The Effect of a Rise in Mean Sea Level on the New Plymouth Coastline: A GIS Investigation.

A Thesis
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Abstract

The world’s sea levels are predicted, by the international scientific community, to rise anywhere between 0.18 metres to 2.2 metres by the year 2100, 87 years away. As a large portion of the population of both the World and New Zealand live by the sea, this prediction is of concern to those in its vicinity. With such a large range in the predicted sea rise level, a range of scenarios have been investigated to determine what effect the rising sea will have on the New Plymouth Coastline, its people, its properties and its places.

This study uses a GIS, in conjunction with property and census datasets, to investigate the areas of potential inundation that should be of most concern to our planners and local authorities. Using 3D models of the coastline and seabed and by projecting the predicted sea level rise onto the 3D model, an assessment of the value of property and numbers of people potentially affected was determined. Erosion / accretion are also considered in the investigation and modelled into the coastal topography of the New Plymouth coastline.

The key findings from this research are that there are areas of high value, high importance or population that are critically exposed to moderate levels of sea rise. Infrastructure such as Port Taranaki, The CBD, New Plymouth Airport and sewage systems are all greatly affected, whilst populations in Waitara and other populations close to river mouths are also at risk from a rising sea.

“Maps are like campfires – everyone gathers around them, because they allow people to understand complex issues at a glance, and find agreement about how to help the land.”

– Sonoma Ecology Centre, GIS/IS Program Web Site

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- Bathyscopic Shapefile
- Spot Heights Shapefile
- Maps of NZ
- Topographical Maps series 260 P19, P20, Q19, Q20

My wife Jenny for her patience, understanding and countless cups of tea.

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List of Abbreviations

3D	Three Dimensional
CD	Chart Datum
CTM	Coastal Terrain Model
DEM	Digital Elevation Model
DTM	Digital Terrain Model
FEMA	Federal Emergency Management Agency
GIS	Geographical Information System
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change (IPCC)
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
NIWA	National Institute of Weather and Atmosphere
NPDC	New Plymouth District Council
RSL	Rising Sea Level
SAS	SAS
SWL	Still Water Level
TIN	Triangular Irregular Network
TRC	Taranaki Regional Council
LINZ	Land Information New Zealand

Chapter 1 Introduction

1.1 Research Objectives

The problem this research will attempt to resolve is

> "What will be the effect of a 0.5 metre or more rise in mean sea level on the New Plymouth Coastline"?

The study has used a Geographical Information System (GIS) as its main tool to determine the effects of sea rise on selected areas of the New Plymouth coastline. These areas are the populated areas of Oakura, New Plymouth, Bell Block and Waitara and other areas of strategic importance such as the New Plymouth Airport and Port Taranaki. Other areas around estuaries are also included because of their potential to affect the areas upstream when river flooding occurs. Other analysis tools such as SAS and Excel have been used to provide detailed statistic analysis.

Contour data (0.5 metre interval) as well as wave, tide, and river flow data have all been used in conjunction with existing erosion data sourced from the numerous publications prepared for local and central government to examine the question of effect.

1.2 Structure of the Thesis.

The first three chapters in this thesis examine the research objectives and structure of the thesis, and then give some background on the subject.

Chapter 4 looks at the elements that describe sea level; Chapters 5 and 6 explain the geography of coastlines, the environmental elements and the issues that will occur in conjunction with a 'Rising Sea', explaining some of the extreme events and how the values were derived.

The use and applicability of GIS is covered in chapters 7 and 8, whilst the investigation of the selected eight coastal areas is reported in Chapter 9, under "Findings". Chapters 10 and 11 summarise and draw conclusions from the findings. The References are found in Chapter 12.

The eight coastal areas examined in Chapter 9 use the local data available and takes two different approaches to answering the research question posed.

The two approaches are:-

i. A non-erosive approach to see the effects of a rising sea level on the coast, how property and population are affected through inundation only.
ii. The effect of erosion and inundation due to a rising sea level, on the coast, how property and populations are affected based on historic erosion / aberration data.

The New Plymouth Coastline has been split into eight areas, each being assessed separately using the approaches above.

The Study areas are:

i. Oakura
ii. Port Taranaki
iii. Moturoa - City
iv. Fitzroy
v. Bellblock
vi. Airport
vii. Brixton
viii. Waitara

The suitability of the various methods of analysis using GIS / SAS / Excel, used to create and analyse some of the data used in this thesis will be discussed.
The GIS software package, ESRI ArcMap 10, was used to create maps to show the areas affected by sea level rise, and Microsoft Excel used to provide graphs and tables of data to support findings.

1.3 Why this Topic

With almost daily mention in the world's media of a rising sea level and comments about populations, particularly in the Pacific, being under threat to abandon their homes, it is only natural that a person’s thoughts turn to those areas closest to home.

Much work has been done in physically protecting the New Plymouth Coast from erosion but very little, if any, quantitative research exists on the long term projections of a rising sea and its effects on the topography, property and populations along the New Plymouth Coast. This thesis explores these issues.

Chapter 2 Location

2.1 Study Location

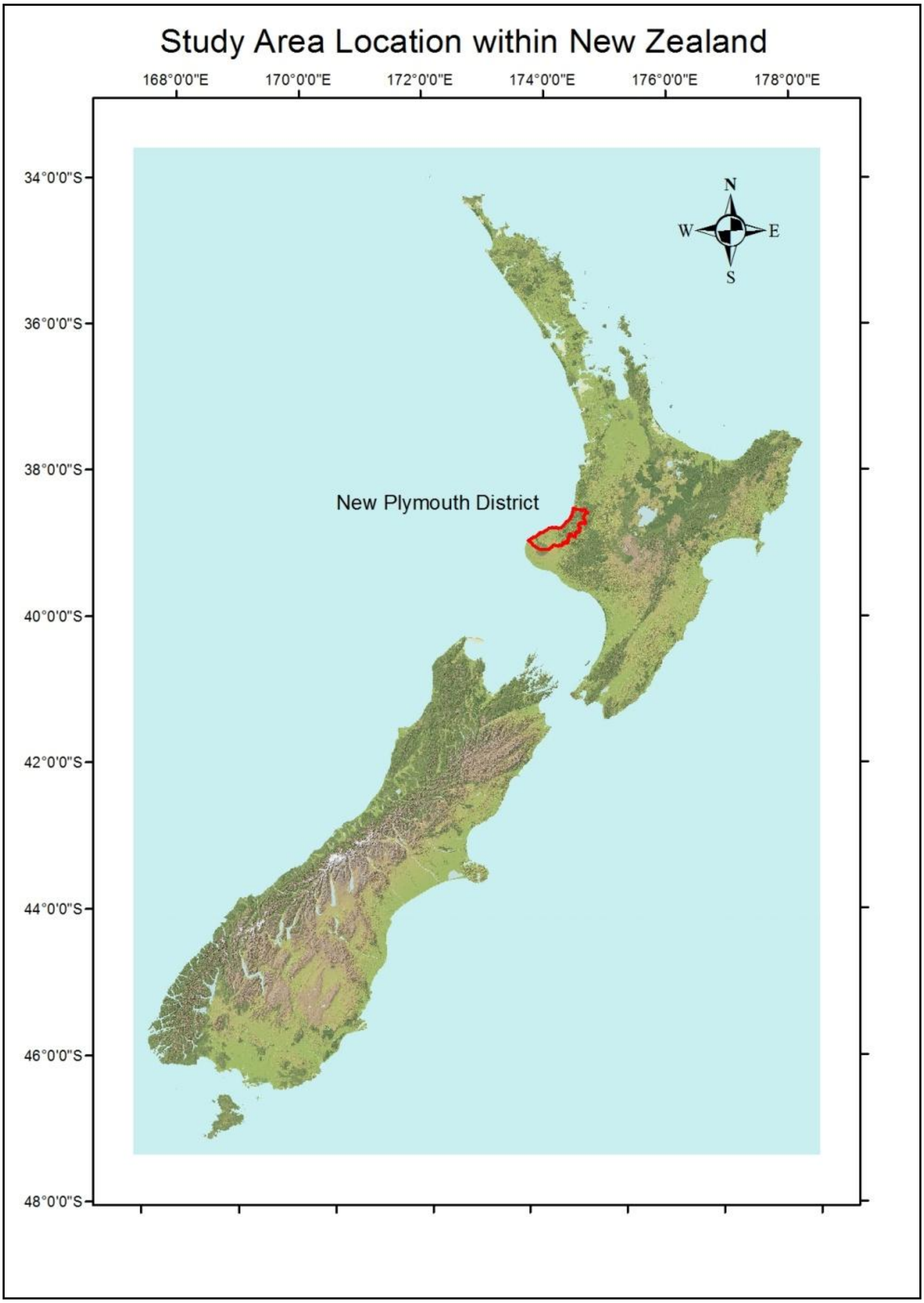
The New Plymouth District covers an area of some 2205 square kilometres and has a population of 68,901 housed in 26748 dwellings according to the 2006 census. Much of the population lives by the coastline and / or along the banks of streams and rivers. Within the study area, there are two major strategic assets – Port Taranaki and the New Plymouth Airport.

Port Taranaki is the only major port on the West Coast of New Zealand and is used to service a wide area of central New Zealand with some 3.9 million tonnes of products passing through in the year 2011 (J.Leung_Wai and Dustow, 2012) which makes it the 3rd largest port in New Zealand by volume. It is one of New Zealand's key import and export ports. It offers nine fully serviced berths and has the ability to handle a wide range of cargo.

New Plymouth Airport has air links with all the major airports in the North Island and Christchurch and with 321,337 people passing through its gates in 2012 which makes it New Zealand’s 11th largest airport.

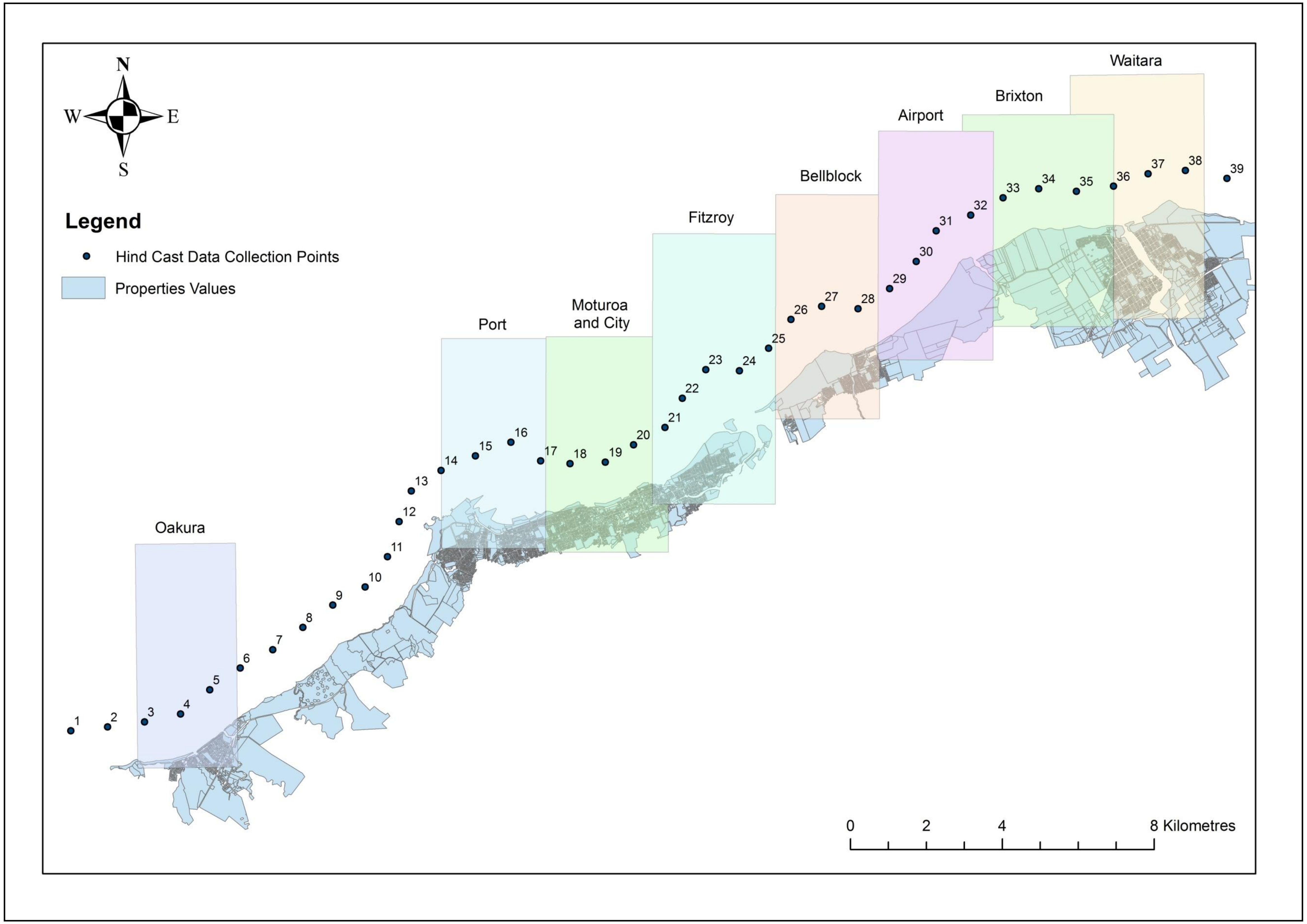
Both assets are close to the sea and therefore both have the potential to be affected by a rising sea.

Map 2.1.1 :- Study area location with New Zealand.



Map 2.1.2 :- Defined study area within New Plymouth District.

Map 2.1.3 :- Wave collection sites, property shape file with named study sites overlain.



Chapter 3 Background

3.1 Threats to those in the study area

3.1.1 Threats to the New Plymouth Coastline

The major natural threats to the New Plymouth Coastline come in the form of:

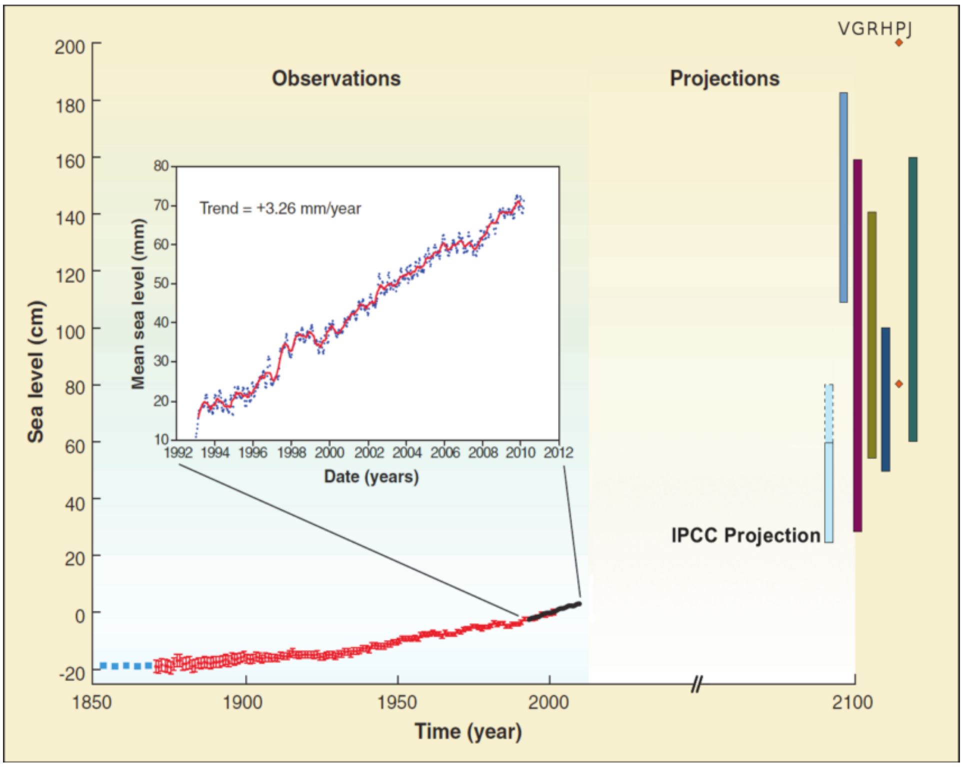
- Volcanic eruption
- Earthquake
- Tornado / Hurricanes
- Tsunami
- Erosion of the foreshore
- Inundation along the coast due to rising sea levels
- Inundation along a river due to rising sea levels

This thesis is concerned with the last three as they involve the rise in sea level. To examine these threats a number of scenarios have been mapped out using several 3D models which cover the New Plymouth Coastline from Oakura in the west to Waitara in the east.

3.2 Sea Level Rise

The Intergovernmental Panel on Climate Change (IPCC) has found that in the last hundred years, the global temperature has risen by 0.7°C and there has been widespread melting of snow and ice with a corresponding sea level rise of 0.17m. Over the last forty years there has been an average rate of increase in the sea level rise from 1.8mm per year to 3.1mm per year for the last 20 years. It is not clear if this is a temporary effect or it is a significant trend (Ministry for the Enviroment and NIWA, 2008).

Figure 3.2.1:- Global mean sea level rise.



Source:- Royal Society of New Zealand, Rising sea Levels – Emerging Issues.

The chart above, Figure 3.2.1, shows tide levels taken from tide gauges. The black portion shows data collected more recently by satellite and expanded into the inserted graph which covers the years 1993 to 2010. To the right are the 2100 IPCC projections (The Royal Society of New Zealand, 2010.

According to the IPCC much of the rising sea level comes from, in order of importance:

i. The increase in volume (thermal expansion) of the sea.
ii. Mountain glacier melting
iii. Melting of Greenland's ice sheet

It has been estimated from various models the sea can be expected to rise somewhere between 0.18m and 0.59m (refer Table 3.2.2) by the year 2100 depending on which model is being used. Some of the models used ignore aspects which would add to the rate of sea level rise, such as carbon-cycle feedbacks or the effects of ice sheet flow because the effects of these are unknown (Ministry for the Enviroment and NIWA, 2008).

Table 3.2.2:- The various climate change scenario's and the expected increase in sea level.

Temperature Change (^{0}C at 2090-2099 relative to 1980-1999)			Sea Level Rise in metres (2090-2099 relative to 1980-1999)
Case	Best Estimate	Likely Range	Model based Range – excluding future changes to Ice Flow.
Constant Year 2000 concentrations	0.6^{0}	0.3^{0} – 0.9^{0}	n/a
B1 Scenario	1.8^{0}	1.1^{0} – 2.9^{0}	0.18 – 0.38
A1T Scenario	2.4^{0}	1.4^{0} – 3.8^{0}	0.20 – 0.45
B2 Scenario	2.4^{0}	1.4^{0} – 3.8^{0}	0.20 – 0.43
A1B Scenario	2.8^{0}	1.7^{0} - 4.4^{0}	0.21 – 0.48
A2 Scenario	3.4^{0}	2.0^{0} – 5.4^{0}	0.23 - 0.51
1F1 Scenario	4.0^{0}	2.4^{0} – 6.4^{0}	0.26 – 0.59

Source:- (Hart, 2011)

In addition to the global sea rise tabled above (Table 3.2.2), local conditions could add an additional 0.1m to the global average through what is often referred to as "El Nino" (Ministry for the Enviroment and NIWA, 2008)

Based on this information the New Zealand Ministry of the Environment sought expert opinion from a number of sources which concluded that the draft advice was "well formulated and well sort after" which meant a base value of 0.5m (based on the computer modelling range of values from 0.18m – 0.59m) was chosen. This was seen as a midterm value which allowed for a further melting of the ice sheet.

Areas around schools, hospitals and other features of significant infrastructure which pose greater risk if affected, should possibly be evaluated using a sea rise value of 0.9m.

For periods beyond 2090 (only 87 years from now), a sea rise rate of 10mm/year after 2100 should be used (Ministry for the Enviroment and NIWA, 2008) in addition to the above recommendations.

Whilst the New Zealand government recommends planners use a 0.5m sea rise level (0.9m for significant infrastructure) some would recommend that a 2.0m level be used for planning purposes, and a bare minimum level of 0.9m should be used. This is based on the premise that the causes of sea level rise are changing and include the melting of ice sheets in Greenland and West Antarctic (Pilkey and Young, 2009).

The Ministry of the Environment (MfE) has considered using a higher prediction level as it has a “High Confidence” that sea level rises will be above the 0.25m level because the drivers that create that level already exist. However, there is less confidence with the higher levels, as some research is predicting higher sea rise levels of between 0.5m and 1.4 metres.

Since the 2007 IPCC report more has been learned about the polar ice sheets and how they behave; largely due to improvements in satellite observations (The Royal Society of New Zealand, 2010)

If we look at the other sources outlined by the Royal Society of New Zealand the levels projected by the MfE could be said to be conservative at best.

Table 3.2.3 :- Recent scientific projections of sea level rise by 2100.

Source	Sea level rise (m) by 2100
Pfeffer	0.8 plausible (2.0 max possible)
Rahmstorf	0.5 – 1.4
Horton	0.5 – 1.0
Grinstead	0.3 – 2.2
Vermeer	0.75 – 1.9
Jevrejeva	0.6 – 1.6

Source:- The Royal Society of New Zealand, 2010

The following table (Table 3.2.4) is recommended for planning purposes.

Table 3.2.4 :- Recent International projections of Sea Level Rise by 2100 relevant to coastal planning.

Source	Sea level rise by 2100 (m)
Dept of Climate Change, Australia	0.6m plausible, 1.5m "can't be ruled out", risk assessment level 1.1m
Dept of Environment, Climate change and water, NSW	0.9m
Dept of Environment and Resource Management, Queensland	0.8m
California Climate Change Centre, USA	1.0 – 1.4m
DEFRA, UK	0.12 - 0.76m , extreme scenario 1.9m
Deltacommissie, The Netherlands	0.55 – 1.2m, planning level 1.1m
United Nations Environment Programme	0.5 – 1.4m
Climate Change Research Centre, UNSW	Double IPCC estimates
International Alliance of Research Universities	0.5 – 1.5

Source:- The Royal Society of New Zealand, 2010

3.3 What's at stake

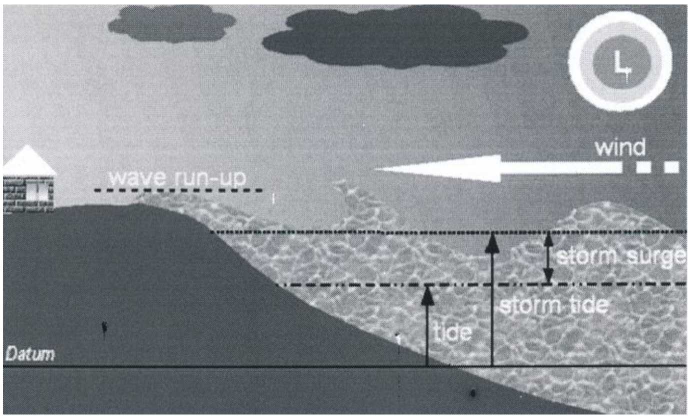
Twelve of New Zealand's fifteen largest towns and cities are along the coast of New Zealand and therefore a large portion of the New Zealand population which is already exposed to existing coastal weather hazards such as coastal erosion, flooding from storm surge, waves, extreme high tides and extreme rainfall plus the salinisation of groundwater (The Royal Society of New Zealand, 2010). A rising sea level will compound these hazards in both frequency and intensity making the populations and infrastructure vulnerable to such extremes. A large number of smaller coastal communities dot the New Zealand coastline, and included in these are the New Plymouth coastal communities of Oakura and Waitara, along with strategic infrastructure such as the New Plymouth Airport and Port Taranaki. These are subject to the effects of a rising sea level and the accompanying affects. In Chapter 4 we examine the elements that make up these hazards, in particular what elements contribute to sea level rise.

Chapter 4 Sea Level Elements

4.1 Elements that make up Sea Level

The sea that reaches the shoreline has a number of components, these being the tide, storm surge and run up (Ministry for the Enviroment, 2008):

Figure 4.1.1:- Basic components that make up sea level.



Source – MfE, Coastal Hazards and Climate Change :- Guidance Manual 2008

4.1.1 Tide

The Mean Sea Level (MSL) is predictable. The tide oscillates about the mean sea level.

The MSL can be influenced by long term climate changes and fluctuations i.e. La Nina which tends to depress sea levels and El Niño when sea levels tend to rise. Estimates put this El Niňo rise at 0.1m for the west coast of the North Island (Laing, 2000). El Nino events are characterised by a warming of the oceans waters, increased rainfall on the west coast and drought on the east coast it reoccurs every 3 – 7 years (NIWA, 2013).

4.1.2 Storm Surge

Storm surge is the increase in ocean level due to low barometric pressure and winds blowing either on shore, or off shore. The converse is true with high barometric pressure which can have the effect of lowering ocean level. 'Storm Tide' is the New Zealand expression used to describe the effect of the components shown in Figure 4.1.1. above.

4.1.3 Runup

At the shoreline wave run-up which includes set-up, further adds to the vertical elevation reached by the sea. This level is in addition to the elevation reached by the storm tide. The above terms are defined in more detail in section 4.4.

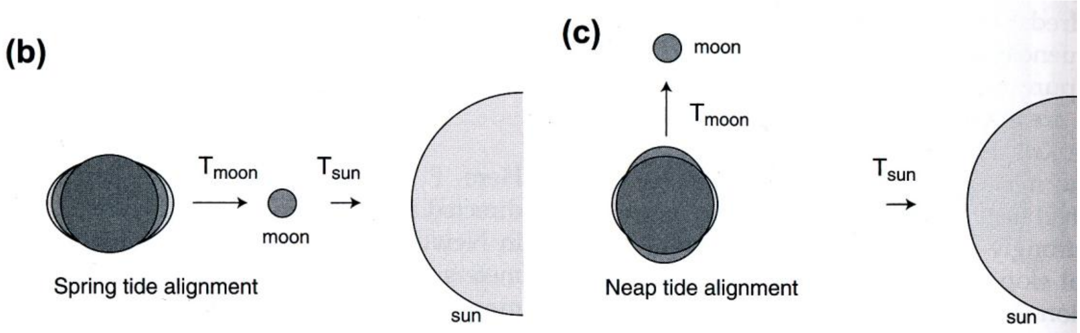
4.2 Tides and Water Levels

It is the rotational distances of The Moon around the earth and the earth around The Sun, and the joint effect of their gravitational forces on the waters of the earth that create tides (Ross D.A., 1995). Whilst the lunar and solar forces cause the water on the near side of the earth to be pulled toward The Moon, inertia attempts to keep the water in place, but the gravitational force exceeds it and the water is pulled toward The Moon, causing a bulge of water (Ross D.A., 1995). The opposite side of the earth (the far side) has less gravitational force on it, but the inertia exerted makes the water want to move in a straight line, which is away from The Moon, making a bulge. The two sides of the earth both have bulges, in alignment with The Moon, due to different forces. Because the ocean is fluid the two bulges are in relative balance as the earth rotates (Ross D.A., 1995).

The Sun also affects the size and position of the two tidal bulges. The interaction of the forces of both The Sun and The Moon are complex. Although The Sun is many times larger than The Moon, it is further away, so The Sun's tide generating force is about half that of The Moon (Thurman, 1994).

When The Moon and The Sun are in alignment with the earth, the effect is a slight increase in the gravitational pull on the earths water and the generation of a Spring Tide as shown in figure 4.2.1 b. A Neap Tide is when The Sun and The Moon don't align as shown in figure 4.2.1 c.

Figure 4.2.1 :- The effect of The Sun and The Moon in generating tides. Illustrating the mechanism which generates both Spring and Neap Tides.



Source:- Descriptive Physical Oceanography : An introduction, 2011

A spring tide occurs approximately every 14 days, as The Moon takes 24 hrs and 50min to rotate around the earth. The same holds true for neap tides.

NIWA has defined tidal terms are as follow.

i. Mean Sea Level (MSL)

The average level of the sea surface over a long period of time or the level the sea would exist at with the absence of tides.

ii. Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS)

The average of the levels of each of a pair of successive high waters and the average of the levels of each of a pair of successive low water levels over a 24 hour period approximately every 14 days when the tide is greatest (Spring range).

iii. Mean High Water Neaps (MHWN) and Mean Low Water Neaps (MLWN)

The average of the levels of each of a pair of successive high waters and the average of the levels of each of a pair of successive low water levels over a 24 hour period approximately every 14 days when the tide is least (Neap range).

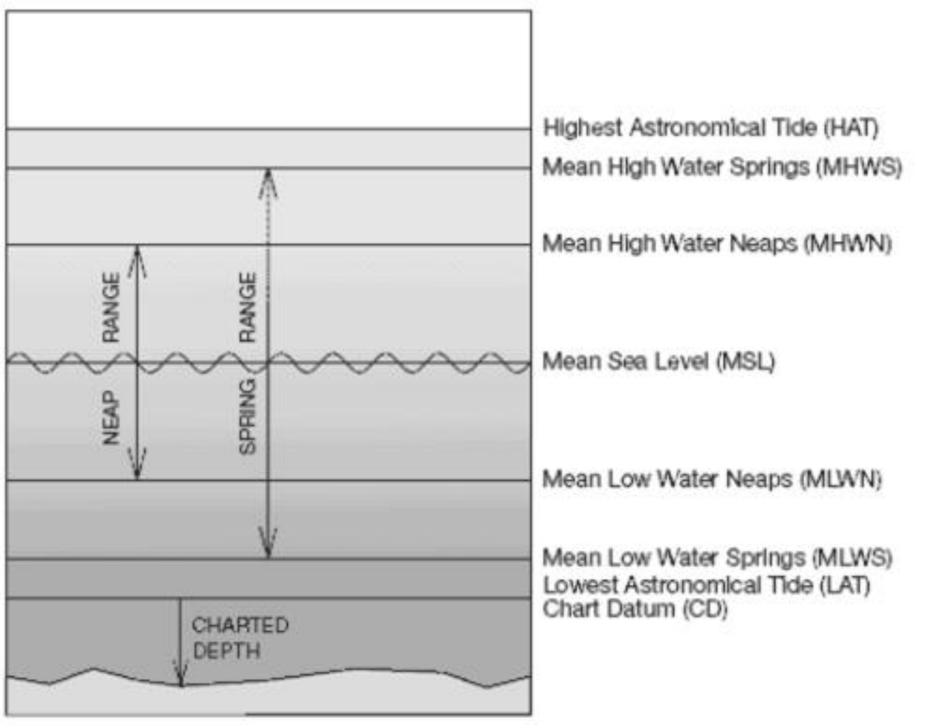
iv. Highest Astronomical and Lowest Astronomical Tide (HAT and LAT)

Highest and Lowest tidal levels which can be predicted to occur under average meteorological conditions over 18 years. Most Chart Datum's are set to the level of LAT.

v. Chart Datum

Chart Datum a water level so low that tide will seldom not go below it. It is possible for sea levels to go below the LAT due to meteorological conditions (i.e. High Pressure).

Figure 4.2.2 :- The relationship between the various tides and MSL (Mean Sea Level).

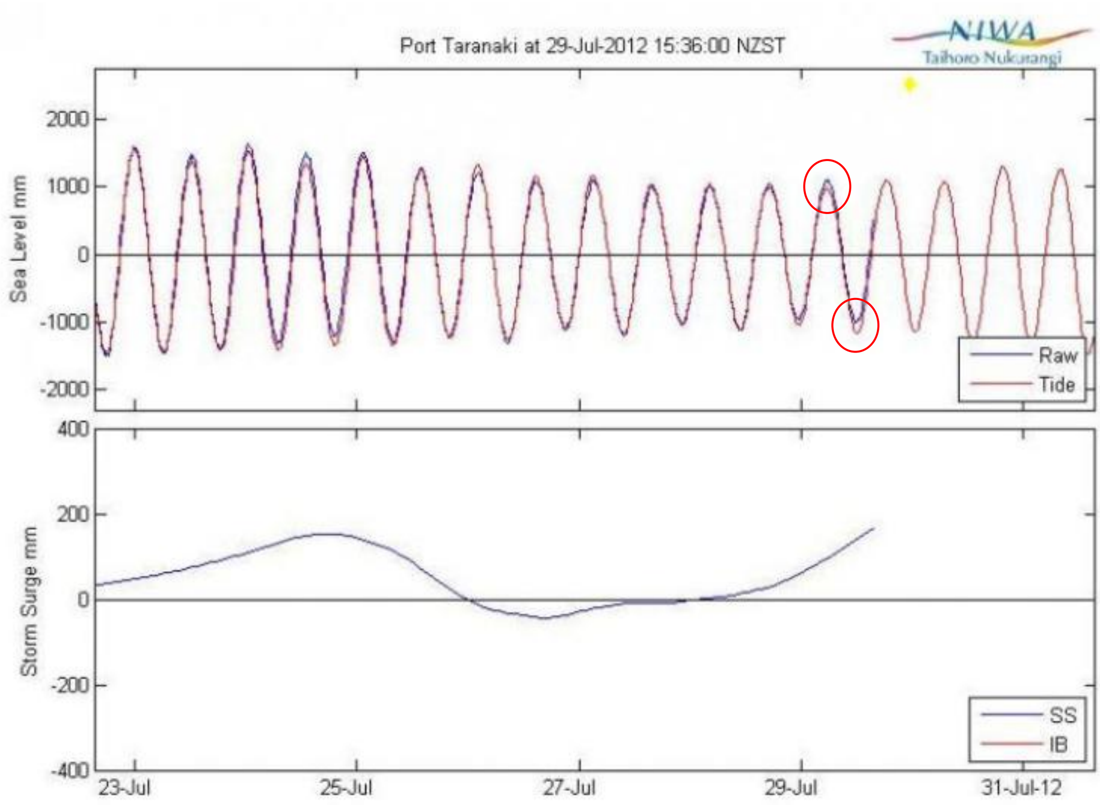


Source:- www.linz.govt.nz/hydro/tidal-info/tidal-intro/definitions

4.3 Storm Surge

Storm surge is the pulse of water that washes onto a shore during a storm and is measured as the difference between the predicted astronomical tide and the actual water level (Hobbs, 2012). It can be seen on charts that show actual tide height vs theoretical height. Refer Figure 4.3.1.

Figure 4.3.1 :- Plot of predicted sea level vs actual sea level and the resulting storm surge of Port Taranaki.



Source:- Port Taranaki via www.niwa.co.nz/sea-levels/port-taranaki

The blue line is the actual tide height (Raw), whilst the red line is the predicted (expected) tide height. The difference, storm surge, is plotted below. When the storm surge is positive it means that there is more water to travel up a beach than would normally be expected.

The highest storm surge ever recorded was in 1899 in Bathurst Bay, Australia. The storm surge was some 13m high and occurred during a hurricane, which can be compared with Hurricane Katrina, which produced a storm surge of 9m. Hobbs 2012 points out that whilst a hurricane can cause lots of damage due to storm surge occurring at a high tide, a strong slower-moving storm can create more damage with its storm surge over a wider area and during multiple high tides. Thus the four factors which control the impact of a storm are:

i. The intensity of the storm
ii. The storms track relative to the coast
iii. The duration of the storm, or the speed of its passing
iv. The time since the last storm.

There are three major factors that are responsible for the intensity of storm surges and these are low pressure, strong winds and waves which often combine at the same time (Beer, 1983, Hobbs, 2012, Masselink, 2011). Low pressure raises the water level, whilst strong winds blowing onshore can pile up the water in the form of waves. The combination of these three factors causes severe flooding. When storm surge is associated with a low tide, it often goes unnoticed. If storm surge occurs when tides are high, the effect is that of a higher tide. Should the converse occur, with combined effects of high pressure and strong offshore winds, a lowering of water levels results, (Hobbs 2012).

Air pressure at sea level is defined as being 101.325 kPa. In periods of fine weather a barometer will read higher than standard, conversely the barometer will read much lower than the standard during a severe storm. Using the formula to derive

Pressure = pgz

Where

p = the density of water.

g = acceleration due to gravity.

z = vertical distance.

100 kPa equates to 10 metres of water, therefore 0.1 kPa will equate to a 10 mm change in water level (Beer, 1983, Masselink, 2011). This shows as a rise in sea level as the barometer falls, and a sea level drop as the barometer rises. This effect is known as the inverse barometer effect.

In New Zealand the mean barometer reading for northern and central New Zealand is above the standard at 101.4 kPa (1014 hPa) whilst southern New

Zealand is 101.2 – 101.3 kPa (Ministry for the Enviroment, 2008) meaning that storm surge reaches greater elevations in the south than the more northern and central parts of the country.

4.4 Wave Setup, Runup and Overtopping

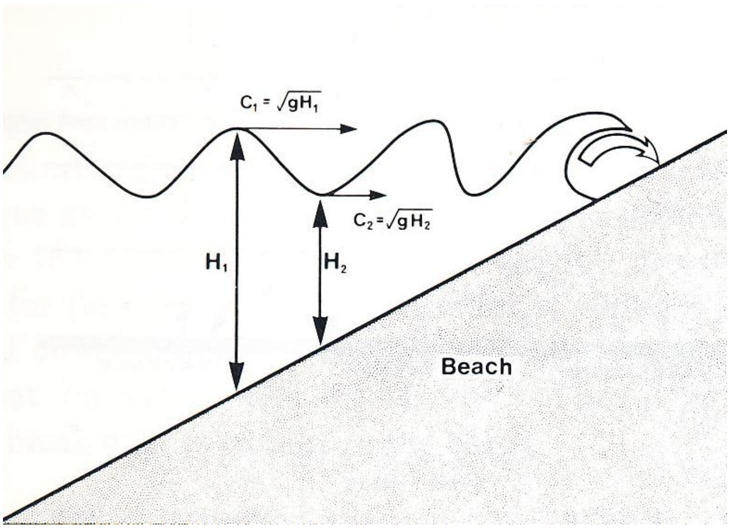
4.4.1 Waves

Ocean waves are generated by wind, which also causes waves to travel across the ocean. Three things determine the size of a wave.

i. The distance the wind blows over open water (“fetch”).
ii. The length of time the wind blows.
iii. The speed of the wind.

