

# **Kapiti Coast Erosion Hazard Assessment**

# Part 2: Inlets

A report prepared for the Kapiti Coast District Council

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**Disclaimer:** before reading this report you need to be aware that an independent panel of coastal experts has found that the information contained in this report is not appropriate for planning purposes. A further independent planning report has subsequently recommended that the Council withdraw from the Proposed District Plan the coastal hazard management areas associated with this report and undertake further work in regard to the underlying methodologies for use in relation to future planning for the Kāpiti District. The information contained in this report should not therefore be relied upon.

<u>Applicability</u>: this report has been prepared to fulfill the specific terms of reference detailed herewithin and the information may not be relied upon in any other context, applied to any other location, or used for any other purpose without prior review and agreement by Coastal Systems Ltd and consent from the client.

Client Report 2008-03

## **Executive Summary**

While the Kapiti Coast has been subject to open coast erosion assessments in the past, these have essentially been *regional assessments* in that they covered large areas at a relatively low level of detail. Given the extent of residential development along the coast and the potential for future development, together with the dire consequence of property damage and loss associated with erosion plus the uncertainties associated with climate change, the Kapiti Coast District Council (KCDC) commissioned a more detailed (localized) assessment. In particular the erosion hazard line methodology should, be robust and defendable, use industry best practices, use a time-span of at least 50 yrs, and incorporate all available information.

In addition, where the coast is protected by structures or management regimes, an erosion assessment for the simulated *natural coast* was also required. Calculating erosion hazard lines for the corresponding natural coast/inlet enables the effect that management has had on coastal processes and morphological behaviour to be identified and the consequences of not committing to existing management for the next 50 to 100 years to be defined. While it is not anticipated that these structures will cease to be maintained, or that other management practices be discontinued, informed decisions will be able to be made on both the continuance of present structures and practices, and also on their future extension.

For practical reasons the *Kapiti Coast Erosion Hazard Assessment* was divided into three parts with Part 1 covering the open coast (*Open Coast Erosion Hazard Assessment*), Part 2 covering the inlets (*Inlet Erosion Hazard Assessment*) and Part 3 consisting of the data-base, (referred to as the *Coastal Erosion Hazard Data-Base*, or simply as the *Data-Base*), which includes all raw and processed data, along with computation details for the various hazard components used in the assessments.

The present report comprises Part 2 of the **Kapiti Coast Erosion Hazard Assessment** and assesses the erosion hazard in the vicinity of the 12 inlets along the Kapiti Coast, from Waikakariki Stream (Paekakariki) in the south to the Waiorongomai Stream (just south of the KCDC/Horowhenua District Council boundary). Both the open coast and inlet erosion hazard assessments incorporate a range of new data which only recently became available. In particular; high resolution colour vertical aerial photographs of the entire Kapiti Coastline and a district-wide beach profile survey, both of which were carried out in 2007. In addition, the latest (2007) information pertaining to climate change and sea-level rise from the International Panel on Climate Change (IPCC) has been incorporated. The *Kapiti Coast Erosion Hazard Assessment* is thus fully up-to-date.

The erosion assessments use an *empirically-based* approach which quantifies the predicted cross-shore erosion hazard distance by summing several components. In particular the components consist of: the *longer-term historical shoreline change* which is derived by statistical analysis of up to 135 years of historical shoreline data; *shorter –term shoreline fluctuation* which is also defined with respect to the historical shoreline record; *retreat* 



*associated with the anticipated acceleration in sea-level rise from global warming,* this is derived via a shoreline adjustment model which utilizd the beach profile data held by the KCDC; *retreat of dune scarps* (following undercut by storm waves) to a stable slope, which is based on a slope stability model that utilized the KCDC's LIDAR (Light Detecting and Ranging) three-dimensional data, and finally a *combined uncertainty* term which provides an acceptable safety margin. In addition to using the highest quality raw data that was available, the assessment utilized the most recent developments in image processing, data abstraction and statistical analysis, thereby ensuring robust and defendable output.

Inlets are particularly dynamic regions, being subject to the interaction of waves, tide, freshwater flow and wind. As such, a different method was devised to determine the *shorter*-*term* shoreline change component. In addition, other inlet behavioural characteristics also had to be incorporated when locating the erosion hazard line(s).

This inlet erosion hazard report contains a section dedicated to each inlet which describes the geomorphological and management history, derivation of the erosion hazard lines and presentation of the lines superimposed upon 2007 aerial photos. These sections have been prepared so the information will be of general interest to the communities and useful for future researchers as well as to the council in deciding on hazard line locations. Note that higher resolution images depicting the hazard lines are available from the KCDC office and web site.

The historical shoreline analysis found considerable differences in characteristics between inlets to the north and south of the foreland. Inlets to the north affect between 550 m and 1500 m of coast, while inlets along the southern coast are smaller, affecting between 200 m and 800 m of coast.

The erosion hazard analysis for the northern coast found that the hazard lines were, on average, 70 m (33 to 120 m) landward of the present shoreline for managed inlets, compared with 113 m for natural inlets (58 to 271 m). Affected properties for the managed inlets ranged between 0 per inlet up to 26 per inlet and for natural inlets 0 to  $165^+$ .

For the southern coast the inlet hazard lines were, on average, 48 m (10 to 88 m) landward of the present shoreline for managed inlets compared, with 54 m (30 to 71 m) for natural inlets. Affected properties ranged between 0 per inlet up to 12 per inlet with no difference between managed and natural inlets.

Finally it is noted that this erosion assessment has been carried out at the *local level* – this being the most detailed level undertaken by local government. Property owners retain the option of commissioning yet more detailed *site-specific* assessments and these may further refine the hazard lines defined in the present report.



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## **1** INTRODUCTION

### 1.1 Background and terms of reference

In June 2005, Coastal Systems Ltd was commissioned to re-assess the erosion hazard along the *open coast* administered by the KCDC and this was later expanded to include the coastal inlets (Fig 1). *The Kapiti Coast Erosion Hazard Assessment* comprises *Part 1* which covers erosion on the open coast, *Part 2* covers erosion at inlets, and *Part 3* consists of the data-base (*Coastal Erosion Hazard Data-Base* also referred to simply as the *Data-Base*), which includes shoreline data and computation details of hazard components. The present report contains Part 2, the *Inlet Erosion Hazard Assessment*. Both the open coast assessment and the inlet assessment incorporate a range of new data which only recently became available. In particular; high resolution colour vertical aerial photographs of the entire Kapiti coastline (this had not been done before), and a district-wide beach profile survey, both of which were carried out in 2007. In addition, the latest (2007) information pertaining to climate change and sea-level rise from the International Panel on Climate Change (IPCC) has been incorporated. The *Kapiti Coast Erosion Hazard Assessment* is thus fully up-to-date.

The Kapiti Coast has been subject of several erosion assessments in the past; for example the generalized empirically-based assessments of Gibb (1978) and later the process-based, but still generalized, assessment of Lumsden (2003). These were both erosion assessments of the open coast and no assessment of the inlets had been carried out. In addition, the previous assessments were *regional assessments* in that they covered large areas at a relatively low level of detail. However, given the extent of residential development along the coast and the potential for future development, the council required more *local* (detailed) open coast and inlet assessments be carried out. The brief for the present inlet erosion study consisted of the following conditions:

- i) Erosion hazard lines should be derived using a robust and defendable approach and using industry best practices;
- ii) The assessment should apply for at least a 50 yr time span or planning horizon<sup>1</sup>;
- iii) The assessment should incorporate all available relevant archival information;
- iv) Where inlets are managed by either structures or management regimes, an assessment for the simulated natural inlet should also be carried out (see Section 1.5).

<sup>1.</sup> The *planning horizon* refers to the period of time for which the hazard zoning applies. While 50 or 100 yrs are often used by hazard assessors, there is no RMA requirement other than to require plan reviews every 10 yrs. This situation reflects the uncertainty involved in extrapolating rates of change into the future for an arbitrary period. Hazard zones should thus be viewed as indicating the degree and spatial extent of risk during the assigned period rather than providing certainly. While inordinate zone widths could be used to ensure hazard avoidance, such an approach is often not acceptable in developed areas. As a compromise, this hazard assessment uses a conservative approach when deriving the component values and these are then applied over a 50 year *prediction period*. The resulting hazard widths are thus expected to apply for well in excess of 50 yrs.



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It should be noted that while a *local erosion hazard assessment* is applicable to longshore reaches as small as a few hundred metres, this should not be confused with a *site-specific erosion hazard assessment* which contains the greatest level of detail and is usually carried out for individual properties at the owners request and expense.

## 1.2 Background

Inlets are those areas on a coast where rivers and streams meet the sea. These areas are subjected to the interaction of waves, tides and freshwater flows with the effect of wind often also being significant. Inlets tend to occur in low lying areas with unconsolidated sediment and as such are highly dynamic with channels, sandbars and spits able to migrate several meters per month (Gibb, 1998). Catastrophic change may also characterize an inlet with spit or bar breaching occurring at a range of time scales. With several forcing agents being present, inlets are often subject to multiple hazards including erosion from marine and fluvial (river-estuarine) processes and also flooding from the sea which may be exacerbated by the impoundment of elevated river or stream flows

Inlet form and behaviour are the product the energy regime, littoral and fluvial-based sediment budgets and (an often overlooked influence) the orientation of the landward channel as it enters the inlet. Inlet hazard assessments therefore need to focus on the identification and analysis of shoreline and channel histories.

It should be noted that wind-blown sand is often a consequence of inlet bank erosion, and this presents a potential hazard where residential development has occurred. When river or stream channels within an inlet migrate laterally and undermine the bank along the inlet margin, steep *escarpments* form. Such morphology is particularly conducive to erosion as wind blows across the now vegetationless surfaces and funnels through undulations in the natural dune topography. *Blowouts* can easily develop with these features providing a landward pathway for eroded sand. If left unchecked, blowouts develop into larger *parabolic dunes* which will then migrate further inland. Because serious dune erosion takes several months develop, and as there is no finite distance at which sand drifts will cease, no provision has been made for the wind-blown sand hazard in this report, or in the Open Coast Erosion Hazard Assessment, and the KCDC must ensure *Sand Conservation Strategies* are in place in relevant locations to control dune erosion. It is noted that the *safety margins* allowed for in the erosion hazard assessments will ensure properties are not threatened during the intervening period between the onset of wind erosion and subsequent stabilization.

## 1.3 Terminology

The terms used to describe aspects of the inlet environment are illustrated in Fig 2. An inlet is an indentation in the coastal shoreline which reflects the interaction between marine and fluvial processes. The terms *outlet* and *entrance* may also be used to describe such a feature. The inlet includes *inter-tidal sand bars and mud flats*. As with the open coast shoreline, the *inlet shoreline* is defined by the permanent terrestrial (c.f. aquatic) vegetation boundary. The





Figure 2 Schematic diagram and associated notation for morphological features found with inlets typical of those on the Kapiti Coast.

*channel* also forms part of the inlet and as noted earlier, this feature is prone to significant and rapid change in terms of both location and form. The area where the channel meets the sea is termed the *river or stream mouth*, although sometimes this term is more broadly used to refer to the whole inlet. A seaward protrusion of sediment (a *delta*), may occur where the channel meets the sea. The inlet narrows to landward and the location where the width thereafter remains relatively constant, and equal to that of the channel itself, is called the *throat*. The inlet may be symmetrical or, as in the illustration, skewed in the longshore direction. The amount of skew (or *offset*) is related to several interacting factors including the dominant marine energy (wave and current) approach direction, the coastal and fluvial sediment budget, and the upstream channel geometry. For the present exercise, the inlet merges with the open coast where the historical set of shorelines become parallel.

