REPORT

Horizons Regional Council

Coastal Hazard Assessment
Waikawa to Waitarere

Report prepared for:

Horizons Regional Council

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Executive summary

Tonkin & Taylor, along with Coastal Systems Ltd has undertaken a coastal hazard assessment for Horizons Regional Council along a section of the west coast from Waikawa to Waitarere Beaches.

Approximately 19km of shoreline from Waikawa Beach to Waitarere Beach has been assessed for coastal hazards. For the three developed areas at Waikawa Beach, Hokio Beach and Waitarere Beach a comprehensive CEHZ (Coastal Erosion Hazard Zone) and CIHZ (Coastal Inundation Hazard Zone) assessment was undertaken. For the areas in between, an ASCH (Area Sensitive to Coastal Hazards) assessment was undertaken.

An assessment of open coast shoreline trends showed that:

- The Waikawa shoreline has shown the greatest rate of shoreline accretion over the study area. The shoreline to the south of the river inlet migration zone is building out at a rate of 3.40 m/yr.
- The Hokio shoreline on the northern side of the river mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the river inlet migration zone is building out at a rate of 1.30 m/yr.
- The Waitarere shoreline on the northern side of the stream mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the stream is building out at a rate of 1.70 m/yr.

For the dynamic inlets at Waikawa, Ohau and Hokio, IMC's (Inlet Migration Curves) were compiled for both managed (man-made controls such as groynes and hard protection) and unmanaged regimes.

CEHZ's were assessed for the current (2012), 50 year (2062) and 100 year (2112) time periods. The table below summarises coastal erosion hazard zones along the open coast and within inlets. The CEHZ for the open coast is measured landward of the 2011 dune toe (i.e. seaward edge of shoreline vegetation). The CEHZ for the inlets is measured landward of the site specific IMC.

	CEHZ Open Coast			**CEHZ Inlet**		
Site	**Current**	**2062**	**2112**	**Current**	**2062**	**2112**
Waikawa	-42	-58	-91	-10	-27	-60
Ohau	n/a	n/a	n/a	-19	-36	-69
Hokio	-42	-58	-91	-10	-27	-60
Waitarere	-42	-58	-91	n/a	n/a	n/a

CIHZ's were also assessed for the same time periods as the CEHZ for all areas and are summarised in the table below. All elevations given in the table below are for a 1% AEP event.

Parameter		**Current**	**2062**	**2112**
Total Tide and Storm Surge (m MVD)		**2.1**	**2.7**	**3.3**
Wave effects	Inlet coast (m MVD)	2.6	3.7	4.7
	Wave set up open coast (m MVD)	4.1	4.7	5.3
	Wave runup open coast (m MVD)	5.5	6.1	6.7

We recommend a reassessment of inundation extents derived by photogrammetric methods, due to possible inaccuracies and inconsistencies of the Digital Elevation Model. We do not recommend the inundation extents derived by photogrammetric methods for Hokio are used for regulatory purposes such as District Plans or for public information such as LIM reports due to these inaccuracies.

1 Introduction

A progressive review of the information available on coastal hazards by Horizons Regional Council (HRC) has identified the need for an assessment of the nature and scale of coastal hazards along the coastline bounded by Waikawa and Waitarere Beaches. Tonkin & Taylor (T&T), along with Coastal Systems Ltd (CSL) has undertaken a coastal hazard assessment for HRC along this section of the west coast from Waikawa to Waitarere Beaches.

The purpose of the assessment is to enable the Council to make informed decisions as to how to manage development (both existing and new) by identifying the coastal hazards affecting these areas.

1.1 Project scope

The scope of the project includes two main objectives:

- Objective 1

  To identify an 'area sensitive to coastal hazards' (ASCH) line, which indicates the landward boundary of the assessment area along the full coastline from Waikawa to Waitarere Beaches. This is approximately 19 kilometres long between NZMS260: S25 904540 and S25 948667
- Objective 2

  To investigate and identify in detail the nature and scale of coastal hazards that exist in relation to the following areas (Coastal Hazard Zone Assessment – CHZ):
  - Waikawa Beach:
    - Landward (eastern) extent: From the coast to the area sensitive to coastal hazards boundary identified in Objective 1 above.
    - Lengthwise (north-south) extent: From NZMS260: S25 904540 to S25 912560.
  - Hokio Beach:
    - Landward (eastern) extent: From the coast to the area sensitive to coastal hazards boundary identified in Objective 1 above.
    - Lengthwise extent: From NZMS260: S25 943649 to S25 948667.
  - Waitarere Beach:
    - Landward (eastern) extent: From the coast to the area sensitive to coastal hazards boundary identified in Objective 1 above.
    - Lengthwise extent: From NZMS260: S25 943649 to S25 948667.

The objectives above include the following limitations and assumptions:

- Some of the information of the CHZ assessments will be assumed to be also relevant for the ASCH (i.e. design water levels and coastal erosion setbacks)
- ASCH is deemed to be the 100 year planning time frame for Coastal Hazards (i.e. one line representing the likely extent of coastal hazards to 2112)
- ASCH to be used as a 'Red Flag' for any proposed developments and requires more detailed assessment, if property seaward of the ASCH
- The river mouth settlements at Waikawa and Hokio are at the boundary between coastal and river process and hazards. This assessment does not assess river processes or hazards.

1.2 Site locations

The study area covers approximately 19 km of shoreline situated on the west coast of the North Island near the southern boundary of HRC and Greater Wellington Regional Council (GWRC). The study area covers four coastal settlements (Waikawa, Ohau, Hokio and Waitarere). Figure 1-1 located in Appendix A shows the location of these settlements and the extents of the two assessment objectives (ASCH and CHZ).

1.3 Information sources

HRC has provided background information for the study. The information has included:

- Relevant reports and documents.
- Aerial Photography.
- Elevation data (LiDAR and Photogrammetric derived Digital Elevation Models (DEM)).

Other information sources include available reports, papers, web sites and a thesis relevant to the study area and processes. Sources of information are detailed within the report and in the References section of this report (Refer to Section 8).

1.4 Datums

All elevations referenced in this report and Figures are relative to Moturiki Vertical Datum 1953 (MVD).

2 Environment setting

The study area is situated on the west coast of the North Island, west of Levin. The study area stretches some 19 km from Waikawa in the south to Waitarere in the north. The shoreline consist of wide dissipative beaches backed by a prograding vegetated dune system.

A number of streams and rivers exit along the coast. The larger rivers form inlets at Waikawa, Ohau and Hokio. The inlets are dynamic with the main channels migrating along the coast. The rivers supply much of the sediment (generally medium grain sized sand) that has formed the beach system.

The backshore behind the active dune system is generally grassland, exotic forest or residential development.

2.1 Site descriptions

2.1.1 Waikawa Beach

Waikawa Beach is a small settlement on the eastern bank of the Waikawa Stream and inlet system. The migrating stream mouth currently forms an inlet some 1000 m wide along the open coast and extends some 250 m inland from the adjacent open coast dune line (Photo 2-1). Appendix B describes changes in inlet migration in more detail.

Waikawa Beach township is located along approximately 900 m of the current inlet/river system. The development straddles the boundary between inlet and river morphologies. We consider that the current shoreline starts to exhibit inlet characteristics (i.e. elevated dunes and possible wave attack) just seaward of the foot bridge that crosses Waikawa stream. East of the footbridge the morphology exhibits more river characteristics.

East of the foot bridge the back shore width (between shoreline and dwellings) ranges between 10 and 70 m and consists of low lying (less than 3 m MVD) land. The inlet backshore width ranges between 20 m and 90 m. The backshore is generally less than 3 m MVD, however elevation rises with vegetated dune formations along the western area. Ground levels within the township are generally between 2 m MVD and 5 m MVD. Figure 2-2 located in Appendix A shows LiDAR derived elevations covering the Waikawa area.

Extensive vegetated dune formations up to approximately 11m MVD are located south of the township, both along the inlet and open coast shore. North of the Waikawa inlet system is an approximately 400 m wide dune system that merges into the adjacent Ohau River inlet system.

Photo 2-1 showing Waikawa Stream inlet

2.1.2 Waikawa Beach to Hokio Beach

The coastline between Waikawa beach and Hokio Beach can be characterised as inlet and dune features. The Ohau River currently exits the shoreline approximately 5 km north of the Waikawa Stream mouth, however the Ohau inlet system starts some 2 km north of the Waikawa Stream. The Ohau inlet extends up to 600 m inland relative to the adjacent open coast dune line.

The back shore of the inlet comprises of low (generally less than 5 m MVD) vegetated dunes fronting the inlet shore and then grades to low lying (predominantly less than 2 m MVD) flat farm land. Figure 2-3 located in Appendix A shows LiDAR and photogrammetry derived elevations covering the Waikawa to Hokio area.

The approximately 6 km stretch of coastline from the Ohau River mouth to Hokio Stream mouth consists of a predominantly vegetated open coast dune system with no significant development. The open coast dunes are in the order of 11 m MVD in elevation. A small stream (Waiwiri) is located approximately 2.5 km north of the Ohau River Mouth.

2.1.3 Hokio Beach

Hokio Beach is a small settlement located on the eastern bank of the Hokio Stream and inlet system. The migrating stream mouth currently forms an inlet some 800 m wide and extends inland some 400 m for the adjacent open coast dune line (refer to Photo 2-2). Appendix B describes changes in inlet migration in more detail.

Hokio township is located approximately 400 m along the current inlet/river system. We consider that the Hokio development area is currently set back from open coast inlet process with the reserve area 'seaward' of development having more river characteristics than inlet characteristics.

East of the road bridge crossing Hokio Stream the backshore width is between 10 and 30 m and is predominantly low lying land less than 3 m MVD. West of the bridge the backshore width (between the shoreline and Tawhiti Street) is between 10 and 30 m and is predominantly less than 3.5 m MVD. Ground levels within the township are generally between 3m and 4 m MVD. Figure 2-4 located in Appendix A shows Photogrammetric derived elevations covering the Hokio area.

Photo 2-2 showing Hokio Inlet, looking south with Hokio Stream in foreground

2.1.4 Hokio Beach to Waitarere Beach

The 4 km open coast section from Hokio inlet north to Waitarere is very similar to the open coast section between the Ohau River mouth and Hokio inlet. The well vegetated dunes rise up to approximately 11 m MVD. The dunes are backed by predominantly exotic forest. Figure 2-5 located in Appendix A shows Photogrammetric derived elevations covering the area from Hokio Beach to Waitarere Beach.

2.1.5 Waitarere Beach

Waitarere Beach is the largest of the 3 settlements. The settlement is located along approximately 2 km of open coast. The development (dwellings) is generally some 150 m landward of the current dune toe. However, a more recent subdivision is some 70 m seaward of the adjacent older Waitarere subdivision and dwellings are approaching 120 m of the current dune toe. The Waitarere surf club is one of the closest buildings to the open coast and is located at least 100 m from the current dune toe and at an elevation of at least 7.0 m MVD.

Apart from a small stream exiting onto the coast some 130 m north of the main beach access road, the settlement is bounded seaward by extensive vegetated dunes some 10 m MVD high. Landward of the dunes the ground levels within the settlement are generally above 3.5 m MVD. Other significant low points through the dune are the main beach access points. The maximum elevation through the dunes of the main beach access is 5.3 m MVD. Photo 2-3 shows the dune area at Waitarere. Figure 2-6 located in Appendix A shows Photogrammetric derived elevations covering the Waitarere Beach area.

Photo 2-3 showing dune area looking north at Waitarere

2.2 Water levels

2.2.1 Predicted tides

MetOcean Solutions Ltd (2010) derived tidal constituents from water levels recorded at Kapiti Island from 1997 to 2006. High and low tide parameters were then calculated for various sites along the Kapiti coast. The closest site to the study area was kpto1, which was located at the southern boundary of the study area near Waikawa Beach. Table 2-1 below shows selected tide parameters for kpto1, which we consider representative for the study area.

Table 2-1 Tidal parameters offshore of Waikawa Beach

Location	MHWS (m)	MHWN (m)	MSL (m)	HAT (m)
Waikawa Beach	1.20	0.56	0.18	1.44

MHWS – Mean High Water Spring, MHWN – Mean High Water Neap, MSL – Mean Sea Level

HAT – Highest Astronomical Tide

Source MetOcean Solutions Ltd 2010. Elevations in (m) relative to MVD.

Note the tidal levels have been adjusted to include both the location tidal amplitude offset and the MVD 1953 sea level increase adjustment to 2012 of 0.08 m and 0.1 m respectively.

2.2.2 Storm surge

The effects of storm events can elevate still water levels above tide levels along the coast (storm surge). Storm surge is caused by barometric set up and wind set up.

A range of storm surge and storm tide (combination of tide and storm surge) parameters were supplied to HRC from various information sources. A storm surge component of 0.9 m was chosen for this project by HRC. We consider the 0.9 m storm surge component is appropriate as an upper bound value.

2.2.3 Future sea level rise

The Ministry of Environment (2008) guideline recommends a base value sea level rise of 0.5 m by 2100 (relative to the 1980-1999 average). Furthermore, the Ministry of Environment (MfE) suggest assessing the potential consequences from a range of possible higher sea level rises, with, at the very least, consideration of the consequences of mean sea-level rise of at least 0.8 m and an additional sea level rise of 10 mm per year beyond 2100. Table 2-2 shows the recommendations as set out by MfE.

Table 2-2 Extract from MfE 2008 showing baseline sea level rise recommendations for different future timeframes

Baseline sea-level rise recommendations for different future timeframes

Timeframe	Base sea-level rise allowance (m relative to 1980–1999 average)	Also consider the consequences of sea-level rise of at least: (m relative to 1980–1999 average)
2030–2039	0.15	0.20
2040–2049	0.20	0.27
2050–2059	0.25	0.36
2060–2069	0.31	0.45
2070–2079	0.37	0.55
2080–2089	0.44	0.66
2090–2099	0.50	0.80
Beyond 2100	10 mm/year	

The planning timeframes used for this study are 2062 and 2112 (i.e. approximately 50 and 100 years from present). Based on the MfE recommendations displayed in Table 2-2, we consider a base sea level rise allowance of 0.3 m (rounded) is appropriate for the 2062 timeframe. Due to the greater uncertainty extrapolating potential sea level rise out 100 years, we have used the additional value shown in column three of Table 2-2 for the 2112 timeframe. The resulting sea level rise for the 2112 timeframe is 0.9 m (rounded) (i.e. 0.8 m plus an additional 10 mm/year).

2.3 Waves

The wave climate for the study area and wave statistics for use in inundation calculations have been derived from hind cast data and wave model undertaken by MetOcean Solutions Ltd (2010). Boundary conditions used wave hindcast wave data. Wave hind cast conditions were derived from NOAA WAVEWATCH III (NWW3) for July 1997 to 2005. From 2006 to 2009 wave boundary conditions were derived from the MetOcean Solutions global WW3 hind cast model. Waves were then generated within the model domain from wind hind cast data.

Table 2-3 shows wave height for various Return Period/Annual Exceedence Probability (AEP) events with the 1%AEP (100 year Return Period) being 7.09 m. The model output showed that during storm events, waves propagated into the study area normal to the shoreline (zero degree wave angle relative to shoreline orientation).

Table 2-3 Wave heights for various return period/AEP events

Return Period (yr)	1	5	10	25	50	100
AEP (%)	100	20	10	4	2	1
Wave height (m)	4.6	5.5	5.9	6.4	6.7	7.1

Source MetOcean Solutions Ltd 2010.

We consider that the wave data derived from the above model is representative of the wave climate along the study area. Figure 2-7 shows the mean monthly wave height, ranging from 0.97 m to 1.52 m. The largest average significant wave height occurs over the winter months from June to October. Therefore we consider the highest waves are likely to occur over the winter months.

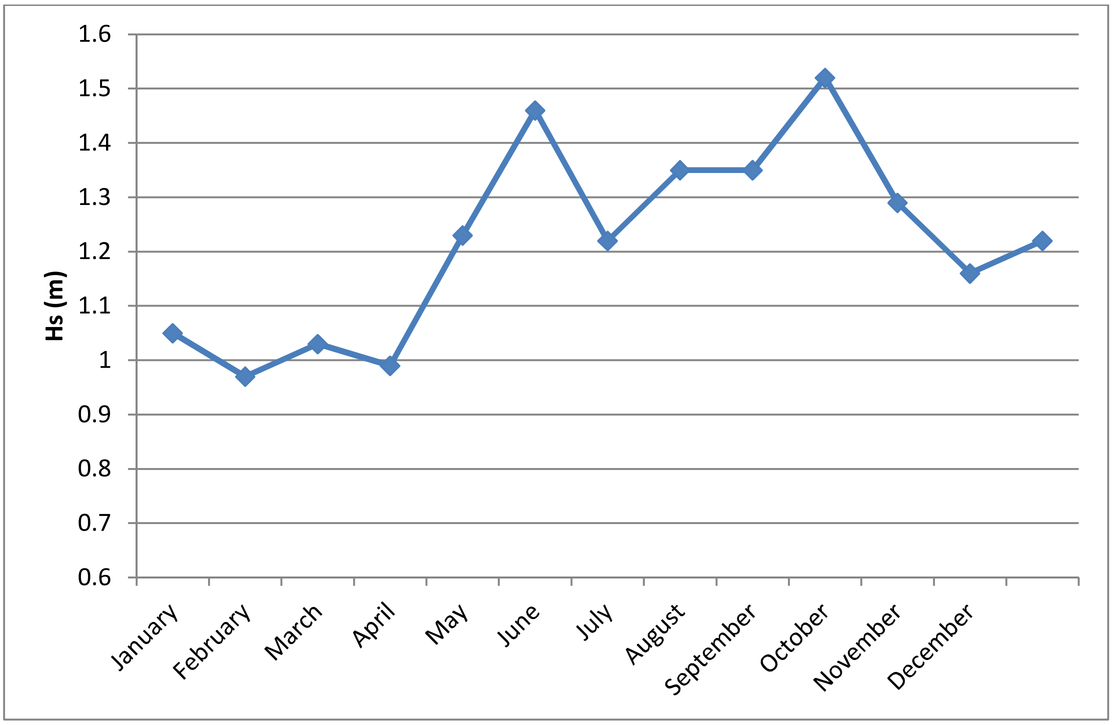


Figure 2-7 Monthly means of significant wave height (Hs) located offshore from Waikawa Beach

2.4 Shoreline changes

2.4.1 Historic shoreline change

Aerial photographs from seven time periods from 1942 to 2011 (refer Table 2-4) were geo-referenced and analysed to determine the historic shoreline trends over 69 years.

