WAIKATO DISTRICT COUNCIL COASTAL HAZARDS

February 2020

+65

Waikato District Coastal Hazard Assessment

FEBRUARY 2020

PREPARED FOR WAIKATO DISTRICT COUNCIL
BY MEMBERS OF FOCUS RESOURCE MANAGEMENT GROUP:

Bronwen Gibberd M.Sc (hons) TMIPENZ
4D Environmental Ltd
22 Dingle Road
RD2
Morrinsville 3372
Email: bronwen4d@outlook.co.nz

Jim Dahm M.Sc MRSNZ TMIPENZ
Eco Nomos Ltd
25 Adams Rd
Thornton Bay
RD 5
THAMES 3575
Email: jdahm@xtra.co.nz

Report submitted:

February 2020

Citation:

FOCUS, 2020: Waikato District Coastal Hazard Assessment. Prepared for Waikato District Council by the Focus Resource Management Group. Focus Report No. 20/130.

CONTENTS

EXECUTIVE SUMMARY

Background

The Waikato District Council ("the Council") is currently reviewing and updating the Waikato District Plan ("the Plan"), including integration of the Waikato and Franklin Sections of the current Plan. The separate sections are the result of the dissolution of the former Franklin District Council and the subsequent amalgamation of the southern portion of the Franklin District into the Waikato District in 2010.

Focus Resource Management Group has been commissioned by the Council to define areas potentially vulnerable to coastal erosion and coastal flooding in the Waikato District. This study has included a District-wide broad scale coastal hazard assessment and management recommendations, and a more detailed assessment of hazards and management approaches for Raglan and Port Waikato. Identified hazard areas include areas of greatest risk with existing sea level, and additional areas that could be affected with projected sea level rise over the next 100 years.

Coastal Hazards in the Waikato District

The shoreline of the Waikato District is extensive and diverse. Key areas around Raglan and Port Waikato are characterised by open coast sandy beaches, estuarine intertidal sand flats and estuarine beaches, cliffed shorelines, and low-lying estuarine margins. While large areas of the District remain remote and essentially untouched, the Raglan Harbour shoreline is heavily developed and has been modified significantly. Existing residential development and some areas of public reserve are vulnerable to coastal erosion and coastal flooding in both Raglan and at Port Waikato. The extent and nature of the hazard varies depending on the physical characteristics of the local environment.

The coastal hazard assessment included a review of all available published and unpublished data available. Community consultation formed an important part of the information gathering and helped to guide the development of management recommendations. Key coastal communities were contacted early in the coastal hazard investigation to inform affected residents and gather any available local knowledge and unpublished information. Two rounds of community workshops were held at Raglan and Port Waikato, and these were well attended. Meetings were also held with local iwi at Port Waikato and Raglan to discuss the draft findings of the study and invite information and feedback.

Two coastal erosion hazard and two coastal flood areas have been defined for developed sites in Raglan and Port Waikato:

- **High risk coastal erosion/flood areas**, identifying the areas where there is significant risk from coastal erosion or flooding with existing sea level and coastal processes in the short term (within the lifespan of the District Plan).
- **Coastal erosion/flood sensitivity areas**, identifying the areas potentially vulnerable to coastal erosion/flooding over the period to 2120, assuming sea level rise of 1.0 m.

The high coastal erosion and flood risk areas are those areas which, in the absence of existing or future intervention, could be impacted by coastal erosion or flooding within the lifetime of the District Plan (approximately 10-15 years). This does not represent a "worst-case" potential coastal erosion or flooding area over this timeframe but identifies the areas at greatest risk and therefore of highest priority for coastal hazard management.

Coastal erosion and flooding hazard reduce with distance inland and elevation (respectively). As we project coastal hazards beyond the short term, the uncertainty increases very considerably. The coastal erosion and flooding sensitivity areas are identified to highlight the much larger areas of land that are potentially vulnerable to coastal hazards, including the effects of sea level rise over the next 100 years.

It is important to note that there is generally a high level of uncertainty around future coastal erosion, even for any given assumed sea level rise. The available information on both existing coastal processes and possible future changes is not adequate to reliably and accurately define the areas vulnerable to coastal erosion over the next 100 years; whether using either traditional deterministic approaches or a probabilistic approach. In regard to coastal erosion, the defined coastal sensitivity areas therefore represent the maximum area that we believe could potentially be affected by erosion with up to one metre of sea level rise. Further and more detailed investigation might reduce the sensitivity areas in some locations, and we recommend that Council provide for such adjustment on the basis of investigations undertaken by a suitably qualified and experienced coastal scientist or engineer. Notwithstanding this, a high level of uncertainty is likely to remain in most areas.

In the rural areas, we have identified a single coastal hazard sensitivity area that identifies areas of the coastal margin that could potentially be impacted by coastal flooding and/or coastal erosion, assuming sea level rise of 1.0 m to 2120. It is important to note that these are not defined hazard areas, but simply areas within which any future development (excluding non-habitable farm buildings) will require a site-specific coastal hazard assessment.

Coastal Hazard Management Recommendations

Management of coastal hazards is extremely complex. There are a wide range of stakeholders on the coastal margin, whose interests may not always align well. While national and regional coastal policy constrain what options may be acceptable in both the short and longer-term, the decision-making process is inherently political and requires involvement of all relevant stakeholders.

There are also huge uncertainties around the nature and scale of future coastal change over the next 100 years (the minimum planning timeframe Council is required to consider). Decision-making must take these uncertainties into account. Activities or management options that might be quite adequate and acceptable in the short-term could be quite inappropriate and have serious adverse effects and costs in the longer term.

Given these complexities, we strongly recommend that Council work with relevant communities and stakeholders to develop agreed adaptive management strategies for the defined high risk and coastal sensitivity areas. The advantage of an adaptive management approach is that it enables Councils, community stakeholders and relevant experts to work together to:

- Develop the most appropriate management responses/strategies for existing coastal hazards and for various future scenarios
- Agree triggers or thresholds to adjust existing strategies (or adopt new strategies) as coastal hazards and goals change.

This adaptive approach enables councils and communities to adopt the most appropriate and cost-effective strategies presently relevant, while also identifying how these strategies will be adjusted or changed if particular coastal change triggers are reached. This provides for a high level of transparency and resilience.

The role of relevant experts in adaptive management is not a decision-making role but rather to empower the Council and community stakeholders by providing a good understanding of the pros and cons of different options and how the costs and benefits of these options may alter with coastal change over time. To assist the Council and community stakeholders in the development of these adaptive management strategies, we have discussed the range of potential measures for sustainable management of coastal erosion and flood risk in the Waikato District, identifying those that are most likely to be applicable. This commentary is founded on a broad "hierarchy" of management approaches, implicit in national and regional coastal policy and developed to reflect the nature of the particular coastal environment, the likely responses of that environment to future climate change and the implications of different management responses. Adaptive management strategies for each location must be developed with relevant community stakeholders and our commentary is simply to assist in that process.

Council also has various statutory and other responsibilities and associated liabilities. This report therefore also provides recommendations for development controls to guide management of development in each area until an appropriate adaptive management strategy is developed and agreed. If these management recommendations prove to be a significant constraint on desired activities in some areas, then those areas should be priorities for the development of adaptive management strategies.

Risk avoidance is recommended as the preferred approach wherever practical in high coastal hazard risk and coastal sensitivity areas when:

- establishing major new infrastructure,
- undertaking major upgrades to existing infrastructure,
- considering applications for Greenfield development or any other significant intensification of land use

In areas of existing development, it is recommended that Council develop appropriate policies and rules to both avoid increasing and, where reasonably practicable to reduce the risk of adverse effects from coastal hazards within the identified high-risk hazard areas and the coastal sensitivity areas. Relevant risk reduction approaches include:

- Development controls to encourage dwellings to move landward within properties away from the high-risk coastal erosion areas
- Development controls that require adaptable design within sensitivity areas – to allow buildings to be moved landward or raised over time in response to changing hazard risk
- Minimum floor levels in low lying areas

We also recommend appropriate development controls within the District Plan to ensure that any intensification of existing development is avoided in high-risk flood and erosion areas. In coastal erosion and flood sensitivity areas, intensification should only occur where a site specific coastal hazard study demonstrates that there will be no increase in coastal hazard risk, and/or effective and sustainable management of the hazards is provided for in an agreed adaptive management strategy (that considers the full range of future sea level rise scenarios).

In all cases where development or activities are restricted by these identified hazard areas, we recommend that the Council allows for the consideration of further, more detailed information including site specific coastal hazard studies, data on sub-surface geology, land stability investigations or detailed surveying of land levels etc, as relevant to the potential hazard. Such data may provide for a better understanding of coastal hazard risk at a site-specific scale.

The adverse effects and long-term implications of hard engineering works have been increasingly recognised, and as such national policy now emphasises the use of alternative approaches. Notwithstanding this, there are cases where "hard" coastal engineering works are the only practicable option.

We recommend that Council broadly discourage the use of "hard" coastal protection structures. However there will be circumstances where hard engineering works are an appropriate solution, particularly where there is significant coastal hazard risk under current conditions or within short time frames, and where adverse effects of the works can either be mitigated or avoided, or are outweighed by the benefits (considering both public and private values).

Ideally, hard protection structures will only be used where they are part of an adaptive management plan that has been developed by the community that ensures a necessary balance between private and public values and long-term sustainability. Where hard engineering is the only practicable option, it should also be designed and located to avoid or minimise adverse effects on the coastline. It is very unlikely in our view that hard protection works will be a viable approach to coastal erosion management on open coast beaches of the Waikato District due to adverse environmental effects and significant engineering costs. Adverse effects will also be a significant issue with use of such structures on estuarine beaches.

There are also many areas of the District where coastal restoration and/or environmentally soft approaches can usefully contribute to effective coastal hazard management. We recommend that the Plan include measures to actively encourage such approaches.

INTRODUCTION

The Waikato District Council ("the Council") is currently reviewing and updating the Waikato District Plan ("the Plan"), including integration of the Waikato and Franklin Sections of the WDP. The separate sections are the result of the dissolution of the former Franklin District Council and the subsequent amalgamation of the southern portion of the Franklin District into the Waikato District in 2010.

As a new matter of national importance set out in section 6(h) of the Resource Management Act 1991 (RMA), territorial authorities are now required to recognise and provide for the management of significant risk from natural hazards, while section 7(i) RMA requires territorial authorities to have regard to the effects of climate change. The District Plan must also give effect to policies within the NZ Coastal Policy Statement 2010 and the Waikato Regional Policy Statement 2016, including identifying areas of coastal hazard risk and regulating land use and development within identified areas to avoid or reduce the risk of adverse effects associated with coastal hazards and hazard responses.

The present study was commissioned by the Waikato District Council to define areas potentially affected by coastal hazards (excluding tsunami), including high coastal hazard risk areas, and to provide recommendations to inform and assist the development of management objectives and provisions for these areas.

This study also draws on the recently published national guidance document "*Coastal Hazards and Climate Change – Guidance for Local Government*" (MfE, 2017), including recommended sea level rise values and policy direction.

1.1 Purpose and Scope of the Study

Focus Resource Management Group was initially engaged to assess coastal hazards and provide management recommendations for the townships of Raglan (Figure 1) and Port Waikato (Figure 2). In particular, in consultation with the affected community and stakeholders, to:

1. Identify and map areas potentially affected by coastal hazards (excluding tsunami) over at least 100 years, including:
    - areas at risk of being affected with existing sea-level
    - additional areas which could be affected over the next 100 years with projected future sea level rise
2. Use a risk-based planning framework to develop broad recommendations for potential management approaches in the hazard areas, including:
    - recommendations for the management of both existing and future land use and development, including provision for use of the precautionary approach and the adaptive management approach
    - recommendations to provide for inland retreat of coastal habitats and continued access to the coast.

The study brief was subsequently extended to include a broad scale coastal hazard assessment and management recommendations for the remaining (largely undeveloped) western coastline of the District (Figure

3). This wider study does not include the small stretch of eastern coastline within the District. This area is presently being assessed through the Kaiaua Coast 2120 Community Plan lead by Hauraki District Council in collaboration with Waikato and Hauraki District Councils.

This report provides a summary of the District-wide hazard assessment and the detailed work undertaken at Raglan and Port Waikato. The report identifies current and future potential hazard areas.

Figure 1: Area of Raglan township covered by the more detailed Raglan study, including key sites.

Figure 2: Area of Port Waikato township covered by the more detailed Port Waikato study.

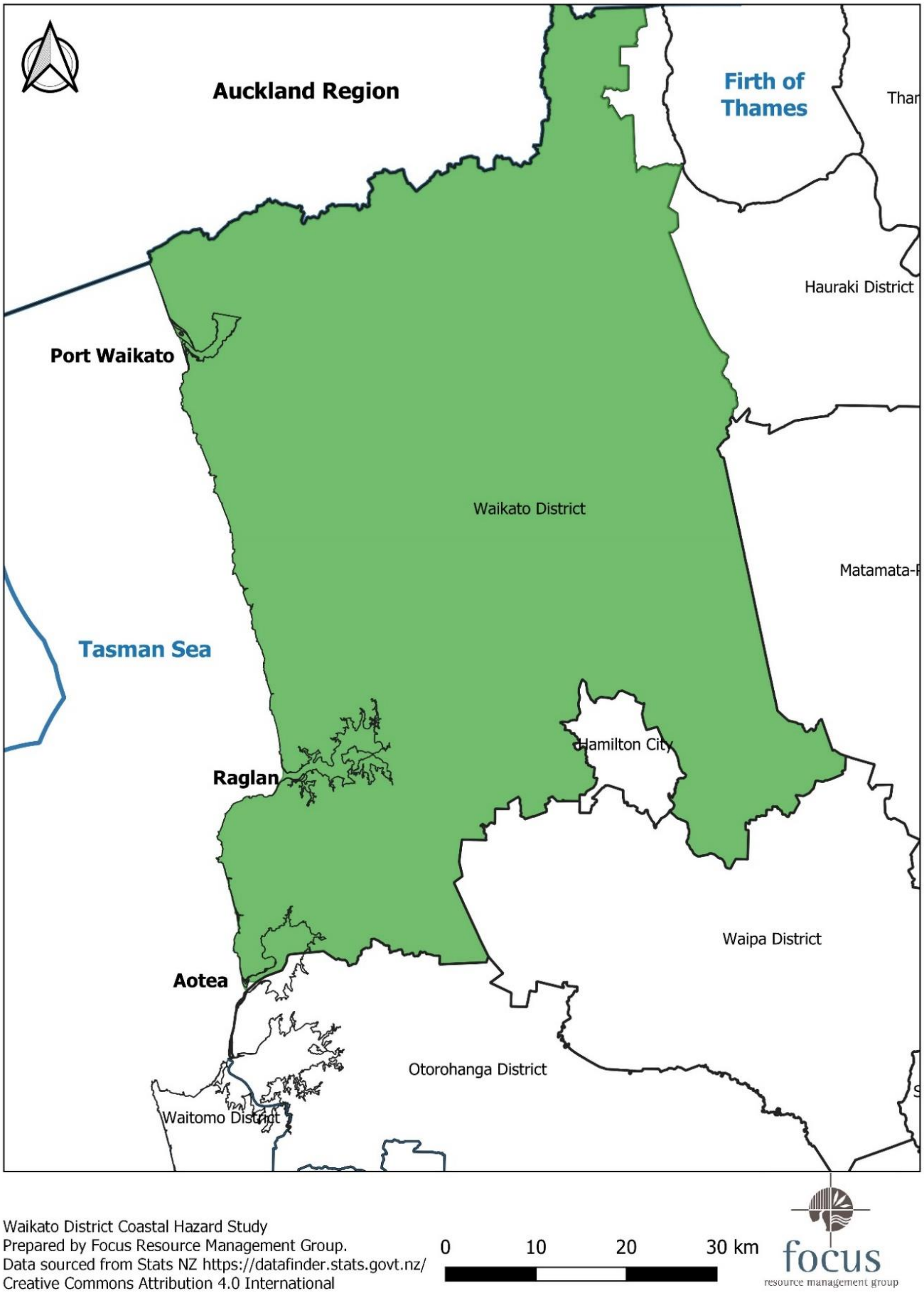


Figure 3: Extent of the Waikato District (green).

1.2 Report Layout

Section 2 outlines the approach to the project including the information considered and the consultation undertaken.

Section 3 summarises the national and regional policy setting, and recently completed national guidance for planning for coastal hazards and climate change in New Zealand.

Section 4 outlines the methodology used to assess the areas potentially susceptible to coastal erosion and inundation hazard, including the approach to calculating hazards with future projected sea level rise.

In Section 5, the policy and guidance are translated into a broad hierarchy of preferred coastal hazard management actions and associated recommendations for the management of new and existing development within identified coastal hazard areas. This section also introduces the concept of adaptive management.

Sections 6 and 7 summarises the site-specific hazard assessments and recommended management approaches for Port Waikato and Raglan, respectively.

Section 8 provides a brief overview of coastal hazards and recommended management for the remaining (and largely undeveloped) areas of the Waikato District coastline.

2 PROJECT APPROACH

2.1 Information Used

A wide range of information was used to assess coastal erosion and coastal flooding hazard, including (though not limited to):

- community and iwi observations and information
- vertical aerial photography dating from the 1940s to the present (including that available via Retrolens, Google Earth and both the Regional and District Council web sites)
- mapping of historic shorelines from ortho-rectified aerial photography undertaken by the Waikato Regional Council for much of the coast of the District using photos dating from 1942 to 2017.
- a wide range of historic photographs and surveys obtained from the National Library, historic survey databases, community members and other sources (some sites dating from the late 1800s and early 1900s)
- early descriptions and maps of the area available from the National Library, community sources, survey databases, local history books and other sources
- available topographic (LiDAR) data and bathymetric information
- geological maps
- existing reports on coastal erosion and other relevant published resources (e.g. local history books and a range of technical reports and studies)
- storm surge modelling and sea level reports as well as tide gauge and coastal flooding data (including reports from historic events)
- physical and geomorphic characteristics of the coast
- field observations around the entire developed coast of Raglan and Port Waikato townships
- most recent central government guidelines in respect to potential sea level rise (MfE, 2017)
- appropriate conceptual geomorphic models (e.g. to assess the potential future impact of projected sea level rise - see Section 4.3 for more detail).

2.2 Community and Stakeholder Consultation

An initial round of four-hour community workshops was held in December 2017. These workshops aimed to inform the communities of the work and to seek relevant community information and knowledge. A wide range of community observations and other information (e.g. photos) was obtained, with further information also provided by some follow-up contacts.

A second round of four-hour workshops was held in November 2018, which presented initial findings and recommendations for community and stakeholder feedback and comment. These meetings also led to further discussion and feedback, including subsequent meetings and field inspection with some stakeholders at Whale Bay and Lorenzen Bay.

In addition, separate meetings (including wide-ranging discussions and field inspections) were held with local iwi at both Raglan and Port Waikato in March 2019 and May 2019 respectively.

Presentations were also given to Waikato District Council staff and councillors, with associated feedback and discussion.

These various meetings provided a wide range of useful information and feedback to help refine the hazard assessments and recommendations. Further opportunity for community and stakeholder feedback will occur with issue of the draft proposed District Plan prior to formal notification.

2.3 Analysis and Reporting

The information from the community and other sources was analysed and synthesised to assess the areas potentially vulnerable to coastal hazards and associated management issues. Various management options were then considered, and recommendations developed, guided by existing national and regional policy and by community and Council feedback from the initial consultation. Useful feedback was also obtained from review of initial drafts of this report by Council staff and consultants.

The hazard analysis indicates that the Waikato District coastline is very complex and there are a wide range of significant uncertainties in respect to both existing and potential future hazard areas. The analysis also indicates that these uncertainties, together with much historic coastal development within existing and potential future coastal hazard areas, combine to present some very significant management challenges (discussed in Chapters 6 and 7). As discussed later in the report, these complex management issues cannot be fully addressed through the proposed District Plan alone and additional measures will be required in many areas.

In particular, at some existing developed sites (e.g. Wallis Street and Lorenzen Bay within Raglan, and the Port Waikato ocean foreshore), the complexities of the existing and potential future management issues are likely to require complex adaptive management strategies, developed in active partnership with affected stakeholders and the wider community. We have attempted where possible to provide some useful discussion of the possible content of such strategies but emphasise that considerable further work with the stakeholders and wider community will be required to develop agreed strategies. It is also very likely that management of these complex issues will require incremental change over a long period of time and the use of triggers.

In order to address the Council's statutory and other duties and associated liabilities, we have provided recommendations for management of coastal hazards until agreed adaptive management strategies have been developed.

3 POLICY SETTING

Councils are directed by National and Regional policy to identify and manage coastal hazards, considering a planning timeframe of at least 100 years and the potential effects of projected climate change. National Policy directs Councils to manage hazard prone land and associated development in such a way that over time builds community resilience and preserves the values of natural processes and ecosystems. The Regional Policy Statement also requires District Councils to identify areas at risk from coastal hazards, with priority on high risk areas.

Council also needs to consider and provide for other coastal values when planning development near the coast, including providing adequate setbacks for natural character, public access, biodiversity, physical processes and amenity. We have provided here a brief overview of the policies most relevant to our assessment of coastal hazards and the associated management recommendations. This aims to set the scene for the management recommendations provided in later sections of the report, but is not intended as a comprehensive policy analysis, which is outside the scope of the current study.

3.1 National Policy

The New Zealand Coastal Policy Statement (NZCPS) 2010 directs Councils in New Zealand to manage coastal hazards by identifying hazard areas and implementing management approaches that mitigate future coastal hazard risk. This statement contains a number of objectives and policies directed at coastal hazard management.

Objective 5 of the NZCPS provides a foundation to coastal hazard risk management by outlining the key aspects of sustainable coastal hazard management:

> *"To ensure that coastal hazard risks taking account of climate change, are managed by:*
>
> - *locating new development away from areas prone to such risks;*
> - *considering responses, including managed retreat, for existing development in this situation; and*
> - *protecting or restoring natural defences to coastal hazards."*

Objective 5 is implemented through a number of policies within the NZCPS, most specifically through Policies 24-27, which are summarised below.

Policy 24 requires Councils to identify the areas potentially at risk from coastal hazards (erosion, flooding and tsunami) over at least the next 100 years, prioritising areas of high risk. To do this, the Council must examine the physical processes and drivers, the geomorphic characteristics of the coast, the short- and long-term natural fluctuations, the human impacts, and the likely impact of climate change.

Policy 25 addresses the management of these hazard areas and directs Councils to avoid redevelopment or land use change that increases the risk of adverse effects from coastal hazards, and to encourage management decisions that reduce the risk of adverse effects over time (e.g. managed retreat or relocatable buildings). This policy discourages the use of hard protection structures.

Policy 26 highlights the importance of natural defences such as beaches, estuaries, coastal vegetation and dunes in providing protection from coastal hazards.

Policy 27 addresses the most challenging aspect of coastal hazard management, where there is significant existing development in areas at risk from coastal hazards. This policy provides guidance for working through the range of potential management options. The focus is on long term sustainable risk reduction approaches, which may include the removal or relocation of development or structures.

Historically, coastal erosion management has been dominated by the use of hard engineering structures to "hold the line" and prevent the erosion of both private and public land and assets. The adverse environmental, social and economic impacts of these approaches are now well recognised globally. "Hard" coastal protection structures interfere with natural coastal processes, can impact severely on the public values of shorelines and often tie communities into a perpetual cycle of ever-increasing financial investment.

National policy therefore now directs Councils to work with communities to manage coastal hazards in a way that over time decreases risk and increases the long-term resilience of coastal environments and communities given the likely impacts of projected sea level rise in coming decades. To achieve this, Councils are now required to emphasise risk avoidance and reduction and discourage the use of engineering works that control natural processes. Specifically, Policy 27.2. directs that when evaluating options for reducing coastal hazard risk, "focus on approaches to risk management that reduce the need for hard protection structures and similar engineering interventions;".

The NZCPS does recognise that in some cases, hard protection structures may be the only practical option for protecting infrastructure of national or regional importance, but that the social and environmental costs of such an approach must be acknowledged and that planning should identify transition mechanisms for moving to a more sustainable approach in the longer term. Policy 27 (4) states that hard protection structures designed to protect private property should not be located on public land unless there is a significant public benefit.

3.2 Waikato Regional Policy

The Waikato Regional Policy Statement (RPS) must give effect to the NZCPS. The RPS contains policies relating to the coastal environment, and specifically to natural hazards, and highlights the need to increase community resilience by mitigating the risk from natural hazards (including coastal hazards) over time.

Policy 6.2 of the RPS sets the framework for managing development in the coastal environment. Among other things, this policy requires that development is sufficiently set back and designed in such as a way as to provide for the full range of environmental and public values and allow for future sea level rise effects including landward migration of habitats. This policy also reflects the NZCPS and requires that development avoids increasing coastal hazard risk and maintains and enhances public access.

Policy 12.3.2 directs Councils to ensure that the amenity values of the coastal environment are maintained or enhanced. As part of this relates to providing suitable development setbacks along the coastal edge and "avoiding forms and location of development that effectively privatise the coastal edge and which discourage or prevent public access to and use of the coast…" and encouraging structure and development design that enhances amenity and maximises public benefits.

Policy 12.3.3 directs District Councils to incorporate the enhancement of public values in the coastal environment in public works and in plans and other planning documents.

Policy 13.1 requires that natural hazard risks are managed using an integrated and holistic approach that limits the risk from natural hazards while enhancing community resilience and recognises and prefers the use of natural features over man-made structures for defences against natural hazards.

There are a range of implementation methods relating to Policy 13.1, including 13.1.1, which states that Regional and District Plans shall incorporate a risk-based approach into the management of subdivision, use and development in relation to natural hazards.

Method 13.1.3 also states that the "Waikato Regional Council will collaborate with territorial authorities, tāngata whenua and other agencies to undertake assessments of coastal and other communities at risk or potentially at risk from natural hazards, and develop long-term strategies for these communities…"

These strategies will identify areas at risk, may include recommendations for hazard areas and will identify and evaluate options for reducing the risk to communities while preserving public access, amenity values and natural character where possible.

3.3 National Guidance on Planning for Sea Level Rise

In the longer term, projected sea level rise associated with global warming is expected to exacerbate both coastal erosion and coastal flooding hazard along much of the New Zealand coast. There are many ways that future climate change may influence coastal hazards, including:

- an increase in sea level and direct impact on coastal flood levels[1]
- potential shoreline retreat in response to a rise in mean sea level and increased wave effects
- an increase in nearshore tidal currents due to a possible increase in tidal prism[2]
- a possible increase in the frequency and/or duration of storm events
- potential loss of sediment to flood and ebb tide deltas due to these features increasing in volume with potential increased tidal prism[2].

National guidance recommends that coastal hazard planning must consider the likely impact of projected sea level rise over the next 100 years and beyond. In the future, accelerated sea level rise is anticipated in response to global warming and so it is not appropriate to simply extrapolate past trends to predict the future. Unfortunately, the impact of these factors and other uncertainties accompanying climate change are very difficult to predict. While scientists believe that sea level rise is inevitable, there is great uncertainty about how long it will take for this to happen. It is not possible to simply extrapolate past trends to predict the future, or to predict one "most likely" future.

[1] As well as increasing the severity and impact of rare and severe events, just a small amount sea level rise will greatly increase the frequency of events that are very rare with current sea level.

[2] The tidal prism is the volume of water in an estuary or inlet between mean high tide and mean low tide, or the volume of water leaving an estuary at ebb tide.

MfE (2017) therefore recommends that Councils consider the likely impacts of a number of plausible scenarios (using lower, intermediate and higher sea level rise projections), and from these develop adaptive management plans that can respond to sea level rise as it occurs (see discussion of adaptive management in Section 5.7). The recommended projections are based on future global emission scenarios developed by the Intergovernmental Panel for Climate Change (IPCC, 2013 & 2014). The establishment of dynamic adaptive plans for at risk settlements will take time. The MfE (2017) document also provides recommendations for the application of "minimum transitional sea level rise allowances" for coastal hazard planning where an adaptive plan is not yet in place (summarised in Table 1).

Table 1: Summary of sea level rise scenarios for coastal management in New Zealand (MfE national guidance note 2017).

Scenario	2070	2120	Transitional Application in Coastal Planning
Low (RCP 2.6) Lower bound "surprise"	0.32 m	0.55 m	
Intermediate (RCP 4.5)	0.36 m	0.67 m	Low-risk non-habitable works and activities, particularly those with a functional need to be near the coast.
Transitional		1.00 m	Recommended sea level rise value for planning in areas of existing development until a dynamic adaptive planning process has been completed.
High+ (RCP8.5) (85th percentile)	0.61 m	1.36 m	Greenfields development and major new infrastructure.

In terms of planning for intensification of land use (including subdivision in areas of existing development), there is no transitional sea level rise value recommended but MfE (2017) advises that a full dynamic adaptive pathways planning approach is required using the four sea level rise scenarios (at the scale appropriate to the scale of the intensification).

We believe that the guidelines for low-risk non-habitable uses are too broad and appropriate sea level rise values will vary considerably according to the nature of the works proposed. Appropriate sea level rise values are therefore best determined on a case by case basis to reflect the permanence of the proposed development or structure and the consequences of future hazard impacts.

Our approach to the identification of coastal areas and our recommendations for coastal hazard management in Sections 5-8 reflect this national guidance, the principles of the NZCPS and RPS and the knowledge gathered during this study.

4 IDENTIFYING COASTAL HAZARD AREAS

4.1 Coastal Erosion

4.1.1 Beaches

Beaches are typically highly used and valued and, particularly in areas with road access are often the chosen location for coastal development. They are also often very dynamic areas and highly susceptible to impact from future sea level rise. The values of these areas can also be severely affected by the impacts associated with hard coastal protection works, particularly with structures placed well seaward or on retreating shorelines. For these reasons, beaches (particularly highly dynamic sandy beaches) are often the most challenging and complex areas to manage.