## 1.4 Environmental Setting

The morphology along the Kapiti coast varies considerably. The northern section consists of wider, accreting sandy beaches backed by dunes and isolated settlements. The exception being the mixed sand-gravel beaches and minimal dune development at, and to the south of, the Otaki River. The KCDC central region consists of an accreting cuspate foreland with



wide sandy beaches backed by dunes and concentrated settlement. The southern coast has narrower beaches backed by higher dunes and in its natural state this coast has erosive tendencies. With the exception of Queen Elizabeth II Regional Park and a small area at south Paekakariki, the south coast has been densely settled. While some of the morphological variation is associated with differences in river sediment and in the level of urban development, the dominant control is Kapiti Island. The island affects wave and current regimes and these in turn affect sediment availability and processes of erosion and accretion. Given that these factors also influence inlet form, it is not surprising that the 12 entrances considered in the present assessment display a wide range of shape and behaviour.

Inlet morphology and behaviour are also affected by management structures and practices. Most of the inlets have some form of bank protection and/or training walls to control channel location. In addition, *trigger conditions* defined in the Wellington Regional Coastal Plan (Greater Wellington Regional Council, 2000) allow for *mouth cutting* to realign and shorten the channel when it either closes off, migrates alongshore beyond pre-defined locations, or stream flows exceed a pre-defined elevation.

## 1.5 Approach

In the *Open Coast Erosion Hazard Assessment*, cross-shore coastal erosion hazard distances (CEHD) were derived using the following formula:

$$CEHD = LT + ST + SLR + DS + CU$$
(1)

Where:

LT = longer-term historical shoreline change during the prediction period or the so called planning horizon<sup>1</sup> was derived by statistical regression analysis;

*ST* = *shorter-term shoreline fluctuation* which was also derived by regression analysis;

*SLR* = retreat associated with predicted accelerated *sea-level rise* during the prediction period was derived by a shoreline adjustment model;

 $DS = dune \ stability$  associated with a dune scarp retreating to a stable slope following an episode of dune erosion was derived by a slope stability model, and

**CU** refers to the *combined uncertainty* resulting from *measurement errors and other factors* affecting the safety margin.

The dynamic nature of inlets mean that regression-based modelling would not always adequately define the longer-term trend or shorter-term fluctuation. For this reason, inlet erosion assessments generally focus on the *shoreline envelope* (Kirk et al., 1999). In the



present (inlet) assessment, the landward margin of the shoreline envelope will be used to derive and locate (landwardmost) *inlet migration*. The actual method is described in Section 2.4. Such inlet migration will essentially take the place of the short-term fluctuation component used in the open coast erosion hazard model .

The *inlet erosion hazard line* is then derived by cross-shore adjustment of the *inlet migration line* by a value equal to the sum of the remaining component values, i.e. *long-term shoreline change, retreat from sea-level rise and retreat for dune stability* for the inlet's closest coastal measurement site (sites located in Fig 1), plus the combined uncertainty value for inlets that will be derived later in Section 2.3. The cross-shore *inlet erosion hazard distance (IEHD)* can thus be expressed as:

$$IEHD = IM - (LT + SLR + DS + CU)$$
<sup>(2)</sup>

Where IM = inlet migration, the remaining terms are as defined earlier, and the negative sign refers to adjustment in a landward direction.

A conservative approach was used when deriving the *inlet migration* component by selecting landwardmost shoreline locations and interpolating between them (2.4). In addition, the range of precautionary measures detailed in the *Open Coast Erosion Hazard Assessment* when deriving hazard component values also apply when using Equation 2. An adequate safety margin is thus provided in the present *Inlet Erosion Hazard Assessment*.

Kirk et al. (1999) stress the importance of identifying the historical channel behaviour as well as the shoreline history. This is necessary as the channel behaviour is very much a product of channel orientation at, and immediately upstream of, the throat. So an inlet on a coast undergoing long-term retreat may not undergo a simple landward translation through the hazard area. Both the inlet shorelines and the channel configuration will be derived from cadastral and vertical aerial photos using the same processing techniques detailed in the *Open Coast Erosion Hazard Assessment*.

As noted in 1.4, most inlets on the Kapiti Coast are subject to some form of structural control and/or artificial mouth cutting. For these managed inlets, erosion hazard lines for their corresponding simulated natural inlet have also been produced. By so doing, the effect that management has had on morphological behaviour can be identified and the consequences of not committing to existing management for the next 50 to 100 yrs can be defined. While it is not anticipated that these structures will cease to be maintained or that other inlet management practices be discontinued, informed decisions can now be made on both the continuance of present structures and practices, and also on future expansion of inlet management.

Once the inlet erosion hazard line has been identified, it is merged with the adjacent open coast hazard line in a manner which retains the general shape of the shorelines. Along the



southern Kapiti Coast where seawalls occur (see Fig 1), the natural inlet erosion hazard line is merged with the *seawalls are removed* erosion hazard line (as defined in the Open Coast Erosion Hazard Assessment), while the managed inlet erosion hazard line is merged with the *seawalls are repaired* hazard line.

This report is structured such that data sources, processing and derivation of the inlet hazard lines are described in Section 2. The geomorphology and management histories for each inlet, together with the derivation of their erosion hazard lines, are then described and depicted in Section 3. Note that higher resolution images depicting the hazard lines are available from the KCDC office and web site.

## 1.6 Peer Review

This hazard assessment report was peer reviewed by Dr Mike Shepherd and a copy of his review is included as Appendix A. Dr Shepherd has over 30 years of research and lecturing experience in coastal geomorphology and hazards at Massey University and is very familiar with the Wanganui, Manawatu and Kapiti Coasts.

Dr Shepherd's review was supportive of the methodology, describing the inlet erosion hazard distance model (Equation 2) as providing a novel and robust method to quantitatively derive erosion hazard lines within an inlet, while reducing the extent of 'best professional judgment' which has characterized most inlet hazard assessments in the past. He also considered that the determination of hazard lines for natural and managed inlet shoreline scenarios, and tying them into the open-coast hazard liners, to be a useful innovation that will help council and communities in decision making and future planning. Furthermore, the shoreline data used were adequate to define the components, and the method ensured an adequate level of precaution.

Dr Shepherd made several comments regarding terminology, clarification and inclusion of additional environmental description, and these were subsequently incorporated into the final report.



## 2 METHODS

### 2.1 Introduction

From Section 1.5, it is apparent that the major difference between the erosion hazard models for the open coast (Equation 1) and inlets (Equation 2) is the substitution of a landwardmost *inlet migration* parameter (IM) for the short-term shoreline fluctuation parameter (ST). In addition, the historical channel configurations must be identified as these influence how the inlet would retreat landward under the various hazard scenarios. This section will describe the data sources and data processing, the shoreline abstraction and analysis techniques, the derivation of IM and application of the erosion hazard model to derive the final hazard distances.

## 2.2 Data

The same raw data were used for identifying *inlet migration* as were used for identifying the long and short-term shoreline behaviour on the open coast, i.e. cadastral survey maps and vertical aerial photographs. The cadastral maps covered the period 1872 to 1924 with at least one map being available for each inlet. The maps were obtained from LINZ in electronic format and subsequently geo-rectified, i.e. transformed to a common spatial scale, orientation and standard map co-ordinate system. Positional errors ranged up to 5 m.

The preferred shoreline indicator used in the cadastral surveys was the high water mark. Unfortunately this location is heavily influenced by neap tide-spring tide variation, marine conditions just prior to the time of survey, and also by beach/inlet morphology at the time of the survey; this introduces random errors into the data. In addition, the low gradients within inlets result in the high water mark often being tens of metres from the permanent vegetation line (the preferred shoreline indicator in New Zealand hazard assessment); this introduces an unresolvable systematic error. These uncertainties meant that the cadastral-based shorelines could not be used in the inlet shoreline migration analysis. However, the channel configurations were defined accurately enough to be used for that aspect of the study.

Vertical aerial photographs span the period 1939 to 2007 with sampling occurring at five to 10 yr intervals. Photographs were obtained from the KCDC archive or purchased from aerial surveyors. The more recent photos were supplied as electronic, geo-rectified files, while earlier photos had to be scanned and then geo-rectified.

The detection of vegetation-based shorelines from aerial photographs are usually based on variation in pattern, texture, tone and colour. However, to maximize accuracy, ground inspection of dune morphology and stereoscopic analysis of the aerial photos were also undertaken.

For each inlet, the shorelines were abstracted from the geo-rectified images and then separated into *natural* and *managed* subsets based on when management practices were



likely to have become effective. Shorelines which were *transitional* between the natural and managed regimes were excluded from the analysis.

### 2.3 Measurement errors

The measurement errors for LT, SLR and DS from the *Open Coast Erosion Hazard Assessment* also apply to the *Inlet Erosion Hazard Assessment*, i.e.  $\pm 3.7$  m for LT,  $\pm 1.8$  m for SLR and  $\pm 2.3$  m for DS (see Section 6.2 in the *Open Coast Erosion Hazard Assessment*). Note that only the negative (shoreward) value need be taken into account in an erosion hazard assessment. The ST measurement error of  $\pm 2.6$  m does not substitute for the inlet migration (IM) error for several reasons.

The ST error resulted from the *geo-rectification error* of 3 m combined with the *shoreline detection error* of 3 m (Section 2.5 in the *Open Coast Erosion Hazard Assessment*). Combining independent terms such as these is carried out using the root sum of squares method as represented by Equation 3.

$$CE = \sqrt{(E_1^2 + \dots + En^2)}$$
(3)

where CE = combined error (shoreward directed),  $E_1 = first error term$ , and  $E_n = n^{th} error term$ .

Applying Equation 3 when E1 = E2 = 3, gives a combined error value of 4.2. However, because of the regression procedure used when deriving ST (see Section 3.5 in the *Open Coast Erosion Hazard Assessment*), the value of 4.2 m reduces to 2.6 m. By contrast, the IM error equals the same *geo-rectification error* as for the open coast (3 m), combined (using Equation 3) with the *shoreline detection error* which in this situation is 2 m c.f. 3 m for the open coast. The lower value for inlets is because the less accurate NWASCO data were not used. The combined value of these independent terms is 3.6 m using Equation 3. This value was not subsequently reduced as regression procedures were not used when deriving IM.

The combined error (CE) in the landward direction for all inlet hazard components equals 5.9 m (using Equation 3), so a representative value of 6 m was selected for subsequent use in the inlet erosion hazard model (Equation 2). Note that this compares with 5.4 m in the *Open Coast Erosion Hazard Assessment* (Section 6.2); however, that value was also rounded up to 6 m.





Figure 3 Illustrated derivation of the inlet erosion hazard line and its relationship with the open coast erosion hazard line

## 2.4 Derivation of erosion hazard distances

For each inlet, the following procedures (illustrated in Fig 3) were used to locate the erosion hazard line:

- The *landwardmost composite shoreline*, or more simply stated, the *shoreline limit*, was identified. Note that this line runs along the landward side of the *envelope* for natural or managed inlet shorelines;
- The *maximum landward migration shoreline*, or more simply stated, the *inlet migration curve*, was then defined by interpolating between the (local) landwardmost points on the *shoreline limit* line such that the shape of the fitted curve was consistent with the general shape of the set of inlet shorelines. Note that this is the inlet migration (IM) term in Equation 2;



- The *erosion hazard line* was next located landward of the *inlet migration curve* by a distance equal to the sum of the hazard component values for LT, SLR and DS from the adjacent open coast site, plus CU for inlets (see Section 2.5 below);
- Finally, the resulting erosion hazard line was merged with the open coast erosion hazard line and with the channel landward of the inlet throat. Adjustments were also required to merge with permanent control structures, e.g. bridge abutments. In addition, adjustments were made to incorporate a change in inlet offset that may occur as the inlet recedes and the inlet configuration will subsequently change (as noted earlier in Sections 1.2 and 1.5).

## 2.5 Uncertainties

In Section 1.5, the *combined uncertainty (CU)* referred to the combination of *measurement errors and other factors affecting the safety margin*. The *measurement error* is a random error defined by the larger differences in repeated measurements for a particular variable and thus affords a high level of confidence that such an error will be accounted for in the hazard model. The measurement errors and their combination were considered earlier in Section 2.3.