The seaward line of vegetation represents a common shoreline feature and was digitised for each photograph. This feature was chosen because it forms a sharp discontinuity in colour contrast on photographs. The shoreline features from all three settlements are plotted in Figures 2-8 to 2-11 located in Appendix A.

The aerial photograph analysis used vertical photographs (i.e. no ortho-rectification), which were geo-referenced and digitised using standard GIS techniques (ArcGIS software). The estimated relative accuracy between images for this methodology is 3 m (+/- 0.04 m/yr).

Table 2-4 Schedule of aerial photographs

Date	Resolution (m)	Reference	Coverage location
25/05/1942	0.5	HRC	Hokio, Waikawa, Ohau and Waitarere
05/05/1965	0.6	HRC	Hokio, Waikawa, Ohau and Waitarere
01/01/1978	1.0	HRC	Waikawa only
01/01/1983	1.0	HRC	Hokio and Waikawa
01/01/1993	0.6	HRC	Hokio, Waikawa and Ohau
31/03/2005	0.6	HRC	Hokio, Waikawa, Ohau and Waitarere
01/01/2011	0.4	HRC	Hokio, Waikawa, Ohau and Waitarere

The digitised shoreline features were then analysed using a GIS program called Digital Shoreline Analysis System (DSAS). DSAS was used to calculate shoreline change statistics at 10 m intervals along the coast. The shoreline statistics are based on linear regression analysis, which provides values for rate of shoreline change over time. The strength of the rate or trend is calculated as the correlation coefficient (r^2). The closer the r^2 value is to 1.0 the stronger the linear fit around the trend (refer to Table 2-4).

Table 2-5 Historic shoreline change

Section	No. Aerial Photographs	Average Shoreline Movement Rate (m/yr)	r2
Hokio (north)	6	2.10	1.00
Hokio (south)	6	1.30	0.82
Waikawa (south)	7	3.40	0.95
Waitarere (north)	4	2.10	1.00
Waitarere (south)	4	1.70	1.00

The results show the shoreline is building out (accreting) along the open coast at an average rate of between 1.3 and 3.4 m/yr. We consider the shoreline adjacent the three settlements can be split into two sections with distinct long term trends either side of the settlement river mouths (refer to Table 2-5).

The Hokio shoreline on the northern side of the river mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the river inlet migration zone is building out at a rate of 1.30 m/yr.

The Waikawa shoreline has shown the greatest rate of shoreline accretion over the study area. The shoreline to the south of the river inlet migration zone is building out at a rate of 3.40 m/yr. The inlet migration zone extends some 5 km from the northern side of the river mouth. The maximum net shoreline envelope fluctuation over this area is approximately 400 m.

The Waitarere shoreline on the northern side of the stream mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the stream is building out at a rate of 1.70 m/yr.

These trends of shoreline movement are derived for the open coast from a limited set of photographs and shoreline changes are also possible between photograph dates due to cyclical (seasonal to decadal) climate change.

2.4.2 Short term changes

The short term erosion rate (factor ST) takes account of both the storm induced erosion and the fluctuations around the observed long term trend of shoreline movement. Short term erosion may occur in response to severe wave storms moving toward the coast from the northwest to southwest quadrant. However, there are also short term fluctuations in shoreline position over a longer period than an individual storm event. These fluctuations are in response to natural variations in climatic conditions and sediment supply. For example, there may be variations in the direction and magnitude of shoreline movements associated with El Nino and La Nina conditions, which typically occur within a three to seven year cycle.

The aerial images used in the historical analysis are 'snap shots' in time of the shoreline position. Monitoring of the shoreline at more frequent intervals over a period of time can detect shorter term fluctuations. The short term erosion rates were determined from a regression analysis of the horizontal dune toe movement based on beach profile data sets from 5 locations (XS17 to XS22). The beach profiles have been surveyed 11 times over a 23 year period (1983 – 2005). The RL 3.5 m contour was taken as the dune toe position for the purposes of shoreline movement analysis using linear regression techniques.

The shoreline fluctuation can be defined by the standard error of estimates (SEE), which is a regression based statistic representing the residuals that is used to estimate population variability. The SEE multiplied by 3 encompasses 99% of the population values and is the most appropriate order of magnitude to represent the maximum extent of shoreline movement that may occur due to significant storm events and cyclical shoreline movement. The 3SEE values obtained from the 5 profile datasets are displayed in Table 2-5 below. The maximum 3SEE value of 30 m (rounded) was applied as the ST factor along the entire coast. We note this method is limited by the number of profiles within the available dataset and therefore a factor of safety should be applied to this component.

Table 2-5 Summary of beach profile data analysis

Section	Maximum negative residual (m)	Maximum movement in an erosion phase (m)	Standard error (SEE) (m)	3SEE (m)
Hokio XS 20 (north)	-15.2	-12.5 (6 years to 2005)	10.2	31
Hokio XS 21 (south)	-5.1	-0.5 (6 months in 1983)	4.2	13
Waikawa XS22 (south)	-3.0	-2.4 (6 months in 1983)	2.0	3
Waitarere XS 18 (north)	-15.2	-3.2 (6 months in 1983)	7.9	24
Waitarere XS 19 (south)	-3.2	-0.6 (4 months in 1984)	2.2	7

Both the maximum negative residual and maximum movement in an erosion phase are also presented for comparison. The maximum negative residual represents the largest horizontal distance the shoreline moved from the average trend position. The maximum movement in an erosion phase represents the maximum horizontal distance of shoreline retreat recorded over the dataset. Due to the limited number of beach profiles a statistical approach is warranted because some erosion episodes may have occurred between profile survey dates. The maximum 3SEE value provides a greater distance than both the other two short term erosion indicators and we consider it to be a suitably conservative value.

3 Coastal erosion hazard zone assessment

3.1 Methodology

The methodology to determine the coastal erosion hazard zones (CEHZ) includes the cumulative addition of:

- Predicted climate change effects
- Expected long term erosion rates
- Episodic storm induced erosion and short term fluctuations in shoreline movement
- Dune stability
- Inlet migration.

3.1.1 Open coast

The coastal erosion hazard zones for the open coast are based on the methodology outlined in Equation 1 below.

$$\boldsymbol{CEHZ(open\ coast) = [[LT]T + SLR + ST + DS + FS} \quad \text{(Equation 1)}$$

Where:

CEHZ is the width of the coastal erosion hazard zone for open coast sandy shorelines.

LT = Historic long term rate of horizontal shoreline movement (m/yr).

T = Planning time frame (years).

SLR = Horizontal coastline retreat due to possible accelerated sea level rise (m/yr).

ST = Horizontal distance of shoreline retreat from both storm induced erosion and short term fluctuations in the long term trend of shoreline movement (m).

DS = Horizontal retreat of the vertical erosion scarp based on the angle of repose for loose sand (m).

FS = Factor of Safety/uncertainty (m).

Further descriptions of the coastal erosion hazard components are set out in Section 3.1.3.

3.1.2 Inlets

Sand dominated inlets, such as occur at Waikawa, Ohau and Hokio are very dynamic with frequent channel migration and other morphological changes. The dynamic morphological processes cause the alongshore and landward extents of inlets to change over time.

The methodology in determining CEHZ's outlined in Equation 1 applies only to areas of open coast and not shorelines located adjacent to inlets. The dynamic nature of inlets means that both short and long term erosion rates are not easily quantified.

The coastal erosion hazard zones for the inlet settlements are based on the methodology developed by Dr Rodger Shand and is outlined in Equation 2.

$$\boldsymbol{CEHZ(inlet) = IMC - ([LT]T + SLR + DS + FS)} \quad \text{(Equation 2)}$$

Inlet erosion assessments generally focus on the shoreline envelope. The landward margin of the shoreline envelope is used to derive the maximum inlet migration curve (IMC). The inlet migration curve essentially becomes the baseline from which the remainder of the components are measured.

A full assessment of the inlet migration curves for the study site s is contained in Appendix B 'Geomorphological Assessment and Shoreline Analysis of Waikawau, Ohau and Hokio Inlets' by Dr Roger Shand.

3.1.3 Components

3.1.3.1 Planning time frame (T)

Three time frames were applied to provide a sufficient time scale for planning and accommodating development:

- Current Erosion Hazard Zone (2012) - CEHZ
- 2062 Erosion Hazard Zone (50 years) - 2062EHZ
- 2112 Erosion Hazard Zone (100 years) - 2112EHZ.

3.1.3.2 Sea level rise effects (SLR)

Future sea level rise will permit waves to attack the backshore and fore dunes more frequently. Sandy open coasts that have been relatively stable over time are likely to show a bias towards erosion with rising sea levels, unless the supply of sand to the beaches can keep pace with erosion. In our opinion, no adjustments for vertical land displacement (uplift from earthquakes) are appropriate to consider for sea level rise during the planning period of 100 years.

One approach is to assume that the sediment supply and active beach width remains constant during a change in sea level (equilibrium beach concept). The beach profile is likely to respond to these conditions with an upward and landward translation over time (Komar, 1999). The landward translation of the beach profile (**SLR**) can be defined as a function of SLR (**Δs**) and the active beach slope (**tanα**). This method of describing the equilibrium beach concept is a variation of the Bruun rule and is given in Equation 3 and displayed in Figure 3-1.

$$\boldsymbol{SLR} = \frac{\Delta s}{\tan \alpha} \qquad \text{(Equation 3)}$$

Where:

SLR is the landward translation of the beach profile due to sea level rise (m).

Δs = predicted rise in sea level (m).

tanα = average inter-tidal slope.

Assuming a predicted sea level rise of 0.3 m by 2062 and 0.9 m by 2112 and an intertidal slope of 1:55, the potential landward movement of the beach profile due to the two sea level rise scenarios is given in Table 3-1.

Table 3-1 Sea level rise summary

Planning Period	Intertidal Slope (tanα)	SLR scenario (m)	SLR Distance (m)
2062	0.018	0.3 m	**17**
2112	0.018	0.9 m	**50**

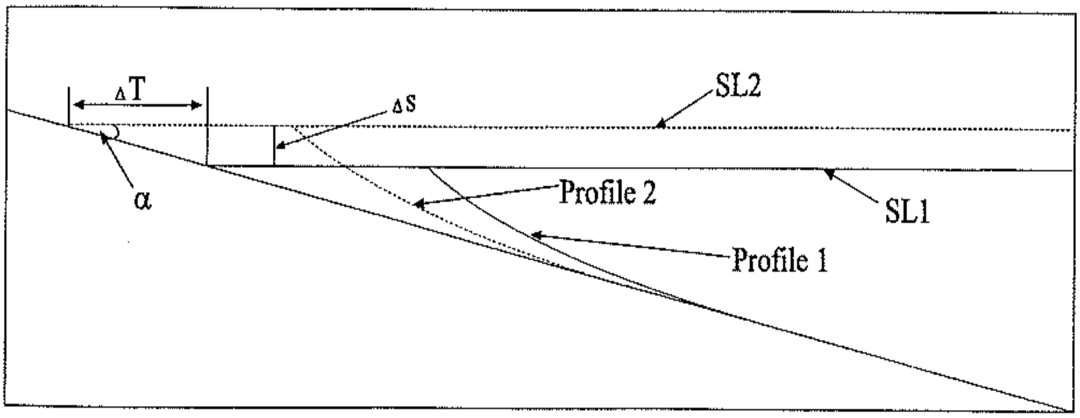


Figure 3-1 Horizontal translation distance of the beach profile under SLR, note the term SLR in Equation 3 is represented by ΔT in this Figure (adopted from Hennecke and Cowell, 2000).

3.1.3.3 Long term rates of shoreline movement (LT)

The long term retreat rate (LT) is an estimate of the average shoreline movement at the toe of the dune. The long term trends were based on linear regression analysis of the dune toe position captured from historical aerial photographs (refer to Section 2.4.1). The analysis provides a linear regression rate (LRR), which utilises all data points over the survey period and is more sensitive to cyclic trends than an end point rate (Dolan *et. al.,* 1991).

The shoreline is experiencing long term accretion. Future shoreline movement may differ from historic trends due to climatic patterns associated with Inter-decadal Pacific Oscillation (IPO) and global climate change. To provide an appropriate precautionary approach, areas of inferred long term accretion has the long term erosion component set to zero. This means that historic accretion is not extrapolated into the future.

3.1.3.4 Short term shoreline movement (ST)

The short term erosion rate takes account of both storm induced erosion and fluctuations around the observed long term trend of shoreline movement.

Short term erosion may occur in response to severe wave storms moving toward the coast from the south west to north east quadrant. However, there are also short term fluctuations in shoreline position over a longer period than an individual storm event. These fluctuations are in response to natural variations in climatic conditions and sediment supply. For example, there may be variations in the direction and magnitude of shoreline movements associated with El Nino Southern Oscillation (ENSO), which typically occur within a three to seven year cycle.

The shoreline fluctuation can be defined by the standard error of estimates (SEE), which is a regression based statistic representing the residuals that is used to estimate population variability. The SEE multiplied by 3 encompasses 99% of the population values and is the most appropriate order of magnitude to represent the maximum extent of shoreline movement that may occur due to significant storm events and cyclical shoreline movement. The 3SEE values obtained from the 5 profile datasets are displayed in Table 2-5. The maximum 3SEE value of 30 (rounded) m was applied as the ST factor along the entire coast.

3.1.3.5 Dune stability (DS)

The dune stability factor delineates the area of potential risk landward of the erosion scarp. This parameter is based on the height of the existing backshore and the angle of repose for loose dune sand (34^{o}). The dune stability factor is outlined in Equation 4 below.

$$DS = \frac{h}{2(\tan \alpha)} \qquad \text{(Equation 4)}$$

The maximum height of existing backshore for the open coast was taken from LiDAR survey as RL 8 m. Based on these parameters the dune stability factor along the open coast was taken as 6 m. This dune stability factor was applied as a horizontal distance from the resulting short term erosion dune toe position for the open coast.

The dune elevations are more variable across the inlet areas. The dune stability factor was based on the maximum elevation along each inlet migration zone for Waikawa (RL 6.6 m), Ohau (RL 18.4 m) and Hokio (RL 7.3 m). The resulting dune stability factors are 25 m, 14 m and 5 m for Waikawa, Ohau and Hokio respectively.

3.1.3.6 Factor of safety (FS)

A factor of safety was applied to account for uncertainties in the short term fluctuation (ST) component due to the limited number of data points. The average Standard Error (SEE) of the 5 beach profile datasets calculated from regression analysis was taken as the FS for this component. The average SEE of 5 m was applied as a factor of safety to all coastal erosion hazard zones.

As the LiDAR survey data and GIS techniques provide a high degree of accuracy in determining dune stability (DS), we did not include a factor of safety in determining (DS). We also consider that sufficient conservatism is incorporated within the (SLR) estimates to negate the need for a further factor of safety component.

3.2 CEHZ results

A summary of the CEHZ open coast distances for the 3 planning time frames is outlined in Table 3-1 below and are shown in Figures 3-2 to 3-5 located in Appendix A. Note constant CEHZ components are applied to all open coast areas resulting in a single CEHZ distance for each time frame.

Table 3-1 Summary of CEHZ open coast components and resulting CEHZ distances

SLR 2062 (m)	SLR 2112 (m)	LT (m/yr)	ST (m)	DS (m)	FS (m)	CEHZ (open coast)		
						Current (m)	2062 (m)	2112 (m)
-17	-50	0	-30	-6	-5	-42	-58	-91

Note that the CEHZ distances shown above are for the open coast sections of shoreline not affected by inlet migration (i.e. as set out in Equation 1). The CEHZ distances for areas adjacent inlets are calculated using Equation 2 which does not include the short term component of 30 m and applies a variable DS component. Table 3-2 displays a summary of the CEHZ distances for inlet areas for the 3 planning time frames.

Table 3-2 Summary of CEHZ inlet component and resulting CEHZ distances

Site	SLR 2062 (m)	SLR 2112 (m)	LT (m/yr)	DS (m)	FS (m)	CEHZ (inlets)		
						Current (m)	2062 (m)	2112 (m)
Hokio	-17	-50	0	-5	-5	-10	-27	-60
Waikawa	-17	-50	0	-5	-5	-10	-27	-60
Ohau	-17	-50	0	-14	-5	-19	-36	-69

3.3 CEHZ mapping

3.3.1 CEHZ origin

The dune toe delineated from 2011 aerial imagery is used as the CEHZ open coast offset origin, which is taken as the seaward edge of shoreline vegetation. The coastal erosion hazard zone is measured horizontally inland from the origin baseline at right angles from the general alignment of the shoreline.

The inlet migration curves (IMC) were used as the inlet offset origin, which are derived from historical inlet shorelines and represent the most landward extent of the inlet. IMC's were derived for both managed and unmanaged inlets. The managed IMC is derived from inlet extents after some sort of channel modification has occurred (such as a groyne, channel protection, etc) that alters the natural inlet processes. The unmanaged IMC is derived from inlet extents prior to any modification. The managed IMC was used as the origin for both the current and the 50 year time frame (i.e. CEHZ and 2060EHZ). The unmanaged IMC was used as the origin for the 100 year time frame (2112EHZ). The exception being Ohau were the unmanaged IMC was used as the inlet offset origin for all 3 planning time frames because no management modifications have been implemented at this site.

3.3.2 CEHZ validation

The GIS model has been tested and validated during development in terms of ensuring the calculations are correct and the results verify what is occurring on the ground.

The model output (i.e. the three coastal erosion hazard risk zones) was validated at four locations:

i. Hokio (E2694935 N6065693 NZMG)
ii. Waikawa (E2691496 N6055228 NZMG)
iii. Waitarere (E2695988 N6071275 NZMG)
iv. Ohau (E2692826 N6058451 NZMG)

The following validation checks were made at each of the four locations:

- The coastal erosion hazard risk zone distances are an accumulation of the correct coastal erosion hazard components (i.e. the correct equation has been applied).
- The coastal erosion hazard risk zones are plotted at the correct distance from the dune toe feature (i.e. the correct transformation from horizontal distance to XY position has been applied).

All four locations passed the two validation checks listed above.

4 Coastal inundation hazard assessment

4.1 Methodology

A coastal inundation hazard zone (CIHZ) was assessed for storm surge and wave events only (i.e. no tsunami or river flooding). Coastal inundation was assessed for three scenarios:

- Current the existing situation
- 2062 possible inundation levels for next 50 years, taking into account predicted effects of climate change
- 2112 possible inundation levels for next 100 years, taking into account predicted effects of climate change

Design levels for each scenario where assessed for both tidal conditions (no wave effects) and tide plus wave effects. Wave effects were assessed for both open coast and inlet coasts. Open coast wave effects included wave set up and wave run up (which included a set up component). Wave effects along inlet coasts (Waikawa and Hokio) was estimated using an estimate on maximum wave height possible based on average water depth at the Waikawa river mouth for the three still water scenarios.