There are a number of components to be considered when estimating the width of coastal erosion hazard areas for any planning period (“t”) in a beach setting, including:

- any long-term trends for permanent erosion or accretion (“LT”)
- maximum likely dynamic shoreline fluctuations over the planning period (“ST”)
- slope instability associated with collapse of over steepened erosion scarps (“S”)
- potential effect of climate change over the planning period, particularly sea level rise (“X”)

Typically, these components are summed to provide a total width of hazard area (Coastal Hazard Erosion Zone or “CHEZ”):

$$CHEZ = (LT \times t) + ST + S + X$$

In areas where sea walls currently (and historically) constrain erosion an allowance must be included for the effect of the sea wall. These effects include the long-term erosion or dynamic fluctuations that would have occurred if the sea wall were not present and any artificial fill that may have been added. Where seawalls have been confirmed as the long-term management approach, coastal erosion hazard areas would need to allow for short term erosion associated with failure of the structure, provided ongoing repair and maintenance was suitably guaranteed.

We have estimated these components for each site where necessary using the available information discussed in Section 2, with particular emphasis on field observations and geomorphology, historic aerial photographs and surveys, historic shoreline mapping and community information. The following sections briefly outline the methods used to assess each component. The derivation of the erosion hazard areas at each site are also discussed in more detail in Sections 6 and Section 7.

Long Term Trends for Shoreline Change

Long term trends for permanent shoreline advance or erosion were assessed using historic aerial and other photography, historic surveys, field observations, geomorphology and community information. Large dynamic shoreline changes occur over many decades on this coast, and it is very difficult to separate these from long-term trends with certainty. For instance, on this coast, large-scale fluctuations can occur on both multi-decadal and even century timeframes, particularly on the open coast and near estuary and river entrances. Centuries of data would therefore be required in many areas to reliably discriminate dynamic shoreline fluctuations from permanent long-term trends.

Our assessment of long-term trends versus dynamic shoreline movements has therefore placed a heavy emphasis on geomorphic considerations; relevant considerations for each site being discussed in Section 6 and Section 7. In general terms, while erosion has sometimes dominated for many decades on some beaches, the weight of existing data and geomorphic considerations suggests that most beach changes in the Waikato District are likely to be dynamic over multi-decadal and century timeframes.

Dynamic Shoreline Fluctuations

Sandy beaches are naturally dynamic and respond rapidly to changes in local coastal processes. Natural functioning of sandy beaches relies on the presence of an intact sand dune, which is part of the natural beach system, and is critical to processes of natural erosion and recovery. Sand dunes are formed when wind blows sand inland from the beach, where it is "caught" by sand trapping grasses and accumulates. This sand is stored in the dune until there is a storm event that erodes the beach and the face of the dune. During storms, sand eroded from the beach and dune is moved offshore to form offshore bars (Figure 4). In calmer conditions, sand from these nearshore bars is worked back onto the beach and beach levels recover over time (Figure 5). Natural dune recovery is slower and depends on suitable sand trapping vegetation on the dune (e.g. spinifex and pingao).

Sandy beaches can also experience dynamic shoreline fluctuations with extended periods of erosion and accretion due to causes such as climate cycles that alter weather patterns (e.g. affect the frequency of storms). On the west coast there is also evidence that longshore transport often occurs in fluxes or "clumps", giving rise to extended periods of accretion when a volume of sand accumulates, and extended periods of erosion when a this "clump" of sand moves away. Areas adjacent to flood- and ebb-tide deltas can also experience periods (often lasting years or even decades) of alternate erosion and accretion; associated with complex sand transfers and bar and channel changes.

The maximum scale of the dynamic shoreline fluctuations (often referred to as the dynamic envelope) is therefore typically only evident over long periods of time (generally many decades and probably even centuries in some areas); particularly along the open coast of the district and the lower regions of tidal estuaries. These changes can be particularly complex and dramatic near the mouths of rivers and estuaries. Within the Waikato District, the main settlements at Port Waikato and Raglan are both at least partly located on sandy beach and dune systems and are adjacent to major estuary or river mouths.

Careful interpretation of coastal geomorphology and long-term records is therefore required to adequately assess the maximum likely dynamic shoreline fluctuations. In some cases, even with such considerations, the available information is not adequate to reliably define existing erosion hazard areas and we have had to adopt a precautionary approach. This is particularly the case in open coast and lower estuarine areas associated with tidal and river entrances.

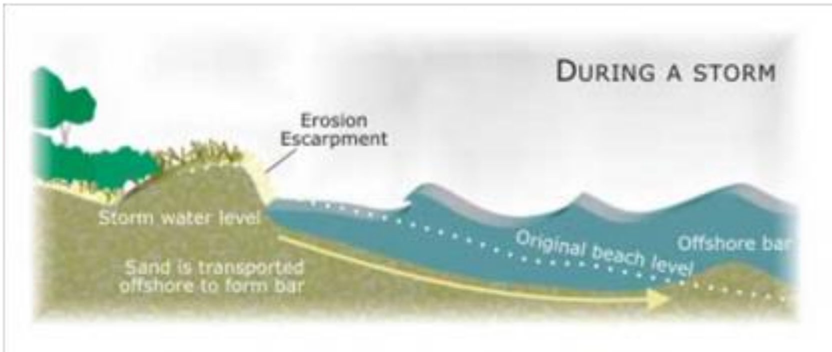


Figure 4: During storms, sand is eroded from the dune and forms bars offshore that absorb wave energy.

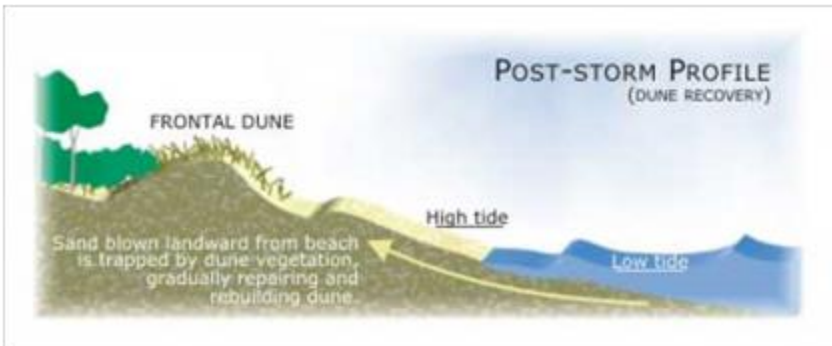


Figure 5: During calmer wave conditions, sand from the offshore bars makes its way to the beach and over time the dunes rebuild (source: Waikato Regional Council, 2011)

In general, the complexities associated with this coast preclude the use of the simple deterministic or probabilistic methods commonly used for erosion hazard assessment in New Zealand and geomorphic considerations play a larger role. The relevant considerations for each area are discussed in more detail in Sections 6 and 7.

Collapse of Erosion Scarps

Following severe storms, dune erosion and beach lowering typically form near vertical erosion scarps. These scarps can collapse to a more stable slope at a later date, generally in the order of 26 degrees (1V:2H slope) in unconsolidated sands. In identifying erosion hazard areas, it has been assumed that the dune face will collapse to this stable slope. In practice, the value of this parameter is generally close to the height of the dune above the dune toe, as material collapsing from the top of the dune face will form a slope at the base of the scarp, stabilizing the slope.

This factor is a relatively minor consideration in the more dynamic open coast and lower estuarine beaches of the Waikato District; considerably dwarfed in these areas by the uncertainties associated with multi-decadal and century scale shoreline change.

4.1.2 Cliffs

Coastal erosion of cliffs typically occurs slowly and unlike beaches is essentially a one-way process. Cliff erosion mechanisms relate to coastal erosion at the toe, and to slope instability processes higher up. Coastal processes work to erode the base of the slope, until over steepening causes slope failure to a stable slope as shown schematically in Figure 6.

There are many cliff shorelines in the Waikato District, including much of the open ocean coastline, and a large proportion of the Raglan Township shoreline. The mechanisms of slope failure and potential for erosion vary greatly depending on cliff geology, height and physical setting.

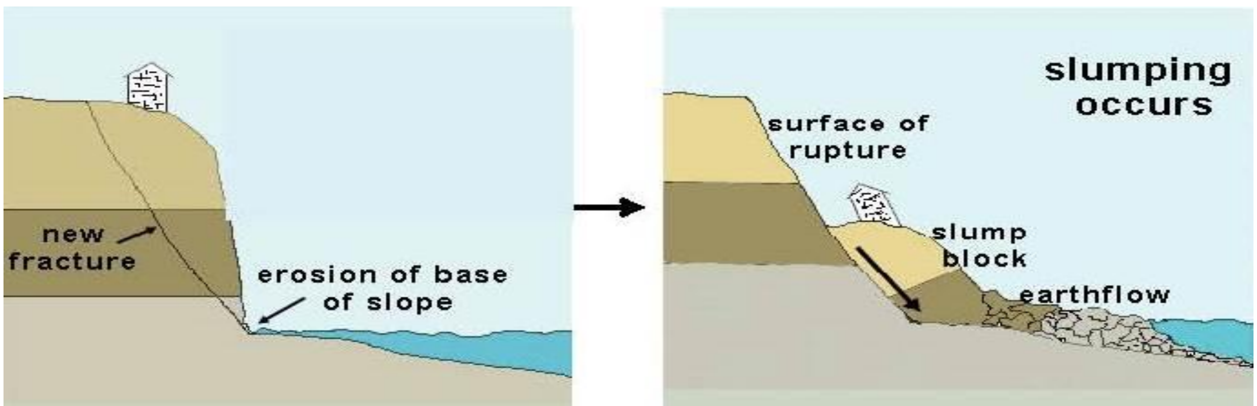


Figure 6: Processes of cliff erosion.

The key factors that need to be considered in erosion hazard assessment for cliff sites are:

- historic long term (i.e. time-averaged) rate of toe erosion
- slope instability arising from the toe erosion (typically assuming failure to a stable slope)
- the potential effect of sea level rise on the above factors (i.e. particularly toe erosion)

A range of data and methods have been used to estimate coastal erosion hazard areas for cliff environments along the Waikato coast including:

- geological, geomorphic and field observations to estimate very long-term erosion rates (e.g. shore platform width) and likely stable slope.
- historical aerial and other photography
- historic shoreline surveys
- empirical techniques to estimate the potential impact of projected sea level rise (discussed further in Section 4.3).

In general, toe erosion rates are slow in the Waikato District and the more significant component of cliff erosion hazard relates to rare, periodic slope adjustment. In general, we have adopted a precautionary approach to slope stability in this first pass assessment; based primarily on the minimum slopes prevailing in any particular area. Accordingly, we recommend that Council provide for the identified hazard areas to be modified by detailed site-specific investigations of slope instability by an appropriately qualified and experienced professional (e.g. an engineering geologist or a geotechnical engineer).

4.2 Coastal Flooding

The key components contributing to coastal flood hazard over the next 100 years comprise:

- astronomical tides
- storm surge (elevation of sea level by barometric and wind effects)
- wave effects, including wave set-up and wave run-up
- rise in relative sea level due to climatic and tectonic changes

These various components are illustrated in Figure 7 and discussed further below.

The Waikato Regional Council has maintained a tide gauge at Kawhia since 2008. A study was commissioned by the Regional Council to analyse tide gauge data from the Waikato Region (including Kawhia) to better understand the components that contribute to storm surges and to estimate storm tide levels and associated probabilities (Stephens et al., 2015). The analysis of the Kawhia tide data and associated tide and storm surge assessment is currently the best data on which base identification of coastal flood hazard areas on the western Waikato District coastal margin.

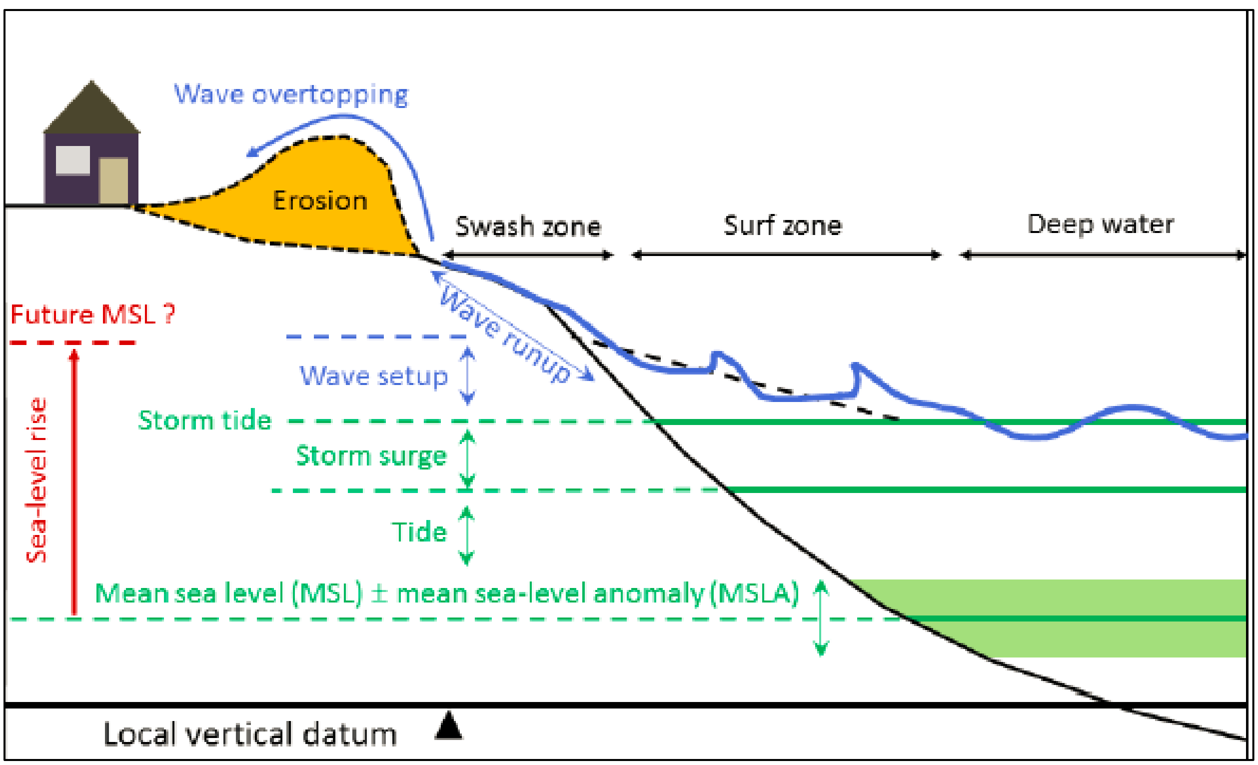


Figure 7: Summary diagram showing the various components that contribute to coastal storm inundation (source: Figure 30 from MfE, 2017)

4.2.1 Astronomical Tides

The total storm tide height during an event is influenced greatly by the state of tide at the peak of the storm surge. Even a very large storm surge may not cause flooding if it peaks during low tide. The relatively large tidal range on the West Coast of the North Island means that the tidal component of any storm water level tends to dominate over other factors. As part of the work completed by Stephens et al. (2015), NIWA provided tide levels for the Waikato Region based on a national tide model, which have been adjusted where possible using local tide data. Mean high water spring and maximum tide levels are given in Table 2. The mean high-water definition given in Table 2 is "MHWS10", which is the level that is exceeded by 10% of all tides. The maximum tide refers to the maximum tide level predicted by the tide model over a 100-year period (not including sea level rise).

Table 2: Elevation of Mean High-Water Spring (MHWS) and Maximum High-Water levels at Raglan and Port Waikato (from Stephens et al. 2015 and Waikato Regional Council http://coastalinundation.waikatoregion.govt.nz/).

	MHWS (MVD)	Max High Water (MVD)
Raglan	1.7 m	2.1 m
Port Waikato	1.7 m	2.0 m

4.2.2 Storm Surge and Storm Tide

Storm surge is the combination of barometric set-up and wind set-up which elevate water level above the predicted tide. The barometric set-up effect occurs when low atmospheric pressure over the ocean drives an increase in water level. A 1 hPa fall in atmospheric pressure drives an increase in water level of 10 mm. The inverse barometric effect driven by low pressure systems typically contributes 100-150 mm of the observed storm surge on the West Coast of the Waikato Region.

Wave breaking processes generate an increase in the average elevation of sea level (wave set-up) during storm events due to the release of wave energy in the surf zone as waves break. When offshore waves are large, wave set-up can raise the water level at the beach substantially. Most weather systems approach the Waikato Region from the west of New Zealand and therefore propagate towards the Waikato coast, generating wind waves and swells that affect the study area. The wave effects are therefore generated by the same events that drive barometric and wind set-up.

During storms, onshore wind and waves can drive water up against the shore, increasing water levels. The tide data analysis undertaken by Stephens et al. (2015) revealed that the sea level at Kawhia seems to be highly influenced by wind. It is thought this is most likely due to wind-set up against the coast further influenced by Coriolis forces. The study revealed that storm surges at Kawhia were dominated by the effects of wind stress associated with persistently strong north-westerly winds from weather fronts blowing over several hours to days.

These conditions drive surges almost double those experienced on the eastern Coromandel Peninsula. This effect is likely to be still somewhat relevant at Port Waikato and Raglan, but it is difficult to ascertain whether the magnitude of effect will be as significant. WRC analysis of Raglan tide gauge data during subsequent severe storm events (e.g. January 2018) indicate that storm surge behaviour at Raglan closely follows that at Kawhia (Hunt, *pers. comm*. 2019).

The sea-level 'anomaly' describes the longer-term variation of the sea level that does not relate to tides. The sea level variations occur at time periods over a year (seasonal changes), several years (El Niño and La Nina Climate Cycles) and over decades (Pacific Decadal Oscillation). Therefore, while tide levels can be accurately predicted, the actual sea level at any given location is likely to differ from the predicted tide. The range of this sea level anomaly is generally up to +/- 0.2 m (Stephens et al., 2015) and is included in the storm tide predictions.

The report by Stephens et al. (2015) examined the components that made up the largest observed storm tides in the tide gauge record at Kawhia. In all cases, the dominant component of storm surge was tide. The relative magnitude of storm surge was small in relation to tide. The overall storm surge height is heavily dependent therefore on the stage of tide (high/low and spring/neap) when the storm is at its peak. Extreme storm-tide (total sea-level) analysis was undertaken to determine the storm tide frequency–magnitude distribution using the Monte Carlo joint-probability technique.

Table 3 presents elevations for the median storm surge at Kawhia, based on the joint-probability analysis of sea level data at Kawhia Harbour (Stephens et al. 2015). The storm tide elevations presented are given relative to a zero MSL and to Moturiki Vertical Datum 1953 ("MVD '53).

1% AEP storm surge values were calculated using joint probability analysis techniques, which factor the likelihood that extreme spring high tide levels will coincide with a peak in storm surge. Analysis of the relatively short (six year) record at Kawhia, Stephens et al. (2015) revealed that of the largest recorded events, none occurred due to a coincidence of high storm surge and a high spring tide. This means there is potential for even larger storm surge events to occur in the future, though it is difficult to accurately determine their probability.

More extreme storm surge components are also likely to be measured as the record lengths increase. In the very short Kawhia record, three surges greater than 0.7 m were observed. Stephens et al. (2015) comment that it appears that Kawhia Harbour (and likely other west-coast estuaries) are subject to large wind-driven storm surges that could conceivably reach well over 1.0 m in magnitude.

Table 3: Storm tide elevations for Kawhia Harbour (Stephens et al. 2015).

AEP (%)	ARI (years)	Median (MSL)	Median (MVD '53)
10	10	2.33 m	2.46 m
5	20	2.42 m	2.55 m
2	50	2.54 m	2.57 m
1	100	2.63 m	2.76 m
0.5	200	2.73 m	2.86 m

In light of this uncertainty, Stephens et al. (2015) also provided the maximum observed tide, maximum storm surge and maximum sea-level anomaly, during the sea-level measurement period; which when combined yield a possible storm-elevated sea level of about RL 3.13m relative to Moturiki Datum (Table 4). Within the record, these maxima occurred at different times so there has not been a storm-elevated sea-level measured to this elevation. This approach does however give an indication of the potential sea-level elevation expected if a very high tide combined with a very large storm surge and a very high sea-level anomaly, all at the same time. The probability of occurrence of the summed sea-level components is unknown due to the short record, but is likely to be very low; having an annual exceedance probability of less than 0.5% AEP based on the 2015 NIWA analysis of existing data shown in Table 4.

Table 4: Maximum measured storm surge components at Kawhia.

Storm Surge Component (Maximum) Relative to MSL	Level (MSL)	Level (MVD '53)
Maximum Tide Level	1.94 m	2.07 m
Storm Surge	0.90 m	0.90 m
Sea Level Anomaly	0.16 m	0.16 m
TOTAL:	3.00 m	3.13 m

As noted above, the 1% AEP level calculated by Stephens et al. (2015) (Table 3) was based on just six years of data and the authors acknowledged the limitations of such a short data record and the likelihood that larger surges would be recorded in a longer record. Accordingly, at this time we believe it is more prudent to estimate the maximum storm tide by summing the various maximum storm surge components.

The maximum storm tide elevations for Port Waikato and Raglan were therefore estimated by combining the maximum tide at each location (Section 4.2.1) with the maximum storm surge components measured at Kawhia as shown in Table 5. As noted above, there is likely to be some conservatism in this estimate, it represents the best available information.

Table 5: Maximum storm tide values for Raglan and Port Waikato (Moturiki Vertical Datum 1953).

	Max Tide MVD '53	Max Storm Surge (m)	Max SL Anomaly (m)	Max Storm Tide (MVD)
Raglan	2.10 m	0.90 m	0.16m	3.16 m
Port Waikato	2.00 m	0.90 m	0.16 m	3.06 m

Table 6: Maximum storm tide values for Raglan and Port Waikato (corrected to New Zealand Vertical Datum (NZVD) 2016).

	Max Storm Tide (MVD)	MVD – NZVD Correction	Max storm (NZVD)
Raglan	3.16 m	0.26 m	2.90 m
Port Waikato	3.06 m	0.29 m	2.87 m

4.2.3 Wave Run-up

"Wave run-up" is the maximum vertical extent of wave "up-rush" on a beach or structure above the still water level (that would occur without waves), and is therefore only a short-term fluctuation in water level relative to wave set-up, tidal and storm-surge time scales. Swash can reach to considerably higher levels than the average water level and can cause ponding if sufficient to overtop dunes or seawalls to reach lower lying areas inland.

The magnitude of wave run-up depends on the angle of the shore to the approaching waves, the nearshore water depth, wave height and period, beach slope and the nature of the shoreline (beach, dunes, vertical or sloping seawalls etc.). Wave run-up is therefore more significant on exposed open coasts and less so on sheltered estuarine shorelines. Wave run-up is not part of the calculations made by Stephens et al. (2015) as it is only a short-term fluctuation in water level and is not measured by tide gauges.

Wave run-up during storms can reach considerably higher levels than the storm surge water level and can aggravate inundation and cause physical damage to structures in nearshore areas. While we have not included an allowance for these wave effects in the above figures, we recommend that the Council include a "freeboard" in minimum floor levels, particularly very close to the coast. This freeboard is also important to provide for known (observed) infragravity wave effects that are seen in Raglan Harbour as surges that amplify total coastal storm surge levels further.

4.3 Sea Level Rise

4.3.1 Effect of Sea Level Rise on Coastal Erosion

Beaches

Observations of historic surveys and photographs indicate that the open coast and estuarine beaches of Waikato District are in most places in dynamic equilibrium or slowly eroding. On such beach systems, sea level rise is expected to drive an overall trend for shoreline retreat; with the beach profile adjusting landwards and upwards in response to the higher water level.

Shand et al. (2013) present a useful summary of the methods commonly used to provide indicative estimates of the erosion likely to arise from any given sea level rise. As they note, the most commonly used method for sandy beaches are simple geometric models which simply consider two-dimensional (cross-shore) changes, such as the standard Bruun Rule (Bruun, 1962 & 1988) used on sandy beaches (Figure 8).

On sandy beaches, the standard Bruun Rule assumes that the equilibrium cross-shore profile of the beach (out to the seaward edge, known as the closure depth) is moved upward and landward conserving mass and original shape. This change results in the upper areas of the beach being eroded with this volume balanced by equivalent deposition offshore (see top diagram in Figure 8). With this simple model, indicative estimates of erosion can be obtained using the following basic relationship:

Erosion = (SLR x L*)/h

Where:

SLR = sea-level rise (m)

L* = distance between the landward and seaward edges of the beach system

h = elevation difference between seaward and landward edges of the active beach system (being the sum of B + h* in Figure 8).

In simple terms, the model simple calculates the average gradient over the entire beach system and extrapolates this slope landward by the amount of sea-level rise to estimate erosion.

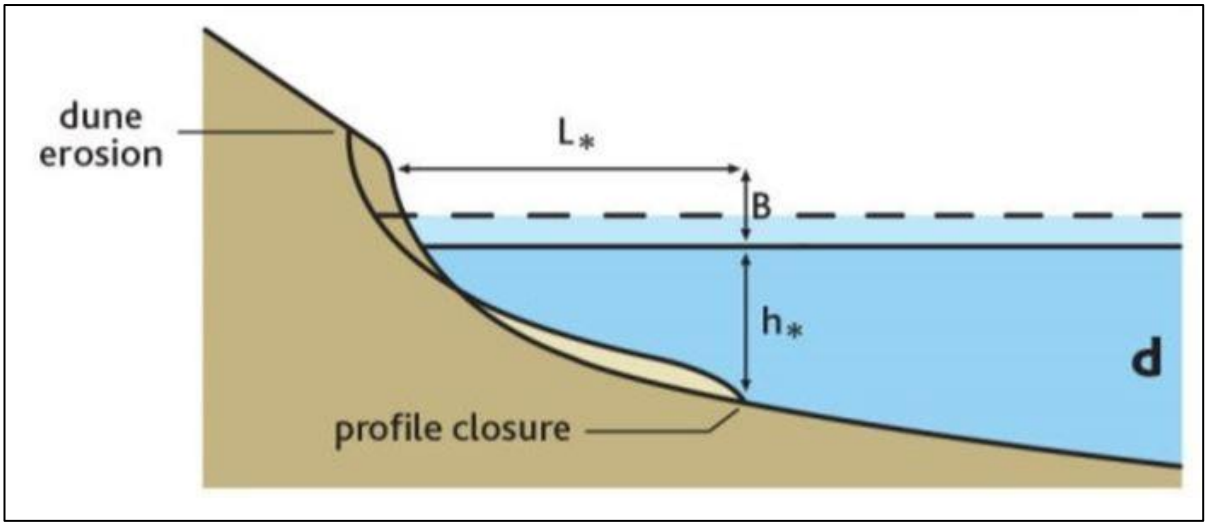


Figure 8: Schematic diagrams showing the standard Bruun Rule (modified from Figure 1 in Shand et al. 2013).

The model is simple and indicative only and there are numerous complications. For example, strictly speaking, the interconnected beaches of the open west coast and lower estuarine regions do not meet the conditions for the Bruun Rule; being complicated by longshore sand inputs and outputs. Wave climate changes could also change shoreline alignment giving rise to quite complex patterns of shoreline response including severe erosion in places and possibly accretion in others. Loss of sediment to ebb and flood tide deltas could be a further complication.

Application of the Bruun Rule on the open coast is also complicated by lack of information on the seaward edge of the beach system (i.e. depth of closure) and variation in average cross-shore slope and dune height. In near entrance areas, ebb tide deltas also complicate offshore bathymetry. However, using available bathymetric and topographic data for the open coast of the Waikato District in areas removed from harbour entrances and adopting a closure depth of 6-8m below Chart Datum suggests that erosion of approximately 75 m might occur for every 1.0 m of sea level rise. If the seaward edge of the beach system lies further offshore (e.g. about 10 m below Chart Datum) the erosion associated with 1 m sea-level rise would be higher (about 120 m). For this first pass assessment, a value of 75 m has been adopted but there is considerable uncertainty and the estimate is indicative only.

The full extent of this erosion will also only occur if there is a sufficient width of sand backing the shoreline. If erosion extends back to a cliff constructed of harder geology (for example), the Bruun Rule will no longer apply, and the rate of erosion will change.

On more sheltered sand beaches within estuaries, the average beach slope (typically 1V:15H-1V:20H) has been used in erosion calculations. In our view, this method is likely to provide lower order estimates in lower estuary areas adjacent to flood tide deltas (e.g. Waimanu Beach at Te Kopua, Raglan). In these areas, the beaches are part of an integrated sediment system which includes the flood- and ebb-tide delta systems. There are significant uncertainties in estimating the likely response of these beaches to sea level rise as there is potential for sediment to be lost not only to cross-shore adjustment of the beach profile (as per the Bruun Rule assumptions) but also to growth of the flood- and ebb-tide delta systems with sea level rise.

The simple two-dimensional geometric models assume that neither the cross-shore shape of the beach profile nor the plan shape of the beach system are otherwise significantly modified; as might occur if climate change affects other key drivers additional (e.g. wave climate; sediment supply/budget). Obviously, this is an area of considerable uncertainty, one of many relating to potential climate change effects. It is our view that any such changes on the Waikato coast are more likely to aggravate rather than offset or mitigate erosion. We therefore believe that the use of these simple geometric models to provide indicative estimates of erosion is not likely to significantly overestimate future erosional response. It is important to appreciate that (regardless of the assessment model used), estimates of shoreline response to sea level rise are always indicative only. Future monitoring and the use of adaptive management approaches are therefore critical to successful long-term management.

Cliffs

Projected future sea level rise is also likely to increase erosion of cliffs and banks; particularly in areas where wave action influences existing toe erosion rates. As sea level rises, the frequency and severity of wave attack increase at the toe of the banks/cliffs.

The influence of sea level rise on bank and cliff erosion rates is still an active area of research and while various methods have been proposed to estimate these effects the methods have significant challenges. Ideally, as Le Cozannet et al. (2014) argue, it is necessary to rely on local observations and models applicable in the local geomorphological context.