The greater any of these three become, then the larger the wave.
The largest waves are found mid-ocean, as a wave will collapse once the height of the wave becomes one-seventh the size of its base. The closer to shore a wave gets the smaller and slower it becomes as it gets broken down. This is described by Beer (Beer, 1983) and seen in the following diagram and formula.

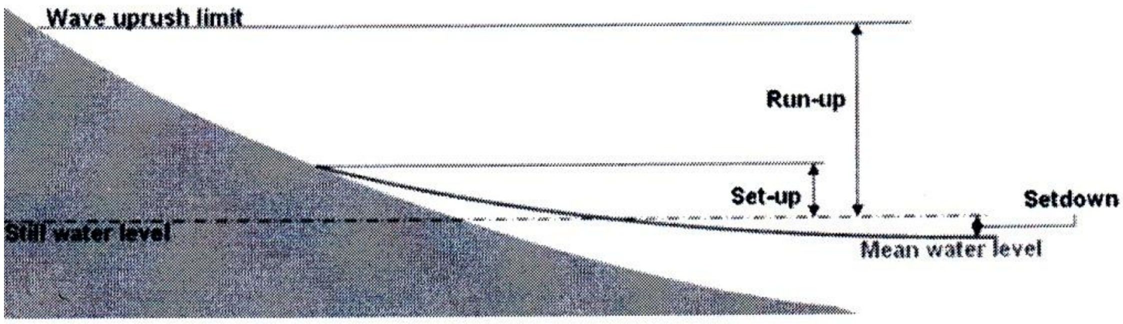
Figure 4.4.1:- The affect of waves being broken down as they get closer and closer to the shore.



4.4.2 Wave Set-up

Wave setup is “the super elevation in water level across the surf zone caused by energy expended by breaking waves” (Ministry for the Enviroment, 2008) and must be a known factor when planning for the effects of sea rise. This is especially important when calculating the effect of hurricanes, as these will exacerbate coastal inundation (Beer, 1983). The Figure 4.4.1 illustrates wave setup.

Figure 4.4.2 :- The relationship between Mean Water Level, Still Water Level, Setup and Runup.



Source – MfE, Coastal Hazards and Climate Change : Guidance Manual 2008

4.4.3 Runup

Wave run-up is seen as being as important as setup for planners. It is the extent to which the energy stored in a wave is converted in to Kinetic energy as it “runs up” the foreshore of the beach until the energy is expended by friction and gravity. Runup is important to factor into calculations because it is the means by which much of the energy that is responsible for erosion of beaches and dunes is delivered against the very barriers that prevent flooding. (Stockdon et al., 2006).

(FEMA, 2003) and the US Army Corps of Engineers (Hughes, 2005) provide different formula for the calculation of Run Up. Based on advise received (pers. comm. Dr Scott Stephens, 2013). for this exercise, we have used Stockdon’s formula.

Stockdon, 2006 offers the following equation for the calculation of setup and run-up .(refer Equation 4.4.1)

Equation 4.4.1:- Stockdon's equation for setup and run-up for dissipative beaches where $\xi_o < 0.30$.

$$\xi_o = \tan\beta f / (H_o\, L_o)^{1/2}$$

$$\text{Setup} = 0.016[H_o\, L_o]^{1/2}$$

$$\text{R}_{2\%} = 0.043[H_o\, L_o]^{1/2}$$

The first part of the calculation (ξ_o) is to determine if the beach is dissipative or not. In all but one case the values generated for ξ_o was less than 0.3. refer Appendix G

Tan ßf = the slope of the forshore (LAT to HAT)

H_o = Significant wave height in deep water in metres.

L_o = Significant wave length in deep water in metres.

$\text{R}_{2\%}$ = Runup value in metres of every 50th wave.

As a cross check the setup value is typically 20% of H_o (Masselink, 2011)

4.4.4 Overtopping

Overtopping is, as the word suggests, waves going over the top of a barrier or coastal defence, resulting in the flooding of land and properties on the other side. Wave spray or splash over these defences cause roads and rail systems problems, even though the volumes of sea water are small, and are according to the New Zealand MfE, not enough to cause major inundation problems (Ministry for the Enviroment, 2008).

4.5 Elements that lead to Flooding

As discussed in section 4.4, coastal flooding hazards arise from wave, tide and wave surge dynamics originating in the ocean and subsequently interacting with the bathymetric and topographic features of a shoreline. Greater wind speeds and higher storm surges create a greater storm surge potential, which has a continuing erosive effect on the topographical features which previously may have reduced the effect of storm surge and waves (National Research Council, 2009). The interaction of the oceanographic elements with the topographical coastal features will be discussed in the next chapter.

Chapter 5 Coastal Elements

5.1 Beaches

In the previous chapter, the various oceanographic and physical weather systems, as they influence sea level, were discussed. In this chapter the interface between the sea and land will be discussed.

A beach is a narrow buffer between the sea and stable land mass. A beach will change shape when forces are applied to it, and as it dissipates the energy of storms. A beach can change its shape in an hour or less. Local studies have shown that a beach can change profile by more than ±1.0 metres (N. A. Cowie et al., 2009) It can take three or four weeks for a beach to recover its original shape by replacing or loosing sand. The entire shore area can change over decades (Hobbs, 2012).

During a storm, sand is eroded from the landward portion of the beach and is moved along the shore, as well as offshore. If there is a storm lasting through many high tides and there is moderate storm surge, then it may well be that the dune front is also eroded. With the sand moved off down the beach and offshore the beach profile becomes lower and smoother, and at the same time, making the water off shore shallower than it was prior to the storm event. During a storm a beach's profile becomes lower and smoother, the sand removed from the beach is deposited in the nearshore and shallow offshore. Measuring and quantifying the change during a storm is difficult (Hobbs, 2012) but as the beach profile changes, waves break away from the shoreline in deeper water. Because larger waves break in deeper water, the waves may then reform and break again and again as the beach becomes shallower before the energy in the waves is finally spent.

A long, slowly sloping, beach is called a dissipative beach (storm beach), since this allows sufficient space for the wave energy to be dissipated. A reflective beach denies the wave energy any chance of dissapating, and is made up of relatively coarse-grained sand and has a steep beach face. Waves hitting a reflective beach tend to collapse and then surge up the beach face with pronounced backwash of wave energy and water (Hobbs, 2012).

Beaches made up of coarse sand are steeper than those made up of fine sand, with those composed of gravel are very steep. Therefore, as the waves approach the shore the waves become shorter as the beach becomes shorter. This is because as the wave moves toward the shore the water has nowhere to go except up, and as it reaches an angle of 120 degrees (1:7 wave steepness), it must break apart as the upper part of the wave is moving faster than the base. Waves break in water that is about 1/3rd of the waves height.

5.2 Waves and Sediment Transportation

Storm waves are relatively long in length and as a result tend to disturb the sea bed at much greater depth than smaller waves. If shallower, there is a stronger wave motion on the bottom, which is enough to move or lift sediment and deposit it elsewhere (Hobbs, 2012). This action is called Erosion.

5.3 Coastal Erosion

In the Ministry of the Environment's "Guidance Manual on Coastal Hazards and Climate Change", it is pointed out that many locations around the New Zealand coast will be affected by climate change and the interaction of spring high tides (MHWS) and the coastline and point to coastal erosion being dependent on the following drivers.

i. Sea Level Rise (relative)
ii. Long-term Sea Level changes
iii. The Frequency and Severity of storms
iv. Tidal Range
v. Storm and Wave conditions
vi. Rainfall patterns and intensity and the effect on cliff sediment supply.

It should also be noted that the above points are not the only influences on coastal erosion but the geomorphology of the coast can be affected either directly or indirectly by human intervention but it is the natural drivers that have the greatest affect on coastal erosion.

A (Taranaki Catchment Board, 1988) report states that, "The geology and morphology of a coast line will determine its susceptibility to erosion. The actual rate of erosion is dependent on the forces acting upon it. These include waves which abrade and erode the coastal fabric as well as transport sediment offshore and along-shore, and coastal currents" (Taranaki Catchment Board, 1988).

Despite the wide range of geomorphic forms found around the New Zealand coast, the effect of climate change on these environments is straightforward. See the following graphic (Figure 5.3.1) summarising the effects of erosion or accretion on the main coastal types. Local conditions will result in significant local deviations to those shown below.

In his book "Waves and Beaches" (Bascom, 1980) explains that the rate of erosion is not always a constant and that sometimes a beach or cliff can show little or no sign of erosion for long periods of time and then very rapidly erode within a few years. What is interesting, and seen in Fig. 5.3.1, is that the coastal profile remains the same, which makes the manipulation of a 3D Model to reproduce an eroded coast reasonably straightforward.

Figure 5.3.1 :- The effect of the ocean on the different coastal types with a rising sea and how the coast will respond.

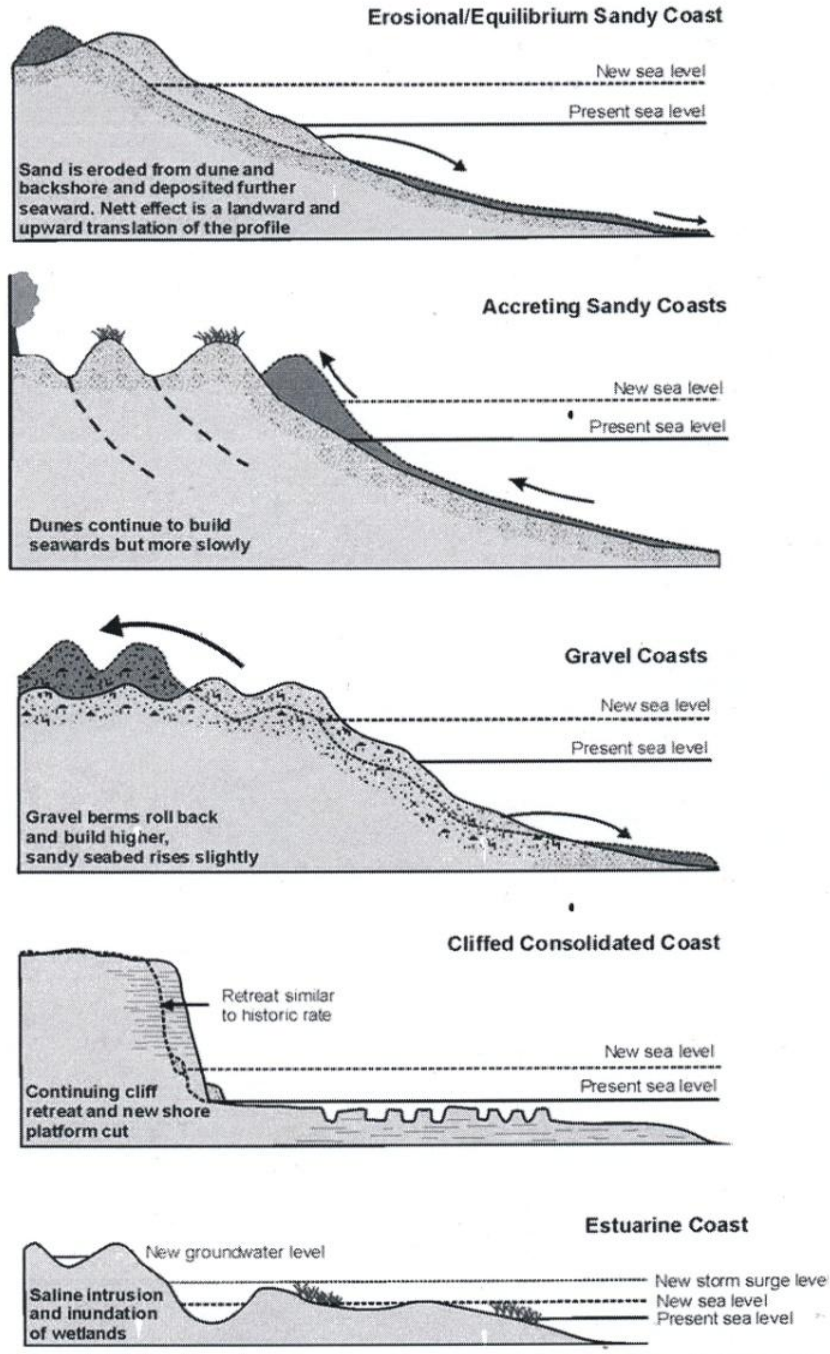


Figure 3.3: Generalised impacts of sea-level rise on different types of coastal morphology. These illustrations are only indicative, as local geomorphology, human impacts and changes to the sediment supply may produce different responses.

Source: – MfE, Coastal Hazards and Climate Change : Guidance Manual 2008

5.4 Erosion of Sandy Coast

The erosion of sandy beaches will continue well beyond 2100 (Ministry for the Enviroment, 2008). Sea rise will permit the attacks on the backshore and fore dunes more frequently and in locations with a relatively small tidal range. If storms increase in frequency and in height, then these would have a harmful effect on the beach system.

Bird (1993) suggests that in the future, beaches that are currently eroding are more likely to erode, stable shorelines will start eroding, and those that are accreting will begin to erode.

Bird (1993), the Ministry for the Environment (2008) and Masselink (2011) agree that extent of the erosion will depend on the supply of longshore sediment transport

5.5 Erosion of Gravel Beaches

Gravel beaches can respond in two ways to a rise in sea level (RSL), storminess and wave height.

1. Where there is sufficient sediment supply the gravel barrier will retreat slightly and increase in height.
2. Where there is insufficient sediment supply the gravel beach will experience an increased rate of retreat (erode). As most beaches on the New Zealand coast are in retreat, a sea level rise will only increase the rate of retreat.

Gravel beaches are more sensitive to changes in storm and wave conditions than sandy beaches (Ministry for the Enviroment, 2008).

5.6 Erosion of Estuaries

Estuaries will widen and deepen as the sea level rises and if tides penetrate further upstream and tidal currents will increase in strength (Masselink, 2011). In estuaries there is a complex mix of Topography, water volume and sediment inputs from river and sea, as well as the erosion of adjacent beaches (Ministry for the Enviroment, 2008). The MfE also state that to date estuaries in the North Island have had sedimentation rates of between 2 – 4 mm / year, about the same rate as the rise in sea level. When, as expected the rate of sea rise accelerates, especially in the later part of the century, it is expected that both inundation and erosion will increase especially in urban areas, where there is a reduced supply of sedimentation.

The rate of erosion will be slower than on those areas open to the sea as estuaries tend to have a low-energy wave climate.

5.7 Erosion of Sea Cliffs

The erosion of sea cliffs depends on the location of the beach or cliff junction (Shih et al., 1994) which is a function of combined tide level, storm surge, set-up and run-up. The shape of the cliff depends on the makeup of the marine and sub aerial (weathering) processes that exist. The angle of a cliff will depend mainly on the structure and lithology (general characteristics of rocks) of cliff materials and of the on the ability of the marine processes (waves and tides) to remove the debris at the bottom of the cliff. If the rate of removal exceeds the rate of debris supply, then a bare cliff face at a constant angle will be maintained. If, on the other hand, the supply of debris is greater than the rate of removal, then the material accumulates into a talus slope (a pile of rubble at the bottom of a cliff). Short cliffs erode at faster rates than higher cliffs as there is less debris to remove from the bottom of the cliff, and this allows the erosion process to continue.

Different types of rock retreat at different rates and it is possible, as the sea level rises that a different type of rock present within the cliff maybe exposed to erosive forces. This also explains why cliff erosion rates need to be interpreted carefully, as short term rates are often site-specific and unrepresentative of long term rates (Masselink, 2011).

5.8 River Mouths and Estuaries

Where a river meets the sea the mouth of the river is affected by the tide level of the ocean in to which it runs. The volume of water in an estuary, with an open connection to the sea, will rise and fall with the rise and fall of the tides (Beer, 1983). The volume of seawater entering the estuary between the low and high tide is called the 'Tidal Prism', which is approximately equal to the tidal range multiplied by the surface area of the estuary.

Figure 5.8.1 :- The Tidal Prism in Plan and Cross Section.

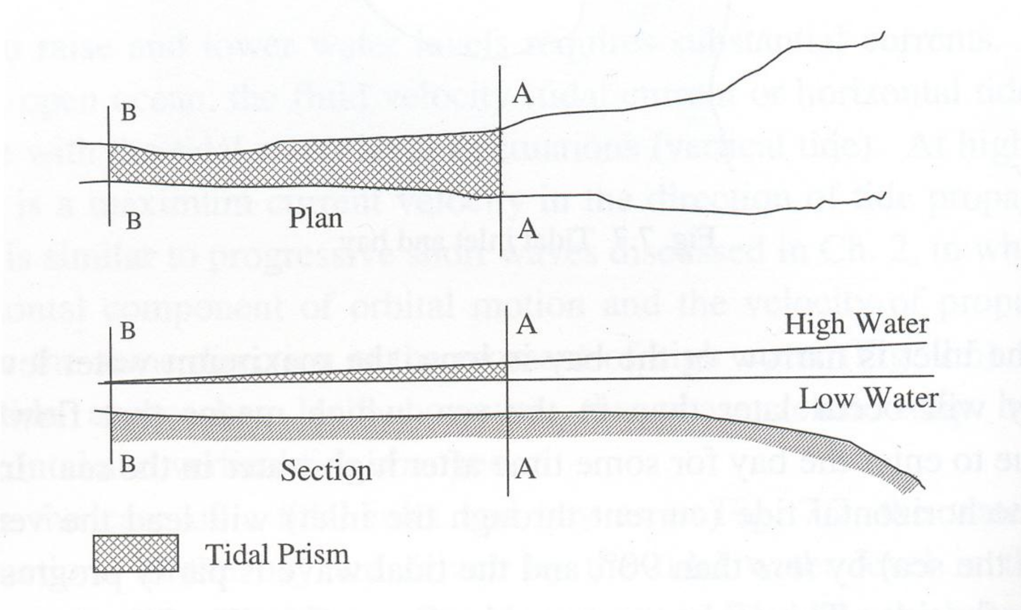


Fig. 7.9 Tidal prism in an estuary

Source:- Introduction to Coastal Engineering and Management

As Kamphuis (2010) explains, the distance of AA to BB can be in the order of several hundreds of kilometres. In the context of the river mouths, the effect of tidal level drop is not worth considering. Most of the tidal effect stops because of the rise of the riverbed.

The calculation of water levels and flows in an estuary is complex and requires sophisticated models to provide results that are accurate (J.W. Kamphuis, 2010).

5.9 Shoreline Prediction using Historic Data

There are a number of methods used to predict the location of the shoreline in the future. Some of these methods use complicated mathematical models such as higher-order polynomials, exponential, or cyclic series and require data which is not always available in the form or the quantity required, in order to get the desired accuracy (Rongxing et al., 2000). It is therefore understandable that an empirical approach is taken by coastal planners, and the norm is to extrapolate historical data. The popularity of this approach is its simplicity (Fenster et al., 1993).

(Rongxing et al., 2000) point out that with the empirical approach there is no need to take into account sand transport systems and all the elements that make up the rate of coastal erosion, as these are encapsulated in the historical rate of erosion.

There are two approaches to using the empirical data. One is to create a linear regression model, which creates a line allowing a predicted value to be extrapolated and interpolated. This choice requires sufficient data to give a statistically significant result.

The other approach is to simply multiply the rate of erosion or accretion by the number of years required for the prediction. For the New Plymouth coast there are only two or three data values available (refer appendix ‘H’. As the results taken from TRC 2009 are the most recent, it is these values that are used to determine the expected shoreline position for the year 2100.

5.10 Shoreline Location Prediction using Calculations in the form of Bruuns rule

The use of historic data is useful as it uses the past to predict the future, however it does not account for the effects of a rising sea level. For that a different approach is taken using Bruuns rule or variants of it: The calculation using this approach is one that comes with many warning from many sources, but still appears to be used to show where the coast line will be given a specific level of sea rise. Bruun’s rule or a variant of it (Masselink, 2011) has advantages and disadvantages that are laid out below:

The Upside:

- It is a simple “off the shelf” model
- It requires little input into the model
- It produces a result that is simple to apply
- There is a numerical outcome in response to sea rise

The Downside:

The models assumes that there is

- A rise in sea level is solely responsible for a shoreline erosion
- A balanced sediment budget.
- An instantaneous response to a rise in sea level
- It can only be applied to soft sediment coasts

It is stated by (Masselink, 2011)), the (Ministry for the Enviroment, 2008)), and (Pilkey and Young, 2009) that this approach should either not be used at all or used as a broad brush tool in conjunction with other models.

The Use of the ‘Bruun Rule’ (theoretical erosion) is suggested in (Gibb, 1994) as a way of assessing coastal hazard zones in New Zealand. However, the application of ‘Bruuns Rule’ to the New Plymouth Coastline gave strange results; possibly because of some of the bathymetric data produced strange results close to shore. It was decided not to proceed with ‘Bruuns Rule’, and therefore it was eliminated from the final result.

5.11 Coastal Hazard Zone – A Safety Factor

In his report 'Standardizing Information for Assessing Coastal Hazard Zones' Dr J.G Gibb (1994) points to the fact that 50% of the 15,000km long coastline of New Zealand was susceptible to erosion, and that even accreting sections of coastline may reverse and begin to erode.

A reducing shoreline is, according to Gibb, a natural part of beach behaviour and constitutes no threat to the existence of the beach, and only becomes a problem when it threatens "development located within the zone of shoreline movements".

For the New Plymouth coastline the Coastal Hazard Zone (CHZ) was developed from work done by Gibb in 1981, and calculates the following zones using these formulae:

Equation 5.11.1 :- Formula to calculate the Coastal Hazard Zone

$$CHZ = (R \times 100) + F(R \times 100)$$

Where R = Rate of Erosion

F is the safety factor (in this case ⅔)

100 is the number of years.

Table 5.11.1 :- Safety Factor distances calculated for the New Plymouth Coastline (the 2009 values have been calculated by the Author).

Area	CHZ in Metres	
	TCB 1988	TRC 2009
Waitara - East	227	261
Waitara - West	90	134
Airport Cliffs	100	70
Bellblock Beach	53	63
Waiwhakaiho - East	52	51
Waiwhakaiho - West	112	111
Fitzroy Beach	40	96
Oakura - East	33	33
Oakura - West	Not Given	111

Source:- Taranaki Catchment Board and Taranaki Regional Council

The CHZ should be of great importance to planners as it gives an indication as to where it is safe to develop infrastructure and housing. A search of the internet did not uncover any more reports which refer to this factor.

5.12 Which Erosion Values

The 2009 report for the TRC states there is a requirement to “reassess” the erosion values that the Taranaki Regional Council has been using because the last “reassessment was done in the late 1980’s”. As a result of this statement the erosion data from the 1980 report (repeated as table 8 in the 2009 report) will be used (refer Appendix ‘F’). These values are conservative if the most recent erosion figures are to be believed but as the report points out there are possible errors in the methodology used to arrive at the more recent results.

Chapter 6 Environmental Elements

6.1 Temperature and Rainfall

According to the Ministry for the Environment (Ministry for the Environment, 2012) the temperature in the Taranaki Region will rise by 0.9^{o}C by the middle of the 21st Century (2040) and 2.1^{o}C by 2090, using 1990 as a base year. This will mean an additional twenty to forty days of temperatures that exceed 25^{o}C, with the number of frosts decreasing by up to 15 per year, with frosts becoming rare in the coastal regions.

With increased temperate comes an increase of rain, according to (Ministry for Primary Industry, 2010). In the Taranaki area this has been projected to be 6% for New Plymouth by 2090 with spring, autumn and summer rainfall decreasing marginally, which means that winter will attract the full 6% of increased rainfall (Ministry for Primary Industry, 2010). This increase will impact on the river systems and with increasing high tides will add further to the increase likelihood of flooding at river mouths, as very heavy rainfall events are likely to become more frequent in the region (Ministry for the Environment, 2012).

6.2 Storms

The number of storms is likely to increase by 2100 with autumn storms likely to occur up to 4 times as often, whilst there is likely to be a decrease in winter and increase in summer because of increased temperatures. An increase in the number of storms will increase the number of times the energy within the storms could double, making the storms more intense, and therefore increasing storm surge which by its very nature leads to an increased rate of sea shore erosion.

6.3 Winds

The return period of extreme winds over the next century is expected to increase by 2% to 5% in winter and decrease by a similar amount in summer.

Changes in wind, temperature, rainfall, storms and sea level rise will increase (Ministry for the Environment, 2012, Ministry for the Enviroment, 2011), leading to :

i. The threats to coastal roads and infrastructure and urban development from both coastal erosion and inundation through high tides and overtopping.
ii. Increase the risk of erosion and landslides.
iii. Drought, water level of rivers and water levels and an increase in the risk of fires.
iv. Warmer weather will increase the risk of pest and weed invasions.
v. Better growing crop growing conditions offset by increased droughts and storms.

Therefore, extreme events will no longer be extreme but become normalized creating new extreme events.

6.4 Extreme Events

Wave data has only started to be recorded around the New Zealand coast in the past seventeen years, with the longest set of records being started some forty years ago (Ramsay, 2006). With such a short recording time span, it is not possible to wait a hundred years to determine a one hundred year maximum wave height return event. We must therefore turn to probability statistics in the form of ‘Extreme Value Type I Distribution’. This statistic is a procedure which allows the determination of extreme values when given a limited data set of maximum events in a given time period, normally a year.

For this analysis the ‘Gumbel distribution’ was used, following the formula stated by (Haan, 2002), who gives a number of alternative approaches. This approach was chosen because it appeared and was referenced in a number of articles and tutorials written about predicting ‘extreme values’ for natural disasters.

The Formula is in two parts:

Equation 6.3.1 :- The first part of the formula, the determination of Kt the maximum frequency factor for use in the second part of the formula.

$$K_t = \frac{\sqrt{6}}{\pi}\left(\gamma_e + ln\left\{ln\left[\frac{Tx(x)}{(Tx(x)-1)}\right]\right\}\right)$$

Where γ_e is the Euler Number (0.577216) and $Tx(x)$ is the desired return period of the quantity to be calculated.

Equation 6.3.2 :- The second part of the formula, the determination of the maximum value for a chosen period factor.

$$x_t = \bar{x} + K_t s$$

Where x_t is the maximum value of the chosen return period.

$\bar{x}$ is the Mean of the maximum values within a period.

s is the standard deviation of the values.

Extreme values have been calculated using the above process for the following data.

i. Significant Wave Heights taken from hindcast data taken 1 km from the New Plymouth coastline at intervals of 1 km (McComb, 2011)

ii. Maximum flow data m^3/sec for

    i. The Waitara River taken at Burtrand Road.

    ii. The Waiongana River.

    iii. The Oakura River.

    Note: These values although calculated were not used in this investigation.

iii. Two years Wave Surge data calculated from data supplied from the Port Taranaki wave buoy and predicted tides supplied by LINZ (LINZ, 2012b).

iv. Atmospheric / Barometric readings taken at Port Taranaki over two years 2010/11.

The results or the results of calculations using the extreme values appear in the following.

Significant Wave Heights	Appendix ‘E’
Storm Surge Data	Appendix ‘C’
Barometric Data	Appendix ‘C’

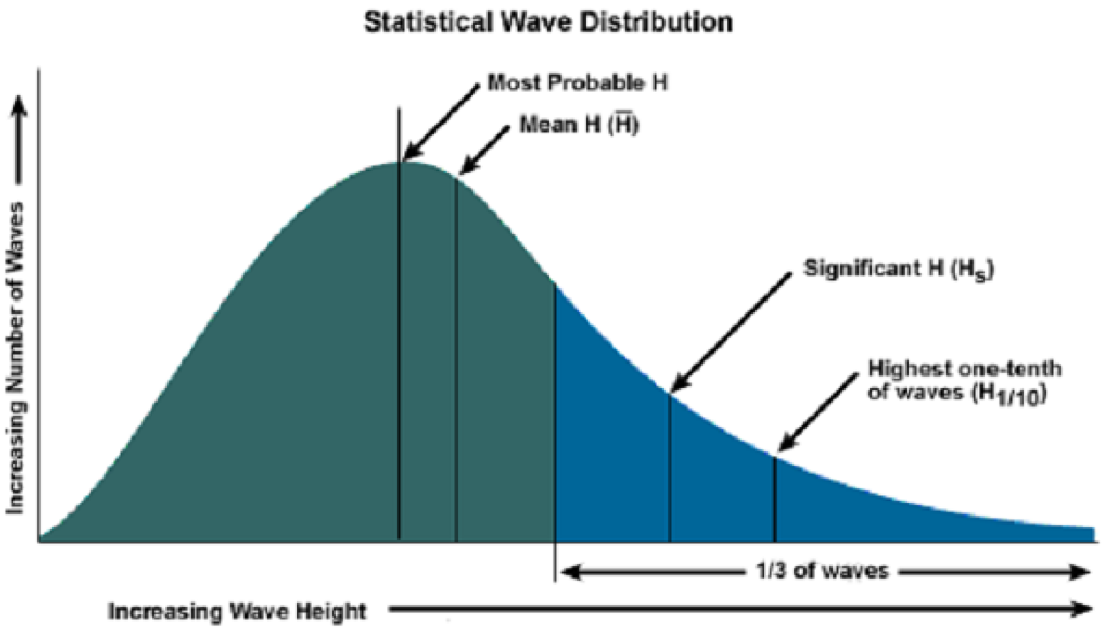
6.5 Significant Wave Height

Significant wave height is used in the determination of run-up and setup and as such relies on the correct calculation of this value to determine the level in which the oceans waves may rise to during a storm.

Significant wave height is a measure of the statistical distribution of ocean waves. H_s or $H_{1/3}$ are the symbols used to denote the use of this measure. The following graphic is used to show the relationship between significant wave height and other statistical measures.

H_s is used to determine the maximum wave height through the use of the following formulae $H_{max} = H_s \times 1.6$ (Tucker M.J., 1963).

Figure 6.5.1 :- Significant Wave Height and its relationship with other statistics taken from a Statistical Wave Distribution.



Source:-www.erh.noaa.govt/box/sigwaveheightdesc

The normal way of presenting such data is to determine the probability of waves reaching such a height and presenting those probabilities in the form of a graph showing how high the waves will climb within the given return period. The table in Appendix ‘E’ shows the significant wave heights for the sampling sites along the New Plymouth Coast. The maximum heights in the above table are not that dissimilar to those predicted in the 1988 report for the then Taranaki District Council, who suggested a maximum wave height in excess of 10m would be possible (Taranaki Catchment Board, 1988). What is interesting to note is the reduction in maximum wave heights as the sampling positions move from west of Oakura to east of Waitara. The effect of this is a reduction in the height of set-up and run-up, and can be seen in Appendix ‘G’. The effect of this is local, and therefore discussed further in the findings of each of the study areas.

Chapter 7 Using Geographic Information Systems to evaluate the rising sea

7.1 GIS and Approaches Taken

A Geographic Information System (GIS) is defined as an "Automated System for the capture, storage, retrieval, analysis and display of spatial data" (Clarke, 1995) and as such permits the use of points, lines and areas to be manipulated to take data and transform it by using a set of powerful tools, into information.
The research question will be answered using GIS as a tool box. At the heart of the system is the Coastal Terrain Model (CTM) in the form of a Triangular Irregular Network (TIN) that forms the 3 dimensional model of both the land and sea. Then, using the model, a series of scenarios in the form of theoretical ocean levels are presented and the results noted. As erosion is a major element in the scenario modelling of the rising sea level, the TIN may be edited, removing coastline where applicable and changing the profile of the coast. This gives the modeller the ability to answer the all-important "what if?" questions with regard to an eroded and / or inundated coast.

The model was derived using Topographic Contours of 0.5m with a given accuracy of ±0.25m and Bathymetric Contours of 0, 2, 5, 10, 20, 30+ meters. The topographic data is considerably more accurate now, compared to earlier researchers prior to the year 2000 who were hampered by the lack of map accuracy (Thumerer et al., 2000).

The GIS use of spatial data in the form of contour and bathymetric data, plus the combining of it with population and property value data, it is possible to determine who and what are going to be affected by a rise in sea level. Projections of basic tide and wave data, from a relatively short period of time allows worst case scenarios to be projected onto the GIS model, thereby answering the 'who?' and 'what?' of the research question.

The use of a model is a simulation and a simplification of reality; hence the results that are derived from the model need to depict the real world as closely as possible. In practice it is necessary to identify the essential real world systems from a multitude of interacting processes and reduce these to three of the most important driving coastal mechanisms; tides, storm surge and rise in sea level (Thumerer et al., 2000).

A GIS model has the ability to be fully interrogated using heights and areas. Without the use of the GIS, the maps being produced would have less meaning. Using a 3D model and given the ability to generate a beach profile, extract the co-ordinates for beach slope analysis, then model the effects of erosion are the most powerful uses of GIS. This is illustrated when determining run-up and setup, as the slope of the foreshore is required to determine the type of beach and hence runup and setup values.

Various hazards associated with a rising sea level have been identified and the best mapping and charting process / model types determined, as seen in the table below (National Research Council, 2004).

Table 7.1.1 :- Table of Coastal Hazards vs Map Type and Model Requirement.

	Map and Data types	Map or Chart Requirements
Coastal Flooding (Storm Surge)	Flood Hazard Maps Surge Models	Blended Bathymetric and Topographic maps and CTMs
Rise in Sea Level	Inundation Maps Risk Assessments	Blended Bathymetric and Topographic maps and CTMs
Wind Waves	Wave Contribution to storm surge , wave runup and setup	Blended Bathymetric and Topographic maps and CTMs
Shoreline Erosion / Accretion	Sea level rise vulnerability assessment. Shoreline erosion and coastal change models	Blended Bathymetric and Topographic maps and CTMs Mapping to quantify the rate and distribution of Change

Source :- National Research Council, 2004

As can be seen from Table 7.1.1 most of the mapping of coastal hazards related to a rising sea level is accomplished using a Coastal Terrain Model (CTM). A CTM comes in two forms; either a Digital Elevation Model (DEM) which is a raster presentation of elevation where each cell represents a height from a chosen datum; or a Triangular Integrated Network (TIN) which uses vector data where a geographic surface is represented as non-overlapping triangles where the vertices are the sample data points with x-, y- and z-values (Clarke, 1995). The majority of the analysis and mapping for this thesis has been done using a TIN, although raster data has been used when it was possible to manipulate 2 D space, as when determining the surface flooding area.

7.2 Planar Models

It is considered that the uncomplicated way to determine a flood (area) is to establish a stillwater level and then display this level topographically (Aguilar, 2009). Using this method a flood area can be determined; it is the simplest method and the first one used in a coastal research project. GIS is often used after this so that other improvements may be added in the form of mathematical models. When the two are used together, a comprehensive tool results.

A number of studies have been carried out using the ‘Stillwater Method’, particularly to determine the effect of sea rise on property and populations exposed to a sea inundation (Hart, 2011).

The use of GIS to show the effects of sea rise are met with some scepticism by those who investigate such things like Masselink (Masselink, 2011) who states that simply placing a sea level onto a contour (Stillwater Method) and shading those areas has a weak scientific basis since there are significant errors in height, and feed backs are not considered. Masselink goes on to assert that such inundation maps are used uncritically by planners and insurance companies to identify areas at risk of flooding. These planar maps fall short when they are applied to large areas of coastal flood plain, because there is a possibility that there will be areas below the maximum flood level, but not connected to the flood (Bates et al., 2005). However, as a simple means of giving a predicted flood outline and / or assessing if there is a potential problem within an area, it is a simple and cost effective approach.

The calculation method for estimating the sea level rise extent is used by FEMA (2003), Pugh (2004) and (Laing, 2000) and is the standard method for mapping floods. It is simply the Highest Astronomical Tide + Storm Surge + (Runup / Setup) and approach was used for this research. To predict the effect of a rising sea level, a predetermined height of sea level rise is added to the above calculation and displayed on the 3D Model.

7.3 Hydrodynamic Modelling

There are those who use GIS technology and apply it to flood delineation and damage assessment problems using a Coastal Terrain Model (CTM) in conjunction with hydraulic calculations (Bates et al., 2005) (Consuegra et al., 1995); (Lanza and Siccardi, 1995). By using a hydraulic model a much better fit is obtained when compared against real situations, although not perfect (Bates et al., 2005).

The hydrodynamic modelling approach has been discounted for this thesis as the approach taken here has been very much from the viewpoint of a planner, or someone who is interested in taking a peek into the future, to see what it may hold, with a view to making broad-brush decisions that affect future development plans.

7.4 Accuracy of the Models

The accuracy of the CTM is important to give believable results (Consuegra et al., 1995). FEMA and the National Research Council see the benefit in having data presented in the form of inundation maps and see issues in the fact that the data from interfaces do not merge as seamlessly as they would like because of differing datums. It is therefore necessary to get the best possible data available prior to building the model regardless of the methodology used in displaying the results. To that end verification of results by ‘Ground Truthing’ should be carried out.

7.5 GIS and Sea Level Rise

In order to demonstrate and make sense of the sea rise data, a map of the affected area is required.

A GIS with its modelling capabilities has been used in numerous studies to show the areas affected by sea level rise and allows for the determination of numbers of people, properties and value of these properties (Hart, 2011). An online library search of the keywords “GIS and Coastal Management” and “GIS and Flood Risk” produces numerous results, and a closer examination of the papers written shows there are few research projects that go into detail on the process of using a GIS to analyse sea rise, flooding and its effects on the coast.

