04
9-Dec-04
9-Feb-05
14-Mar-05
9-Jun-06
7-Sep-06
15-Mar-07
1-Aug-08
Calculated Erosion Profile

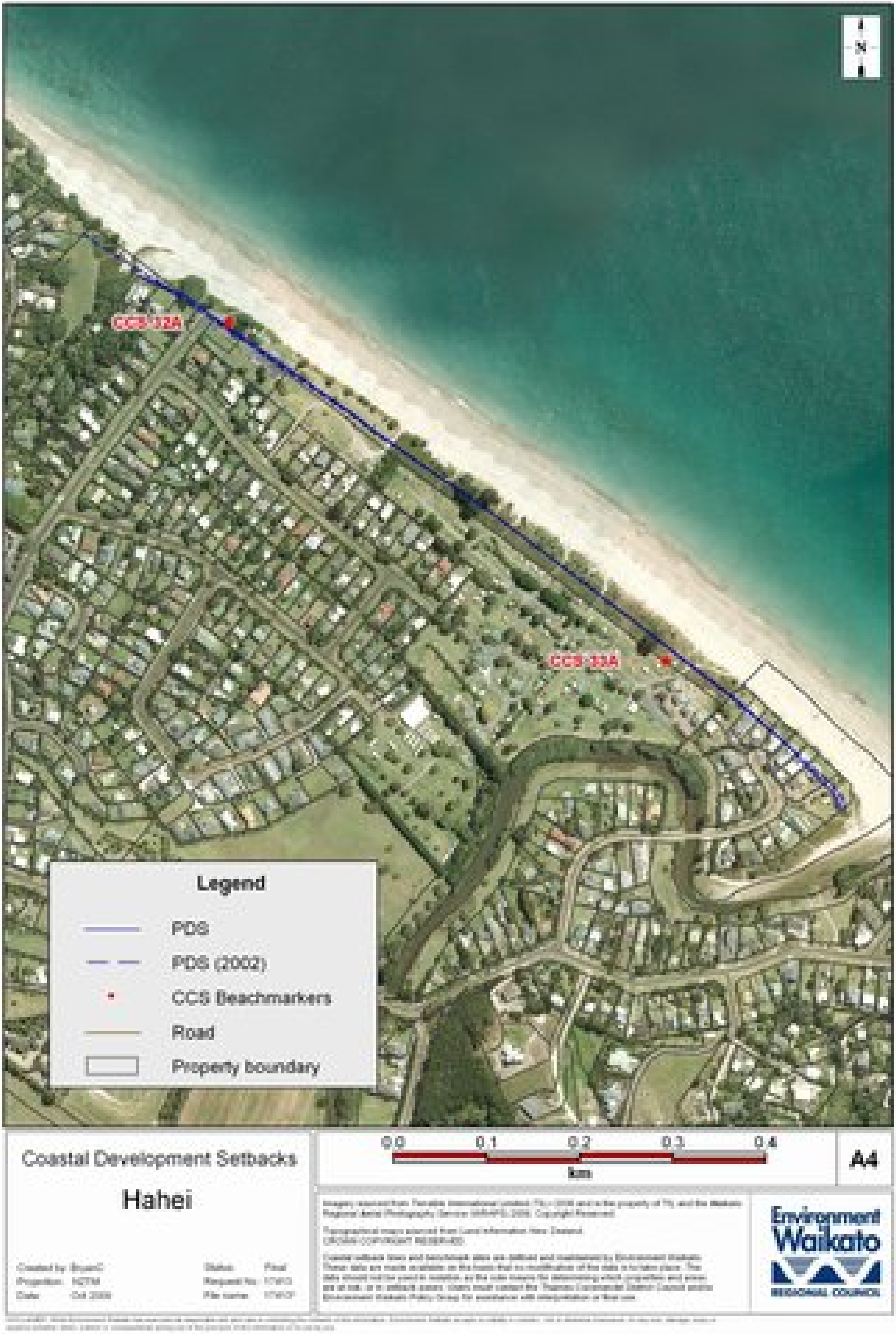

Kennedy Bay at CCS10/1
Elevation (m) above mean sea level
Distance (m)
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
28/01/81
Jul-96
14-Jul-00
31-Oct-00
15-Aug-01
10-Jun-02
15-Nov-02
17-Jan-03
17-Mar-03
13-Jun-03
19-Aug-03
8-Sep-03
5-Dec-03
3-Feb-04
18-Mar-04
9-Dec-04
9-Feb-05
7-Mar-05
12-Dec-05
14-Mar-06
9-Jun-06
7-Sep-06
Calculated Erosion Profile