The equations and parameters required to determine the required inundation elevations are discussed below.

The 1% AEP still water level in terms of MVD at the open coast and inlets was assessed using equations 3, 4 and 5 below.

Current 1% AEP = $MHWS + S_s$ *Equation (5)*

2062 1% AEP = $MHWS + S_s + \gamma + SLR$ *Equation (6)*

2112 1% AEP = $MHWS + S_s + \gamma + SLR$ *Equation (7)*

The 1% AEP still water plus 1% AEP wave effects level in terms of RL at the open coast was assessed using equations 7 to 15 below.

Wave Set up:

Current 1% AEP = $MHWS + S_s + \eta_{max}$ *Equation (8)*

2062 1% AEP = $MHWS + S_s + \gamma + SLR + \eta_{max}$ *Equation (9)*

2112 1% AEP = $MHWS + S_s + \gamma + SLR + \eta_{max}$ *Equation (10)*

Wave Run up:

Current 1% AEP = $MHWS + S_s + R_{2\%}$ *Equation (11)*

2062 1% AEP = $MHWS + S_s + \gamma + SLR + R_{2\%}$ *Equation (12)*

2112 1% AEP = $MHWS + S_s + \gamma + SLR + R_{2\%}$ *Equation (13)*

Inlet Wave effects:

Current 1% AEP = $MHWS + S_s + Iw$ *Equation (14)*

2062 1% AEP = $MHWS + S_s + \gamma + SLR + Iw$ *Equation (15)*

2112 1% AEP = $MHWS + S_s + \gamma + SLR + Iw$ *Equation (16)*

Where:

MHWS	=	'pragmatic' MHWS tide level based on tide data (Kapiti Island) and local observations
S_s	=	storm surge
η_{max}	=	maximum open coast wave setup
$R_{2\%}$	=	2% wave run-up elevation (including wave setup)
γ	=	IPO/ENSO/annual variation in MLOS of 0.25 m.
SLR	=	sea-level rise (0.3 m for 2062 and 0.9 m for 2112)
Iw	=	maximum wave at river mouth based on average water depth.

The following sections provide further descriptions of the parameters.

4.1.1 Components

4.1.1.1 MHWS

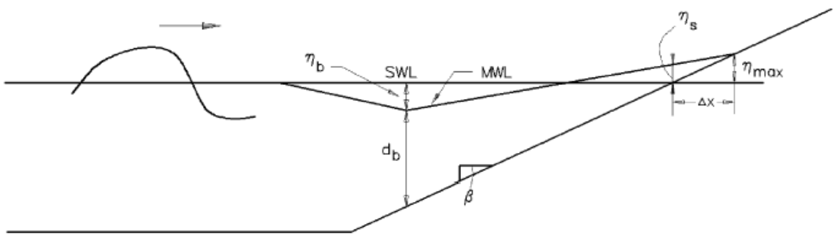
MHWS of 1.2 m was used, refer Section 2.2.1.

4.1.1.2 Storm surge (S_s)

A storm surge value of 0.9 m, refer Section 2.2.2.

4.1.1.3 Open coast wave set up (η_{max})

The variation of the still water level (SWL) due to wave setup was evaluated using the offshore wave conditions derived from McComb et.al 2010 (refer to Section 2.3). The maximum wave setup was calculated using the methodology detailed in Chapter II-4-3 of the Coastal Engineering Manual (2008). Relevant parameters describing the derivation of wave setup are shown below.



Where:

η_b = wave set down (m)

η_s = wave setup at the still water level (m)

η_{max} = maximum wave setup (m)

d_b = depth of wave breaking (m)

SWL = still water level (m)

MWL = mean water level (m)

β = beach slope from the break point to the upper beach.

A water depth of 12.9 m at the break point was estimated using a breaking ratio of 0.55 and 1% AEP wave of 7.09 m Hs. Beach slope was estimated using hydrographic chart NZ4631 at the most northern extent. Using the above method and parameters resulted in a wave setup along the open coast of **2.01 m** for a 1% AEP event.

4.1.1.4 Open coast wave runup assessment ($R_{2\%}$)

The estimate of wave runup elevation is defined as the level exceeded by 2% of the waves, which includes wave setup. An assessment of wave run up elevations has been undertaken by Shand et.al (2012) at Otaki, located just outside the southern extent of the study area. We consider the beach morphologies and wave climate for Otaki and are very similar and can be applied for this project.

The Shand et al (2012) study undertook wave runup measurements which were correlated with a number of wave runup formula. Based on the local wave and beach conditions at Otaki the runup formula of Mase (1989) and Hedges & Mase (2001) provided the best correlation with measured wave runup.

The two wave runup equations that best represent wave run up at Otaki are below:

Mase (1989)

$$\frac{R_{2\%}}{H_0} = 1.86\xi_0^{0.71}$$

Equation (16)

Hedges and Mase (2001)

$$R_{2\%} = (0.34 + 1.49\xi_0)H_S$$

Equation (17)

Where:

H_s & ***H_0*** = Deepwater significant wave height

ξ_0 = Iribarren number.

Wave run up elevation for this project were calculated using an average of both Mase (1989) and Hedges and Mase (2001) based on the1% AEP design wave (7.09 m H_s and 12 s Period, T) and average intertidal beach slope along the study area of 1:55. The average intertidal beach slope was calculated using available HRC beach profile data (XS17 to XS22). Table 4-1 shows a summary of wave run up estimates.

Table 4-1 Summary of wave runup estimates

	Mase (1989)	**Hedges and Mase (2001)**
Average (m)	3.09	3.78
Maximum (m)	3.43	4.00
Minimum (m)	2.90	3.66
Combined Average (m)	3.43	
Combined Maximum (m)	3.71	
Combined Minimum (m)	3.28	

The combined average of **3.4 m** was used to estimate wave runup ($R_{2\%}$) for open coasts for a 1% AEP event.

4.1.1.5 Sea level variation (γ)

Sea level variation occurs due to thermal expansion and contraction due to changes in sea surface temperatures and associated currents. This variation in sea level is related to climate cycles of varying time periods. The combined variation in sea level over the climate cycles results in a total variation of +/- **0.25 m, which applies to the 2062 and 2112 scenarios only**. Figure 4-1 summarises the components and variations.

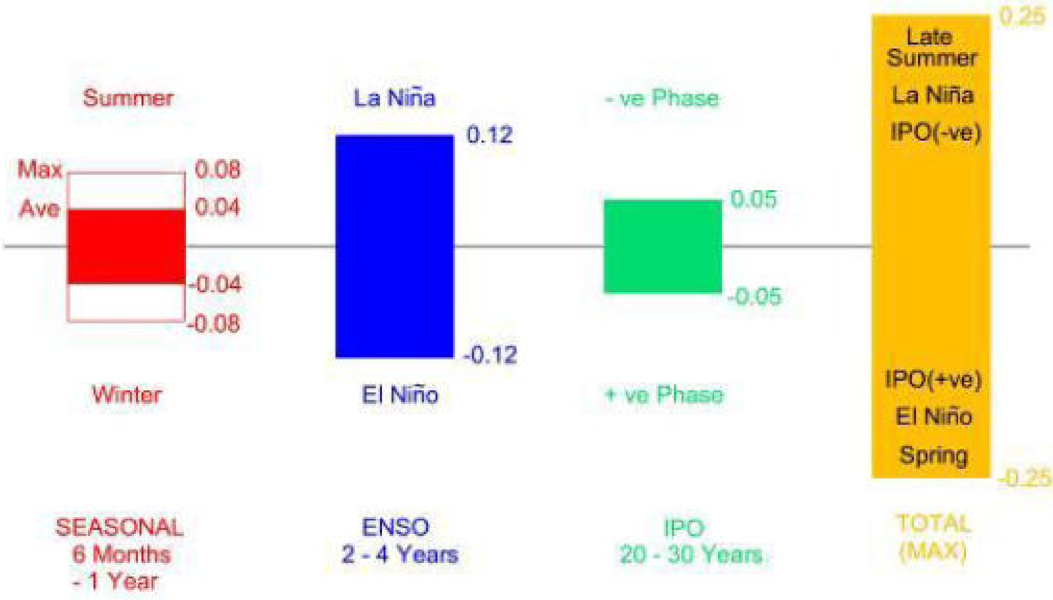


Figure 4-1 Components contributing to sea level variation over long term periods. Source Bell 2012.

4.1.1.6 Sea level rise (SLR)

The SLR components for 2062 is 0.3 m and for 2112 is 0.9 m (refer to Section 2.2.3).

4.1.1.7 Inlet wave effects

Wave shoaling within inlets is likely to dissipate wave height affecting the inlet shorelines. Wave heights within the inlets where estimated based on water depths for the Waikawa inlet for the current, 2062 and 2112 1% AEP tide and storm surge scenarios. The average water depth (above MHWS) for Waikawa was estimated using elevations sourced from LiDAR derived DEM data. A breaker ratio of 0.78 was used to determine a typical wave height.

A breaker ratio of 0.78 represents a solitary wave rather than incident wave conditions. We consider that the use of the resulting solitary wave height is sufficient to account for wave effects within both Waikawa and Hokio inlets. Table 4-2 shows the estimates of inlet wave heights for the three still water level scenarios.

Table 4-2 Estimated inlet wave heights

Scenario	Tide and Storm surge elevation (m)	Water depth (m)	Max wave height (m)
Current 1%AEP	2.1	0.70	0.55
1% AEP 2062	2.7	1.31	1.02
1% AEP 2112	3.3	1.85	1.44

4.2 Coastal inundation hazard results

Table 4-3 Summaries the components and final coastal inundation levels (1% AEP) for the Current, 2062 and 2112 scenarios. The resulting inundation levels are considered appropriate for providing guidance on both existing development areas and possible future development areas.

Table 4-3 Summary of inundation components and final inundation levels

Parameter		Scenario		
		Current	2062	2112
Tide and Storm Surge	MHWS (m MVD)	1.2	1.2	1.2
	Sea level rise (m)	0.00	0.3	0.9
	Storm surge (m)	0.90	0.90	0.90
	Sea level variation (m)	0.00	0.25	0.25
Total Tide and Storm Surge (m MVD)		**2.1**	**2.7**	**3.3**
Wave effects	Inlet coast (m MVD)	2.6	3.7	4.7
	Wave set up open coast (m MVD)	4.1	4.7	5.3
	Wave runup open coast (m MVD)	5.5	6.1	6.7

The combination (joint probability) of a 1% AEP Total tide and Storm surge event with a 1% AEP wave event is likely to produce an AEP less than 1%. Therefore, we consider the total inundation elevation including wave effects is likely to provide a conservative estimate of inundation hazards currently and in the future.

4.3 Coastal inundation hazard mapping

All inundation elevations were mapped using a HRC derived DEM to the nearest 0.1 m. A ‘bath tub’ GIS model was used to map the extent of each inundation elevation. The model only inundated areas when water could flow. Therefore low lying areas behind elevated land (i.e. dunes or stop banks) could only be ‘flooded’ if the water elevation over topped raised land.

Inundation extents using the IMC extents have also been undertaken for Waikawa and Hokio. A modified DEM was used with the area seaward of the IMC (100 year unmanaged) lines being set to an elevation of MHWS. The DEM inlet modification was to ascertain if additional inundation was possible should the inlets retreat. The inundation model was rerun using the modified DEM and the 2112 scenario with inlet wave effects (4.7 m MVD).

The landward extent of inundation due to wave effects has been truncated using local catchment boundaries.

The inundation extents are shown in Figures 4-2 to 4-10 located in Appendix A.

We note that the accuracy of the DEM derived from photogrammetric methods may be insufficient to clearly identify inundation extents. The DEM derived by photogrammetric methods includes non ground features such as buildings and vegetation (trees).

In particular, caution should be given to the inundation extents for the Hokio area due to DEM accuracy issues. We also note that the DEM does not cover the entire developed area of Hokio.

Therefore, we do not recommend the inundation extents derived by photogrammetric methods for Hokio are used for regulatory purposes, such as District Plans or for public information such as LIM reports.

5 Areas Sensitive to Coastal Hazards

An ASCH (Area Sensitive to Coastal Hazards) was used as a conservative setback from Waikawa to Hokio and from Hokio to Waitarere. The ASHZ is derived from both the 100 year CEHZ (including unmanaged IMC's) and inundation zones. The most landward extent of all hazard zones represents the ASCH. In most areas the ASCH represents the 2112 coastal erosion hazard.

Refer to Figures 5-1 to 5-5 showing the ASCH line. In Figures 5-1 and 5-2 the inundation extent is truncated by the landward limit of the DEM supplied. We recommend that further investigation is required to determine the landward extent of coastal inundation for the Ohau River area.

6 Summary

Approximately 19km of shoreline from Waikawa Beach to Waitarere Beach has been assessed for coastal hazards. For the three developed areas at Waikawa Beach, Hokio Beach and Waitarere Beach a comprehensive CEHZ (Coastal Erosion Hazard Zone) and CIHZ (Coastal Inundation Hazard Zone) assessment was undertaken. For the areas in between an ASCH (Area Sensitive to Coastal Hazards) assessment was undertaken.

An assessment of open coast shoreline trends showed that:

- The Hokio shoreline on the northern side of the river mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the river inlet migration zone is building out at a rate of 1.30 m/yr.
- The Waikawa shoreline has shown the greatest rate of shoreline accretion over the study area. The shoreline to the south of the river inlet migration zone is building out at a rate of 3.40 m/yr.
- The Waitarere shoreline on the northern side of the stream mouth is building out at an average rate of 2.10 m/yr. The shoreline to the south of the stream is building out at a rate of 1.70 m/yr.

For the dynamic inlets at Waikawa, Ohau and Hokio, IMC's (Inlet Migration Curves) were compiled for both managed (man-made controls such as groynes and hard protection) and unmanaged regimes.

CEHZ's were assessed for the current (2012), 50 year (2062) and 100 year (2112) time periods. The table below summarises coastal erosion setbacks along the open coast and within inlets. The CEHZ for the open coast is measured landward of the 2011 dune toe (i.e. seaward edge of shoreline vegetation). The CEHZ for the inlets is measured landward of the site specific IMC.

	CEHZ Open Coast Setbacks			**CEHZ Inlet Setbacks**		
Site	**Current**	**2062**	**2112**	**Current**	**2062**	**2112**
Waikawa	-42	-58	-91	-10	-27	-60
Ohau	na	na	na	-19	-36	-69
Hokio	-42	-58	-91	-10	-27	-60
Waitarere	-42	-58	-91	na	na	na

CIHZ's were also assessed for the same time periods as the CEHZ for all areas and summarised in the table below. All elevations given in the table below are for a 1% AEP event.

Parameter		**Current**	**2062**	**2112**
Total Tide and Storm Surge (m MVD)		**2.1**	**2.7**	**3.3**
Wave effects	Inlet coast (m MVD)	2.6	3.7	4.7
	Wave set up open coast (m MVD)	4.1	4.7	5.3
	Wave run up open coast (m MVD)	5.5	6.1	6.7

Further refinement of the inundation elevations, especially the effects of waves along the inlet shorelines are recommended. We also recommend a reassessment of inundation extents derived by photogrammetric methods, due to possible inaccuracies and inconsistencies.

Therefore, we do not recommend the inundation extents derived by photogrammetric methods for Hokio are used for regulatory purposes, such as District Plans or for public information such as LIM reports.

7 Applicability

This report has been prepared for the benefit of Horizons Regional Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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Hccl

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Appendix A: Coastal Hazard Figures

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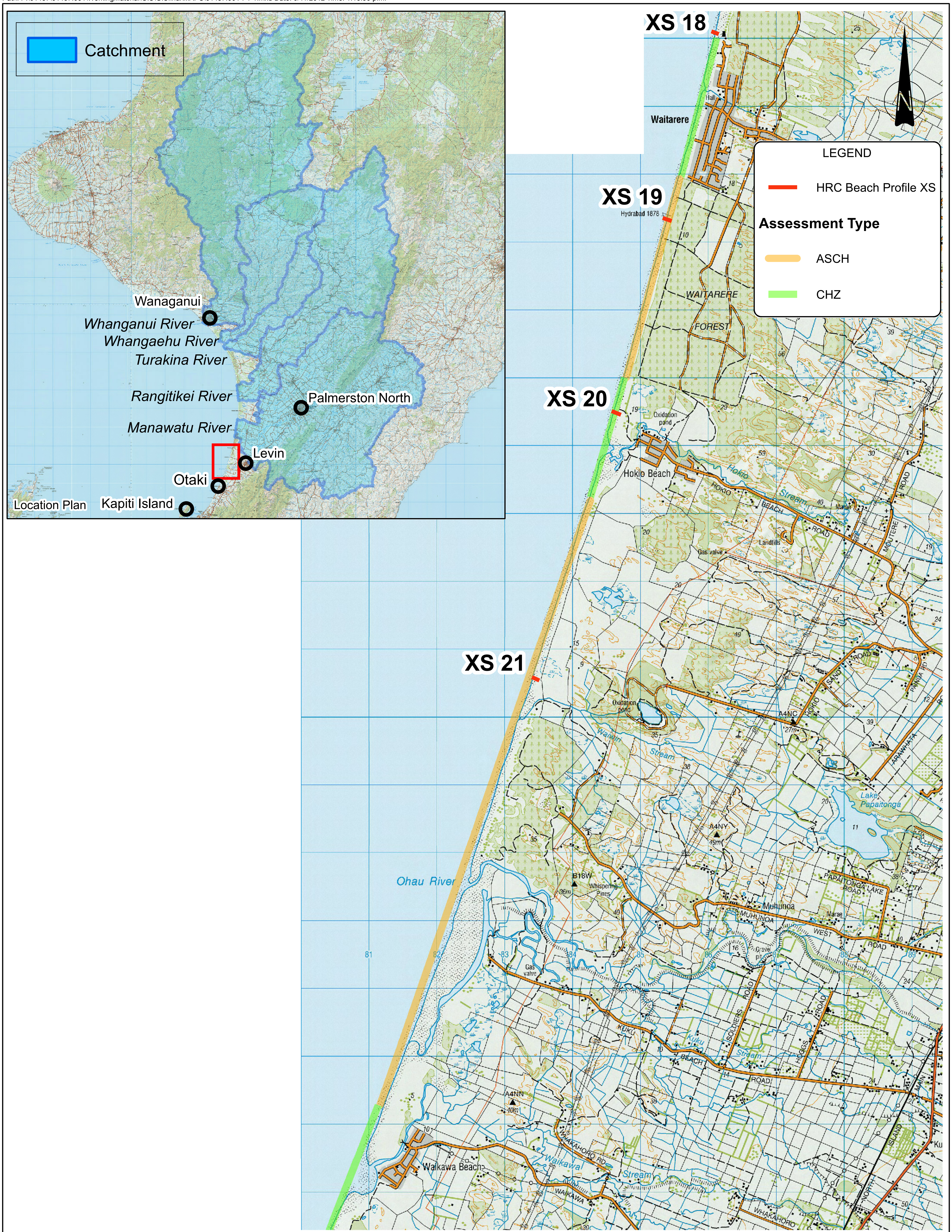

Notes: Map: NZTOPO50

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SCALE (AT A3 SIZE) 1:50,000

PROJECT No. 61457.001

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Locations

FIGURE No. Figure 1-1.