At this point in time, there are no models developed in the local Waikato context that can be used to predict the potential influence of future sea level rise on bank/cliff erosion. However, Ashton et al. (2011) propose the following generic cliff retreat framework/equation for the response of a wide range of cliffed shores to sea level rise:

$$R_2 = R_1(S_2/S_1)^m$$

Where R_2 is the future rate of toe erosion, R_1 is the historic (and presumed present) rate, S_2 is the projected future rate of sea level rise and S_1 is the historic rate of sea level rise. The constant m ranges from -0.5 (inverse feedback – damped erosion), through 0 (no effect) to 1 (instant response). This model is the best available approach for estimating the effect of sea level rise on future cliff erosion rates where wave erosion is the principal mechanism acting on the cliff face. However, the difficulty lies in choosing an appropriate value of the power function *m.*

On open coast sites with high rates of bank or cliff recession, the SCAPE (Soft Cliff and Platform Erosion) predictive model (m = 0.5) has provided reasonable estimates when tested against the known record of sea level rise and cliff retreat for various open coast soft cliffs in the UK; including The Naze, Essex (Walkden and Hall, 2005), NE Norfolk (Dickson et al., 2007) and the Suffolk Coast (Brooks and Spencer, 2010). However, a value of *m*=0.5 is probably too high for the Waikato coast where rates of cliff recession are slow on both open and estuarine coasts. Accordingly, a value of *m* = 0.4 has been adopted for this study.

Given an effective sea level rise of 1.0 m to 2120 and an historic rate of sea level rise of 0.2 m over the last century, this yields a multiplier of approximately 2 – suggesting that existing erosion rates could be doubled. In identifying the coastal erosion sensitivity areas, we have therefore assumed that the existing toe erosion rates will double in response to 1.0 m sea level rise. In reality, this may only likely to occur in areas with relatively soft and erodible banks, but nonetheless with the limited available data we feel it is prudent to acknowledge this possible increase in erosion rates on all cliffs and banks.

In defining the slope stability component of cliff erosion, we have adjusted the elevation of the toe of the bank by the relevant sea level rise. For instance, in estuarine areas the existing toe of bank is typically about RL 2.0 m and therefore in areas where 1.0 m of sea level rise has been considered, the stable slope has been calculated from RL 3.0 m.

4.3.2 Effect of Sea Level Rise on Coastal Flooding

Sea level rise is expected to greatly exacerbate the frequency and severity of coastal flooding over the next 50-100 years. Severe coastal inundation events that are currently very rare will become common with even relatively small sea level rise. The extent and severity of flooding during rare storm events will also be much greater in areas where coastal land is low lying; with areas not presently subject to coastal inundation likely to be affected.

4.4 Coastal Erosion and Flooding Hazard Areas

We have identified two coastal erosion and coastal flood hazard areas in areas of existing development:

- **High risk coastal erosion/flooding areas**, identifying the areas where there is significant risk from coastal erosion or flooding with existing sea level and coastal processes in the short term (within the lifespan of the District Plan).
- **Coastal erosion/flooding sensitivity areas**, identifying the areas potentially vulnerable to coastal erosion/flooding over the period to 2120, assuming sea level rise of 1.0 m.

The high-risk coastal erosion and coastal flooding areas are those areas which, in the absence of existing of future intervention, could reasonably be impacted by coastal erosion or flooding within the lifetime of the District Plan. This does not represent a "worst-case" potential coastal erosion or flooding area over this timeframe but identifies the areas at greatest risk and therefore of greatest priority for coastal hazard management.

Coastal erosion and flooding hazard reduce with distance inland and elevation (respectively). As we project coastal hazard beyond the short term, the uncertainty increases very considerably. The coastal erosion and flooding sensitivity areas are identified to highlight the much larger areas of land that may be vulnerable to coastal hazards over the next 100 years. These sensitivity areas reflect areas with uncertainty in regard to future coastal hazard vulnerability. It is important to note that these areas are not areas where coastal hazard has been identified with any certainty but are simply areas where further detailed investigation of coastal hazard is recommended prior to any future intensification of land use. In many of these areas, the uncertainty may preclude definitive identification of hazard areas even with more detailed investigation. Accordingly, adaptive approaches to land use and development will typically be required in most of these areas.

It is important to note here that (unless otherwise stated) we have generally calculated coastal erosion hazard areas as if coastal protection works such as seawalls were not present. This approach acknowledges the residual risk landward of the structure. In the development of adaptive management plans, the management of these hazard areas may reflect the presence of structures, but until such a plan is agreed, we cannot assume that the existing structures provide long term protection.

In the rural areas, we have only identified coastal hazard sensitivity areas. These sensitivity areas simply define the areas within which any future development (excluding non-habitable farm buildings) will require a site-specific coastal hazard assessment and potentially adaptable design.

<u>The criteria for identifying these hazard risk and sensitivity areas is summarised in Appendix A.</u>

5 BROAD MANAGEMENT RECOMMENDATIONS

This report recommends a range of measures for sustainable management of coastal erosion and flood risk in the Waikato District until relevant site-specific adaptive management strategies are developed. In discussing individual sites within the townships of Raglan and Port Waikato, we also provide commentary on possible measures that could be relevant to adaptive management strategies for these locations; to assist Council and community stakeholders in the development of site-specific adaptive management strategies.

These various management recommendations are based on a broad "hierarchy" of management approaches, implicit in national and regional coastal policy and developed to reflect the nature of the coastal environment, the likely responses of that environment to future climate change and the implications of different coastal hazard responses.

5.1 Risk Avoidance

Risk avoidance is an "ideal" approach to coastal hazard management to ensure long term sustainability and resilience. This approach is generally most relevant to the management of proposed new development.

In areas of existing development, there are still opportunities in some cases to relocate infrastructure outside of hazard areas, particularly where land parcels are large and/or where the existing hazard is not severe.

In the context of the Waikato District, a risk avoidance approach should be applied as the preferred approach wherever practical when:

- establishing major new infrastructure,
- undertaking major upgrades to existing infrastructure,
- considering applications for Greenfield development or any other significant intensification of land use

In the case of major new infrastructure or Greenfield development within the identified coastal erosion and flooding sensitivity areas, Council should ensure that any such proposal considers the impacts of coastal hazards over at least the next 100 years, including consideration of the RCP 8.5+ sea level rise scenario, to ensure that there will be no increase in the risk of adverse effects associated with coastal hazards in the future.

As discussed in Section 4.1.1, beaches are often a target for development, and historically this has occurred with insufficient allowance for natural coastal dynamics. Beaches are also particularly susceptible to the significant adverse effects of hard engineering works placed over time to protect the development. Public recreational and access values along the beach can be degraded when coastal protection structures are used to protect private property or other assets on land. These effects could become very severe with the aggravation of erosion expected to accompany projected sea level rise (4.3.1). It is therefore particularly important that Council takes a hazard "avoidance" approach to subdivision or development in currently undeveloped beach and wetland areas.

5.2 Risk reduction

Land use and development should be managed over time in high risk areas to implement approaches that reduce the risk from coastal hazards and the adverse effects of human responses to coastal hazard management.

In areas of existing development, it is recommended that Council develop appropriate policies and rules to reduce existing and future coastal hazard risk over time within the identified high-risk coastal erosion and flooding areas and to manage future hazard risk and associated effects in the coastal erosion and flooding sensitivity areas. Relevant risk reduction approaches include:

- development controls within identified coastal hazard areas to encourage dwellings and infrastructure to move landward away from high risk coastal erosion areas
- development controls that require adaptable design within coastal erosion sensitivity areas on beach shorelines and in coastal flooding sensitivity areas, to allow buildings to be moved landward or raised over time in response to changing hazard risk
- controls that require a site-specific geotechnical report in coastal erosion sensitivity areas on cliff shorelines to ensure future development is not at risk from slope failure.
- minimum floor levels in low-lying areas

In all cases where development or activities are restricted by these identified hazard areas, we recommend that the Council provides for the consideration of further, more detailed information including site specific coastal hazard studies, data on sub-surface geology, land stability investigations or detailed surveying of land levels etc., as relevant to the potential hazard. Such data may provide for a better understanding of coastal hazard risk at a site-specific scale.

In areas where existing development is located within the high-risk coastal erosion area, and there is insufficient space to relocate assets landward of these areas, a more detailed site specific plan is likely to be necessary to determine the most appropriate course of action, as described in Section 6 and Section 7.

It is relevant to note here that in terms of implementing minimum floor levels, where design provides for the house to be readily and practicably lifted at some future date, a lesser standard (than 100 years with sea level rise) can be adopted, though ideally minimum floor levels should be adequate for at least 50 years, including sea level rise of 0.4 m. Triggers tied to future sea level rise could be included in resource consent conditions and/or timeframes and appropriately recorded (e.g. on LIM data for the property) to ensure the dwelling will be further lifted if required in the future. Minimum floor levels should be sufficiently elevated above predicted flood levels to provide for water level fluctuations and wave effects ("freeboard"). This freeboard would vary depending on the setting but should not be less than 0.25 m.

Adaptability (e.g. buildings that can be practicably relocated and/or lifted if required) is a key consideration in reducing existing and future coastal hazard vulnerability. As such, we recommend that Council work with appropriate local professionals (e.g. architects, civil or structural engineers) to help develop and promote guidelines to encourage increased use of more adaptable design.

Ground levels will very likely need to be raised in coastal inundation hazard areas over time; in response to both significantly increased frequency and severity of flooding as sea level rises and complications from potential groundwater level changes (which are often strongly influenced by sea level in coastal settings). However, this a very complex consideration as ad hoc raising of ground levels can also aggravate existing and future coastal flood hazard for adjacent areas. Appropriate guidelines can therefore only be devised as detailed adaptive management strategies are developed and will need to consider coastal flooding, stream/river flooding (including overland flow paths) and stormwater flooding.

We also recommend appropriate development controls within the District Plan to ensure that any intensification of existing development is avoided in high-risk coastal erosion and flooding areas. In coastal erosion and flooding sensitivity areas, intensification should ideally only occur where a site-specific coastal hazard study demonstrates that there will be no increase in coastal hazard risk, and/or effective and sustainable management of the risk is provided for in an agreed adaptive management strategy that considers the full range of future sea level rise scenarios.

Risk reduction is rarely a standalone management approach, but the outcome of many other actions that may be taken within this hierarchy. Risk reduction over time is generally central to any long-term adaptive management plan.

5.3 Living with hazards

In some cases where avoidance of coastal hazard areas is not practicable, it may be acceptable to live with a coastal erosion or flooding hazard. This approach is potentially viable where:

- coastal hazards only affect the area periodically and do not prevent ongoing use of the area (e.g. land may be affected but not dwellings or infrastructure, coastal erosion associated with dynamic fluctuations rather than permanent retreat)
- where the environmental/social/economic impacts of protection measures are unacceptable due to the sensitivity or values of the natural coastline (i.e. high value beach, ecologically significant wetland) and these values outweigh the impacts of the hazard
- the affected area is not developed, or development is of low intensity and/or is resilient to the hazard.

Living with coastal hazards can often form part of a longer term dynamic adaptive plan, with associated triggers to move to an alternative approach when the extent or frequency of the hazard impact is considered no longer acceptable.

5.4 Enhancing natural buffers

Natural coastal systems such as beaches, dunes and wetlands provide considerable protection against coastal hazards. National Policy promotes the protection and enhancement of these buffers to aid in the management of long-term coastal hazards.

Maintaining, restoring and/or enhancing natural coastal features and buffers can be a valuable tool to preserve, preserve the natural and amenity values of the shoreline over time. These natural features/buffers could include:

- naturally vegetated riparian margins
- naturally vegetated dunes
- storm ridges on gravel shorelines

- beaches or cheniers
- saltmarsh and other coastal wetlands
- combinations of the above

Enhancing natural buffers such as beaches, dunes and wetlands can be viable and bring significant benefits where:

- natural buffers are already present or have been previously degraded (i.e. they used to exist)
- coastal erosion is dynamic and therefore natural dunes are required for shoreline recovery
- wetlands can provide protection from wave action and flooding on estuarine shorelines.

It is important to recognize that natural buffers are natural coastal systems and are only sustainable in an environment that is geomorphologically suited. That is, there is little value in constructing a buffer such as a wetland or dune in a setting where the coastal processes are not compatible with that feature (i.e. where that buffer would not naturally exist). While naturally functioning dunes provide a buffer for erosion and are critical to dune recovery between periods of erosion, they will not prevent erosion from occurring.

In the Waikato context, Council should manage future development in low-lying areas provide for restoration of coastal wetlands where these features have been lost historically and for landward expansion and migration of wetland habitats in response to sea level rise of at least 1.36 m (i.e. RCP8.5+). These habitats provide critical ecosystem services including protection against coastal flooding and erosion.

We recommend therefore that infilling of these areas be strongly discouraged within the coastal flooding sensitivity areas. However, it is also important that controls do not impact on existing farming activities, which are often very reliant of existing measures such as drains, bunding and flap-gated culverts. The adverse effects of these measures can be relatively readily reversed when and if opportunity for wetland restoration occurs. A co-operative approach is strongly recommended in working with farmers to avoid future wetland loss and, where practical, encourage wetland restoration. It is also recommended that policy development examine potential incentive mechanisms to encourage appropriate wetland restoration within these areas.

5.5 Soft engineering

Soft engineering approaches work with nature and aim to provide protection from coastal hazards while avoiding the adverse effects associated with hard engineering works. In many cases, soft engineering approaches will provide amenity and/or ecological benefits as well as hazard protection. Soft engineering approaches are most likely to be a viable approach where:

- the local wave environment is low to moderate (i.e. estuarine or sheltered coastal setting)
- the coastal setting is part of a relatively discrete, enclosed sediment transport system (for beach nourishment)
- there are important land-based assets that require protection (that cannot be relocated), but the shoreline is also highly valued for recreation/amenity/ecology

Soft engineering approaches in high energy open coast environments can be applicable if the value of assets to be protected are sufficiently high but are often prohibitively expensive and performance can be uncertain.

Approaches such as beach scraping and beach nourishment require ongoing maintenance and can only be applied in suitable circumstances.

Soft engineering approaches in sheltered environments can be cost effective and generate very positive outcomes. It is critical that soft engineering approaches are designed and implemented based on principles of coastal geomorphology and hydrodynamics and a clear understanding of the local coastal system. In some cases, it may be appropriate to combine soft engineering with “hard” approaches such as sand retention structures.

5.6 Hard engineering structures

“Hard engineering” refers to structures that act as barriers to natural processes in order to prevent erosion or flooding of the land. These approaches have historically been the first line of action in response to coastal erosion. These approaches include sea walls, rock revetments, breakwaters, groynes and offshore reefs.

The most applied hard engineering structures are seawalls such as vertical walls or sloping rock revetments. Unfortunately, seawalls have severe adverse effects on eroding beaches (Pilkey & Wright, 1988; Wright & Pilkey, 1989). By way of example, Figure 9 and the associated text illustrates the impact of a seawall placed on an eroding beach. It is very unlikely that hard protection works will be a viable approach to coastal erosion management on the open coast beaches of the Waikato District due to such adverse effects and the significant engineering cost. They are also unlikely to be appropriate on estuarine beaches within the district unless the adverse effects can be avoided or mitigated (e.g. by beach nourishment).

Over time, the adverse effects and long-term implications of hard engineering works have been increasingly recognised, and as such National Policy now emphasises the use of alternative approaches. This shift in emphasis in coastal planning and management is occurring globally. The current national policy broadly discourages the use of hard engineering structures for coastal erosion management due to the now well understood adverse effects that these structures can have on wider coastal values and the potential for these adverse effects to be increased significantly with future sea-level rise.

We therefore recommend the District Plan broadly discourages the use of “hard” coastal protection structures.

There will, however be circumstances where hard engineering works are an appropriate solution, particularly where there is significant coastal hazard risk under current conditions or within short time frames, and where adverse effects of the works can either be mitigated or avoided, or are outweighed by the benefits (considering both public and private values)

In the context of the Waikato District, these structures may be appropriate as a temporary or permanent part of a chosen management approach where they are part of an adaptive management plan that has been developed with the community. Such a plan would need to ensure long term sustainability and that an appropriate balance is achieved between private and public values.

Where hard engineering is judged to be the best practicable option, measures to avoid risk/damage should include:

- locating the structure as far landward as reasonably practicable

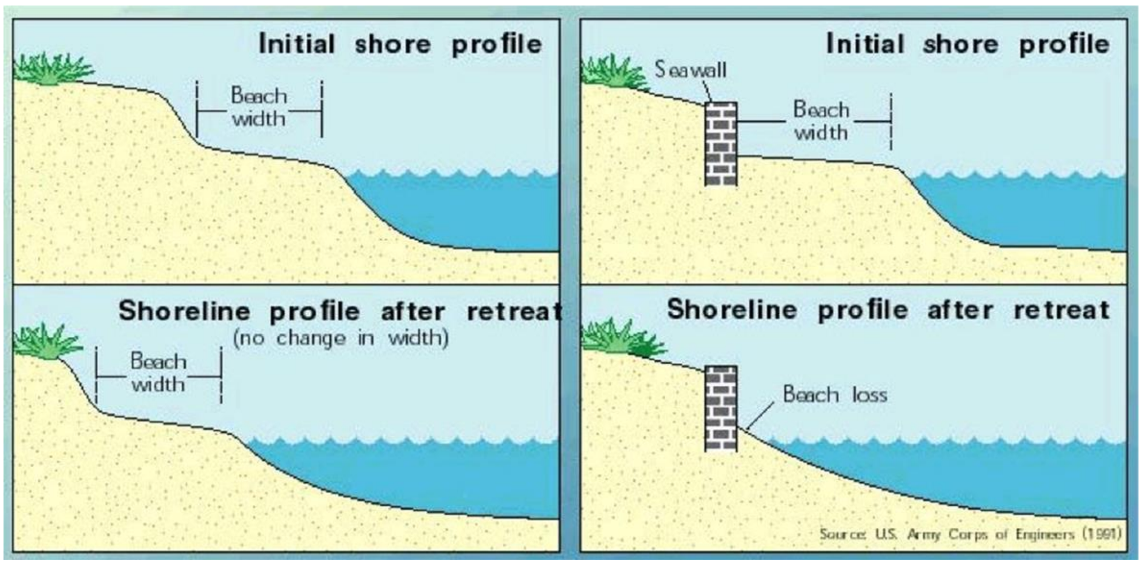
- using vertical structures where appropriate in preference to sloping structures to minimise seaward encroachment
- designing hard structures to resemble natural shorelines (e.g. in cliff settings) where possible to reduce natural character impacts
- minimising the length of the structure required
- ensuring environmental impacts are given sufficient weighting in location and design of the structure
- planning appropriately and using other measures to reduce the need for the structure over time.

Impact of Seawalls on Beaches

On a natural beach, the shoreline adjusts in response to a phase of erosion. The dune and high tide beach re-establish to landward and the recreational and ecological and amenity values of the beach and dunes are unchanged. Where the erosion is part of a natural cycle, over time the dune and beach will build slowly seaward and the erosion will be reversed.

If a seawall is constructed to protect the land from erosion, the seawall does not change the natural coastal processes driving the erosion. The seawall simply prevents landward movement of the dune. The erosion of the beach will continue, and with the profile unable to move landward, useable beach is lost.

A seawall separates the beach from the dune and interrupts the natural processes of beach recovery. Without a functioning dune, it is more difficult for the shoreline to recover from short term erosion. Loss of beach impacts on the recreational value of the beach as well as on natural character and ecological values.



As the beach level drops in front of the seawall, wave and tidal impacts on the seawall also increase. Larger waves can impact the structure, requiring more robust engineering to avoid wall failure. Beach lowering can also expose seawall foundations, or cause slumping of sloping rock structures. Seawalls often also cause increased “end effect” erosion of unprotected shorelines nearby.

Figure 9: The effect of placing a seawall on an eroding beach.

5.7 Adaptive Management Plans

Along some stretches of coastline within the established communities of Port Waikato and Raglan, extensive development and infrastructure already exists within identified coastal hazard areas. To prevent an ongoing increase in the level of risk and associated adverse effects, management approaches are likely to conflict with private use of the affected properties or with public values of the coast.

There is also much uncertainty about the long-term hazard, particularly with regard to the future effects of sea level rise. The issues are very complex and difficult, and it is not possible to simply avoid all coastal hazard risk in the short to medium term. In the past there has been a tendency to plan for either the “worst-case” or “most likely” scenario. While this approach is intuitively sensible, the huge uncertainties and long timeframes involved mean it can place unduly severe restrictions on current use of coastal properties and assets.

Reducing risk over time requires difficult decisions to be made about the long-term sustainability of development and structures in the risk areas and to establish a balance between public and private benefits and costs. In this context, the District Plan cannot alone provide the necessary outcomes and coastal hazards are best managed using an adaptive management approach. Adaptive management is a flexible approach to managing development, which can adjust in response to changes over time.

The aim of adaptive management is to transition over time to a more sustainable management approach while allowing for ongoing use in areas of existing development as the transition occurs. The intention is to develop a plan of actions that can respond to events as they occur (e.g. rates of sea level rise) without requiring unnecessarily drastic changes in the short term based on the worst-case scenario.

Adaptive management aims to be sensitive to the community and its aspirations, and local variations in aspirations and sensitivities to increasing risk. It also helps to cope with uncertainty by establishing trigger or decision points with the community and making a plan to implement these in both the short and long term.

There are five key stages to adaptive management:

1. building a shared understanding (processes, hazards, community resilience)
2. exploring the future and how communities are affected and identifying objectives
3. building adaptive pathways manage risk sustainably over time
4. implementing the strategy in practice
5. monitoring the strategy using early signals and triggers (decision points) for adjusting between pathways.

Where existing development is located in an area at risk from coastal hazards, there is often a conflict between the preservation of private and public assets. The development of such a plan requires the community and stakeholders to agree on long term outcomes and to identify appropriate signals and triggers to initiate the staged integration of the plan. Establishing an adaptive management strategy at sites such as the ocean beach at Port Waikato and the most developed sites in Raglan will be challenging and will take time and requires patience and open dialogue. Ongoing commitment is also required to keep the strategy live and relevant over the planning timeframe.

6 PORT WAIKATO

Port Waikato township is primarily located on a large sand spit on the southern side of the Waikato River entrance, with parts of the settlement and Cobourne Reserve also located on Putataka (a large headland extending into the river just north of the present wharf) (Figure 10).

For the purposes of hazard assessment and reporting, we have divided Port Waikato Township into three broad compartments:

1. Port Waikato Township – including both the ocean and river foreshore of the township.
2. Maraetai Bay – a sheltered estuarine embayment
3. Putataka Headland (Cobourne Reserve).

Figure 10: Port Waikato Township

6.1 Port Waikato Township

6.1.1 Coastal Erosion Hazard

The Port Waikato sand spit is known to be a very dynamic feature and has extended northwards considerably since the earliest available survey of 1863 (Dahm, 1999; Earthtech, 2006; Tonkin and Taylor, 2007 & 2009; ASR, 2007). The present main river entrance is located over 3,200 m north of the entrance position surveyed in 1863 (Figure 11). There is also evidence of significant earlier changes. For instance, Smith (1878) reports being informed by local Maori that the coastline between Manukau Heads and Port Waikato once extended much further seaward, projecting in a curved line and composed of low sand country with numerous sand dunes, freshwater lakes and clumps of tall manuka. There is also evidence that the river entrance channel was once hard against the hills on the southern side of the township, field inspections indicating wetlands and low-lying areas that appear to have been a former channel. Similar evidence was noted by ASR (2007).

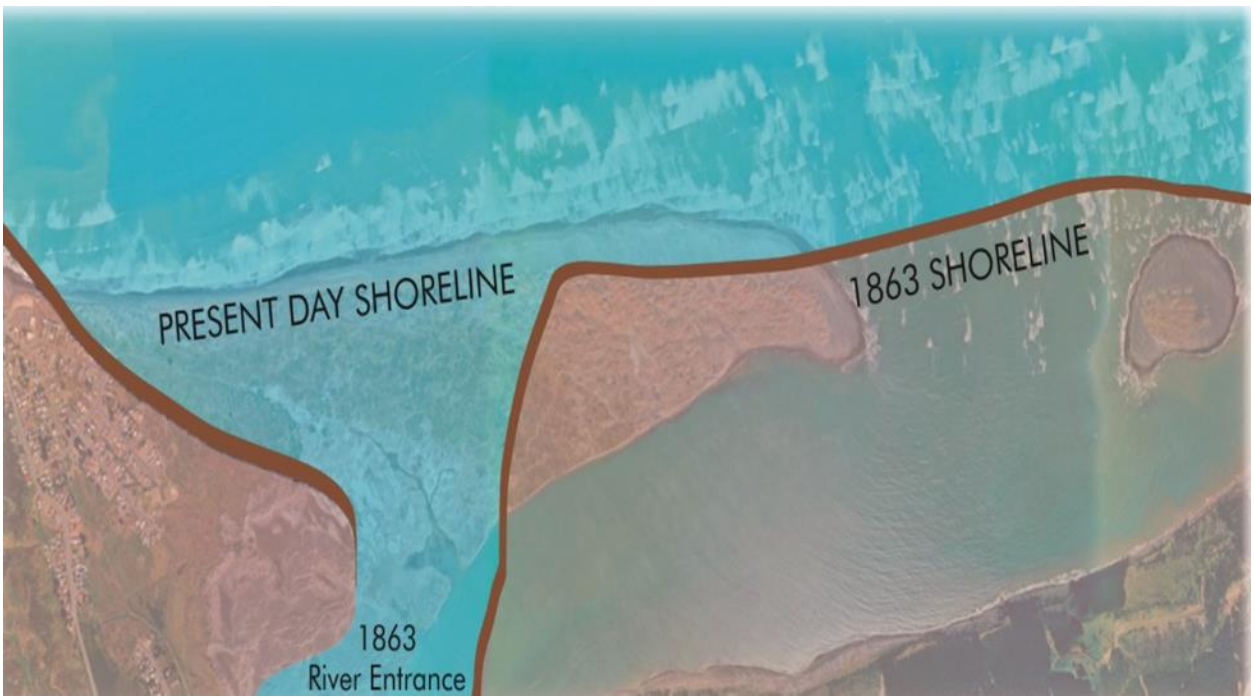


Figure 11: Overlay of the 1863 and a relatively recent (1990s) shoreline. Note the severe erosion of the 1863 shoreline that has accompanied the northward growth of the spit. Source – Waikato Regional Council

Tonkin and Taylor (2009) note that spits are dynamic features by nature with a cycle generally following a sequence of:

- growth in the direction of longshore transport
- potential breach at a relatively narrow or low-lying section
- post breach spit extension in the direction of net longshore transport.

Accordingly, over very long periods of time, much or all of the spit may be periodically eroded and rebuilt. Tonkin and Taylor (2009) argue that the risk of a breach affecting the township is low, with any future breach likely to be further north. One factor supporting this argument was the control on river channel position exerted by the Putataka headland. They also note that carbon dating of a single shell from a shallow core indicates that the township area has been relatively stable over approximately the last 6000 years.

Nonetheless, given the significant changes to the spit over the period since 1863, the large-scale changes in the area in earlier human history reported to Smith (1878) and the old river channel along parts of the southern margin of the township, we believe caution is warranted until further investigation has more firmly established the dynamics of the spit over century and longer timeframes. We must therefore assume the township could be affected by future large-scale changes to the spit.

In the period since the earliest vertical aerial photography of 1942, large-scale changes have continued and the spit at Port Waikato has changed in size and shape and extended northwards; now approximately 1,200 m longer than it was in 1943 (Figure 12). An equivalent amount of erosion has occurred on the northern shore of the river mouth. This location of the river mouth appears to have largely stabilised since 2002 and there have been relatively small changes in the length of the spit in the last 15 years.

Over this same period (1942-2002), the overall width of the spit increased by up to 300 m in some areas, including accretion on the ocean beach near the township in the order of 100 m between 1943 and 2002 (Figure 14). Over the last 10 years however, this trend for accretion has reversed and since 2007, there has been erosion of approximately 50 m fronting the township (i.e. the houses and Surf Club on Sunset Beach). A broadly similar pattern of erosion has occurred along the length of the Port Waikato spit.

At present (2019), the erosion along the ocean shoreline of the township appears to be continuing (Figure 13); with WRC shoreline mapping data indicating the average rate of shoreline retreat over the last 10 years being just over 5 m/yr. The landward edge of the spit has also experienced severe erosion in places, particularly near the apex of meander bend on the landward edge of the spit; the erosion in this vicinity over the last decade varying alongshore but commonly averaging at least 5-10 m/yr.

However, the ocean shoreline of the township is still seaward of the 1942 shoreline (Figure 14) and so the recent erosion might simply be associated with multi-decadal shoreline fluctuations; in which case it would likely eventually slow or stop and may even be followed by a period of shoreline recovery

On the basis of the available information and the present relatively poor understanding of the dynamics of the spit over multi-decadal and multi-century timeframes, it is not yet possible to reliably predict future shoreline trends and associated coastal erosion hazard.

The uncertainty in regard to future erosion is illustrated in Figure 15 which shows (by way of example only) various potential future scenarios with different erosion rates and timeframes. It can be seen that even with average erosion rates as low as 1.5 metres per year, erosion could extend considerably landward into the township over the next century. Obviously, if the much higher erosion rate experienced over the last decade (5 m/yr) were to persist longer term, much more severe erosion would be experienced. Equally, if the erosion is simply part of a multi-decadal shoreline fluctuation, much lesser erosion might occur and eventually some recovery.

Figure 12: Recent aerial photograph of Port Waikato Township and spit. The yellow line illustrates the position of the shoreline in 1942. The scale of shoreline change over many decades is clearly evident.

Figure 13: Erosion fronting the car park and private properties at the southern end of Sunset Beach.

Potential future sea level rise adds additional uncertainty to long term projections of shoreline change. As discussed in Section 4.3.1, the complex and interconnected nature of open west coast beaches such as Sunset Beach at Port Waikato makes it very difficult to predict long term response to sea level but it is reasonable to assume that quite significant aggravation of erosion may occur. This erosion is likely to be in the order of 75 m erosion for every 1 m of sea level rise.

Overall, the uncertainty precludes any reasonable prediction of future erosion and accordingly any reliable or accurate mapping of erosion hazard areas. However, a cautious approach is sensible given the large-scale changes which have characterised this area historically, the very high rates of erosion that have occurred since the early 2000s (on both the landward and seaward sides of the spit) and the potential for aggravation of erosion by projected future sea level rise.