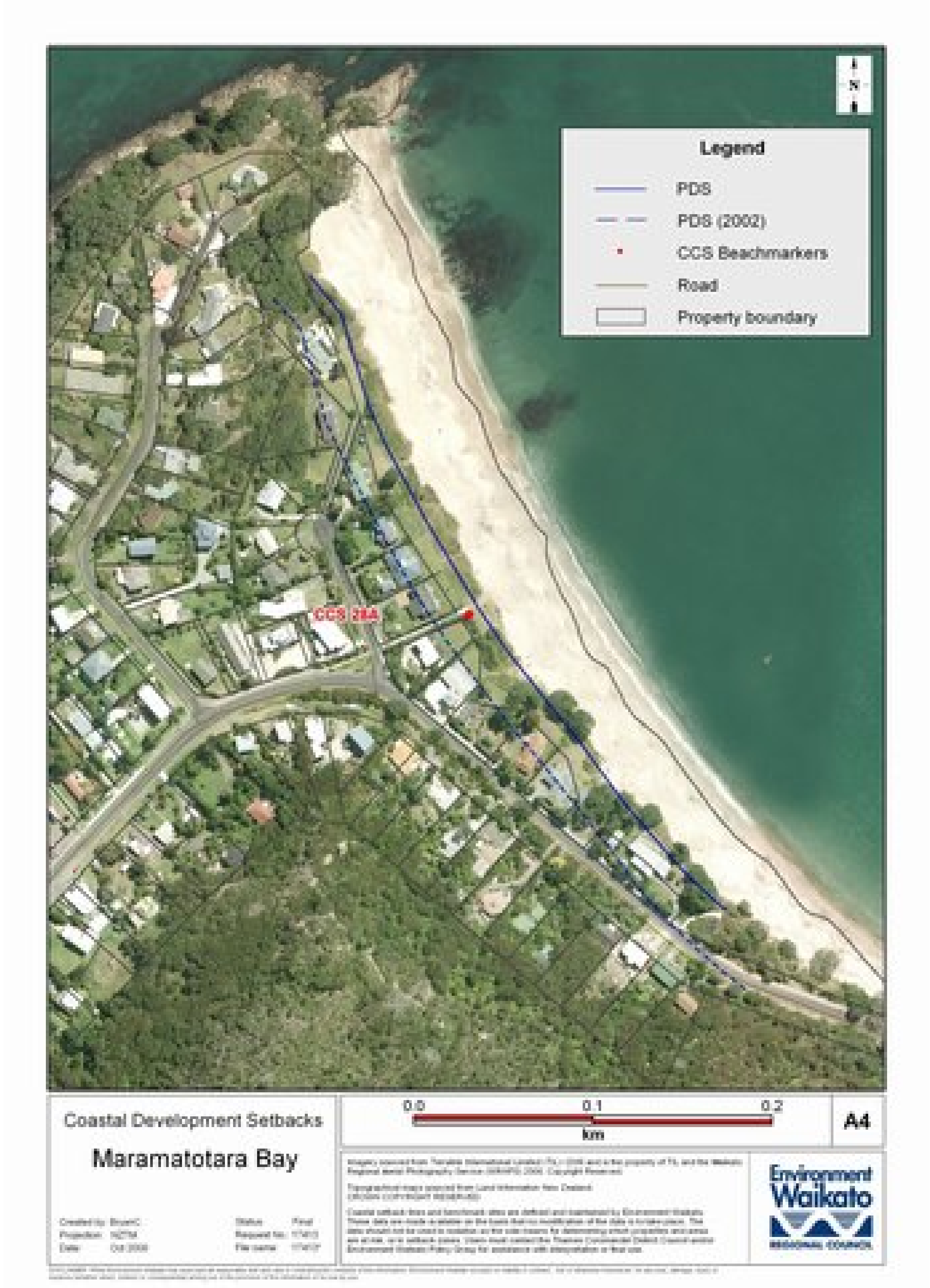

Sandy Bay at CCS5
Elevation (m) above mean sea level
4
3
2
1
0
-1
Distance (m)
0
20
40
60
80
100
120
140
17-Jan-79
30-Jan-81
5-Jul-90
3-Dec-91
22-Aug-95
2-Jul-96
8-Apr-97
14-Jul-00
1-Nov-00
11-Jun-02
6-Sep-02
14-Nov-02
17-Jan-03
19-Aug-03
8-Sep-03
7-Oct-03
3-Feb-04
14-Sep-04
9-Feb-05
12-Dec-05
18-Dec-06
15-Mar-07
Calculated Erosion Profile

Appendix 2: Revised Setback Maps


N
CCS 55/1
CCS 56C
CCS 57A
CCS 57/3
CCS 57/2
CCS 58C
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Whangamata
0.0
0.2
0.4
0.6
0.8
1.0
km
A4
Environment Waikato
REGIONAL COUNCIL