(Huxbold, 1995) defines a Geographic Information System (GIS) as a collection of information technology, data and procedures for collecting, storing, updating, manipulating, analysing and presenting maps and descriptive information about features that can be represented on maps. There are a number of commercial GIS systems available. The three considered for this exercise were ArcGIS from ESRI, IDRISI and Quantum GIS. All systems had to satisfy the following criteria

i. Be able to handle large data sets with ease.
ii. Produce detailed analysis.
iii. Be familiar to the author.
iv. Have a local support should problems be encountered.

After trying the three contenders, it became obvious that the ESRI product best fitted the criteria as it was able to quickly generate detailed maps that held specific spatial data relating to the coastal / land interface, was familiar to the author and was supported locally.

The GIS system used in this study was ArcGIS version 10, using predominantly 3D Analyst and the geoprocessing tools merge, buffer and clip in order to break up the study area into manageable areas, mainly to reduce the redrawing time required by the TIN.

The use of 3D Analyst was chosen over Spatial Analyst as it was more familiar to the author and still enabled the display of areas and overlain photographs.

Whilst there are many studies into the effects of sea-level rise using GIS, the methodology of how their results are produced is minimal when it comes to the detail required to reproduce a particular methodology as the majority of the reports concentrate on the results / aims of the report and / or thesis. However (Sun Yan Evans, Unkown) concludes that the use of GIS is fundamental to the efficient and effective creation of a CTM and for the creation of a 2D model (map) and that GIS is an excellent means of conveying the extent, depth and velocity of flood progression and flood hazards.

(Baron, 2009) agrees that GIS is the tool to use, as it has “The ability to integrate physical, ecological, socioeconomic, and hazards information makes it an ideal assessment tool to support management efforts in the coastal zone. Through the use of GIS, researchers are able to model vulnerability to sea-level rise, coastal erosion, and other hazards so that decision makers have the necessary tools to protect communities and effectively manage coastal resources”.

Chapter 8 Building the GIS Model

8.1 Vertical Datum

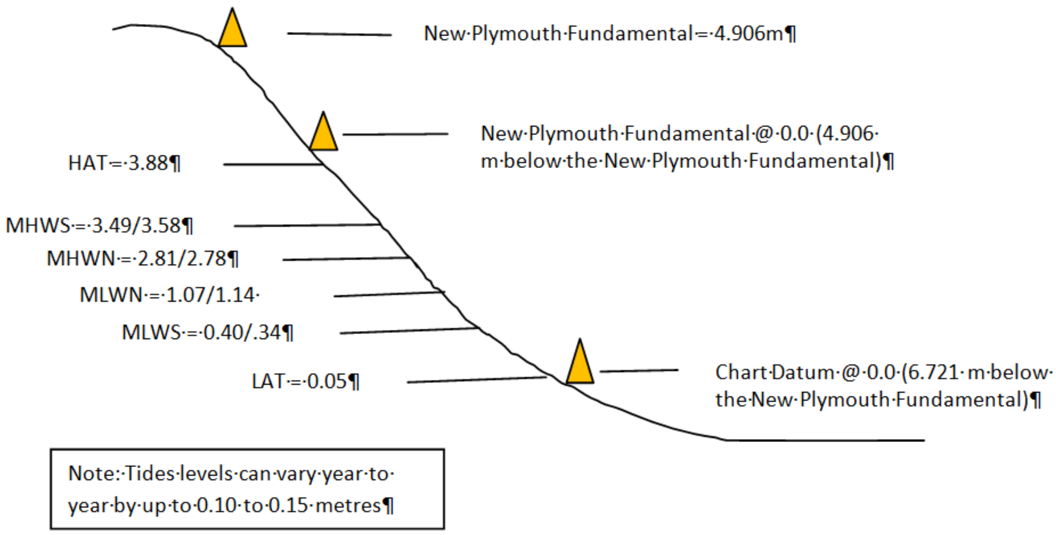
For this project to function two vertical datums are used.

1. This references the height of sea data and is called a Sounding Datum (Iliffe and Lott, 2000). The purpose of the Sounding Datum (also known as the Datum of Soundings or Chart Datum) is to allow the preparation of nautical charts and allows for the correction of tide level at time of measurement.

2. In Taranaki there is a physical datum that is located at Port Taranaki. It is called the New Plymouth Fundamental AGMH and is located at Lat. 39^0 03' 26.6406" and Long. 174^0 01' 49.7795" and consists of a stainless steel pin located under a steel cover in the middle of a car park at Port Taranaki.

The Taranaki 1970 datum uses the New Plymouth Fundamental as a reference mark, setting zero at 4.906 metres below (LINZ, 2012a) the stainless steel pin whilst the wave and tide soundings datum also uses the New Plymouth Fundamental as its reference mark, setting zero 6.721 metres below the New Plymouth Fundamental, a difference of 1.815 (1.82) metres (Hydrographic Office of the New Zealand Navy, 2006). When this figure appears as an elevation on maps throughout this thesis is the 'Soundings (Chart) Datum Zero'.
This means that when relating bathymetric to topographic data, a correction factor must be applied to allow for the difference in the two datums (National Research Council, 2004), the correction factor in this study being 1.815 metres.
As a test to ensure the contour and bathymetric data were referenced to the correct data, a TIN was created from the respective files and the height of the TIN at the New Plymouth Fundamental reference mark determined and was found to be within the tolerance of the contour file ie ± 0.25m (Standon, 2011).
A scanned image of a chart of Port Taranaki was georeferenced and superimposed over a TIN, and whilst not as accurate as the land based TIN, nevertheless the TIN was found to be within ±0.5m of the data on the hydrographic map NZ4432.

The Following graphic explains the relationship between the two datum's, Figure 8.1.1.:- Relationship of Datum's to Tide Levels at Port Taranaki.



Source:- Drawn by the Author

The mean sea levels in Figure 8.1.1 quote two figures, the first is from the chart NZ 4432, the second figure is the calculated average levels from 1st Jan 2000 to 31 Dec 2018. The difference in the two set of figures reinforces the variability of tide levels and confirms the statement that these values will change from year to year by up to 15cm (LINZ, 2012c).

8.2 Building the GIS Model

The GIS Model interface between land and sea is referred to as a CTM (Coastal Terrain Model). It is a combination of a DTM (Digital Terrain Model) and a DDM (Digital Depth Model) (National Research Council, 2004). At a minimum the CTM covers the LAT (Low Astronomical Tide) and the HAT (High Astronomical Tide) and to make it requires the combination of the two sets of contour data, with different datums, to be joined seamlessly as one. To do this requires either of the contour datasets to be modified to change the elevation or depth so both sets have a common datum. It then remains for any calculations of tide or land data to be adjusted so the figures are meaningful. In this thesis the bathymetric data was changed to match the topographic data simply because there was less data to change and subsequent interaction with the completed CTM is simplified because it is the terrain that is being affected and hence edited, not the sea.

In order to create a combined CTM, it is necessary to combine the two contour datasets as the software being used does not allow the direct combining of DTM and DDM, both in the form of TINs.

Once the Bathymetric dataset was modified to conform with the datum of the Terrain dataset and whilst still in contour mode, it was necessary to break the datasets into areas. This was because the vast amount of data required to produce a combined CTM was too much for the desktop computer being used ,namely a desktop PC with - an i7 processor, 1Gb graphics card and 8Gb of memory. The smaller areas had advantages insomuch as redrawing times were reduced significantly, especially when it became necessary to add other datasets such as property values, census data and most importantly the aerial photographs. The downside was that at the edges of the TINs there was edge distortion, which required an overlapping of the study sites.

Determination of where the study areas started and ended was largely governed by the type of beach; and in one case, Oakura, limited by the data that was available.

Once the CTM had been produced, the elevations and relationship to tides needed to be verified; and to do this ground truthing was carried out using a number of known locations that appeared on both the model and those that were accessible to the author on foot. The ideal locations were boat ramps found at the extreme ends of the study areas. The method consisted of determining the tide height given in LINZ’s website and using an aerial photo of each ramp, locating the intersect of the observed tide and ramp, and interrogating the model to see if the two numbers are within acceptable limits.

Once the model had been confirmed as acceptable, the adding of the aerial photos, which had already been orthographically rectified, was followed by adding the properties data and census data.

Manmade objects, that made an impact on the models, such as seawalls and breakwaters were then added to the CTM in the form of shape files, these were checked by the author, but it was not possible to check all parts of the coast

8.3 The Use of and Overlaying of Aerial Photographs

The combination of DTM (Digital Terrain Model) and DDM (Digital Depth Model) to produce a CTM (Costal Terrain Model) gives a plain surface which can, if placed in a 3D viewer, show the various aspects of the model. However there is limited information that can be gleaned from the model in such a state, as it is difficult to determine locations and the interrelationships with other locations from such a view. Including an aerial photograph as a layer, so it is viewed over the 3D Model, makes the interpretation of the model extremely simple and those interrelationships clear.

This is clearly demonstrated by FEMA in their approach to creating inundation maps where they combine elevation, flood data and imagery (aerial photos) to produce a ‘Digital Flood Insurance Map’ (National Research Council, 2009).

The use of aerial photos made it possible to carry out a number of important functions.

i. Determination of Vegetation Limits and the height of the beach where this occurred.

ii. Determine the type of beach being examined, especially when access to the shore line was not possible.

iii. Types of properties being counted, whether they were commercial or domestic buildings (this information was not on the property database).

iv. Distances from hazards of important infrastructure; namely the distance of the airport to the eroded cliff faces.

v. Locate important infrastructure and thereby allow further investigation be carried out.

Two types of aerial photograph were available from the New Plymouth District Council.

i. Rural photos with a resolution of 1:5000. These images were in full colour and allowed sufficient detail to determine a vegetation line and debris lines as well as property boundaries.

ii. The other images, of urban areas, were 1:500 and clear enough to determine if a beach was of gravel or sand construction. It also allowed for the clarification of vegetation lines and cliff edges.

Much of this thesis would not have been possible but for the use of a CTM and the vast array of interrogation tools, with photos to clarify and make sense of the surface data.

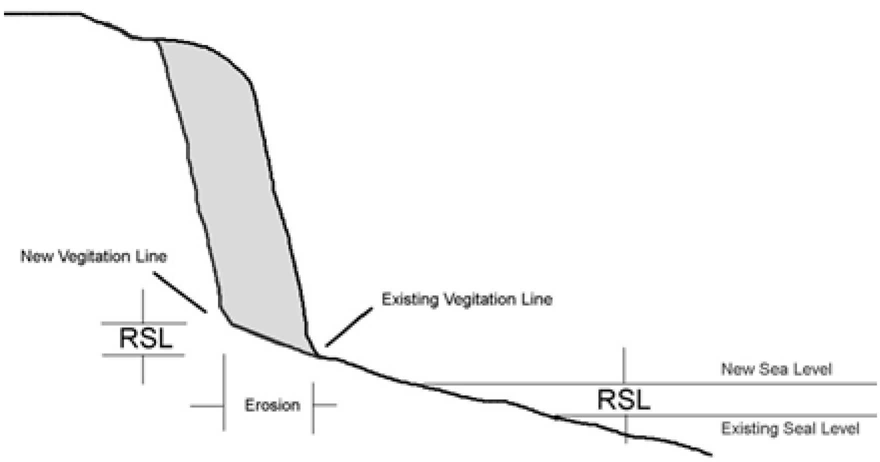
8.4 Modelling the CTM for Erosion

The completed CTM model needs to be edited in a number of areas to show the effects of erosion; the main reason being to expose any low lying areas, so the extent of coastal inundation can be assessed.

The CTM in the form of a TIN was put into 'edge mode'. The effect of this was to display the three principle elements which make up the TIN namely the 'soft edge', 'hard edge' and 'regular edge'.

The first step in the process was to establish a reference line which should be recognizable on the coast in the year 2100 or beyond – this line was the 'Vegetation Line', the line that can be drawn between the beach and any vegetation that interfaces with the beach. Using the Vegetation Line visible on the aerial photos, a shape file line was created. The Vegetation Line was then offset by the amount of erosion (refer Figure 8.4.1).

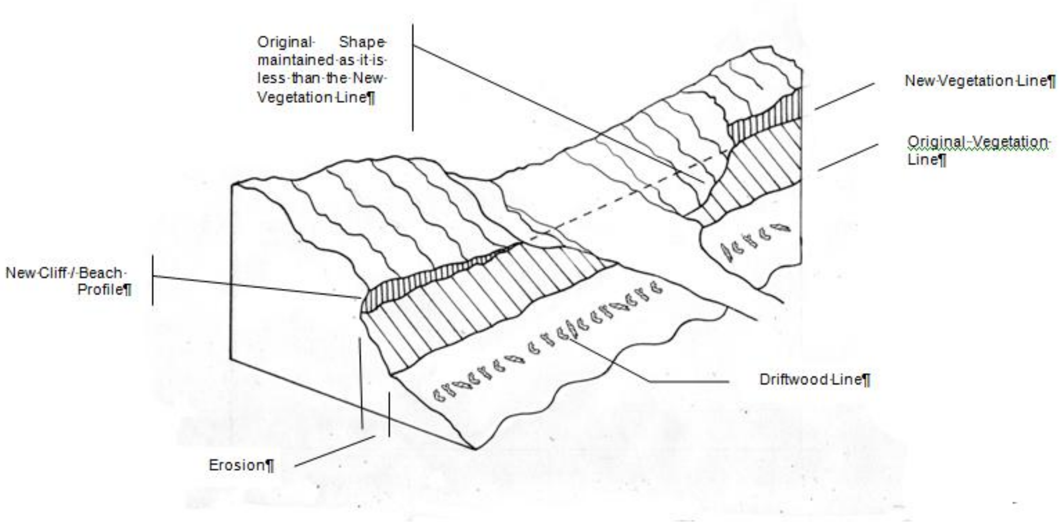
Figure 8.4.1 :- Theoretical profile modelled into the CTM TIN



Source :- Drawn by the Author

Having calculated the erosion extent, a shape file was made to mark the extent of the erosion, and in so doing creating a new Vegetation Line that will hold the new elevation. The new line is moved to its new position, split into segments, and the model interrogated to determine the mean elevation beneath the segment of the new line. Those segments less than the new RSL Vegetation Line were left untouched, whilst those above were changed to the new Vegetation Lines elevation. (Refer Figure 8.4.2.) This new line was then edited into the model once the area between the new Vegetation Line and an elevation of zero had been "gutted" of 'Hard', 'Soft' and 'Standard' edges. The effect was to create a new beach further inland, which was elevated to a higher level. For this study 1.5 metres was selected as it was the maximum used by a number of organizations that feature in Table 3.2.4. It not was practical to have a model for each of the four sea rise levels due to the time required to create and "modify" each CTM.

Figure 8.4.2 :- Illustration demonstrating the need to sample the land prior to creating the new eroded beach profile.



Source:- Drawn by the Author

The editing of the CTM TIN was done using the tools provided by the software supplier and allowed for the removal and manipulation of edges and nodes.

Once the sea levels were applied to the model, it was then overlaid with photos to discover the resultant effect.

The manipulation of the CTM TIN was not without its problems, as a node on the wrong side of the New Vegetation Line, by the smallest of amounts, could cause the model to behave in a manner which did not allow the projected sea levels to show correctly. This caused an excessive amount of time to be spent correcting these issues.

8.5 Modelling the CTM for Inundation

When Modelling the CTM for inundation, the following was taken into consideration using as a guide the work done by Laing (Laing, 2000) and his report on the Kapiti Coast.

Using the Laing report as an example, four different scenarios were compiled. Common to all scenarios are the four water levels, ranging from 0.5m to 2.0m in half metre increments that represent a rise in sea level and the High Astronomical Tide (HAT). Storm surge is common to the New Plymouth coast whilst setup and runup are affected by local conditions. The various extreme events are added together to give the four levels of rising sea.

.Table 8.5.1). Reading left to right are:-

i. In column 2 the Still Water Levels, showing just the rises in sea level

ii. In column 3 the storm surge value is added to the values in column 2.

iii. In column 4 the setup value is added to the values in column 3.

iv. In column 5 the runup value is added to the values in column 4.

Table 8.5.1:- This is an example of an Inundation Height Build up Table. Expected extreme sea level projection for 2100 with the various elements shown that make up sea level. A different value has been calculated for each study area.

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02*	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level		2.98	2.98	2.98
Setup 1:50 year level	-	-	0.69	0.69
Runup 1:50 year level	-	-	-	1.16
Max Storm Level	2.02	2.98	3.74	4.90
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.55	4.24	5.40
Total Level (1.0)	3.02	4.05	4.74	5.90
Total Level (1.5)	3.52	4.55	5.24	6.40
Total Level (2.0)	4.02	5.05	5.74	6.90

Runup includes Setup

In Table 8.5.1, the highlighted numbers are the elevations that appear in the elevation maps for each study area as elevations. As the inundation maps rise in units of 0.5m, it makes it possible to display an elevation that may represent multiple sea level scenarios. An example would be the level representing an RSL of 1.5 (now 3.52m above sea level) and would also represent an RSL of 0.5m with storm surge (3.55m above sea level). It is for this reason that the sea levels displayed on the maps are in 0.5 m increments.

A number of additional scenarios were considered and investigated; including the effect of river flooding, but this event was decided to be outside the terms of reference.

Using the elevation feature of a TIN, the various levels shown in the inundation height build up table were entered into the model. Each level was assigned a specific solid colour with the last layers representing set-up, run-up being hatchings and broken line in a highly contrasting colour(s).

The requirement to determine the inundation area for valuation purposes required a DEM (Digital Elevation Model) to be created and the various inundation levels created by reclassifying them. Once reclassified the Raster's were changed into polygons and the area calculated. Using the automated functions that came with the GIS software made this process very quick.

The colour pallet chosen to represent the various levels came from a range of colours suggested by the software manufacturer once the initial and pen-ultimate colours chosen by the author namely Deep Blue to Mid Red (refer Table 8.5.2). The Blue is to represent the ocean and the Red to indicate a warning that there are problems ahead. It was important that there was sufficient difference in the colours to see the elevation bands clearly against the aerial photos colours of the green of the land, greenish blue of the Sea and the grey of the beaches and urban areas. The TIN display properties were set at between 30% and 50% transparency so it was possible to see what was being affected by the inundation.

Table 8.5.2 :- The Colours used on the Flood Maps to indicate height are as follow.

Colour	Elevation	Red	Green	Blue
Purple Broken Line	Runup	255	0	197
Green Broken Line	Runup	85	255	0
Yellow Hatching	Setup	255	255	115
Red	4.5 to 5.0	178	24	43
Mid Red	4.0 to 4.5	214	96	77
Pink	3.5 to 4.0	244	165	130
Pale Pink	3.0 to 3.5	253	219	199
Pale Blue	2.5 to 3.0	209	229	240
Mid Blue	2.0 to 2.5	67	147	195
Dark Blue	1.8 to 2.0	33	102	172

Note : Some of the elevations may change depending on the build-up of the extreme wave heights.

8.6 Determining Populations under threat

With the model constructed and erosion simulated, the next step is to determine the numbers of people being affected by the inundation because of the RSL. To do this, census data was used where large populations were concerned and property data where census blocks were too large to give a realistic answer, mainly in the country areas, where populations are sparse. The method of choosing the affected area was initially done using the selection feature of the software then completed by either adding or subtracting records by eye. The census database was edited to hold three sets of data – Population, Dwellings and Average age (Wu et al., 2002) and then joined to the Meshblock shapefile for the area.

The data of the selected records was interrogated by the Statistics feature of the GIS Software and the sums and / or averages recorded. When the data was complete for all levels of inundation, actual inundation area was factored into the table as a given value/area to give a more accurate result. Where there was a sparse rural population or the inundated area was covered only partially by one or two blocks, the data was prorated to give a better result. The use of data with a finer scale than Meshblock data is required to make the results more accurate (Hart, 2011). The tables of values of properties inundated, where erosion was considered, did not include the eroded property value as this value was shown in a separate table.

Property data supplied by the NPDC proved useful in defining the area, capital value and land value of properties. If land value is subtracted from capital value then the result is improved value. The areas that were inundated were in many cases small, affecting only a small number of houses and as the property dataset did not distinguish between commercial and residential vacant sections or those with dwellings on them, the dwellings were selected and counted manually. Using the census data the average number of people per dwelling was prorated to determine the population directly affected by a rising sea level.

Chapter 9 Findings

9.1 New Plymouth Coastline Findings – Common Elements

9.1.1 Within the New Plymouth area there are eight Study Areas

i. Oakura
ii. Port Taranaki
iii. Moturoa - City
iv. Fitzroy
v. Bellblock
vi. Airport
vii. Brixton
viii. Waitara

Within each study area storm surge and rises in sea level are common elements, the results being the same regardless of the study area. Other elements such as set up and runup are dependent on the bathymetric and topographic features of the area.

9.1.2 Storm Surge

There is only one storm surge level used in this study and that is based on the predicted level of storm surge extrapolated using the Equation 6.3.1; a hundred year return value is calculated to be 1.04m based on historic data, the fifty year return value 0.96m was used.

9.1.3 Rises in Sea Level

The Rising Sea Levels range from 0.5m to 2.0m in 0.5 metre increments and are a constant in the “Table of Sea Levels”, which is unique to each study area.

9.2 Oakura Findings

Map 9.2.1 :– Oakura Location.

9.2.1 Oakura Location

Oakura is a town 12 km to the west of New Plymouth, 15 km east of Okato and to the south, Mount Egmont / Taranaki plus the Kaitaki ranges. Oakura is dissected by State Highway 45 which goes from New Plymouth around the coast to where it meets up with State Highway 3 in Hawera. The town is best known for its beach and its surf. It has a population of some 1,338 persons, 486 dwellings, and the population has a mean age of 30 according to the last available census data from 2006. Much of the population commutes daily to and from New Plymouth for work.

To the east of the town is the Oakura River which feeds into the North Taranaki Bight and has its source in the Kaitake Ranges. To the east and west of the river mouth is Corbett Park and the Oakura Marae. Several streams run through the town, namely the Wairau and Waimoku.

To the west of the Waimoku stream is the Oakura Camp Ground, the Surf Club building being situated close to the beach edge on what is identified as ‘the Vegetation line’, as described in Chapter 8.

9.2.2 Oakura Elevation

Most of Oakura is located on high ground (20m) except where there have been or are streams / gullies. These have carved out the landscape to give some low lying ground, mostly at the sea / waterway interface.

The areas of low lying ground, that which is less that 6 metres, are Corbett Park, the Oakura Marae, some houses to the south of State Highway 45 on the banks of the Oakura River, the Oakura Surf Clubhouse, the Oakura Beach Camp Grounds and the area between the Waimoku and Wairau streams. Refer Map 9.2.2

Map 9.2.2 :– Oakura Elevation.

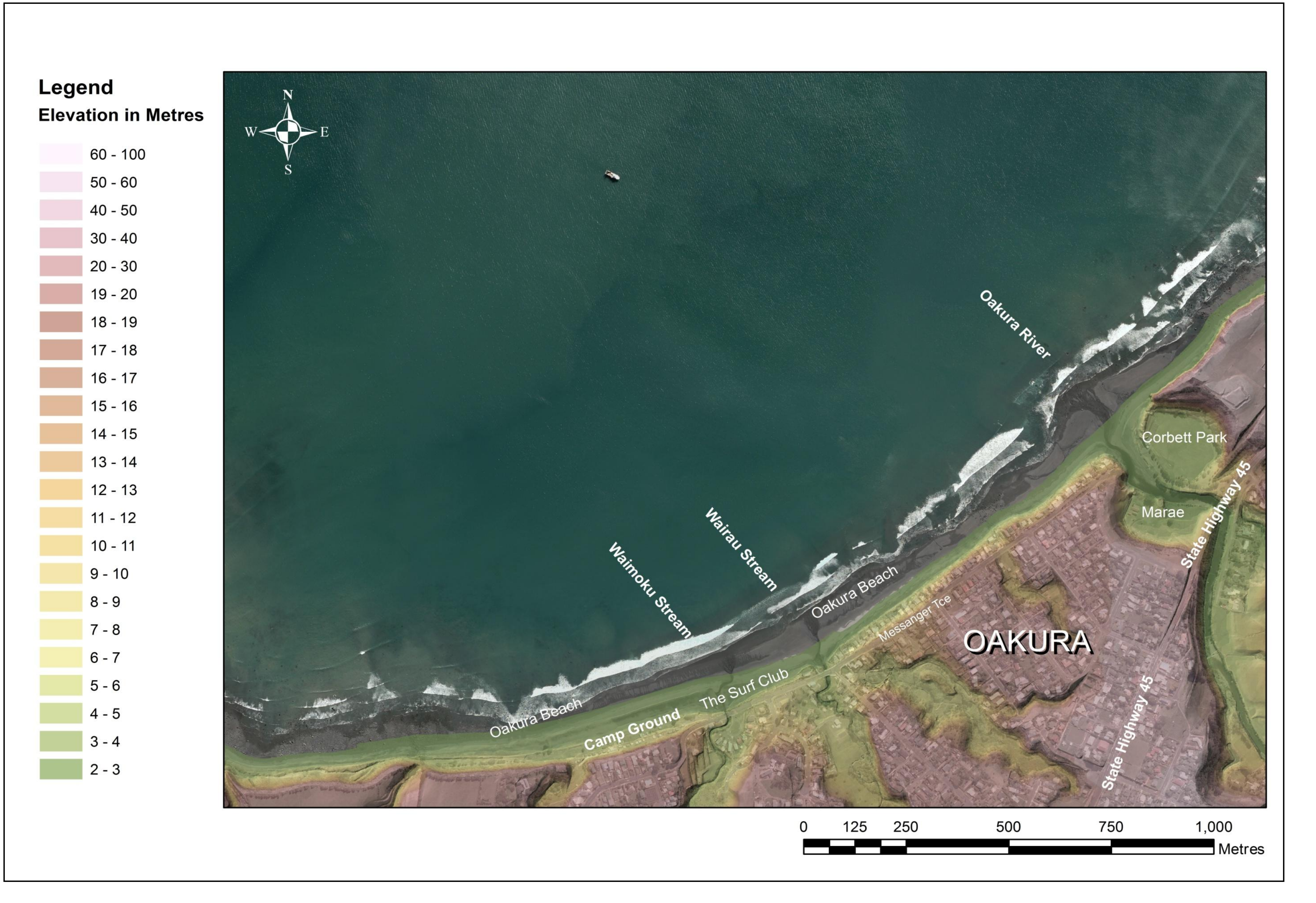


Table 9.2.1 :– Oakura; Table of Sea Levels showing using different scenarios.

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level	2.02	2.98	2.98	2.98
Setup 1:50 year level	-	-	0.84	0.84
Runup[ø] 1:50 year level	-	-	-	1.42
Max Storm Level	2.02	2.98	3.83	5.25
Rise in Sea Level	0.5 to 2.0 by 0.5m	0.5 to 2.0 by 0.5m	0.5 to 2.0 by 0.5m	
Total Level (0.5)	2.52	3.48	4.33	5.75
Total Level (1.0)	3.02	3.98	4.83	6.25
Total Level (1.5)	3.52	4.48	5.33	6.75
Total Level (2.0)	4.02	4.98	5.83	7.25

*Converted to land elevation
ø less Setup

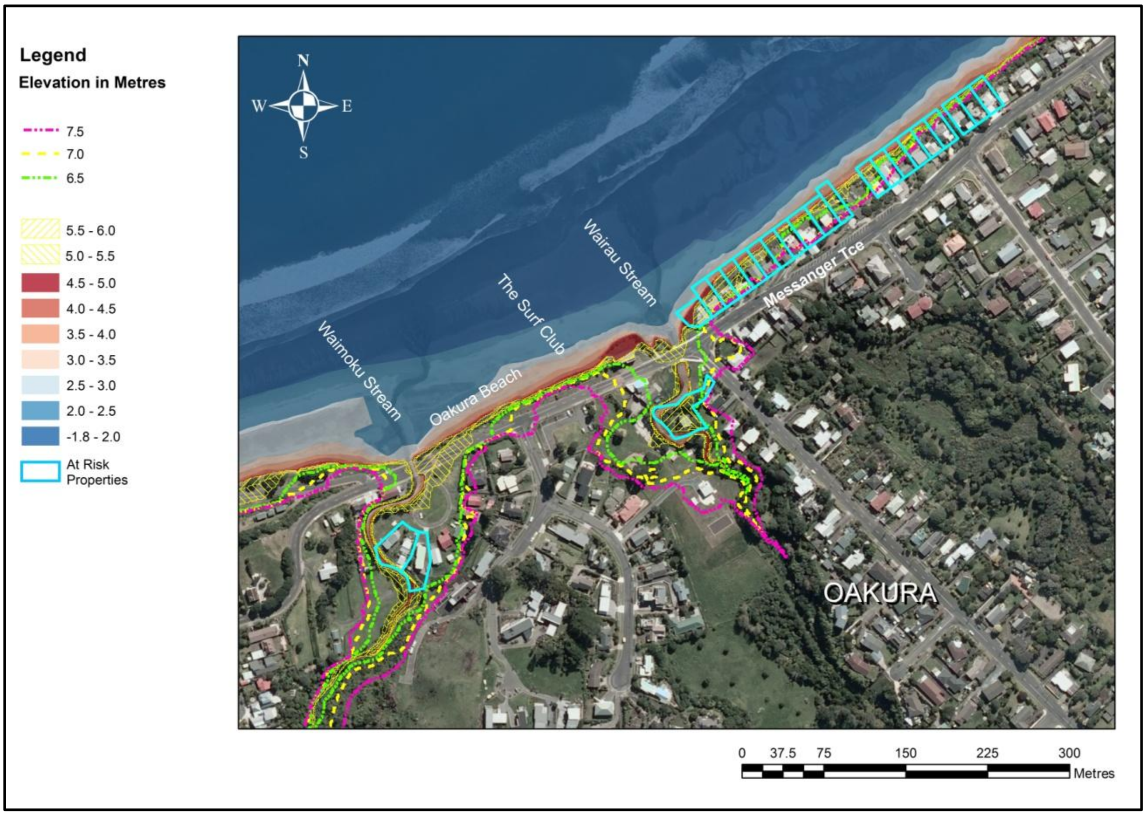
9.2.3 Inundation through a Rise in Sea Level without the effect of erosion

In the year 2100, it is possible for the Mean Sea Level (MSL) to have risen anywhere from 0.5m to 2.0m. Transferring the results from Table 9.2.1 onto Maps 9.2.3, the map shows the effect of the rise in 0.5m increments based on MSL only. What this map shows is the effect of only sea level rise without any waves or atmospheric conditions being taken into account. The area between the two streams and the Surf Club Clubhouse comes under threat, as does the Oakura Marae and the Clubhouse on the western edge of Corbett Park. As the water level rises so does the water level in the Oakura River, and whilst not showing inundation with this scenario, should the river be in flood then the properties on the southern side of State highway 45 would undoubtedly be flooded.

Maps 9.2.4 and 9.2.5 show the effects of storm surge and runup when added to Map 9.2.3.

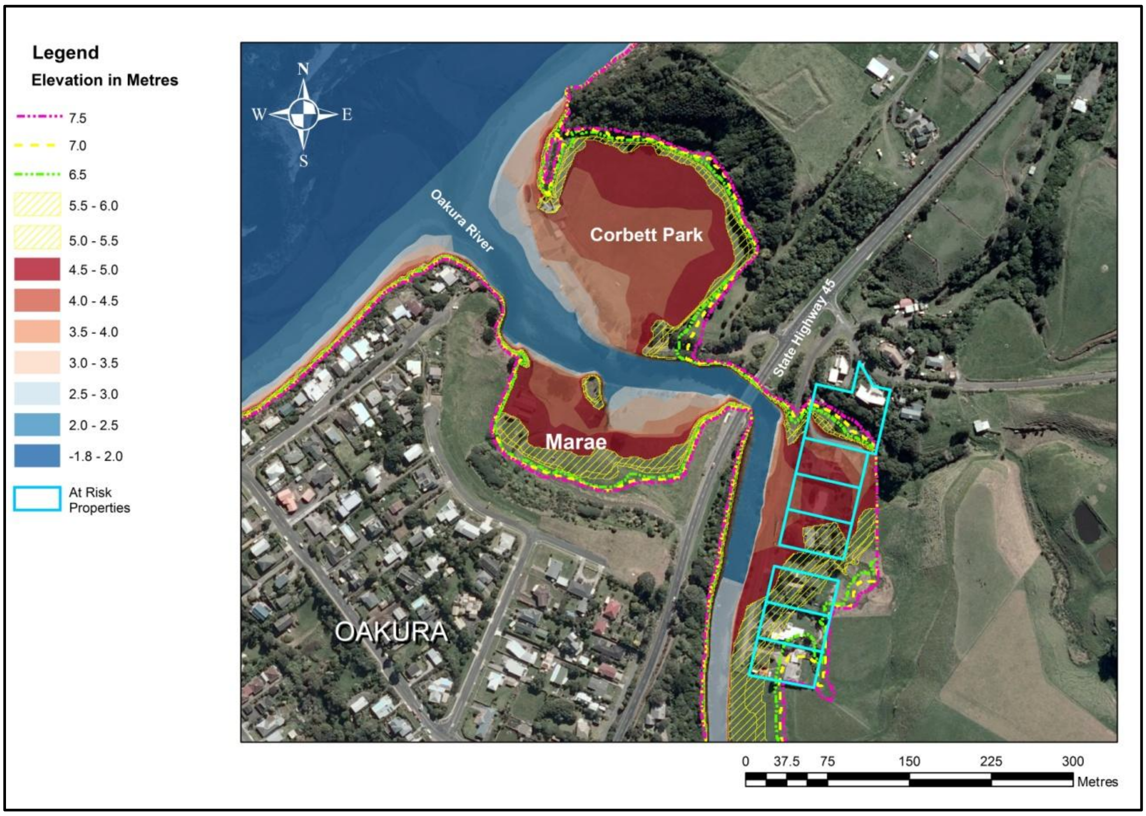
Map 9.2.3 :– Oakura Showing the Rise in Sea Level from 0.5 to 2.0 metres only, excludes Storm Surge, Setup and Runup.

Map 9.2.4 :- Area 'A' showing inundation detail of Messenger Terrace and the two streams Wairau and Waimoku. Sea Levels include Storm Surge, Setup and Runup.



The map above (Map 9.2.4) gives a closer look at the properties that will be affected by the various scenarios outlined in Table 9.1.1. Most of the properties are unaffected until the 4.0 metre level is reached. The area between and around the two streams is the most affected. Levels over 5.0 metres cause the most inundation as demonstrated in Table 9.2.2. The Surf Club clubrooms are not highlighted like the other properties because the property does not appear on the properties Database / Shapefile.

Map 9.2.5 :- Area 'B' showing inundation detail of Corbett Park, Sea Levels include Storm Surge and Runup.



At the mouth of the Oakura river, Corbett Park and the Oakura Marae will be inundated when the sea reaches an elevation of more than 4 metres. Whilst it is doubtful that runup could cause an issue that far up the river, it is possible that some wave action in the form of setup could still be present 400m up the river from the river mouth. The buildings on the Corbett Park site would be inundated over the 3m level, whilst the Oakura Marae land would be affected by seas over the 4.5m level. The buildings are not houses but do have a comercial value.

9.2.4 Inundation through a Rise in Sea Level and its effect on the Oakura Population in the year 2100 without the effect of erosion

Table 9.2.2 :- Rise in Sea Level with the current shoreline, Property values of affected areas when inundation is projected for the year 2100.

Sea Level in Metres with the current shoreline - Inundation	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CP/ ha	LV/ ha	IV / Ha ($,000)
2.0	0	0	0	0.0	0	0	
2.5	0	0	0	0.0	0	0	0
3.0	0	0	0	0.0	0	0	0
3.5	18	15308	11648	12.5	1230	936	294
4.0	27	24368	18358	16.0	1528	1151	377
4.5	44	34113	24921	19.1	1784	1303	481
5.0	55	47233	35126	20.1	2348	1746	602
5.5	57	48053	38378	22	2225	1655	570
6.0	58	48873	36366	23.2	2103	1565	538
6.5	74	61878	46326	24.3	2546	1906	640
7.0	78	62394	46512	26.3	2375	1771	605
7.5	89	74188	54421	32.4	2288	1678	610

Table 9.2.2 shows the value of land and improvements for the scenario's shown in Map 9.2.3 and Map 9.2.5. The areas calculated are those areas above the vegetation line. It is not until the 3.5m water level is reached, does the value of the property affected start to increase. Missing from these values are the values of the Oakura Camp Ground and the Surf Club Clubhouse building. For some reason these are missing from the data set provided by the NPDC.