Rev. 0

Notes: Aerial photograph 2011. Source HRC
DEM 2006 LiDAR derived. Source HRC

A3 SCALE 1:5,000

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Location Plan

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SCALE (AT A3 SIZE) 1:5,000

PROJECT No. 61457.001

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Topography Waikawa

FIGURE No. Figure 2-2

Rev. 0

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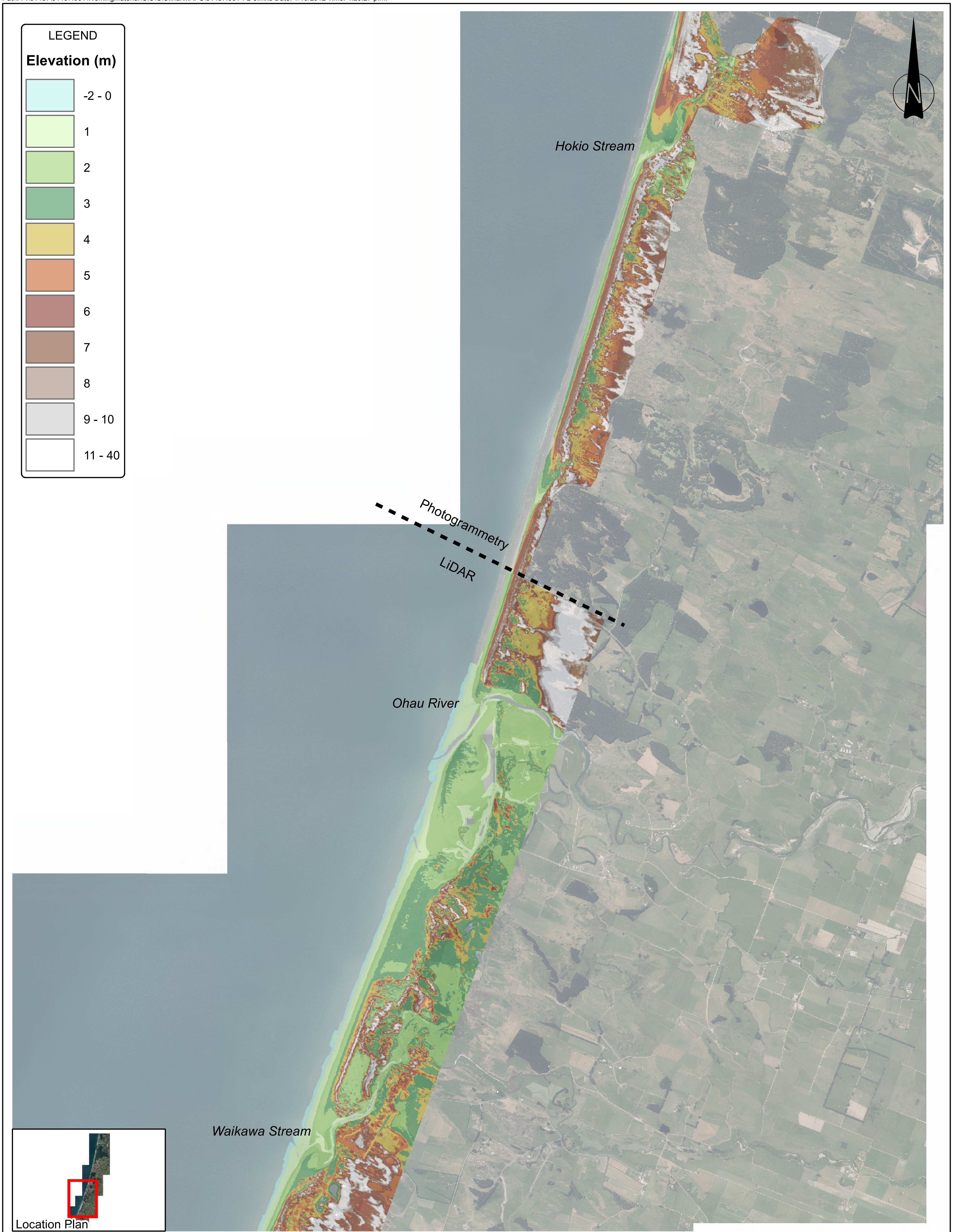

Notes: Aerial photograph 2011. Source HRC
DEM combined 2006 LiDAR and
2011 photogrammetry derived. Source HRC

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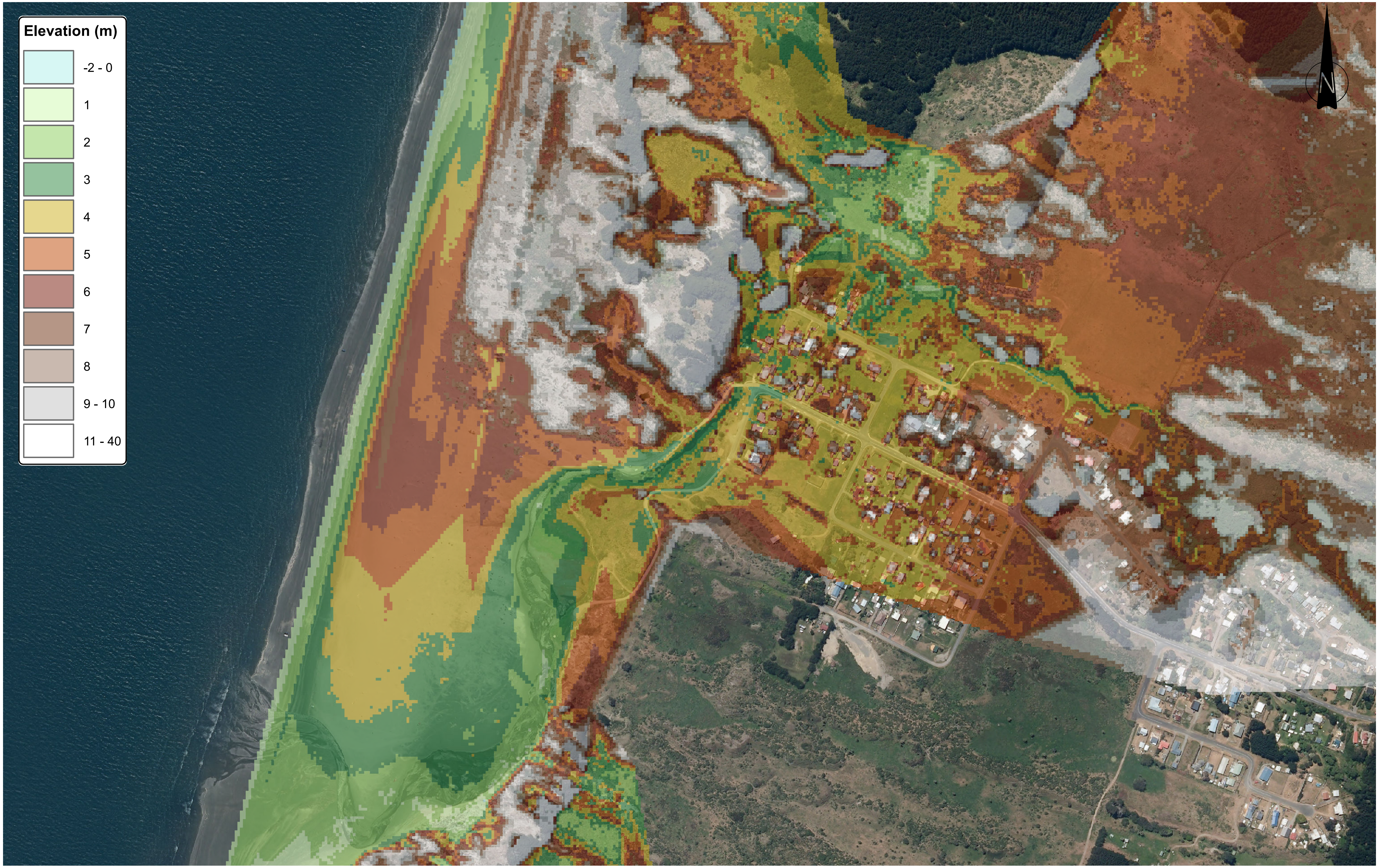
PROJECT No. 61457.001		

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Topography Waikawa to Hokio

FIGURE No. Figure 2-3

Rev. 0



Notes: Aerial photograph 2011. Source HRC
DEM 2011 photogrammetry derived. Source HRC

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Location Plan

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PROJECT No. 61457.001		

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Topography Hokio

FIGURE No. Figure 2-4

Rev. 0

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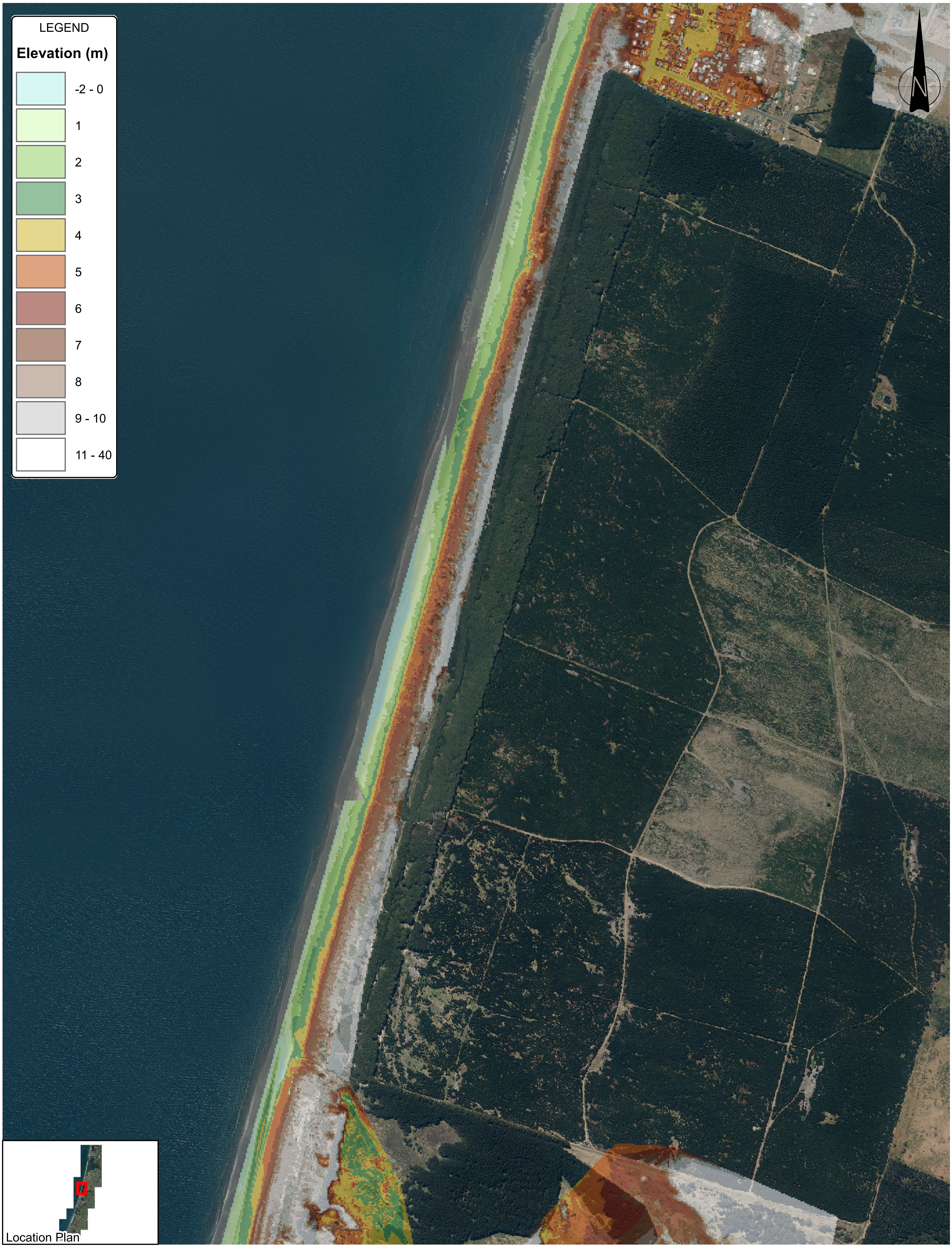

Notes: Aerial photograph 2011. Source HRC
DEM 2011 photogrammetry derived.
Source HRC

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DRAWN	Hccl	Oct.12
CHECKED		
APPROVED		

ARCFILE 61457.001-F2-5.mxd

SCALE (AT A3 SIZE) 1:10,000

PROJECT No. 61457.001

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Topography Hokio to Waitarere

FIGURE No. Figure 2-5

Rev. 0

Notes: Aerial photograph 2011. Source HRC
DEM 2011 Photogrammetry derived. Source HRC

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Location Plan

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DRAWN	Hccl	Oct.12
CHECKED		
APPROVED		
ARCFILE 61457.001-F2-6.mxd		
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PROJECT No. 61457.001		

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Topography Waitarere

FIGURE No. Figure 2-6

Rev. 0

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Notes: Aerial photograph taken in 2011 and sourced from Horizons Regional Council

A3 SCALE 1:10,000

0 0.1 0.2 0.3 0.4 0.5 (km)

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COASTAL HAZARD ASSESSMENT
Historic Shoreline Positions
Waikawa

FIG No. Figure 2-8.

Rev. 0

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Historic Shoreline Positions
Ohau

FIG No. Figure 2-9.

Rev. 0

Notes: Aerial photograph taken in 2011 and sourced from Horizons Regional Council

A3 SCALE 1:10,000
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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Historic Shoreline Positions
Hokio

FIG No. Figure 2-10.

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Historic Shoreline Positions
Waitatere

FIG No. Figure 2-11.

Rev. 0

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Notes: Aerial photograph taken in 2011 and sourced from Horizons Regional Council

A3 SCALE 1:5,000

0 100 200 300 Meters

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Erosion Hazard Zones
Waikawa

FIG No. Figure 3-2.

Rev. 0

Notes: Aerial photograph taken in 2011 and sourced from Horizons Regional Council

A3 SCALE 1:15,000

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PROJECT No. 61457.001		

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Erosion Hazard Zones
Ohau

FIG No. Figure 3-3.

Rev. 0

Notes: Aerial photograph taken in 2011 and sourced from Horizons Regional Council

A3 SCALE 1:5,000
0 100 200 Meters

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PROJECT No. 61457.001		

HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Erosion Hazard Zones
Hokio

FIG No. Figure 3-4.

Rev. 0

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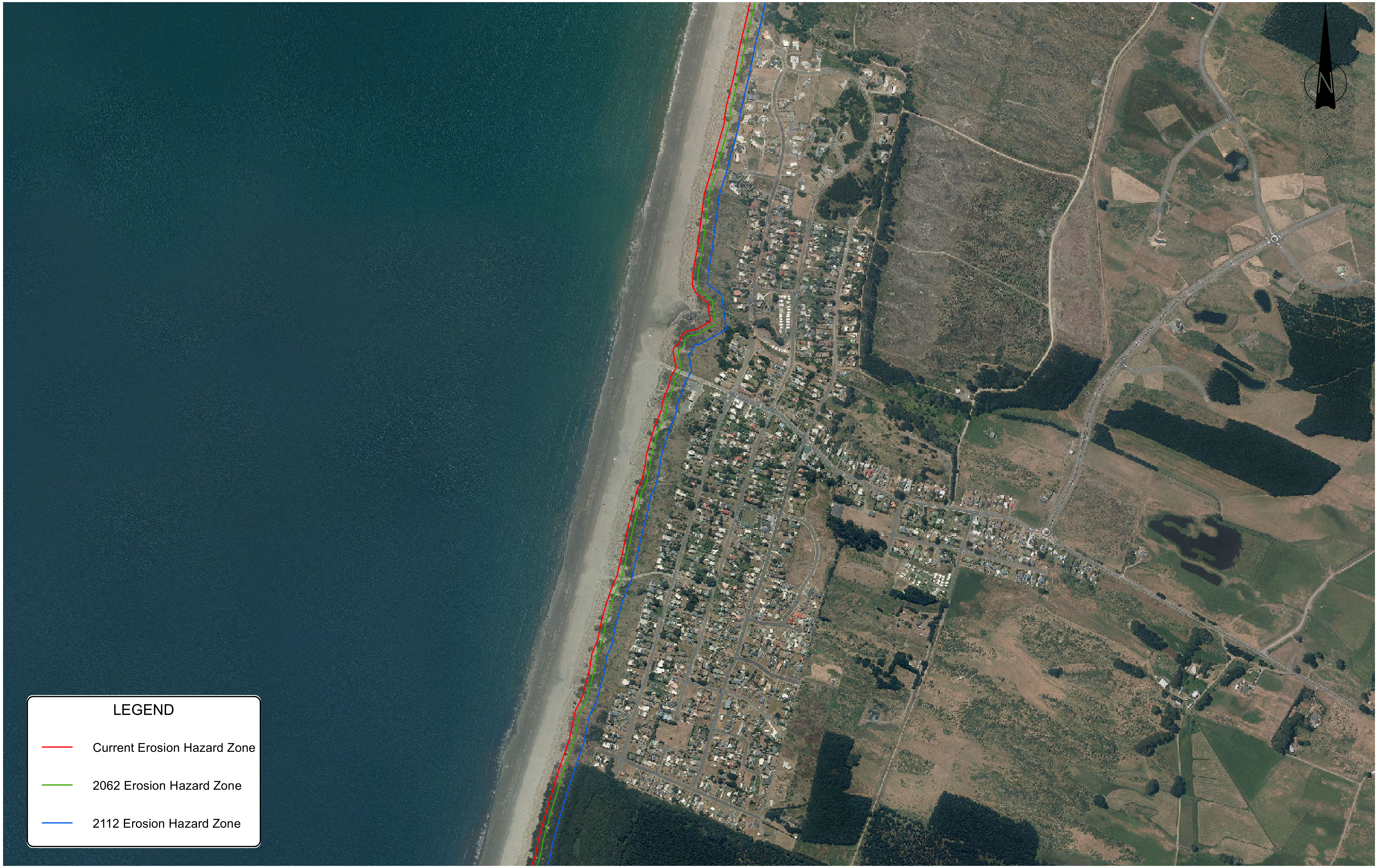

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Erosion Hazard Zones
Waitatere

FIG No. Figure 3-5.