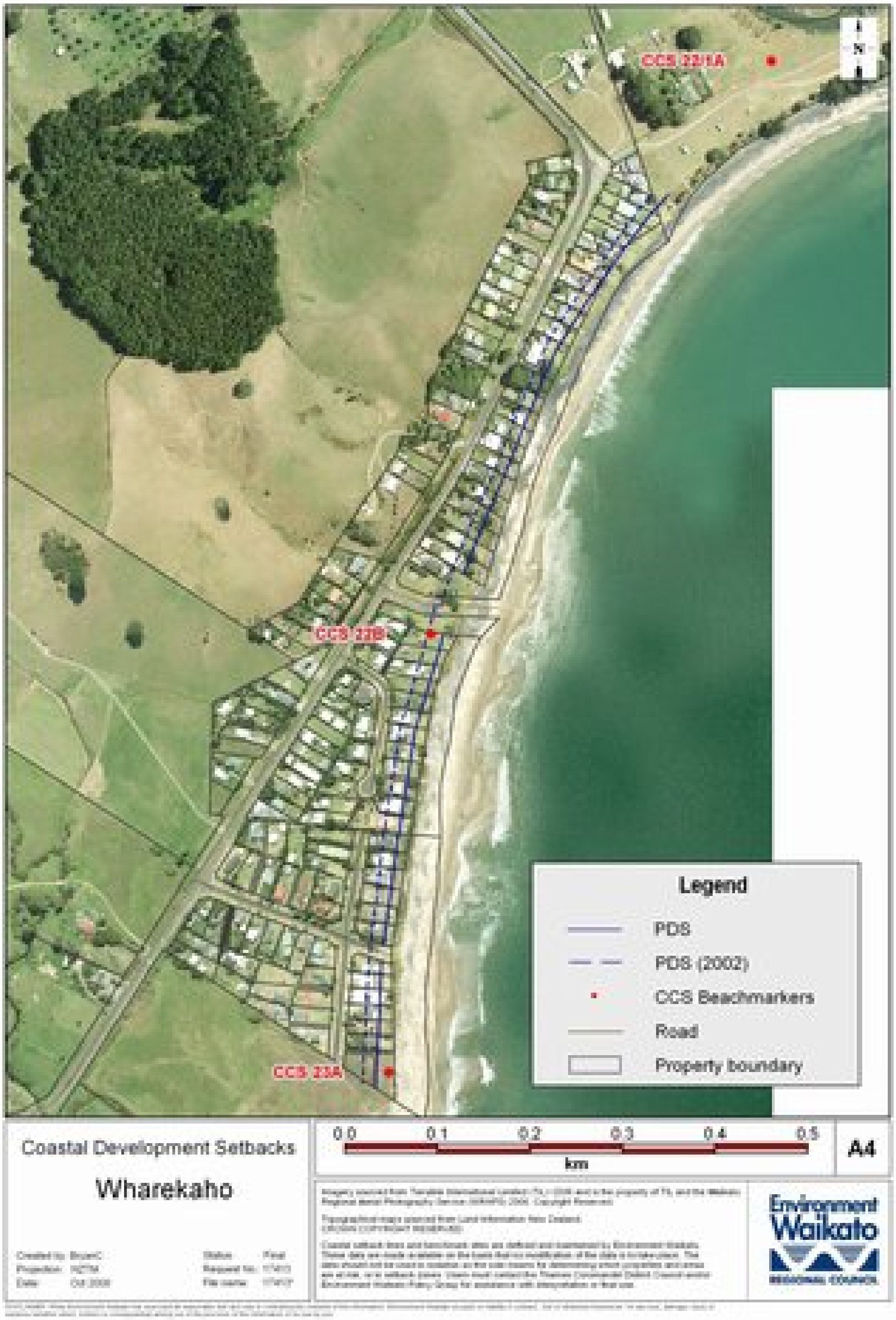

N
CCS 37A
CCS 36-1
CCS 36A
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Tairua
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Environment Waikato
REGIONAL COUNCIL


N
CCS-32A
CCS-33A
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Hahei
Created by: BryanC
Projection: NZTM
Date: Oct 2009
Status: Final
File name:
0.0
0.1
0.2
0.3
0.4
km
A4
Environment Waikato
REGIONAL COUNCIL