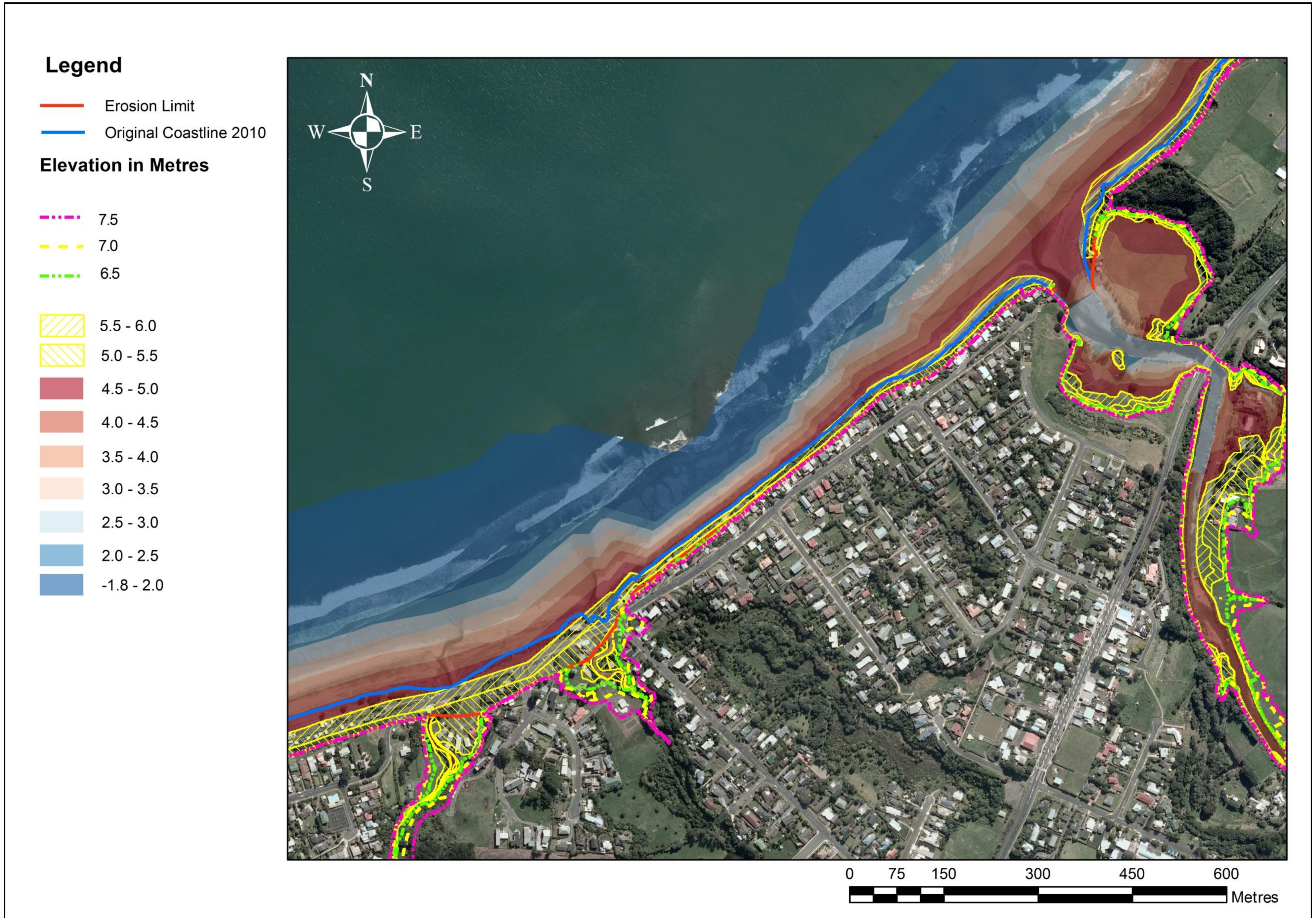
Table 9.2.3 :- Rise in Sea Level with the current shoreline – House only values of affected areas when inundation is projected for the year 2100.

Sea Level in Metres The Current Shoreline - Damage caused to Houses by Inundation	Houses	Total Capital Value ($,000)	Total Land Value ($'000)	Improved Value ($,000)	Capital Value Per House	Land Value Per House	People Effected
2.0	-	-	-	-	-	-	-
2.5	-	-	-	-	-	-	-
3.0	-	-	-	-	-	-	-
3.5	-	-	-	-	-	-	-
4.0	6	5470	4065	1405	912	678	16
4.5	18	14495	10393	4102	805	577	49
5.0	19	14945	10493	4452	787	552	51
5.5	30	24385	16418	7967	813	547	81
6.0	30	24385	16418	7967	813	547	81
6.5	38	31555	22948	8607	830	604	102
7.0	44	36065	25753	10312	820	585	119
7.5	74	62105	45908	16197	839	620	200

The number of dwellings affected by inundation is shown in Table 9.2.3. (Maps 9.2.4 and 9.2.5). Noticeable in this table is the high value of the houses and properties – i.e. 18 houses having a combined capital value of just under $15 million. The other housing stock shown in area 'B' (Map 9.2.5) has a similar value; although there are fewer properties, they are on bigger sections. The major value is in the land which is approximately 70 to 75% of the Capital Value.

If the 2006 Census data for Oakura is used and the average population density per house applied on a pro rata basis to Table 9.2.3, the number of people affected by inundation ranges from 16 to 200.

Map 9.2.6 :- Oakura shoreline showing the effects of inundation when an historic rate of erosion is considered.
West Oakura erodes at a rate of 0.67m per annum and East Oakura erodes at a rate of 0.20m per annum. The erosion limit has been calculated for 2100.



9.2.5 Erosion of the Oakura Shoreline

The TRC report of 2009 considers the rate of erosion in Oakura as being different in two areas; one to the west of the Wairau Stream and the other to the east. The eastern side has an historic erosion rate of 0.2m per year whilst the western side is 0.67m per year. Several reports (TRC, 2009) , (Taranaki Catchment Board, 1988) state that Oakura Beach changes from being in an eroding state to an accreting state over the periods it has been measured. The value of houses affected by erosion is shown in Table 9.2.4. The different rates of erosion, as stated above, are calculated as having the shoreline retreating, 17.4m and 58m respectively, by the year 2100,, which is 87 years hence.
In Map 9.2.6, the red line defines the extent of the erosion calculated to 2100. Once eroded, the coastline does not expose any new areas to inundation, the sea rise being contained by a cliffed shoreline, as can be seen at present in various locations.

9.2.6 Rise in sea level when actual erosion is considered

Map 9.2.6 shows the Oakura shoreline, the 3D model modified to replicate an historic rate of erosion until the year 2100. Like the previous map the main area of inundation is to the east of the town at Corbett Park. The projected erosion has not exposed additional areas that would be subject to inundation.
However the loss of land and property by the erosion of the foreshore is quantified in Tables 9.2.4 below.

Table 9.2.4 :– Rise in Sea Level with the eroded shoreline; House-only values of affected areas when erosion is projected for the year 2100.

The Historically Eroded Area Damage caused to Houses by Erosion	Houses	Total Capital Value ($,000)	Total Land Value ($'000)	Improve d Value ($,000)	Capital Value Per House ($,000)	Land Value Per House ($,000)	People affected
17 - 58m shoreline Retreat	57	55350	43695	11655	971	767	153.9

Table 9.2.4 shows the high capital value of houses near the seashore and the effect that only erosion will have at the projected level for 2100. Table 9.2.5 shows how inundation will affect more houses and therefore more people when

areas are exposed. If the rate of erosion increases, as it may well do with increased storm activity, then the number of properties and people affected will increase.

When comparing the Maps 9.2.3 and 9.2.6 it can be seen that inundation along the shoreline does not affect any more houses, than if there had been no erosion. The only area to have significant increased inundation is Corbett Park, where the buildings are not homes.

9.2.7 Inundation through Rise in Sea Level and its effect on the Oakura Properties in the year 2100 when erosion is considered

Table 9.2.5 :- Rise in Sea Level with an eroded shoreline, Property values of affected areas when inundation is projected for the year 2100.

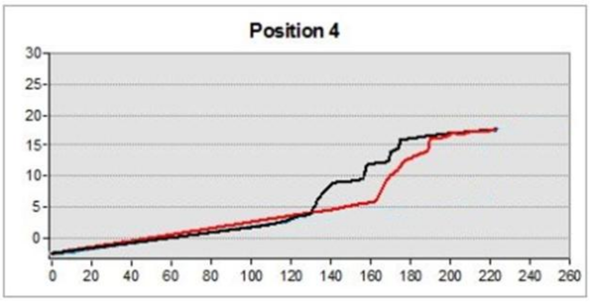
Sea Level in Metres with an eroded shoreline - Inundation	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2.0							
2.5							
3.0							
3.5	1	1125	920	3.48	323.3	264.4	58.9
4.0	2	1915	1280	8.25	232.1	155.2	77.0
4.5	4	2600	1480	8.65	300.6	171.1	129.5
5.0	7	4210	1928	9.45	445.5	204.0	241.5
5.5	10	5945	2718	9.99	595.1	272.1	323.0
6.0	17	10055	5573	11.92	843.5	467.5	376.0
6.5	23	13695	8648	18.89	725.0	457.8	267.2
7.0	27	16395	10383	20.23	810.4	513.2	297.2
7.5	28	17265	10773	20.36	848.0	529.1	318.9

To best appreciate the effect of erosion on the Oakura coastline, profile charts graphically show these effects. The profiles have been taken from the 3D models that make up maps 9.2.3 and 9.2.6 and clearly show the extent to which the shoreline is cut back by erosion and how the lay of the land will protect most of the township from inundation.

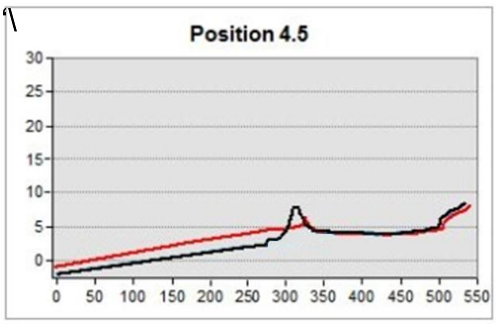
Position 3 is a profile of the area where the Oakura Motor Camp currently resides. The tall cliffs protect the population, but not the motor camp, from inundation but the houses atop the cliff are very close to the cliff face if the projected rate of erosion is allowed to occur.

Note The position numbers on the relate to the sampling positions of the hindcast data shown in Map 2.1.3 . Black = profile in 2013. Red = profile in 2100.

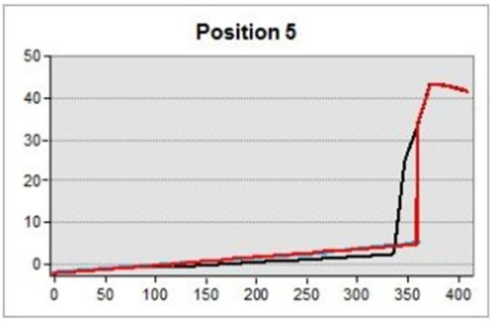
Position 4 is taken at a point east (200m) of the Waiaru Stream this shows the road at the 10 metre mark as a platform on the black line, the houses that are inundated at this point are to the left of position 4.



Position 4.5 is the profile of Corbett Park parallel to the Oakura River. The modelling for erosion shows an effect of a raised beach level and removal of the spike of land which keeps some of Corbett Park shielded from the sea. Once this shield has been removed the profile resumes its pre-erosion shape.



Position 5 the profile east of Oakura where the erosion does not affect the current line of cliff-tops. Had the rate of erosion been the same as the cliffs in position 3, then the tops would have been affected.



9.2.8 Oakura Setup / Runup

Runup is based on supplied hindcast data for a five year period and has been calculated using equation 4.5.1 the results for Oakura being shown in Appendix G for positions 3, 4, 5.

The foreshore slope has been calculated from data provided by the ESRI's 3D Analyst profile tool. This tool provided not only visual representation of the foreshore but x, y coordinates of the profile so foreshore slope could be calculated.

The three values created by Stockdon's setup and runup formula for dissipative shores have been averaged to come up with a single figure of 0.84m.

9.2.9 Oakura Ground Truthing of Model

The topographical map which covers the Oakura area shows one reference site i.e. A7E4 B Oakura at a height of 44m. The best reading obtained from the 3D Model was 43m, which is outside the expected result of 44 metres ± 0.25m. However as the ground-truthing results from the other study sites have been within the expected accuracy, this 3D model will be used.

9.2.10 Oakura – Discussion of Findings

The studies and measurements done on the Oakura shoreline show that it has been accreting and eroding (TRC, 2009) over the period it has been measured. In order to evaluate how the area will be affected by a rising sea level, the erosion scenario has been considered, since this was the condition the beach was in when the latest measurements were taken.

When Map 9.2.2 of Oakura elevation is viewed it shows quite clearly the low lying areas of the study area. It is these sections which will be the first to become inundated when the sea rises.

Unlike the basic levels of RSL + storm surge, which are the same as the other study sites, the level of setup and runup is significantly greater for the Oakura area mainly because the Significant Wave Height (H_s) is greater at the western end of the study area. The increase in setup and runup means that any inundation will move further inland.

Using the SWL only values, Map 9.2.3 shows that on a calm day with no wind and with normal conditions, then the Highest Atmospheric Tide will inundate areas either side of the Oakura River mouth once the 3.0m elevation is reached.

When storm surge, set up and runup are added in the form of a 50 year storm more areas and houses (maps 9.2.4 and 9.2.5) will be inundated. The frequency and severity of storms are set to increase, so these areas and values must be seen as the minimum.

With a 2011 year valuation of the properties affected by erosion reaching $55 million (Table 9.2.4), it is unlikely that the local authorities responsible for the area will allow any significant erosion of the foreshore to occur, should they not provide engineering solutions, a large portion of the sea front properties will be eroded and houses be destroyed. Any armouring of the coast line will need to be extensive to ensure overtopping does not bypass the shores defences.

There are four commercial buildings and areas that are likely to be lost to extreme conditions; these being the Surf Club Clubhouse, the Corbett Park Building, the Oakura Marae and the Oakura Beach Camp Grounds. What will become of these buildings under a rising sea scenario can only be surmised and that retreat or protection as suggested in (Pugh, 2004) be investigated.

9.3 Port Findings

Map 9.3.1 :- Port Location with named features.

9.3.1 Port Location

Port Taranaki lies 3.5 kilometres to the west of New Plymouth's CBD and 9.5 kilometres to the east of Oakura. To the northwest are the Sugar Loaf Islands, the remnants of a volcano core some 1.25 million years old.

Port Taranaki began its history in 1880 when the Main Breakwater was built to allow ships to enter a protected habour to service a growing dairy industry. The Port owes its existence to two breakwaters, both of which have been built to withstand heavy seas and are in constant need of maintenance. The Port is currently owned by the Taranaki Regional Council.

The Port has developed and much land has been reclaimed and built on, namely Blyde Wharf and the area between Fitzroy Yachts and the lee breakwater. In the 1990's the area around the Lee Breakwater was developed into shops and restaurants. The Coast Guard is based here and the boat ramp is used by recreational boaters

Behind the Port is the New Plymouth power station, which has been decommissioned and will at some stage be removed to allow expansion of the port facility (Daily News, 2013) and the petrochemical tank farm.

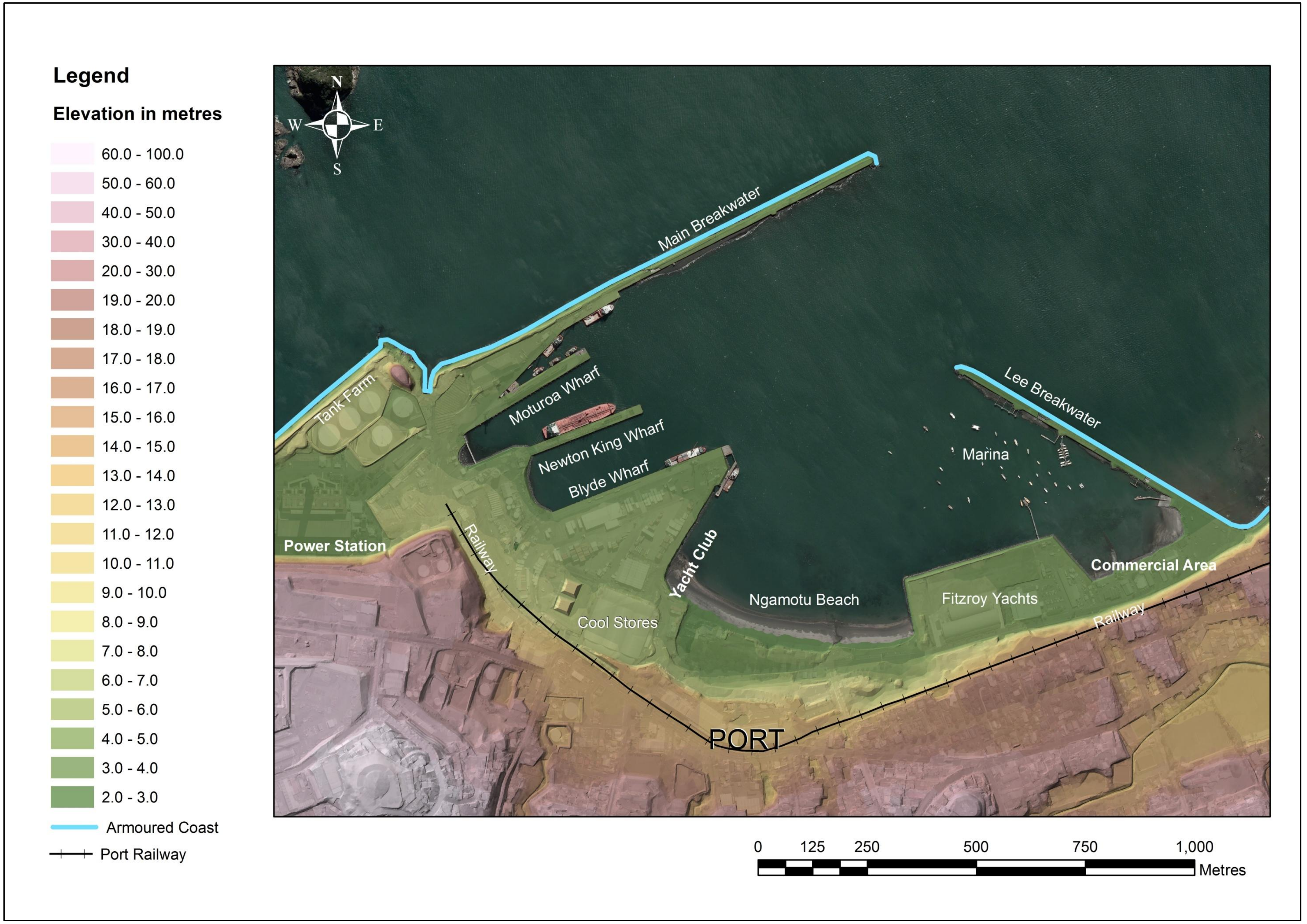
Between the wharves and the commercial area lies Ngamotu Beach, once the preferred beach for recreation, and the New Plymouth Yacht Club.

South of the Yacht Club are the 'Cool Stores' through which much of Taranaki's dairy output passes.

South of the Port lies New Plymouth's residential area, which is not included in the study area, as it in a well elevated area far away from any potential flooding.

There are no houses in the study area which is on the seaward side (north) of the railway line.

Map 9.3.2 :- Port Elevation with Place names and armoured shore.



9.3.2 Port Elevation

The Port area, as shown in Map 9.3.2, lies low along the coast with a steep rise where the railway line runs south of the port at an elevation of ±10m.

The area along the foreshore is well within the inundation range, particularly the reclaimed areas to the east by the Lee Breakwater, where the commercial area lies. See Map 9.3.3

Map 9.3.3 :- Rise in Sea Level with the current shoreline –when inundation is projected for the year 2100 – Refer Table 9.3.1.

9.3.3 Inundation through a Rise in Sea Level and its effect on the Port property in the year 2100, without the effect of erosion

Table 9.3.1 :- Port; Build up of highest sea levels given different conditions and extreme events.

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge $_{1:50\ year\ level}$		0.96	0.96	0.96
Storm Tide $_{1:50\ year\ level}$	2.02	2.98	2.98	2.98
Setup $_{1:50\ year\ level}$			.88	.88
Runup[⦰] $_{1:50\ year\ level}$	-	-	-	1.48
Max Storm Level	2.02	2.98	3.86	5.34
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.36	5.84
Total Level (1.0)	3.02	4.98	4.86	6.34
Total Level (1.5)	3.52	4.48	5.36	6.84
Total Level (2.0)	4.02	4.98	5.86	7.34

*Converted to land elevation

⦰ less Setup

Table 9.3.2 shows the effect, in terms of monetary value, any rise in sea level. This table when viewed in conjunction with Map 9.3.3 and Table 9.3.1 shows that a RSL up to the 1.0m mark will, on its own, cause little monetary damage, although the car park that services the lee breakwater will be submerged, as will the area by the Yacht Club. It is not until the SWL RSL reaches the 1.5m+ mark (3.5m above sea level) that the damage begins to occur. What is surprising is that the Lee Breakwater will become submerged and the commercial area in the east of the study area that comprises shops, restaurants and small businesses will be inundated. Table 9.3.1 shows the combination of levels required to reach or exceed 3.5m.

An increase in the RSL to 2.0m sees the Power Station site (currently mothballed), the Yacht Club building and facilities, and the Blyde and Moturoa wharves succumb.

When storm surge, setup and runup are added to these levels, the inundation will push further inland until a level of 7.41m is reached and a potential damage to property is estimated as to be in the region of $171 million from the property Table 9.3.2, not to mention the loss of revenue to business.

The main concern is the effect of an SWL RSL in excess of 1.5m (3.5 metres).

Table 9.3.2 :- Port; The Value of Properties affected by inundation projected for 2100 – refer Map 9.3.3.

Sea Level in Metres with the current shoreline	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CP / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2.0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0
3.0	1	103608	43704	42.73	2424.7	1022.8	1401.9
3.5	2	104836	44234	43.12	2431.3	1025.8	1405.4
4.0	3	151086	48109	64.64	2337.3	744.3	1593.1
4.5	4	156856	48709	66.42	2361.6	733.3	1628.2
5.0	5	158322	49909	70.01	2261.4	712.9	1548.5
5.5	6	158613	50199	70.75	2241.9	709.5	1532.4
6.0	7	158883	50469	70.98	2238.4	711.0	1527.4
6.5	7	158883	50469	70.98	2238.4	711.0	1527.4
7.0	8	161628	51997	74.52	2168.9	697.8	1471.2
7.5	9	171278	53297	77.1	2221.5	691.3	1530.2

9.3.4 Erosion of the Port Shoreline

Because of the protected shoreline erosion is not considered for this study area.

9.3.5 Port Erosion Actual

Because of the protected shoreline erosion is not considered for this study area

9.3.6 Port Setup / Runup

Setup and runup values have been determined using study sites 14,15,16 in Appendix ‘G’ and averaged to give a setup value of 0.88m and a runup value of 1.48m. This gives a total Storm Tide of 3.83m for every 50 years.

9.3.7 Port; Ground Truthing of Model

Figure 9.3.1 :- Ground shot of Boat Ramp (photo by the author, 1st Sept 2012).

The image on the left was taken on the 1st September 2012 at 10.03am when the tide was predicted to be at +3.5m above MSL. The sign on the jetty end was used as a reference point for the location and the level of water's edge at that time. See the yellow dot on the aerial image in Figure 9.3.2. This gave a reading of from the 3D model of 1.72m. Add to this the difference between the two datum’s (1.815m) and we have a chart depth of 3.535m. This result from ground-truthing shows the method is reliable, given the possible inaccuracies available, in making the reading and proves that the levels of the tides are in relation to the land are accurate.

Figure 9.3.2 :- Aerial Photo of Boat Ramp (source NPDC, 2010).

9.3.8 Rise in Sea Level and its effect on the Port Population in the year 2100 when erosion is considered

As erosion is not considered to an issue and the residential area is outside the study area there is no effect on the human population.

9.3.9 Port – Discussion of Findings

The port is an integral part of the trading infrastructure, not only to New Plymouth but New Zealand, The export of bulk was < 2,500,000 tonnes in 2013 with minimal containerised exports. Large quantities of produce to the overseas markets. Imports were bulk ± 500,000 tonnes and containerised 250,000 tonnes.

Any disruption to that flow of produce would cause local and national economic harm.

Because the Port is so low-set a small rise in SWL RSL would start to affect the area; not the port initially, but the shops, restaurants, business and clubs that are in the Port area. The breakwaters will be breached when the SWL RSL reaches 1.5m, unless they are raised in height. The wharves will also need to be raised in order to continue operating.

As the sea level rises, the affects of storm surge start to impinge on the workings of the Port and infrastructure. Any sea level over 3.5m will cause damage to the Port area and cause it to become unusable.

9.4 Moturoa and City Findings

9.4.1 Moturoa and City Location

Moturoa is a suburb to the west of the CBD and north of SH45. It starts at the Port and the Lee Breakwater. It has a number of parks and public buildings that are near the shore, namely Kawaroa Park, the Aquatic Centre and the Belt Road Motor Camp. This suburb merges with the New Plymouth CBD, past the Puke Ariki landing, and runs eastwards to the Te Henui stream, all being connected by the New Plymouth Walkway and protected from the sea by an armoured foreshore. The Moturoa area is predominately residential housing, whilst the City are has more commercial property. The area to the east, around the mouth of the Te Henui River is included in the Fitzroy Study Area.

New Plymouth's CBD has as its heart the Huatoki Stream and the Puke Ariki Landing.

The study area has a night-time population of approximately 3144 persons with an average of age 38.5 and 1143 dwellings, as well as numerous commercial buildings (Statistics NZ, 2006).

9.4.2 Moturoa and City Elevation

Map 9.4.2 shows the elevation of the Moturoa to City study area. What is noticeable, is the low lying area at the mouth of the Huatoki Stream and the low elevation of the Aquatic Centre. The majority of the City and Moturoa are protected by cliffs at elevations in excess of 10m. The cliffs are protected at their bases by large boulders, which in some areas, form the construction of the New Plymouth Walkway.

The valley which has formed either side of the Huatoki Stream continues inland for some 740m before it reaches a 5.86m elevation when it can be considered out of danger of being flooded, as it exceeds the 50 year Storm Tide Level for a 2.0m SWL RSL.

Map 9.4.1 :- Moturoa and City Location with place names.

Map 9.4.2 :- Moturoa and City Elevation and Place Names.

Table 9.4.1 shows the calculations of the sea levels with the possible scenarios. These levels have then been translated onto map levels, on to non-eroded 3D models, to produce Maps 9.4.3 and 9.4.3. This shows the properties that will become accessible to rising sea levels and associated extreme events.

Table 9.4.1 :- Moturoa and City; Build up of highest sea levels given different conditions and extreme events for the Moturoa and City shoreline.

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level	2.02	2.98	2.98	2.98
Setup 1:50 year level			.81	.81
Runup[ø] 1:50 year level	-	-	-	1.36
Max Storm Level	2.02	2.98	3.79	5.15
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.29	5.65
Total Level (1.0)	3.02	4.98	4.79	6.15
Total Level (1.5)	3.52	4.48	5.29	6.65
Total Level (2.0)	4.02	4.98	5.79	7.15

9.4.3 Inundation through a Rise in Sea Level and its effect on the Moturoa - City property in the year 2100, without the effect of erosion.

The major threat to the Moturoa shoreline comes from the rise in sea level and associated storm surge. The threat of erosion is minimised, if not eliminated, due to the fortification of the shoreline (TRC, 2009).

Map 9.4.3 (Site A) shows an aerial photo of the New Plymouth Aquatic Centre, known locally as the Kawaroa Baths. The image clearly shows where the seawall would be breached at a low point and how the baths and surrounding area would be inundated. The limit that would be reached by setup and runup is defined by the dashed lines for runup and the hatched areas for setup.

To the right of the image is the Coastal Walkway which is inundated when the Sea Level reaches 4.5m. The path would not be able to be used when sea levels are at this level or a lower level, because of overtopping and / or the dangers of overtopping would present. Reference to Table 9.4.1 shows under what conditions the walkway at this elevation would be unusable.

Other areas of the Walkway that would be inundated are shown in Map 9.4.2, these areas become inundated and unusable under similar conditions to the walkway in Site ‘A’.

Map 9.4.3 :- Moturoa and City Shoreline – Site ‘A’ showing Rise in Sea Level with Storm Surge, Setup and Runup and properties affected.

Map 9.4.4 (Site B) shows an aerial photo of the mouth of the Huatoki Stream. The Huatoki has always caused the centre of New Plymouth a lot of problems with flooding of the CBD. The last flood was in 1979, after which a flood control system was constructed to control the flow of water through the City. As can be seen the stream is encased by buildings either side as it travels through and under the CBD. The threat of inundation in the future is not from upstream with high volumes of river water causing the flooding; but from water travelling up the river from the rising sea and thus inundating the low lying areas.
The CBD has some of the most expensive properties in New Plymouth when compared to other areas in this study. The interesting point with this image is the large light blue area (2.0m sea level) to the east of the stream. This is the “Centre City” retail mall building and whilst it has a basement (car park) there is a low probability of water entering it. Also to be noted is that there are other buildings ,with basements, on the same street but these do not show on the 3d model. The image has been unaltered because there is every chance, that given the effects of setup and runup, the basement could be flooded.

Directly opposite the Centre City car park is an area called the Puke Ariki Landing, the area where the first European settlers came ashore. This area would be inundated starting at 2.5 metres (0.5 RSL), the Museum / Library (Puke Ariki) and its treasures would not be affected, but once the 5.0m – 5.5m level had been reached, the library / museum and several other commercial buildings would be affected. Because the flooding is inland, the effect of runup and setup is reduced but at this level, the attack would be directly from the sea, setting the full force of any storm against the properties in a direct line from the sea.

There is a small amount of flooding at lower sea levels but the major amount occurs at the extreme end of the scale. However, because the 3D model looks at the ground surface, the effect of the stream being filled with a rising sea is unclear. A number of these properties, which show as being flooded on the surface, may have basements which have access to the river from within the building and therefore flood the building from within.

Map 9.4.4 :- Moturoa and City Site 'B' at Huatoki with the current shoreline: showing Rise in Sea Level with Storm Surge and the properties affected.

Table 9.4.2 :- Property Values as a result of a Rise in Sea Level with the current shoreline - Site A.

Rise in Sea Level with the current shoreline - Site B	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CP / Ha	LV / Ha	IV / Ha ($,000)
6.0 Sea level	1	1250	500	2.956	423	169	254

Table 9.4.2 deals with one building, the Aquatic Centre, which is a community asset and run by the NPDC. A rise in sea level to 6m and over will see the entire complex inundated.

Table 9.4.3 :- Property Values as a result of a Rise in Sea Level with the current shoreline - Site B.

Sea Level in Metres with the current shoreline - Site A	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CP / Ha	LV / Ha	IV / Ha ($,000)
2.0	1	42310	14880	1.42	29796	10479	19317
2.5	3	42310	17705	1.87	22626	9468	13158
3.0	3	42310	17705	1.87	22626	9468	13158
3.5	3	42310	17705	1.87	22626	9468	13158
4.0	6	51015	19785	2.2	23189	8993	14195
4.5	11	56462	21883	2.609	21641	8388	13254
5.0	17	70408	27823	9.09	7746	3061	4685
5.5	36	113531	45807	10.88	10435	4210	6225
6.0	51	126765	52067	13.31	9524	3912	5612
6.5	62	133785	55767	13.89	9632	4015	5617
7.0	71	147240	61382	14.67	10037	4184	5853

Table 9.4.3 shows the relative values of buildings affected as they become inundated by the increasing rise in sea level, in some cases only part of the property is inundated but is shown here as the entire property. A number of the properties in this study area are car parks or communal areas and as such have low improved values but high land values. The values when compared with other study areas is extremely high.

9.4.4 Erosion of the Moturoa and City Shoreline

The entire Moturoa – City Shoreline has been protected, using large boulders, to reduce the rate of erosion to zero according to a 2009 TRC report.
Building a sea wall, i.e. protecting the shoreline with large boulders, does not however, prevent erosion, the sea can undermine these defences (scour the sea bed) and render them useless (Goda, 2000).

9.4.5 Moturoa and City Runup

Runup is based on the hindcast data for a five year period, the results for Moturoa – City being shown in Appendix G for positions 17, 18 and 19.
The foreshore slope was calculated from data provided by the ESRI's 3D Analyst profile tool. This tool provided not only visual representation of the foreshore but x,y coordinates of the profile, so foreshore slope could be calculated.
The three values created by Stockdon's setup formula have been averaged to come up with a single figure of 0.81m. Runup has been calculated at 1.36, although a coast armoured with boulders will reduce Runup significantly (Goda, 2000) possibly by as much as 50%.

9.4.6 Moturoa and City – Discussion of Findings

The high cliffs of the Moturoa and City study area protect much of the area from inundation and the armoured seawalls protect the coast from erosion. There are two areas where property damage will occur with a rising sea and they are properties at and along the mouth of the Huatoki Stream and Puke Ariki Landing and the Aquatic Centre.

Whilst property is of concern, the contents of the Puke Ariki Museum and Library which hold the historic treasures of the city would be at risk, as they have been in past floods.

The properties in this study area all have high values and whilst there may not be any loss of land, the improved value of properties that could be flooded could be as high as $86 million based on 2011 values.

9.5 Fitzroy Findings

9.5.1 Fitzroy Location

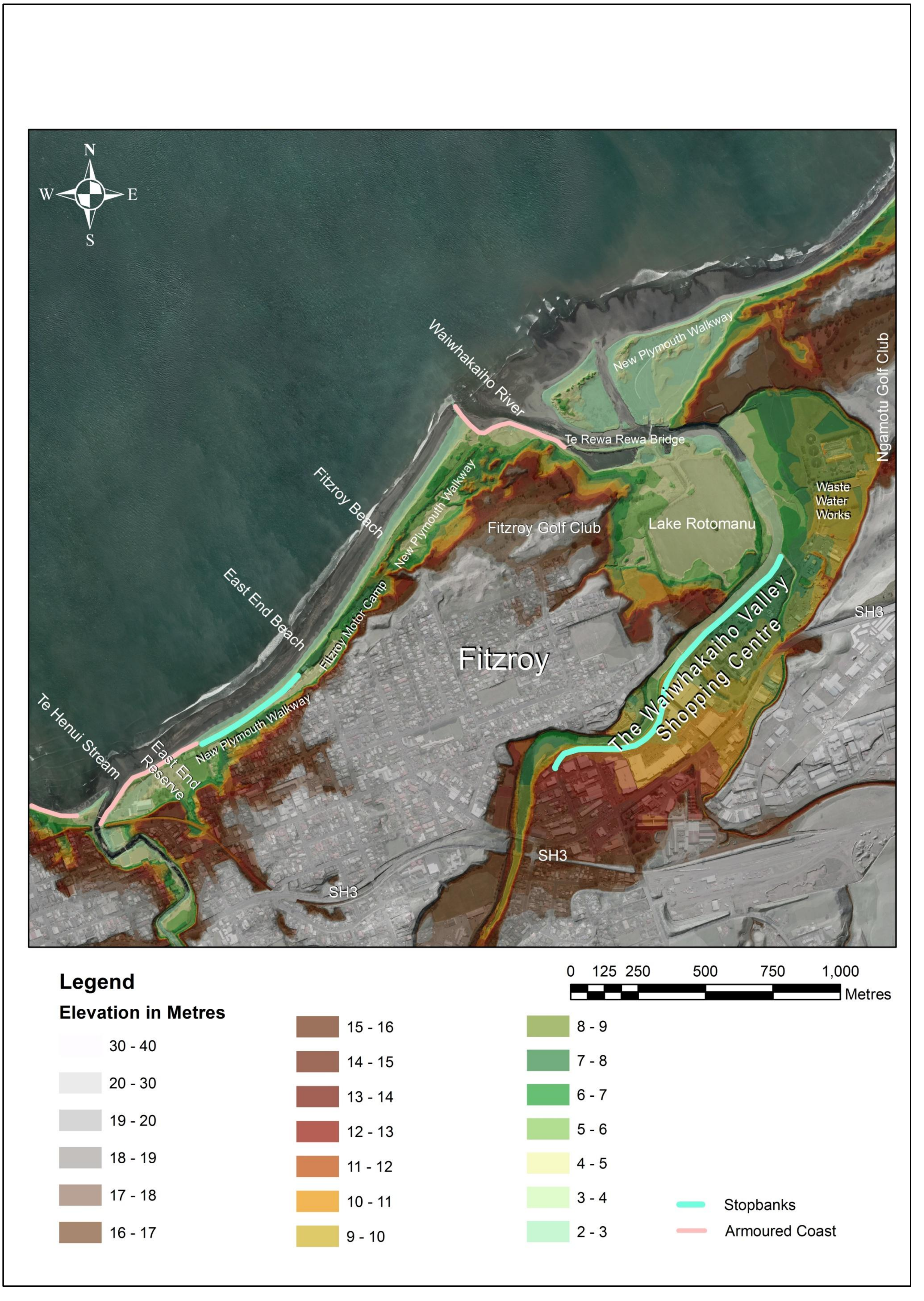
Fitzroy is a coastal suburb that lies to the east of New Plymouth central. The study area comprises 44 mesh blocks (Statistics NZ, 2006) that has a total population of 4,040 and includes 1,767 dwellings. The average age of inhabitants in the area is 36.4 years old.

On the western edge of the study area is the Te Henui Stream, with the Waiwhakaiho River to the east. Fitzroy has two main beaches, the Fitzroy Beach and East End Beach. Both beaches are popular with surfers and wind-kite surfers because of the beach conditions; namely the waves, off shore winds and the sandy beaches. The Fitzroy Motor Camp is right at the water's edge, with baches, sites for caravans, the usual amenities block and an accommodation office. To the east, along the beach, the foreshore dunes become more prominent, rising up and protecting the New Plymouth Walkway and Fitzroy Golf Club.