The **high risk coastal erosion hazard area**, the area that could potentially be impacted within timeline assumed for a District Plan, has therefore assumed an average erosion rate of 5 m/yr over the next 10 years (i.e. the average erosion rate of the last decade). In terms of the 100 year planning timeframe and a sea level rise scenario of 1.0 m, consideration has to be given not just to current erosion rates along the ocean shoreline and parts of the river shoreline but also potential large scale changes (e.g. possible spit breaches) and the potential sea level rise. Accordingly, we recommend that the entire spit be defined as a **coastal erosion sensitivity area** for this planning timeline. It is very important to emphasise that this is not a prediction that the entire spit may be eroded but simply an indication of the high level of long-term uncertainty.

Figure 14: Shoreline change at Port Waikato Township. The current shoreline is still seaward of the 1942 shoreline location.

Figure 15: Potential future shorelines at Port Waikato. These shorelines are based on historical shoreline change rates and illustrate a range of possible futures.

6.1.2 Coastal Flooding Hazard

The frontal dunes at Port Waikato Township are sufficiently elevated to be at little or no risk from coastal inundation with current sea level and following 1.0 m of sea level rise. Further landward however, there are large areas of the Township that could experience coastal inundation during an extreme storm event; via hydraulic linkages though low-lying areas on the landward margin of the spit (Figure 16). Currently such flooding events would be very uncommon, but even with minor sea level rise these impacts could become relatively frequent. Observations by residents suggests that during periods of high storm surge with very large ocean swells, wave run-up can affect lower areas of the carpark. These effects are currently minor and occasional but may become more severe with future erosion of the shoreline, and by future sea level rise, causing additional flooding hazard to lower lying areas to landward (Figure 17).

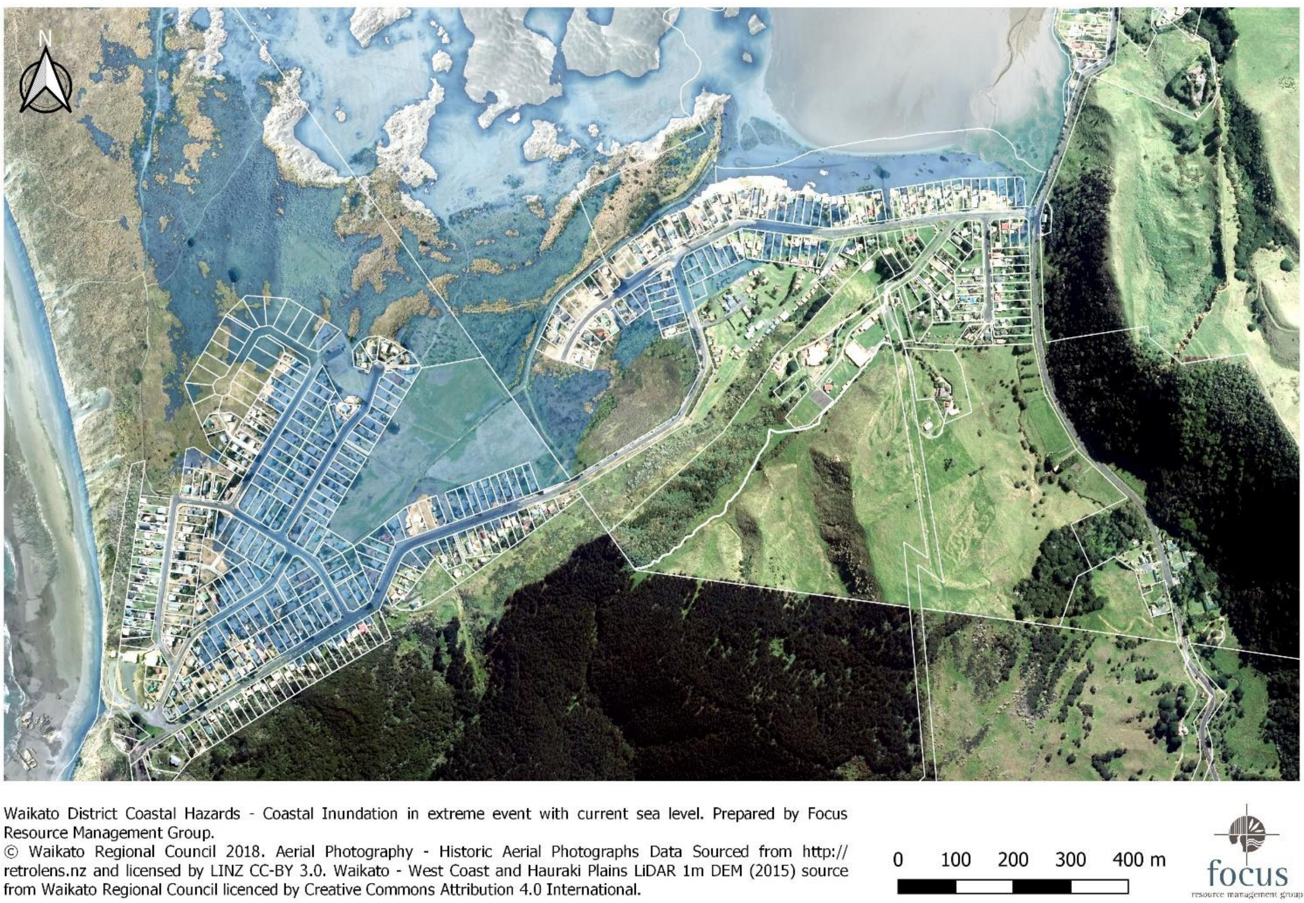


Figure 16: Areas of land below the elevation of coastal inundation in an extreme storm surge event (3.1 m MVD '53). For discussion of levels see Section 4.2.

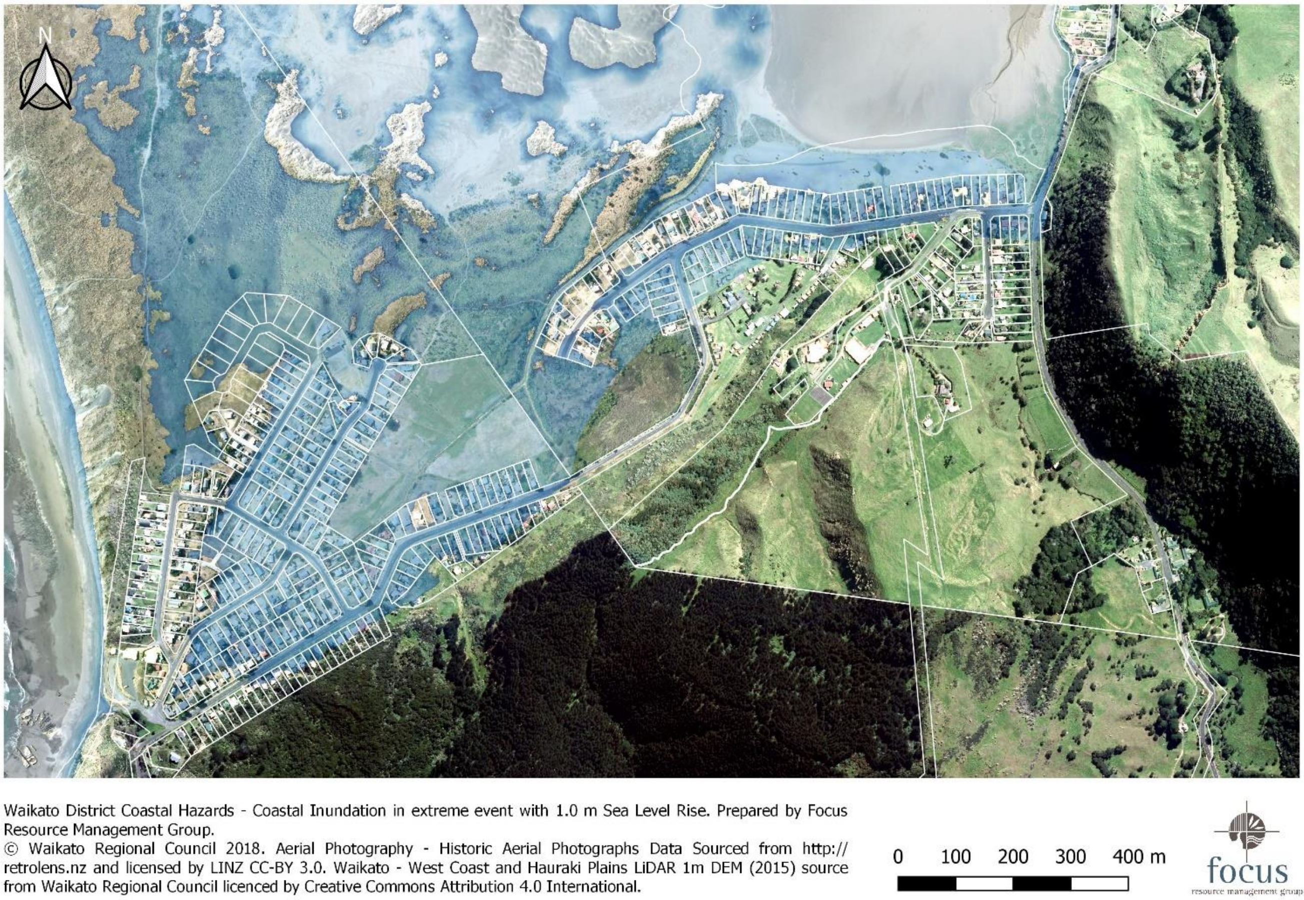


Figure 17: Areas of land below the elevation of coastal inundation in an extreme event with 1.0 m of sea level rise (4.1 m MVD '53). For discussion of levels see Section 4.2.

6.1.3 Management Options and Recommendations

The erosion hazard analysis highlights that there is great uncertainty about whether existing erosion will continue and, if so, at what rate. There are many plausible future scenarios for Port Waikato. It is not possible (or reasonable) to predict one most likely future shoreline position for any given timeline.

The analysis also indicates that if the current erosion trend were to continue over the next 100 years, significant areas of the township could be affected. The more seaward assets (e.g. the car park at the southern end, hall, surf lifesaving club and the private properties seaward of Ocean View Road) could be severely impacted or lost within the 10-20 year timeframe assumed for the proposed District Plan; even if erosion rates slow to only half those observed over the last decade. If recent erosion rates continue these assets could be threatened in the very near future.

The options available to stop erosion along the ocean shoreline are very limited and are not likely to be practicable at this site. For instance, use of hard protection (e.g. a rock wall) would be very expensive (probably >$10,000/m, possibly significantly more) and would impact severely on public values of the popular public beach with ongoing erosion, due to effects such as those illustrated and discussed in Section 5.

Soft protection (e.g. beach nourishment held in place by shore perpendicular groynes or by offshore reefs) would likely be prohibitively expensive relative to the assets most at risk. Beach nourishment would require vast volumes of sediment at this low gradient dissipative beach, and would come with huge capital cost, great uncertainty and ongoing maintenance costs even if a local sediment source could be found. The high energy, interconnected nature of the local environment would mean that any placed sediment would be rapidly lost alongshore unless held in place by groynes and/or offshore reefs; which structures would be extremely expensive in this high energy environment. Even if practicable, the total cost of protecting the approximately 400 m ocean foreshore of the township would likely be in the order of at least $40-50 million and possibly considerably more; likely disproportionate to the value of the assets to be protected and the ability of the local community and/or Council to support.

It is therefore unlikely to be practicable to hold the line if the erosion trend continues, and assets will have to be progressively retreated over time as they are threatened. As part of the District Plan review, community meetings at Port Waikato were well attended, by both beachfront residents and the wider community. Many landowners acknowledged that some Port Waikato properties may not be viable in the long term if erosion continues. However, it was emphasised that they wish to continue to use their properties for as long as possible.

Landward adaptation is likely to be most effectively achieved by way of an adaptive management strategy developed with the affected landowners, iwi and other relevant stakeholders. This strategy will likely have to address:

- thresholds and triggers for relocation of assets as required
- provisions to provide for reasonable use of the properties while practicable, without incurring liability for the wider community
- whether there is compensation and/or alternatives for affected landowners.

In the interim, we recommend that the Council limits ongoing risk by including provisions in the District Plan that:

- **Prevent any further subdivision or intensification anywhere on the sand spit** (e.g. non-complying or possibly even prohibited activity status). If applications for such activity are provided for in the proposed District Plan, it is important to require a legally enforceable adaptive management strategy (or other suitable legal instrument) prepared at the applicant's expense requiring relocation of dwellings and (if required) abandonment of properties in the event that the dwelling(s) and/or practical use of the property is threatened by erosion, with mandatory trigger requirements specified. These various requirements should be noted on LIMs and elsewhere as required to ensure that prospective purchasers are aware of the risks.
- **Promote adaptable dwellings:** Given the existing and potential future issues with both coastal erosion and (longer term) coastal inundation, it is important that the proposed District Plan include measures that promote dwellings and other assets that are readily able to be both moved and/or lifted if required at some time in the future. These requirements are relevant over the entire area of the spit.

- **In the high-risk coastal erosion area**, it is recommended that these requirements are mandatory for any upgrade or replacement of existing dwellings and other buildings, together with clear triggers that specify when the building must be relocated further landward. While relocatability triggers may vary with property and dwelling, it is recommended that a minimum mandatory trigger be imposed (e.g. 10 m from the top edge of an erosion scarp) unless a lesser trigger is supported by advice from a suitably qualified expert (e.g. an engineer, architect or building removal specialist). Damage waivers to exempt Council from any liability (e.g. in the event the owner fails to move the dwelling in time) are also recommended.
- **In the coastal erosion sensitivity area** (remainder of the spit), adaptable buildings should be actively encouraged and non-adaptable buildings (i.e. buildings not able to be readily relocated or lifted) subject to specification of action that will be taken in the event the dwelling is ever threatened by erosion (e.g. removal at owner's expense). Ideally, non-adaptable dwellings should also be subject to a mandatory s72 hazard notification.

- **Provide minimum floor levels for any new dwellings or renovation in identified coastal flood hazard areas.** If the dwelling is not able to be practicably/readily lifted, the minimum floor level should provide protection from extreme storm events including allowance for 1.0 m sea level rise and a suitable freeboard (the latter likely to vary with location but not <0.25 m). A lesser minimum standard could be adopted if the dwelling is able to be practicably and readily lifted as discussed in Section 5.2.
- **Encourage the development of an adaptive management strategy.** For instance, the proposed District Plan could provide for the above controls, where appropriate, to be waived in favour of the provisions of any future agreed and Council-approved adaptive management strategy; as it is likely that such a strategy will provide far more effective and flexible management of coastal hazard risk.
- **Dune restoration be actively encouraged.** Appropriate dune restoration is likely to play a useful role in any adaptive management strategy developed at this site to assist in the management of coastal hazards. For instance, dune restoration within Maraetai Bay and other low-lying areas along the river side of the spit could potentially assist in reducing coastal flood hazard risk by reducing hydraulic connectivity. If the present erosion trend along the ocean foreshore ceases at some future date, then dune restoration in this area will also encourage more rapid dune repair. It is therefore recommended that all activities associated with Council supported dune restoration (e.g. Coastcare) be a permitted activity in the proposed District plan, including earthworks where required. Earthworks are commonly required to fix damaged dunes and these earthworks present no significant issues in properly managed dune restoration.

6.2 Maraetai Bay

6.2.1 Coastal Erosion Hazard

Coastal erosion may have occasionally been experienced within Maraetai Bay but currently presents no significant hazard and is simply part of normal shoreline dynamic fluctuations. Historical data contains no clear evidence of significant fluctuations (i.e. periods of erosion and subsequent shoreline recovery) indicating any such changes in the past have been less than 5 m. There has been no long-term trend for erosion observed.

With future sea level rise of 1.0 m, erosion may be aggravated – probably by up to approximately 15 m (see Section 4.3.1).

In addition, eastwards migrating dunes are slowly infilling the bay on the western side and have narrowed it considerably since 1942 (Figure 18). The river shoreline immediately west of Maraetai Bay has also significantly accreted since 1942, which tends to suggest some movement of the river channel away from the shoreline in this area.

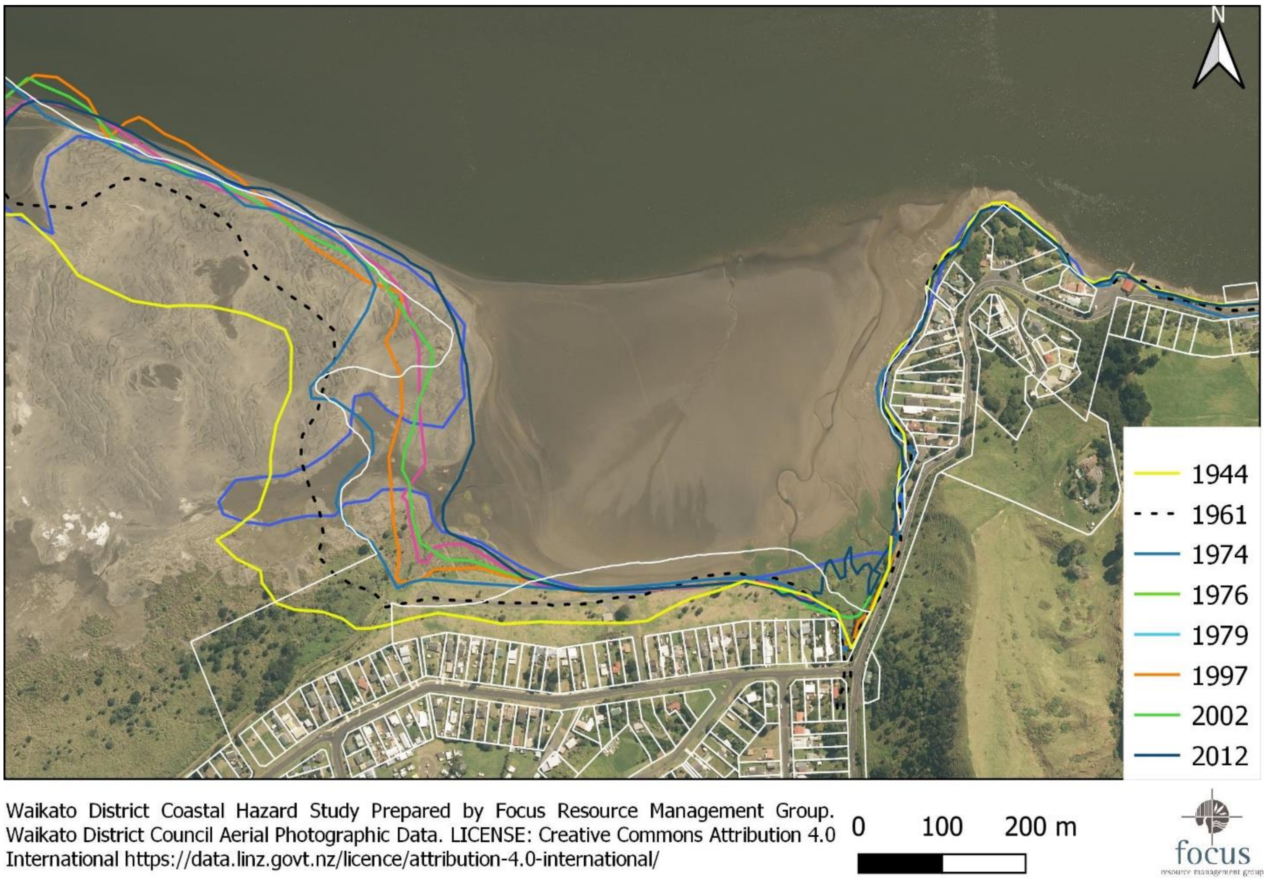


Figure 18: Historical shoreline change at Maraetai Bay at Port Waikato.

6.2.2 Coastal Flooding Hazard

The coastal margin around Maraetai Bay is very low-lying in many areas, particularly along the western side and the head of the bay. These low-lying areas provide a hydraulic conduit between the bay and the township.

With existing sea level, the risk from an extreme coastal flooding event is limited to localised areas (Figure 16). However, with 1.0 m of future sea level rise, flooding through the low-lying areas around the bay could affect much of the township (Figure 17). Accordingly, flooding through these low-lying areas are likely to become an increasingly significant issue with future sea level rise.

6.2.3 Management Options and Recommendations

Coastal erosion hazard presently poses no significant threat to the wide reserve and we strongly recommend that it should be lived with to maintain the amenity and natural character of the beach. In the longer term, there is potential for sea level to aggravate erosion. However, in this setting, any such aggravation of erosion could be relatively easily and cost-effectively managed using beach nourishment with local dunes as a sand source. For these reasons we have not recommended the implementation of coastal erosion hazard areas at the present time.

The migrating dunes progressively infilling the bay along the western margin may over time effect the recreational value of the Bay but also provide increased protection from coastal erosion processes.

The low-lying coastal margins provide a hydraulic conduit through which significant areas of the township could be exposed to increasing coastal flood hazard at the township with projected sea level rise.

We believe the various issues around Maraetai Bay are most effectively addressed as part of the adaptive management strategy, developed with the Council and local community and other stakeholders. Dune restoration and improved dune management is likely to be a particularly useful activity in this area; to assist in arresting migrating dunes along the western margin and lifting the coastal margin over time to reduce hydraulic conduits for coastal flooding.

Obviously, there are also important local hydraulic conduits which will need to be maintained (e.g. small natural waterways discharging to the bay). In the longer term with projected sea level rise, additional measures may eventually be required on some of these natural waterways to prevent or reduce ingress of coastal flooding.

Recommendations in respect to managing land use on the spit are as discussed in Section 6.1.3 above.

6.3 Putataka Headland

Various private properties and the Cobourne Reserve are located on a small headland extending out into the river from Putataka, a locally and culturally very significant hill. The Cobourne Reserve occupies the seaward end of the headland and there is a wide public reserve around the coastal margin (Figure 19).

Figure 19: Aerial view of the Putataka Headland with property boundaries overlaid.

6.3.1 Coastal Erosion Hazard

Historical shoreline mapping data indicates that there has been very little change in shoreline position since the 1940s (Figure 18). Field inspection indicates that the headland appears to be composed of relatively erosion resistant material and is eroding only very slowly. Steep erosion escarpments do however occur in many places around the coastal margin, indicating that some erosion does occur from time to time, with the more active erosion occurring in the more exposed areas of the headland extending into the river, including the margin of Cobourne Reserve. Judging from available data and field inspections, we believe existing natural toe erosion rates probably average in the order of 1-2 m per century and believe a figure of 2.5 m per century is likely to be adequately conservative for natural unprotected areas for planning purposes.

There are a number of ad hoc coastal protection structures around the base of the headland. It is not entirely clear how important these structures are in preventing erosion. In many cases, these structures are also related to significant private encroachment onto public reserve land. Detailed site-specific assessment would be required to estimate the likely erosion that would occur if these structures were removed as some may be backed by placed fill that could erode more rapidly than the natural banks.

In the interim, when identifying the **high-risk coastal erosion area**, we have adopted 2.0 m of toe erosion to allow for sea wall effects and a steep stable slope of 1V:1.5H for natural unprotected banks.

Future sea level rise will increase the frequency that the bank is exposed to coastal processes and may stimulate a trend for more active coastal erosion around the margin of the reserve. For projected sea level rise of 1.0 m, we have assumed a doubling of existing erosion rates as per earlier discussion (see discussion of potential effect of sea level rise on cliff erosion in Section 4.3.1). The **coastal erosion sensitivity area** therefore is defined by an average rate of erosion of 5 m per century, and an allowance for a stable slope of 1V:2H.

Figure 20: Putataka Headland.

6.3.2 Coastal Flooding Hazard

Most existing development on Pututaka Headland is sufficiently elevated to be above the level of likely storm surge with current sea level (Figure 16). Low lying areas are generally located within marginal reserves, and while currently privatised in many places, do not indicate risk to private property or dwellings.

While the current risk is low, there are several properties that may be at risk from coastal inundation during storms with 1.0 m or more of sea level rise (Figure 17).

6.3.3 Management Options and Recommendations

With current sea level, it is likely that erosion would continue to be completely contained within the existing public reserve even over a period of up to 100 years. With projected sea level rise of 1.0 m over the next 100 years, erosion could extend slightly within some properties, but would not be sufficient to preclude reasonable use of the property. Accordingly, it is likely that erosion can be managed without the need for hard engineering works and Council may wish to work with affected landowners to remove existing structures over time. If landowners wish their structures to remain, they should over time be moved landward onto private property except where Council considers the structures usefully contribute to public access and use of the reserve and foreshore. There is potential to greatly improve public access to this area over time through management of these effects.

In the Cobourne Reserve, it is recommended that existing shrub and tree plantings close to the edge which are presently being undermined by erosion be replaced with plantings further landward where it is desired to maintain shelter along the coastal margin. The existing residential sections are sufficiently deep to make living with erosion a viable option in the foreseeable future in most cases. Accordingly, we believe development controls discussed in Section 5 are adequate for management of erosion risk to private development within the hazard areas.

7 RAGLAN

Figure 21 provides a broad overview of the Raglan township area, including areas of existing and future urban development.

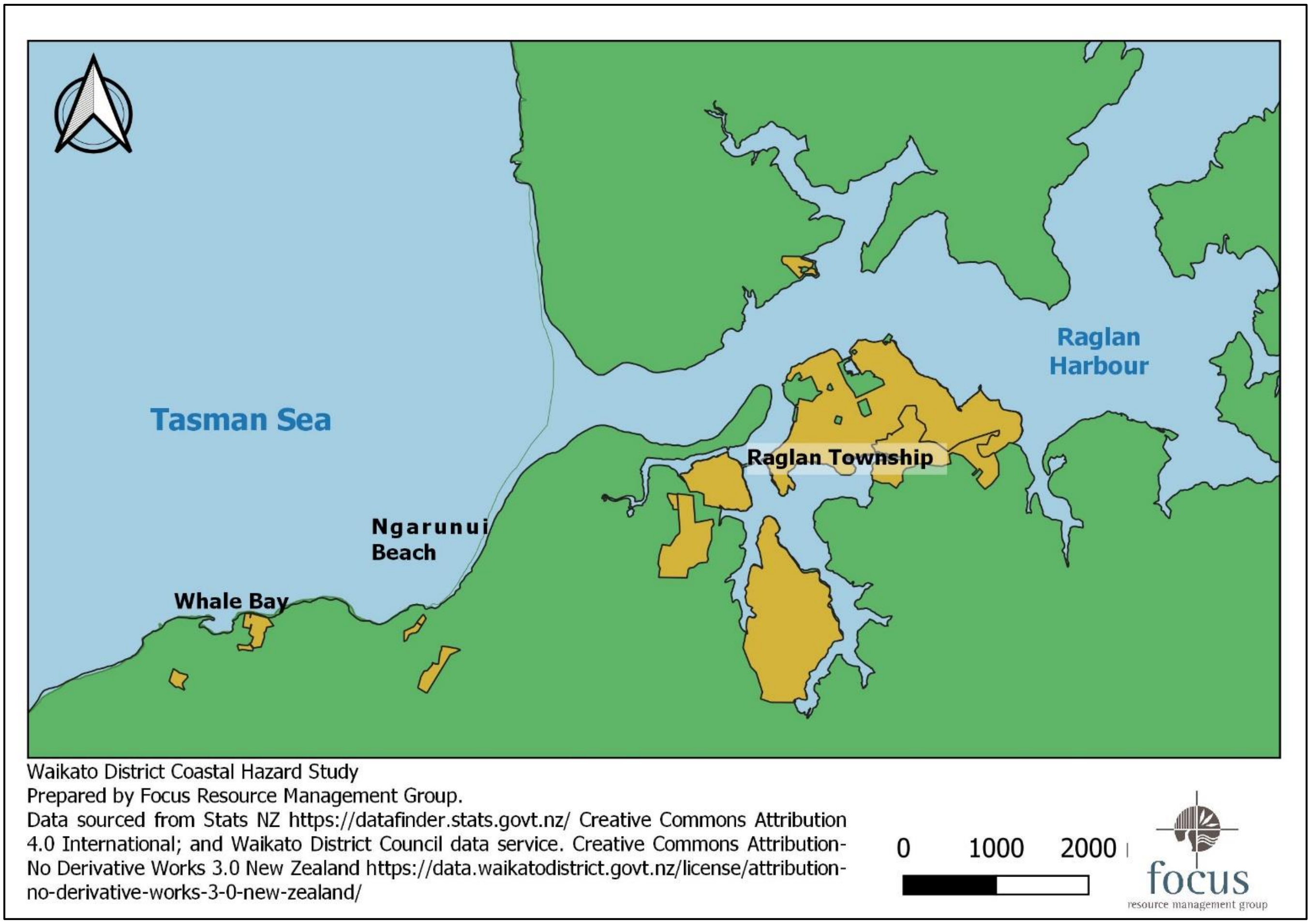
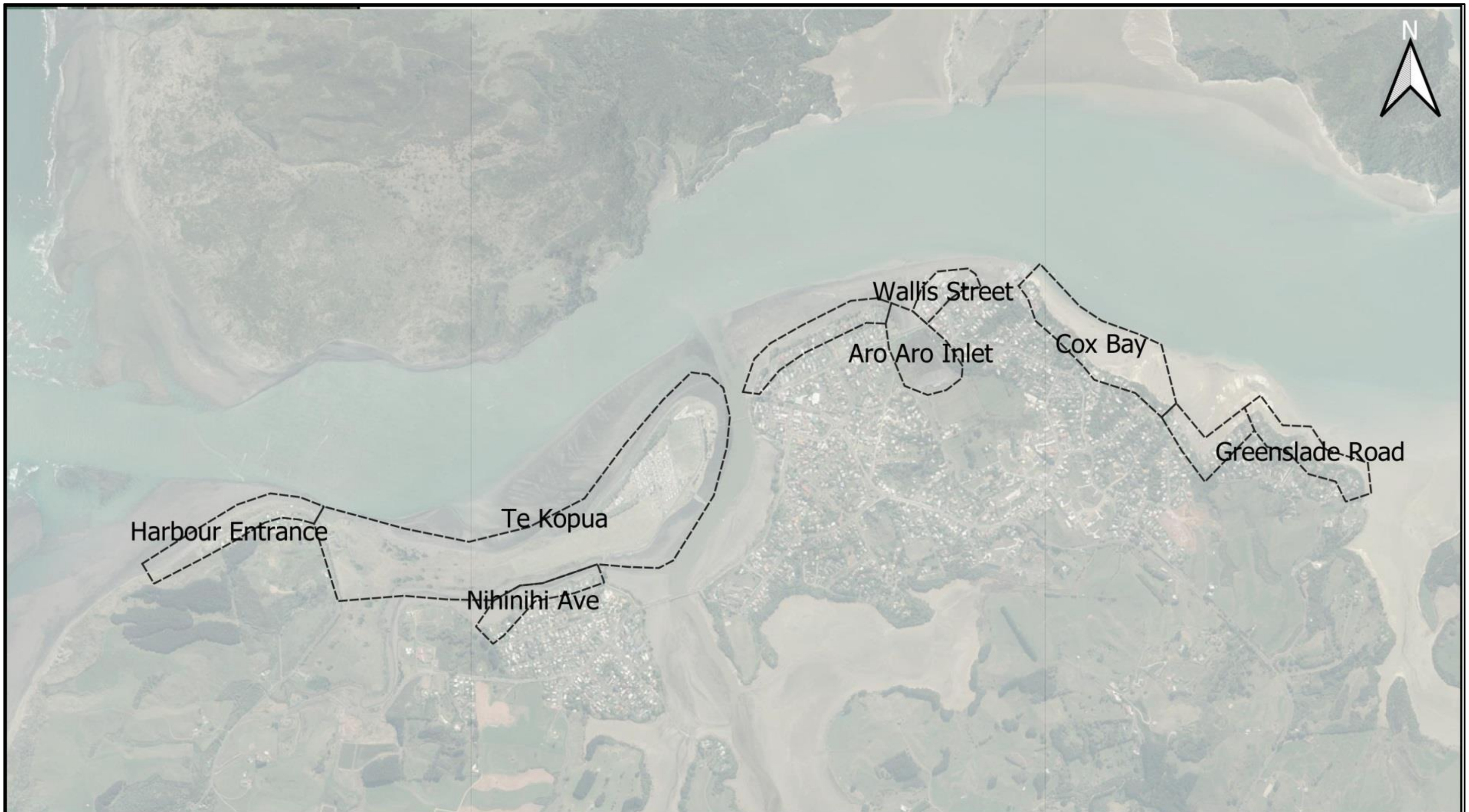


Figure 21: Overview of Raglan township area showing areas of existing and future development (orange) and areas generally zoned for rural or conservation land use (green)

The coastal environment in the township and surrounding area is diverse and complex. For the purposes of hazard assessment and reporting, we have divided the area into the following broad management areas (see Figure 21 and Figure 22):

1. **Whale Bay and Manu Bay:** exposed open coast backed by residential development on a steeply sloping bank.
2. **Harbour Entrance**: sandy open coast beach and dynamic harbour entrance area backed by sand dunes. Low intensity development and reserve.
3. **Te Kopua**: low lying sand spit backed by low intensity development, including airfield and campground. Recreationally important area currently experiencing erosion in some areas.
4. **Wainui Stream – Nihinihi Avenue**: area of residential development fronted by a steeply sloping bank with many coastal protection structures. Sheltered estuarine environment.
5. **Cliff Street**: important coastal reserve in the town centre. Steep low bank with ongoing slow erosion in unprotected areas.
6. **Aro Aro Bay and Inlet**: highly modified (drained) coastal wetland with extensive low-lying areas including some used for sports grounds. Small low lying and potentially erodible recreational reserve at the mouth of the inlet.
7. **Wallis Street**: residential development with narrow reserve and many historical coastal protection structures.
8. **Cox Bay**: residential development on elevated cliffs, fronted by shore platform.
9. **Lorenzen Bay**: existing residential development on low lying flats backed by coastal cliffs. Many historical structures and difficulties with coastal flooding and access.
10. **Greenslade Road**: narrow beaches backed by steep slopes and residential development on cliff top.