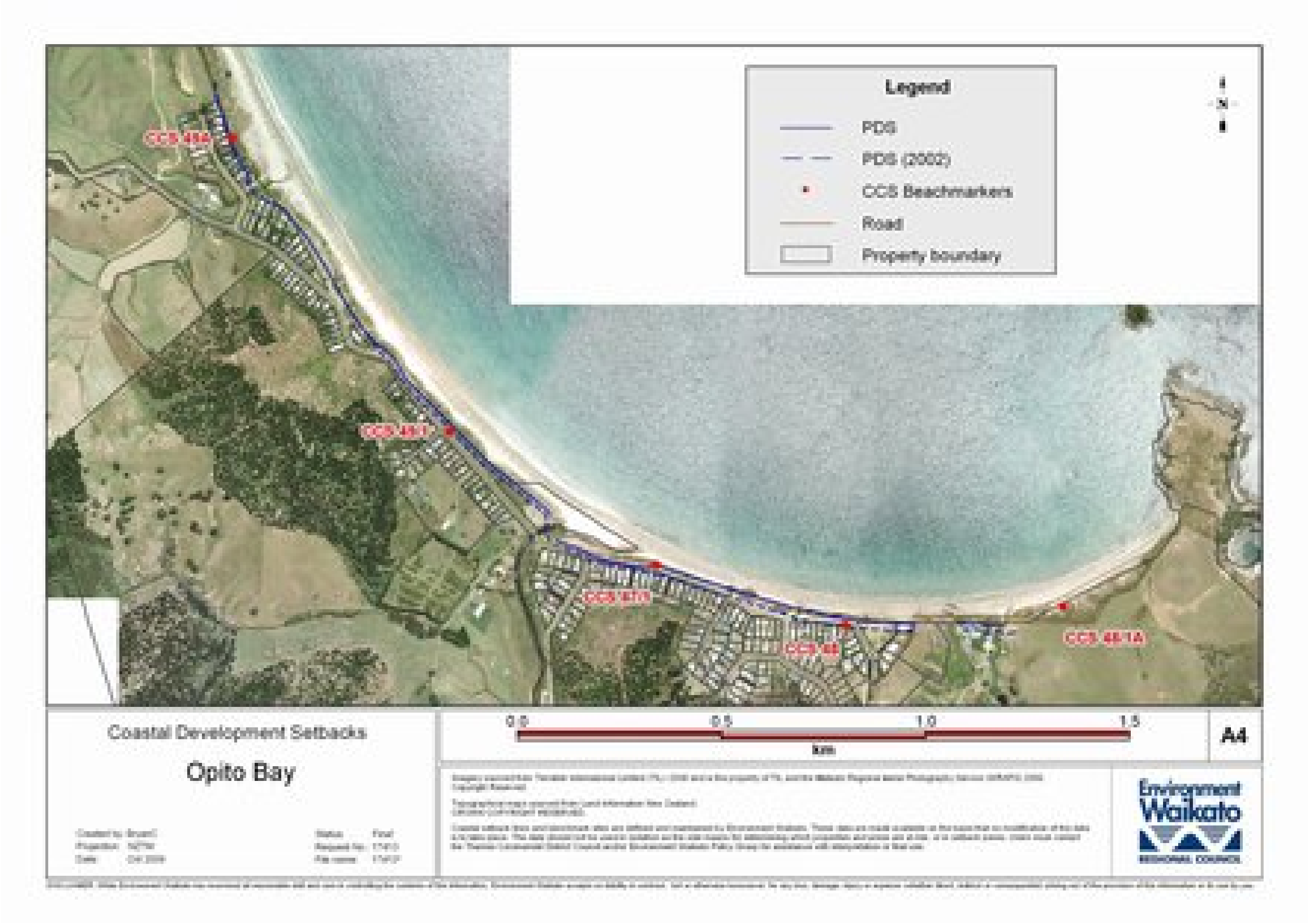

N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
CCS 28A
Coastal Development Setbacks
Maramatotara Bay
0.0
0.1
0.2
km
A4
Environment Waikato
REGIONAL COUNCIL


CCS 28C
CCS 28/1
CCS 28C
CCS 27B
CCS 28
N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Buffalo Beach
0.0
0.2
0.4
0.6
0.8
1.0
km
A4
Environment Waikato
REGIONAL COUNCIL


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
Coastal Development Setbacks
Brophy's Beach
0.0
0.1
0.2
0.3
0.4
km
A4
Environment Waikato
REGIONAL COUNCIL


N
CCS 22/1A
CCS 22B
CCS 23A
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Coastal Development Setbacks
Wharekaho
Environment Waikato
REGIONAL COUNCIL


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
Coastal Development Setbacks
Matapaua Bay
0.0
0.1
0.2
km
A4
Environment Waikato
REGIONAL COUNCIL


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
CCS 48
CCS 48/1A
0.0
0.5
1.0
1.5
km
A4
Coastal Development Setbacks
Opito Bay
Environment Waikato
REGIONAL COUNCIL


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
CCS 21 BM 06A
CCS 20/24
CCS 20C
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Coastal Development Setbacks
Kuaotunu East
Environment Waikato
Regional Council