A range of precautionary measures, i.e. the *other factors*, were also mentioned in Section 1.5 and these are detailed in the *Open Coast Erosion Hazard Assessment*. In addition, the method of deriving the *inlet migration curve* by selecting landwardmost shoreline locations and interpolating between them (Section 2.4), further increases the safety factor. However, as these *other factors* are qualitative, CU equals CE = 6 m.



## **3 INLET ASSESSMENTS**

## 3.1 Introduction

This section contains the geomorphological and management histories for each inlet, together with the derivation of erosion hazard lines. It is noted that these inlet histories are by no means exhaustive, being based upon information derived from cadastral survey maps and aerial photos, together with additional information supplied by local government authorities, from readily available literature, and from field inspections. Nonetheless, they provide an adequate basis upon which to carry out the inlet erosion hazard assessment.

The inlets are considered sequentially beginning with Waitohu at northern end of Otaki Beach and moving southward to the Waikakariki Inlet at south Paekakariki. The rural-based Waiorongomai Inlet near the KCDC northern boundary appears last, being included as a late addition.



## 3.2 Waitohu Inlet

#### 3.2.1 Background

The historical shoreline record for the Waitohu inlet is presented in Fig 4 and shows that this inlet affects about 1500 m of coast with the throat being about 300 m behind the adjacent open coast shoreline. The earlier records indicate the channel had a more direct path to the sea, with the southern shoreline undergoing systematic seaward and northward migration since the 1940s. The seaward trend is associated with the general coastal progradation of approximately 0.55 m/yr on the adjacent southern coast and about 0.7 m/yr on the northern coast. Lateral (alongshore) changes in channel location are related to littoral sediment variation with influxes being indicated from the aerial record during the early 1940s, the 1960s and the 1990s. In addition, management practices since the 1960s also affect the channel location.

A range of management structures and practices are used to control such erosion and flooding, and these are summarized below and illustrated in Fig 5. When streams along the northern Kapiti Coast run close to the inlet shorelines, bank erosion results in loss of pasture, initiates dune erosion, or threatens buildings and private property. In addition, stream flow can *back up* and exacerbate flooding.

Management in the vicinity of the Waitohu inlet was first noted in official reports in 1967 (Wallace, 2006). In particular, a more direct channel to the sea was excavated through intertidal sand bars (*stream-mouth cutting*), and rock was used to protect sections of stream bank and train the channel to flow northward as it enters the inlet. The 1948 Otaki River Scheme (Brougham, 1978) proposed cutting the mouth in line with what is now Konini Street, a location and alignment very similar to the 'older mouth' shown in Adkin (1948), these mouth locations are marked in Fig 5. However, the actual cuts were never as severe as proposed in the scheme.

The final stage in formalizing inlet management for erosion and flood control came during the 1990s when *trigger conditions* were defined in the Wellington Regional Coastal Plan. In particular, stream mouth cutting is a permitted activity *when the channel outlet within the coastal marine area migrates either north or south of the area defined by projected lines 250 m north and 1000 m north of Konini Street* (see Fig 5), *or the channel outlet creates a vertical scarp in the sand dunes which exceeds 2 m in height, or the water level increases 500 mm or more above normal river levels adjacent to Mahoe Street*".

Restricting channel migration allows *back-beach* areas to grow and sand dunes to subsequently develop. Particularly notable is the 5 ha of dunes that have formed to the north of Konini Street since the 1940s. Such dune development provides for recreational opportunities and minimizes the likelihood of shoreline erosion being able to affect property. However, these dunes will continue to grow and may present a future hazard in terms of wind-blown sand should sections of their vegetation cover be lost. There are a range of



natural means by which vegetation damage can occur including stream and/or wave cut of the dune toe, and wind desiccation. The latter effect is particularly relevant to the landward relict foredunes which are higher and deprived of fresh sand (and nutrients) making them more fragile. In addition, some human activities are particularly effective at damaging vegetation and encouraging wind funneling.

### 3.2.2 Erosion hazard

The natural inlet shorelines comprise the 1942 to 1966 samples, together with later shorelines on the northern side of the inlet which were not affected by management practices. The managed inlet shorelines comprise the 1973 to 2007 samples.

The inlet's landwardmost *composite shoreline* is shown in Fig 5, together with the inlet's erosion hazard lines. It will be recalled from Section 2.4 that the composite shoreline is the landwardmost side of the shoreline envelope and is used to construct the inlet migration curve. The migration curve has not been shown in Fig 5 for reasons of simplification and clarity, given that its location is inferred from the depicted composite and hazard shorelines, and both natural and managed inlet scenarios also need to be depicted.

The remaining hazard component values used to locate the erosion hazard line are the LT, SLR and DS values for the nearest open coastal measurement sites, these being C33.82 to the south and C35.54 to the north, together with the combined uncertainty (CU) value for inlets. The sum or these component values for C33.82 is 25.3 m (LT = 0, SLR = 16.7 m, DS = 2.6 m from Appendix B) and CU for inlets = 6 m (sections 2.3 and 2.5), while the sum for site C35.54 is 26 m (LT = 0, SLR = 16.7 m and DS = 3.3 m). The derived inlet hazard lines were then merged with the adjacent open coast erosion hazard lines.

On the southern side of the inlet, the erosion hazard line for the natural (unmanaged) entrance is, on average, 68 m landward of the present shoreline and affects the 4 properties on the seaward side of Marine Parade. By contrast, the hazard line for the natural inlet lies, on average, 147 m landward of the present shoreline and affects over 30 private properties. As noted earlier, should significant dune erosion occur, wind-blown sand will create a hazard in terms of nuisance and burial from sand drifts. No allowance for such a hazard has been made in this assessment and a sand conservation strategy should be in place for this area.

On the northern side of the inlet, the natural and managed erosion hazard lines have both similar shape and location with the managed inlet hazard line being 93 m landward of the present shoreline and the natural inlet hazard line being 100 m landward. Both hazard lines lie landward of the only dwelling on the northern side of the inlet.





Disclaimer: an independent panel of coastal experts has found that the information contained in this report is not appropriate for planning purposes.

COASTAL SYSTEMS

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## 3.3 Otaki Inlet

#### 3.3.1 Background

The Otaki River is the largest on the Kapiti Coast with a catchment area of  $\sim 400 \text{ km}^2$  and mean annual flow of  $\sim 950 \text{ m}^3$ . It also contrasts with the other rivers and streams in that it is a gravel dominated braided system. In its natural state the channels migrated laterally between river banks which were separated by about 900 m (Fig 6), and the rivermouth affected at least 1400 m of coast. Inlet dynamics were also affected by the adjacent Rangiuru Stream mouth (Fig 6).

Between 1886 and 1930 extensive forest clearance within the catchment lead to significant hill county erosion and channel aggradation, particularly during the severe storms of the 1930s. This situation possibly contributed to the long-term shoreline progradation in this area which is about 0.4 m/yr on the northern side of the rivermouth and about 0.55 m/yr on the southern side. The official response in 1946 from local and central government was the Otaki Scheme, a project which consisted of stopbanking, drainage, erosion control and channel alignment works.

The stopbank development sequence is shown in Fig 7. The historical aerial photo record shows that the northern entrance stopbank was completed about 1949 and its location and extent remained unchanged thereafter. This stopbank intercepted the Rangiuru Stream which passes through floodgates to enter the Otaki River. By contrast, the extent and alignment of the southern stopbank was completed much later.

Initial work on the southern stopbank finished ~600 m upstream from the present terminus and was located on the northern side of the present structure. It appears that this wall was outflanked, and the 1966 photo shows it located further south along its present alignment, but still over 600 m short of the present terminus. Channel morphological signatures show that further outflanking occurred, and the stopbank was then extended to its present length with the 1978 aerial photo showing that it had been completed by that time. The orientation of the stopbanks over the seaward 1500 m changed the river's coastal offset from being slightly to the north to being slightly to the south.

A range of river management techniques are used to protect existing river control structures and mitigate the flood hazard. Of particular importance for minimizing erosion of the inlet shorelines are *river training methods* which maintain the channel within *its preferred alignment*, and *mouth cuts* when the trigger criteria defined in the Wellington Regional Coastal Plan are exceeded. In particular, *when the channel outlet in the coastal marine area is either 300 m south or 300 m north of the centre line of the river as measured 700 m upstream. In addition, the entrance is opened when the mouth is closed off, or the Rangiuru flood gates are unable to be effectively operated due to high water levels.* The trigger projection lines are shown in Fig 7.



A wetland has established in the original (pre-scheme) northern rivermouth area. This has occurred firstly because the area was sheltered from higher energy river and marine processes following the diversion of the Rangiuru Stream laterally into the Otati River. Secondly, the river mouth appears to have taken on a more southward exit following stopbank construction. Indeed, the left bank is now 200 m further to the south in spite of mouth cutting. The southward trend is to be expected given the change in channel offset noted earlier. In addition, southerly directed littoral drift and channel configuration within the lower river may also contribute to this behaviour; however, a more detailed assessment is beyond the scope of this report.

#### 3.3.2 Erosion hazard

The natural shorelines used for analysis are those obtained from the 1939 and 1946 aerial photos plus earlier shorelines evident by geomorphic signatures. The managed shorelines were obtained from the 1957 to 2007 aerial photos and only those seaward of the stopbank were analysed.

The landwardmost *composite shorelines* are shown in Fig 7, along with the *inlet hazard lines*. The southern *inlet migration curve* (defined by the maximum landward indentations on the composite shoreline) was then adjusted by 11.7 m to define the natural and managed inlet hazard lines, this being the sum of components LT = 0, SLR = 4.8 m and DS = 0.9 m from Coastal Measurement Site C30.16 (Appendix B in the Open Coast Erosion Hazard Assessment), plus the inlet combined uncertainty value of 6 m. For the northern side, the inlet migration curve was adjusted landward by 18.5 m to derive the hazard lines, this being the sum of LT = 0, SLR = 11.1 m and DS = 1.4 from Coastal Measurement Site C32.54, plus CU = 6 m. The derived hazard lines were then merged with the open coast erosion hazard lines. Note that the southern managed inlet hazard line has been weighted to the most recent shoreline adjacent to the terminus of the southern stopbank, rather than using a more general shoreline fit which would have placed the line further seaward. This approach reflects the underlying tendency for that shoreline to migrate southward.

On the southern side of the inlet, the erosion hazard line for the natural entrance lies seaward of the managed inlet hazard line; this is the only inlet on the Kapiti Coast where this occurs and results from the stopbank alignment and the (associated) southern migration tendency of the channel (Fig 7). The natural hazard line is about 150 m seaward of the terminus of the southern stopbank and extends about 100 m further northward, i.e. into the river. On average, the natural inlet hazard line is about 50 m inland from the present shoreline. By contrast, the managed river hazard line extends from the end of the stopbank, and on average, is about 120 m inland from the present shoreline. Two dwellings are affected by the hazard areas.

On the northern side of the entrance, the hazard line for the unmanaged river lies on the inland side of the stopbank for all but the final 100 m, and four dwellings are affected (Fig 7). In addition, a further 40 dwellings along Marine Parade lie within the hazard area. The managed river hazard line extends from the point where the stopbank becomes aligned with



the river, this being over 400 m inland from the present shoreline. The hazard line then curves to the north and follows the general shape of the shorelines to merge with the open coast erosion hazard line at Coastal Measurement Site C32.54. No private property lies within the hazard area of the managed inlet.





Figure 6 Historical shorelines lines for the Otaki inlet superimposed upon the first vertical aerial photo (1939). The 19th century shorelines are derived from survey cadastral plans and relate to the high water mark and the spring high water mark for 1879 and 1897 surveys respectively, while the remaining shorelines are derived from aerial photos and relate to the permanent vegetation front. The contemporary roading and stopbanks have been overlayed to assist interpretation.