South of the forked river mouth of the Waiwhakaiho River is Lake Rotomanu which is 11.3ha and sits at an elevation of 4.5m. The lake is used for recreational purposes i.e. swimming and motorised water sports. The Lake is not affected by the rise and fall of the tide. On the east side of the river is the New Plymouth Waste Water Treatment Plant, the Rifle Range, and beyond that the Ngamotu Golf Course.

Map 9.5.1 :- Location of the Fitzroy Study Area with important features.

Map 9.5.2 :- Fitzroy elevations with positions of stopbanks shown.



9.5.2 Fitzroy Elevation

The Fitzroy study area is dominated by the Waiwhakaiho River and the Te Henui Stream which create low lying areas for a rising sea to reach inland.

The foreshore is partially armoured from the mouth of the Te Henui to the Surf Club Rooms. From there, eastwards, are stopbanks which protect houses inland from the beach. Where the stopbanks finish, the land rises, protecting the majority of Fitzroy's buildings from inundation.

At the mouth of the Te Henui River there are a number of recreational buildings which are on low lying ground, including the Te Henui waste water pumping station which pumps sewage from the western suburbs to the New Plymouth Waste Water Works (Treatment Plant). The Te Rewa Rewa Bridge, New Plymouth Walkway and Waste Water Works are all on or very near to low ground, all of which are within the inundation range.

The Waiwhakaiho Valley and associated shopping complex is protected from flooding by the River with a recently raised stop bank. It has no specific protection from a rising sea level.

The suburb of Fitzroy, sandwiched between the ocean and the Waiwhakaiho Valley, has an elevation of between 20 - 30m

Table 9.5.1 :- Fitzroy; Build up of highest sea levels given different conditions and extreme events for Fitzroy Shoreline.

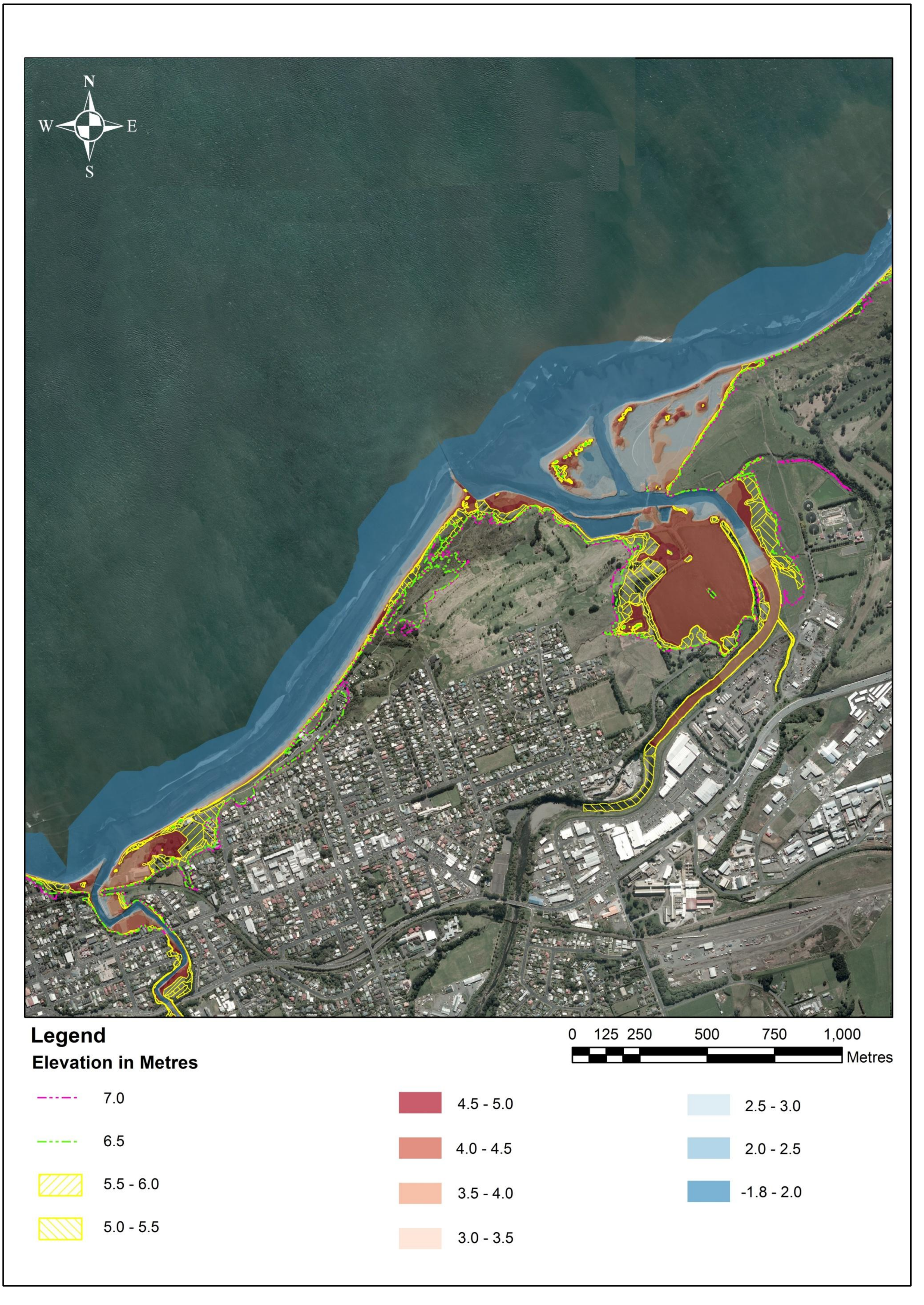
Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level	2.02	2.98	2.98	2.98
Setup 1:50 year level			0.82	0.82
Runup[ø] 1:50 year level	-	-	-	1.38
Max Storm Level	2.02	2.98	3.79	5.15
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.29	5.65
Total Level (1.0)	3.02	4.98	4.79	6.15
Total Level (1.5)	3.52	4.48	5.29	6.65
Total Level (2.0)	4.02	4.98	5.79	7.15

*Converted to land elevation

Table 9.5.1 calculates the sea levels for a range of possible scenarios. These levels were then transferred onto map levels on Non-eroded 3D models, to produce maps 9.5.3 and 9.5.4, showing the details and elevations that will become accessible to rising sea levels and associated extreme events.

Maps 9.5.6 is treated in the same manner, except the 3D model has been edited to take into account the effects of historic erosion.

Map 9.5.3 :- Inundation levels for the different Sea Rise Levels including Storm Surge, Setup and Runup projected for the year 2100.



9.5.3 Inundation through a Rise in Sea Level without the effect of erosion

Map 9.5.3 gives an overview of the areas where inundation of the coast and along the two rivers in the area, the Waiwhakaiho and the Te Henui Stream, is likely to occur, without the effect of erosion being taken into account. What is immediately noticeable is that the rise in sea level, without storm surge and runup, will cause damage to the low-lying areas around the mouth of the Te Henui Stream and inundate part of the East End Reserve including the Bowling Green and Sewage Pumping Station. If storm surge, setup and runup are added then the area inundated increases and properties further up stream become threatened, as will be described, and shown on Map 9.5.4.

Whilst no buildings, other than a toilet block, are affected at the Waiwhakaiho River mouth and the nearby areas by a rise in sea level, the northern side base of the Te Rewa Rewa Bridge becomes inundated and the coastal walkway, which was newly completed in this aerial image, is submerged by a 1.0m RSL.
The effect of the RSL on the river is shown as it sweeps past to the south of Lake Rotomanu. Stopbanks on the southern side of the river protect “The Valley” retail area.

Setup and runup have an effect up-river, because as the sea levels increase the area up-stream then becomes open to the sea and the wave action that will bring.

9.5.4 Rise in Sea Level with the current shoreline and its effect on the Fitzroy Properties and Population in the year 2100

With storm surge, setup and runup added, the full extent of inundation becomes clear in the areas shown in Maps 9.5.4 and 9.5.5. Properties with boundaries beside the Te Henui Stream have a high risk of being inundated as does the bigger part of the East End Reserve with its community buildings and Pumping Station. Either through good planning or by good fortune the area’s most affected by inundation happen to be sports or recreation facilities. However the

Pumping Station must be of concern given the force with which storms can destroy buildings no matter how well designed and hearsay evidence of sewage seepage, during storms, must be a concern especially when there is the possibility of inundation from rising sea levels.

For the Waiwhakaiho River, the effect of inundation is less severe, with no buildings being affected other than a toilet block at the mouth of the Waiwhakaiho. However the New Plymouth Walkway and the Te Rewa Rewa Bridge are affected, and the rifle range, located between the Waste Water Plant and the river, will be awash. What does become apparent is that when Lake Rotomanu becomes exposed, the small strip of land that separates the lake and the river is directly open to the sea and its erosive elements. Once breached, the lake, which is 3m higher than the river, would drain into the river, and may or may not cause issues that affect the Waiwhakaiho Valley Shopping Centre (The Valley).

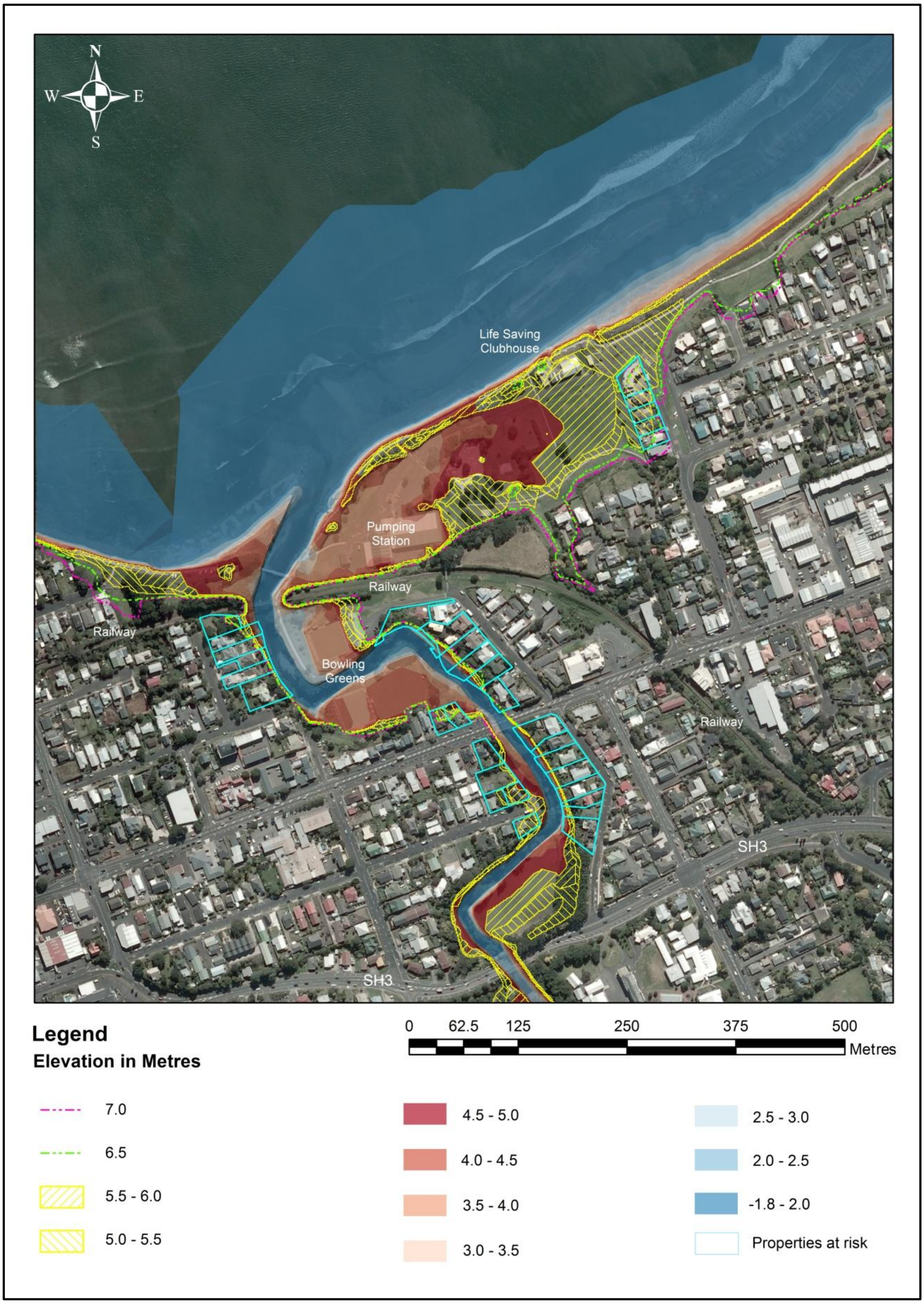
Table 9.5.2 :- The affect on properties when the existing shoreline for 2100 is Inundated and Rise in Sea Level when Storm Surge and Runup are included.

Sea Level in Metres with the current shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CP / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2.5	1	240	240	6.35	37.8	37.8	0.0
3.0	2	4645	2385	11.43	406.4	208.7	197.7
3.5	6	6717	4032	11.78	570.2	342.3	227.9
4.0	10	10027	6810	13.04	768.9	522.2	246.7
4.5	20	20231	14589	53.91	375.3	270.6	104.7
5.0	27	24973	18291	70.9	352.2	258.0	94.2
5.5	36	28938	21201	71.45	405.0	296.7	108.3
6.0	40	34238	25545	110.18	310.7	231.8	78.9
6.5	48	39613	29915	110.9	357.2	269.7	87.4
7.0	59	52023	36780	112.81	461.2	326.0	135.1

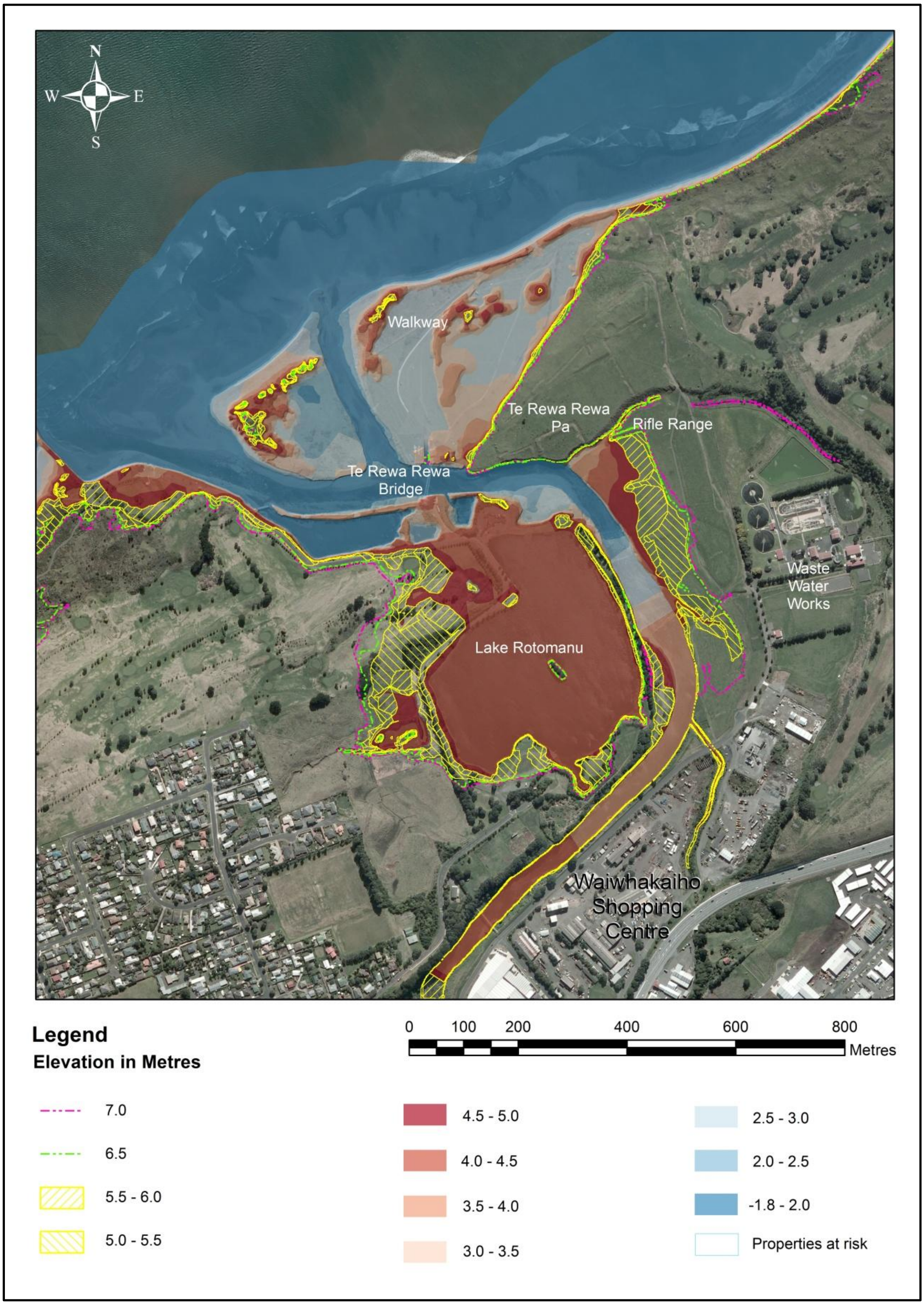
Table 9.5.3 :- The affect on houses when the existing shoreline for 2100 is Inundated by a Rise in Sea Level when Storm Surge and Runup are included.

Sea Level in Metres The Current Shoreline - Damage caused to Houses by Inundation	Houses	Total Capital Value ($,000)	Total Land Value ($'000)	Improved Value ($,000)	Estimated population Affected
2.5	0	0	0	0	0
3.0	0	0	0	0	0
3.5	0	0	0	0	0
4.0	4	1962	1292	670	11
4.5	12	4782	3317	1465	33
5.0	18	6749	4304	2445	49
5.5	30	16989	10274	6715	81
6.0	33	18549	11559	6990	90
6.5	39	22334	14594	7740	106
7.0	46	25759	17807	7952	125

Map 9.5.4 :- Site 'C' The Mouth of the Te Henui Stream showing the existing shoreline and the affects of inundation on properties and population with a Rise in Sea Level in the year 2100.



Map 9.5.5 :- Site 'D' The Mouth of the Waiwhakaiho River showing areas that have the potential to be affected by Rising Sea Levels and storm extremes in the year 2100.



9.5.5 Erosion of the Fitzroy Shoreline

Part of the Fitzroy Coast is armoured and therefore is not included in the erosion scenario which is shown in Map 9.5.6.

The eroded area of land is 16.2ha which will retreat at the rate of 0.58m per annum, giving a total retreat of 50.5m by the year 2100. The majority of the land is of low quality but not all. It represents a capital value of $3.48 million, and land value of $2.63 million; giving an improved value of $0.84 million when the eroded area is multiplied by the 'values per hectare' that appear in Table 9.5.4.

Map 9.5.6 :- Fitzroy with projected erosion at a rate of 0.58m per annum for the year 2100 showing Rising Sea Levels including Storm Surge and Runup.
Included are house properties that will be affected.

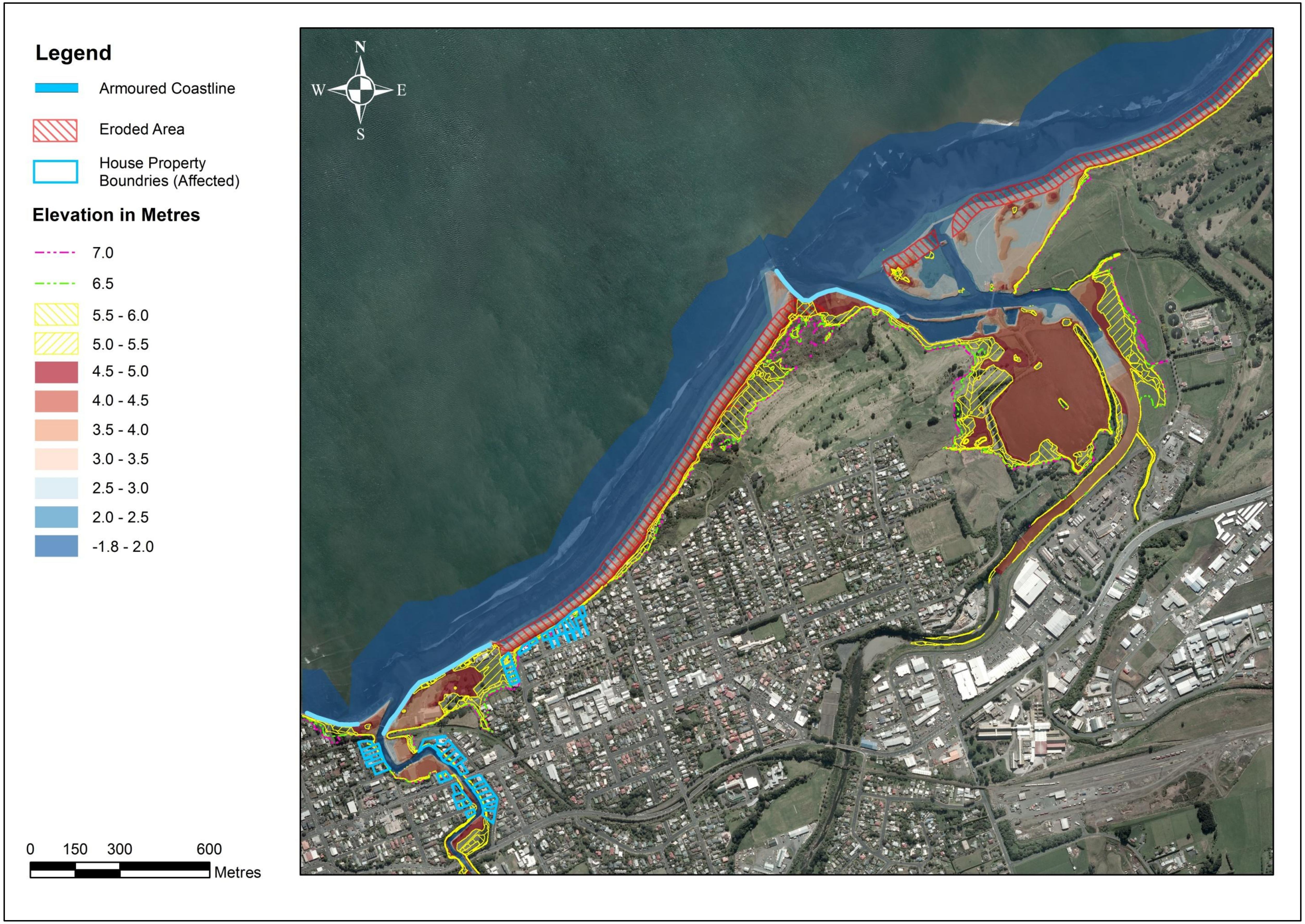


Table 9.5.4 :- Property Loss due to a 50.5 metre eroded shoreline only.

The Eroded Shoreline - Damage caused to Property by Erosion only	Records	Total Capital Value ($000)	Total Land Value ($000)	Total Land Area (ha)	CV/Ha ($000)	LV/Ha ($000)	IV/Ha ($000)
50.5 Onshore Retreat	23	28340	21460	132	214.7	162.6	52.1

Table 9.5.5:- Property Loss due to Rise in Sea Level with a 50.5 metre eroded shoreline due to inundation.

Sea Level in Metres The Eroded Shoreline - Damage caused to Property by Inundation	Records	Total Capital Value ($,000)	Total Land Value ($'000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2.5	1	240	240	6.53	36.8	36.8	0.0
3.0	2	4645	2384	11.43	406.4	208.6	197.8
3.5	4	4647	2387	11.46	405.5	208.3	197.2
4.0	9	8857	5770	12.95	683.9	445.6	238.4
4.5	19	17848	11961	52.04	343.0	229.8	113.1
5.0	27	26638	19240	93.77	284.1	205.2	78.9
5.5	44	38783	28630	110.5	351.0	259.1	91.9
6.0	49	41828	31250	110.98	376.9	281.6	95.3
6.5	57	50258	35520	112.75	445.7	315.0	130.7
7.0	67	57839	41041	113.4	510.0	361.9	148.1

Table 9.5.6 :- Houses only lost due to the 50.5 metre Eroded Area by Erosion.

The Eroded Shoreline - Damage caused to Houses by Erosion Only	Houses	Total Capital Value ($,000)	Total Land Value ($'000)	Improved Value ($,000)
50.5 Onshore Retreat	11	9675	6500	3175

Table 9.5.7 :- Houses only lost due to the 50.5 metre Eroded Area by Inundation.

Sea Level in Metres The Historically Eroded Area Damage caused to Houses by Inundation	Houses	Total Capital Value ($,000)	Total Land Value ($'000)	Improved Value ($,000)	Estimated population Affected
2.5	0	0	0	0	0
3.0	0	0	0	0	0
3.5	0	0	0	0	0
4.0	4	1692	1292	400	11
4.5	12	4782	3317	1465	33
5.0	18	6749	4304	2445	49
5.5	31	23719	13869	9850	84
6.0	43	34084	21324	12760	117
6.5	47	37539	23499	14040	127
7.0	61	40630	25720	14910	165

Figure 9.5.1 :- Fitzroy stopbank and low lying housing behind the New Plymouth Walkway.

Map 9.5.6 shows that, close to the East End Reserve, erosion can be seen to impinge on the properties that have been highlighted in blue. These properties are currently protected by a stopbank as can be seen in Figure 9.5.1

Land loss due to erosion has the potential to expose low lying areas to inundation. Once the 3D model of erosion has removed any barriers that may exist, inundation can then be determined. For Fitzroy the losses to land and property can be seen in Map 9.5.6 and the associated values of areas and property loss determined in Tables 9.5.4 and 9.5.5.

The above tables show the loss of land and property (CV) ranging from $36,800 per ha to $510,000 per ha the higher figure being the worst case scenario. The cost and loss of just the housing stock has been calculated and appears in Table 9.5.6. These tables show some 11 houses could be affected by erosion when historic erosion rates are used.

Included in the figures of Table 9.5.5 but missing from the housing list, are the buildings which make up the Fitzroy Camping Grounds, Surf Club and those that are within the East End Reserve. This omission is due to the way the value of an area is spread over many properties in the NPDC property database.

9.5.6 Fitzroy Runup

Runup is based on supplied hindcast data for a five year period, the results for Fitzroy being shown in Appendix G for positions 20,21,22,23 and 24

The foreshore slope has been calculated from data provided by the ESRI's 3D Analyst profile tool. This tool provided not only visual representation of the foreshore but x,y coordinates of the profile, so foreshore slope could be calculated.

The five values created by Stockdon's formula have been averaged to provide a single figure of 0.82m for setup and 1.38 for runup.

9.5.7 Fitzroy Model Check

To check that the model is showing elevations and positions correctly the data was checked against the Trig Stations located along the New Plymouth Coast in terms of position and elevation. Trig B1B2 Fitzroy was checked against data contained in LINZ Trig Database and was found to be found to be correct as far as the X and Y co-ordinates were concerned. For elevation, the 3D Model gave a reading of 30.8m for that point, compared to 31m expected. This is acceptable given the ± 0.25m accuracy of the model,.

9.5.8 Fitzroy – Discussion of Findings

With so many key recreational facilities for New Plymouth being in the Fitzroy area it is concerning that even a modest rise in sea level will cause the loss of these facilities. A 3.5m rise in sea level will see the loss of the East End Reserve and see properties up the Te Henui Stream start to be affected, including the Sewage Pumping Station.

The mouth of the Waiwhakaiho River will be inundated at 2.5m and whilst there is no property threatened, a large stretch of the New Plymouth Walkway will be underwater. At Lake Rotomanu (4.0m above sea level), The Te Rewa Rewa Bridge and areas up the Waiwhakaiho will be inundated creating various scenarios, depending on the extent of the sea level rise.
Most of the inundation modelled around the Te Henui comes not from a direct assault from the Sea (at lower levels of sea rise) but from the rise in the river level and spilling over onto the land. Once the levels reach 4.0 metres the current armoured coast will be breached, exposing the area to direct assault from the sea and all the issues that will come from exposing the area to the forces of setup and runup.

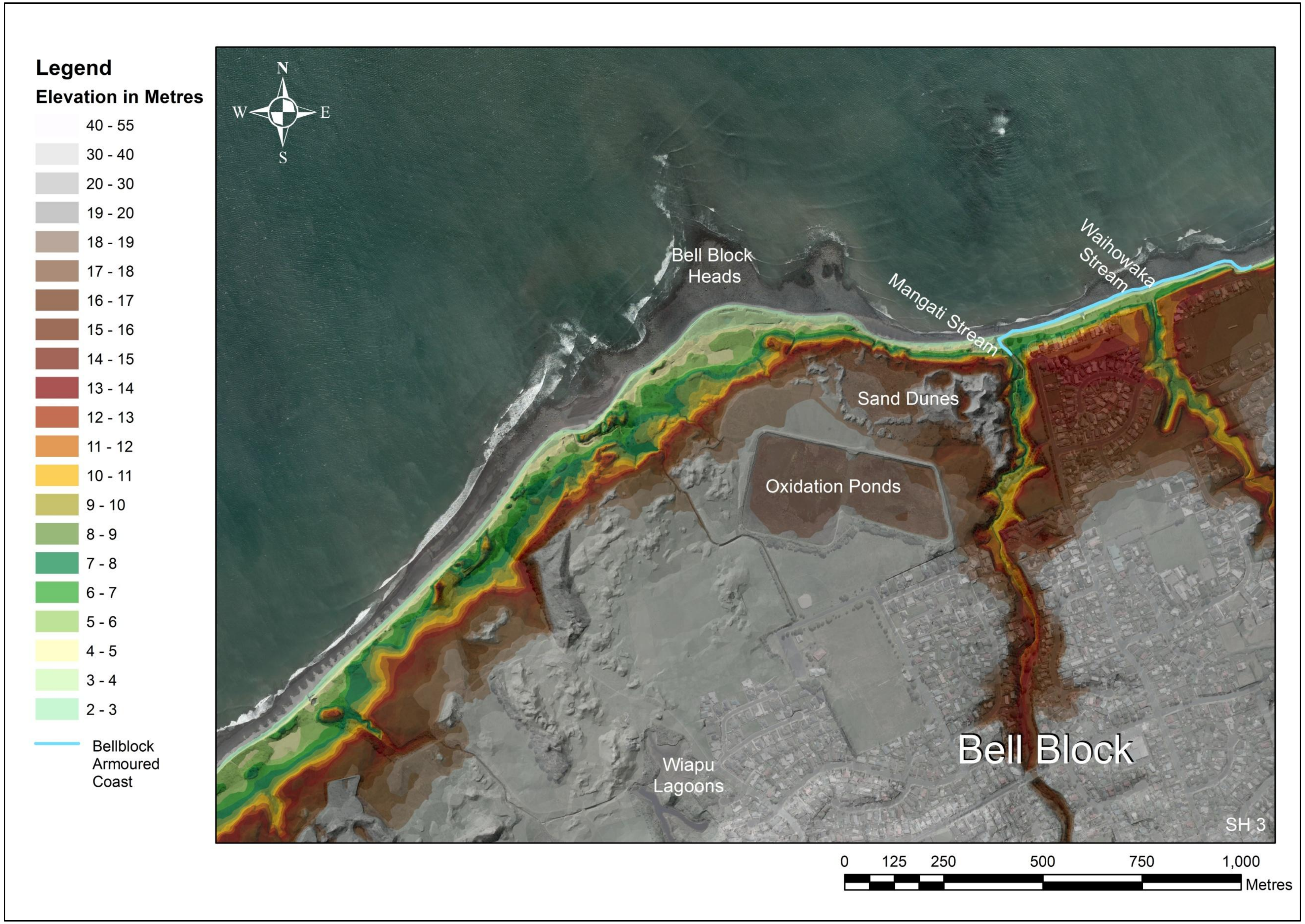
Erosion around the mouth of the Te Henui Stream has been modelled to be zero whilst the rest of the Fitzroy coast has been set back 50.5m, exposing expensive seaside dwellings to the sea. At the mouth of the Waiwhakaiho River, a rising sea will assault the foundations of the Te Rewa Rewa Bridge, obliterate the New Plymouth Walkway and threaten what remains of the Te Rewa Rewa Pa.

Like other areas exposed to the potential of erosion and inundation due to sea rise, the local Council will need to continue to protect homes and the infrastructure that the peoples of New Plymouth have come to take for granted. The New Plymouth District Council will have some issues to face, and it will require strategic planning to cope with changes affecting homes, businesses and infrastructure due to potential erosion and inundation from a sea level rise"

9.6 Bell Block Findings

Map 9.6.1 :- Bell Block Location Map.

Map 9.6.2 :- Bell Block Elevation Map with Locations.



9.6.1 Bell Block Location

Bellblock is a satellite township of some 4,065 persons and 1,461 dwellings according to the 2006 census (Statistics NZ, 2006). Most of the inhabitants either work in an industrial area on the southern side of SH3 or commute to work in New Plymouth, the centre of which is 6km to the west. Waitara is 9km to the north-east. Bell Block has small number of dwellings near the coast, where coastal work has been done to reduce erosion.

The Mangati Stream runs through the heart of Bell Block and exits to the sea north of the coastal settlement. To the west of the Mangati Stream are sand dunes and the remains of the old Bell Block sewage scheme.

9.6.2 Bell Block Elevation

Bell Block sits on a relatively flat area some 20+ metres above sea level, the two streams which dissect Bell Block are the Mangati and Waihowaka streams. Both streams disrupt travel from one side of the township with only a small number of crossing points. Between the two streams the township slopes gradually to the sea when it drops suddenly to the coast.

There are two major low lying areas, one at the apex of this study area, the Bell Block heads, the other to the bottom left of the Elevation Map (9.6.2).

9.6.3 Threats to the Bell Block Shoreline

The major threat to Bell Block is through erosion of the western shoreline, west of the Bell Block Heads, which is currently eroding at a rate of 0.38m per annum. The north-eastern area, where housing is close to the shoreline, has been reinforced to protect the area from erosion.

The other threat is due to sea rise and potential inundation of low lying areas along the coast and at the mouths of the two streams which discharge into the sea. The housing is well elevated sitting some 10m above sea level.

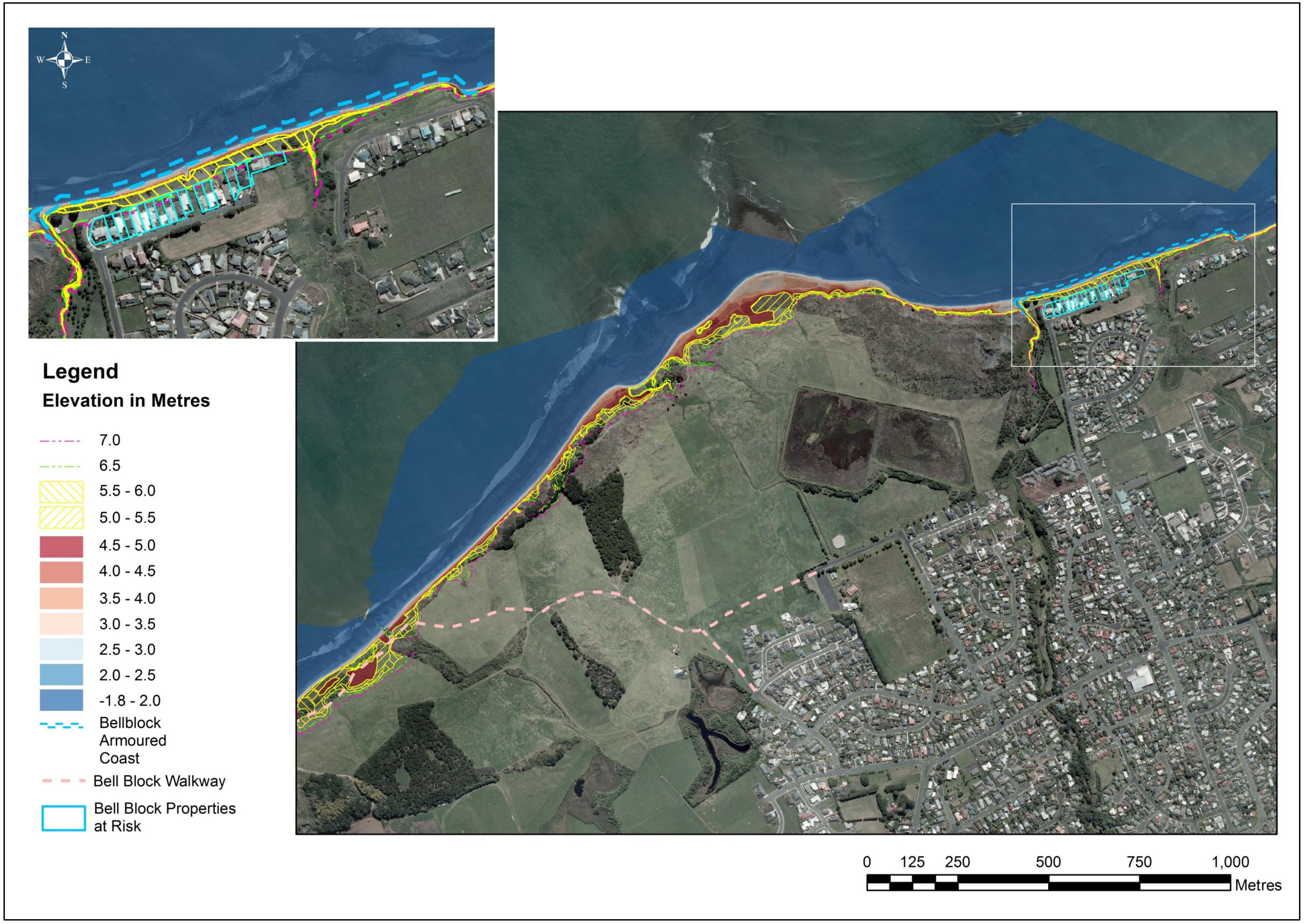
Table 9.6.1 :- Build up of highest sea levels given different conditions and extreme events for Bell Block shoreline.