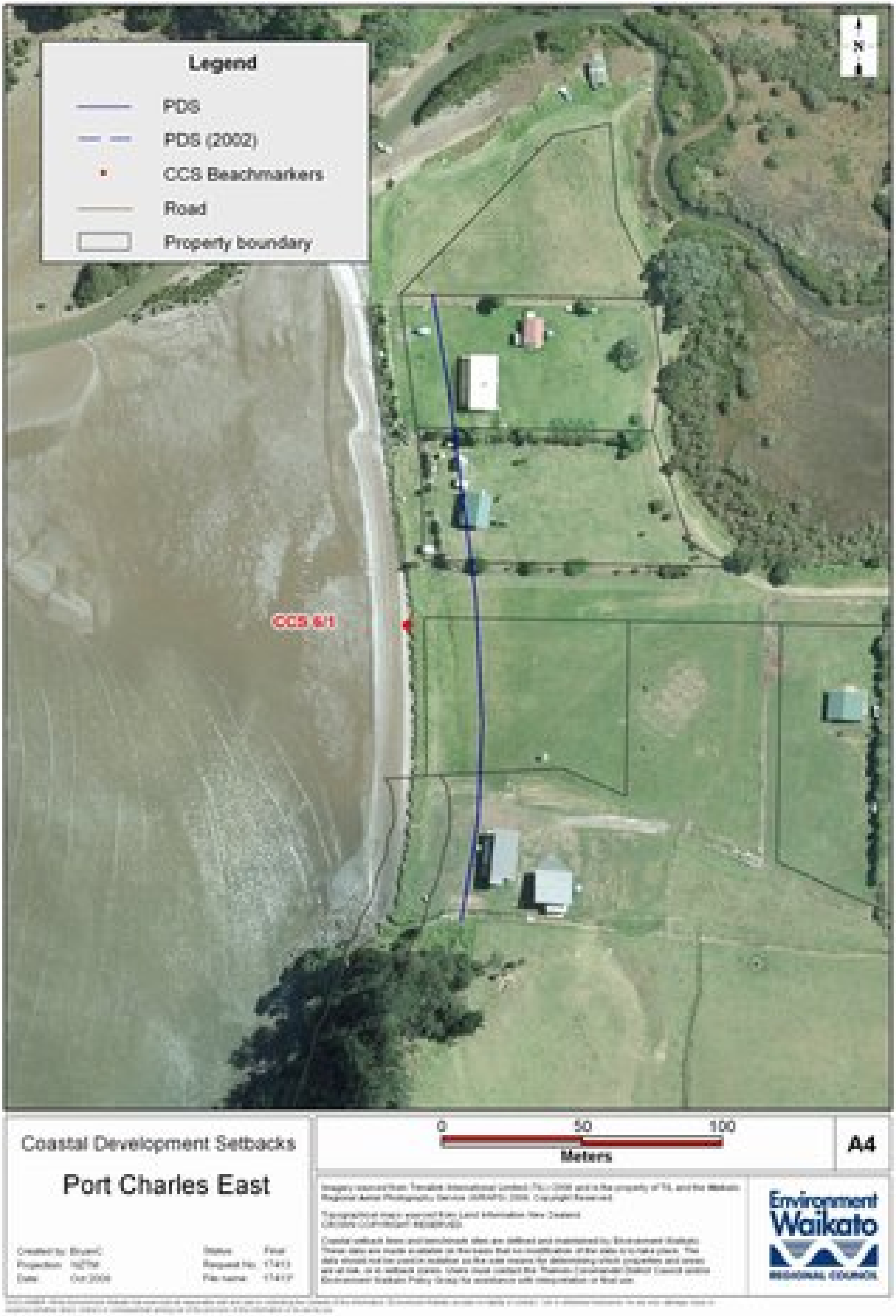

Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
CCS 18
0.0
0.1
0.2
0.3
0.4
km
A4
Coastal Development Setbacks
Rings Beach
Environment Waikato