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Figure 7 Erosion hazard lines for the natural and managed Otaki inlet superimposed upon the 2007 aerial photo. The shoreline envelopes are also shown for the full set of shorelines depicted in Fig 6, together with the landwardmost composite shorelines used to define inlet migration. Inlet migration was then combined with the other hazard components for coastal measurement sites C30.16 in the south and C32.54 in the north to derive the erosion hazard lines. Also depicted are river stopbanks and their development stages, together with trigger lines for mouth cutting.



## 3.4 Mangaone Inlet

#### 3.4.1 Background

The historical shoreline record for the Mangaone Inlet (Fig 8) shows that its influence extends almost 300 m to the north and about 400 m to the south. Rapid accretion on the northern coast is evident during the earlier part of the record with the shoreline now being relatively stable. Note that for the adjacent open coast the long-term rate of shoreline progradation each side of the inlet is ~0.4 m/yr. Larger indentations occur on the southern side of the inlet, for example see \* in Fig 9. Geomorphic evidence shows that the Mangaone embayment was considerably larger some one to two thousand years ago. The historical record shows that while the Mangaone inlet may have originally had a sight northerly offset, since the 1940s it has had a slight southerly offset. This southern offset would help explain inlets asymmetric (southern offset) morphology.

The Te Horo coast is regionally significant with its mixed sand and gravel sediment and steep inter-tidal beach. A wide berm backs the beach and merges into a series of shore-parallel sand dunes. These dune belts formed in association with major longshore influxes of sand which occurred several times during the last 6000 yrs and changed steep gravelly beaches to wide sandy ones. The present gravel-dominated sediment regime, together with the more stable morphology, makes significant channel fluctuations and erosion embayment development, i.e. large shoreline indentations, less likely to occur in the future.

Any early inlet management history is unknown to the writer, so while the change in offset from north to south may be associated with channel realignment, it may also be the result of the significant sediment input from terrestrial sources as noted earlier in section 3.3. More recently, erosion and flood prevention management has been carried out when formal trigger conditions defined in the Wellington Regional Coastal Plan are exceeded. In particular, *stream mouth cutting is carried out when the channel outlet within the coastal marine area migrates either 100 m south or 300 m north of Te Horo Beach Road* (see Fig 9), or when *the water level increases 300 mm or more above its normal level at Sims Road*.

#### 3.4.2 Erosion hazard

Given the apparent lack of significant management practices in the past and the more recent trend toward shoreline stability, it was not considered necessary to carry out a separate hazard assessment for a managed inlet scenario. It was, however, considered necessary to modify the method of defining the *inlet migration curve* as the early samples greatly influenced the form of the *composite shoreline* (Fig 9), and significant indentations occurred during this period which are not evident in later samples. Because such erosion embayment formation would have been facilitated by the relatively low berm that occurred during the accretionary phase associated with early land settlement, a repeat of such behaviour is considered to be most unlikely. It would therefore be unreasonable to allow these erosion embayments to control the *inlet migration curve* location as would otherwise be the case.



The dominant undulations were therefore *averaged out* to subdue their effect, and this produced a *modified inlet migration curve* as inferred in Fig 9 by the final *hazard line* being particularly close to, or even seaward of, the *composite shoreline* in embayed areas.

The inlet migration defined by this *smoothing* process was adjusted landward by the remaining hazard component values for Coastal Measurement Site C26.58 in the south and site 27.63 in the north to produce the *modified erosion hazard lines* depicted in Fig 9. In particular an adjustment of 19 m was made on the south side of the inlet (LT = 0, SLR = 12.5 m, DS = 0.5 m and CU = 6 m). On the northern side the adjustment was for Coastal Measurement Site C27.63 was 15.6 m (LT = 0, SLR = 8.8 m, DS = 0.8 m and CU = 6 m). The hazard lines were then merged with the adjacent open coastal erosion hazard lines.

On the southern side of the inlet, the erosion hazard line is, on average, 72.5 m landward of the present shoreline and affects several dwellings closer to the stream. On the northern side the hazard line is, on average, 62 m behind the present shoreline and no properties are affected.





Figure 8 Historical shorelines lines for the Mangaone inlet superimposed upon the first vertical aerial photo (1948). The 19th century shorelines are derived from survey cadastral plans and relate to the high water mark, while the remaining shorelines are derived from aerial photos and relate to the permanent vegetation front. The contemporary roading has been overlayed to assist interpretation.



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Figure 9 *Modified* erosion hazard lines for the natural Mangaone inlet superimposed upon the 2007 aerial photo. The shoreline envelopes are also shown for the shorelines depicted in Fig 8, together with the land-wardmost composite shoreline used to define inlet migration. Because this inlet has only been subject to minimal management, there is no managed hazard scenario. However, the migration line (and hence the subsequently derived hazard line) has been modified to account for this particular inlet's characteristics (see text). Inlet migration was then combined with other hazard components for coastal measurement sites C26.58 in the south and C27.63 in the north to derive the erosion hazard line. Also depicted are trigger lines for mouth cutting and the asterisk locates the large embayment discussed in text.



## 3.4 Hadfield Inlet

#### 3.5.1 Background

The historical shoreline record (Fig 10) shows that the Hadfield Inlet has maintained a strong southerly offset during most of the past century, and that this inlet affects the coastal shoreline for about 300 m to the north and 500 m to the south. The open coast shoreline beyond the inlet is undergoing long-term progradation at rates of about 0.44 to 0.5 m/yr.

Substantial morphological change occurred between 1948 and 1966 when the channel migrated about 140 m to the south and the northern shoreline prograded up to 70 m. This behaviour coincided with the large sediment influx that affected much of the northern coast during the 1940s. While the inlet throat has remained relatively stable since the 1966 photo, cross-shore fluctuations of 30 to 50 m have characterized both the northern and southern shorelines.

The aerial photo record for the Hadfield shows no evidence of inlet management in terms of channel diversion, bank protection or guide walls, and this makes it the most natural sand-dominated inlet on the Kapiti Coast. However, precautionary mouth cuts are now performed *when the channel outlet within the coastal marine area migrates either south or north to an extent that it undermines sand dunes and creates a vertical scarp of at least 1.5 m* (Wellington Regional Coastal Plan).

#### 3.5.2 Erosion hazard

Given the lack of inlet management, the hazard assessment was based on the full set of shorelines, i.e. no *managed scenario* was considered.

The landwardmost composite shoreline and the inlet hazard lines are shown in Fig 11. The inlet migration defined by the southern composite shoreline was adjusted landward by 28.1 m to define the hazard line, this being the sum of components LT = 0, SLR = 18.8 m and DS = 3.3 m from Coastal Site 22.06 (Appendix B in the Open Coast Erosion Hazard Assessment), plus CU (for inlets) of 6 m. On the northern side of the inlet, the inlet migration was adjusted landward by 25.6 m to derive the hazard line; this being the sum of LT = 0, SLR = 17.7 m and DS = 1.9 from Coastal Site 23.50, plus CU = 6 m. The hazard lines were then merged with the adjacent open coastal erosion hazard lines.

On the southern side of the inlet the erosion hazard line is, on average 58 m landward of the present shoreline and cuts across the front of several properties, partially affecting one dwelling. On the northern side the hazard line is, on average, 95 m landward of the present shoreline and no properties are affected.





Figure 10 Historical shorelines for the Hadfield Inlet superimposed upon the first vertical aerial photo (1948). The first two shorelines are derived from survey cadastral plans and relate to the high water mark, while the remaining shorelines are from aerial photos and relate to the vegetation front. The northern end of Paetawa Road is marked to assist with interpretation.



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Figure 11 Erosion hazard lines for the Hadfield Inlet superimposed upon the 2007 aerial photo. The shoreline envelopes are also shown for the set of shorelines depicted in Fig 10, together with the landwardmost composite shoreline used to define inlet migration. Inlet migration was then combined with the other hazard components for adjacent coastal measurement sites C22.06 to the south and C23.50 to the north to derive the erosion hazard lines. Because this inlet has only been subject to minimal management, no managed inlet erosion hazard scenario was included.



## 3.6 Waimeha Inlet

#### 3.6.1 Background

The Waimeha inlet is the most modified inlet on the Kapiti Coast. This stream was originally the northern arm of the Waikanae River (Fig 12), with the outlet being at the entrance of the present Waimeha Lagoon. However, stream flow was greatly reduced in the early 1890s, possibly following a "natural realignment" near the state highway-railway bridge some 5 km upstream (Maclean 1988). In 1921, an 800 m long diversion channel along the line of Huiawa Street was excavated to facilitate subdivision of the beach settlement (Easther, 1991); this enabled the Waimeha to reach the sea approximately 2300 m north of the Waikanae Rivermouth (Fig 12). In addition, it appears that the (Rawanahia ?) Inlet further to the north (see Fig 12) was diverted into the new Waimeha outlet, possibly via the Nagarara Stream which drained the areas of intervening swamp.

The northerly offset of the Waimeha Inlet has its origin in the alignment of the diversion channel. The northerly orientation of this channel would have allowed dunes to establish along the southern side of the inlet and this would then result in the channel being progressively diverted further northward. The channel must have reached its most northward location relatively soon after the diversion as since the beginning of the aerial record (1942) the northern shoreline has undergone net southward accretion of some 50 m at its seaward end and some 90 m closer to the throat (Fig 13). The inlet influence on the northern coast extends for some 300 m, and the open coast in this area is undergoing long-term progradation at ~0.4 m/yr.

On the southern side of the inlet the historical shoreline record (Fig 13) shows the shoreline retreated during the 1950s then migrated seaward by about 40 m during the 1960s. Thereafter the shoreline location has continued to fluctuate in response to the channel periodically migrating southward. The inlet influences the southern coast for some 250 m, and the open coast in this area is undergoing long-term progradation at ~0.35 m/yr.

The second type of management used at this inlet consists of earth groynes or training walls (see Fig 14). Manawatu Catchment Board reports note that temporary structures exited prior to the mid 1980s; however, these are not evident in the aerial photo record. The first observed groyne appears in the 1988 photo and was probably designed to keep the channel away from the northern dunes. This earth structure was not evident in later photos. The 1993 photo shows a groyne extending seaward by some 30 m from the northern end of the carpark off Field Way. This earthern structure has been maintained and is effective in preventing the stream cutting into dunes along the northern side of the inlet. The third earth groyne, depicted in Fig 14, extends seaward some 90m from the northernmost point of the dunes on the southern side of the inlet channel. This structure impedes the southward migration of the channel and hence minimizes undercut of the foredune.



It is noted that as the dunes around the Waitahi Inlet continue to grow, so too will the potential for dune erosion and the hazard of wind-blown sand. As at Waitohu in the north, a sand conservation strategy must be operative for this area.

The third form of inlet maintenance consists of mouth cutting. Manawatu Catchment Board reports (Brougham and Gestro, 1986) note that occasional cutting of the mouth occurred prior to the mid 1980s. The Wellington Regional Plan trigger conditions now allow for stream mouth cutting when the channel migrates either 250 m south or 150 m north of the Field Way car park groyne (see lines in Fig 14), or the channel creates a vertical scarp in the sand dunes in excess of 2 m in height. Alternatively, when the water level increases 300 mm or more above normal at the Field Way road bridge.

### 3.6.2 Erosion hazard

Increasing management over the last few decades justifies the division of shorelines into an *early* and a *late* set. However, given that the earlier shorelines probably reflect morphological adjustment to the artificially created mouth, it is not entirely appropriate to describe them as occurring under a natural regime. Nonetheless, to remain consistent with terminology used for the other inlets, the *natural* and *managed* headings will be used. The natural set consists of the 1942 to 1966 shorelines, while the managed set contains the 1973 to 2007 shorelines when inlet management using groynes and mouth cutting occurred.