Rev. 0

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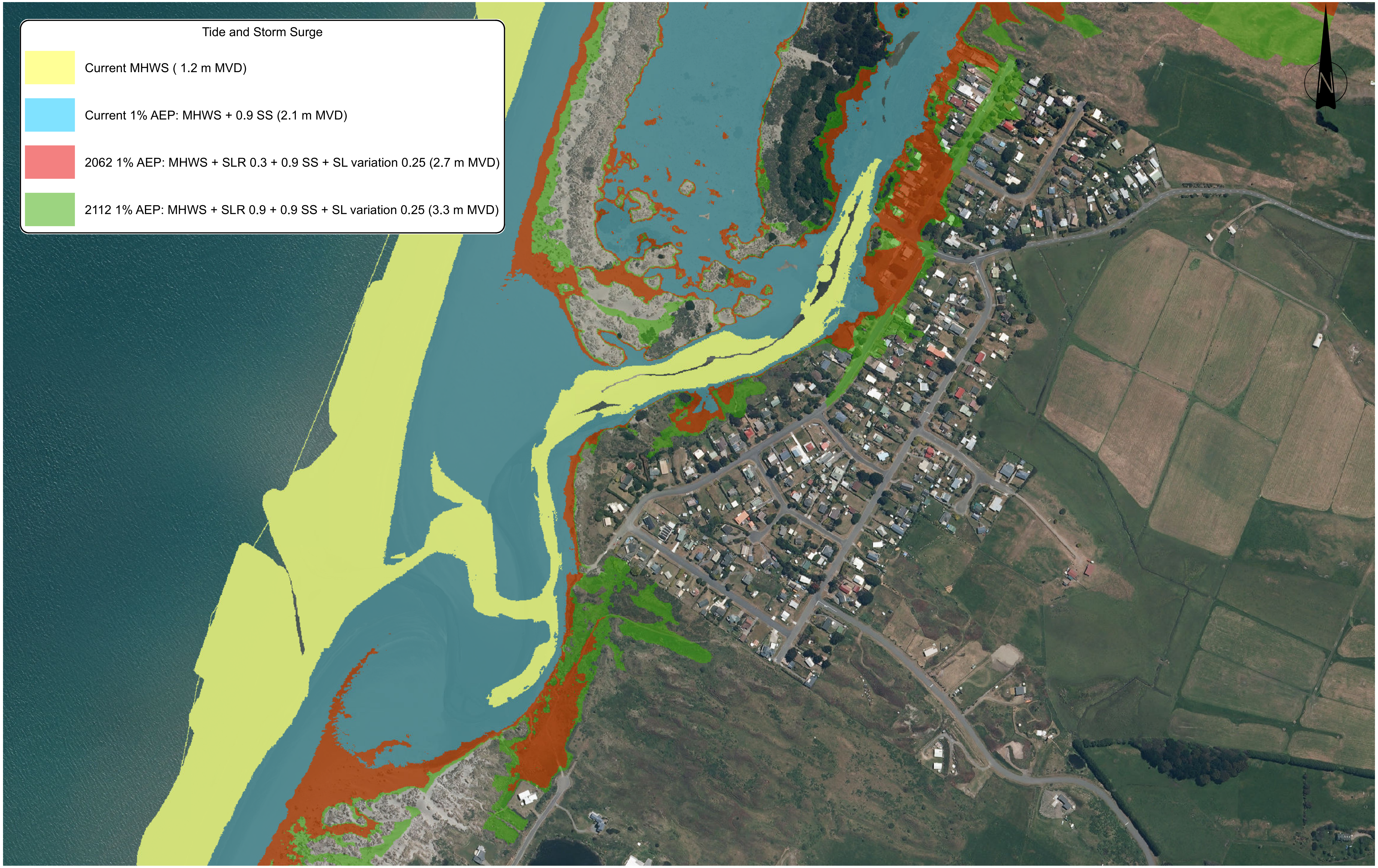

Notes: Aerial photograph 2011. Source HRC
2062 and 2112 set up extents truncated at watershed boundaries shown.
Inundation based on LiDAR derived DEM. Source HRC

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)


Location Plan

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waikawa

FIGURE No. Figure 4-2.

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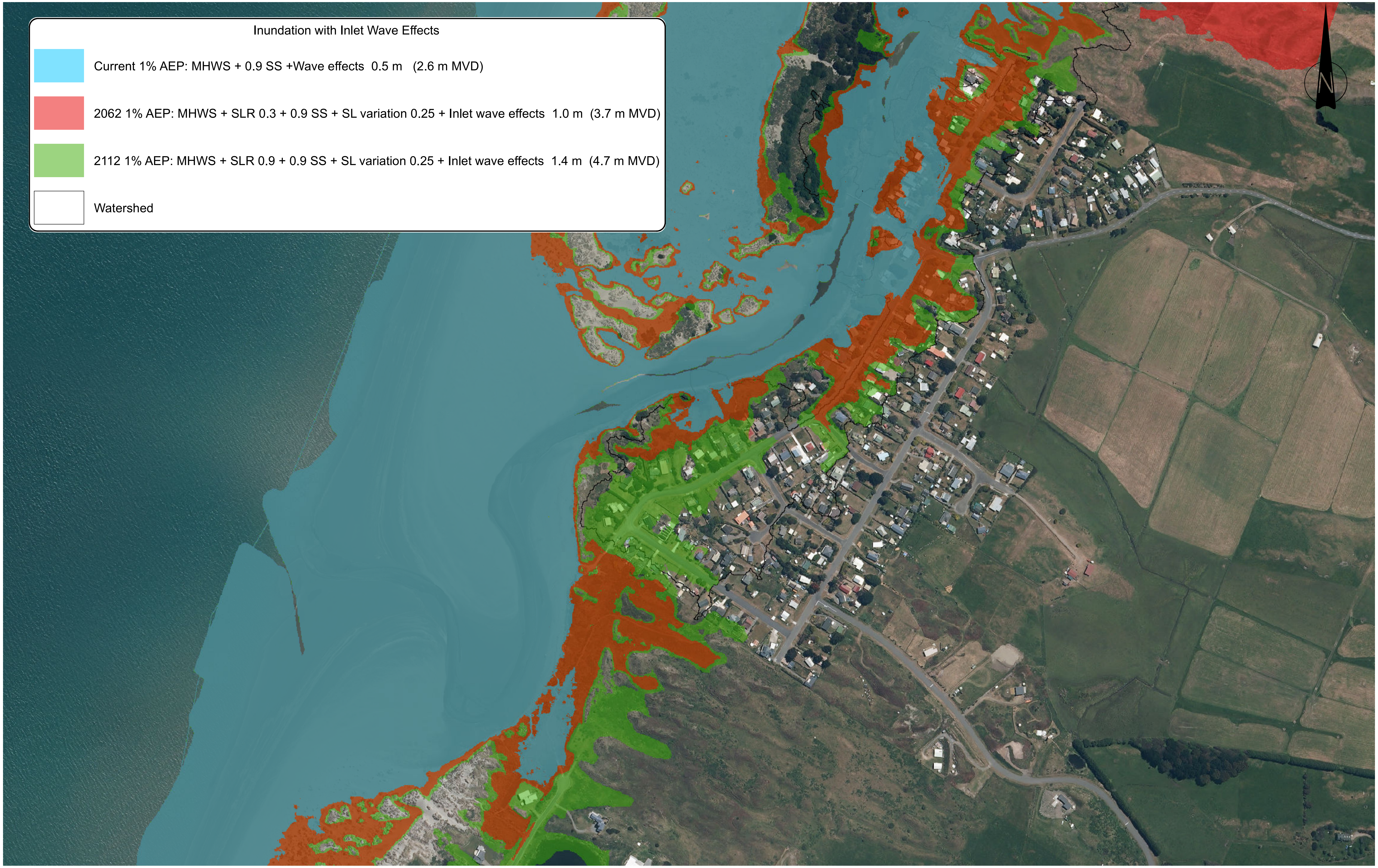

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Inundation based on LiDAR derived DEM. Source HRC

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)


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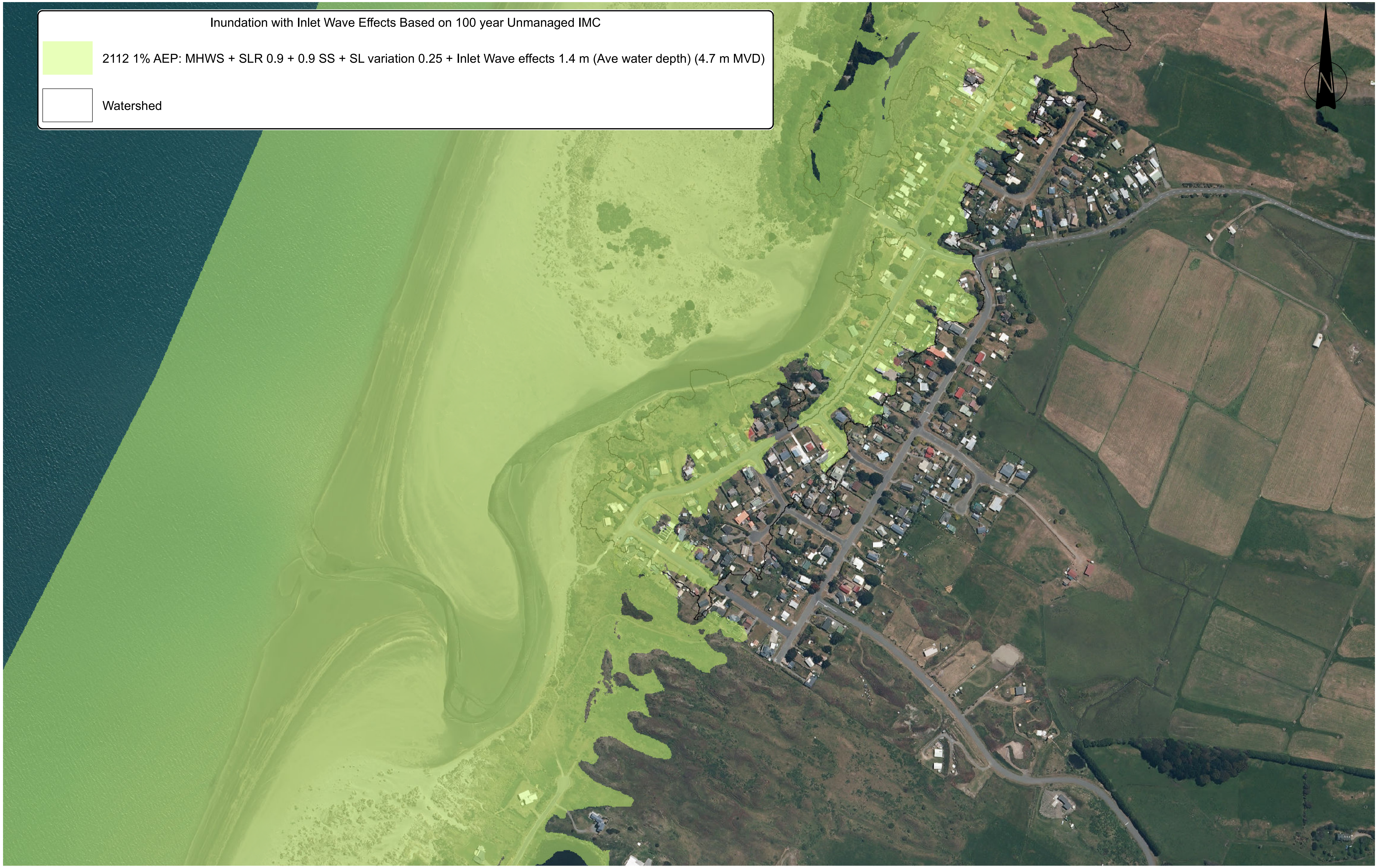
HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waikawa

FIGURE No. Figure 4-3.

Rev. 0



Notes: Aerial photograph 2011. Source HRC
2112 set up extents truncated at watershed boundaries shown.
Inundation based on LiDAR derived DEM. Source HRC

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waikawa

FIGURE No. Figure 4-4.

Rev. 0

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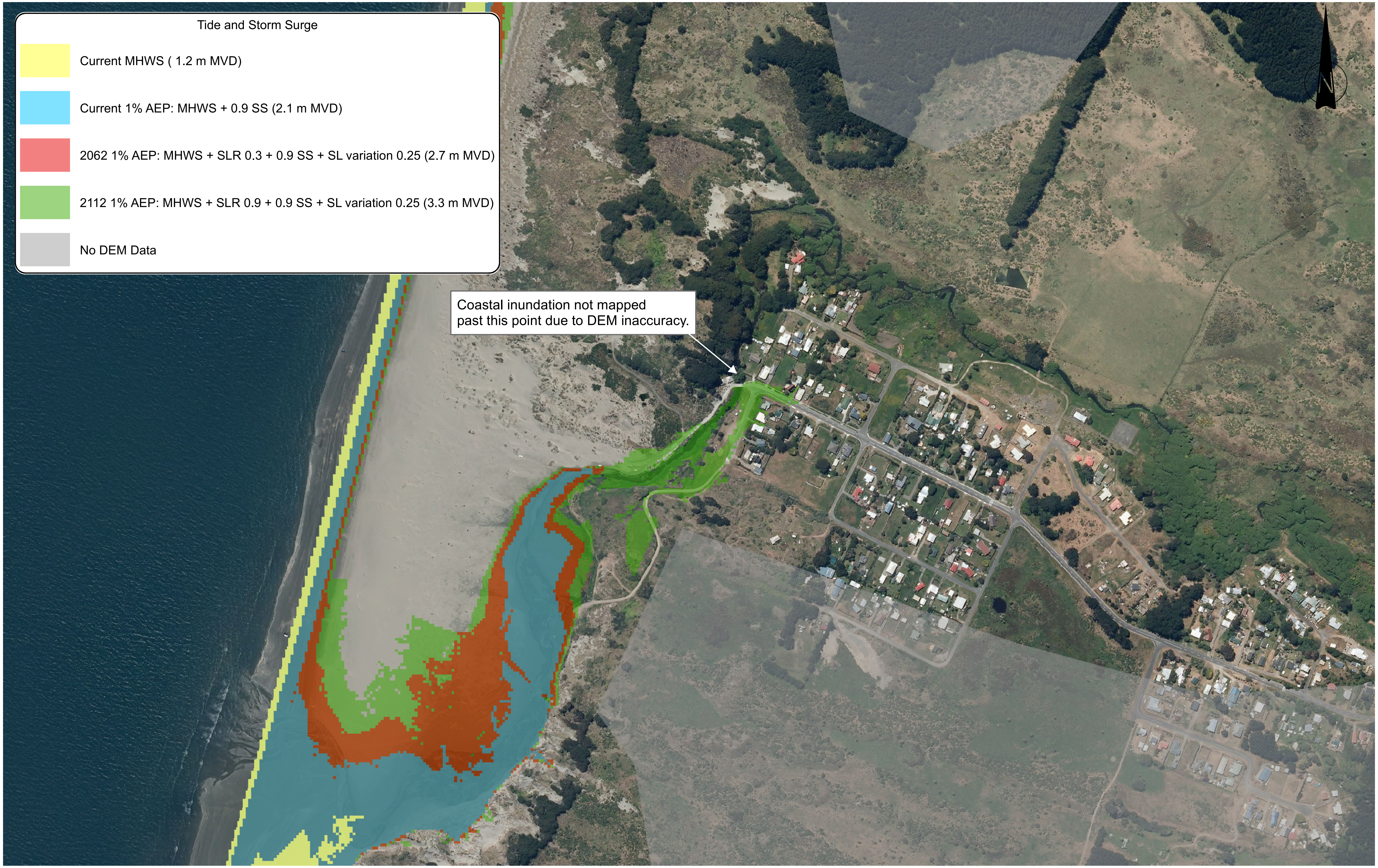

Notes: Aerial photograph 2011. Source HRC
Inundation based on Photogrammetry derived DEM. Source HRC
Coastal inundation not mapped landward of DEM extent

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)

Location Plan

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Hokio

FIGURE No. Figure 4-5.