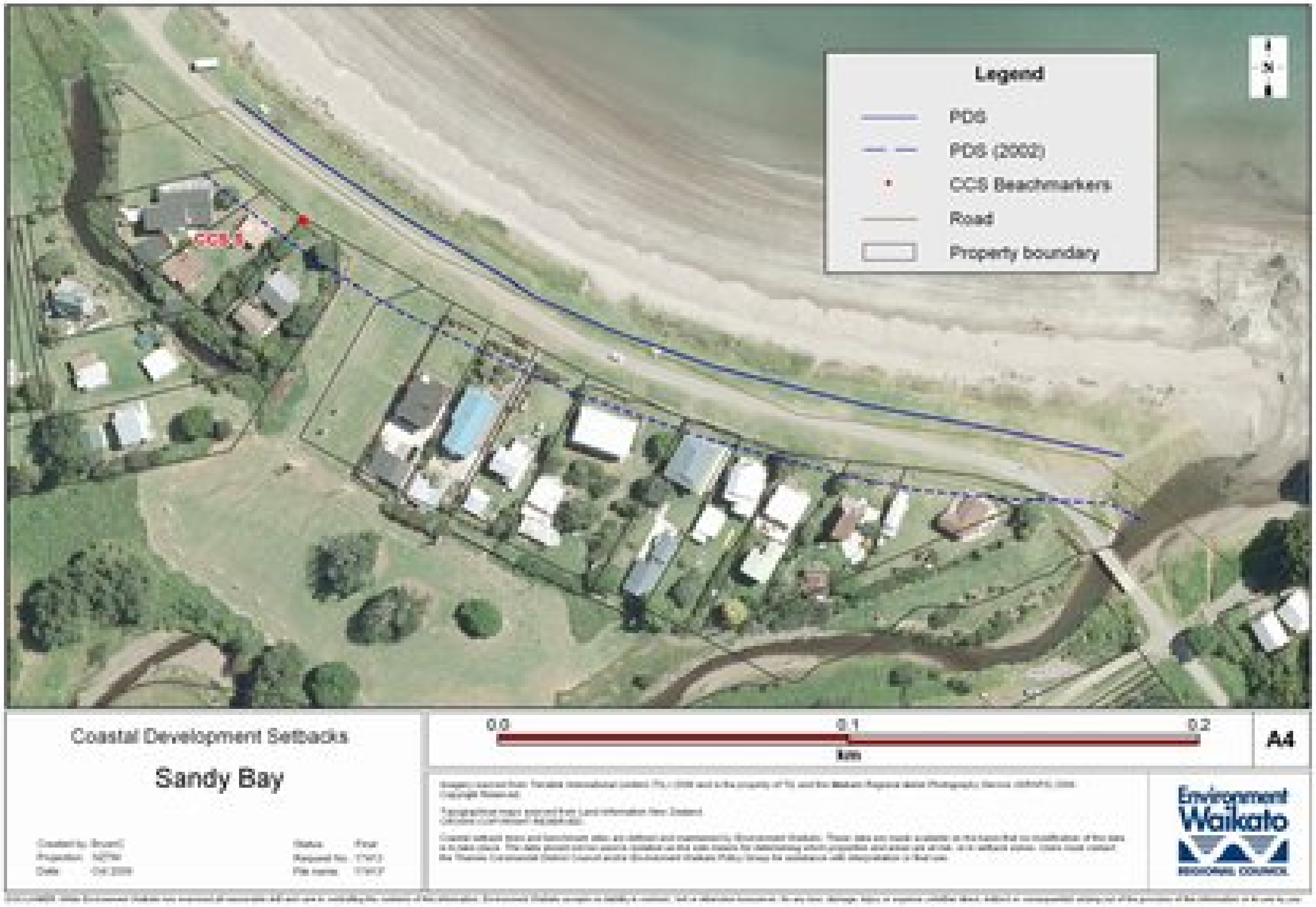

Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Matarangi
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Environment Waikato
Regional Council


N
CCS 12B
CCS 11A
CCS 11/1B
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Whangapoua
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Environment Waikato