Waikato District Coastal Hazard Study Prepared by Focus Resource Management Group. Waikato District Council Aerial Photographic Data. LICENSE: Creative Commons Attribution 4.0 International https://data.linz.govt.nz/licence/attribution-4.0-international/

0 500 1000 m

focus
resource management group

Figure 22: Broad coastal management areas in Raglan Harbour.

7.1 Whale Bay

This area includes the short length of shoreline fronting the small community at Whale Bay but excludes the area of the boulder spit and sand flats at 108c Whanga Road which has its own site-specific coastal hazard provisions approved by the Environment Court.

7.1.1 Coastal Erosion Hazard

Detailed evaluation of shoreline change at Whale Bay is difficult due to the limited features available for orthorectification of old historic aerial photographs. Shorelines digitised from these photographs therefore contain considerable error and cannot be used to calculate erosion rates. However, qualitative analysis using photographs dating from the 1940s indicate that the shoreline at Whale Bay has experienced very slow rates of shoreline erosion over the historical record. Erosion-induced slope instability appears to be very rare and banks along the shoreline are generally steep.

Field inspections and community information indicate that the coastal margin is subject to periodic bank erosion during severe storms, with a steep scarped bank along the edge of the grassed reserve fronting much of the developed area. The bank, composed largely of natural materials including colluvium (though there is also evidence of fill placement in some areas), appears from available evidence to be eroding relatively slowly.

Figure 23: View of vegetated erosion scarp fronting the grassed reserve in Whale Bay township

The average rate of toe retreat is estimated to be less than 5 m per century, though community advice indicates that localised erosion can be severe after rare and major storms. Accordingly, in identifying the **high-risk coastal erosion area** we have allowed for up to 2.0 m toe erosion over the short period (up to 20 years), together with failure to a relatively steep stable slope (1V:1.5H). This suggests erosion is unlikely to extend more than 5-7 m landward of the existing toe of bank in the short term and we have adopted the upper end value in plotting the high-risk area.

In defining the **coastal erosion sensitivity area**, considering projected sea level rise of up to 1.0 m over the next 100 years, we have allowed for a doubling of the existing toe erosion rate (i.e. up to 10 m per century) and failure to a more gentle stable slope (1V:2H). In the steeper and higher areas of Whale Bay, this gives an erosion sensitivity area of up to 30 m width, with this higher value has been adopted for mapping.

7.1.2 Coastal Flooding Hazard

Coastal inundation is not a significant hazard to private properties at Whale Bay (apart from 108c Whanga Road, which is covered by existing provisions), the properties are sufficiently elevated to be at low risk from coastal flooding from an extreme coastal storm event for both existing sea level and future sea level rise of up to 1.0 m. At this open coast setting, wave set-up and run-up would significantly increase the level of flooding impact, and this has been considered as part of the site-specific provisions at 108c Whanga Road. These calculations relate directly to the unique geomorphic setting of the specific site and cannot be directly applied to the rest of Whale Bay. The other existing residential properties are elevated approximately 10 m above mean sea level, so are unlikely to be affected by wave effects.

7.1.3 Management Options and Recommendations

Erosion rates at Whale Bay appear to be slow and pose little immediate threat to existing dwellings with current sea level, any erosion likely to be limited to within 5-10 m of the shore (including toe erosion and the worst likely slope adjustment).

Over the next 100 years, there is potential for much or even all the grassed reserve to be lost to erosion and for erosion to extend significantly into adjacent private properties. However, this will depend on actual toe erosion and associated slope adjustment and total erosion could be much less, particularly if hard rock materials underlie the properties. Moreover, even with severe erosion, the existing residential sections are sufficiently deep to make living with erosion a viable option in the foreseeable future in most cases. Accordingly, we believe development controls discussed in Section 5 are adequate for management of erosion risk to private development within the hazard areas.

7.2 Harbour Entrance

This area includes the seaward end of Riria Kereopa Memorial Drive and the car park area to the immediate south (Figure 24).

7.2.1 Coastal Erosion Hazard

In the southern parts of this area, just south of the car park, the dune toe has fluctuated by up to about 60 m in the historical record (Figure 24). However, the scale of the dynamic fluctuations decreases markedly nearer the entrance, the maximum fluctuation being approximately 40 m along this section of Riria Kereopa Memorial Drive and decreasing markedly in the entrance area near the toilet block. During the community consultation, local residents observed that during periods of erosion the beach level can drop dramatically, revealing large rocks. This may indicate that sub-surface geology plays a role in the greater shoreline stability noted near the entrance and toilet block, though sub-surface investigations would be required to confirm this.

In this area, we have adopted the 2017 shoreline, which is also the landward edge of the shoreline fluctuations (i.e. the most eroded line) as the baseline for the hazard areas. In the area fronting the southern areas of Riria

Kereopa Memorial Drive and the car park, we have defined the **high-risk coastal erosion area** assuming toe erosion of 15 m and a stable slope of 1V:2H. In the entrance area where lesser shoreline fluctuations have occurred historically, toe erosion of 10 m has been adopted and a stable slope of 1V:2H.

The response of ocean beaches along the west coast to sea level rise is very uncertain, but there is potential for significant permanent erosion. Estimates based on nearshore beach slopes suggest potential for up to 75 m permanent erosion for every 1.0 m of sea level rise (as discussed in Section 4.3.1) This erosion is additional to that associated with dynamic shoreline fluctuations. The response of the shoreline in this entrance area to sea level rise could also be severely complicated by effects related to changes to the flood and ebb-tide deltas, tidal prism and other factors.   With future shoreline change so highly unpredictable, we have assumed that all areas on sand could potentially be affected by erosion when defining the **coastal erosion sensitivity area**. While the historic shoreline data indicates that erosion of properties landward of the road is unlikely with existing sea level and processes, it is not possible to definitively rule this out without further, more detailed investigation, including information on sub-surface geology.

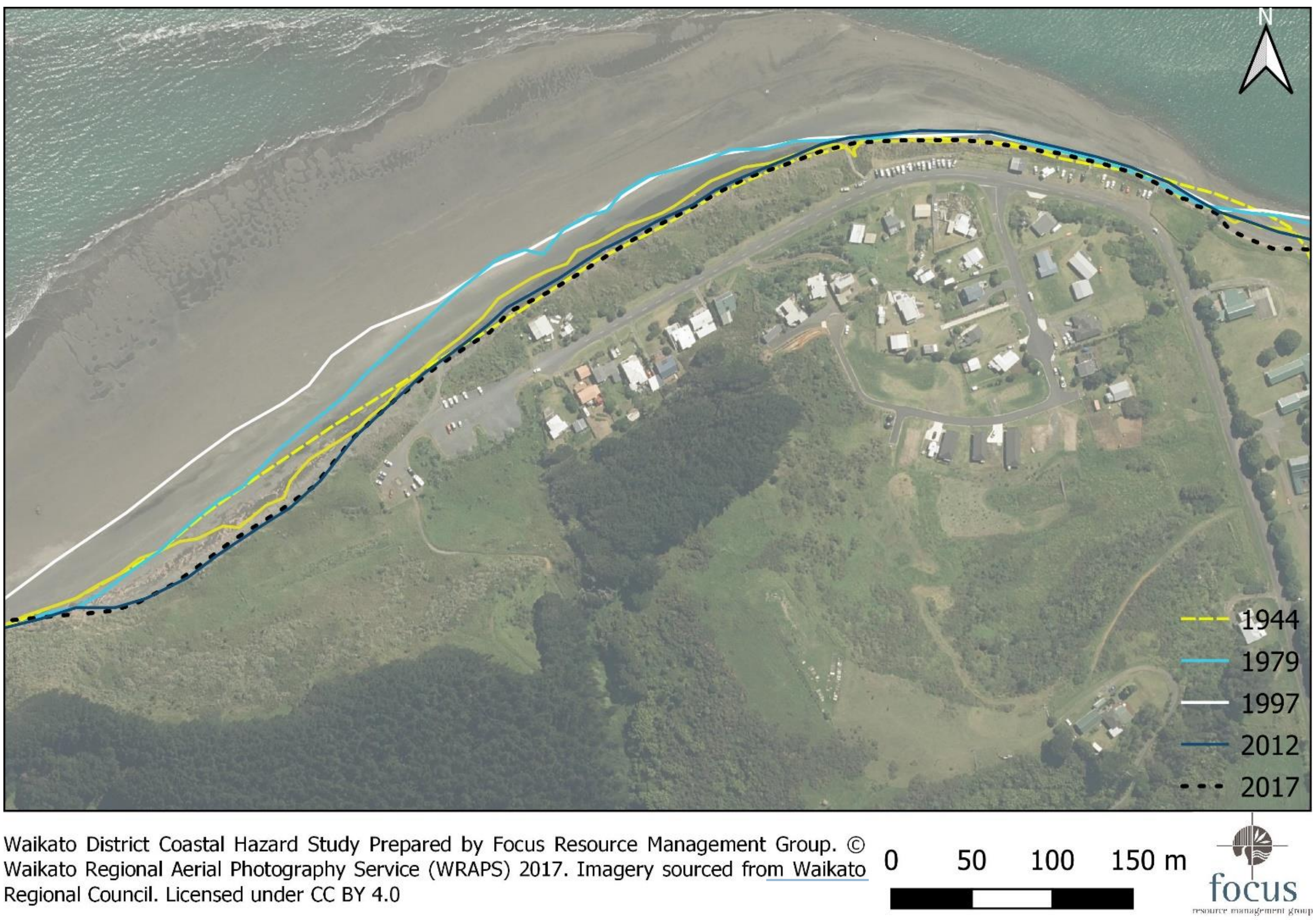


Figure 24: Shoreline change at the Raglan Harbour Entrance.

7.2.2 Coastal Flooding Hazard

The car park and private properties have existing ground elevations above RL 5.0 m and in most areas at least RL 6.0-8.0 m; above the elevations likely to be affected by coastal storm inundation over the next 100 years even with 1.0 m of sea level rise.

7.2.3 Management Options and Recommendations

The high-risk coastal erosion area indicates short term risk to the single private dwelling and the public toilet block seaward of Riria Kereopa Memorial Drive. It is important to note that this is not certain, and these assets would not have been affected by historic shoreline changes since 1944. With minor erosion hazard, it may be possible to protect these assets using relatively cost-effective options. However, with serious erosion it may not be practicable or appropriate to defend these assets and the best approach may be to relocate or remove them. It would be useful to agree appropriate triggers for this action with relevant stakeholders prior to erosion threatening the assets. Given the importance of the toilet block to local recreational use, it would also be useful to start considering alternative locations for this facility, in the event that the trigger for relocation or removal is reached.

In the medium-longer term, parts of Riria Kereopa Memorial Drive may also become vulnerable to erosion and possibly even the properties landward of the road. Accordingly, it would be useful to work with relevant stakeholders to develop an appropriate long-term adaptive management strategy for this area, including triggers for relocation of assets and infrastructure if required.

In the interim, it is recommended that land use and development within the potential hazard areas be managed as discussed in Section 5.

7.3 Te Kopua Spit (incl. Wainamu Beach)

The Te Kopua Spit, as discussed in this report, refers to the low spit-like landform located between Wainui Stream and Wainamu Beach. The northern shoreline (Wainamu Beach, Figure 25) is located in the lower harbour adjacent to the flood-tide delta; a very dynamic area of the harbour subject to strong tidal currents, very active sediment transport and dynamic (and largely subtidal) channels and banks. Refracted ocean waves migrate through the entrance and further influence patterns of erosion and accretion here. The spit is very low lying and all available information suggests the spit is entirely composed of sand (i.e. erodible), making it very vulnerable to both coastal erosion and coastal flooding now and in the future.

The feature is shown on geological maps as a late Pleistocene (Haweran) age terrace (Waterhouse and White, 1994), but field inspections indicate a considerable width (>100 m in places) of Holocene dunes along the northern side backing Wainamu Beach. Any original dune landforms further landward were destroyed by earthworks prior to the earliest (1940s) aerial photographs of the site. More detailed field investigations would be required to assess whether the entire feature seaward of Wainui Stream is composed of Holocene dunes and is a Holocene sand spit; or whether older (and potentially less erodible) Pleistocene sediments exist in more landward areas. For the purposes of this study, we must assume that the feature is a spit composed largely of loose erodible Holocene sands.

Figure 25: Shoreline at Te Kopua, looking toward the Raglan Harbour Entrance.

7.3.1 Coastal Erosion Hazard

Dahm and Gibberd (2010) completed a review of shoreline change and coastal hazards at Wainamu Beach and Te Kopua Spit and provided recommendations for a coastal development setback based on historical photography and cadastral survey data (going back to 1885) and field investigations. The data and outcomes from this study have been combined with the high quality orthorectified photography that has since become available in the area. Some of the mapped shorelines are shown over an aerial photograph of the area in Figure 26.

Shoreline change has varied greatly along the Te Kopua shoreline since records began. At the western end fronting the Te Kopua Whanau Camping Ground, there has been accretion of up to 100 m since the earliest survey records began, with a general pattern of accretion suggesting slow eastward migration of a large slug of sand. While there has been a recent trend for some erosion along this area (since about 2003), the shoreline is still well seaward of its 1940s location (Figure 26). While this erosion has continued slowly through to the present, it is still too early to ascertain if the erosion signals the beginning of multi-decadal erosion.

Further east, in central areas adjacent to the airfield, there have been dynamic fluctuations in the position of the shoreline by up to 75 m. The pattern of dynamic shoreline fluctuations in this area is also consistent with pulses of sediment migrating eastward alongshore into the harbour.

Figure 26: Historical shorelines at Te Kopua (Dahm & Gibberd, 2010; Waikato Regional Council, 2019).

There have also been significant shoreline fluctuations on the shoreline of the campground, further east. Historical records show multi-decadal fluctuations of up to 60 m and a 50 m increase in the length of the spit since the 1940s. This is consistent with net eastwards sediment transport along this coastline, probably under refracted ocean waves migrating through the entrance into the harbour. Tidal currents in the Opoturu arm of the estuary provide an eastern limit to longshore extension of the spit. Sediments transported into this channel are likely swept out into the ebb-dominated main channel and then seaward into the lower harbour. The sediment transport eastwards along the Wainamu Beach shoreline and subsequent subtidal transport back through the lower harbour are likely part of a slow, complex sediment transport pathway, by which pulses of sediment arriving at the harbour entrance are bypassed.

Shoreline changes on the landward side of the seaward end of the spit are generally small and dynamic; though there does appear to be slow net accretion over time as the 1924 and 1941 shorelines lie up to 50 m inland of the present toe of vegetation. This sediment input likely reflects, transport around the end of the spit by low refracted waves and surges. The southern shoreline of the Te Kopua Spit, adjacent to the Wainui Stream Estuary, has remained either stable or in an accretionary phase over the period of the record, with this shoreline largely fronted by intertidal wetlands. However, field observations indicate evidence of very slow erosion towards the western end on the outside of a bend in the tidal channel (Wainui Stream). However, most shoreline changes observed from the historic surveys and aerial photography are within the known error of the data.

Overall, the data suggests that the Wainamu Beach shoreline experiences multi-decadal to century scale dynamic shoreline fluctuations; these fluctuations (periods of erosion and accretion) exceeding 100 m at the western end, decreasing eastwards to at least 50-60 m towards the eastern end. It is important however to note that the "snapshots" provided by available aerial photography and historic surveys probably do not adequately define the maximum scale of shoreline fluctuations over multi-decadal to century timeframes. The distal end of the spit appears to be slowly accreting over time, gradually extending further to the northeast. The landward margin adjacent to Wainui Stream is largely stable, apart isolated areas of very minor erosion on the outside of bends in tidal channel.

It is difficult to reliably define a high-risk erosion hazard area for the next 10-15 years as the shoreline trends at any location during that period will depend on whether the particular area of shoreline is in a multi-decadal erosion or accretion phase. While shoreline fluctuations of at least 50-60 m (eastern end) to >100 m (western areas) can be experienced over periods of 50-100 years, lesser changes will generally be experienced over 10-15 years. We have simply adopted a constant 12 m **high-risk coastal erosion area** along the northern shoreline of the spit, incorporating 10 m of toe erosion and allowance for slope instability. We emphasise however that it is still possible that erosion may exceed this over 10-15 years in localised areas experiencing an erosion cycle. On the more sheltered southern shoreline bordering the Wainui Stream estuary, we recommend the high-risk coastal erosion area can be reduced to a total width of 7 m, including 5 m of toe erosion and allowance for slope adjustment.

The effect of sea level rise in the medium to long term is highly uncertain. Future sea level rise could impact the Wainamu Beach shoreline in a number of ways due to the geomorphic setting. Erosion could be aggravated not just by a simple rise in water level, but also by increases in the velocity of nearshore tidal currents associated with a possible increase in tidal prism. There also could be a loss of sediment to the nearby flood and ebb tide deltas due to these features increasing in volume with increasing tidal prism. It is clear from existing data that shoreline fluctuations of <u>at least</u> 100 m can be experienced towards the western end over a period of a century and <u>at least</u> 50-60 m in eastern areas of the shoreline. Giving the existing beach slope and other effects that may accompany sea level rise, we believe that sea level rise of 1.0 m could potentially increase erosion by at least 15-20 m, but possibly more. Given the uncertainties around both the scale of existing shoreline fluctuations over multi-decadal and century timeframes, and the effects of projected sea level rise, we recommend that the entire spit presently be defined as a **coastal erosion sensitivity area** over the period to 2120 including the effects of 1.0 m sea level rise. We note that this extent of erosion may not occur, and that this assumption assumes the entire spit is composed of loose erodible Holocene sands which is not yet confirmed. However, more detailed investigations (including subsurface investigations and dating as well as modelling of potential sea level rise effects) would be required to reliably refine the erosion sensitivity area.

The more upstream margins of Wainui stream (west of Nihinihi and Te Kopua) are relatively low lying, particularly on the northern side of the stream. While this area is currently undeveloped, the land is in Maori ownership and there is potential for Papakaianga development. Although exposed banks in this area appear to suggest long term erosion, historical photography suggests this rate of erosion is very slow.

We recommend a **coastal erosion sensitivity area** of 15 m width be identified along this shoreline to provide for potential shoreline fluctuations and the effects of future sea level rise. We believe more detailed investigation may reduce this width over some of the area. In much of this area, coastal flooding will be a much more serious hazard than coastal erosion.

7.3.2 Coastal Flooding Hazard

Te Kopua Spit is low lying and potentially vulnerable to coastal inundation. With existing sea level, large areas of the campground could be inundated in an extreme storm surge event (Figure 27). With 1.0 m of sea level rise, the entire spit could potentially be inundated during an extreme storm event (Figure 28).

Sea level rise might also cause problems with high groundwater levels, particularly in lower-lying areas.

Figure 27: Illustration of the areas likely to be inundated (coloured) in a severe storm. Waikato Regional Council Coastal Inundation Tool http://coastalinundation.waikatoregion.govt.nz/.

There are also extensive areas upstream adjacent to the Wainui Stream that are vulnerable to flooding during extreme events with current sea level and these areas would become more frequently and severely impacted with any future sea level rise. These areas include the Wainui Road shops and the road to Whale Bay.

Figure 28: Broad area potentially at risk from coastal inundation in an extreme event after 1.0 m of sea level rise. Waikato Regional Council Coastal Inundation Tool http://coastalinundation.waikatoregion.govt.nz/.

7.3.3 Management Options and Recommendations

Wainamu Beach is a high value beach for recreational use and is easily accessible and heavily utilised by the public. Hard engineering structures (i.e. various kinds of sea wall) would be likely to impact on public values of the beach including beach loss and associated effects (e.g. impacts on public access, recreational use and visual/landscape values).

While soft options such as beach nourishment can sometimes be useful and practicable in harbour settings, the high energy and very dynamic nature of this shoreline means they are unlikely to be cost-effective, with significant longshore losses and ongoing maintenance requirements. Given the strong net eastwards longshore transport, groynes and beach nourishment might be effective in the short term. However, effective structures would be costly, and the potential adverse effects on natural character, public access along the beach and landscape values would be added considerations.

Dune restoration is useful to assist dune recovery once the beach is in an accretion phase. It is however important to appreciate dunes do not stop erosion. A naturally functioning dune around the coastal margin can also help to provide protection against coastal inundation.

Overall, erosion cycles will likely have to be lived with along the Wainamu Beach shoreline. Accordingly, the considerable uncertainty around the maximum likely erosion over the next 100 years (and the potential for increased inundation hazard) means that any future development in this area needs to be carefully managed.

The uncertainty around future shoreline change means that this area is not well suited to permanent (e.g. freehold) subdivision with fixed boundaries and significant permanent roading and other infrastructure. However, the spit is quite suitable for readily adaptable uses, including buildings that can be readily relocated or raised if required. Any development will therefore likely require an adaptive management strategy with suitable triggers to ensure assets are relocated and/or lifted in the longer term if required

Despite the entire area being identified as a coastal hazard sensitivity area, it is likely that more detailed investigation will identify some areas that are at low risk from coastal hazards, particularly erosion. We therefore recommend that the shoreline analysis undertaken as part of this work be complemented by detailed sub-surface investigations to establish the landward boundary of more erodible materials such as loose Holocene sands.

Discussions with the Maori landowners indicate that any permanent development at the western end (e.g. Papakainga housing) would likely be located well inland of the spit. This area is not likely to be affected by erosion but is potentially vulnerable to coastal flooding (Figure 27 and Figure 28). Accordingly, this aspect would need to be addressed in any such development (e.g. by minimum floor levels and possible raising of ground levels).

7.4 Wainui Stream - Nihinihi Avenue

Nihinihi Avenue is located upstream from Te Kopua adjacent to the Wainui Stream. Residential development is located on a raised terrace fronted by sloping banks (Figure 29).

Figure 29: Properties on Nihinihi Avenue.

7.4.1 Coastal Erosion Hazard

The bank appears to be experiencing periodic erosion, but data from historical surveys suggests that the average rate of any such erosion is very slow (no more than 2.5 m per century and possibly <1m/century). There is a relatively wide (10-15 m) coastal reserve in this area and so erosion alone would not pose a significant risk to the reserve. In many locations, private coastal erosion protection structures have also been placed to enhance the reserve for private use (Figure 29). These various ad hoc structures are not consented as a long-term solution to erosion and have therefore have not been considered in defining erosion hazard areas.

The toe erosion has the potential to give rise to occasional slope instability and a previous study (Blair, 1998) identified slope failure as a possible concern in this area. However, historic aerial and other photographs provide no evidence of significant slope failure, suggesting any such occurrence is rare. Nonetheless, we believe a precautionary approach to slope instability is warranted until more detailed information is available.

Given the very low rate of toe erosion, we have assumed no significant toe erosion in defining the **high-risk coastal erosion area**, but have adopted a precautionary approach to potential slope instability by assuming a stable slope of 1V:2H measured from RL 3.0 m (Table 7). We recommend that Council provide for adjustment of the high-risk area where justified by more detailed investigations of slope instability by an appropriately experienced geotechnical engineer or engineering geologist.

Over the period to 2120 with 1.0 m sea level rise, we have defined a **coastal erosion sensitivity area** based on toe erosion of up to 5.0 m (including landward movement of the shoreline with sea level rise and some possible erosion associated with removal of sea walls) and potential for significant localised slope failure to a slope of 1V:2H (Table 7).

We recommend that coastal erosion hazard areas can be similarly defined for the shoreline fronting Marine Parade (south of the bridge to Te Kopua), Oputuru Road, Goodare Road, Smith Street, Karioi Crescent and Wainui Road from the one lane bridge to Raglan Town Centre.

Table 7: Coastal erosion hazard areas at Nihinihi Avenue (Wainui Stream).

Sea Level Scenario	Toe Erosion	Stable Slope (V:H)	Total Erosion
Current	0.0 m	1:2	6.0-7.5 m
1.0 m	5.0 m	1:2	16.0-19.0 m

7.4.2 Coastal Flooding Hazard

The residential sections along most of Nihinihi Avenue are approximately 8.0 m above mean sea level so there is no foreseeable risk from coastal inundation. However, several sections at the western end of the road are low lying and may be vulnerable (Figure 30). There is also an area on the corner of Nihinihi Avenue and Marine Parade (around 12 Marine Parade) that is very low lying and is potentially at risk from coastal inundation during extreme events even with current sea level.

With 1.0 m of sea level rise to 2120, these areas will be impacted more frequently and extensively (Figure 31).

Figure 30: Broad area currently at risk from coastal inundation in an extreme event. Waikato Regional Council Coastal Inundation Tool http://coastalinundation.waikatoregion.govt.nz/.

Figure 31: Broad area currently at risk from coastal inundation in an extreme storm surge event following 1.0 m of sea level rise. Waikato Regional Council Coastal Inundation Tool http://coastalinundation.waikatoregion.govt.nz/.

7.4.3 Management Options and Recommendations

The defined high-risk coastal erosion area is likely to be limited to the reserve seaward of the private properties. In the longer term, the identified coastal erosion sensitivity area indicates there is potential for properties to be affected by erosion. However, it is important to appreciate that as most of the defined hazard is associated with potential slope instability any severe impacts are likely to be localised rather than widespread. Moreover, in all areas potentially impacted, the properties are deep with large areas landward of the defined hazard areas. Accordingly, even with localised worst-case effects, reasonable use of the properties will not be precluded.

We recommend that the risk from coastal erosion to private development can be primarily managed using appropriate development controls within the defined hazard areas, as discussed in Section 5. Coastal flood hazard fronting Marine Parade may require action in the medium to long term to ensure safe access is retained to adjacent properties and to Te Kopua.

Coastal flooding risk will increase significantly with sea level rise of 1.0 m for a few low-lying properties and land use in these areas will need to be managed using development controls (including minimum floor levels and/or adaptable foundations) and other measures as discussed in Section 5.

Management of the reserve is also a relevant consideration. The reserve areas are currently privatised by adjacent landowners (Figure 29) and there appears to be little or no public use in most areas. However, despite the potential for localised (and probably rare) impact by slope instability in both the short and longer term, it is our view that the reserve is likely to remain largely intact in the near future (i.e. next 20-30 years) and probably also most of the next 100 years. Accordingly, it is important for Council to appreciate the nature of the potential hazard and recognise that the reserve could still be developed for public use. In developing the reserve in this way, an appropriate adaptive management strategy would be important to provide for the long-term low risk from erosion and localised slope instability.