Rev. 0

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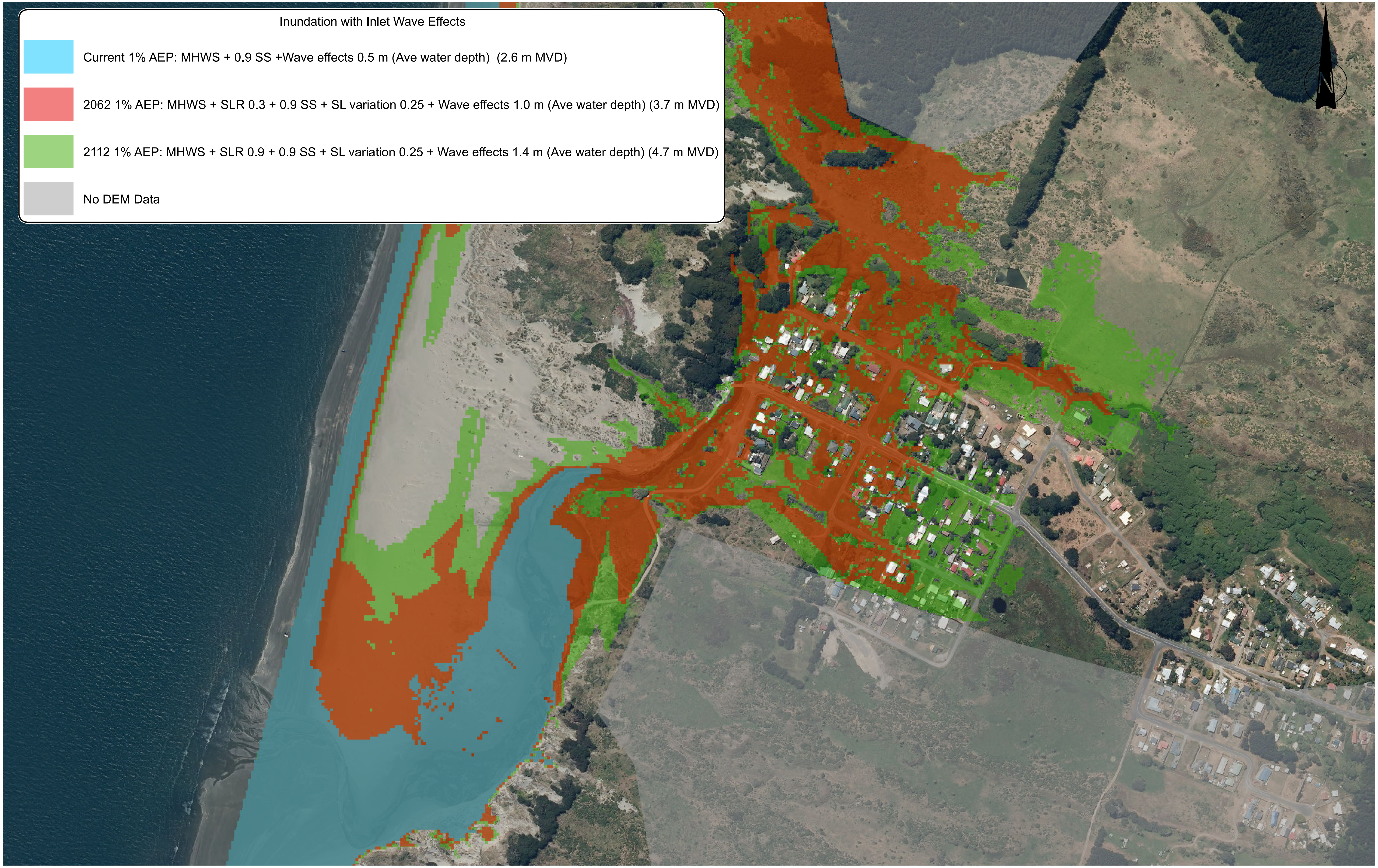

Notes: Aerial photograph 2011. Source HRC
Inundation based on Photogrammetry derived DEM. Source HRC
Coastal inundation not mapped landward of DEM extent

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)

Location Plan

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Hokio

FIGURE No. Figure 4-6.

Rev. 0

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Coastal inundation not mapped landward of the DEM extent

A3 SCALE 1:5,000

0 100 200 300 400 500 (m)

Location Plan

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COASTAL HAZARD ASSESSMENT
Coastal Inundation Hokio

FIGURE No. Figure 4-7.

Rev. 0

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Notes: Aerial photograph 2011. Source HRC
Inundation based on Photogrammetry derived DEM. Source HRC

A3 SCALE 1:10,000

0 200 400 600 800 1,000 (m)

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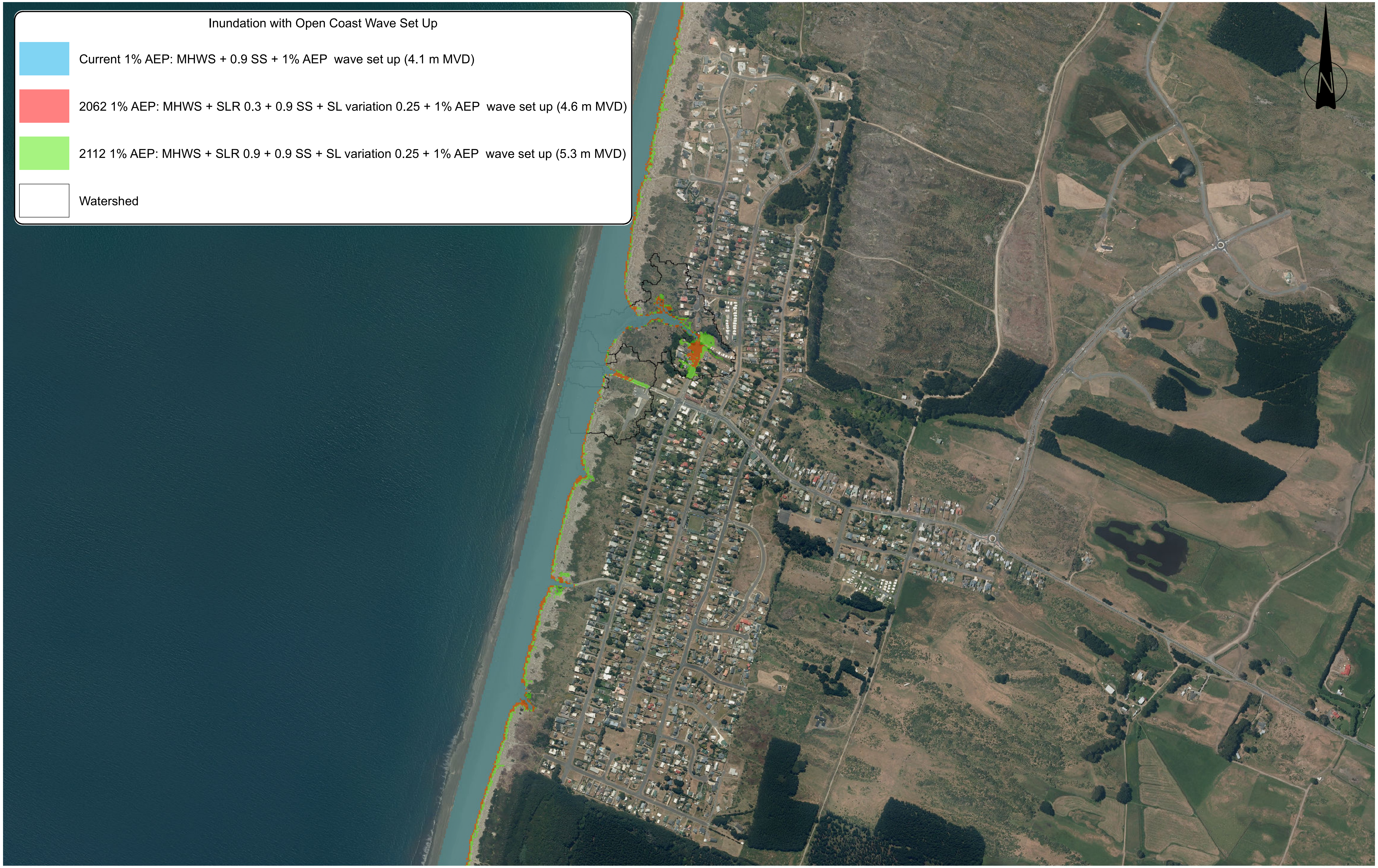
HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waitarere

FIGURE No. Figure 4-8.
Rev. 0



Notes: Aerial photograph 2011. Source HRC
Current, 2062 and 2112 run up extents truncated at watershed boundaries shown.
Inundation based on Photogrammetry derived DEM. Source HRC

A3 SCALE 1:10,000

0 200 400 600 800 1,000 (m)

Location Plan

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waitarere

FIGURE No. Figure 4-9.

Rev. 0

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Inundation based on Photogrammetry derived DEM. Source HRC

A3 SCALE 1:10,000

0 200 400 600 800 1,000 (m)

Location Plan

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
Coastal Inundation Waitarere

FIGURE No. Figure 4-10.

Rev. 0

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Notes: Aerial photograph 2011. Source HRC

A3 SCALE 1:10,000

0 0.1 0.2 0.3 0.4 0.5 (km)

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COASTAL HAZARD ASSESSMENT
ASCH Waikawa and Ohau

FIGURE No. Figure 5 -1

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Notes: Aerial photograph 2011. Source HRC

A3 SCALE 1:10,000

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
ASCH Ohau North

FIGURE No. Figure 5 -2

Rev. 0

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Notes: Aerial photograph 2011. Source HRC

A3 SCALE 1:10,000

0 0.1 0.2 0.3 0.4 0.5 (km)

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
ASCH Ohau North to Hokio

FIGURE No. Figure 5 -3

Rev. 0

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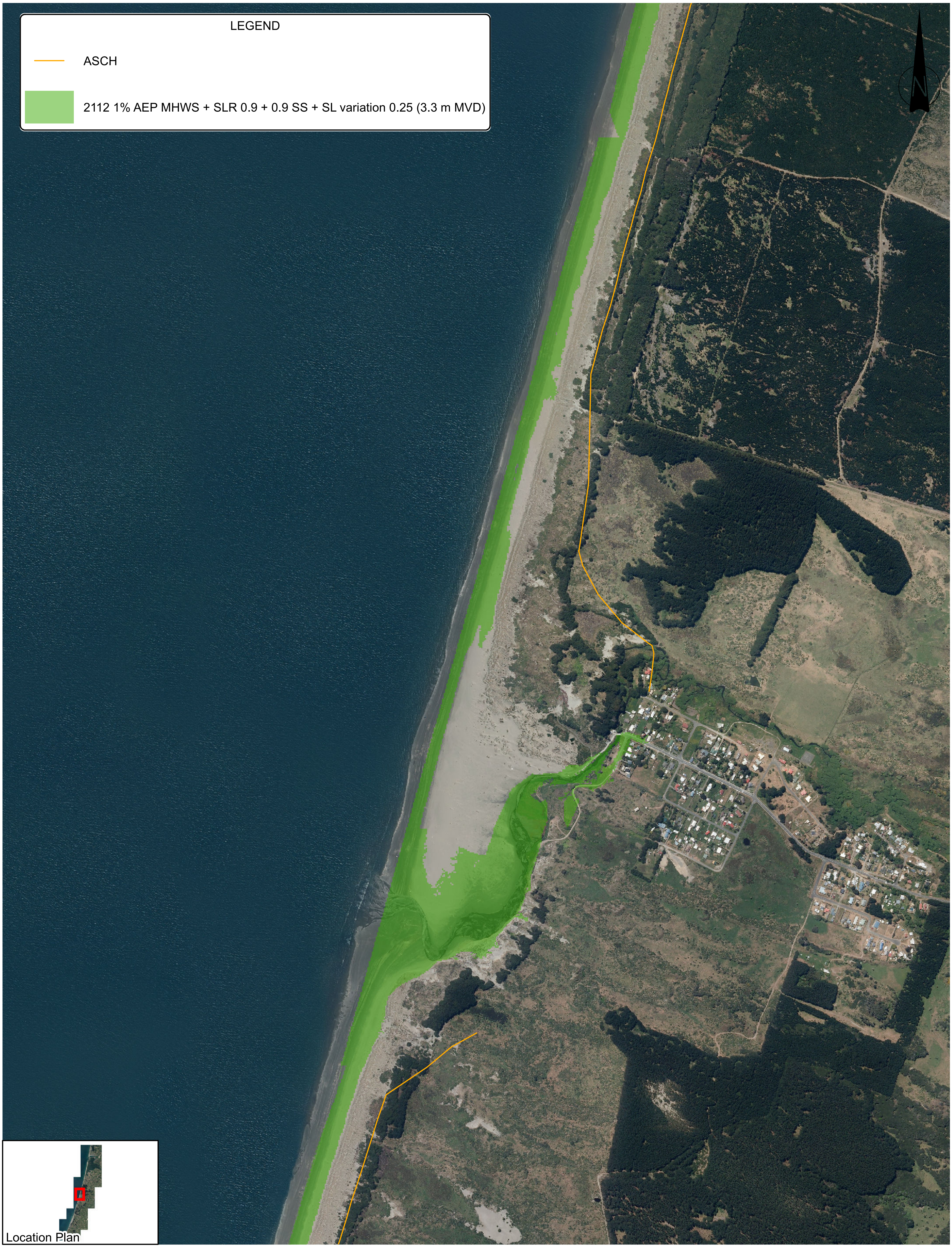

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A3 SCALE 1:10,000

0 0.1 0.2 0.3 0.4 0.5 (km)

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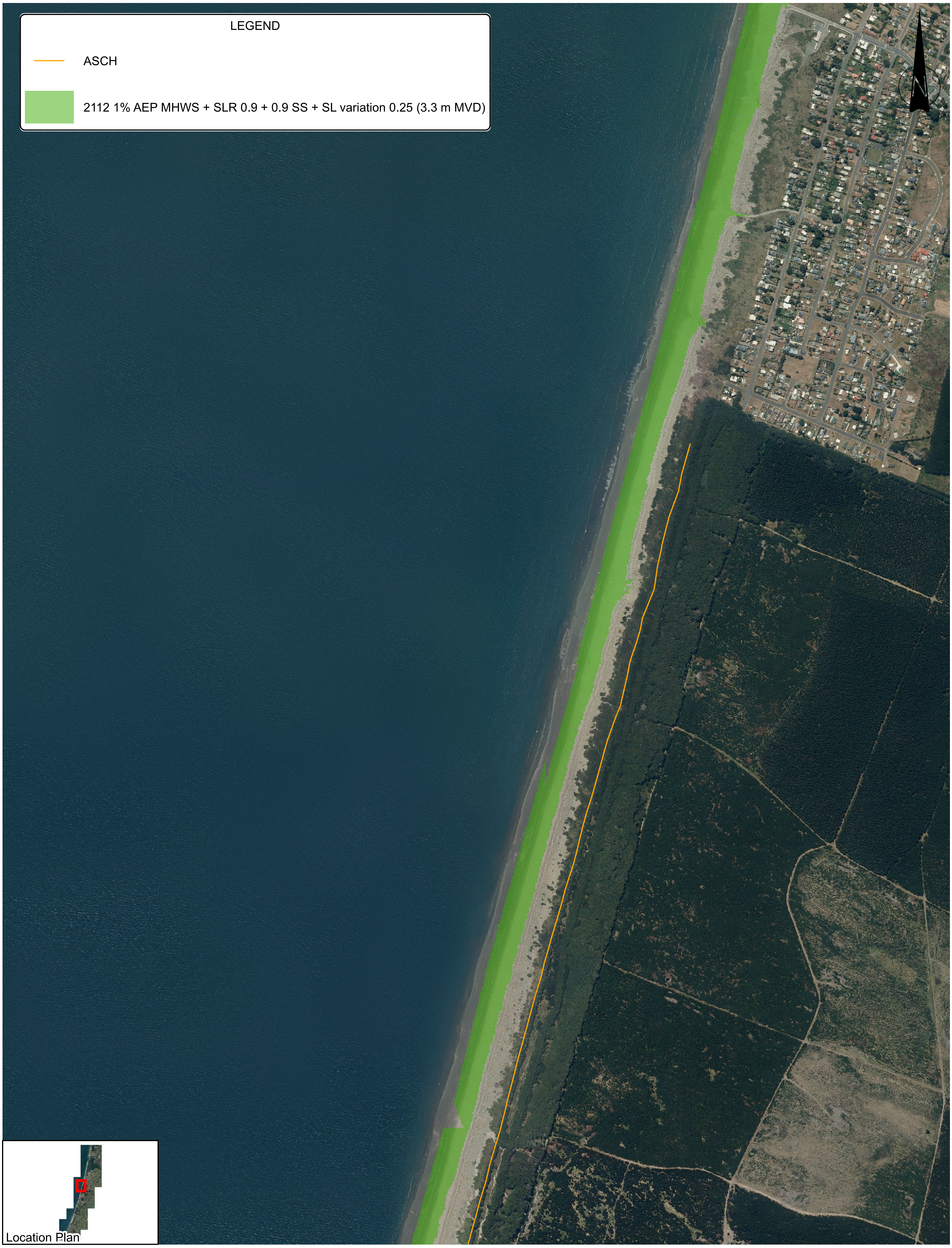
HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
ASCH Hokio

FIGURE No. Figure 5 -4

Rev. 0



Notes: Aerial photograph 2011. Source HRC

A3 SCALE 1:10,000

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HORIZONS REGIONAL COUNCIL
COASTAL HAZARD ASSESSMENT
ASCH Waitarere

FIGURE No. Figure 5 -5

Rev. 0

Appendix B: Inlet Migration Curve (IMC) Report

Geomorphological Assessment and Shoreline Analysis of Waikawa, Ohau and Hokio Inlets

A background report prepared as part of the Waikawa to Waitarere Coastal Hazard Assessment for Horizons Regional Council

By Dr Roger D Shand

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Research, Education and Management Consultancy

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Wanganui, New Zealand.

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enquiry@coastalsystems.co.nz
www.coastalsystems.co.nz

Client Report 2012-10 CRep September, 2012

TABLE OF CONTENTS

1.0 INTRODUCTION

Coastal Systems Ltd have been engaged to prepare a background report assessing the geomorphology and defining inlet migration curves for the Hokio, Ohau and Waikawa Inlets on the Horowhenua Coast (Figure 1) as part of the coastal hazards assessment being undertaken by Tonkin and Taylor Ltd (primary consultants) for the Horizons Regional Council.

Inlets, arguably, are the most dynamic of coastal geomorphological systems, driven by the interactions between marine and fluvial processes. Sand-dominated inlets are typically characterized by frequent channel migration and changes in bar and spit morphology which often result in considerable shoreline change both within and between inlets. Inlets often offer shelter, food resources and picturesque settings, making them favoured sites for indigenous and colonial settlement and more lately holiday and retirement developments. This pattern has been accompanied by increasing hazard risk due to increasing property density coupled with changes in coastal processes which are to some extent anthropogenically-induced. A schematic diagram and associated terminology of a typical inlet on the North Island's southwest coast is shown in Figure 2. Note that the offset can be substantial as it is for the three inlets under consideration in this report.

Open coast erosion hazard distances (CEHD) are assessed using equation 1, and this requires modification to account for inlet morphological behaviour. Equation 2 was then used to predict inlet (cross-shore) erosion hazard distances (IEPD).

$$CEPD = LT + ST + RSLR + DS + CU \qquad (1)$$

$$IEPD = IMC – (LT + RSLR + DS + CU) \qquad (2)$$

Where, LT = longer-term shoreline change, ST = shorter-term shoreline fluctuations, RSLR = shoreline retreat associated with sea-level rise, DS= dune stability, CU = combined uncertainty and IMC = inlet migration curve.

Values for the bracketed terms in equation 2 are as derived for the adjacent open coast. The *inlet migration curve* (IMC) replaces the open coast's SE (shorter-term fluctuation) component. The IMC is derived by fitting a curve to the landwardmost locations of the inlet (aerial photo-based) shoreline migration envelop (see Figure 3). The IMC differs for managed and unmanaged inlets with the managed curve being derived from that subset of shorelines corresponding to the time inlet management practices have occurred, while the unmanaged IMC is derived from the subset of shorelines for the time prior to management. Note, inlet management consists of structures such as guide walls, groynes and mouth cuts (channel excavations) to constrain channel shape and alongshore migration.