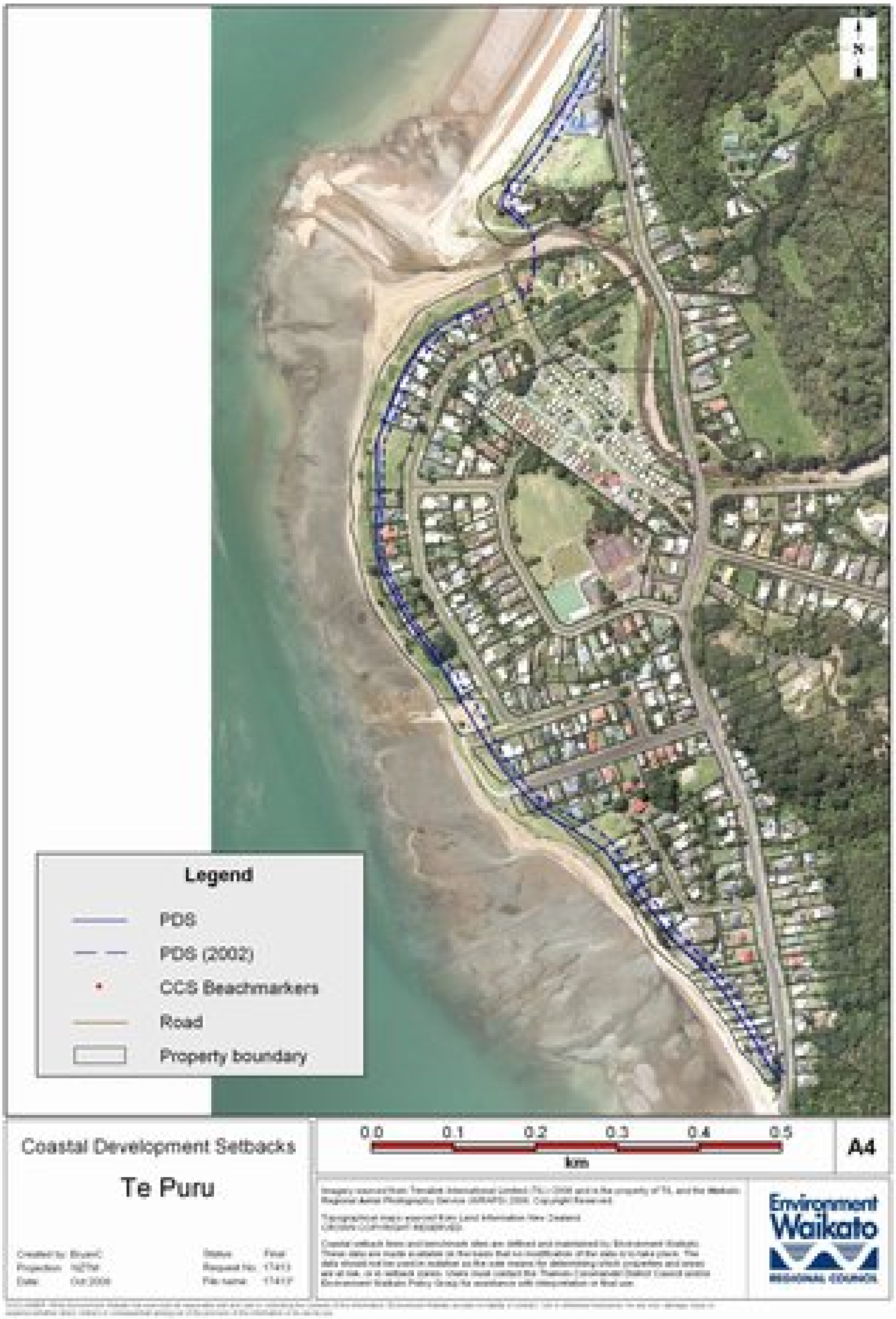

Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
CCS 100
CCS 101
0.0
0.1
0.2
0.3
0.4
km
A4
Coastal Development Setbacks
Kennedy Bay
Environment Waikato
REGIONAL COUNCIL


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
CCS & BM
N
0.0
0.1
0.2
km
A4
Coastal Development Setbacks
Port Charles West
Environment Waikato
Regional Council


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
N
CCS 6/1
0
50
100
Meters
A4
Coastal Development Setbacks
Port Charles East
Environment Waikato
Regional Council


Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
CCS 4
N
0.0
0.1
0.2
km
A4
Coastal Development Setbacks
Sandy Bay
Environment Waikato
REGIONAL COUNCIL


N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Tararu
Created by
Projection
Date
Status
Request No.
File name
0.0
0.1
0.2
0.3
0.4
km
A4
Environment Waikato
REGIONAL COUNCIL


N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Te Puru
0.0
0.1
0.2
0.3
0.4
0.5
km
A4
Created by
Projection
Date
Oct 2009
Status
Final
Request No
File name
Environment Waikato
REGIONAL COUNCIL


N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Waiomu
0.0
0.1
0.2
km
A4
Environment Waikato
REGIONAL COUNCIL


N
Legend
PDS
PDS (2002)
CCS Beachmarkers
Road
Property boundary
Coastal Development Setbacks
Waikawau
0
20
40
60
80
100
120
Metres
A4
Environment Waikato
REGIONAL COUNCIL

Coastal Development Setbacks

Waikawau

Created by: BryanC
Projection: NZTM
Date: Oct 2009

Status: Final
Request No.: 17413
File name: 17413*

0 20 40 60 80 100 120
Metres

A4

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