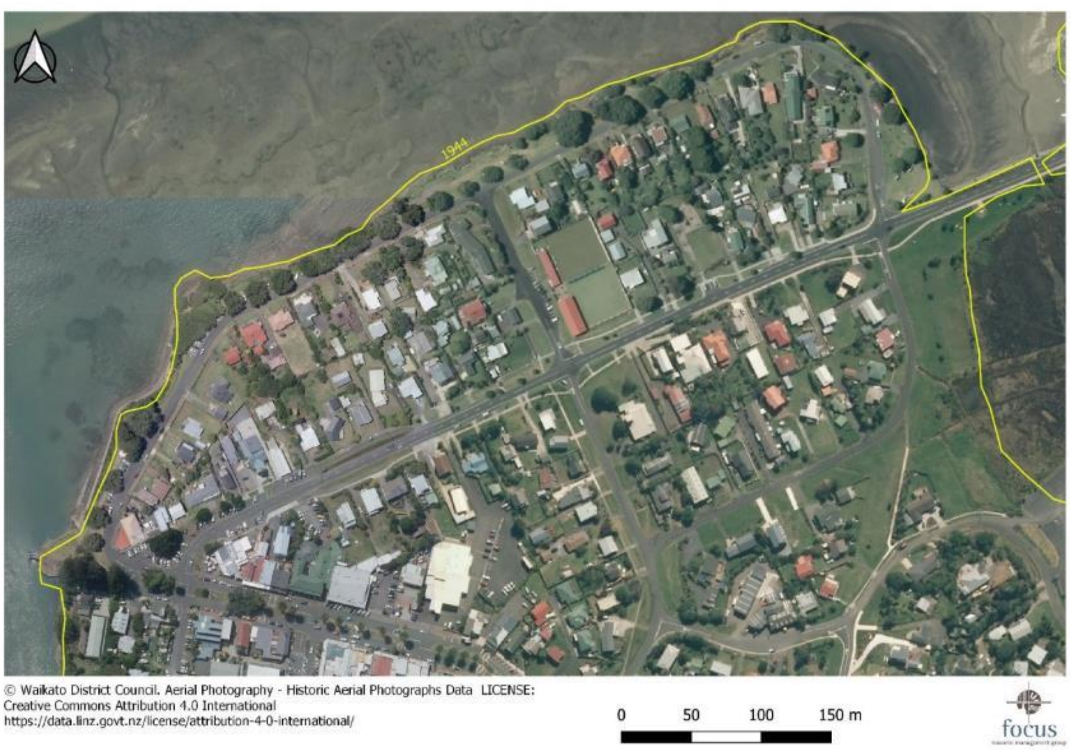
7.5 Cliff Street

7.5.1 Coastal Erosion Hazard

Cliff Street is located on a Pleistocene terrace fronted by a slowly eroding bank. Historical shoreline change analysis indicates that the average rate of erosion along the bank has been generally less 5.0 m since 1944 (Figure 32 and Figure 33), with localised areas of slightly greater erosion particularly towards the western end more exposed to longer period refracted ocean waves and surges migrating through the entrance.

Sea level may aggravate the current rate of erosion as the bank is exposed to wave action for a higher proportion of the tide (see Section 4.3.1).

The **high-risk coastal erosion area** (area at risk in the immediate future - i.e. next 20-25 years) has been identified assuming 2 m toe erosion and a relatively steep stable slope of 1V:1.5H, giving a high-risk area of 5.5-8.0 m wide, varying slightly with bank height (Table 8). It is emphasised that erosion of this magnitude is only likely to occur in very isolated areas if at all, but the hazard width applies along the entire bank because it is not possible to reliably predict the location where such erosion may occur. In most areas we would expect erosion to average less than 1.0 m and be characterised by steep, near vertical erosion scarps, totalling only 1-2 m bank width at most.



© Waikato District Council. Aerial Photography - Historic Aerial Photographs Data LICENSE: Creative Commons Attribution 4.0 International https://data.linz.govt.nz/license/attribution-4-0-international/

Figure 32: Cliff Street showing 1944 shoreline (yellow) over a modern photograph.

Figure 33: Cliff Street in 1951. Whites Aviation Collection, Alexander Turnbull Library. https://creativecommons.org/licenses/by/4.0/

It is difficult to reliably predict the response to sea level rise, but based on the considerations outlined in Section 4.3.1 we have assumed that sea level rise of 1.0 m over the period to 2020 could double the existing average rate of cliff toe erosion (<5 m per century); therefore adopting up to 10 m of toe erosion and a stable slope of 1V: 1.5H in defining the **coastal erosion sensitivity area**. The width of the potential coastal erosion hazard areas is summarised in Table 8.

Table 8: Coastal erosion hazard areas at Cliff Street.

Sea Level Scenario	Timeframe	Future erosion	Slope stability	Total Erosion
Current	n/a	2.0 m	6.0 m	8.0 m
1.0 m	100	10.0 m	4.5 m	14.5 m

7.5.2 Coastal Flooding Hazard

The reserve at Cliff Street is typically 5-6 m RL there is little risk from coastal storm inundation under current conditions and risk will still be low even following 1.0 m of sea level rise.

Figure 34: Broad area at risk from coastal inundation with current sea level (left) and with 1.0 m of sea level rise (right). Waikato Regional Council Coastal Inundation Tool (http://coastalinundation.waikatoregion.govt.nz/).

7.5.3 Management Options and Recommendations

Cliff Street is located in the heart of Raglan Township and is a very important reserve for public use and amenity. While it may be possible to live with slow erosion in some places at least in the short to medium term, increased erosion is likely to occur with future sea-level rise.

Decisions about future management of coastal erosion along the margin of this popular reserve are best addressed by way of an adaptive management plan developed in consultation with the community. If engineering protection is deemed necessary, a plan would include triggers for protection of unprotected areas and a low impact structure design that mitigates impacts on amenity, natural character and public access.

Ideally, any structure adopted for this high use amenity area should attempt to maintain the visual appearance of the natural cliff sediments, with modern design increasingly able to replicate such materials (e.g. recent work at Kohimarama). Given the good foundation provided by the shore platform at this location, it should be possible to construct a vertical or steep seawall built in a way that imitates the natural cliff feature and materials.

7.6 Aro Aro Bay and Inlet

The Aro Aro inlet was originally an estuarine arm with an extensive wetland (Figure 35). The upper reaches of this arm are now reclaimed (Figure 36). The road causeway currently restricts water flow to the remaining estuarine wetland. The reserve adjacent to Puriri Street an important recreational area.

7.6.1 Coastal Erosion Hazard

The Aro Aro inlet is very sheltered and coastal erosion processes are not particularly active. Coastal erosion has however been an issue at the reserve seaward of Puriri Street, adjacent to the toilet blocks; though the structures in this area probably relate more to seaward encroachment rather than a genuine trend for erosion. Sea level rise is likely to aggravate these issues.

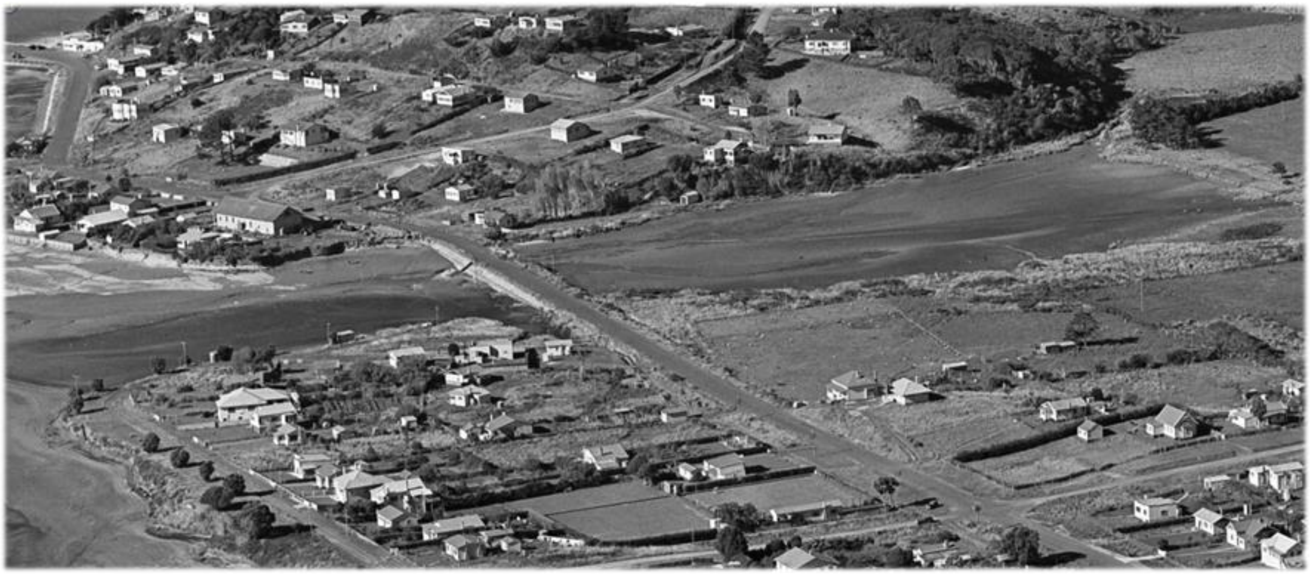


Figure 35: Aro Aro Inlet in 1951. Whites Aviation Collection, Alexander Turnbull Library. Attribution 4.0 International (CC BY 4.0). The upper reaches of the estuarine arm (not shown) had already been reclaimed from the sea at this time.

Figure 36: Aro Aro Inlet showing 1944 shoreline (white), clearly illustrating the extent of drainage and reclamation.

7.6.2 Coastal Flooding Hazard

This area is very low-lying (<3 m RL), including significant areas of existing residential development. These areas are very vulnerable to coastal inundation even with current sea level (Figure 37, left), though mitigated by various existing measures. The frequency and severity of flooding will increase significantly with 1.0 m sea level rise (Figure 37, right).

Figure 37: Broad area currently at risk from coastal inundation in an extreme event with current sea level (left) and following 1.0 m of sea level rise (right) (Waikato Regional Council Coastal inundation tool, http://coastalinundation.waikatoregion.govt.nz/).

7.6.3 Management Options and Recommendations

Sports fields and associated facilities have historically been developed in this low-lying former wetland, as well as some private properties and dwellings and there are already existing issues with flooding and drainage. These issues will be severely complicated by projected future sea level rise.

Detailed investigations and development of an adaptive management strategy with key stakeholders and the community will be required to identify the best short-, medium- and long-term options for management of existing sports fields and associated facilities, appropriate protection of private properties and restoration of ecological values. With future sea level rise, it is possible that some existing uses may not be sustainable in the longer term and may need to be progressively retreated or removed over time, but this would need to be assessed by detailed investigation and costing of management options.

In the existing absence of an appropriate adaptive management strategy, it is recommended that Council manage land use and development within the defined coastal inundation hazard areas as outlined in Section 5. In particular, adaptable buildings (i.e. able to be lifted or relocated, as required) and minimum floor levels will be critical requirements.

The reserve at Puriri Street has significant recreational amenity value, and future management should therefore provide for protection of reserve while enhancing amenity. As the current structures are replaced, it is likely that beach nourishment (with retaining structures if required) will best provide both erosion protection and enhanced amenity. The reserve is relatively low-lying and will likely require lifting in the longer term with projected sea level rise. The management of this reserve will influence the flood vulnerability of properties to landward, so these decisions are best made in collaboration with the local community.

7.7 Wallis Street

Wallis Street is a heavily developed Pleistocene age terrace fronted by slowly eroding banks (Figure 38). Most of the shoreline is armoured but geological maps (Waterhouse and White, 1994) and field inspection of limited remaining bank exposures indicate it is composed of moderately cemented sands similar to Cliff Street. The coastal protection structures are of varying age and state of repair.

Figure 38: Wallis Street shoreline.

7.7.1 Coastal Erosion Hazard

Natural rates of bank erosion are hard to ascertain as shoreline protection works have been in place for a long time and typically pre-date the earliest aerial photos. It is likely however that average bank erosion rates were similar to Cliff Street, less than 5 m per century. Fill may also have been placed in some areas as or before the sea walls were constructed and so if the current structures were removed at some future date, reasonably rapid erosion of such materials could occur in any areas it exists, followed by a resumption of natural slow erosion rates once the original bank was exposed.

In defining the **high-risk coastal erosion area**, we have assumed short-term erosion of up to 4 m (including 2-3 m allowance for any rapid erosion of fill behind existing sea walls) and a stable slope of 1:1.5, giving a typical high risk erosion hazard width of up to 7.0 m in the absence of effective protection (Table 9). The **coastal erosion sensitivity area** for 1.0 m sea level rise and the period to 2120 has assumed potential for toe erosion of up to 10 m and a stable slope of 1:1.5. This is the same approach as that adopted for Cliff Street.

Table 9: Coastal erosion hazard areas at Wallis Street.

Sea Level Scenario	Timeframe	Future erosion	Slope stability	Total Erosion
Current	n/a	4.0 m	3.0 m	7.0 m
1.0 m	100	10.0 m	1.5 m	11.5 m

7.7.2 Coastal Flooding Hazard

Ground elevations at Wallis Street are typically 3-4 m above current mean sea level. While this is above the level of vulnerability with current sea level, these areas may become at risk in the longer term with future sea level rise (Figure 39). These areas may also be vulnerable to wave effects.

Figure 39: Broad area at risk from coastal inundation with current sea level (left) and with 1.0 m of sea level rise (right). Waikato Regional Council Coastal Inundation Tool (http://coastalinundation.waikatoregion.govt.nz/).

7.7.3 Management Options and Recommendations

There is a very long history of coastal armouring structures at Wallis St. Designs are varied and many of the structures will require maintenance or replacement in coming years/decades. Although natural erosion rates are slow, existing use is located very close to the coast with little space to adapt and would be severely impacted by removal of the current structures.

Given the intensity of existing development with the defined hazard areas (including some within the narrow high-risk coastal erosion area), it is strongly recommended that a site-specific adaptive management plan be developed for this area. There are two broad approaches for ongoing management of coastal erosion hazard in this area which could be considered, though also variations (e.g. mixes of the two options):

Option 1: Remove ad hoc structures over time and live with erosion:

This option would simply manage erosion through development controls in identified hazard areas to avoid and reduce risk over time. The option would restore a natural shoreline over time as houses were replaced further landward. This option would reduce section size over time, the rate of loss dependent on future erosion rates. Future subdivision and intensification of use would likely be precluded unless appropriate provision were made to avoid erosion risk.

Option 2: Accept shoreline protection and upgrade over time:

This option would involve replacement of the existing structures with a well-engineered seawall capable of providing long term protection. Ideally, any seawall built to provide long term protection would be designed to recover some of the natural character lost with construction of the structures built in the past. For instance, with present technology, it should be possible to construct a structure with visual properties similar to the original natural shoreline, similar to the option briefly discussed above in regard to future management of erosion in Cliff Street.

If located on public land, a "new" seawall would ideally also provide public benefit, probably including public access. A new seawall would be relatively expensive but would provide some long-term certainty for owners and less restriction on land use.

Until an agreed adaptive management strategy is developed for this area, we recommend that the Council implements coastal development controls in the identified coastal hazard areas to manage risk over time – as discussed in Section 5. These measures would avoid any further development in the high-risk coastal erosion area and would progressively retreat existing development from this area as it was upgraded or replaced. Development in the coastal erosion sensitivity area would be provided for, but subject to standard relocatability requirements. Minimum floor levels would also be required within the coastal flooding areas.

7.8 Cox Bay

The coastal cliffs at Cox Bay extend from the Wharf to Lorenzen Bay; being typically 10-15 m high near the wharf and reaching elevations up to 30 m east of Lily Street (Figure 40).

7.8.1 Coastal Erosion Hazard

Existing data suggests that the toe of the cliff is eroding only very slowly; with an average rate of erosion of less than 2.5 metres per century and possibly even less than 1.0 m per century. The average slope of these cliffs varies between 1V:1H and 1V:1.5H.

Slope instability is known to have occurred in the area, but we were not able to obtain useful information about these historic events. Field observations and historic aerial photography suggest that most slip features are relatively shallow, but a precautionary approach is required in the present absence of detailed information.

Figure 40: Cliffed shoreline at Cox Bay.

Accordingly, we have defined the **high-risk coastal erosion area** based on a stable slope of 1V:2H. The actual area of high erosion vulnerability is likely to be less in many (possibly even most) areas and so we recommend that Council provide for adjustment of this high-risk area where justified by site-specific investigations by an appropriately experienced geotechnical engineer or engineering geologist. Toe erosion has been ignored in defining the high-risk erosion area as the rate of toe erosion is very slow and we believe there is sufficient conservatism in definition of this area given the stable slope of 1V:2H assumed.

The **coastal erosion sensitivity area** to 2120 (including 1.0 m sea level rise) has assumed existing rates of toe erosion may be doubled (i.e. up to 5 m per century) (see Section 4.3.1) and also assumes potential for deeper-seated slope failure by adopting a stable slope of 1V:2H.

The width of these high risk and sensitivity areas vary greatly depending on the elevation of the coastal margin.

7.8.2 Coastal Flooding Hazard

This area is elevated above any current or future coastal inundation events.

7.8.3 Management Options and Recommendations

It is recommended that coastal development within the defined hazard areas be managed using development controls as outlined in Section 5; with new development avoided in the high-risk coastal erosion area and requirement for a report from suitable experienced geotechnical expert for any development within the coastal erosion sensitivity area.

Current coastal erosion protection structures at the toe of the bank are of little value in this area as the rate of toe erosion is extremely slow, and the primary cause of erosion risk to the properties above is slope instability. Seawalls detract from the natural character of the shoreline and would also be buried or destroyed by periodic slope failure.

7.9 Lorenzen Bay

Field inspections and geomorphic considerations suggest the original shoreline at Lorenzen Bay was an estuarine beach backed by a narrow coastal and/or flood plain; composed of sands and gravels deposited by the two small streams which discharge into the bay. The narrow plain, widest near the stream entrances and of very limited width in other areas, is backed by higher topography.

The earliest subdivision in Lorenzen Bay, in eastern areas of the bay, was formed in 1918-19 (Deeds 589). No foreshore reserve was taken, and the seaward property boundaries were located at Mean High Water Mark (MHWM) (Deeds 589), likely seaward of the vegetated shoreline at the time. In some cases, a narrow reserve has since been taken upon later subdivision of some of the original lots. Early subdivision in more western area dates from surveys in 1936 and 1941, where the seaward boundary of the narrow reserve was also fixed at MHWM (DP 31092). The shoreline is now largely fronted by coastal protection works (Figure 41 and Figure 42).

Figure 41: Eastern shore of Lorenzen Bay, at the end of Lorenzen Bay Road.

Figure 42: Western shoreline of Lorenzen Bay (accessed from Greenslade Road).

7.9.1 Coastal Erosion Hazard

Shoreline armouring works have been widespread since the date of the earliest aerial photographs, likely reflecting the proximity of the properties to the coastline (in some cases, seaward of the natural coast) and the narrow reserves (e.g. as owners attempted to hold or reclaim out to their seaward boundaries).

These structures mean it is very difficult to assess natural erosion rates. The only information we were able to locate was a short section of shoreline change shown on DPS38349; indicating erosion averaging 6.0-6.5 m (and up to about 8.0 m) between 1919-1985 along part of the eastern side of the bay. If part of a long-term trend for erosion, this would equate to an erosion rate of approximately 10 m per century. However, we believe it is more likely that the changes were simply dynamic as the relevant shoreline is close to a stream entrance.

An additional complication is that many properties have been reclaimed and so seawalls may be backed by readily erodible fill rather than a natural shoreline. There is evidence for instance that some properties in the eastern areas of the bay were reclaimed out to the original boundaries. One property in this area has more recently (in the late 1950s or early 1960s) even been reclaimed well seaward of the legal property boundary (Figure 43).

It is therefore very difficult to reliably assess the erosion that could occur in the absence of the existing erosion protection works. In the original natural environment, the coastal areas around the stream entrances were likely very dynamic, experiencing periods of severe erosion with changes in stream channels and entrances; particularly during stream floods and coastal storms. However, with the present confined stream entrance, there is less potential for severe erosion associated with stream changes. As an interim measure, we have defined a **high-risk coastal erosion area** of 10 m relative to our adopted baseline. More detailed investigations, including subsurface investigations, would be required to improve definition of this area.

With sea level rise of 1.0 m, the estuarine beaches may retreat approximately 15 m (in the absence of shoreline protection); based on other estuarine beach slopes (Section 4.3.1). Accordingly, the **coastal erosion sensitivity area** has assumed a total erosion of 25 m. In some cases, this exceeds the width of the coastal plain and we have cut-off the landward edge of this area at the base of the adjacent hills.

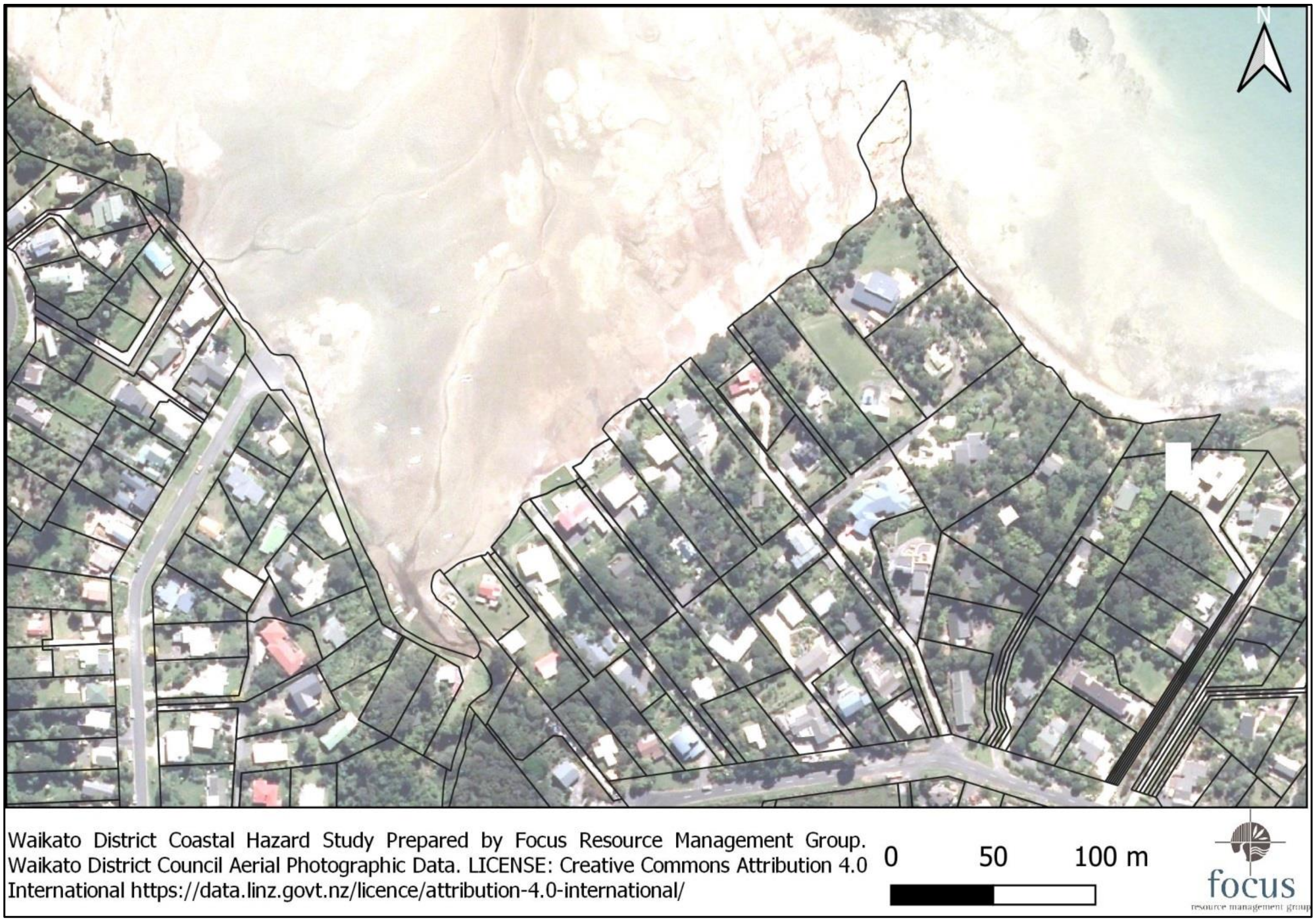


Figure 43: Property boundaries at Lorenzen Bay, showing the variation in seaward boundary location associated with different title dates, and illustrating localised reclamation.

7.9.2 Coastal Flooding Hazard

The low-lying properties on the narrow coastal plain have typical existing elevations of 2-3 m above MSL and are presently vulnerable to coastal flooding during storm surge events (Figure 44 and Figure 45). With 1.0 m of sea level rise, this flooding would become more frequent and severe, and also more widespread (Figure 45).

Figure 44: Flooding at the end of Lorenzen Bay Road in 2018.

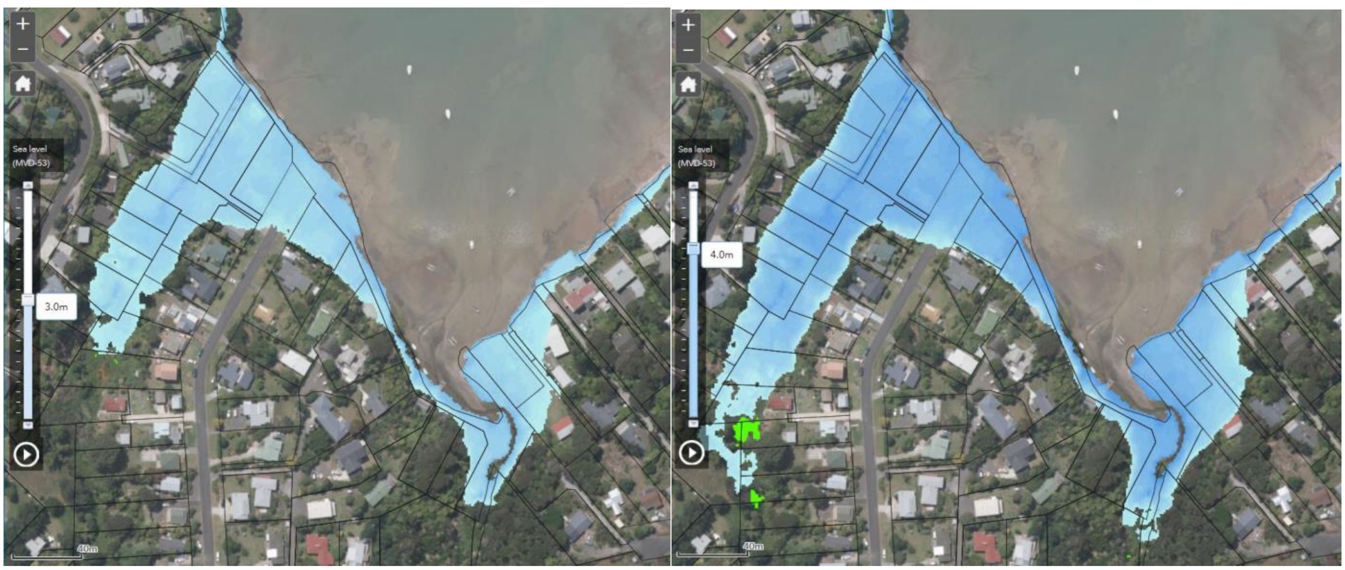


Figure 45: Broad area at risk from coastal inundation with current sea level (left) and with 1.0 m of sea level rise (right). Waikato Regional Council Coastal Inundation Tool (http://coastalinundation.waikatoregion.govt.nz/).

7.9.3 Management Options and Recommendations

The hazard assessments indicate that there are significant coastal erosion and coastal flood hazard vulnerability with existing sea level and that these problems will become very severe with sea level rise of 1.0 m.

In the absence of protection works, coastal erosion is likely to severely impact a number of private properties, including some dwellings, even in the short term; particularly properties on the western side of the bay. The popular public access path along the western foreshore of the bay would also likely be completely lost in the relatively short term. Erosion hazard also has the potential to significantly complicate existing vehicle access problems for a few properties. As such, it is unlikely to be practicable to simply live with erosion at Lorenzen Bay, given the established development and infrastructure and the high level of hazard risk. However, existing ad hoc structures have a number of serious deficiencies and are unlikely to be consented as long term solutions.

Most of the low-lying properties and roads are presently vulnerable to coastal flooding during severe events. With existing land elevations, low-lying properties would likely be subject to flooding every tide following 1.0 m of sea level rise; and during extreme events would be flooded to depths of about 1.0 m over a wide area, with wave effects likely superimposed. These issues would be compounded by stream and stormwater flooding.

In our opinion, the coastal hazard problems at Lorenzen Bay are very complex and difficult and can only be resolved through a comprehensive adaptive management strategy. It is also likely that appropriately located and designed sea walls will be required, particularly in western areas of the bay. In the longer term, land elevations will also need to be substantially raised if ongoing use was to continue in many areas. Raising ground levels comes with associated complications (e.g. avoiding exacerbation of flooding in neighbouring properties; existing in-ground infrastructure).

In the absence of an agreed adaptive management strategy, we recommend that the Council manage land use in the identified hazard areas using the various development controls discussed in Section 5. Minimum floor levels will be particularly important in this area, together with avoiding any further subdivision or intensification that is likely to increase risk over time.

7.10 Greenslade Road

The shoreline at Greenslade Road is hard and rocky, backed by a steeply sloping shoreline, rising to 15-20 m elevation (Figure 46 and Figure 47). In places, the steeply sloping shoreline is also fronted by narrow and shallow beaches. Original subdivision occurred in 1918-19, with titles extending down to MHWM (Deed 589), likely seaward of the original vegetated shoreline. No foreshore reserve was taken at the time of the original subdivision, but a useful width of reserve has subsequently been taken in some areas as part of further subdivision.