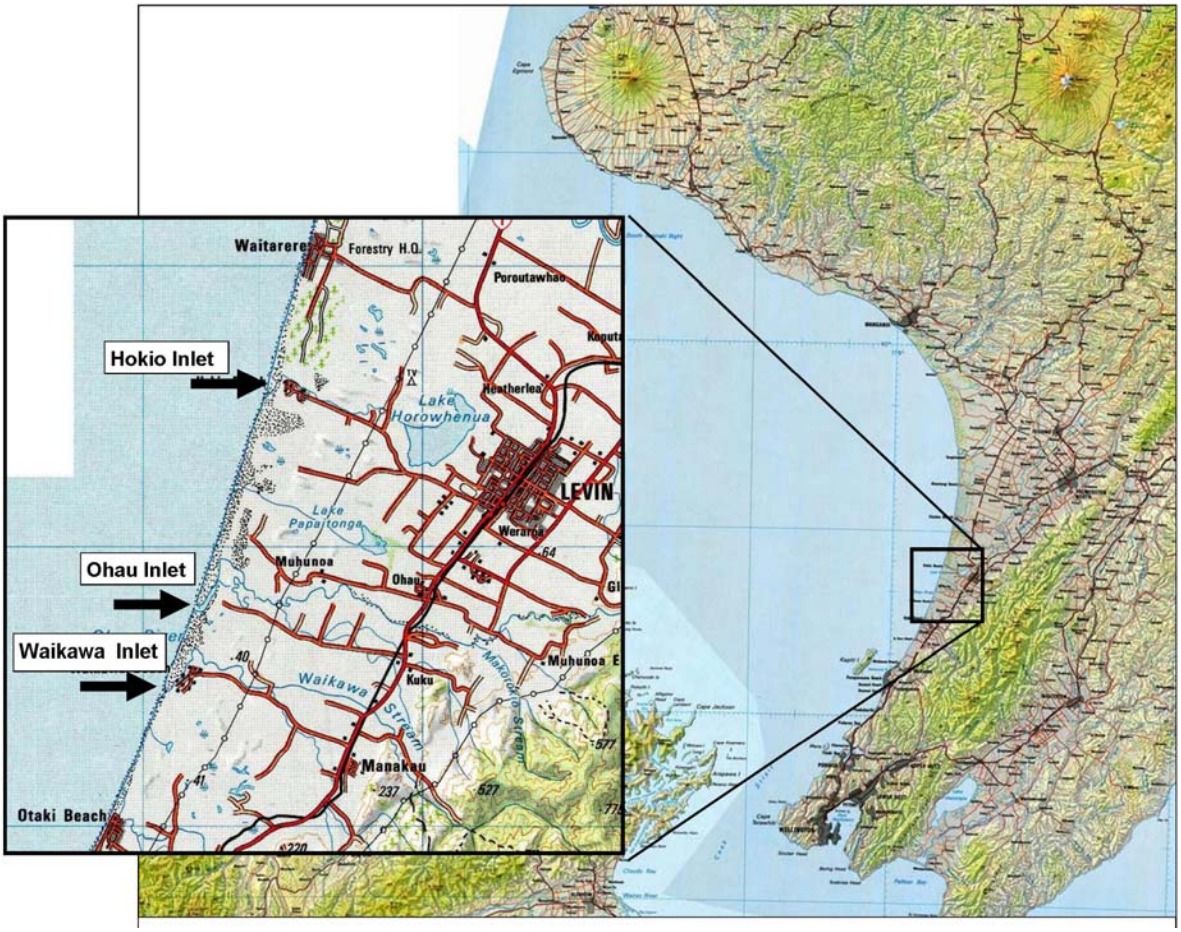

Figure 1 Location map of Hokio, Ohau and Waikawa Inlets on the Horowhenua Coast

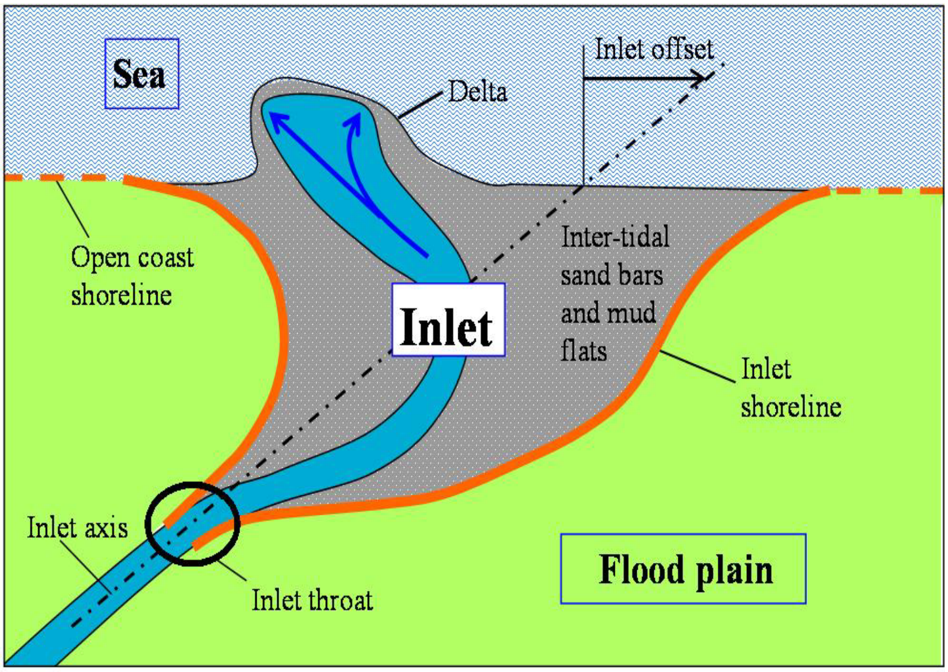

Figure 2 Morphology and terminology of a typical inlet on the Manawatu Coast

While such partitioned data sets are "broadly suitable" to represent 50 yrs of inlet behaviour, they are often too short to confidently represent 100+yrs of shoreline change, so extrapolation must be done with caution. In particular, the underlying geomorphology of the inlet must be well understood in term of its past behaviour and its predicted future behaviour. Such an approach is also now required by the NZCPS 2010, Policy 24 (a) and (c).

Geomorphological assessments utilize information from the following sources: early survey plans, which in the present investigation date back to 1872 to 1894; vertical aerial photographs; LIDAR, and any other readily available, reliable materials. Field inspection also provides useful evidence. The shoreline indicator on early survey plans was typically the mean high water (MHW) line; however, other indicators could have been used including the dune line, spring high water line, channel margin or inlet vegetation line. The usual shoreline indicators abstracted from aerial photos are the seaward edge of vegetation (approximates the dune toe). In addition, aerial photos contains a wealth of morphological signatures, especially under stereo analysis (3D vision). More recedntly, LIDAR provides high resolution 3D data for generation of a digital terrain model (DTM) which allows for detailed inspection and analysis. Many features on early aerial photos find expression (and explanation) within the more recent DTM.

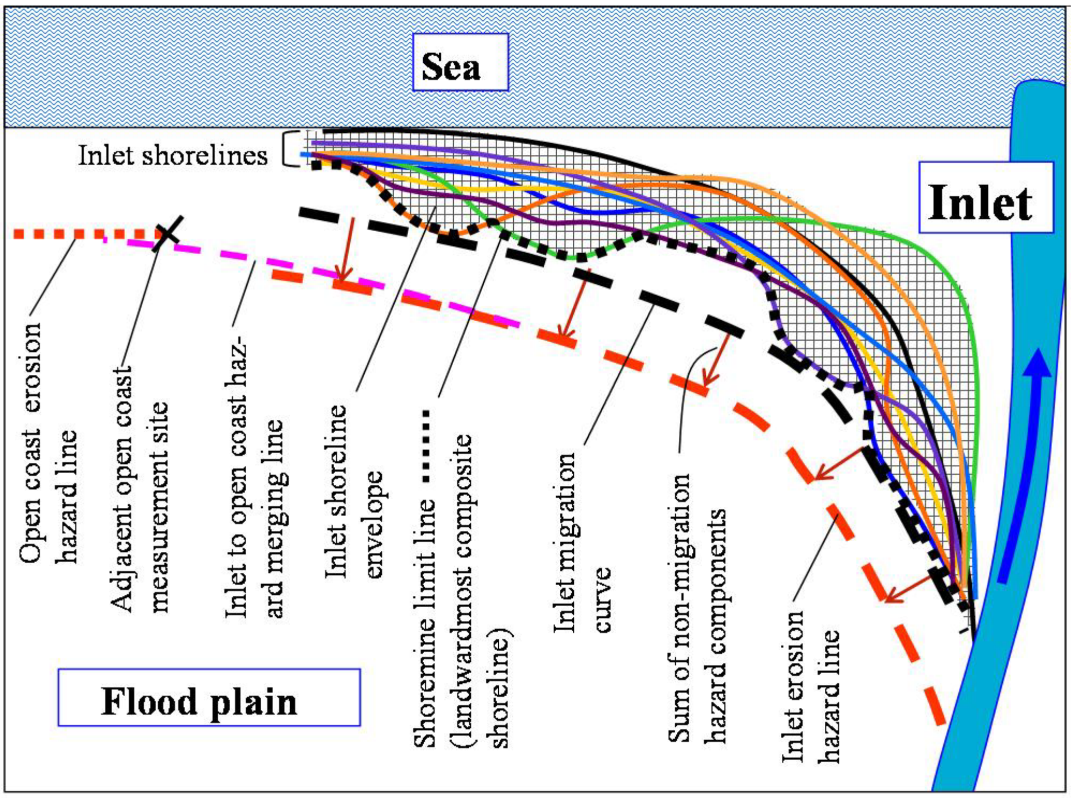

Figure 3 Conceptual illustration of derivation of inlet migration curve (IMC), inlet erosion prediction (hazard) line and relationship to the open coast erosion hazard line.

If inlets are subject to systematic influences such as open coast progradation and/or net alongshore migration, then particular care is required when selecting shoreline subsets to be used for deriving natural and managed IMCs as some shorelines may represent morphology that will not be replicated in the assessment period, and some potential future moprphologies may not be evident within the existing shorelines/morphology. These situations occur at all three subject inlets (Waikawa, Ohau and Hokio).

Further complication in determining IMCs occurs when upstream fluvial (meander) processes cut new entrances into the inlet which results new inlet throat locations. This behaviour is a characteristic of the Ohau inlet.

Erosion hazard is usually assessed over both 50 yr and 100+ yr prediction periods. The former applies to existing development so owners can make interim use of property which may be subject to potential coastal hazard. In such cases special resource consent conditions apply to address the hazard risk such as removal of a building when erosion reaches a predetermined trigger point. Councils' may also need to have policies to maintain/strengthen protection works as required. As it is feasible to predict erosion with a period of 50 yrs, the managed IMC is an appropriate base curve for deriving a 50 yr erosion hazard line.

The 100+ yr assessment period applies to new development including subdivision (NZCSP 2010, Policy 25). Predicting landform, shoreline, protection structure performance and environmental effects in such dynamic environments necessarily involves much higher uncertainty than for the 50 yr period. The present assessment focuses on future geomorphological change to provide both managed and unmanaged IMC options (for use in the subsequent derivation of managed and unmanaged erosion hazard lines) for the client's consideration. It is noted that the neighbouring Territorial Authority, (the Kapiti Coast District Council) is presently proposing erosion hazard policy based on open coast and inlet assessments in which no protection structures were taken into account over the 100+ yr period, i.e. the 100+ yr erosion hazard line is based on the unmanaged IMC.

Of particular relevance to (windward) west coast inlets is the susceptibility of eroded inlet shorelines (by the range of fluvial/coastal drivers) to subsequent wind erosion. These inlets are typically boardered by dune sand and the steep, bare scarps which facilitate blowout and parabolic dune development with frontal wind drifts able to travel inland at rates of several metres per month particularly during aggressive El Nino conditions (CSL data from the Rangitikei Inlet in September to November 2007). Episodes of wind erosion may last months to years and it is thus desirable to incorporate an adequate buffer within a coastal erosion zone in the vicinity of inlets.

The following three sections provide a geomorphological description for each of the Waikawa, Oha and Hokio Inlets, including size and geometry (based on the aerial-based shorelines and envelope), catchment size and mean annual flood flow at the mouth (from http://wrenz.niwa.co.nz). Historical inlet behaviour and historical shorelines are described.

Inlet management regimes are described. The derived inlet migration curves (IMCs) are identified as are areas considered susceptible to future dune erosion processes. Tonkin and Taylor Ltd will subsequently adjust the IMCs landward to incorporate other erosive effects such as shoreline retreat associated with predicted climate change, erosion scarp adjustment and sand dune instability to derive the erosion hazard lines (EHLs).

2 WAIKAWA INLET

2.1 General

The Waikawa Inlet has a maximum area of ~68 ha and alongshore length up to ~2400 m based on the aerial photo analysis. The channel typically has a southerly offset, the catchment area is 7700 ha (77 km^2) and the mean annual flood flow at the mouth is 50 m^3/s. The inlet's adjacent seaward shorelines are undergoing long-term progradation of about 1.5 m/yr.

2.2 Past and present morphological behaviour

Past shorelines are overlayed in Figure 4. The earliest shoreline (1872) had its mouth 2.2 km north of the present mouth (defined here as the seaward end of the rock groyne), and at that time it flowed into the Ohau River. Other morphological evidence on the survey plans indicate the Waikawa may have flowed even further north prior to this. By the late 1879s the Waikawa was had its own oceanic mouth some 700 m to the south. The 1894 survey plan shows a very large "sandbank" fronting the coast and the Waikawa being constrained and deflected alongshore with the mouth having moved some 500m to the south (but still 1 km north of the present mouth).

Morphological evidence on the 1942 aerial photo indicates this large sediment body was able to force the entrance yet further alongshore and at the time of photography it was some 1600 m south of the present mouth and close to the Waiorongomai Stream which lies some 600 m south of the territorial boundary. Dune vegetation had established on this "welded sandbank" as far south as the present footbridge and the southward extending spit beyond had relatively low elevation and appears subject to breaching.

The 1965 mouth had returned northward with the inlets southern bank some 200 m north of the present entrance groyne and the north bank being a further 600 m. The 1965 aerial photo shows a major episode of dune instability was underway (Figure 5), possibly linked to a previous influx of sand along the coast. Since that time, the northern side of the inlet has migrated some 600 to 700 m to the south where it is constrained by the channel which has been fixed since the 130 m long stone groyne was established along the left bank during the 1983 to 1993 period. The foredune on the northern side of the inlet have steadily increased in height and extent and now enclose an 80 ha area of 1960s riverbed (see area marked #### in Figure 6) which now becomes a backwater during floods.

The southern side of the inlet migrated south following its 1960s northward excursion at a rate of ~50 m/yr! with the 1978 and 1983 photos showing the mouth extending southward with bracketing shorelines some 500 and 750 m from the groyne end.

The rivermouth groyne constructed after 1983 has fixed the orientation (southern offset) of the channel as it enters the inlet and limited the alongshore migration with the northern side stabilizing and the southern side systematically migrating northward some 200 m (~7

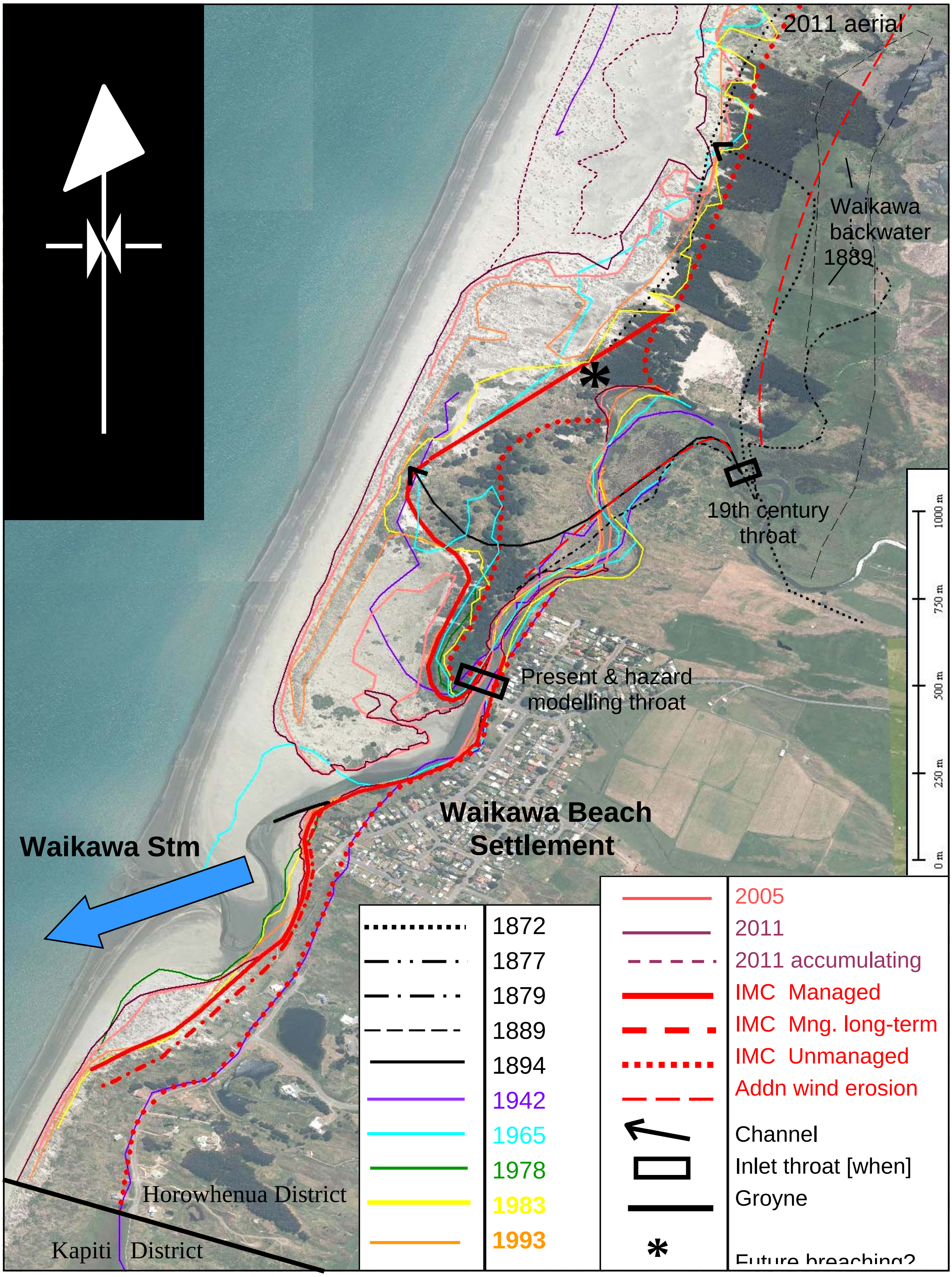

Figure 4 Waikawa Inlet showing historical shorelines and inlet migration curves (IMCs) for managed and unmanaged scenarios. Where no *managed long-term IMC is* shown then the *managed IMC* applies. Note the final erosion hazard lines will be offset landward to account for other influences such as effects from predicted climate change and possible additional offset for wind erosion hazard (marked).

m/yr). The back of the inlet (immediately south of the groyne) has prograded some 20 m along the first 100 m then eroded some 35 to 55 m over the following 400 m with more recent behaviour limited to ~10 m fluctuations.