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level	2.02	2.98	2.98	2.98
Setup 1:50 year level			0.79	0.79
Runup[ø] 1:50 year level	-	-	-	1.34
Max Storm Level	2.02	2.98	3.77	5.11
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.27	5.61
Total Level (1.0)	3.02	4.98	4.77	6.11
Total Level (1.5)	3.52	4.48	5.27	6.61
Total Level (2.0)	4.02	4.98	5.77	7.11

*Converted to land elevation

Table 9.6.1 uses the various extreme components namely high tide, storm surge, runup and the expected levels of sea rise (RSL) that make up the various extreme sea levels that will be investigated. All the criteria are common to the New Plymouth coastline, with the exception of runup, which is affected by local conditions.

Map 9.6.3. :- Bellblock – Rise in Sea Level with the current shoreline when inundation is projected for the year 2100.



9.6.4 Inundation through a Rise in Sea Level and its effect on the Bell Block Property and Population in the year 2100 without the effect of erosion

The rise in sea level along the Bell Block coast will have little effect on the majority of the Bell Block population. The area that is affected is protected by a sea wall to stop erosion, but not a rising sea, which will see some of the houses have the front of their properties inundated when the more extreme events occur. The nearest house properties will start to be inundated at a sea level of 6m, but because the properties rise sharply to a 10m to 12m level, the actual houses may not be touched. The effect of the inundation that takes place on first the property and then the houses is shown in Tables 9.6.2 and 9.6.3

Table 9.6.2 :- Bellblock - Rise in Sea Level with the current shoreline and its effect on Property east of the Mangati Stream.

Sea Level in Metres with the current shoreline and its effect on Property east of the Mangati Stream	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0
5	1	345	330	1.087	317.4	303.6	13.8
5.5	2	475	460	1.25	380.0	368.0	12.0
6	8	3393	2606	1.96	1731.1	1329.6	401.5
6.5	21	12023	8471	2.63	4571.5	3220.9	1350.6
7	23	13168	9211	4.28	3076.6	2152.1	924.5

Table 9.6.3:- Bellblock - Rise in Sea Level with the current shoreline and its effect on Houses east of the Mangati Stream.

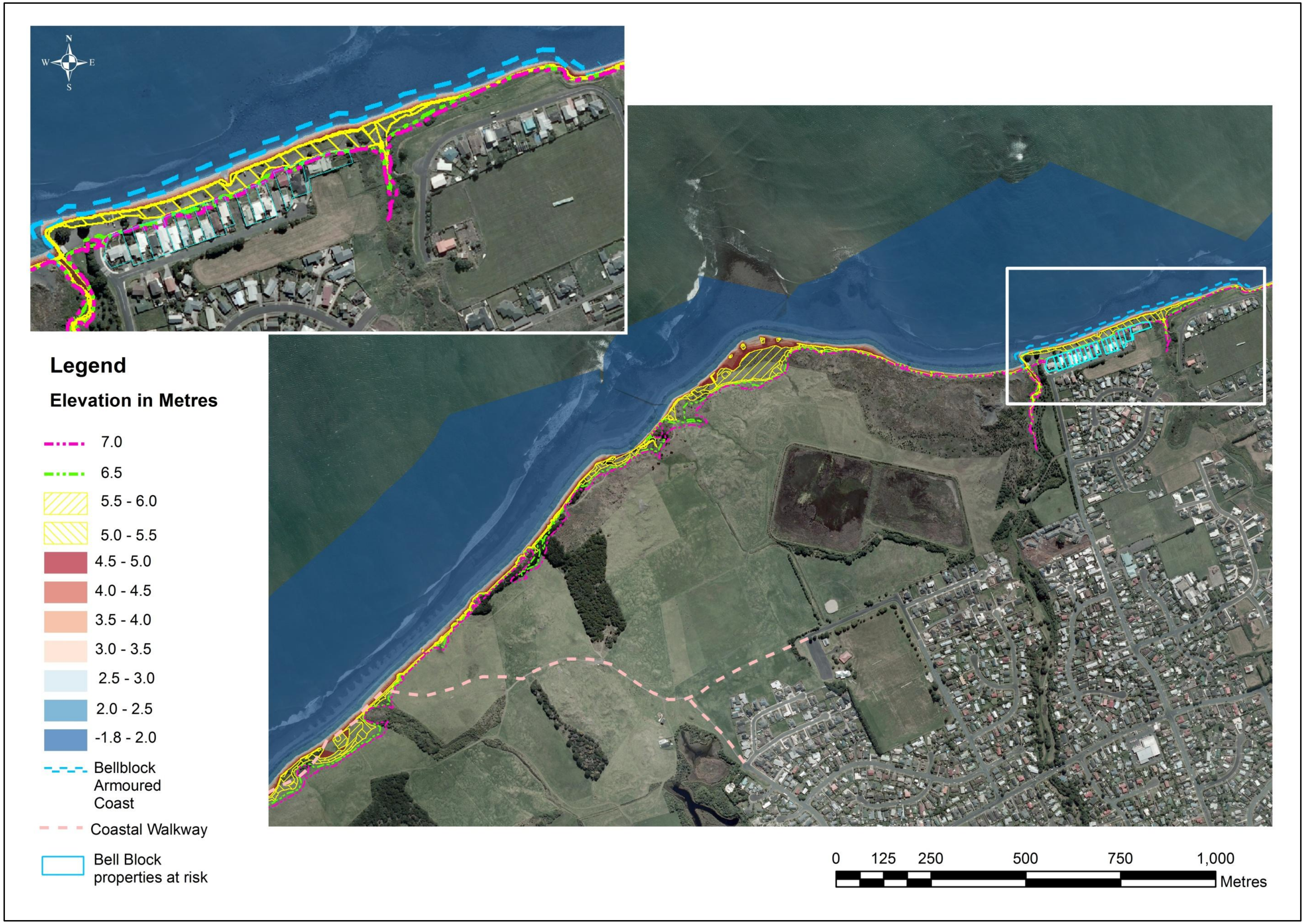
Sea Level in Metres with the current shoreline and its effect on Houses east of the Mangati Stream	Houses	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)	Value per House Property
2	0	0	0	0	0.0	0.0	0.0	0
2.5	0	0	0	0	0.0	0.0	0.0	0
3	0	0	0	0	0.0	0.0	0.0	0
4	0	0	0	0	0.0	0.0	0.0	0
4.5	0	0	0	0	0.0	0.0	0.0	0
5	0	0	0	0	0.0	0.0	0.0	0
5.5	0	0	0	0	0.0	0.0	0.0	0
6	3	2090	1330	0.219	9543.4	6073.1	3470.3	696.7
6.5	16	10720	7195	0.887	12085.7	8111.6	3974.1	670.0
7	17	11570	7640	0.937	12347.9	8153.7	4194.2	680.6

Table 9.6.4 :- Bellblock, Shoreline west of the Mangati Stream –The value of land affected through inundation by a Rise in Sea Level with the current shoreline.

Sea Level in Metres with the current shoreline and its effect on the Shoreline west of the Mangati Stream	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)	Inundated Area	Capital Value ($,000) 0	Land Value ($,000)	Improved Value ($,000)
Total Value	2	5900	5650	152.08	38.8	37.2	1.6	0.0			
2.5	0	0	0	0	0	0	0	0.9	36.7	35.1	1.6
3	0	0	0	0	0	0	0	1.9	72.5	69.5	3.1
3.5	0	0	0	0	0	0	0	3.6	137.7	131.9	5.8
4	0	0	0	0	0	0	0	5.0	194.0	185.8	8.2
4.5	0	0	0	0	0	0	0	6.4	249.1	238.5	10.6
5	0	0	0	0	0	0	0	8.4	327.0	313.2	13.9
5.5	0	0	0	0	0	0	0	9.9	384.1	367.8	16.3
6	0	0	0	0	0	0	0	12.1	469.0	449.2	19.9
6.5	0	0	0	0	0	0	0	16.1	624.6	598.1	26.5
7	0	0	0	0	0	0	0	18.6	720.4	689.9	30.5

To the east of the Mangati Stream is open farmland. The affect of inundation on this area is shown in Table 9.6.4. As there are only two property records from which to derive values, the inundated area has been prorated to derive a calculated value.

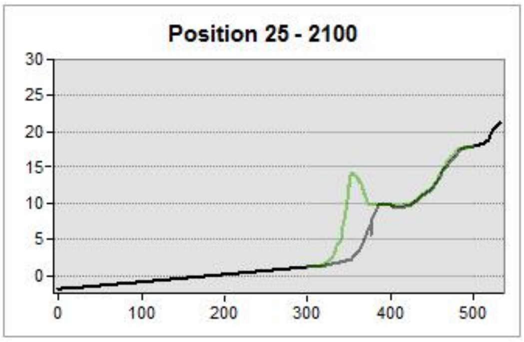
Map 9.6.4. :- Bellblock – Rise in Sea Level with an eroded shoreline when inundation is projected for the year 2100. Erosion is calculated at a rate of 0.38 per annum. Inundation includes Storm Surge, Setup and Runup and an increasing RSL of 0.5m to 2.0m.



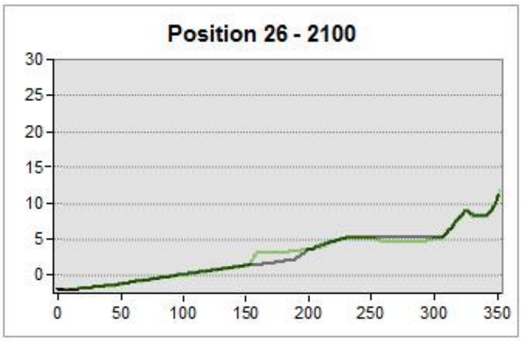
9.6.5 Erosion of the Bell Block Shoreline

Along a good portion of the Bell Block coast there is a walkway which will be affected by a rising sea level. This walkway is expected to become part of the New Plymouth Coastal Walkway and join Bellblock and New Plymouth.

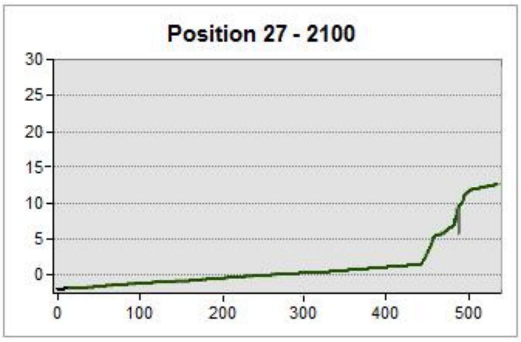
The profiles below have been taken from Maps 9.6.3 and 9.6.4 in positions 25,26 and 27 (refer Map 9.6.1). to show the effect of erosion and sites of potential inundation.



Position 25 on Map 9.6.1 is the cross section (profile) of the foreshore at that location. The green line is the current profile whilst the black line is the expected profile of the shoreline in 2100 should the rate of erosion continue at the historic rate of 0.38m per annum. The Bush, at the edge of the shoreline, is affected by a rising sea and erosion.



Position 26 shows little change, as the erosion in 2100 will see only the low lying area at the 150m mark removed. The remaining profile is little changed. This area is the most exposed, and subjected to inundation.



Position 27, in front of the armoured wall, should remain unchanged however in extreme circumstances at sea levels over 6m inundation will occur. The Mangati Stream will be affected by higher sea levels and this could be a concern if the stream banks start to erode.

To the west of the Mangati Stream is a large expanse of coast that will be exposed to both erosion and inundation. Erosion of the unprotected coast is most noticeable at the most northern point of the Bell Block study area, the Bell Block Heads. Based on historic rates of erosion, there would be a 33 metre loss of shoreline and this would equate to 8.3ha approximately, $309,100 of land and improvements of $137,000, given average land values in the area. Refer Table 9.6.5.

Table 9.6.5 :- Bell Block – The value of land and property lost to erosion by 2100 based on a retreat of 33 metres, west of the Mangati Stream.

Bellblock											
Property lost with an eroded shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV/Ha ($,000)	LV/Ha ($,000)	IV/Ha ($,000)	Eroded Area (ha)	CV ($,000)	LV ($,000)	IV ($,000)
Area Eroded	2	5900	5650	152	38.8	37.2	1.6	8.3	322.8	309.1	13.7
Length of Coast	2521.5m		83209	8.32							
Depth of Erosion	33										

Table 9.6.6 :- Bell Block – The value of land and property west of the Mangati Stream affected by inundation on an eroded shore,

Sea Level in Metres with an eroded shoreline and its effect on the shoreline west of the Mangeti Stream	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)	Inundated Area	Capital Value ($,000)	Land Value ($,000)	Improved Value ($,000)
Total Value	2	5900	5650	152.8	38.8	37.2	1.6	0.0			
2.5	0	0	0	0	0	0	0	3.5	133.8	128.2	5.7
3	0	0	0	0	0	0	0	4.2	164.5	157.5	7.0
3.5	0	0	0	0	0	0	0	5.0	194.8	186.5	8.3
4	0	0	0	0	0	0	0	5.8	225.0	215.5	9.5
4.5	0	0	0	0	0	0	0	6.8	263.4	252.3	11.2
5	0	0	0	0	0	0	0	7.9	307.3	294.2	13.0
5.5	0	0	0	0	0	0	0	8.9	343.7	329.2	14.6
6	0	0	0	0	0	0	0	11.0	426.4	408.3	18.1
6.5	0	0	0	0	0	0	0	14.2	549.3	526.1	23.3
7	0	0	0	0	0	0	0	16.1	624.2	597.8	26.4

Inundation of the rural coast covers basically the same area regardless of there being erosion or not. Inundation only begins at 2.0 metres and continues until the rise in sea level with storm surge, setup and runup reaches 7.0 metres. If the maximum areas inundated are taken from Tables 9.6.5 and Table 9.6.6 , 8.32ha and 16.1ha respectively and added together, the loss totals a land area 24 ha ($924,000).

9.6.6 Inundation through a rise in sea level and its effect on the Bell Block Population in the year 2100 considering the affects of erosion.

As in the scenario with no erosion, the rise in sea level along the Bell Block coast will have little effect on the bulk of the population of Bell Block, the area that would be affected is protected by a sea wall and the houses are well above the highest storm level of 7m, sitting at between 10 and 12 metres. However the distance between the two levels is less than 5m, so without doubt the houses would be affected in some manner.

9.6.7 Bell Block Setup / Runup

Setup and runup for the Bell Block foreshore has been calculated using Stockdon’s setup and runup formula for dissipative beaches and positions 25, 26, 27 from Appendix G. The results averaged out at 0.79m for setup and 1.34m for runup

9.6.8 Bell Block Ground Truthing of Model

Figure 9.6.1 :- Outlet of the Mangati Stream to the ocean. Taken by the Author at High Tide.

Two methods are available for the checking of the 3d Model against real world results they are:

The checking of the Bell Block trig station B1AP stated on the Topographic map at 54 metres the model reported a height of 53.8 which is satisfactory given the accuracy of the contours ie ± 0.25m.

Figure 9.6.2 :- Aerial photograph of the same area as Figure 9.5.1.

The other method is the checking of the high tide level at the Mangati Stream.

The red dot in Figure 9.6.2 is an estimate of where the mean level of the high tide is. The elevation of 2.228m verses a predicted tide level of 3.9m – 1.815m = 2.085 metres, to adjust for the use of the land datum. A difference of 2.228 - 2.085 = 0.143m, which is well within the accuracy stated above.

9.6.9 Bell Block – Discussion of Findings

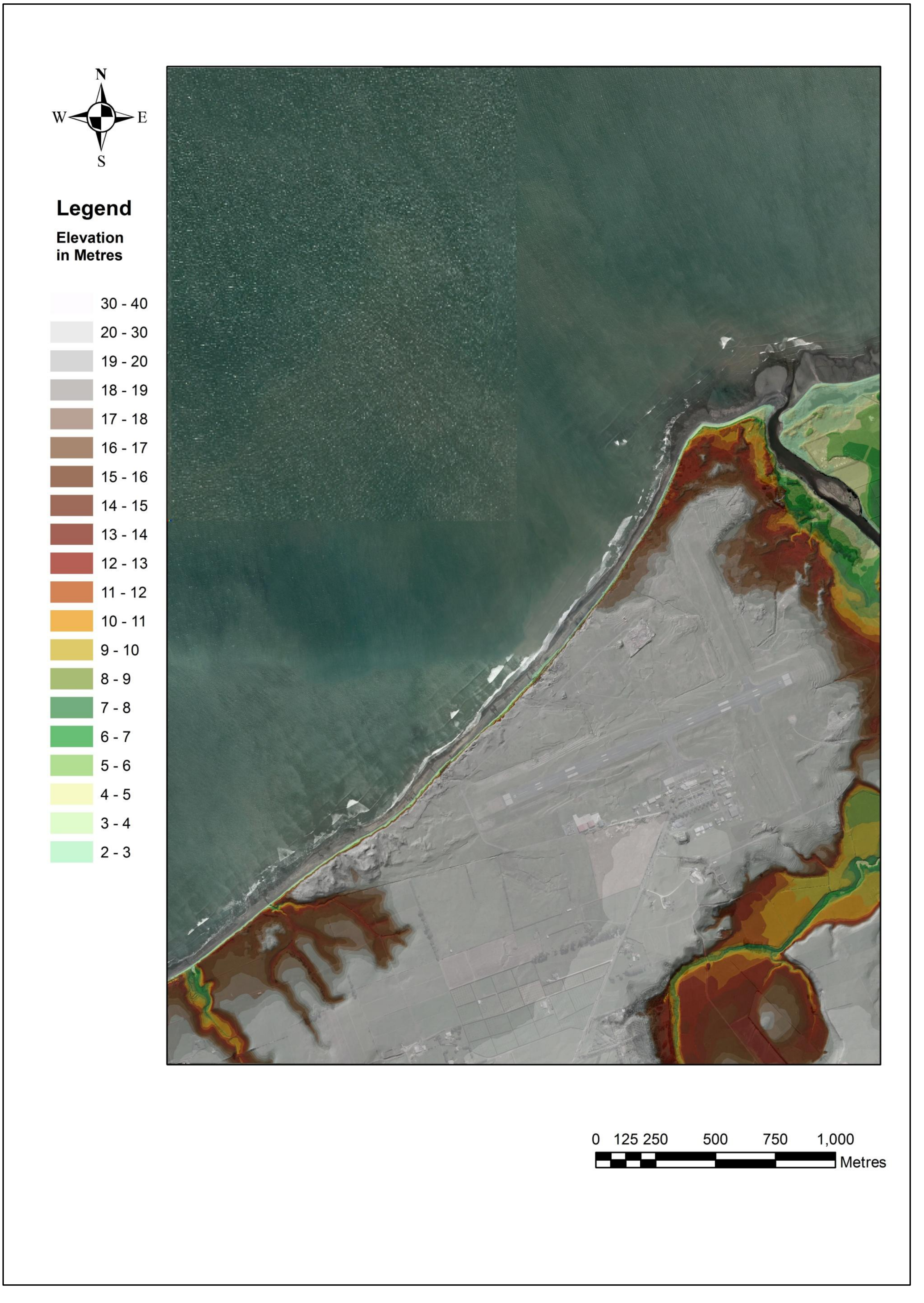
With the majority of the Bell Block population living more than 400 metres from the shoreline, there is low risk to most homes. But within 400 metres there are 154 dwellings and 36 dwellings of those are within 100 metres of the shoreline. Those 36 dwellings have a capital value of $20 million at 2011 values.

The only threats facing the Bell Block area are from erosion and inundation of coastal land in the lower lying areas. The potential loss of some of the Coastal Walkway, to the west of Bell Block, is also an issue.

9.7 Airport Findings

Map 9.7.1 :- Airport Study Area showing locations.

Map 9.7.2 :- Airport Elevations.



9.7.1 Location

The New Plymouth Airport is the major airport used to service the Taranaki area with its population of some 100,000 inhabitants, and is located on the coast, two kilometres to the east of Bell Block, north of State Highway 3, and west of the Waiongana Stream. The surrounding area is flat.

The Airport has a sealed runway running east to west and a grass runway running north to south which is less frequently used, and then by light aircraft. The western end of the sealed runway is approximately 250m from the edge of the coastal cliff with the northern edge of the grass runway being 130m away from the sea cliff.

The Airport study area does not include the Waiongana Stream nor the eastern edge of Bell Block which are shown on the maps of the area.

9.7.2 Elevation

The study area (Airport) sits atop sea cliffs which rise some 15 to 30 metres and gently rises toward the south and only descends to sea level at the mouth of the Waiongana Stream.

9.7.3 Threats to the Airport Shoreline

The major threat to the Airport is through erosion of the sea cliffs which are some 130 to 250 m from the sealed runway and less than 100 metres from the boundary of the CHZ . Other threats due to sea rise and potential inundation from river flooding do not exist due to the elevation of the Airport, it being some 15 to 30 metres above sea level.

9.7.4 Inundation through a Rise in Sea Level and its effect on the Airports Property and Population in the year 2100 without the affects of erosion

Table 9.7.1 uses the various extreme components namely high tide, storm surge, setup and runup and the expected levels of sea rise (RSL) that make up the various extreme sea levels. With the cliffs being so high inundation is not a problem even with the effects of overtopping being considered. It is setup / runup against the cliffs that is to be considered as it is one of the key factors in erosion.

Table 9.7.1 :- Expected extreme sea level projection for 2100 with the various elements shown that make up sea level (RSL is in Brackets).

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level	2.02	2.98	2.98	2.98
Setup 1:50 year level			0.77	0.77
Runup⁸ 1:50 year level	-	-	-	1.30
Max Storm Level	2.02	2.98	3.75	5.05
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.25	5.55
Total Level (1.0)	3.02	4.98	4.75	6.05
Total Level (1.5)	3.52	4.48	5.25	6.55
Total Level (2.0)	4.02	4.98	5.75	7.05

*Converted to land elevation

The values in Table 9.7.1 are projections for the year 2100 specific to the Airport. Runup is at its normal value. The level is calculated for a 1 in 50 year value for Positions 29, 30, 31 from Appendix G to give a value of 0.77 for setup and 1.30 m for runup using Stockdon's formula.

9.7.5 Airport Erosion Actual

The historic rate of erosion for the airport shoreline is between 0.32m to 0.96m per annum (refer Appendix H), although the latest study done for the TRC (2009) gives a rate of between 0.32m to 0.51m per annum and for Gibb, a value for the Coastal Hazard Zone of 0.6m (See Chapter 5.10 and Table 5.11.1). For the purposes of this study I will compare the rates used in the TRC report of 2009.

a. At the lower erosion rate of 0.51m per annum until the year 2100, in 87 years time, the shore retreat will have moved 44.37m inland (rounded up to 45m), thus bringing the paved runway to within 175m of the cliff-faced shoreline. It is currently 220m from the cliff. The grassed, north/south runway which is currently 130m from the edge, will be within 85m of the shoreline.

b. If we take the higher rate of 0.96m per annum (83m of retreat) and apply it to the runway edge scenario, the paved runway moves to within 137 m, and the grassed runway to within 47m of the cliff faced shoreline.

As we know that the rate of erosion is due to increase as storms increase in intensity and frequency, then this should be of some concern. In Table 5.11.1 the CHZ for the Airport in 2009 was calculated as 70m.

9.7.6 Rise in Sea Level and its effect on the Airport Population and Property in the year 2100 when an erosion retreat of 45m is considered

The Airport coast is all cliff and as such no inundation is visible within the study area once erosion has been taken into consideration.

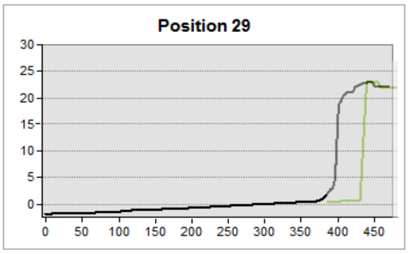
The loss of land and improvements such as Buildings, Fences and the like are a real consequence of the effects of erosion. Whilst the loss of cliff face on the Airport comes to some 16.9ha the value of that land can be prorated as $421,000 of land Value and $53,000 of improvements. (Refer Table 9.7.2).

The Meshblocks which cover the study area are MB1562601 and MB1562602 (partially covers the area) show a total population of 144 residing in 51 dwellings. All the dwellings and hence population are to the south of the Airport Terminal and closer to State Highway 3 and not affected by either sea rise or inundation.

Table 9.7.2 :- Area of land lost to erosion at a rate of 0.51 metres per annum, projected for the year 2100.

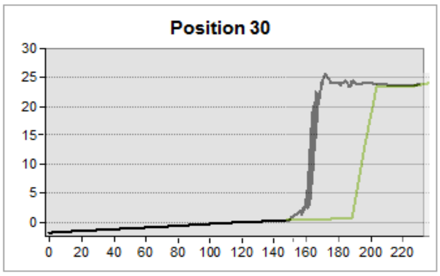
Rise in Sea Level with an eroded shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV/Ha ($,000)	LV/Ha ($,000)	IV/Ha ($,000)	Eroded Area (ha)	CV ($,000)	LV ($,000)	IV ($,000)
Value of land effected	4	257	228	9.15	28.1	24.9	3.2	16.9	474.7	421.1	53.6
Length of Coast	3760		169200	16.9							
Depth of Erosion	45										

The following graphics, positions 29 to 31, when viewed in conjunction with Map 9.7.3 shows the profiles of the beach and cliffs. The Green line is the 2100 erosion limit.



Position 30s graphic shows the effect of a cliff which is in a state of collapse and the inability of the contours, from which the 3D model was constructed, to make sense of the sudden variations in height. (Refer Figure 9.7.1).

Position 31s graphic shows the cliffs decreasing in height as they get closer to the Waiongana River.



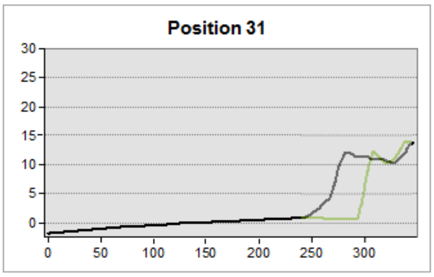
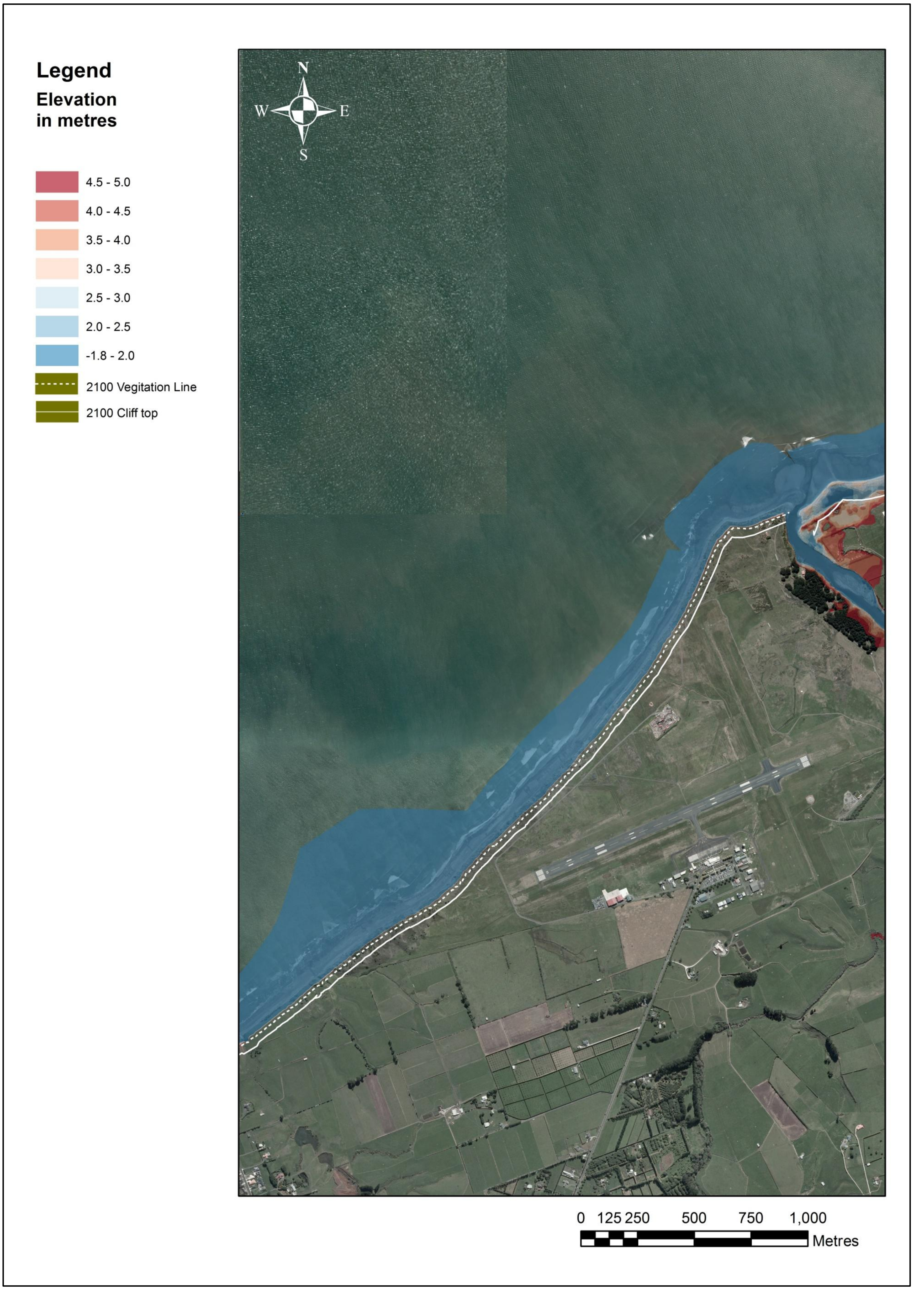


Figure 9.7.1 :- Aerial photograph showing a close up of the Airport cliff breaking up. The elevation above sea level at this point is 10.8m. Note the rough shoreline on the beach and in the surf.

Map 9.7.3 :- Airport erosion limit for 2100 based on 0.51m per annum and the affect of Inundation.



9.7.7 Airport Setup / Runup

Setup and runup for the Airport foreshore has been calculated using Stockdon's setup and runup formula for dissipative beaches and positions 29,30 and 31 from Appendix G. at 0.77m for setup and 1.30m for runup using Stocktons calculation .

9.7.8 Airport Ground Truthing of Model

There was no ground truthing undertaken for the Airport TIN model.

9.7.9 Airport – Discussion of Findings

The Airport study area has little to worry about as far as inundation of the area is concerned. The population and dwellings are well away from the coast and therefore at no risk from either inundation or erosion however with a rising sea level and an increasing number of storms predicted, the historic rate of erosion, currently at 0.51 metres per annum, is likely to increase and move the cliffs closer to the runways by 2100, specifically the north / south runway. The highest rate of erosion measured to date, some 0.96 metres per annum will bring the cliffs to with 47m of the runway.

9.8 Brixton Findings

9.8.1 Location

Brixton is a small settlement that gives its name to the area between the Airport and Waitara. This coastal area has a sparse rural population as the area is all farmland. The Waiongana River is on the western boundary. On the eastern side is the township of Waitara which, whilst it appears on this map, is covered in the 'Waitara Findings'.

The Brixton Coast Study Area runs 2600m east of the Waiongana Stream and 310m west, there being some overlap with both the Airport and Waitara study areas. The area is largely rural with some forestry on the banks of the river and coastline. The study area includes 1200m inland from the shore, to enable the effects of tides on the Waiongana Stream to be assessed. At the mouth of the stream there is a large collection of buildings, close to the river but well in from the coast. The same distance in but further east are farm sheds for raising stock.

The coastline in the centre of the study area mainly comprises cliffs, which rise from 7m in the west to 16m in the east. The shore at the base of the cliffs is predominately gravel, and a normal high tide often hits the base of the cliffs. Either side of the cliffed area are sandy beaches. Lagoons to the east of the Waiongana stream mouth are a Key Native Ecosystem and can be clearly seen in Map 9.8.1

The Waiongana Stream has its source in the foot hills of Mount Taranaki / Egmont.

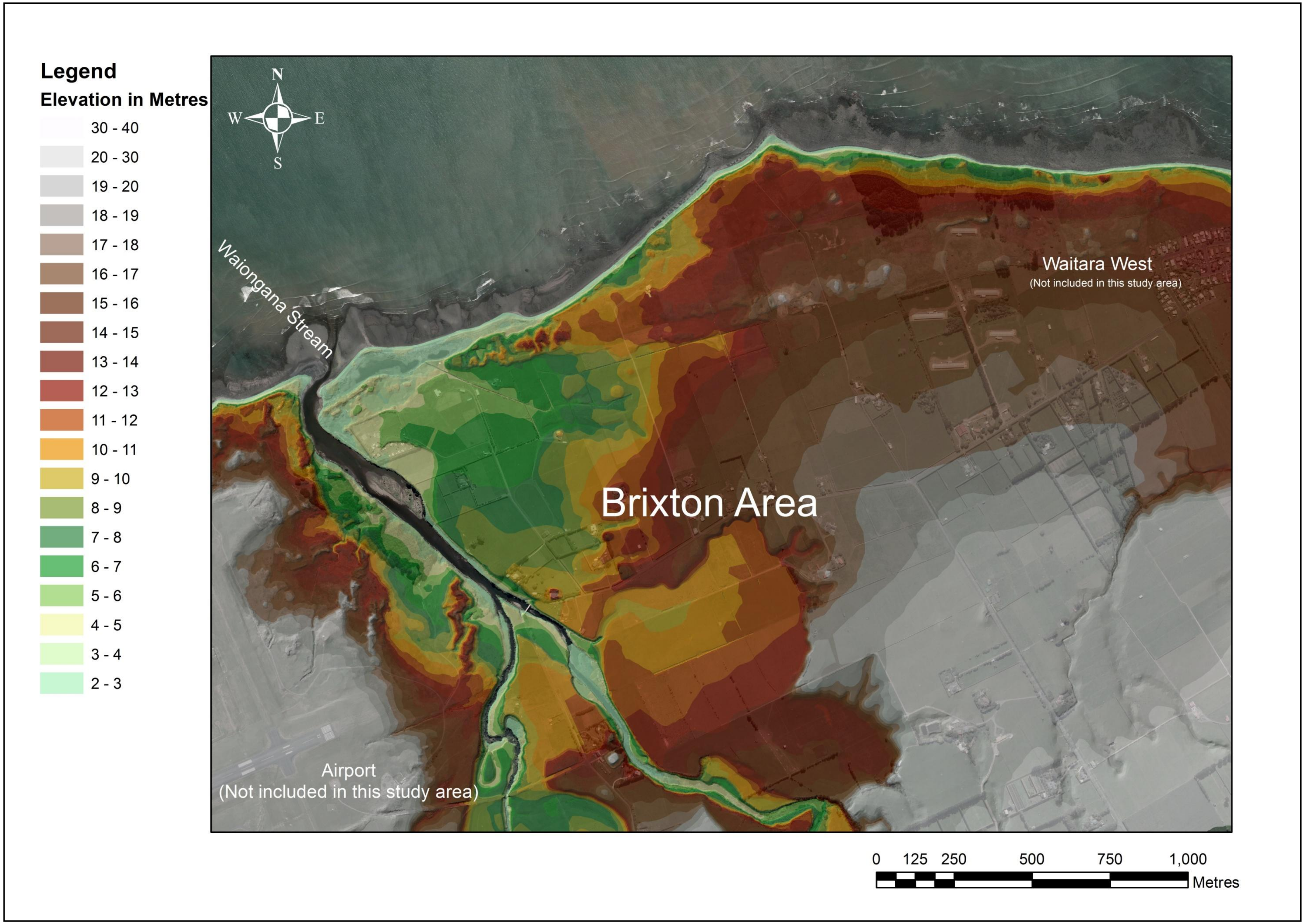
Although it cannot be seen, the Waitara to New Plymouth sewage line is planned to run through the Brixton study area and cross the Waiongana Steam where it “forks”. Prior to it reaching the Waiongana Stream, the sewage line gets very close to the Brixton cliffs.

9.8.2 Elevation

Map 9.8.2 shows the elevation of Brixton the majority of the area being over 10 to 12 metres, the only areas that fall into the inundation range being an area around the mouth of the Waiongana Stream and to the east. The lagoons on the eastern side of the stream are at 2.0m elevation, the same as a High Astronomical Tide.

Map 9.8.1 :- Brixton Location Map.

Map 9.8.2 :- Brixton Elevation Map with Locations.



9.8.3 Threats to the Brixton Shoreline

The major threats to the Brixton shoreline comes from

i. Erosion along the shoreline

ii. Inundation at the mouth of the Waiongana Stream due to RSL

iii. Inundation along the mouth of the river due to RSL

9.8.4 Inundation due to Rise in Sea Level in the Brixton Area in the year 2100

Table 9.8.1 uses the various extreme components namely high tide, storm surge, runup and the expected levels of sea rise (RSL) that make up the various extreme sea levels we will be investigating in this thesis. All the criteria are common to the other New Plymouth sites, with the exception of runup which is affected by local conditions.

Table 9.8.1 :- Expected extreme sea level projection for 2100 with the various elements shown that make up sea level (RSL is in Brackets).