Figure 46: Coastline fronting the eastern section of Greenslade Road.

Figure 47: Coastline fronting the western section of Greenslade Road.

7.10.1 Coastal Erosion Hazard

Field observations in the western portion of the shoreline at Greenslade Road indicate some areas of active erosion scarps, but historic mapped shorelines and other data indicate that the rate of shoreline erosion is very slow. In many places, the seaward property and/or reserve boundaries extend seaward of the current vegetated shoreline. However, this appears to be primarily a function of the original title surveys which extended to MHWM, quite often seaward of the vegetated shoreline of the time.

The steeply sloping banks further landward typically have a gradient between 1V:1H and 1V:2H. Historic photographs do not provide any record of significant slope failures. However, there has been a recent slip in the Council reserve fronting 104c Greenslade Road. Concerned property owners have undertaken planting efforts to stabilise the slope where possible. Lidar data indicates that this slope failure occurred in an area that was previously particularly steep compared to the adjacent shoreline (1V:1H slope) but the community member who alerted us to the site believes that uncontrolled stormwater also played a role in causing the slope failure. Overall, there is clearly potential for shallow slope failures, particularly in steeper areas. The risk of more significant or deeper-seated slope failure is unknown and though there is no evidence of such features in the available historic aerial photography, a precautionary approach until further, more detailed investigation confirms site specific land stability.

As with Cox Bay, a **high-risk coastal erosion area** has been defined on the basis of a slope of 1V:2H, reflecting a precautionary approach to any erosion-induced slope instability until more detailed investigations are undertaken. The same approach as Cox Bay has also been adopted in identifying the **coastal erosion sensitivity area** to 2120, including the effect of 1.0 m sea level rise; assuming potential for a doubling of existing toe erosion rates up to 5.0 m per century and a stable slope of 1V:2H. The horizontal distance from the base of the cliff will vary greatly depending on the elevation of each property.

7.10.2 Coastal Flooding Hazard

Properties at Greenslade Road are well elevated and not at risk from coastal flooding.

Management Options and Recommendations

The primary erosion risk in this area arises from potential slope instability, albeit rare, associated with very slow rates of toe erosion. Accordingly, seawalls will not greatly influence hazard risk and would be buried or severely damaged when and if slope instability events occur.

We recommend that the identified erosion hazard areas are managed using development controls (as outlined in Section 5) to avoid and reduce risk. Given the limited site-specific information available on slope instability, we recommend that the plan provide for adjustment of the development controls where a property-specific assessment of slope instability (by a qualified geotechnical engineer or engineering geologist) indicates this is appropriate.

8 WIDER WAIKATO COASTLINE

8.1 Coastal Compartments

The coast outside of the townships of Raglan and Port Waikato is predominantly rural, and in many areas has only limited road access or none at all. We have broadly divided this coastline into the following coastal compartments based on geomorphology and coastal process considerations:

- Open coast sandy shorelines (including stream entrances)
- Open coast cliffs
- Major river/estuary entrances
- Estuarine banks and cliffs
- Estuarine beaches and low-lying coastal margins

The following sections provide a brief description of each of these compartments and the coastal processes relating to coastal erosion and coastal storm inundation hazard, followed by recommendations for the identification of coastal hazard areas and management approaches.

8.2 Open Coast Sandy Shorelines

8.2.1 Description

Beaches are backed by dunes at a number of locations along the open coast, but in many areas the dunes are relatively narrow and backed by sea cliffs (e.g. the areas of Pleistocene sand cliffs discussed above). As noted above, cliff erosion is may be reactivated by erosion associated with projected sea level rise and therefore cliff erosion hazard becomes relevant.

This compartment includes several very dynamic stream entrances long the sandy coast, often including dunes, actively migrating sands and extensive low-lying areas.

8.2.2 Erosion Hazard

Historical shorelines mapped from historic aerial photography indicate that West Coast beaches can undergo significant multi-decadal dynamic shoreline fluctuations over long periods of time; including lengthy periods of erosion followed by lengthy periods of accretion. For instance, the location of the dune toe along the main area of at Ngarunui Beach has fluctuated by up to 65 m since the 1940s, except towards the northern end where erosion is limited by geological control (Figure 48). Erosion of up to 60 m occurred between 1943 and 1974. Since then the shoreline has recovered by approximately 25 m. A longer record may indicate even larger fluctuations.

As discussed in Section 4.3.1, while the response of west coast ocean beaches to sea level rise is uncertain, there is potential for these beaches to erode significantly; in the order of 75 m of beach retreat for every 1.0 m of sea level rise. In many areas, this will exceed the width of dunes indicating potential for the dunes to be (at least periodically) completely lost.

Figure 48: Historical shoreline positions at Ngarunui Beach.

Stream entrances are vulnerable to a number of hazards including coastal erosion, wind erosion, coastal storm inundation, tsunami hazard and stream flooding, and these areas are subject to significant fluctuations in shoreline position (Figure 49). Fluvial processes (and interactions between fluvial and coastal processes) may also cause erosion further inland. The low-lying areas can be vulnerable to coastal storm inundation (including wave effects) for some distance inland; as well as complex interactions between coastal inundation and stream flooding. These potential hazard areas are very complex to define, particularly where significant coastal streams intersect the coast (e.g. Kaawa, Waikaretu, Waikorea, Waimai, Ruapuke and Torepara Streams) and are backed by low-lying flood plains and wetlands.

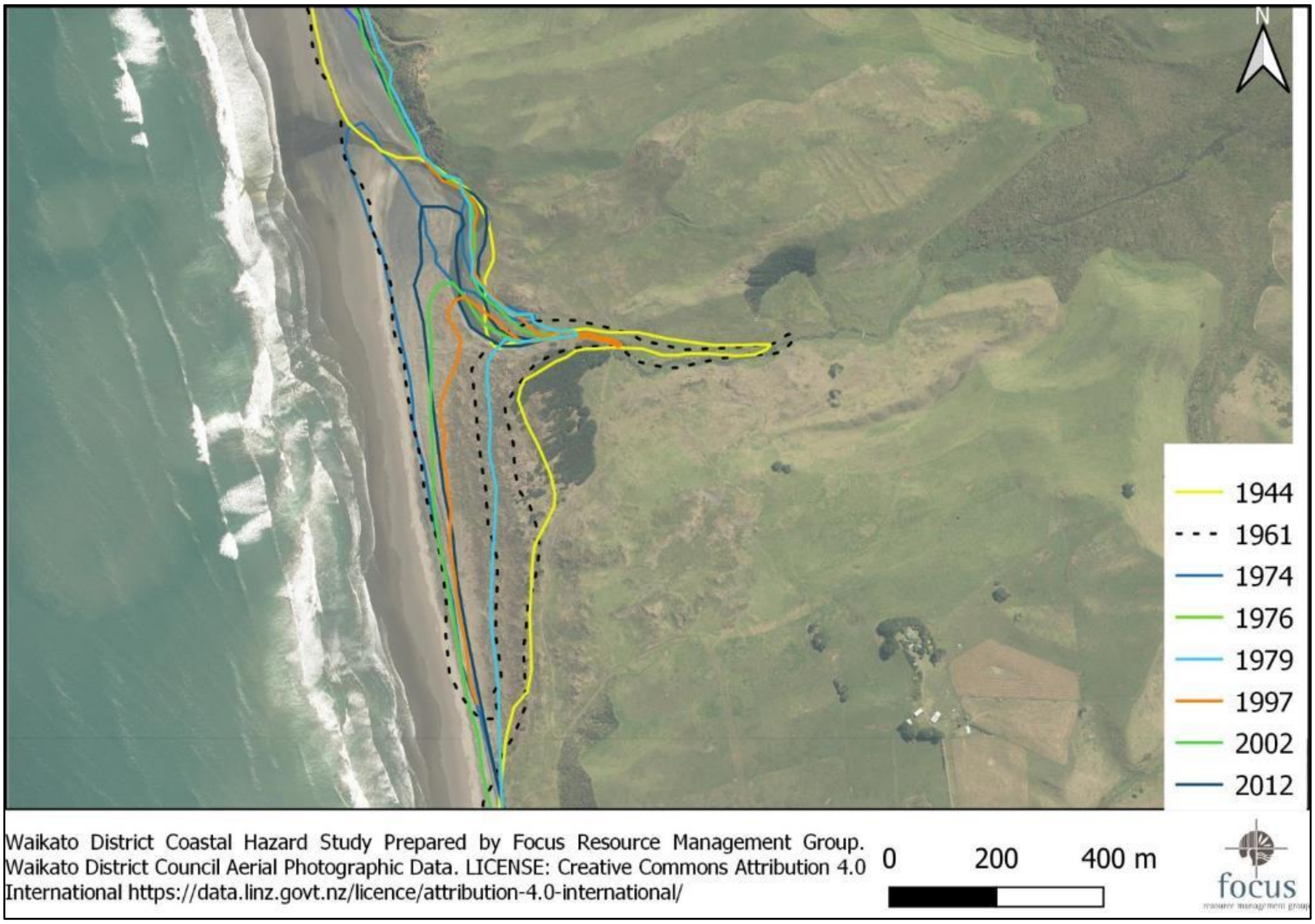


Figure 49: Historical shoreline change at Toreparu Stream, south of Raglan.

8.3 Open Coast Cliffs

8.3.1 Description

The open coast of the District is bordered by hill country over the full length and in many areas this high topography directly abuts the coast. Accordingly, cliffed and bluffed coastlines are common over the full length of the coast and are probably the predominant landform on this coast.

North of the Waikato River entrance, the cliffs are generally formed in cemented or weakly cemented Pleistocene sands. The cliffs are fronted by a sandy high tide beach and in many areas also by dunes, being only periodically subject to wave attack. In some cases, (e.g. immediately north of the Waikato River entrance), the cliffs are therefore protected from waves for long periods (in some cases many decades) (Figure 50).

Figure 50: Shoreline north of Port Waikato. Old sea cliffs are protected from wave attack by dunes.

Tertiary (and, in northern areas, sometimes older) sedimentary rocks dominate the cliffs between Port Waikato and Raglan. In some areas, the cliffs outcrop seaward of the beach and are subject to wave action most of the tide (Figure 51). In other areas, the cliffs are fronted by a sandy beach, but the beaches are most commonly narrow and sometimes intertidal; with the cliffs subject to wave attack at high stages of the tide, or during periods of significant waves. Accordingly, most of the cliffs along this coast are active.

South of Raglan Harbour, the cliffs around the base of Mount Karioi are formed of hard basaltic and andesitic volcanic rocks which outcrop seaward of the coast (Figure 52). Further south towards Aotea Harbour, the cliffs are primarily composed of cemented Pleistocene dune sands and, like similar cliffs north of Port Waikato, are typically fronted by a high tide beach and dunes (e.g. Ruapuke Beach). A short section of cliffs outcrop seaward of the beach near the centre of Ruapuke Beach at Matawha point; but this outcrop is composed of harder and more erosion resistant volcanic rocks which geological maps indicate are of similar age and geology to Mount Karioi (Waterhouse and White, 1994). Further south from Schnackenberg Bay to Taranaki Point, hard Tertiary aged limestones of the Te Kuiti Group outcrop seaward of the coast (Figure 53).

Figure 51: Cliffs between Port Waikato and Raglan (photo Waikato District Council).

Figure 52: Hard basaltic cliffs at the base of Mt Karioi (photo Waikato District Council).

Figure 53: Tertiary aged limestones of the Te Kuiti Group north of Aotea Harbour (photo Waikato District Council).

8.3.2 Toe Erosion Rates

The pattern of the cliffs along the Waikato District coast indicates that the cliffs composed of Tertiary age sedimentary rocks or of andesitic and basaltic volcanics are relatively erosion resistant, quite often outcropping seaward of the coast and subject to wave attack at most stages of the tide. It is difficult to reliably estimate the erosion rates of these cliffs, but the shoreline mapping data and geomorphic considerations suggest the erosion rates are very slow (less than 5 m per century). The toe erosion rates of these cliffs may increase with projected sea level rise, driven by increased water depths and therefore higher wave energy, but the increase is likely to be relatively modest, with future cliff erosion rates probably less than 10 m per century.

In contrast, the cliffs composed of weakly cemented Pleistocene sands (e.g. north of Port Waikato and landward of Ruapuke Beach) are likely to be much more erodible. Historically these cliffs have eroded, creating embayments that over time develop significant beach and dune widths directly seaward of the cliff. These beaches and dunes protect the cliffs from wave attack on most occasions. Accordingly, these cliffs could experience significant erosion if the beaches and dunes to seaward are lost due to the effects of future sea level rise. As discussed in Section 4.3.1, while the response of west coast ocean beaches to sea level rise is uncertain, there is potential for these beaches to erode significantly; in the order of 75 m of beach retreat for every 1.0 m of sea level rise. The weakly cemented Pleistocene sands may not erode as rapidly as the loose Holocene sands, but nonetheless significant cliff erosion rates could occur, and it would seem unlikely that this accelerated erosion would cease until a useful width of high tide beach and dunes was re-established. It is important therefore to allow for this potential for significant cliff erosion in these areas. We have assumed that cliff erosion in these areas is likely to follow a similar pattern to the beaches to seaward (i.e. of up to 75 m erosion per 1.0 m of sea level); even though the rate of erosion is uncertain (i.e. the cliffs will likely erode more slowly than the beaches to seaward, but the long term outcome would be similar).

8.3.3 Slope Stability

Examination of LiDAR data indicates that the cliffs and seaward escarpments along the coast are steep, with typical slopes steeper than 1V: 2H with only localised exceptions. This is similar to the conclusions of earlier work (Tonkin and Taylor, 2007).

Caution is required however as local variations can occur. As an example, Tonkin and Taylor (2007) noted evidence of active earthflows that extend inland with slopes of 1V:6H or less in the area between Kaawa Stream and Otangaroa Stream (the central-northern part of the coastline between Raglan and Port Waikato). The main hazard identified was regression of the head scarp associated with each earthflow and the earthflow mass becoming a rapid debris flow following a heavy rainfall event. It is not clear if these features are wholly or partly related to coastal processes. There is also evidence of other slope instability types in many areas just inland of the coast (Figure 54).

Cliff height is typically less than 50 m but can reach up to 100 m in some areas.

Figure 54: Land instability between Port Waikato and Raglan.

8.4 Major River/Estuary Entrances

There some locations where beaches are backed by wide dune fields, most notably on the northern coasts of the Waikato River, Raglan Harbour and Aotea Harbour entrances. These areas are subject to very large shoreline fluctuations driven by complex coastal and fluvial processes.

8.4.1 Waikato River

As the Port Waikato Spit has extended northwards, the harbour entrance has migrated approximately 3200 m over the last 150 years (i.e. an average of about 20 m per year) and about 2000 m since 1944 (i.e. an average of about 28 m per year); this change has coincided severe erosion on the northern side of the river (Figure 55). In places, the existing shoreline lies up to 1200-1300 m landward of the 1863 and 1944 shorelines (for a full discussion of shoreline change at Port Waikato spit, refer to Section 6.1). It is unlikely that the spit will continue to extend northwards indefinitely. As noted in Section 6, the spit is likely to eventually become unstable and breach. Nonetheless, it not possible to predict how far northwards the spit will continue to extend before this occurs. A precautionary approach to future development is therefore required on the northern side of the river entrance.

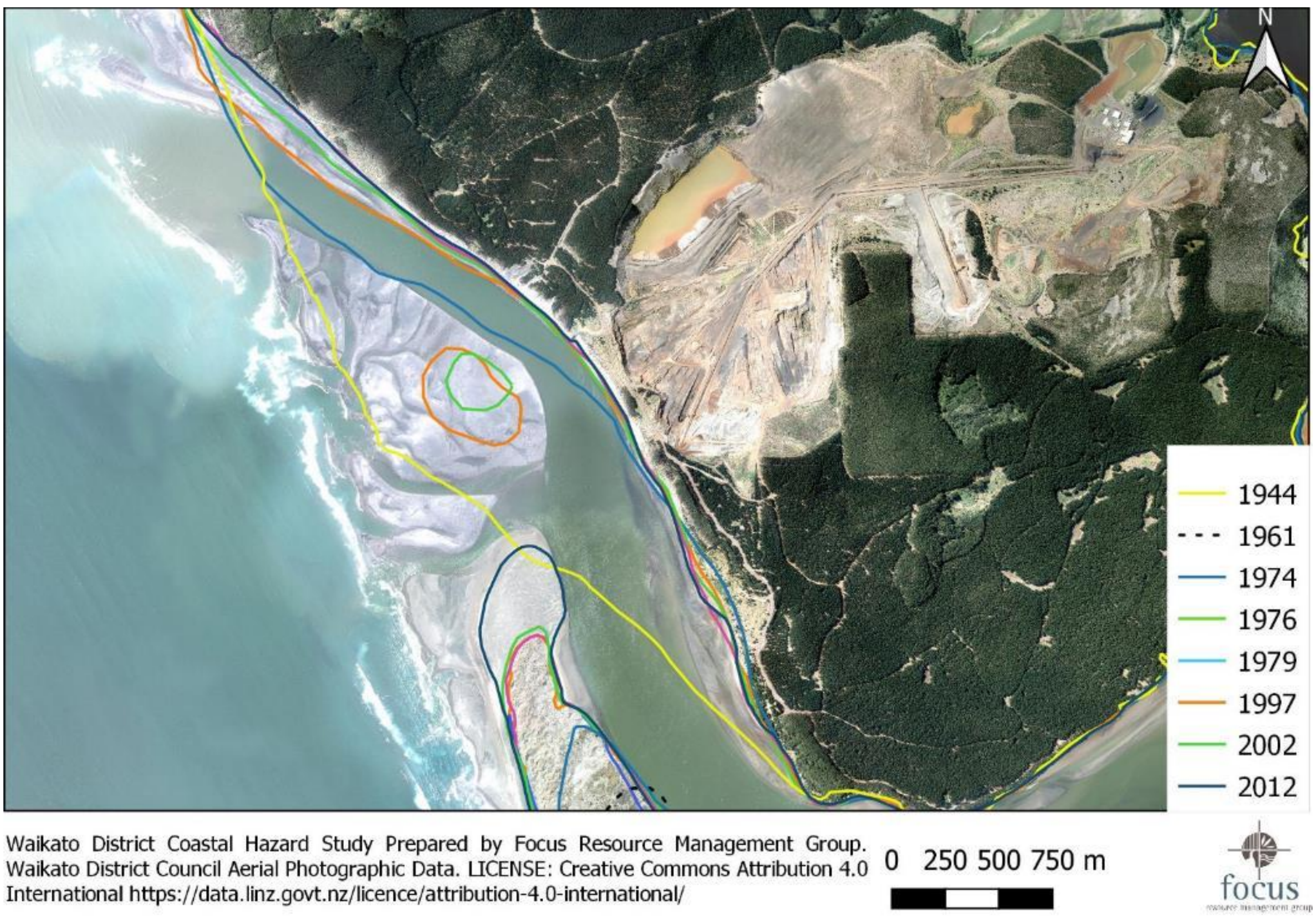


Figure 55: Historical shoreline change north of the Waikato River mouth.

8.4.2 Raglan

On the northern side of the Raglan entrance, extensive dune fields variously extend at least 350-950 m inland. The widest dune areas occur near the entrance and decrease in width northwards. The Raglan entrance has shown no trend for northwards migration and therefore the predominant erosion risk is likely to arise from dynamic shoreline fluctuations and the potential effects of future sea level rise. Since 1943, dynamic fluctuations of up to 100 m have been recorded (Figure 56). However, this is a relatively short record and larger fluctuations may occur over longer timeframes.

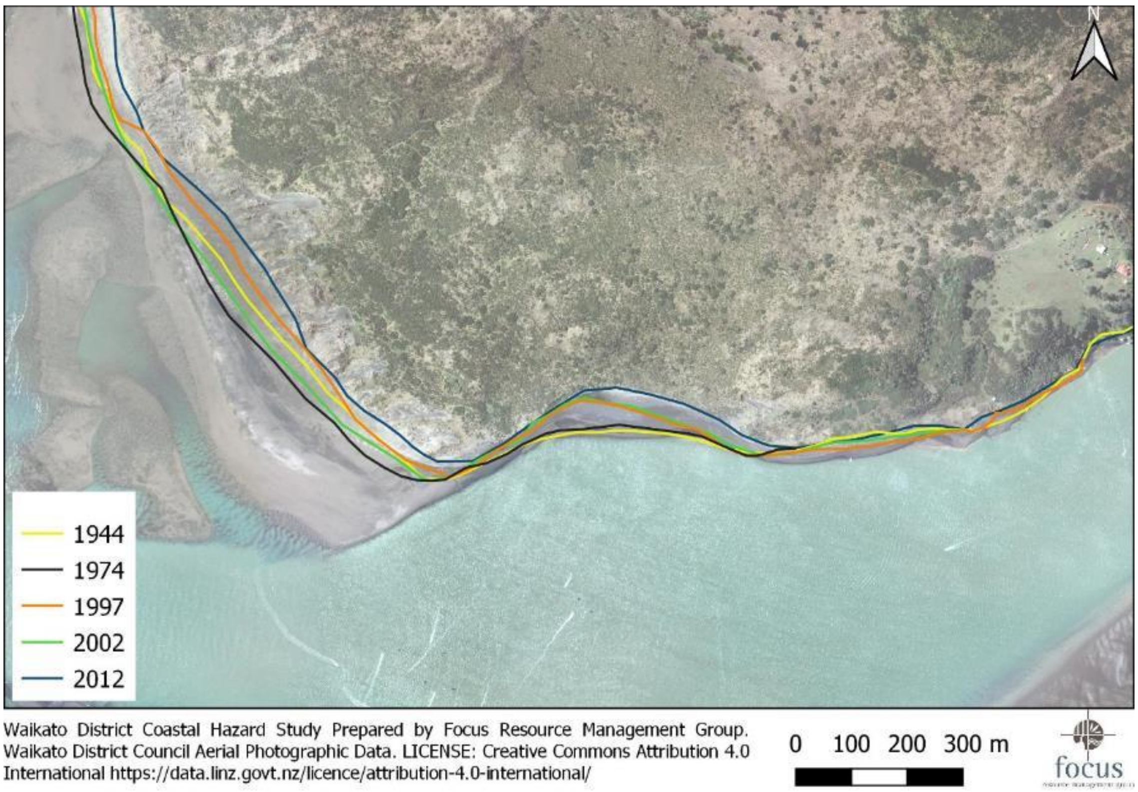


Figure 56: Shoreline change on northern shore of Raglan Harbour entrance.

8.4.3 Aotea

A large dune field occurs on the northern side of Aotea Harbour. The end of this sand spit forms the northern bank of the Aotea harbour entrance and has been subject to major dynamic fluctuations (>500 m) since records began (Figure 57). This area, known as Oioroa, is culturally very significant to relevant tangata whenua and much of the area is also a DoC scientific reserve. The migrating sand sheets also pose a significant hazard. Accordingly, it is unlikely that subdivision and development will ever occur in this area.

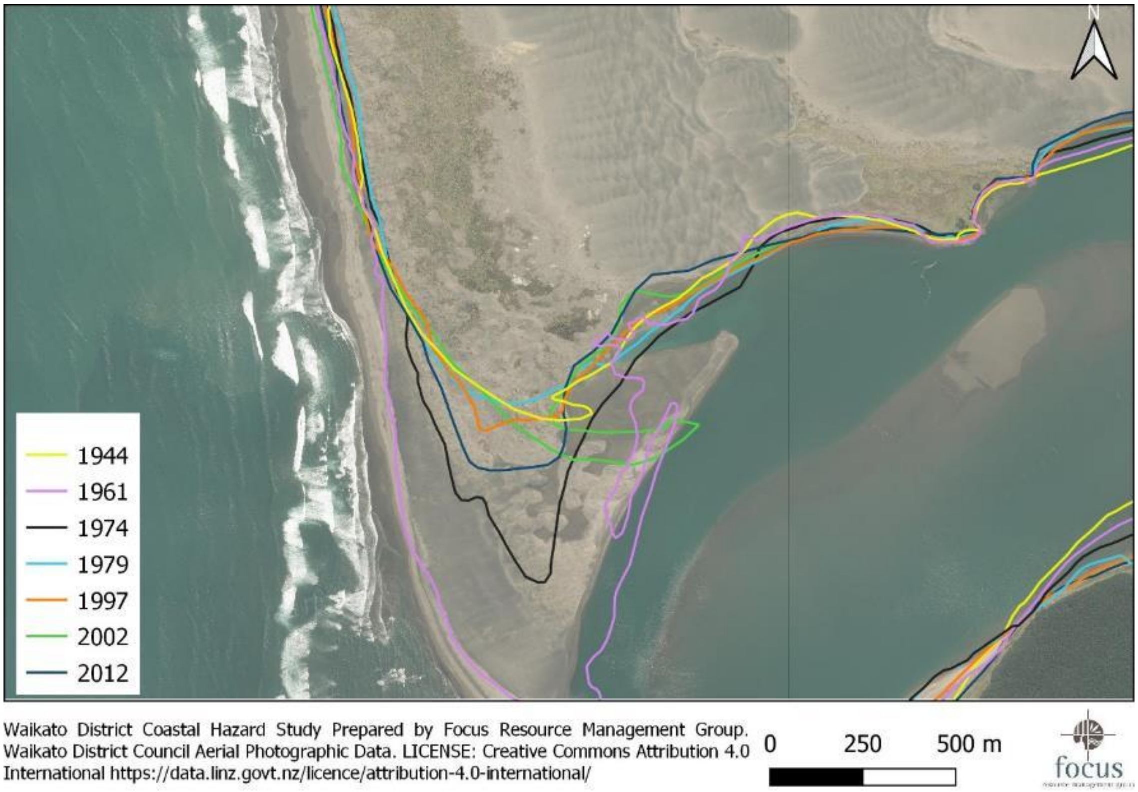


Figure 57: Shoreline change north of Aotea Harbour entrance.

8.1 Estuarine Banks and Cliffs

8.1.1 Description

The original cliffs and bluffs in the Waikato River estuary lie along the southern side of the estuary and are primarily composed of Jurassic sedimentary rocks. However, these cliffs and bluffs are now separated from the estuary by the road into the township, and no longer subject to active wave erosion.

The estuarine coast of Raglan Harbour is primarily composed of Tertiary sedimentary rocks, with volcanics also outcropping in a number of areas along the southern margin. However, there are also various areas where the more erodible, weakly cemented Pleistocene sands are exposed, particularly around the southern side of the harbour (e.g. much of the shoreline of Haroto Bay and the peninsula on the seaward side of Okete Bay).

The southern coastline of Aotea Harbour coastline is largely composed of Holocene mobile sand dunes near the entrance, Pleistocene weakly cemented sands on the western harbour shoreline and Tertiary aged limestone and calcareous sandstone along the eastern shoreline (Waterhouse and White, 1994).

8.1.2 Toe Erosion

Available data including historic aerial photographs, mapped shorelines and field inspections indicate that the existing rates of toe erosion are very slow (probably <2.5 metres per century for the volcanic rocks and Tertiary sedimentary materials and <5.0 m per century for the Pleistocene sediments). While the Pleistocene cliffs on the high wave energy open coast could potentially be very vulnerable to increased sea level rise (Section 8.3), we believe this is less likely within the much lower energy harbour; based on the relatively low historic rates towards the eastern end of Cliff Street (i.e. the end that is less subject to higher energy refracted ocean waves); despite frequent local wind wave action against this bank. Accordingly, while time-averaged erosion rates are likely to be increased by projected sea level rise, it is our view that they are unlikely to be more than 5 m per century for the Tertiary limestones and volcanics, and 10 m per century for the Pleistocene cliffs.

8.1.3 Slope Stability

Aerial photography does not reveal any obvious areas of major instability and so any severe slope failure appears to be very infrequent at most sites. However, we understand there have been claims lodged with the Earthquake Commission for land slippage on the old sea cliff behind Aotea Township (Waitomo District). These landslips occurred within the fixed Pleistocene weakly cemented dune sands. These Pleistocene sands are likely to be much more erodible than the Tertiary sedimentary rocks (as discussed in Section 8.3). For instance, there has been active wave erosion of the bluffed foreshore fronting Te Papatapu Marae (composed of Pleistocene sediments and located in the north-eastern area of the upper harbour) over the past few decades – though the exact retreat in this area has not yet been quantified.

Cliff and bluff slopes around the harbours are highly varied, but the actively eroding banks are typically relatively steep (generally steeper than 1V:1.5H). Accordingly, a slope of 1V:2H has been adopted in defining the coastal sensitivity area for estuarine banks and cliffs.

8.2 Estuarine Beaches and Low-Lying Coastal Margins

Estuarine beaches and low-lying areas occur in a number of areas of Raglan and Aotea Harbour, with low-lying areas also common adjacent to the Waikato River estuary.

Estuarine beaches with dunes tend to be limited to the lower areas of the harbours (e.g. Te Kopua in Raglan), which are dynamically interlinked to the open coast by sediment transport, including longshore transport and intertidal and subtidal sediment transfers between the flood and ebb tide delta systems either side of the entrance. The shorelines in these areas are often very dynamic and are addressed in Section 6 and 7.

Narrow shallow beaches have formed perched over intertidal shore platform in some embayments in both Raglan and Aotea; such as the large seaward facing embayment on the southwestern side of Paritata Peninsula in Raglan Harbour (Figure 58). These beaches are typically very narrow and often just a thin veneer of sand over rock, with the beaches often backed by steeply rising topography, though also narrow widths of coastal plains in very rare areas. The sand appears to be largely derived from very slow onshore migration of low sand and shell ridges; the sand probably reworked onshore by waves from sediments deposited in the harbour by local rivers and streams during floods, together with shell from marine sources.

Chenier beaches formed by onshore migration of sand and shell ridges (cheniers) appear to be the most common beach types in central and upper harbour areas. In some cases, the cheniers are backed by low-lying areas, including existing and/or drained wetlands and some limited chenier plains. A notable example is the shoreline at the seaward end of the large peninsula between Bridal Creek and Okete Bay on the southern side of Raglan Harbour (Figure 59). In this area, chenier ridges migrate onshore and alongshore, accumulating on a low coastal plain located at the end of Wallis Road. A number of small cheniers and wetland areas also occur within and near the Pakoka River estuary in Aotea Harbour, including a significant chenier spit feature formed near Mowhiti Point (Figure 60).