The landwardmost composite shorelines are shown in Fig 14, along with the inlet hazard lines. The inlet migration defined by the southern composite shoreline was adjusted landward by 23.6 m to define the hazard line, this being the sum of components LT = 0, SLR = 15 m and DS = 2.6 m from Coastal Measurement Site C17.88 (Appendix B in the Open Coast Erosion Hazard Assessment), plus the inlet combined uncertainty value of 6 m. On the northern side, the inlet migration was adjusted landward by 23 m to derive the hazard lines; this being the sum of LT = 0, SLR = 15 m and DS = 2.0 from Coastal Measurement Site C18.85, plus CU = 6 m. The derived hazard lines were then merged with the coastal erosion hazard lines.

On the southern side of the inlet the average hazard distance landward of the present shoreline is 61 m for the managed inlet and 77 m for the natural inlet. This results in 11 properties including 7 dwellings lying at least partially within the hazard area for the managed inlet, and 16 properties including 13 dwellings for the natural inlet.

On the northern side the average hazard distance landward of the present shoreline is 44 m for the managed inlet and 80 m for the natural inlet. This results in 15 properties including two dwellings lying at least partially within the hazard area for the managed inlet, and 32 properties including 26 dwellings for the natural inlet.







Figure 12 Cadastral survey plan ML 504A compiled in 1880 showing early water courses in the Waikanae flood plain area. The 1921 diversion channel (green) of the Waime(h)a River to create the Waimeha Inlet are shown, together with the present Waimeha Mouth. Note the old inlet at top of figure; it appears that this stream (the Rawanahia?) may have been diverted into the Waimeha via the Nagarara Stm which drains the intervening swamps. Note how the Waimeha originates where the Waikanae River diverges (lower right of figure) which the approximate location of the railway bridge. This branch appears to have been cut off during the early 1890s by natural processes.



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Figure 13 Historical shorelines for the Waimeha Inlet superimposed upon the first vertical aerial photo (1942). The first two shorelines are derived from survey cadastral plans and relate to the high water mark, while the remaining shorelines are from aerial photos and relate to the vegetation boundary. The modern roading is included to assist with interpretation.







Figure 14 Erosion hazard lines for the Waimeha Inlet superimposed upon the 2007 aerial photo. The shoreline envelopes are also shown for the set of shorelines depicted in Fig 13, together with the landwardmost composite shoreline used to define inlet migration. Inlet migration was then combined with the other hazard components for coastal measurement sites C17.88 in the south and C18.85 in the north to derive the erosion hazard lines for both managed and natural inlet scenarios.



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## 3.7 Waikanae Inlet

#### 3.7.1 Background

The historical shoreline record for the Waikanae River (Fig 15) has affected about 1700 m of coastal shoreline, of which approximately 400 m lies on the northern (Waikanae Beach) side and 1300 m on the southern (Paraparaumu) side. The back of the inlet, i.e. the eastern (Otaihanga) side, lies about 200 m landward of the coastal shoreline at its northern end (nearer the river), and about 400 m landward at its southern end (towards the residential area). In the early 20<sup>th</sup> century the inlet area was about 55 ha. The Waikanae River has the second largest catchment (147 km<sup>2</sup>) and second largest mean annual flow (160 m<sup>3</sup>/s) of all the Kapiti water courses (Jamieson, 1991). While river control works and current management practices have halved both the extent of the inlet's lateral migration and the inlet area, this inlet is still the largest and most dynamic on the Kapiti Coast. Before considering the historical geomorphological changes in greater detail, the history of river management will be described.

The lower Waikanae River has undergone substantial change in terms of channelisation, bank protection and mouth control for the purposes of flood mitigation and erosion prevension. In addition, in 1921 the northern branch (the Waimeha Stream), was diverted directly to the sea (see Section 3.6) some 2.3 km to the north of the Waikanae Rivermouth. The Waimeha and Waimanu Lagoons formed in the seawardmost section of the original Waimea River channel.

Both the Waikanae River Catchment Control Scheme, which was implemented between 1956 and 1964, and the intensive gravel extraction which occurred until the 1970s (Brougham and Gestro, 1986), could have affected the entrance hydrodynamics. Until the construction of a southern groyne in the mid 1960s, no structural control works occurred at the entrance to limit the southward migration of the channel. However, rivermouth cutting has occurred at 5 to 10 yearly intervals since the 1930s and the years such management were carried out are listed in Easther (1991). The following trigger conditions are contained within the Wellington Regional Coastal Plan: *when the channel outlet migrates either 500 m south or 200 m north of a projected line parallel to the centre line of the southern rivermouth groyne*. These trigger lines are depicted in Fig 16. *Alternatively, mouth cutting occurs when the water level increases to 300 mm above normal at the Otaihanga footbridge*.

A range of river control structures were established during the late 1960s to early 1970s in association with residential development at Waikanae Beach and these are depicted in Fig 16. While these structures fix the location at which the upstream channel enteres the inlet, the mouth is still able to migrate laterally.

The historical shorelines show that while the northern side of the entrance has fluctuated laterally over a range of about 300 m, rivermouth structures and mouth cutting now limit the variation to about 20 m. It is noted that on the adjacent open coast the shoreline is slowly moving seaward at about 0.25 m/yr.



The southern side of the inlet has, in the past, extended some 700 m beyond its present location. The 1872 cadastral shoreline had an extreme southern mouth location, and this configuration also occurred during the 1940s and 1950s (Fig 15). Remnants of even more southerly inlet channel locations can be identified by stereographic analysis of aerial photos, and one such shoreline is included in Fig 15. The two dated episodes of spit extension suggest that the process may be quasi cyclic with a period of 50 to 60 yrs. Artificial mouth cuts have prevented any further episode(s) of significant southward inlet migration.

The occurrence of extreme southern inlet shorelines are a consequence of the channel being constrained and redirected by growth and extension of the northern spit. This situation is relieved by spit breaching which occurs either by natural or artificial (mouth cutting) near the Waikanae Beach end of the inlet. Sediment contained within the dissected north spit is then washed landward by wave action and merges with the southern side of the inlet. This process was particularly evident in the 1950s and 60s when about 20 ha of accretion occurred following the (artificial) spit breaching in 1947. Some 16 ha of this 'new land' was subsequently used for residential development in what is now the Manly Street North area. This particular episode of inlet sedimentation may have been exacerbated by construction of the entrance jetties (groynes) in the late 1960s and early 1970s and this is discussed further below.

The entrapment of north spit sediment within the southern part of the estuary in the 1950s and 60s appears to have affected the coastal sediment budget. In particular, the southern open coast shoreline changed from a state of long-term advance to one of stability or slight erosion as illustrated in Fig 3A of the Open Coast Erosion Hazard Assessment and on sheets C14-20 and x14-48 in the Erosion Hazard Data-Base. In addition, shorter-term fluctuations (10 - 20 yrs) are superimposed upon the longer-term shoreline trend and this may, in part, relate to the more frequent mouth-cutting regime.

Along the landward (Otaihanga) side of the inlet, the shoreline has remained relatively stable apart from changes which have occurred closer to the groyne (on the southern side of the mouth). It is evident from Fig 15, that the southern riverbank in this area was about 200 m further south than the present bank in the 19<sup>th</sup> century. Infill of the old bed is evident in the early aerial record. In addition, the southern entrance groyne has further affected the sedimentation in this area with the shoreline reaching the end of the groyne by the 1990s. In total, the inlet area here has been reduced by some 9 ha.

### 3.7.2 Erosion hazard lines

A sharp increase in management since the late 1960s provides the basis upon which to divide the shoreline data into earlier (natural) and later (managed) subsets. However, because the jetties at the northern end of the inlet and the subdivision earthworks at the southern end resulted in systematic shoreline changes, the 1966 to 1980 shorelines were classed as 'transitional' and not included in the analysis.



The landwardmost composite shorelines are depicted in Fig 16, along with the inlet hazard lines. The inlet migration defined by the southern composite shoreline was adjusted landward by 44.1 m to define the hazard line, this being the sum of components LT = 15 m, SLR = 20 m, DS = 3.1 m from Coastal Site C14.20 (Appendix B, Open Coast Erosion Hazard Assessment), plus the inlet combined uncertainty value of 6 m. While the Otaihanga side of the inlet is in fact part of the southern inlet shoreline, it is unreasonable to adopt the 44.1 m offset because the long-term trend is relatively stable compared with the negative LT value for the southern open coast. An offset value of 29 m (setting LT = 0) was thus used to derive the hazard line for the central inlet. On the northern side, the inlet migration was adjusted landward by 24.3 m to derive the hazard lines; this being the sum of LT = 0, SLR = 15 m and DS = 3.3 from Coastal Site C16.69, plus CU = 6 m. The derived hazard lines were then merged with the adjacent open coast erosion hazard lines

On the southern side of the inlet adjoining the Paraparaumu open coast, the average hazard distance landward of the present shoreline is 74 m for the managed inlet and 271 m for the natural inlet. This results in 10 properties (2 dwelling) lying at least partially within the hazard area for the managed inlet, and at least 150 properties for the natural inlet. The high number of Paraparaumu residences lying within the erosion hazard area for the natural inlet is a consequence of the 1960s-70s subdivision which occurred on the accreted land lying within the inlet's *dynamic zone*. Should the present management practice of mouth cutting be discontinued and maintenance of existing river control structures cease, then the inlet will inevitably return, on occasion, to its southernmost historical configuration. Needless to say, this situation also occurs on the northern side of the inlet.

For the central inlet (Otaihanga side), the mean hazard distances landward of the present shoreline are 96 m and 118 m for the managed and natural inlets respectively with no properties being affected in either case.

The peer reviewer, Dr Shepherd, raised the possibility of the southern entrance groyne being outflanked and thus the need to protect the left bank further upstream (Appendix A). Should such bank failure occur, it is unlikely that the newly formed channel would extend south of the 19<sup>th</sup> century left bank (Fig 15) due to topographic elevation, and reinstatement will almost certainly occur. At the present time there is no private property in the potentially affected area which carries a *ponding* classification in the present flood hazard zoning (Wellington Regional Council, 1997, Fig 7). While the zoning regulations state that new development may be permitted under such a classification, the effect of bank failure as raised by Dr Shepherd should be considered if future building applications are made to the KCDC.

On the northern side of the inlet, the average hazard distances landward of the present shoreline are 33 m for the managed inlet and 99 m for the natural inlet. This results in 4 properties including 3 dwellings lying at least partially within the hazard area for the managed inlet, and 15 properties including 14 dwellings being affected by the hazard line for the natural inlet.





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## 3.8 Tikotu Inlet

#### 3.8.1 Background

The Tikotu inlet has had a southerly offset since the first (cadastral) survey in 1905 (see Fig 17), with stream dynamics affecting up to 100 m of coast to the north and up to 200 m to the south. While the open coasts adjacent to this inlet have long-term accretional shoreline trends of approximately 0.5 m/yr, since the early 1990s the rates have increased to about 2 m/yr on the northern side and to over 1 m/yr on the southern side.

The adjacent southern coast has been intensely developed for recreation and amenity since the 1960s. The 1965 photo shows the first 50 m of channel immediately downstream from the Marine Parade bridge flowing in an open culvert, and a 90 m guidewall extending along the left bank to where the present day open culvert ends. Also clearly evident in the 1965 photo is a new seawall extending from the terminus of the guidewall for some 290 m along the southern coast (marked on Fig 18). The seawall was located at, or slightly seaward of, the then foredune toe, and appears to have been made for reclamation (to facilitate the development project), rather than for coastal protection. However, the structures did affect coastal processes, with morphological *end effects* consisting of retarded (seaward) shoreline migration immediately south of the wall, and dune instability to the north. By 1980 the open culvert had been extended 90 m to replace the southern guidewall. As demonstrated by the rates of shoreline change noted above, significant progradation has been occurring along this stretch of coast and the wall now buried behind a foredune that is up to 20 m wide.

Inlet management is also achieved via stream mouth cutting which is carried out *when the channel outlet migrates either 20 m north or south of the pole retaining walls on the north side of the inlet by the Kapiti Boating Club.* Alternatively, when the stream mouth closes or *the distance from the soffit to the water level at the downstream end of the Armco Culvert at Marine Parade is less than 900 mm in normal flow at low tide (Wellington Regional Coastal Plan).* The trigger lines are depicted in Fig 18.