*Converted to land elevation

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02	2.02*
Storm Surge $_{1:50\ year\ level}$		0.96	0.96	0.96
Storm Tide $_{1:50\ year\ level}$	2.02	2.98	2.98	2.98
Setup $_{1:50\ year\ level}$			0.78	0.78
Runup^{ø} $_{1:50\ year\ level}$	-	-	-	1.32
Max Storm Level	2.02	2.98	3.76	5.08
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.48	4.26	5.58
Total Level (1.0)	3.02	4.98	4.76	6.08
Total Level (1.5)	3.52	4.48	5.26	6.58
Total Level (2.0)	4.02	4.98	5.76	7.08

*Converted to land elevation

9.8.5 Inundation due to Rise in Sea Level and its effect on the Property and Population in the Brixton Area in the year 2100

Because the Brixton Study Area is sparsely populated and is largely protected by cliffs, there is little risk to the population. However there are a number of houses, which are near the banks of the Waiongana Stream and by the coast, that are at risk of being effected by inundation as well as the Key Native Ecosystem at the mouth of the stream and it associated wild life.

Table 9.8.2 :- Brixton - Value of properties inundated with the current shoreline.

Sea Level in Metres with the current shoreline	Houses	People	Capital Value @ $228K per Dwelling
2	0	0	0
2.5	0	0	0
3	0	0	0
3.5	0	0	0
4	1	3	228
4.5	1	3	228
5	3	9	684
5.5	3	9	684
6	3	9	684
6.5	5	14	1140
7	5	14	1140

Table 9.8.2. As these houses show as being part of large property blocks it is not possible to report on them as urban house properties have been reported on. As the Meshblock data for Brixton returned null data, because of the small number of people in the area, the population per dwelling ratio of 2.7 ,used in other areas, has been used in this table.

Table 9.8.3 :- Brixton - Value of properties inundated with the current shoreline.

Sea Level in Metres with the current shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CP / Ha	LV / Ha	IV / Ha ($,000)
2	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0
3	1	143	143	1.51	94.7	94.7	0.0
3.5	3	1603	1218	34.8	46.1	35.0	11.1
4	7	3478	2378	47.4	73.4	50.2	23.2
4.5	10	4259	3137	55.15	77.2	56.9	20.3
5	14	5692	4341	65.5	86.9	66.3	20.6
5.5	16	6902	5331	77.1	89.5	69.1	20.4
6	18	7892	5714	79.8	98.9	71.6	27.3
6.5	19	8842	6324	86.8	101.9	72.9	29.0
7	21	9612	6769	88.13	109.1	76.8	32.3

Meshblock Data has not been used as the entire Brixton study area is covered by one Meshblock.

9.8.6 Brixton Erosion Historic

The Brixton shoreline is calculated to erode at a rate of 0.57 meters per year, which at this rate, will place the coastline inland some 50 meters from its present position in the year 2100.

As previously stated most of the coast is cliff, with sandy beaches on either side of the Waiongana Stream. The beaches could experience greater rates of erosion than the cliffed areas.

The extent of the actual erosion can be seen in looking at Map 9.8.3 and in the close up images of that map. The major effect is the loss of plantation forest in Figures 9.8.1 and 9.8.2 and further encroachment of the shoreline at the mouth of the Waiongana Stream. The erosion at the mouth of the stream doesn't significantly increase the inundation as can be seen when Maps 9.8.4 and Maps 9.8.5 are compared.

Table 9.8.2:- Area of land lost to erosion at a rate of 0.57m per annum, projected for the year 2100.

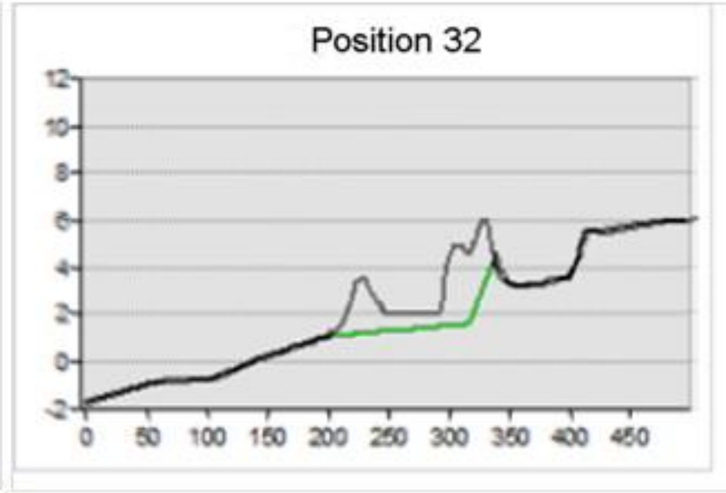
Sea Level in Metres with an eroded shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)	Eroded Area (ha)	Capital Value ($,000)	Land Value ($,000)	Improved Value ($,000)
Value of land affected	3	1603	1218	34.8	46.1	35.0	11.1	15.8	728	553	175
Length of Coast	3161			15.8							
Depth of Erosion	50										
Area m2	158050										

The area lost to erosion is calculated at being 15.8ha. The low lying area to the east of the Waiongana Stream is not included in this figure as the area that would be eroded is at the 2.0m water level, so it can be argued that there is no erosion to take place in this area, but only further up the beach. Refer Map 9.8.5.

The erosion at the river mouth places multiple structures at risk, not just from an eroding Waiongana Stream bank but also from inundation resulting from storms and sea rise.

Using Table 9.8.2 Land Values, the loss of land can be put at 15.8ha x $46.1K / Ha = $728K. However, the loss of the forested portion of the coastline could increase this figure.

Figure 9.8.1 :- Cross section (profile) of Map 9.8.3 and Map 9.8.2 taken at Position 32 which is at the mouth of the Waiongana Stream.



Position 32 has been taken at the mouth of the Waiongana Stream where lagoons have formed. The top-most line is the original profile of the shoreline, the bottom line (green), the profile after the TIN had been edited to simulate how the coast will appear in 2100. It should be noted that there is an increase in the erosion offset i.e. greater than 50m, due to the low lying nature of the foreshore. The affect of the erosion is to remove some of the protection from setup and runup for areas further inland.

9.8.7 Inundation due to a Rise in Sea Level and its effect on the Brixton population and properties in the year 2100, taking erosion into account

Table 9.8.4 :- Brixton – Houses and people affected by inundation with an eroded shoreline.

Sea Level in Metres with the current shoreline	Houses	People	Capital Value @ $228K per Dwelling
2	0	0	0
2.5	0	0	0
3	0	0	0
3.5	0	0	0
4	1	3	228
4.5	1	3	228
5	3	9	684
5.5	3	9	684
6	3	9	684
6.5	5	14	1140
7	5	14	1140

Due to the rural nature of Brixton, the properties are large, in most cases the inundated areas are a small portion of the total property area. A house may be included in the property value but be well beyond the inundation area, so a value including a house in the inundation would be misleading. Table 9.8.5 shows an increase in capital values as the sea level rises. Whilst this could be explained away by the fact that more buildings are affected, there is also an increase in land values per hectare. In short the further the property is from either the sea or the Waiongana Stream the more valuable it becomes.

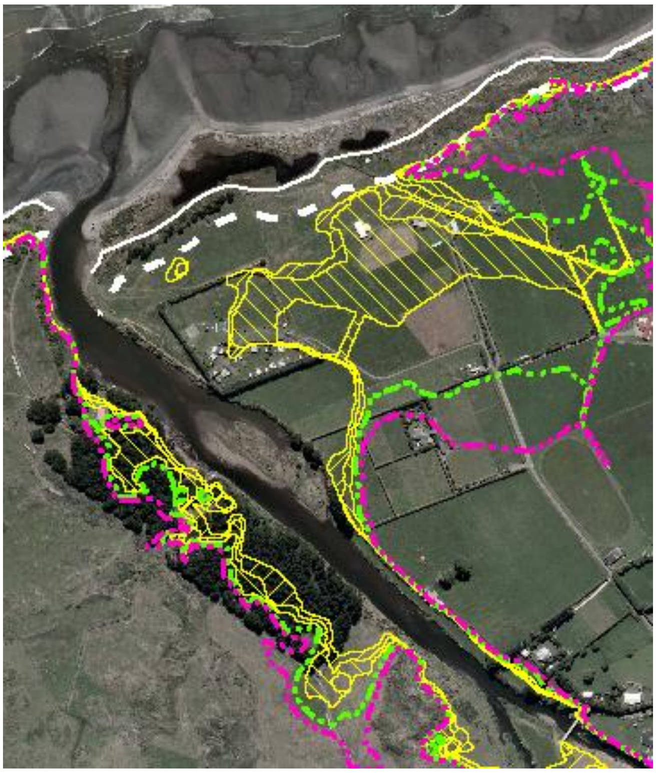
Table 9.8.5 :- Brixton - Value of properties inundated with an eroded shoreline.

Sea Level in Metres with an eroded shoreline	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0.0	0.0	
2.5	0	0	0	0	0.0	0.0	0.0
3	1	143	143	1.51	94.7	94.7	0.0
3.5	3	1603	1218	34.8	46.1	35.0	11.1
4	5	2163	1678	39.35	55.0	42.6	12.3
4.5	7	3158	2408	45.36	69.6	53.1	16.5
5	11	4188	3206	53.87	77.7	59.5	18.2
5.5	12	5007	3656	60.69	82.5	60.2	22.3
6	14	6217	4331	65.28	95.2	66.3	28.9
6.5	16	7497	5256	76.75	97.7	68.5	29.2
7	19	8683	6116	80.55	107.8	75.9	31.9

Figure 9.8.2 :- The effect of erosion will result in the loss of forest.

Figure 9.8.2 shows the vegetation line as a solid white line whilst the area lost to erosion is shown as the white dotted line. The loss of land in this case will also mean a loss of the trees (not native bush). It is conceivable that the trees would be harvested long before any erosion had had a chance to inflict any commercial damage.

Figure 9.8.3 :- The mouth of the Waiongana Stream showing the inundation of Forrest, Foreshore, Farmland and Buildings. Note: The inundation levels 2m to 5m are not shown to give a better view of the affected area.

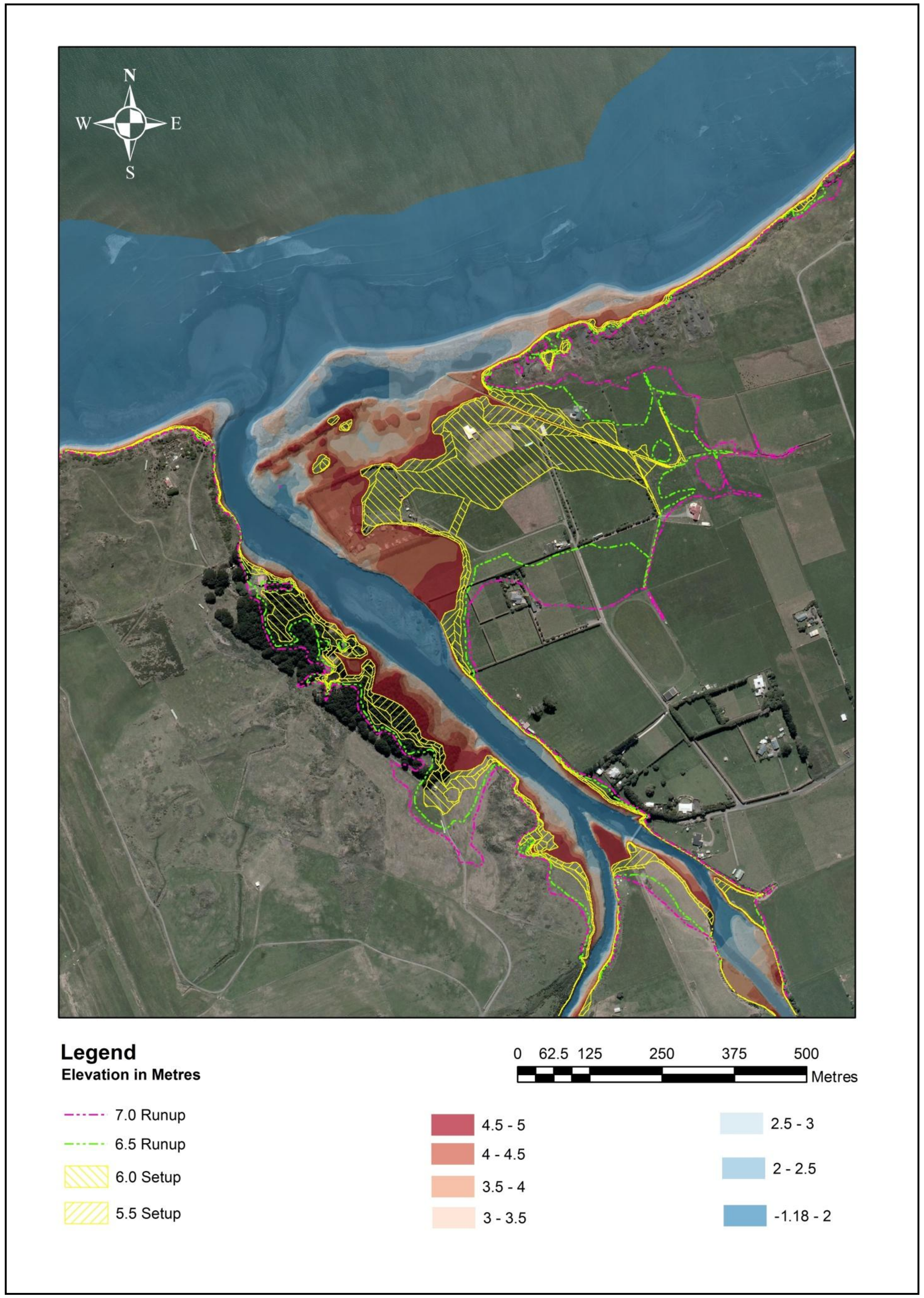


The Trees in Figure 9.8.3 are not under threat by erosion but by inundation as is the majority of the land shown in this image. The clusters of houses east of the Waiongana Stream mouth are the most susceptible to inundation especially with any high ground on the shoreline being removed due to erosion, hence removing any protection from the full force of the sea refer Figure 9.8.1 which shows the removal of that protection.

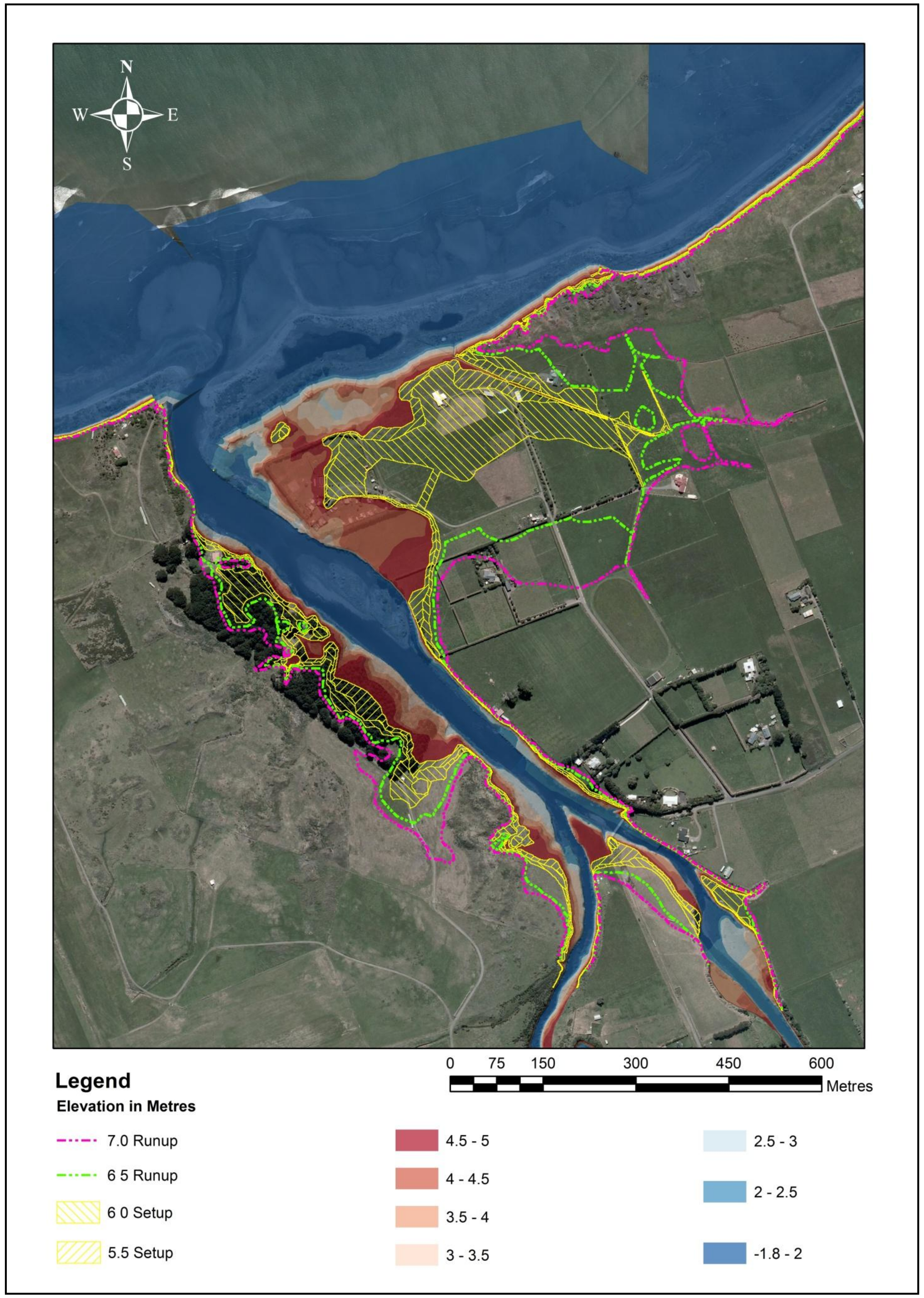
Map 9.8.3 shows that on its own sea rise is not an issue, other than at the mouth and up the Waiongana Stream, where Key Native Eco systems in the form of the lagoons will be destroyed. When Maps 9.8.4 and 9.8.5 are compared side by side, they show little or no change in inundation areas between the eroded and current shorelines. The difference in areas shown in Tables 9.8.3 and 9.8.5 is simply the effect of erosion, meaning that erosion has not opened up more areas to inundation but has removed some protection.

Map 9.8.3 :- Brixton –Still Water Level Inundation due to a Rise in Sea Level with an eroded shoreline at a rate of 0.54m is projected for the year 2100.

Map 9.8.4 :- Waiongana Steam Mouth – Rise in Sea Level with the current shoreline – when inundation is projected for the year 2100.



Map 9.8.5 :- Waiongana Steam Mouth – Rise in Sea Level with an eroded shoreline – when inundation is projected for the year 2100.



9.8.8 Brixton Runup

The setup and runup for the Brixton foreshore has been calculated using Stockton's calculation at 0.78m for setup and 1.32m for runup.

9.8.9 Brixton Ground Truthing of Model

There was no ground truthing undertaken for the Brixton 3D model

9.8.10 Brixton – Discussion of Finding.

Brixton is predominately a rural area with a few buildings, forests and farmland. The main effect of a rise in sea level is the loss of coastline through erosion and the flooding of the Waiongana Stream mouth causing a loss of a key native eco system, some forestry, farmland and buildings but of most concern are the houses and the families they contain. Because of the way the property information is collected, they are part of a larger block of land, so the value of the houses had to be estimated. The loss of land to erosion equates, at 2011 values, to $728,000; whilst the value of homes at risk due to inundation ranges from $228,000 to $1,140,000 depending on the severity of the flooding.

9.9 Waitara – Findings

9.9.1 Location

Waitara is located 16.4km to the east of New Plymouth, and the Brixton study area, and gets its name from the Waitara River. It has a population of 6,291 and consists of some 2,458 dwellings, according to the 2006 census.

The Waitara study area covers the area 1,500m to the west of the Waitara River to 2,000m to the east of the river, and as far south as the SH3 bridge. This covers most of the township and river.

Both sides of the river mouth have sandy beaches with the western beach having significant levels of driftwood above the spring high tide level. South of this beach is a road which services houses and a camping ground with cabins. The land drops away from the level of the road. There are a number of public buildings such as a toilet block, tennis court, boat ramp that make up the marine park. To the south is a ‘Significant Wetland’, a ‘Key Native Ecosystem’ (TRC, 2013). South of the Ecosystem and on the river bank is the Waste Water Works and old AFFCO meat processing plant which is currently in use. To the west of the camping grounds is a suburban development.

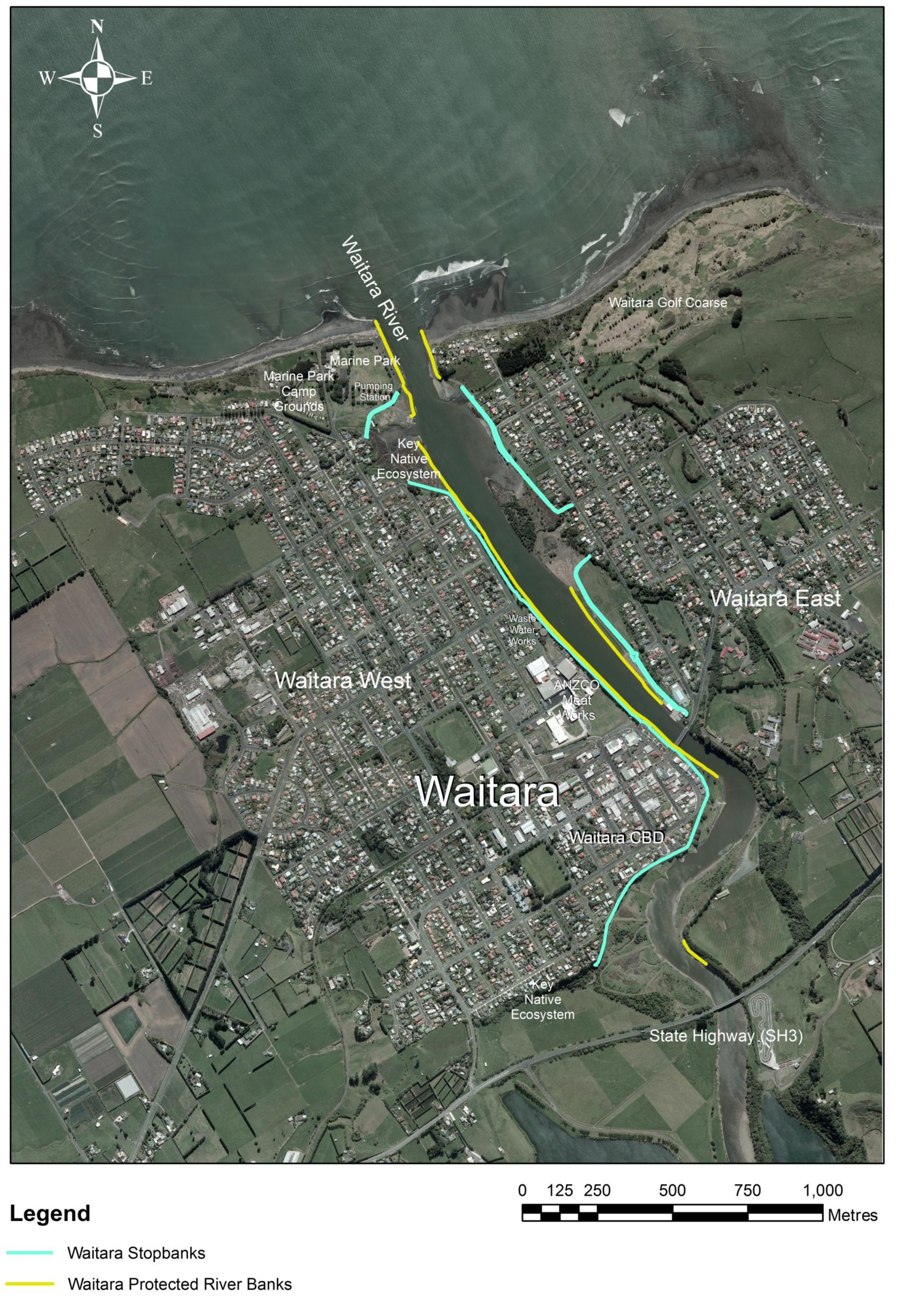
On the eastern side of the river are a number of buildings, including the Surf Club and boat ramp. Behind the shoreline, dunes and dwellings that are below the upper level of the stopbanks. Further east is the Waitara Golf Course that sits above a cliff rising some 13m from the beach.

In the past the Waitara River has been known to burst its banks, the last major event was in 1990; the cause of which was the realignment of SH 3 and the building of approaches to the new highway bridge. The constructions interfered with the flow of the river. The 1990 event saw some of the existing stop banks fail which later resulted in extensive work being undertaken to protect the town from further damage, should a rising river erode the stop banks, to such an extent that the town flood again (TRC, 1993). Prior to going to print there are plans to have the stopbanks raised yet again to protect the town from the river (Harper, 2013).

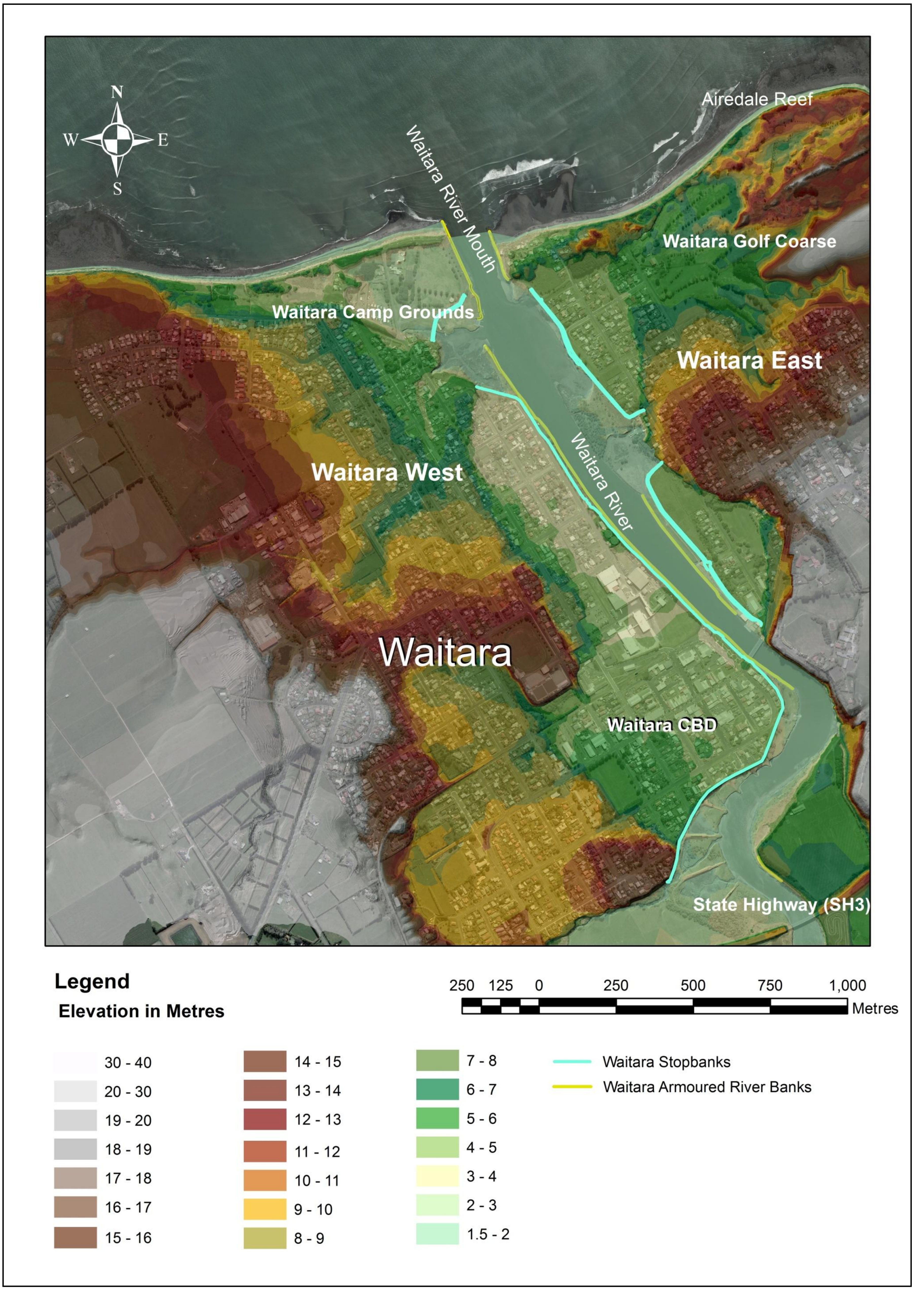
9.9.2 Elevation

The area around the Waitara River mouth is tidal. The Waitara River splits the town into two distinct areas, West Waitara and East Waitara. Both sides of the river are lined with stop banks ranging in height from 3m to 6m according to contour data supplied by the NPDC, with the higher stop banks being south of the town to protect it from river flooding. As can be seen in Map 9.9.2 there are areas behind the stop banks that are at the same or lower levels than the stop banks.

Map 9.9.1 :- Waitara Township and the Waitara River with the locations of Stop banks.



Map 9.9.2 :- Showing Waitara elevations in 1 metre increments in addition to stop banks and armoured river banks.



9.9.3 Threats to Waitara Township and Waitara River from Sea Rise

Threats to Waitara from the sea come in the form of;

- Erosion of the foreshore
- Inundation along the coast due to rising sea levels
- Inundation along the river due to rising sea levels

Table 9.9.1 shows the extreme components namely high tide, storm surge, runup and the expected levels of sea rise (RSL) that contribute to the various extreme sea levels and were investigated.

Table 9.9.1 :- Expected extreme sea level projection for 2100 with the various elements that contribute to sea level (RSL is in Brackets).

Factor	Sea Level Projections for 2100			
	Still Water Level	+Storm Surge	+ Setup	+ Runup
High Tide (HAT)	2.02*	2.02*	2.02*	2.02*
Storm Surge 1:50 year level		0.96	0.96	0.96
Storm Tide 1:50 year level		2.98	2.98	2.98
Setup 1:50 year level	-	-	0.69	0.69
Runup 1:50 year level	-	-	-	1.16
Max Storm Level		2.98	3.67	4.83
Rise in Sea Level	0.5 to 2.0 by 0.5m			
Total Level (0.5)	2.52	3.55	4.17	5.33
Total Level (1.0)	3.02	4.05	4.67	5.83
Total Level (1.5)	3.52	4.55	5.17	6.33
Total Level (2.0)	4.02	5.05	5.67	6.83

*Converted to land elevation

Map 9.9.3 :- Waitara – Inundation through Sea Rise Levels of 0.5m to 2.0m only for the current shoreline without Storm Surge or Runup.

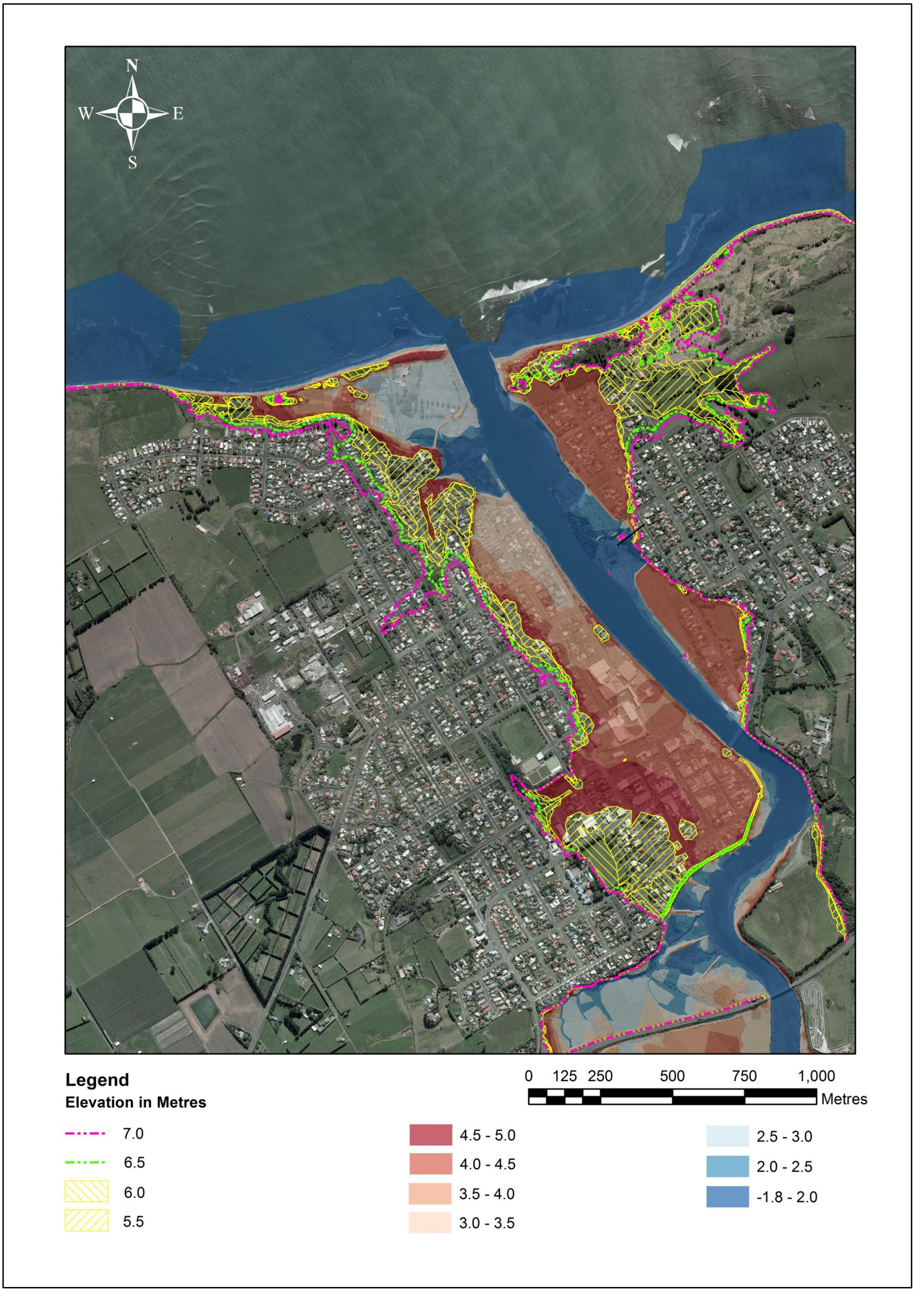
9.9.4 Rise in Sea Level only without extreme events

Map 9.9.3 shows that even the lowest level of sea rise, projected by the IPCC ,on the Waitara Township will cause some inundation. Initially on ground next to the river and within the confines of the stop banks then moving to inundate the marine park, marine park campgrounds, the pumping station and parts west of the river mouth. It is not until the SWL RSL reaches 1.5 metres (3.5m elevation that the township would become inundated. A 2.0m (4.0m elevation) SWL RSL, which is the full extent of the sea rise predicted for 2100, would engulf the western side of the river, including the CBD and some light industry. Fortunately the ‘Waste Water Works’ is on high ground and not touched by the rising water. The extent of property loss and the numbers of dwellings, people and property effected can be seen in Tables 9.9.2 and 9.9.3.

The use of the SWL RSL demonstrates the vulnerability of Waitara in its present state. The following analysis looks at the effects of the various storm elements which are present during a storm.

The IPCC predict that the rate of RSL will continue at 10mm per year past the year 2100, which means that by the year 2200 an additional metre (1000mm) should be added to the RSL.

Map 9.9.4 :- Waitara – Inundation for Sea Rise Levels of 0.5m to 2.0m for the current shoreline showing extreme Storm Surge, Setup and Runup.



9.9.5 Rise in Sea Level and its effect on Waitara Property and Population in the year 2100 with the shoreline remaining as it is currently

The intent of Table 9.9.2 is to show the impact, using the FEMA guidelines, of the inundation upon urban areas. The data comes from meshblock statistics, the most recent census data available is for 2006 and is for those areas inundated for specific levels of RSL and calculated in the following table. It should be noted that meshblock data is, but not always, the same as the population that is covered by the projected inundation area. This is because the meshblocks are quite large.

Table 9.9.2 :- Expected population and dwellings affected by Sea Level Rise with Strom Surge and Runup for various levels projected for 2100 and without any erosion. Refer Map 9.9.3 and Maps 9.9.4.

Sea Level in Metres Current Shoreline	Population	Average Age	Dwellings
2	0	0	0
2.5	0	0	0
3	162	43	69
3.5	327	44.5	156
4	465	26.5	204
4.5	975	28	426
5	1302	28.7	558
5.5	1953	29.1	798
6	2187	29.4	891
6.5	2187	29.4	891
7	2481	29.2	993

Data sourced from 2006 Census Data

In Tables 9.9.2 no dwellings or people are affected until the RSL reaches 3m. At this level it is only 1 meshblock that is affected, and then only partially, with the camping ground being underwater. By 3.5m the stopbanks have been breached which accounts for the four-fold jump in potentially affected dwellings.

Table 9.9.3 :- Capital and land values and land areas affected by Sea Level Rise projected for 2100 with Storm Surge and Runup for various levels and without any erosion.