There are very extensive low-lying areas, largely drained wetlands, adjacent to the estuarine areas of the Waikato River; including the northern (e.g. Aka Aka area) and southern sides of the river. These areas are extensively used for agriculture and many are now currently fully or partly protected from flooding by the Lower Waikato Waipa Flood Control Scheme (LWWFCS). There are also some low-lying, drained wetland areas around both Raglan and Aotea Harbour. Remnant areas of estuarine wetlands are now relatively uncommon in these harbours but do occur in limited areas near the mouths of some of the larger catchment streams; including the Waitetuna and Waingaro Rivers in Raglan Harbour and the Pakoko River in Aotea Harbour, with very small areas also in some upper embayment areas near other stream entrances.

Estuarine beaches and low-lying areas are high risk areas for both coastal erosion and coastal inundation. For example, cheniers are wave formed landforms and are regularly overtopped by waves during storms. As such, they can be very dynamic features migrating onshore and alongshore over time. The erosion problems experienced with the early subdivision at the end of Wallis Road in Raglan Harbour are good example of the issues that can arise in these areas. The low-lying nature of these landforms means they are also vulnerable to coastal inundation even with existing sea level.

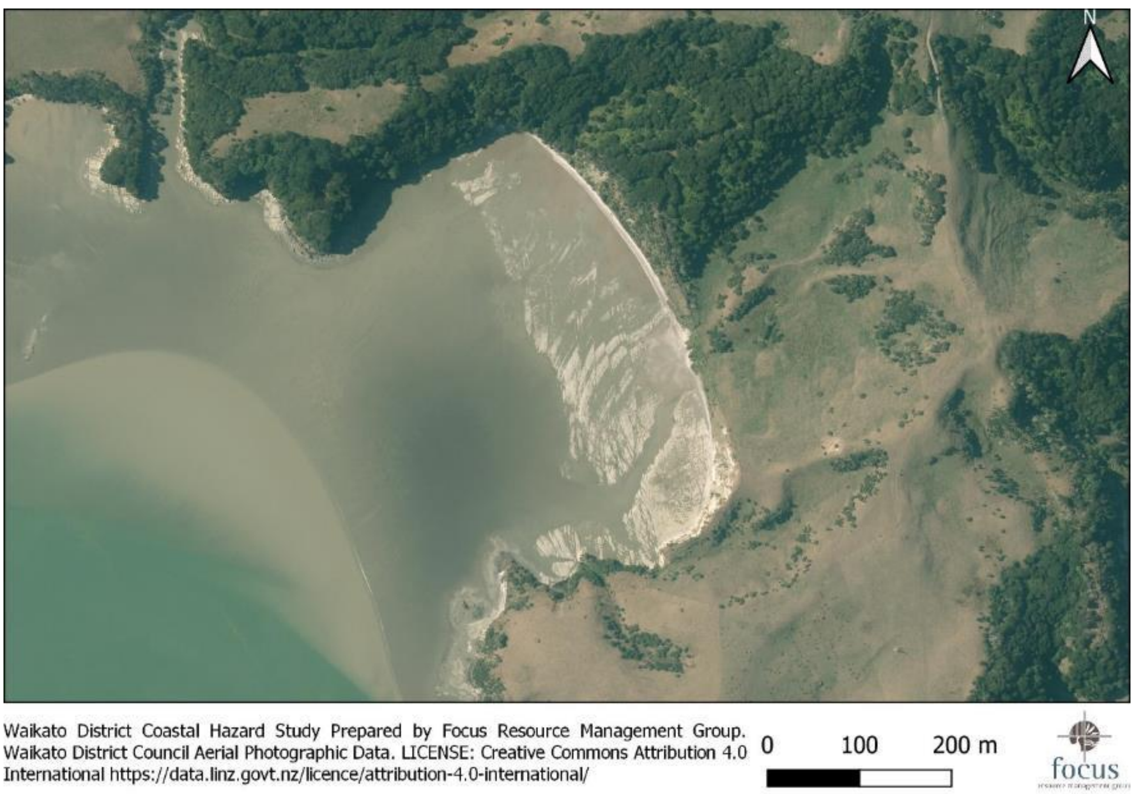


Figure 58: Narrow estuarine beach in an embayment on the southwestern side of Paritata Peninsula (Raglan).

Figure 59: Chenier ridge on the southern shore of Raglan Harbour.

Figure 60: Chenier feature in Aotea Harbour.

Estuarine beaches in central and upper harbour areas also typically have very limited sediment reserves and as such are extremely vulnerable to erosion with sea level rise; with many beaches likely to be either lost or reduced to intertidal beaches by future sea level rise. Low-lying areas, including chenier beaches and existing or drained wetlands will be frequently and severely flooded with projected sea level rise.

8.3 Management Recommendations

The wider Waikato District coastline outside Port and Raglan Townships has been broadly divided into coastal compartments that reflect geomorphological characteristics of the coastline. We have provided broad recommendations for defining a **coastal hazard sensitivity area** for each of these compartments, which identifies the area that is potentially vulnerable to coastal erosion and/or flooding over the next 100 years, including the effect of future sea level rise. The identified sensitivity areas are designed to be conservative and serve as a trigger or “flag” to indicate areas where further site-specific investigation is required prior to further development.

Current land use along this coastline is almost entirely rural or conservation land, and as such our recommendations here reflect the guidelines proposed in Section 5.1.

Any proposed significant development within any of the rural coastal sensitivity areas should be subject to a detailed coastal erosion and inundation hazard assessment conducted by an appropriately qualified specialist (e.g. coastal scientist, geotechnical engineer or engineering geologist). This assessment should consider local geology (including potential geological controls underneath sand features) and the potential impact of natural coastal hazard processes that may impact the area over the next 100 years, including the potential impact of future sea level rise. The provisions for this area should not however apply to non-habitable farm buildings (e.g. hay sheds or implement sheds) or relocatable structures associated with the adjacent sand mining operations.

Where it is deemed that there is any potential coastal hazard, development should only occur with an approved site-specific management plan to manage these potential impacts in the future in a way that avoids adverse effects on the coastal environment (including avoiding the use of hard engineering works to address hazard risk).

It is important to note that the sensitivity areas address only coastal processes and will not be sufficient to address other unrelated slope instability issues that may also be relevant in some areas. Waikato District Council staff advise that a slope stability assessment is generally required for any development on sloping land and it is our opinion that this requirement should continue.

As discussed in Section 5.4., we recommend that the Council plan for future land use in low lying coastal margins to provide for long term landward migration and restoration of coastal and estuarine wetlands and their riparian vegetation in response to future projected sea level rise. It is recommended that the Plan also include strong provisions to preclude filling or raising of land levels in areas likely to be required to provide for landward migration of these ecosystems in response to future sea level rise, considering sea level rise of at least 1.4 m (i.e. the RCP 8.5+ sea level rise scenario discussed in Section 3.3). Council should also consider developing incentive provisions to encourage landowners to set these areas aside and to protect and restore existing coastal wetlands.

8.3.1 Open Coast Cliffs and Beaches

As described above, the open coast of the Waikato District is diverse. The coast is backed in many areas by high coastal cliff outcrops of erosion resistant rock. In other areas, cliffs are formed from "softer" Pleistocene sands that are currently protected at the base by beaches and dunes. If these beaches and dunes are lost in the long term due to the effects of sea level rise, these Pleistocene cliffs may also retreat.

On the basis of the above considerations, the area potentially vulnerable to coastal erosion and associated slope instability (including the effects of sea level rise) can be broadly identified as:

- 10 m toe erosion + 1V:2H slope for <u>tertiary sedimentary rocks</u> on the open coast
- 75 m of erosion (per 1.0 m of SLR) + 1V:2H slope for <u>Pleistocene sands</u> on the open coast
- 200 m at <u>stream mouths</u> on the open coast

8.3.2 Major Harbour and River Entrances

The northern shores of the Waikato River, Raglan Harbour and Aotea Harbour are currently undeveloped, but potentially vulnerable to significant fluctuations in shoreline position typical of such areas. The 200 m sensitivity area described above for stream mouths is unlikely to be adequately precautionary in these areas. We have therefore developed site-specific recommendations to define the coastal hazard sensitivity area on the northern (undeveloped) shoreline of these three entrances.

There are significant complications and uncertainties with regard to future shoreline change north of the Waikato River. As discussed in Section 6.1, the <u>Waikato River entrance</u> migrated approximately 3200 m northwards between 1863 and the present, which is equivalent to an average annual northwards movement of about 20 m per year or 2000 m per century. The northwards extension of the spit and associated erosion of the northern shoreline is unlikely to continue indefinitely. It is more likely that the spit will eventually breach. However, there is no way to be certain when this northwards migration will cease. As a precaution, we have tentatively identified a coastal erosion sensitivity area of 1500 m width (relative to the toe of dune on the <u>ocean</u> coast) on the northern side of the river. This area assumes a further northward migration of the river entrance by 2000 m, with a similar level of landward erosion to that observed in association with past entrance migration. However, this sensitivity area encompasses a very large area of land, and we believe further discussions with relevant stakeholders is appropriate to best determine ongoing management of this area to reflect the considerable uncertainty.

Dynamic shoreline fluctuations of up to 100 m have been observed on the northern side of the Raglan Harbour entrance, and even larger fluctuations (up to 500 m) on the northern side of Aotea Harbour entrance. These fluctuations have been observed using the limited available "snapshots" provided by historical aerial photography from the 1940s. However, it is well known that near-entrance areas of this nature can be extremely dynamic over long periods of time, for a wide range of reasons. In the longer term, sea level rise is likely to be a further major complication. Accordingly, there is considerably uncertainty around potential future change in this area, which will need to be addressed by detailed site-specific investigations.

A precautionary approach is therefore appropriate, and we recommend a 400 m wide erosion sensitivity area on the northern side of Raglan and Aotea Harbour entrance, extending 1.5 km northwards from the harbour entrances. Appropriate detailed investigations may reduce these areas, but a precautionary approach is appropriate with limited existing information. For instance, it is possible that the dunes are underlain by much harder and less erodible materials as extensive areas of landward migrating dunes occurred along this coast in the early-mid 1900s.

8.3.3 Estuary Shorelines

In identifying coastal hazard sensitivity areas within Raglan and Aotea Harbours, we recommend providing for a long-term toe erosion of 10 m per century for all cliffs and bluffs around the estuary shorelines, as well as an allowance for stable slope angle (1V:2H). While the rate of toe erosion will vary significantly (particularly with geology and with wave exposure), this provides for the potential long-term effects of sea level rise and identifies an appropriate trigger for further investigation of these site-specific influences.

Estuarine beaches and low-lying estuary margins with ground elevation below 5.0 m RL may be vulnerable to coastal inundation in the long term with projected sea level rise. Sea level rise also poses a significant potential threat to the small areas of estuarine wetlands left in the various harbours. Unless these systems are able to migrate landward in response to sea level rise, many of these ecologically critical ecosystems may be lost to coastal squeeze effects. These same low-lying environments are typically formed from mobile sediments (as opposed to erosion resistant cliffs) and are also potentially vulnerable to erosion. Accordingly, the coastal hazard sensitivity area for these features is defined by the 5.0 m contour.

8.3.4 Recommended Sensitivity Areas

The above sections provide broad criteria for the identification of areas potentially subject to coastal hazards over the next 100 years. However, there are a number of potential complications associated with local factors and considerable uncertainties in relation to these and future sea level rise. Accordingly, we recommend use of a single, conservative sensitivity area within which more detailed site-specific investigation of coastal hazard should be required to support any future development.

Initial plotting of the recommended sensitivity areas based on the above criteria suggest that on the open coast the sensitivity area would be typically be 150-200 m wide. On estuarine shorelines the recommended sensitivity area is typically up to 50-100 m wide based on the criteria described in the above sections. Accordingly, to simplify mapping, generic sensitivity areas of 200 m wide and 100 m wide could be adopted on the open and estuarine coast, respectively. However these generic areas are potentially not adequate for the northern entrances of Waikato River, Raglan Harbour and Aotea Harbour, where the wider sensitivity areas identified in Section 8.3.2 should apply. Similarly, the sensitivity area for Port Waikato Spit is defined in Section 6.1.

There may be isolated high cliff areas where these generic widths are not adequate. However, WDC have a general policy of requiring a report on slope instability on steeply sloping sites (K. Nicolson, pers. comm). As long as this requirement is maintained, we believe that generic sensitivity areas will be adequately conservative to highlight areas where site-specific investigation of coastal hazards is warranted.

In terms of coastal flooding, the generic 200 m coastal sensitivity area recommended for the open coast will adequately encompass areas likely to be vulnerable to coastal flooding. However, in estuarine areas where there are more widespread low-lying areas with road access, we recommend a coastal flooding sensitivity area be defined as all areas below 5.0 m above MSL.

9 APPENDIX A: SUMMARY OF RECOMMENDED HAZARD AREAS

Location	Shoreline Type	High Risk Hazard Area	Coastal Sensitivity Area	Notes
Open West Coast (Rural) Erosion	All	n/a	200 m	Provides for diverse range of coastal hazards on the open west coast, which could be otherwise estimated by: 10 m toe erosion + 1:2 slope for tertiary sedimentary rocks 75 m of erosion (per 1.0 m of SLR) + 1:2 slope for Pleistocene sands 200 m at stream mouths on the open coast Also provides for long term potential sensitivity to coastal flooding, including the effects of wave run-up. Measured from 2012 shoreline baseline.
Estuary Shorelines (Rural) Erosion	All	n/a	100 m	Flags the area that may be dynamic/erodible for further investigation. Coastal erosion hazard could be estimated by: 10 m toe erosion + 1:2 slope. Measured from 2012 shoreline.
Estuary Shorelines (Rural) Flooding	All	n/a	<5.0 m elevation	Provides for long term coastal inundation risk including effects of sea level rise.
Port Waikato Northern Coast	Major River Entrance	n/a	1,500 m	Reflects very large historic changes in entrance location. Provides for large dynamic fluctuations and future sea level rise. Reflects uncertainty. Measured from 2012 shoreline (ocean shoreline alignment)
Raglan Harbour Entrance Northern coast	Major Estuary Entrance	n/a	400 m	Provides for dynamic shoreline fluctuations and future sea level rise. Measured from 2012 shoreline
Aotea Harbour	Major Estuary	n/a	400 m	Provides for dynamic shoreline fluctuations and future sea level rise.

Northern Coast	Entrance			Measured from 2012 shoreline
Estuary Shorelines (Developed)	Banks/Cliffs	1:2 slope	5 m toe erosion + 1:2 slope	Includes Nihinihi, Cox, Greenslade. Also extend to cover the shoreline fronting Marine Parade (south of the Te Kopua Bridge), Oputuru Road, Goodare Road, Smith Street, Karioi Crescent and Wainui Road from the one lane bridge to Raglan Town Centre. High risk measured from 2.0 m RL contour (MVD '53) Sensitivity measured from 3.0 m contour (MVD '53).
Estuary Shorelines (Developed)	Beaches	10 m	25 m	Applies to Lorenzen Bay. Uses site specific baseline. Limited to landward by 5.0 m contour at Lorenzen.
Port Waikato Sunset Beach	Beach	60 m		Provides for 10 years of erosion + stable dune slope. Measured from 2019 shoreline
Port Waikato Spit	Wider spit	n/a	Entire spit.	Flagging entire spit as sensitivity area due to extreme uncertainty and long-term potential for spit breach.
Port Waikato Upstream	Putataka Headland	2 m + 1:1.5 slope	5 m + 1:2 slope	Consistent with developed estuary sensitivity area with small allowance for seawall effects. Measured from 2017 shoreline
Whale Bay	Bank/cliff	7 m	30 m	Allowance for 2 m toe erosion and stable slope. Sensitivity: toe erosion increased based on SLR effects – 10 m + 1:2 slope. High risk measured from 2.0 m RL contour (MVD '53) Sensitivity measured from 3.0 m contour (MVD '53).
Raglan Entrance Area	Beach	24 m on open coast, reducing to 16 m at toilet block continuing at 16 m around to Te Kopua	All areas on sand	Allowance for 15 m dune fluctuations in short term on open coast, 10 m at toilet block, plus stable dune slope. Sensitivity area reflects harbour entrance setting and lack of knowledge about subsurface geology. Measured from 2017 shoreline.
Te Kopua	Estuarine beach/entrance	Northern shore: 12 m, Southern	All areas on sand	Provides for 10 m short term fluctuations plus stable dune slope. 5 m plus stable slope on southern Te Kopua shoreline. Measured from 2012 shoreline baseline

		shore: 7 m		
Cliff Street	Low Estuary Bank	5.5-8.0 m	14.5 m	2 m toe erosion + stable slope (1V:1.5H). Sensitivity 10 m toe erosion + stable slope (1V:1.5H). High risk measured from 2.0 m RL baseline (MVD ‘53) Sensitivity measured from 3.0 m contour (MVD ‘53).
Wallis Street	Low Estuary Bank	7.0 m	11.5 m	High risk provides for seawall effect and minor erosion + stable slope (1V:1.5H) Sensitivity: 10 m toe erosion + stable slope (1V:1.5H). High risk measured from 2.0 m RL contour (MVD ‘53) Sensitivity measured from 3.0 m contour (MVD ‘53).
Estuary Coastal Flooding (developed)	All	3.1 m RL (MVD)	4.1 m (MVD)	These include no allowance for wave effects or freeboard.

10 APPENDIX B: KEY NZCPS POLICIES

Policy 24: Identification of coastal hazards

(1) Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed having regard to:

(a) *physical drivers and processes that cause coastal change including sea level rise;*

(b) *short-term and long-term natural dynamic fluctuations of erosion and accretion;*

(c) *geomorphological character;*

(d) *the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent;*

(e) *cumulative effects of sea level rise, storm surge and wave height under storm conditions;*

(f) *influences that humans have had or are having on the coast;*

(g) *the extent and permanence of built development; and*

(h) *the effects of climate change on:*

(i) *matters (a) to (g) above;*

(ii) *storm frequency, intensity and surges; and*

(iii) *coastal sediment dynamics;*

taking into account national guidance and the best available information on the likely effects of climate change on the region or district.

Policy 27: Strategies for protecting significant existing development from coastal hazard risk

(1) *In areas of significant existing development likely to be affected by coastal hazards, the range of options for reducing coastal hazard risk that should be assessed includes:*

(a) *promoting and identifying long-term sustainable risk reduction approaches including the relocation or removal of existing development or structures at risk;*

(b) *identifying the consequences of potential strategic options relative to the option of 'do-nothing';*

(c) *recognising that hard protection structures may be the only practical means to protect existing infrastructure of national or regional importance, to sustain the potential of built physical resources to meet the reasonably foreseeable needs of future generations;*

(d) *recognising and considering the environmental and social costs of permitting hard protection structures to protect private property; and*

(e) *identifying and planning for transition mechanisms and timeframes for moving to more sustainable approaches.*

(2) *In evaluating options under (1):*

(a) *focus on approaches to risk management that reduce the need for hard protection structures and similar engineering interventions;*

(b) *take into account the nature of the coastal hazard risk and how it might change over at least a 100-year timeframe, including the expected effects of climate change; and*

(c) *evaluate the likely costs and benefits of any proposed coastal hazard risk reduction options.*

(3) Where hard protection structures are considered to be necessary, ensure that the form and location of any structures are designed to minimise adverse effects on the coastal environment.

(4) Hard protection structures, where considered necessary to protect private assets, should not be located on public land if there is no significant public or environmental benefit in doing so.

Policy 25: Subdivision, use, and development in areas of coastal hazard risk

In areas potentially affected by coastal hazards over at least the next 100 years:

(a) *avoid increasing the **risk** of social, environmental and economic harm from coastal hazards;*

(b) *avoid redevelopment, or change in land use, that would increase the risk of adverse effects from coastal hazards;*

(c) *encourage redevelopment, or change in land use, where that would reduce the risk of adverse effects from coastal hazards, including managed retreat by relocation or removal of existing structures or their abandonment in extreme circumstances, and designing for relocatability or recoverability from hazard events;*

(d) *encourage the location of infrastructure away from areas of hazard risk where practicable;*

(e) *discourage hard protection structures and promote the use of alternatives to them, including natural defences; and*

(f) *consider the potential effects of tsunami and how to avoid or mitigate them.*

[The NZCPS 2010 glossary states that 'Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence (AS/NZ ISO 31000:2009 Risk management—Principles and guidelines, November 2009)'.]

Policy 26: Natural defences against coastal hazards

(1) Provide where appropriate for the protection, restoration or enhancement of natural defences that protect coastal land uses, or sites of significant biodiversity, cultural or historic heritage or geological value, from coastal hazards.

(2) Recognise that such natural defences include beaches, estuaries, wetlands, intertidal areas, coastal vegetation, dunes and barrier islands.

11 APPENDIX C: REGIONAL POLICY STATEMENT

11.1 POLICY 6.2 PLANNING FOR DEVELOPMENT IN THE COASTAL ENVIRONMENT

Development of the built environment in the coastal environment occurs in a way that:

a) ensures sufficient development setbacks to protect coastal natural character, public access, indigenous biodiversity, natural physical processes, amenity and natural hazard mitigation functions of the coast;

b) protects hydrological processes and natural functions of back dune areas;

c) avoids the adverse effects of activities on areas with outstanding natural character, and outstanding natural features and landscapes;

d) ensures that in areas other than those identified in (c) above, activities are appropriate in relation to the level of natural character or natural feature and landscape;

e) has regard to local coastal character;

f) allows for the potential effects of sea level rise, including allowing for sufficient coastal habitat inland migration opportunities;

g) protects the valued characteristics of remaining undeveloped, or largely undeveloped coastal environments;

h) ensures adequate water, stormwater and wastewater services will be provided for the development;

i) avoids increasing natural hazard risk associated with coastal erosion and inundation;

j) has regard to the potential effects of a tsunami event, and takes appropriate steps to avoid, remedy or mitigate that risk;

k) avoids ribbon development along coastal margins;

l) does not compromise the function or operation of existing or planned coastal infrastructure;

m) provides for safe and efficient connectivity between activities occurring in the coastal marine area and associated land-based infrastructure;

n) manages adverse effects to maintain or enhance water quality; and

o) maintains and enhances public access.

11.2 POLICY 12.3.2 AMENITY VALUE OF THE COASTAL ENVIRONMENT

Regional and district plans shall ensure that the amenity values of the coastal environment are maintained or enhanced, including by:

a) recognising the contribution that open space makes to amenity values and providing appropriate protection to areas of open space;

b) maintaining or enhancing natural sites or areas of particular value for outdoor recreation;

c) employing suitable development setbacks to avoid a sense of encroachment or domination of built form, particularly on areas of public open space and along the coastal edge;

d) avoiding forms and location of development that effectively privatise the coastal edge and which discourage or prevent public access to and use of the coast;

e) recognising that some areas derive their particular character and amenity value from a predominance of structures, modifications or activities, and providing for their appropriate management;

f) ensuring the removal of derelict or unnecessary structures within the coastal marine area;

g) encouraging appropriate design of new structures and other development to enhance existing amenity values;

h) maximising the public benefits to be derived from developments;

i) ensuring public access to public areas is enhanced where practicable; and

j) recognising the role of esplanade reserves and strips in contributing to public open space needs.

11.3 POLICY 12.3.3 ENHANCE PUBLIC VALUES IN THE COASTAL ENVIRONMENT

Local authorities should seek to incorporate the enhancement of public amenity values, including when undertaking works and services or preparing or reviewing growth strategies, structure plans, or regional and district plans.

11.4 POLICY 13.1 NATURAL HAZARD RISK MANAGEMENT APPROACH

Natural hazard risks are managed using an integrated and holistic approach that:

a) ensures the risk from natural hazards does not exceed an acceptable level;

b) protects health and safety;

c) avoids the creation of new intolerable risk;

d) Reduces intolerable risk to tolerable or acceptable levels;

e) enhances community resilience;

f) is aligned with civil defence approaches;

g) prefers the use of natural features over man-made structures as defences against natural hazards;

h) recognises natural systems and takes a 'whole of system' approach; and

i) seeks to use the best available information/best practice.

11.5 POLICY 13.1.1 RISK MANAGEMENT FRAMEWORK

Regional and district plans shall incorporate a risk-based approach into the management of subdivision, use and development in relation to natural hazards. This should be in accordance with relevant standards, strategies and plans, and ensure that:

a) new development is managed so that natural hazard risks do not exceed acceptable levels;

b) intolerable risk is reduced to tolerable or acceptable levels

c) the creation of new intolerable risk is avoided;

d) any intolerable risk as a result of existing use and development is as low as reasonably achievable; and

e) where intolerable risk remains, the risks will be managed until an acceptable level is achieved.

11.6 POLICY 13.1.3 ASSESS NATURAL HAZARD RISK TO COMMUNITIES

Waikato Regional Council will collaborate with territorial authorities, tāngata whenua and other agencies to undertake assessments of coastal and other communities at risk or potentially at risk from natural hazards and develop long-term strategies for these communities. The strategies will, as a minimum:

a) include recommendations for any hazard areas that should be applied, including primary hazard areas;

b) identify risks to the community and existing infrastructure from natural hazards; and

c) identify options for reducing the risks to the community to an acceptable level and the relative benefits and costs of those options, including taking into account any effects on:

d) public access;

e) amenity values; or

f) natural character (including natural physical processes, indigenous biodiversity, landscape and water quality).

12 APPENDIX D: REFERENCES

ASR, 2007: Coastal Hazards Assessment Review for a Subdivision at Port Waikato. Technical document prepared for Franklin District Council, November 2007.

Ashton A.D, Walkden M.J.A, & Dickson M.E. 2011: Equilibrium responses of cliffed coasts to changes in the rate of sea level rise. Mar Geol 284:217-229.

Blair, S. 1998: Coastal Stability and Failure Mechanisms in the Vicinity of Raglan Township. Master of Science Thesis, University of Waikato. 217 p.

Brooks, S.M. and Spencer, T. 2011: Shoreline retreat and sediment release in response to accelerating sea level rise: Measuring and modelling cliff line dynamics on the Suffolk Coast, UK. Global and Planetary Change 80-81 (2012) 165-179.

Bruun. P., 1962: Sea-level rise as a cause of shore erosion. J. Waterways Harbors Div 88:117–130.

Bruun, P., 1988: The Bruun Rule of erosion by sea-level rise: a discussion on large-scale two- and three-dimensional usages. JCR, 4, 627–648.

Dahm, 1999: Coastal Erosion Hazard in the Waikato Region. Environment Waikato Technical Series 1999/07. 30 p.

Dahm, J. and Gibberd, B. 2010: Te Kopua Spit – Raglan. Coastal Hazards and Setback Recommendations. Internal report prepared by Eco Nomos and 4D Environmental Ltd for Environment Waikato. 21p.

Department of Conservation, 2010: New Zealand Coastal Policy Statement.

Department of Conservation: NZCPS 2010 Guidance Note: Natural Hazards – Objective 5 and Policies 24, 25, 26 and 27.

Dickson, M.E., Walkden, M.J.A. and Hall, J.W., 2007. Systemic impacts of climate change on an eroding coastal region over the twenty-first century. Climatic Change 84 (2), 141–166.

Earthtech Consulting Ltd, 2006: Weatherall Subdivision-Geotechnical, Stormwater and Groundwater Investigations report. Report prepared for Michael Weatherall.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Le Cozannet, G., Garcin, M., Yates, M., Idier, D. and Meyssignac, B. (2014) Approaches to evaluate the recent impacts of sea level rise on shoreline changes. Earth-Sci. Rev., 138, 47–60.

Mullen, B., Salinger, J., Thompson, C., Ramsay, D. & Wild, M. (2005): Chatham Islands climate change. Report prepared by NIWA for MfE. NIWA Client Report: WLG2005-35.

MfE, 2017: Coastal Hazards and Climate Change – Guidance for Local Government. Publication number: ME 1341.

Pilkey, O. and Wright, H. 1988. Seawalls vs Beaches. Journal of Coastal Research. SPECIAL ISSUE NO. 4. The Effects of Seawalls on the Beach (AUTUMN 1988), pp. 41-64

Shand, T., Shand, R., Reinen-Hamill, R., Carley, J. and Cox, R. 2013: A Review of Shoreline Response Models to Changes in Sea Level. 2013 Coasts and Ports Australasian Conference, Sydney.

Smith, S. P. 1878. Notes of a traditional change in the coast-line at Manukau Heads. Transactions of the N.Z. Institute, 11: 514–516.

Stephens, S., Robinson, B. & Bell, R. 2015: Analysis of Whitianga, Tararu and Kawhia sea-level records to 2014. Prepared by NIWA for the Waikato Regional Council. NIWA Client Report No. HAM2015-046.

Tonkin and Taylor, 2007: Port Waikato Coastal Hazard Assessment, Report prepared for Michael Weatherall by Tonkin and Taylor Ltd. April 2007.

Tonkin and Taylor, 2009: Port Waikato Coastal Hazard Assessment, Additional Information. Prepared for Michael Weatherall by Tonkin and Taylor Ltd. January 2009. 30 p.

Waikato Regional Council, 2011: Fragile: a guide to Waikato Dunes. Waikato Regional Council Publication Revised Edition. https://www.waikatoregion.govt.nz/assets/WRC/Services/publications/other-publications/Fragile-2011-web.pdf.

Walkden, M.J.A. and Hall, J.W., 2005: A predictive mesoscale model of the erosion and profile development of soft rock shores. Coastal Engineering 52 (6), 535–563.

Waterhouse, B.C.; White, P.J. 1994. Geology of the Raglan-Kawhia area. Lower Hutt: Institute of Geological & Nuclear Sciences. *Institute of Geological & Nuclear Sciences geological map 13* 48 p.

Wright, H.L and Pilkey, O.H: 1989: The Effect of Hard Stabilization Upon Dry Beach Width. In Coastal Zone `89, American Society of Civil Engineers, pp 776-790.