#### 3.8.2 Erosion hazard lines

Coastal engineering works were under construction when the 1965 aerial photo was taken, so the managed inlet shorelines will consist of those from 1973 to the present, and the natural inlet shorelines from those prior to 1965.

The landwardmost composite shorelines, and the inlet erosion hazard lines, along the northern side of the inlet under managed and natural scenarios are depicted in Fig 18. Inlet migration defined by the composite shorelines was adjusted landward by 26 m to derive the hazard lines, this being the sum of LT = 0, RSLR = 18.8 m and DS = 1.2 m (from Coastal Measurement Site C12.77), plus the combined inlet uncertainty value of 6 m. The derived hazard lines were then merged with the adjacent open coast erosion hazard line to seaward, and tied in with permanent engineering structures to landward.



On the southern side of the inlet under the managed scenario, the hazard line has been located at the seawall for the following reason. As noted earlier, the shoreline in this area has been in a state of long-term accretion and the seawall is now several metres landward of the present shoreline and buried beneath a well developed foredune. Under the *seawall repair scenario* for the open coast, the maximum retreat at site C12.50 is 20.4 m where LT = 0, ST = 12 m, SLR = 0, DS = 2.4 m, CU = 6 m (Appendix B-2 in the Open Coast Erosion Hazard Assessment). The existing foredune provides for much of this distance, so should erosion manage to reach the seawall it would be most unlikely to fail. The seawall itself thus provides an appropriate location for the hazard line under the managed inlet scenario.

On the southern side of the inlet under the natural inlet scenario, the inlet migration defined by the southern composite shoreline was adjusted landward by 26.1 m to define the hazard line, this being the sum of components LT = 0, SLR = 17.7 m and DS = 2.4 m from Coastal Measurement Site C12.50 (Appendix B-3 in the Open Coast Erosion Hazard Assessment), plus the inlet combined uncertainty value of 6 m. The derived inlet hazard line was then merged with *the seawalls remove* coastal erosion hazard line for site C12.50 and the Marine Parade Armco Culvert to landward. However, in this case, these fixed endpoints required the hazard line to be located further seaward in approximately the same location as the landward side of the shoreline envelope (Fig 18).

On the northern side of the inlet, the average erosion hazard distances landward of the present shoreline are 55 m for the managed inlet and 60 m for the natural inlet. The only property affected is the Kapiti Boating Club which, for the natural inlet scenario, lies partially within the hazard area. On the southern side of the inlet, the average erosion hazard distances landward of the present shoreline are approx 10 m (4 to 20 m) for the managed inlet and 34 m for the natural inlet. The hazard area for the natural inlet affects utilities in McLean Park.



Disclaimer: an independent panel of coastal experts has found that the information contained in this report is not appropriate for planning purposes.



Figure 18 Erosion hazard lines for natural and managed Tikotu inlet superimposed upon the 2007 aerial photo. The shoreline envelopes, landward limit (composite) lines, and control structures (buried seawall and culvert), are also depicted. Note that for the managed southern inlet the landwardmost shoreline limit line is the seawall and is not depicted.



Figure 17 Historical shorelines for the Tikotu inlet superimposed upon the first vertical aerial photo (1942). The bold black line on the southern side of the inlet locates the 1965 to 85 shorelines which were controlled by the seawall. The contemporary roading is also shown.



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### 3.9 Wharemauku Inlet

#### 3.9.1 Background

The Wharemoukau inlet is one of the most managed entrances on the Kapiti Coast with seawalls and guidewalls restricting its influence to about 100 m of shoreline on the northern side and no influence on the southern side. The need for such control reflects the low lying terrain and dense settlement pattern coupled with a relatively stable coastline.

While the historical shorelines (Fig 19) show the northern side of the inlet has changed little during the aerial record (1942 to 2007), it has changed significantly since the 19<sup>th</sup> century. Of particular note is the northern shoreline in the 1874 survey which was up to 75 m inland of its present position, and extended some 600 m alongshore before joining the present coast. By contrast, during the 1940s, the northern inlet only influenced about 200 m of shoreline and subsequent seawalling further reduced the distance to 100 m. The northern seawall was established by residents between 1948 and 1952 when the area was subdivided for residential development.

When carrying out an erosion hazard assessment any extreme shoreline locations must be explained, lest they reoccur. The origin of the landward located 1874 shoreline lies in the history of stream realignments (see Fig 19) which were made to improve drainage and alleviate control flooding. In particular, the seawardmost 450 metres of stream was diverted to the coast just seaward of the Matatua Road bridge possibly some time around the turn of the century. The 1874 channel is shown entering the inlet from the south, i.e. flowing to the north, and this explains the inlet's early northern offset and recessed shoreline. By contrast, the channel diversion resulted in the stream meeting the coast with a southerly alignment and the inlet's shorelines display a slight southerly offset in the early aerial photos prior to seawalling. Engineering structures now permanently fix the channel (see below) so the 19<sup>th</sup> century shoreline can safely be discarded from the hazard analysis.

While the southern shoreline record depicted in Fig 19 shows the Wharemauku Inlet has influenced almost 200 m of coast in the past, a seawall and guidewall now fix the entire shoreline. The seawall along the southern coast was first constructed by the Hutt County Council in the 1950s following a series of damaging storms. The wall was made of railway iron and brushwood (Donnelley, 1959); however, when official maintenance ceased the brushwood infill became ineffective (McHugh, 1981). Sections of early seawall are clearly evident along the southern coast in the 1973 aerial photo and these are marked in Fig 20. Following the storms of the mid to late 1970s, a continuous wooden seawall was constructed from the Wharemauku inlet to QEII by 1980. The wall has since been upgraded and is maintained by the KCDC.

During the 1970s, channel guide walls were constructed along the entire 190 m of the left (southern) bank from the Matahua Road Culvert to the coast, and for ~100 m along the right (northern) bank below the road culvert. The longer southern wall controls the channel's



natural tendency to migrate to the south. The shorter northern guide wall still enables the stream to migrate northward; however, this is controlled by artifical mouth cutting. The Wellington Regional Coastal Plan provides for mouth cutting *when the channel migrates either 20 m south or 70 m north from the corner of the southern bank protection (guide) wall.* Alternatively, when the stream mouth closes off, or the distance from the soffit to the water surface at the downstream end of the culvert on Matatua Road is less than 1.7 m in normal flow and low tide. The trigger lies are shown in Fig 20.

#### 3.9.2 Erosion hazard lines

On the northern coast the seawall was in place by 1952, so the set of managed shorelines consists of those from 1952 to the present. In contrast, on the southern coast the seawall and guide wall became effective during the 1970s, so shorelines from 1942 to 1966 will represent the natural (southern) inlet, with the 1973 shoreline being classed as transitional and excluded from the analysis

For the northern side of the inlet, the landwardmost composite shorelines, and inlet hazard lines are depicted in Fig 20. The inlet migration curves (not shown) as defined by the composite shorelines, were approximately the same for both inlet scenarios so the hazard lines are also the same. These similarities reflect the general stability of the coast in this area. The hazard adjustment (offset) for the northern inlet was 23 m in both the managed and natural scenarios. This was based on component values from Coastal Measurement Site C10.4 which was the closest equivalent (seawalled) site on the northern side of the inlet (LT = 0, SLR = 15 m, DS = 2 m, plus CU for inlets = 6 m). Note that SLR still affects the inlet shoreline even though it has no affect on the adjacent coast due the seawall. Note also that the wooden guide wall on the northern side of the channel does not affect the analysis as it would be outflanked at the seaward end.

For the southern side of the inlet, the landwardmost composite shoreline for the natural scenarios and the inlet erosion hazard lines under both scenarios are depicted in Fig 20. There is no composite shoreline as such for the managed scenario because the southern side of the inlet is entirely controlled by the seawall, i.e. it is located at the seawall. The hazard offset distance is made up of the full set of open coast components, and the hazard measurement is made directly from the seawall (and guide wall). Using the component values for Coastal Measuremeth Site C9.43 (Appendix B2 and B3 of the Open Coast Erosion Hazard Assessment), the managed inlet offset is 28.6 m (LT = 0, ST = 15, SLR = 0, DS = 4.6 m, CU = 9 m), while the natural inlet offset is 35.6 m (LT = 10, SLR = 15 m, DS = 4.6 m plus CU for inlets = 6 m).

For the northern side of the inlet, the hazard line is, on average, 30 m behind the present shoreline. Four private dwellings are affected. By contrast, along the southern side of the inlet the hazard lines are, on average, 28 m and 69 m behind the present shoreline for the managed inlet and the natural inlet respectively. Five private properties plus the reserve are affected under each scenario; with the pool complex and dwellings lying partially within the hazard area under the natural inlet scenario.









Figure 20 Erosion hazard lines for natural and managed Wharemauku inlet superimposed upon the 2007 aerial photo. The shoreline envelopes, landward shoreline limit lines, and control structures (seawalls and guidewalls) are also depicted. Note that for the northern inlet, the hazard line is the same for both inlet scenarios and for the southern inlet the managed inlet shoreline limit line is the seawall and is not depicted.



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## 3.10 Whareroa Inlet

#### 3.10.1 Background

The historical shoreline record (Fig 21) shows that this inlet influences about 350 m of coastline. While the present inlet configuration is relatively symmetrical, a southerly offset developed during the 20<sup>th</sup> century, probably in response to the stream channel taking on a more northerly approach to the coastline. More recently inlet structures and management practices (detailed below) have kept the channel alignment centralized

On average, the northern inlet shoreline underwent seaward migration of 70 m between 1942 and 1980. By contrast, over the past 25 years this inlet shoreline has retreated, on average, about 45 m. The large fluctuation appears to be associated with a substantial input of littoral sediment during the 1960s and 70s and has been subsequently eroding. The ongoing shoreline retreat is probably also reflecting the underlying coastal recession of about 0.7 m/yr during this period.

The channel configuration has been very changeable. A meander loop immediately upstream of the inlet throat eroded into the left bank during the 1940s and a remedial groyne-guidewall is evident in the 1956 photo (depicted in Fig 22). The groyne appears to have been destroyed during the 1970s and early 80s, but it was then rebuilt in a similar location (Fig 22). This 100 m long structure has remained effective in both controlling the lower channel position, and as described below, in stabilizing the southern inlet shoreline.

The southern side of the inlet remained relatively fixed until the large sediment input of the 1960s-70s resulted in the burial of the frontal portion of the existing foredune. This area subsequently recovered until, later in the 1970s, the channel migrated to the south and caused up to 35 m of shoreline erosion. This southward extension of the channel appears to have been facilitated by release of the sediment that had accumulated within the inlet and on the northern side of the inlet, coupled with the entrance groyne falling into disrepair. Following construction of the replacement groyne in the mid 1980s, the southern shoreline recovered, albeit not to its 1973 seaward maxima, and since 1993 it has fluctuated by about 10 m. Underlying these shorter-term geomorphological behaviours, the coast has been systematically retreating at about 0.5 m/yr.

An artificial mouth cutting regime is also used to keep the channel away from the inlet shorelines with the following trigger conditions being defined as follows in the Wellington Regional Coastal Plan: when the channel migrates either 20 m south or 50 m north of the end of the bank protection wall, or when the stream mouth closes, or the distance between the bridge deck and the water level in normal flow and low tide is less than 1.6 m. The trigger lines are depicted in Fig 22.



#### 3.10.2 Erosion hazard lines

While the QEII open coast is in a natural state, the open coast shoreline data analysis found that it is subject to *end effects* from the South Raumati and possibly also from the Paekakariki seawalls. The assessment assumed that the end effects will continue and two different hazard lines (for the *seawalls repair and removed* options) were thus derived for the QEII coast (see Appendices B-2 and B-3 of the Open Coast Erosion Hazard Assessment). Two inlet erosion hazard lines will therefore also be derived for the Whareroa Inlet using the seawalls repair and seawalls remove component values from the adjacent coastal measurement sites.