Sea Level in Metres with the Current Shoreline - All Properties	Records	Total Capital Value ($,000)	Total Land ($,000)	Total Land (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0.0	0.0	0.0
2.5	12	1688	862	3.4	496.5	253.5	242.9
3	24	3730	2106	14.6	255.5	144.2	111.2
3.5	76	14356	6805	28.5	503.7	238.8	264.9
4	137	36011	15511	58.01	620.8	267.4	353.4
4.5	338	72162	30867	77.47	931.5	398.4	533.0
5	448	95863	40508	92.48	1036.6	438.0	598.6
5.5	538	114131	49977	144.4	790.4	346.1	444.3
6	608	126989	55708	150.1	846.0	371.1	474.9
6.5	652	134802	59272	153.77	876.6	385.5	491.2
7	719	148088	65580	160.69	921.6	408.1	513.5

Properties Values data from NPDC 2011

Table 9.9.4 :- Capital and land values and land areas affected by Sea Level Rise projected for 2100 with Storm Surge and Runup for various levels and without any erosion - for areas < 3000 m2.

Sea Level in Metres with the Current Shoreline - Properties < 3000 m2	Records	Total Capital Value ($,000)	Total Land Value ($,000)	Total Land Area (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0.0	0.0	0.0
2.5	3	422	225	0.35	124.1	66.2	57.9
3	9	1395	703	1.09	95.5	48.2	47.4
3.5	61	11551	5072	5.69	405.3	178.0	227.3
4	107	19754	8964	9.20	340.5	154.5	186.0
4.5	299	53077	22515	23.23	685.1	290.6	394.5
5	401	71499	30168	30.45	773.1	326.2	446.9
5.5	501	89672	38719	38.49	621.0	268.1	352.9
6	562	100276	43582	43.03	668.1	290.4	377.7
6.5	601	107221	46585	46.07	697.3	303.0	394.3
7	673	121214	53436	52.30	754.3	332.5	421.8

Properties Values data from NPDC 2011

The table above shows that if the shoreline stays as it is at the present, then with the smallest of sea rise increases, then several millions of dollars worth of damage could be done. This table includes a number of large properties of high value like the ANZCO meat processing works, (ANZCO is one of New Zealand's largest beef and lamb exporters with annual sales of $1.3 billion and more than 3000 staff worldwide) that could distort the above values. By removing these, by setting an area limit of 3000m^2, Table 9.9.4 was created. By restricting the property area, the effect on housing values can be seen.

Comparing the two Tables (9.9.3 and 9.9.4) reveals a significant difference in areas and values, when the larger areas (including the meat processing industry) are removed. The smaller areas decrease by 60% (90.5ha to 30.45ha) for a 5m Sea Level, whilst the number of records drops from 448 to 401, a 10% reduction.

9.9.6 Waitara Erosion Actual

The Waitara coast has recorded some of the highest rates of erosion along the New Plymouth Coast.

West Waitara has recorded an average erosion rate of 0.81m per year and East Waitara at 1.57m per year (refer Appendix H). Whilst this figure does vary between samplings, the above rates are reasonable and therefore form the basis of the investigation into the effect of actual erosion rates.

The extent of erosion was calculated using the equation explained in Chapter 11.3, then the TIN of the Waitara study area was modified using the TIN editing tools to cut away the coast that would be eroded. In some cases this exposed low lying ground that was behind the sea frontage, which in turn increased the potential area of flooding.

9.9.7 Rise in Sea Level projected to the year 2100 and its effect through inundation on property and population in Waitara, when actual erosion is considered.

Table 9.9.2 :- Population and dwellings expected to be affected by inundation on an eroded coast. Refer Map 9.9.5.

Sea Level in Metres Population and Dwellings affected by inundation on an eroded coast	Population	Average Age	Dwellings
2	0	0	0
2.5	0	0	0
3	96	48	51
3.5	279	44	132
4	510	25.9	210
4.5	975	26.35	426
5	1362	27.5	576
5.5	1938	27.9	792
6	2049	28.22	840
6.5	2313	28.95	945
7	2682	28.5	1068

The effect of erosion on the Waitara coastline is to remove much of the foreshore that protects the campground and land to the west of that.

Map 9.9.5 :- Waitara– Inundation for Sea Rise Levels of 0.5 to 2.0 projected for the year 2100 with Storm Surge and Runup for an eroded Shoreline. The annual rate of erosion of East Waitara is 1.57m per annum and 0.81m per annum for West Waitara.

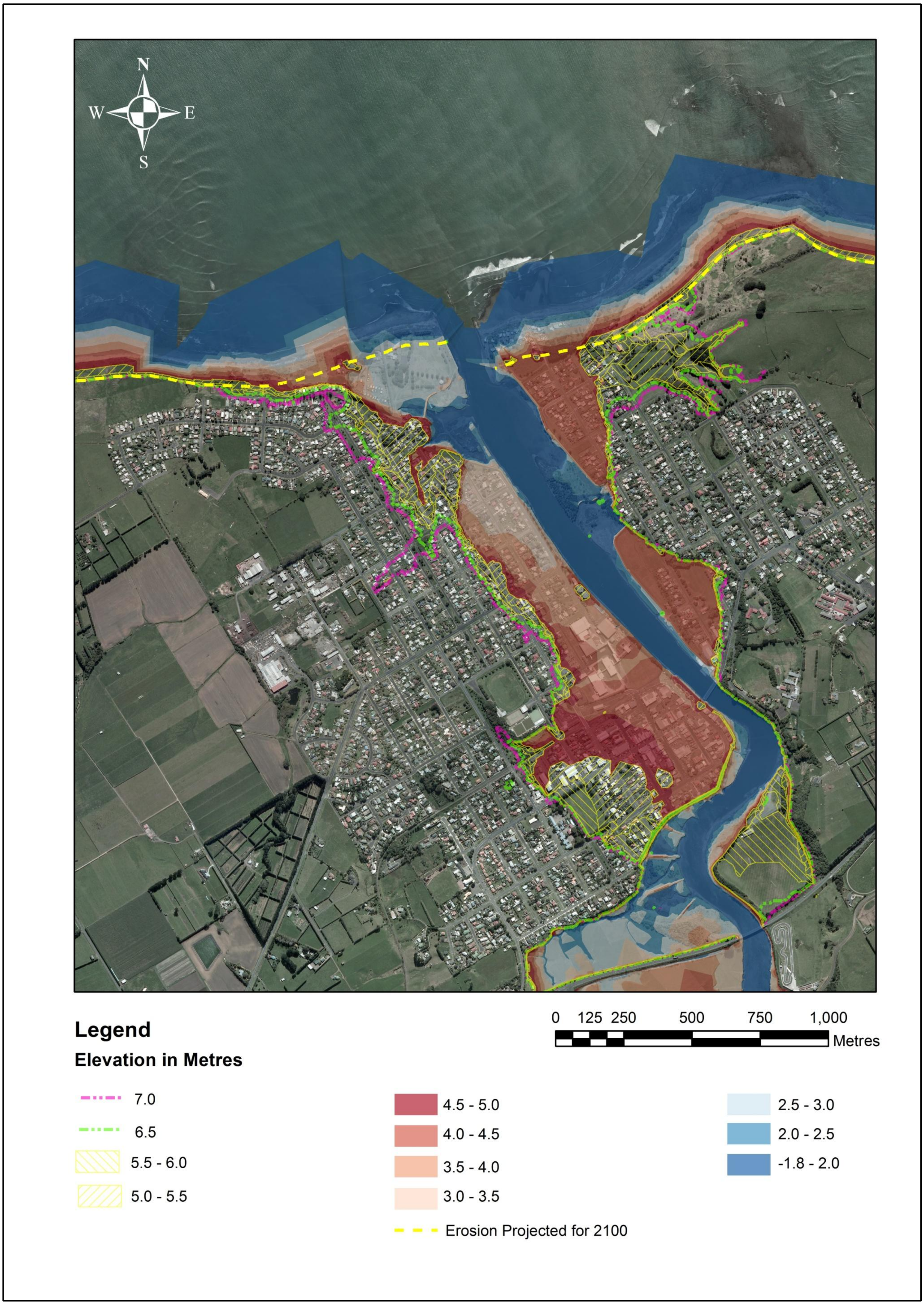


Table 9.9.3 :- Capital value, land value and land areas of properties that are inundated with an eroded shore; for all properties.

Sea Level in Metres with the Eroded Shoreline - All Properties	Records	Total Capital Value ($,000)	Total Land ($,000)	Total Land (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0.0	0.0	0.0
2.5	12	1688	862	3.4	496.5	253.5	242.9
3	17	2927	1686	11.95	244.9	141.1	103.8
3.5	65	12253	5713	16.15	758.7	353.7	405.0
4	119	32170	1308	28.56	1126.4	45.8	1080.6
4.5	354	72649	30158	55.91	1299.4	539.4	760.0
5	483	98755	40816	69.61	1418.7	586.4	832.3
5.5	600	124377	51941	93.83	1325.6	553.6	772.0
6	673	137316	57543	98.68	1391.5	583.1	808.4
6.5	723	148943	63779	162.32	917.6	392.9	524.7
7	796	163652	70734	168.39	971.9	420.1	551.8

Table 9.9.6 :- Capital value, land value and land areas of properties that are inundated with an eroded shore; for properties < 3000 m^2.

Sea Level in Metres with an Eroded Shoreline - Properties < 3000 m2	Records	Total Capital Value ($,000)	Total Land ($,000)	Total Land (ha)	CV / Ha ($,000)	LV / Ha ($,000)	IV / Ha ($,000)
2	0	0	0	0	0.0	0.0	0.0
2.5	3	422	225	0.35	124.1	66.2	57.9
3	14	2425	1113	1.52	202.9	93.1	109.8
3.5	65	12400	5432	6.11	767.8	336.3	431.5
4	111	20412	9269	9.58	714.7	324.5	390.2
4.5	312	54347	23136	24.06	972.0	413.8	558.2
5	417	73623	31225	31.62	1057.6	448.6	609.1
5.5	507	89263	38728	38.86	951.3	412.7	538.6
6	576	101773	44247	44.16	1031.3	448.4	583.0
6.5	619	109272	47673	47.85	673.2	293.7	379.5
7	669	119250	52450	51.97	708.2	311.5	396.7

Tables 9.9.5 and 9.9.6 use the much finer property values provided by the NPDC to determine how property values are affected. With both tables it can be seen that as the sea level begins to rise, so to do the number of properties affected, and therefore increasing area and value. Once the water level gets to 4.0m to 4.5m and overtops the stop banks, the numbers of properties, the area affected and the values are significant.

Table 9.9.7 :- Capital value, land value and land areas of the buildings that have been lost only to erosion without the effects of inundation by 2100.

Buildings lost due to Erosion Only	Properties	Area (ha)	Capital Value ($000)	Land Value ($000)	Improved Value ($000)
	1	7.49	1641	641	1000
Average				85.58	

Table 9.9.8 :- Capital value, land value and land areas of the land that has been lost only to erosion without the effects of inundation by 2100.

Land lost due to Erosion Only	IV / Ha ($,000)	Area (ha)	Land Value ($000)
West Waitara	85.58	10.22	875
East Waitara		29.04	2485

The values of property lost solely due to erosion as tabled in 9.9.7 and 9.9.8 shows the value to be relatively minor at $1 million for buildings and $3.36 million for land when the total values affected by inundation are added. This low value is due the small number of buildings in the eroded area.

9.9.8 Waitara Setup and Runup

Setup and runup are based on supplied hindcast data for a five year period (McComb, 2011) the results for Waitara being shown in Appendix G for positions 35, 36, 37.

The foreshore slope has been calculated from data provided by the ESRI's 3D Analyst profile tool. This tool provided not only visual representation of the foreshore but x,y coordinates of the profile, so foreshore slope could be calculated.

The three values created by Stockdon's setup and run-up formula have been averaged to come up with a single figure of 0.69m for setup and 1.16m for runup.

The actual effect of setup and run-up further up the river, is most likely less than it would be if it were on the coast, however as some locations in the study area the ocean has unrestricted access to the town, the setup and run-up levels are shown.

9.9.9 Waitara Ground Truthing of Model

The Waitara boat ramp was used as the ground-truthing site, principally because of its sloping nature and the ability to determine from the slope of the boat ramp if any error may have occurred. A ramp provides a vertical translation for an aerial view.

At the height of a spring tide on the 11th January 2013, the Waitara boat ramp was visited and the extent of the water's edge noted. This was then compared with the TIN value. The expected tide value was 2.018m which compared favourably with a TIN elevation of 2.029m.

Figure 9.9.1 shows the Waitara boat ramp at High Spring Tide (3.9m) there was a small amount of run-up as can be seen by the wet area on the Tarmac and the water was calm only 300m in from the mouth of the river. The red line on Figure 9.9.2 shows the reference line where the 2.029m TIN reading was taken ie the tarmac / concrete interface.

Figure 9.9.1 :- A picture of the Waitara River Boat Ramp – taken at High Spring Tide by the Author.

Figure 9.9.2 :- An Aerial photograph of the Waitara River Boat Ramp overlaid on a TIN, The red line denotes the edge of the concrete.

9.9.10 Waitara – Discussion of Findings

The recent history of the Waitara River shows the river flooding a number of times, causing engineering works to be undertaken so that the town could be protected from the rising of the river. This is most evident on the northern side of the river north of the SH3 Bridge. The flow of the river has been changed and groins installed to protect the town from extensive river flooding, circa 1990 (TRC, 1993). Close examination of Map 9.9.4 shows the northern stop banks remain clear of the projected sea water rise as they are some 6m high, dropping away to 4m, as the river bend straightens. It is obvious that the focus of flood protection to date has been to deal with the threat from the Waitara River.

Looking at Map 9.9.3 (SWL Rise only) we see that levels up to 2m are contained within the confines of the stopbanks and rivers edges. Water levels of 2.0m to 2.5m, will see an encroachment into the eastern bank between the two stopbanks. Water levels between 2.5m to 3.0m sees the Camping Ground being inundated and the areas between the groins starting to be filled. At levels between 3.0m to 3.5m there will be more encroachment into the Camping Ground with the 3.5m to 4.0m level, seeing the inundation of land currently protected by stopbanks.

Under the SWL scenario, we only see the Waitara population being affected once the very extreme IPCC prediction levels have been reached. Unfortunately, low pressure weather systems bring with them storms and additional sea height in the form of storm surge, which will raise those levels. The historic storm surge 50 year extrapolation, using extreme value calculation, for the New Plymouth coast is 0.96m. When this is added to the SWL the effect is reflected in the values seen in Tables 9.9.2 and 9.9.3. These show that whilst the SWL RSL breaches Waitara's defences at 1.5m RSL, if a storm surge is added, the stopbank defences succumb much earlier, at just 1.0m RSL. Knowing that the storms are predicted to increase in frequency and ferocity, the levels of inundation shown here could be exceeded.

Chapter 10 Discussion

With predictions that the MSL is going to rise anywhere between 0.5m to 2.0m by the year 2100, 87 years away, it is most important that research is undertaken to get some idea of how the rise in sea level will affect those places where you live, especially if you live by the sea and / or work by the sea.

Gathering data from a number of sources and processing the data, using GIS, has enabled a picture to be painted of how the New Plymouth coastline will look if and when changes in climate occur, the associated sea level rise and extreme storms, which will present the communities with problems with which to contend.

There are a number of surprises that have been raised during this research. These are; the extent of the sea rise that is being forecast, how the forecasts have been updated giving new higher levels of inundation based on data from the Royal Society of New Zealand, how different planning groups are using quite varying ranges of levels of sea rise with which to plan and that the expected climate change will increase storm frequency and ferocity, with increases in rainfall and windiness in some areas and the reverse in others.

One of the problems associated with forecasting the effects of storms, is being able to factor in this increased storminess and to predict what may happen, when the data available for analysis is for what has been in the past. However, even with the current data, an image and therefore understanding of what effects are likely to affect the coastline can be drawn. Low lying areas are still going to be low lying areas and it is these areas, particularly at the mouths and along the banks of the rivers and streams, which are going to be affected.

Erosion of the New Plymouth coastline has been monitored and has been a known hazard for many years. Taking conservative erosion rates from a number of publications provides a reasonable basis on which to predict where the shoreline might be in 2100, if nothing is done to stall the advancing waves. Increases in sea level will increase the extent of erosion according to Bruuns rule, but because of insufficiently accurate bathysopic data, the predictions based on this rule could not be used without producing some strange results which cannot be relied upon.

The use of Extreme Event forecasting has been used to provide the models with levels of sea rise. The levels of storm surge were taken from Port Taranaki wave data, with setup and runup values being derived from hindcast data along the New Plymouth coast. Without the ability to be able to extrapolate these data as extreme events, then the project would have lost much of its value. Important to developing these values was the requirement to find other values, from other studies such as Laings study in 2000 on the Kapiti Coast, which verified that the results being obtained were in the right “Ballpark”.

Once the extreme data had been calculated, a GIS was used to combine the various elements of topographic, bathyscopic and sea rise data to create a 3D model which could indicate where potential problems could occur. The availability of 0.5m contour data meant that modelling the effect of sea rise on the coast would be more accurate, and therefore have more meaning, than the coarse contours which were available at the time the project was first mooted. The ability to manipulate the coastline in the form of a 3D model into a coastline that shows the effects of erosion – removing coastal barriers which are currently impediments to inundation, was extremely important, as was the testing of the 3D model to ensure that the elevations were correct in relation to sea levels.

The limits of the study areas were easily defined using a combination of three factors; the type of beach, the contour data, or obvious features on the aerial photographs. In some cases the data set was so large, there was a need reduce the data and add-ons to a size where the computer could refresh the data in what was considered a reasonable time frame i.e. 3 seconds, so more study areas were created.

The analysis of data and the effect of different inundation levels on the population and property of those who live in affected areas, was done using property data supplied by the New Plymouth District Council and census data downloaded from New Zealand Statistics. Most of the data had to be refined predominantly because of the sheer number of records, and because it was in the wrong form for easy analysis within the GIS Model. For example, dwellings and age are not on the same spreadsheet, so the spreadsheets had to be manipulated using SAS. It was not possible to use Excel for this task, as the amount of data was excessive and Excel was unable to cope with that amount of data. Once combined, it was possible to have all the data on the same record, which then made summation of the selected records very easy, using the GIS Spatial Statistics toolbox.

One of the main issues relating to the use of property values and Meshblocks was that many times the mesh or property block was bigger than the inundated portion. It was considered at one stage that prorating the data would give a better indication as to the true value of loss but this was not true as it was really only valid where there were areas of consistent value which, as the study progressed, was found not to be the case.

The results of the different study areas showed that the first metre of sea rise alone is not such a problem. It is only when the extreme elements of storm surge, setup and run-up are added, that the problems start to occur. The main study areas where inundation to this level will cause a problem are The Port, Fitzroy and Waitara. A sea rise of 1.5m and 2m levels will affect all study areas to a greater or lesser extent. The three study areas where the economic impact is greatest are the, Port and City, because of the high value of the properties and infrastructure; and Waitara, because of the sheer number of properties and people affected.

The financial effect of inundation cannot be underestimated and in the total study area runs into hundreds of millions of dollars, increasing as the sea level increases. The overall effect is summarised in appendix ‘H’. Whilst inundation is the greater cost, the total loss of land due to erosion is calculated at 74 million with the bulk of the value of the loss coming from Oakura and Fitzroy and the high value properties that would be affected if the projected erosion eventuates and no action is taken to protect those properties.

In 1988 a report to the TCB (Taranaki Catchment Board), values for a CHZ (Coastal Hazard Zone) were given, yet recent developments and plans for development seem to ignore such zones. The fact that the TRC report of 2009 questions the accuracy of some of the erosion data being currently presented, and calling for a “recalculation”, would tend to indicate that there is some confusion in that area. This study shows there are significant areas along the New Plymouth Coast where it is crucial to know the current rates of erosion and monitor any change to those rates, so that the planning of where to site future projects or take corrective actions can be done with a reasonable amount of certainty.

There are a number of issues surrounding infrastructure such as the inundation of rail links with the port, waste water treatment plants, library and museum and the threat to the airport by erosion which must be addressed, as these are critical items vital to the running of the city and surrounding towns.

As well as the above issues there are four areas that have not been addressed by this study and could be the subject of further study. These are:-

i. The effect of a river in flood on an extreme sea tide; specifically the Oakura, Waiwhakaiho and Waitara Rivers as well as the Huatoki, Te Henui Streams.

ii. The effect of sea rise on ground water systems and sewage particularly in Oakura, The Waiwhakaiho Valley and Waitara

iii. The loss of wild life habitat along the New Plymouth Coast due to either sea rise and / or erosion.

iv. The development of future residential areas within the New Plymouth Area and how sea rise and / or erosion will affect them.

Chapter 11 Conclusion

This research has shown that by using publicly available data and analysing this with a GIS, using basic rules for the determination of extreme events, it is possible to determine where and to what extent inundation may occur along the New Plymouth Coast.

Whilst some data could have been of better quality, or over a greater sampling period, the majority of the data has given results that have fallen within ranges given by other studies in other areas.

The issues raised by this research indicate that without the planning and perhaps intervention of the local authorities, there are a number of areas where a rising sea will cause extensive damage and loss, not just to property but to important infrastructure such as transport and sewage systems. These areas are the Port Taranaki and other low lying areas along the coast, often where a river or stream meets the sea, which by their very nature, will act as a conduit and allow inundation from the sea up the river.

Local authorities have serious planning issues ahead of them, and will need to provide for a ’worst case scenario‘ when granting consents for building within the ‘Coastal Hazard Zone’ and provide alternative sites for important infrastructure such as sewage pumping stations.

The impact of inundation on the communities within the study area will not just be physical but have implications through all aspects of a community. People need to feel safe and know that issues that affect their safety are being addressed by those who have been charged with that safety, whether that be the people who run Civil Defence or plan the districts infrastructure. There must be recognition that in the future there will be a rise in sea level and an increase in the rate of erosion, that these two issues will cause problems, and plan accordingly. Even if the local authorities want to call this research a ‘worst-case scenario’, we will certainly not doing our duty as far as ‘kaitiakitanga’ or guardians for our future generations, if sea rise is ignored or a ‘wait and see’ approach is adopted.

Whether the sea rises as projected or not, these research results give pointers to where the most vulnerable areas are, and to what extent they will be affected, and thus answer the research question “What effect will a 0.5m plus rise in sea level have on the New Plymouth Coastline?”

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Appendices

Appendix A

Data used in this Thesis.

Data	Source	Period	Format	Coverage	Datum	Projection
0.5 metre contour	New Plymouth District Council	2010	Shape file	Covers Oakura and New Plymouth to Waitara	4.9 meters beneath New Plymouth Fundamental 1971	NZGM 2000
0.5 metre contour		2004	Shape file	Covers an Area between the Airport and Waitara not covered by the 2010 contour data.	4.9 meters beneath New Plymouth Fundamental 1971	NZGM 2000
Bathymetric contours	Ko-ordinates	Unknown	Shape file	The depths of the ocean from 0 to 50 metres covering the coast from Oakura to Waitara	6.7 meters beneath New Plymouth Fundamental 1971 – the chart datum	NZGM 2000
Hindcaste Wave Data	MetOcean Solutions Ltd	Jan 2007 to Dec 2011	Txt	Covers a distance 1 km from the New Plymouth shore at intervals of 1 km Contains H_s, T_p and wave direction data taken at three hour intervals	N/A	N/A
Tide Data	Port Taranaki Ltd	Jan 2010 to Dec 2011	DBF	Contains tide data taken from the Port Taranaki wave buoy. Data is taken at one minute intervals and includes Barometer, Tide and wave direction data.	6.7 meters beneath New Plymouth Fundamental 1971 – the chart datum	N/A
Predicted Tide Data	LINZ	Jan 2010 to Dec 2011	CSV	Contains high and low tide height, date and times.	6.7 meters beneath New Plymouth Fundamental 1971 – the chart datum	
River Data	Taranaki Regional Council	Jan 2004 to Dec 2010	Txt	Covers the major rivers that flow into the seas off the New Plymouth coast. Data is taken at thirty minute intervals and includes flow and level data.	N/A	N/A
Rainfall Data	Taranaki Regional Council	Jan 2004 to Dec 2010	Txt	Covers the areas within the catchment of the rivers that flow into the seas off the New Plymouth coast. Data is taken at thirty minute intervals and reports on mm of rainfall .	N/A	N/A
Property Parcel Data	New Plymouth District Council	2012	Shape file	Covers a New Plymouth coastline to a depth of 1 km. Contains the Land, Capital and Area value of properties within the parcel.	N/A	NZGM 2000
Meshblocks 2006	Statistics NZ	2006	Shape file	Contains polygons of the Meshblocks used in the 2006 census.		NZGM 2000
Meshblock 2006 analyzed data	Statistics NZ	2006	DBF file(able to be read by MS Excel)	Contains dwelling, age and population counts / averages within each Meshblock.		

Appendix B

Images used in this Thesis.

Image	Source	Date	Format	Coverage	Projection
Urban Images	New Plymouth District Council	2010	JPG	From Oakura to Waitara with some images missing between the Port and Oakura. The intention of the images is to show the shoreline in great detail so high tide refuge and feature of interest can be noted. The images are High Resolution and have been orthorectified.	NZMG 2000
Rural Images				From Oakura to Waitara with some images missing between the Port and Oakura. The images are used to show the shoreline and surround areas in sufficient detail so the contour data and TIN images can be interpreted correctly and with ease. The images are Medium Resolution and have been orthorectified.	
Site photographs	Author	2010 to 2013	JPG	Various images taken for the purposes of clarifying a point	N/A

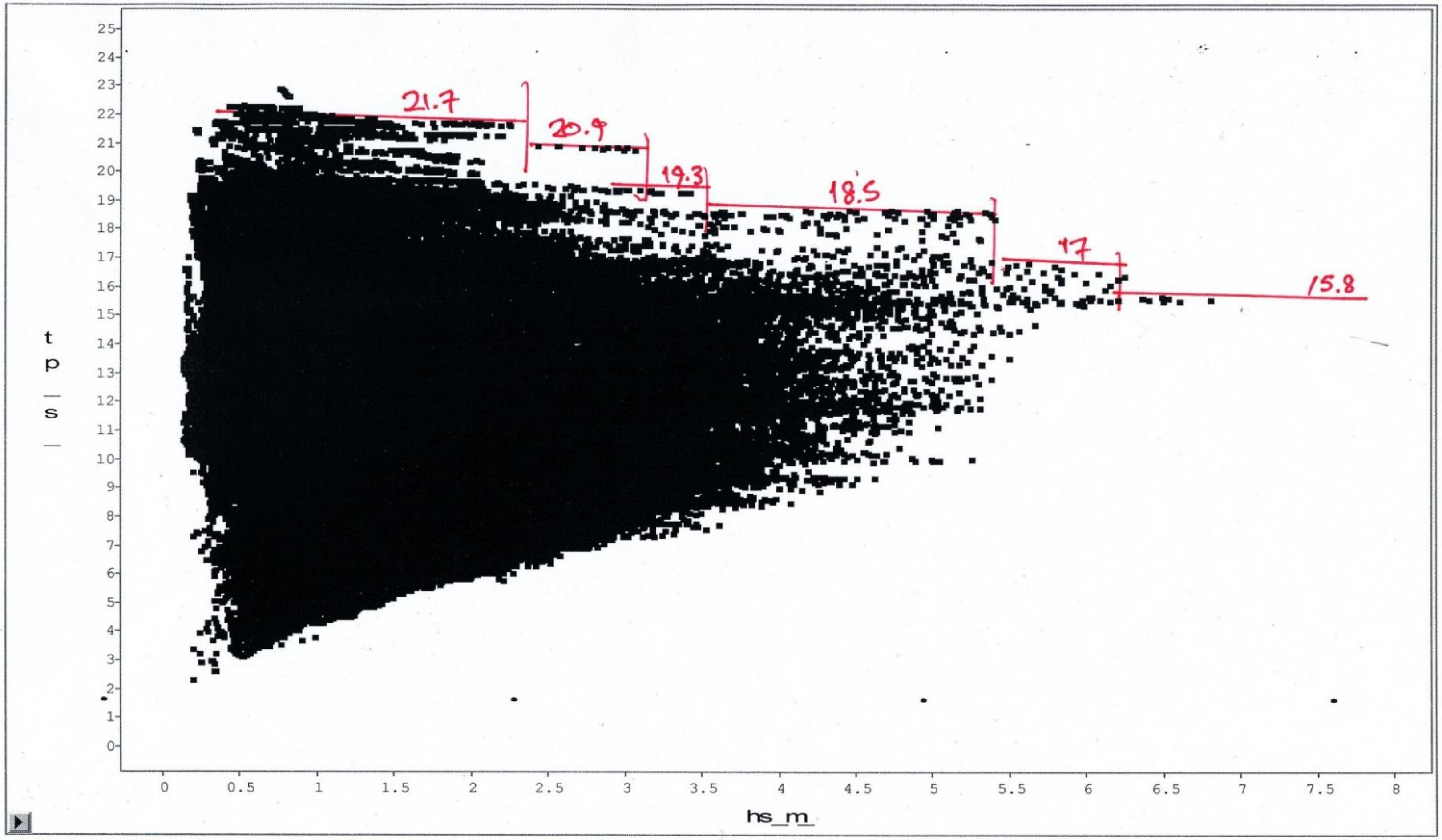
Appendix C

Prediction of Storm Surge and Barometer Readings for the next 100 years.

	Mean	Std Dev.	K_{25}	K_{50}	K_{75}	K_{85}	K_{98}	K_{100}
Max Barometer Readings	1036	4.13	1052.5	1054.8	1056.1	1056.5	1056.9	1057.0
Min Barometer Readings	1000	-7.91	968.4	964.1	961.6	960.8	959.9	959.8
Storm Surge	0.289	0.147	0.88	0.96	1.00	1.02	1.03	1.04

Appendix D

Scatter plot of T_p in Seconds verses H_s in Metres taken from raw hindcast data (figures in red are T_p values).



Appendix E'

Projection of wave heights for the use in the calculation of Setup and Runup

Position	number of nonmissing values, hs_m	the mean, hs_m	the standard deviation, hs_m	the largest value, hs_m	the median, hs_m	the smallest value, hs_m	H_s Projected Wave Heights				
							Year	Year	Year	Year	Year
							10	50	75	90	100
							3.28	4.54	4.86	5.00	5.08
Waveset3	60	3.40	1.00	6.36	3.31	1.69	6.68	7.94	8.26	8.40	8.48
Waveset4	60	3.16	0.87	5.62	3.08	1.65	6.01	7.10	7.38	7.50	7.57
Waveset5	60	2.69	0.60	4.32	2.67	1.60	4.67	5.43	5.62	5.71	5.76
Waveset14	60	3.48	1.02	6.49	3.35	1.68	6.82	8.10	8.42	8.57	8.65
Waveset15	60	3.39	0.96	6.04	3.29	1.66	6.53	7.73	8.03	8.17	8.25
Waveset16	60	3.29	0.89	5.56	3.21	1.65	6.20	7.32	7.60	7.73	7.80
Waveset17	60	3.16	0.82	5.12	3.11	1.62	5.84	6.87	7.13	7.24	7.31
Waveset18	60	3.03	0.74	4.68	3.00	1.60	5.47	6.40	6.64	6.75	6.81
Waveset19	60	2.73	0.60	3.99	2.73	1.56	4.69	5.44	5.63	5.71	5.76
Waveset20	60	2.49	0.48	3.44	2.52	1.52	4.07	4.67	4.82	4.89	4.93
Waveset21	60	2.70	0.57	4.00	2.72	1.62	4.59	5.31	5.49	5.57	5.62
Waveset22	60	3.11	0.77	5.05	3.08	1.76	5.64	6.61	6.85	6.96	7.02
Waveset23	60	3.13	0.78	5.04	3.07	1.76	5.68	6.66	6.91	7.02	7.08
Waveset24	60	2.76	0.58	4.08	2.77	1.70	4.65	5.37	5.55	5.64	5.68
Waveset25	60	2.58	0.47	3.62	2.64	1.68	4.12	4.71	4.85	4.92	4.96
Waveset26	60	2.98	0.67	4.66	2.98	1.79	5.18	6.02	6.23	6.33	6.38
Waveset27	60	3.12	0.74	4.90	3.11	1.79	5.56	6.50	6.73	6.84	6.90
Waveset28	60	2.76	0.57	4.05	2.76	1.70	4.62	5.34	5.52	5.60	5.65
Waveset29	60	2.31	0.35	3.09	2.35	1.62	3.47	3.91	4.02	4.07	4.10
Waveset30	60	2.42	0.40	3.35	2.45	1.65	3.72	4.22	4.34	4.40	4.43
Waveset31	60	2.94	0.64	4.47	2.98	1.77	5.03	5.83	6.04	6.13	6.18
Waveset32	60	3.04	0.66	4.44	3.04	1.75	5.19	6.01	6.22	6.31	6.37
Waveset33	60	2.82	0.54	3.91	2.85	1.68	4.59	5.26	5.43	5.51	5.55
Waveset34	60	2.60	0.43	3.44	2.65	1.60	4.02	4.57	4.70	4.77	4.80
Waveset35	60	2.26	0.32	2.88	2.29	1.47	3.31	3.71	3.81	3.86	3.88
Waveset36	60	2.04	0.27	2.62	2.05	1.37	2.93	3.28	3.36	3.40	3.42
Waveset37	60	2.00	0.31	2.74	1.98	1.33	3.03	3.43	3.53	3.57	3.60
Waveset38	60	1.95	0.32	2.69	1.91	1.27	3.00	3.40	3.50	3.54	3.57

Appendix F

Historic Erosion Rates of the New Plymouth Coast.

Historic Rates of Erosion

	Gibbs 1978			TCB 1988	TRC 2009 (Table 8)
Grid Reference	Location	Year	In Metres	In Metres	In Metres
N108/525843	Oakura	1865-1961	0.67	-0.2	-0.2 / -0.67
N108/531845	Oakura	1865-1961	0.35		
N109/658927	New Plymouth	1842-1901	-0.17		
		1901-1921	-0.5	-0.45	-0.46
		1921-1944	-0.39		-0.54
		Seawall built, cliffs stabilized			
N109/664926	New Plymouth	1842-1921	-1.09		
N109/668929	Fitzroy Beach	1842-1958	-0.58		-0.58
N109/672933	Fitzroy Beach	1842-1958	-0.58	-0.24	
N109/675917	Fitzroy Beach	1842-1958	-0.86		
N109/679942	Fitzroy Beach	1842-1952	-0.08		-0.06
	Waiwakaiho River			-.31 East -.67 West	Use 1988 values
N109/710966	Bellblock	1907-1974	-0.42	-0.32	-0.38
N109/724967	Wills Road	1852-1945	-0.25		
		1945-1950	-2.38		
		1950-1957	0		-0.37
		1957-1970	-0.69		
		1970-1976	-0.39		
N109/730972	Pukitapu Trig	1917-1945	-0.71		
		1945-1950	-2.5		
		1950-1957	0		
		1957-1964	-1.37		-0.76
		1964-1970	-0.41		
		1970-1976	-0.07		
N109/742982	Airport	1917-1964	-0.96	-0.6	-.51 / -.32
N109/742990	Airport	1917-1964	-0.32		
N99/800006	Waitara	1913-1958	-2.89	-1.37 East -.54 West	-1.57 East -0.81 East

Calculation of Runup and Setup using Stocktons Equation

Calculation of Runup and Setup using Stocktons Equation

Position (refer Map 2.1.3)	Angle in degrees of the Foreshore	Tanß	$T_{p\ in\ Metres}$	L_o	$H_{o\text{-}50\ in\ Metres}$	ξ_o	Run up in metres for a dissipative Beach (inc Setup)	Setup in metres for Dissipative Beaches
3	0.97	0.0169	15.8	390	7.94	0.12	2.392	0.890
4	2.57	0.0449	15.8	390	7.10	0.33	2.262	0.842
5	0.98	0.0171	17	451	5.40	0.16	2.123	0.790
14	1.10	0.0193	15.8	390	8.10	0.13	2.416	0.899
15	3.47	0.0607	15.8	390	7.73	0.43	2.360	0.878
16	1.24	0.0216	15.8	390	7.32	0.16	2.297	0.855
17	1.18	0.0206	15.8	390	6.87	0.16	2.225	0.828
18	1.30	0.0227	15.8	390	6.40	0.18	2.148	0.799
19	2.75	0.0481	17	451	5.44	0.44	2.130	0.793
20	0.51	0.009	18.5	534	4.67	0.1	2.148	0.799
21	1.07	0.0187	18.5	534	5.31	0.19	2.291	0.852
22	1.45	0.0254	15.8	390	6.61	0.2	2.183	0.812
23	0.93	0.0162	15.8	390	6.66	0.12	2.191	0.815
24	0.93	0.0162	18.5	534	5.37	0.16	2.303	0.857
25	0.55	0.0097	18.5	534	4.71	0.1	2.157	0.803
26	0.48	0.0084	15.8	390	6.02	0.07	2.083	0.775
27	0.36	0.0062	15.8	390	6.50	0.05	2.164	0.805
29	0.46	0.008	18.5	534	3.90	0.09	1.963	0.730
30	0.56	0.0098	18.5	534	4.22	0.11	2.042	0.760
31	0.63	0.011	17	451	5.83	0.1	2.205	0.821
33	0.75	0.0131	18.5	534	5.26	0.13	2.280	0.848
34	0.02	0.0003	18.5	534	4.57	0	2.125	0.791
35	0.49	0.0086	18.5	534	3.71	0.1	1.915	0.712
36	1.30	0.0227	19.3	582	3.28	0.3	1.878	0.699
37	0.37	0.0065	18.5	534	3.43	0.08	1.841	0.685
38	0.84	0.0147	18.5	534	3.40	0.18	1.833	0.682

Appendix H

Graph of capital value in millions of properties inundated vs sea level.