Consideration was given to separating the shorelines into those associated with natural and with managed inlets; however, it was found that the control structures were outflanked by the hazard lines under both scenarios. In addition, the area will not be subject to future development, so all shorelines were analysed together and a single composite shoreline and migration curve was identified for each side of the inlet. Different inlet hazard lines were still derived, however, by applying open coast hazard component values from *the seawalls repair and removed* options to the inlet erosion hazard model (Equation 1).

The landwardmost composite shorelines, and the inlet erosion hazard lines, are depicted in Fig 22. For the southern side of the entrance, the inlet migration defined by the composite shoreline was adjusted landward by 57.4 m to derive the hazard line in the case of the *seawalls being repaired*, and 40.9 m if the seawalls were *removed*. These values being the sum of LT = 26.5 m, SLR = 13.6, DS = 11.3 m and CU = 6 m, and LT = 10 m, SLR = 13.6 m, DS 11.3 m and CU = 6 m respectively. The component values for LT, SLR and DS are listed in Appendices B-2 and B-3 of the Open Coast Erosion Hazard Assessment for Coastal Measurement Site 4.93. Note that Coastal Measurement Site C4-93 was used to derive the hazard distances rather than C5.15 as the latter was found to be subject to minor inlet influence. The derived hazard lines for the southern side of the inlet were then merged with the corresponding adjacent open coast erosion hazard lines.

For the northern side of the entrance, the inlet migration defined by the composite shoreline was adjusted landward by 66.8 m to derive the hazard line in the case of the open coast *seawalls being repaired*, and 45.5 m if the seawalls were *removed*. These values being the sum of LT = 33.5 m, SLR = 14.3 m, DS = 13 m and CU = 6 m, and LT = 12.5, SLR = 14.3, DS = 13 and CU = 6 respectively. The component values for LT, RSLR and DS are listed in Appendices B-2 and B-3 of the Open Coast Erosion Hazard Assessment for Coastal Measurement Site 5.70. The derived hazard lines were then merged with the corresponding adjacent open coast erosion hazard lines.

On the southern side of the inlet, the hazard line for the *seawall repair* scenario is, on average, 77 m landward of the present shoreline, while for the *seawall remove* scenario it is 60 m landward. On the northern side of the inlet, the hazard line for the *seawall repair* scenario is, on average, 88 m landward, and the line for the *seawall remove* scenario is 71 m landward. Minimal park utilities lie within these hazard areas.





depicted. Note that the northern coastal measurement site (C5.70) is 96 m Figure 22 Erosion hazard lines for the Whareroa inlet superimposed upon the 2007 aerial photo. The shoreline envelopes, landwardmost composite shorelines (limit line), and control structures (groyne-guidewalls) are also seyond the upper boundary of image.

are from aerial photos. The earliest stream channel (1874) and the present

road are marked.

black) are derived from cadastral plans, while the remaining shorelines

ipon the first vertical aerial photo (1942). The earliest 3 shorelines

guidewall-groyne

**Frigger lines** 

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## 3.11 Wainui Inlet

#### 3.11.1 Background

The historical shoreline record (Fig 23) shows that the Wainui Inlet (also known as the Wharerata Inlet) influences about 400 m of coastline. While this inlet has had a northerly offset throughout the record, there is morphological evidence of southerly offsets having occurred in the more distant (pre-colonial) past. During the aerial record, i.e. since 1942, the channel throat has translated southward by about 40 m.

The behaviour of the northern shoreline during the aerial photo record has been characterized by cross-shore fluctuations of about 25 m. The photos show that shoreline aggradation through the 1980s and 90s was a consequence of a substantial volume of (littoral) sand entering the inlet during the 1960s and 70s. This sediment input also forced the inner channel to erode the south bank and the (present) guide wall was built to prevent further erosion (see Fig 24). The outer channel response was also to migrate southward, and the present groyne (Fig 24) was built. More recently, the channel has returned to the northern orientation which characterized the earlier part of the record, and the northern shoreline has been eroding accordingly.

During the aerial record, however, the inlet-affected coastline south of the throat (fronting the Surf Club), behaved quite differently to the fluctuating northern inlet shoreline, and also to the open coastline further to south which has an underlying erosion trend of ~0.1 m/yr. Since the first aerial photo in 1942, this section of shoreline systematically prograded some 20 m up until the late 1990s after which it stabilized. The earlier seaward migration may have been a response to a different pre-historic inlet alignment, while the latter behaviour may, to some extent, be related to localized sand conservation work.

In addition to the guidewall and groyne, mouth cutting has also been used to control channel orientation. In particular: when the outlet migrates either 20 m south of 60 m north of the end of the pole retaining structure, or when the mouth closes, or when the distance between the deck of the footbridge and water surface is less than 1.5 m in normal flow at low tide (Wellington Regional Coastal Plan).

#### 3.11.2 Erosion hazard lines

No attempt was made to separate the shorelines into those relating to managed and natural inlets given the following circumstances: inlet management has had a minimal effect on shoreline location, control structures will be outflanked under both natural and managed inlet scenarios, and residential development is not expected to occur in the general vicinity of the inlet. A single landwardmost composite shoreline was thus identified. Different inlet hazard lines were then derived by applying open coast hazard component values for the *seawalls repair and removed* options to equation 1, i.e. the same approach used for the Whareroa Inlet in Section 10.



The landwardmost composite shorelines and the inlet erosion hazard lines are depicted in Fig 24. For the southern side of the entrance, the inlet migration defined by the composite shoreline was adjusted landward by 21.2 m to derive the hazard line in the case of the *seawalls being repaired*, and 31.2 m if *the seawalls are removed*. These values being the sum of LT = 0 m, SLR = 10.7 m, DS = 4.5 m and CU = 6 m, and LT = 10 m, SLR = 10.7 m, DS = 4.5 m and CU = 6 m, and LT = 10 m, SLR = 10.7 m, DS = 4.5 m and CU = 6 m respectively. The component values for LT, SLR and DS are listed in Appendices B-2 and B-3 of the Open Coast Erosion Hazard Assessment for Coastal Measurement Site C2.62. As noted above, the existing groyne–guidewall does not affect this analysis as it would be outflanked during the recession process. The derived hazard lines for the southern side of the inlet were then merged with the corresponding adjacent open coast erosion hazard lines.

During the merging process, an adjustment was made for the southerly inlet offset that will occur during the shoreline recession process, i.e. the channel will enter the inlet with a southward orientation. This adjustment was based on the general shape of the northern inlet shorelines which are a product of on the present northern offset.

For the northern side of the entrance, the inlet migration defined by the composite shoreline was adjusted landward by 40.8 m to derive the hazard line in the case of the open coast *seawalls being repaired*, and 31.3 m if the seawalls are *removed*. These values are the sum of LT = 14.5 m, SLR = 13.6 m, DS = 6.7 m and CU = 6 m, and LT = 5, SLR = 13.6, DS = 6.7 and CU = 6 respectively. The component values for LT, SLR and DS are listed in Appendices B-2 and B-3 of the Open Coast Erosion Hazard Assessment for Coastal Measurement Site C3.60. The derived hazard lines were then merged with the corresponding adjacent open coast erosion hazard lines.

On the southern side of the inlet the hazard line for the *seawall repair* scenario is, on average, 49 m landward of the present shoreline, while for the *seawall remove* scenario it is 59 m landward. Reserve land, the Surf Club and one private property lie within the hazard areas. On the northern side of the inlet, the hazard line for the *seawall repair* scenario is, on average, 65 m landward, and the line for the *seawall remove* scenario is 52 m landward. In these cases only reserve land and park utilities are affected.







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Figure 24 Erosion hazard lines for the Wharcrata inlet superimposed upon the 2007 aerial photo. The shoreline envelopes, landward limit lines (composite shorelines), and control structures (the inlet groyne and guidewall, plus the Packakariki seawall on the open coast) are also depicted.

## 3.12 Waikakariki Inlet

#### 3.12.1 Background

The Waikakariki Inlet in south Paekakariki affects about 200 m of coast and the configuration has had a northerly offset at least since 1942 when the first vertical aerial photos were taken (see Fig 25). However, earlier shorelines from 1894 and 1905 obtained from cadastral plans and included in Fig 25 do not show any landward indentation which suggests that an inlet may have been excavated some time after the turn of the century. Of particular interest is the shoreline configuration from the first cadastral plan of 1874 (not shown) which has an indentation on the south side of Beach Road some 200 m to the north of the present inlet. There is an underlying erosional trend along this section of coast of about 0.15 m/yr.

The 1956 shoreline is the most landward and this coincides with the particularly erosive storms of 1954 and 1956. Indeed, it was the extent and magnitude of this erosion which lead to the establishment of the original rail and brush seawall along the Raumati and Paekakariki coasts (Donnelley 1959). While the effect of this protection lessened over time, the railway irons have persisted and in many cases have been incorporated into private seawalls in the vicinity of the Waikakariki inlet. Since the 1980s these seawalls have largely fixed the inlet's seaward shoreline in its present location (see Fig 26).

The shoreline record shows that the rear of the inlet prograded after 1956 and has remained approximately stable since the early 1990s. A guidewall trains the channel as it enters the inlet and also provides bank protection. Realignement of the mouth is carried out *when the channel undermine the seawalls or creates a dune scarp exceeding 1 m in height, or when the mouth closes or becomes blocked with debris* (Wellington Regional Coastal Plan).

### 3.12.2 Erosion hazard lines

The natural inlet shorelines consist of the 1942 and 1956 samples when the inlet was free of any structures. As the effectiveness of the original rail and brush seawall during the 1960s and early to mid 1970s is unclear, the 1966 and 1973 samples were excluded from analysis. The managed inlet samples thus comprise the 1979 to 2007 shorelines.

The coastal shorelines on each side of the inlet are protected by private seawalls of varying standard. The present exercise has been based on the adjacent coastal shoreline having seawalls; however, the Open Coast Hazard Assessment demonstrates the difference is level of hazard that occurs for seawalled and non-seawalled sections of coast in this area. Should the KCDC subsequently determine that private seawalls in this area should not be incorporated within the hazard assessment, then the managed inlet hazard line will move landward as indicated in the Open Coast Erosion Hazard Assessment.



The landwardmost composite shorelines and the inlet erosion hazard lines are depicted in Fig 26. As with the other inlets where seawalls comprise part of the inlet shoreline, the landwardmost composite shoreline for the managed inlet coincides with the seawall and is not depicted. The hazard line offsets were based on LT, SLR, DS values for Coastal Measurement Site 1.51 as this site is closer than the southern coastal measurement site (C0.73) and has physical characteristics more closely matching those of the inlet, e.g. dune height. The same component values were applied to each side of the inlet; however, they were reduced by 20% at the rear of the inlet because of channel orientation change during the predicted shoreline retreat process (see below). For the *natural inlet*, the hazard component total was 27.6 m (LT = 12, SLR = 7.9, DS = 11.7 and the inlet CD = 6). By contrast, for the *managed inlet*, the hazard component total was 28.6 m (LT = 0, SLR = 7.9, DS = 11.7 and CU = 9). Finally the inlet erosion lines were merged with the coastal erosion hazard lines in the usual manner, i.e. the *natural inlet hazard line* was merged with the *seawalls removed coastal hazard line*.

Of particular note is the differing inlet shape for the *natural scenario* after 50 yrs of adjustment compared with the present and future *managed inlet* shape (see Fig 26). The reason for this is that the stream channel will approach the shoreline with a slight south offset compared with the present northerly orientation. This will result in the development of a more funnel shaped entry for the natural scenario. However, the asymmetry of the northern shoreline would still be evident as the northern offset of the channel would persist for much (estimated at 80%) of the recession period.

The inlet hazard lines on the southern side of the inlet are, on average, 41 m behind the present shoreline for the managed scenario and 62 m for the natural scenario. On the northern side the hazard lines are 35 m (managed) and 47 m (natural) behind the present shoreline. Twelve properties lie at least partially within the hazard area under each scenario.





upon the 2007 aerial photo. The shoreline envelopes, landward limit (composite) lines, seawalls, stream guide and debris grate are also depicted.

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## 3.13 Waiorongomai Inlet

#### 3.13.1 Background

The Waiorongomai Stream is about 1 km long and drains Lake Waiorongomai. The channel's present northerly offset is evident in the early cadastral plans and through the aerial photo record (Fig 27). The inlet affects about 250 m of coast to the south and about 350 m to the north. The open coast shoreline beyond the inlet is undergoing long-term progradation at about 0.6 m/yr.

While the Waiorongomai is a relatively stable inlet, the larger Waikawa Stream (presently located about 1600 m to the north), is very dynamic with the mouth having migrated south almost as far as the Waiorongomai in the early 1940s (see the underlying photo in Fig 27). The Waikawa has the potential to affect territory administered by the KCDC as the boundary with the Horowhenua District Council lies about 600 m north of the Waiorongomai Stream (see Fig 28). Furthermore, in recent years subdivision has been extending south of the Waikawa settlement and has now reached the boarder. The Waikawa Inlet has consequently been incorporated into this hazard assessment for the Waiorongomai Inlet.

While the Waiorongomai Inlet is not subject to channel management, the Waikawa has been controlled by rock groynes located on the southern side, and also occasional channel realignment by mouth cutting. Since 1999, the mouth cutting regime has been controlled by (Horizons Regional Council's) Coastal Permit 100182 which contains trigger and operational conditions for the applicant, i.e. the Horowhenua District Council.

#### 3.13.2 Erosion hazard

As with several of the KCDC inlets to the south, if inlet structures are not maintained and management practices are not carried out, then the channel will very likely once more migrate south into KCDC territory. It is thus relevant to consider both the managed and natural Waikawa inlet when assessing the erosion hazard north of the Waiorongomai Stream. In particular, the 1942 to 1965 shorelines will comprise the natural inlet set, while the 1972 to 2007 shorelines will make up the managed inlet set. By contrast, the full set of shorelines were analysed for the south Waiorongomai Inlet assessment as this inlet has no management and as there is no development in this area, nor is there likely to be in the foreseeable future.

The landwardmost composite shorelines (landward shoreline limit) and the inlet hazard lines are shown in Fig 28. The hazard lines were derived by adjusting the inlet migration curve (defined by the composite shoreline, see section 2.4) landward by 27.3 m, this being the sum of components LT = 0, SLR = 18 m and DS = 3.3 m from the closest coastal measurement site (see data for C36.86 in Appendix B of the Open Coast Erosion Hazard Assessment), plus the general inlet CU of 6 m. The hazard lines were then merged with the adjacent open coastal erosion hazard lines in the usual way. Note that unde the natural shoreline scenario,



the Waikawa Inlet controls the hazard line throughout the entire area north of the Waiorangomai Stream. By contrast, under the managed scenario it has no affect in the KCDC region.

On the southern side of the inlet the (natural inlet) erosion hazard line is, on average, 92 m landward of the present shoreline. On the northern side the managed hazard line is, on average, 57 m landward of the present shoreline, while the natural inlet hazard line is, on average, 262 m landward. The erosion hazard area on the southern side of the Waiorangomai Inlet, and also the hazard area for the managed scenario on the northern side, comprises duneland. However, the erosion hazard area for the natural inlet incorporates farmland and, as noted earlier, lies adjacent to present residential development, so such zoning could have relevance in the future.





Figure 27 Historical shorelines for the Waiorongomai and southern Waikawa Inlets superimposed upon the first vertical aerial photo (1942). The first shoreline is derived from a survey cadastral plan and relates to the spring high water line, while the remaining shorelines are from aerial photos and relate to the vegetation front. Roading and major accessways are marked to assist with interpretation.





Figure 28 Erosion hazard lines for the Waiorongomai Inlet superimposed upon the 2007 aerial photo. The shoreline envelopes are also shown for the set of shorelines depicted in Fig 27, together with the land-wardmost composite shoreline (landward shoreline limit) used to define inlet migration. Inlet migration was then combined with the other hazard components for the closest coastal measurement site (C36-89) to derive the erosion hazard lines. Note that on the nortern side of the inlet there are hazard lines for both managed and natural shorelines; this relates to management of the Waikawa inlet some 1600 m to the north by the Horowhenua District Council (see text).



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# 4.0 FURTHER CONSIDERATIONS

## 4.1 Erosion hazard line options

At managed inlets, erosion hazard lines for both the managed and the simulated natural inlet have been produced, so Council will need to decide which alternative to apply to which inlet.

Such dual scenarios were developed so the effect that management has had on morphological behaviour can be identified and the consequences of not committing to existing management for the next 50 to 100 yrs can be defined. Provision of this information now enables informed decisions to be made on both the continuance of present structures and management practices, and also on future expansion of inlet management.

## 4.2 Site-specific assessments

The council should recognize that subsequent privately commissioned *site-specific* erosion hazard assessments may further refine the hazard lines defined in the present report.

In Section 1.1 the concept of different levels of erosion hazard assessment was raised. In particular these consist of *regional, local and site-specific assessment* with the spatial application decreasing and analysis detail increasing accordingly. Regional assessments therefore tend to be undertaken for rural areas and local assessments for urban areas. The present Kapiti Coast erosion assessments were undertaken at the local level within, and on the margins of, settled areas, while somewhat less detail, albeit still greater than the usual regional level, was applied in the rural areas. Nonetheless, even with data points spaced at only a few hundred (local assessment level) significant variation within sectors can still occur for components such as dune stability and the largest observed value is applied throughout the sector. A site-specific assessment can often take such variation into account.

## 4.3 Sand conservation strategy

Inlets such as the Waitohu and Waimeha have the potential for significant dune erosion with subsequent wind-blown sand creating hazards in terms of nuisance and burial from sand drifts. No allowance has been made in the present assessment for such hazards and *sand conservation strategies* should be in place for such inlets.

## 4.4 Monitoring and future reassessment

The council must ensure that an adequate long-term monitoring programme is implemented which will provide information and data suitable for updating the erosion hazard assessment.

This present erosion hazard assessment should apply for at least 10 yrs, after which it should be reviewed to incorporate additional monitoring data, climate change information, hazard assessment technique refinement and relevant output from any site-specific erosion hazard assessments.



## ACKNOWLEDGEMENTS

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# Appendix A

## Peer Review by Dr Mike Shepherd

of

## Kapiti Coast Inlet Erosion Hazard Assessment. Part 2: Inlets Prepared for: the Kapiti Coast District Council By: Dr Roger D Shand (Coastal Systems Ltd)

#### Introduction

I have been asked to review the Draft Kapiti Coast Inlet Erosion Hazard Assessment Report prepared by Dr Roger Shand (Coastal Systems Ltd). I have over 30 years of research and lecturing experience in coastal geomorphology at Massey University and am very familiar with the Wanganui, Manawatu and Kapiti Coasts. My work also involved a variety of coastal hazards.

The Inlet Erosion Hazard Assessment complements the Open Coast Erosion Hazard Assessment, with these reports comprising Parts 2 and 1 respectively of the **Kapiti Coast Erosion Hazard Assessment**. In 2006 I reviewed the Open Coast Erosion Assessment.

As with the Open Coast Assessment, major objectives of the Inlet Assessment included the provision of an assessment that would be defendable and robust using best practice methods and based on archival data in the form of historical cadastral maps, aerial photographs, bathymetric data, topographic data (LIDAR) and existing literature.

#### Methods

This assessment uses a local rather than regional approach. The latter is less detailed and is more commonly used for hazard assessments covering larger areas. The use of a local approach, however, is appropriate for the Kapiti situation, given the proximity of settlement to many of the inlets. In addition, the local approach provides for a more defendable assessment.

The best practice open-coast erosion hazard model was adapted to the inlets by replacing the short-term fluctuation term by a landwardmost migration shoreline (see equation 1). The manner in which the landwardmost migration shoreline was derived is described in Section 2.4 and Fig 3. The same long-term, retreat from sea-level rise, and dune stability components' values used for the adjacent open coast site were used for the inlet model, but a slightly larger combined uncertainly value was applied.

This adaptation of the open coast model provides a novel and robust method to quantitatively derive erosion hazard lines within an inlet, and reduces the extent of 'best professional judgment' which has characterized most inlet hazard assessments in the past. The model's generality is demonstrated by its successful application to the contrasting range of inlet types found along the Kapiti Coast, including eroding, stable and accreting shorelines, low to moderate energy regimes, sand to gravel sediment size and contrasting inlet geometries.



About 10 historical shorelines per inlet were used to derive the landwardmost migration shoreline. Such data were adequate to define this component and, in addition, the method ensured an adequate level of precaution. The historical inlet configurations were also identified and used to predict the configuration of the recessed hazard shoreline. This aspect of the approach is vital to hazard assessment but rarely incorporated.

The determination of hazard lines for natural and managed inlet shoreline scenarios, and tying them into the open-coast hazard line (seawalls-removed and repaired scenarios where applicable) is a very useful innovation that will help council and communities in decision making and future planning.

#### Presentation

The inlet erosion model was applied to 11 inlets located along the Kapiti Coast, with separate sections backgrounding the general geomorphological development of the inlet and the management techniques that have been applied. A follow-on erosion hazard section details the model component values for both the natural and managed sets of shorelines. Separate figures are used to depict the set of shorelines from each inlet and the associated hazard lines. These two figures are underlain with the earliest aerial photo and the most recent photo. The different photos, together with the background materials nicely illustrate the extent of change that has affected the inlets during the past 100 yrs.

It is pleasing that the inlet presentations also address the effect of inlet behavior upon dune destabilization. Inlets are particularly mobile features and channel change may easily erode existing dunes, thereby presenting a hazard to nearby settlement, as occurred at Himatangi Beach about 10 years ago.

#### Modifications/considerations

#### Methodology:

There should to be greater consistency between the terms used to describe the same component in the text (maximum landward migration shoreline) and in Fig. 3 (inlet migration curve). I also note that in section 2.5 you state that "... the erosion safety margin may be further increased by a range of other uncertainty factors". While you go on to list them, you do not say if you actually carried them out! One hazard that has not been mentioned is the tsunami hazard, that at this stage is difficult to assess. However, if allowance is made for any possible tsunami hazard along this coast, the hazard lines proposed in this report should not be regarded as too conservative.

#### The Mangaone inlet (general background comments):

Your suggestion of a much larger early historical embayment for the Mangaone inlet is consistent with paleo-evidence from elsewhere. The sand/gravel ratio has fluctuated greatly along this coast over the past 6000 yrs and I suspect that Te Horo beach has been influenced by such changes. There have been major longshore influxes of sand several times in the Holocene that have changed reflective gravelly beaches to dissipative sandy beaches, resulting in the development of several major dune belts. There do seen to have been some fluctuations in the sand supply during the past 100 years which ties in with your comments in section 3.3.



#### Sediment influxes:

For several inlets you have identified distinct sediment influxes and the role these have played in controlling inlet shorelines, configuration and even dune behaviour. This approach is very explanatory and you may wish to consider extending it to the remaining inlets.

#### Waikanae River:

What is to stop the Waikanae River cutting a new more direct channel which passes to the south of the groynes (I have marked this on Fig 14). Perhaps there is a higher dune barrier, although I can't make it out on the aerial photo. If not, then the southern groyne may have to be extended landward c 300 m.

I have made several other minor comments on the manuscript.

#### Conclusions

Overall, the report has utilized a comprehensive and reliable set of data. It reads very well, the figures and maps were excellent and very clear, and calculations correct.

The use and derivation of the components seem fine, and I support the location of the hazard lines.

Notwithstanding the modification/comments noted above, the assessment meets the inlet hazard assessment objectives.

Dr Mike Shepherd

1<sup>st</sup> November, 2007