2.3 Future morphological behaviours

If the groyne is maintained, over time it is reasonable to expect the northern dunes and shoreline will encroach on the channel which in turn will be forced against the structure and thus result in bed scour, the need for ongoing maintenance and strengthening, and flow restriction possibly contribute to upstream flooding. Yet further into the future, should open coast progradation continue, ongoing accumulation on the northern side of the inlet may well outflank the groyne thus causing a new southward dogleg in the channel and thus increasing the likelihood of erosion along the back and southern sides of the inlet along with and a more southward mouth location. Of course climate change predictions could markedly change shoreline behaviour on the open coast in which case the groyne could be under more frequent wave attack under storm conditions and the adjacent inlet more susceptible to erosion. If the groyne were allowed to fall into disrepair, the channel migration range will likely increase with the systematic southward trend evident in the pre-groyne data once again occurring. Depending on the balance between the underlying long-term progradation vs climate change-induced recession will depend the extent of inlet erosion in the vicinity of the present groyne and residential area.

There is also an area of interest regarding future morphological behaviour to the north of the present inlet where a dogleg in the channel (marked on Figure 4) that approximates the location where the 19th century sand influx diverted the channel southward. This area is of interest as the meander is migrating seaward at a rate of 1.5 to 2 m/yr and the Ohau channel in the late 1979s/early 1980s was only about 100 m from the present Waikawa dogleg meander (see Figure 3). The intervening topography is low lying at about 2 m above MSL. The Waikawa thus has the potential to once more flow into the Ohau, especially with the possibility of increased high flows associated with climate change. This could lead on to the Waikawa once more migrating south, this time by eroding existing dunes which are lacking substance in many areas where previous channels occurred (Figure 6), and even eventually joining the present channel - a process that has partially occurred at the Turakina Rivermouth, some 65 km north of the study area, over the past decade. This scenario demonstrates how significant morphological change can be in the longer term.

2.4 Inlet migration curves

The present inlet throat is approximately located at the footbridge, and while some evidence of meander development exists upstream, the long established channel approach to the inlet should persist into the future. The inlet's southern offset is long established both before and after the groyne construction so can be assumed to occur into the future.

Figure 5 Wind erosion and associated sand drifts (arrows indicate direction) about the Waikawa area in 1965. Note that while the stream presents a barrier to landward progression of mobile dunes, wind-blown sand can cross water courses and affect person and property further inland. Stabilized parabolic dunes on the inland side of the channel (marked *) would have formed when the stream has a more northern outlet such as in the 19th century (see Figure 4).

Managed IMCs

The post 1983 (managed) shorelines were used to define the managed inlet migration curve (IMC) using the method illustrated in Figure 2. The only variation is on the northern side of the inlet where the curve stays on the inland side of the infilled 1960s riverbed (Figure 6) as this low lying area will not be particularly resistant should the seaward foredune circum to erosion. Management would include groyne maintenance and strengthening, and also river control works to ensure the orientation as the channel approaches the inlet and also to ensure the Waikawa does not merge with the Ohau in the vicinity of the channel dogleg (Figure 4) some 900 m upstream of the Waikawa footbridge.

Because the post 1983 (managed) shorelines are too limited to confidently define the full IMC for the “longer-term” (100+ yrs) given the possible morphological responses already discussed, the following IMC modifications have been applied. No change is required for the northern side of the inlet as this shoreline has become very stable since groyne construction and the underlying tendency for morphological change will be for this shoreline to migrate south (by outflanking the groyne). Some additional shoreline response may occur along the rear and southern sides of the inlet, so a 100+ yr managed IMC is set

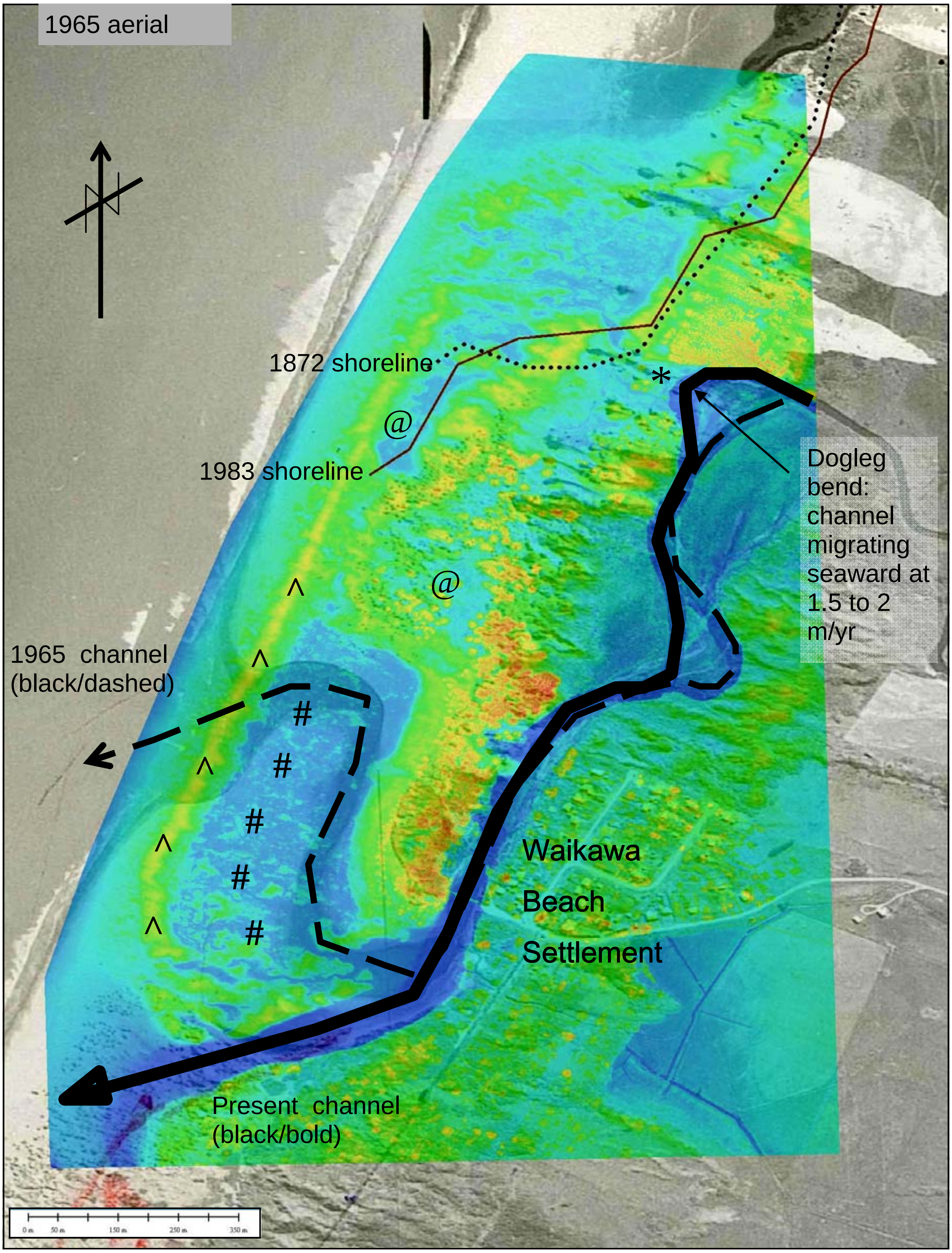

Figure 6 Digital terrain model (based on 2005 LIDAR) depicting elevation (lower=blue, moderate =green, high=yellow/brown) superimposed upon the 1965 aerial photo (same as in Figure 5) to illustrate (i) low relief area between dogleg bend and earlier Ohau Inlet shorelines (marked *), (ii) area with low relief in dunes associated with 1960s inlet channel (marked (###), (iii) other low elevation areas in the northern dune complex associated with earlier channels (marked @), and (iv) narrow present foredune (marked ^ ^ ^).

landward by some 10 m, this being the average fluctuation observed within the post groyne shoreline envelope. The combination of the northern shoreline outflanking the groyne and the effects of climate change mean that the observed northward migration of the southern shoreline since groyne construction cannot be assured in the longer-term and it is beyond the scope of this assessment to model any such behaviour. As a precautionary measure, the longer-term managed southern IMC has been offset southward by some 100 m, this being 50% of the observed post groyne shoreline change.

Unmanaged IMC

The pre-managed shoreline samples (1942 to 1983) are used as a basis to define the 100+ yr unmanaged IMC (method illustrated in Figure 2). In most places the initial (1942) shoreline is the most landward so is used to define the IMC. Given the tendency for the inlet to migrate southward and the open coast to prograde, the landwardmost shoreline is likely to over predict the landward extent of the northern side of the inlet. However, this side of the inlet is undeveloped and likely to be so for the foreseeable future so over-estimation of inlet margin retreat in this area is acceptable. Given the dynamic nature of the Waikawa Inlet, und the uncertainties in morphological response to future changes in forcing and sediment supply, the landwardmost and southernmost location of the initial shoreline is considered appropriate to define the long-term unmanaged IMC.

The unmanaged IMC also incorporates possible erosive effects associated with any future merging of the Waikawa Stream and Ohau river. The IMC in this area is topographically constrained so defined using the DTM.

2.5 Erosion Hazard Lines

The 50 yr EHL can confidently be based upon the managed IMC, subject to the stipulated management conditions noted in Section 2.4, plus additional conservation measures required to contain wind erosion.

There are two options for the 100+ yr EHL.

1) The EHL is based upon the “longer-term” managed IMC, and subject to the stipulated management conditions noted in Section 2.4 plus additional conservation measures as required to contain wind erosion.

2) The EHL is based upon the unmanaged IMC. This option requires no management assurances from council and makes some allowance for wind effects which occasionally affect this area. However, the Waikawa Beach Settlement is particularly vulnerable to wind-blown sand given its location downwind of (i) the seaward reach of the Ohau River, (ii) the confluence of a future Waikawa-Ohau merger, (iii) subsequent southward migration of rerouted Waikawa, and (iv) an unstable northern open coast should climate change effects lead to significant foredune erosion. Additional buffer against wind hazard is thus advised and **consideration should be given to adjusting the EHL landward on the northern**

side of the inlet as depicted in Figure 4 by the dashed red line. This additional precautionary measure should be acceptable given that this area is presently undeveloped.

Option 2 better meets the purpose of the RMA 1991 in that it more comprehensively promotes the sustainable management of natural and physical resources

3 OHAU INLET

3.1 General

The Ohau Inlet has a maximum area of ~160 ha and alongshore length up to ~3900 m based on the aerial photograph record. The channel typically has a southerly offset, the catchment area is 18,800 ha (188 km^2) and the mean annual flood flow at the mouth is 265 m^3/s. The inlet's adjacent seaward shorelines are undergoing long-term progradation of about 1.1 m/yr.

3.2 Past and present morphological behaviour

Past shorelines are overlayed in Figure 7. The 2012 aerial photo shows the Ohau Inlet throat at the northernmost extent of the inlet. However, the early survey plans (1872, 1879 and 1889) show the throat some 450 m south with the aerial photo shoreline record showing the river systematically migrated northward to its present locations at ~4 m/yr, although the rate has slowed to ~2 m/yr over the past 20 yrs. Of further relevance in the earlier aerial photo record is a relict throat some 1000 m south of the present throat. This configuration appears to have resulted from a large meander evident in the early survey plans breaching the inlet side some time between the 1889 survey and the 1942 photo (location marked in Figure 7 as *Early 20th century throat*). River control works have cut off the culprit meanders with the channel now maintained further landward (see Figure 7).

A north (attached) spit characterizes the inlet and at times has extended over 3 km to the south of the present throat. The 1872 survey plan shows the spit at full extension and intercepting the Waikawa Stream (Figure 4). The early spit was 200 to 500 m wide and the 1879 plan notes that it was covered by extreme tides. This is a very large sediment body appears to be the same sand bar responsible for diverting the Waikawa southward in the late 19th century.

The 1879 survey plan shows the spit breached and the river entering the sea some 1200 m from the present throat. This pattern of spit extension and breaching appears throughout the aerial photo record with the latest extreme configuration being in the late 1970s/early 1980s. More recently the mouth has been confined to the northern half of the inlet with substantial sand accumulation and vegetation establishing on the southern half as depicted in Figure 7. The shoreline envelope at the rear of the inlet varies in width between 50 and 380 m (mean = 140 m).

3.3 Future morphological behaviours

Continued systematic northward migration of the inlet must be considered viable if natural processes and/or river control works maintain the orientation of the inlet's approach channel.

That area between the southern meander breach (Early 20th century) and the present throat some 1000 m to the north is low lying, has many relict channels (oxbow lakes) and lacks dune development along its inlet margin, all characteristics which make it vulnerable to fluvial erosion and inlet throat change.

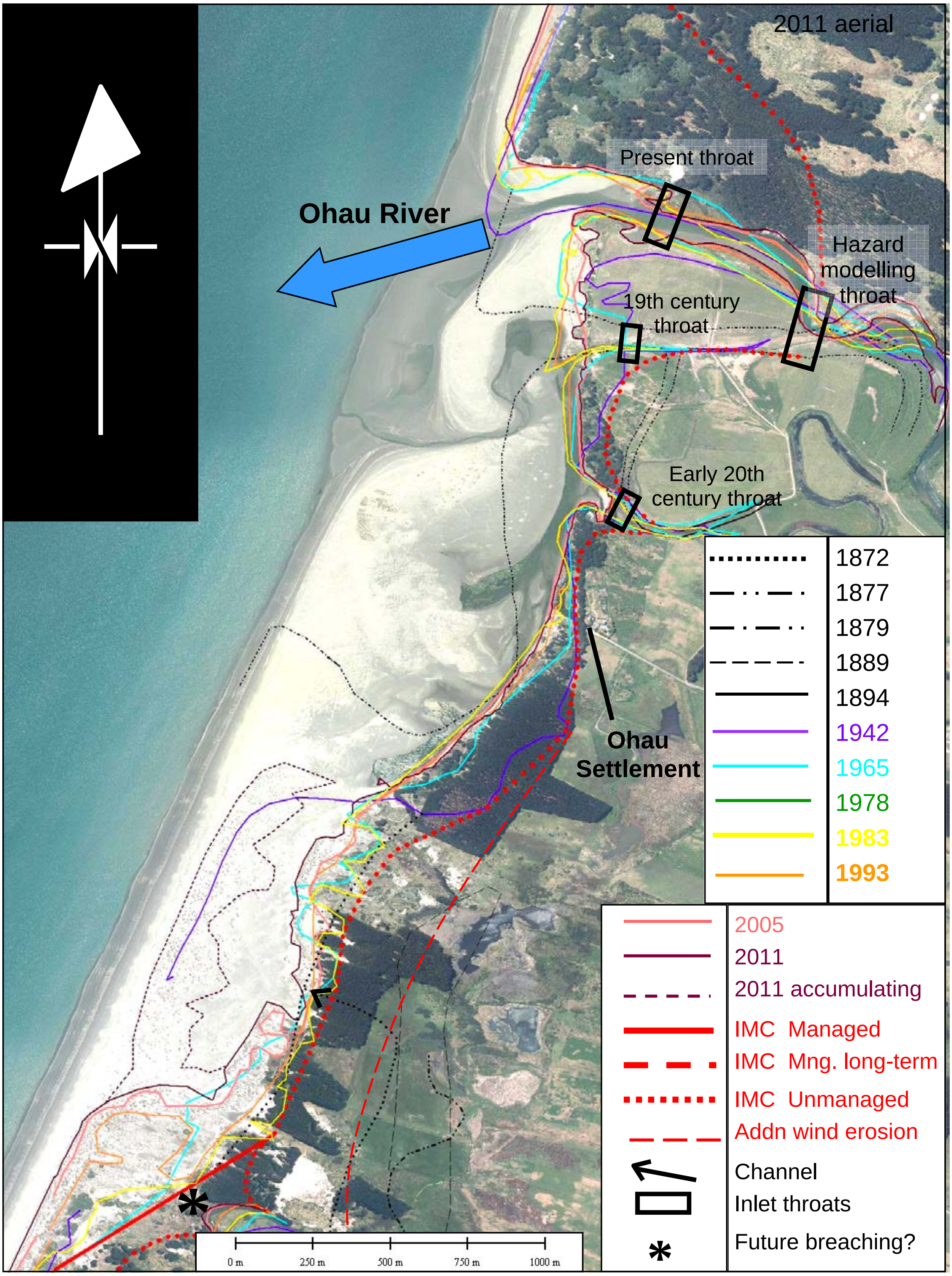

Figure 7 Ohau Inlet showing historical shorelines and inlet migration curves (IMCs) for managed and unmanaged scenarios. If no *Managed long-term IMC* is shown, then the *Managed IMC* applies. Note the final erosion hazard lines will be offset landward to acount for other influences such as effects from predicted climate change and possible additional offset for wind erosion hazard (marked).

The southern part of the historical inlet must also be considered potentially active in the future for the following reasons. While river control works may constrain the throat to the north of the inlet, the fact that the mouth occupied its southernmost location as recently as the 1980s suggests that the full range of potential (historical) locations should be considered viable, especially under an extended timeframe (100+ yrs).

3.4 Inlet migration curves

The IMCs are constructed using both the early survey plans and aerial photo-derived shorelines and approach channels as this envelope is considered potentially active. Consequently, the IMCs originate from a throat common to this extended data set, such that this throat lies several hundred metres landward of the present throat (Figure 8). With the exception of upstream river control works, **which are assumed to be maintained into the future such that the river approaches the coast within the historical envelope**, the Ohau inlet is unmanaged so a single IMC is derived.

The northern inlet IMC extends at a low angle from the throat to reflect the orientation of the approach channel, before curving seaward in keeping with the present inlet shape then bending northward to merge with the landwardmost shoreline some 1000 m beyond the present inlet. This *cubic spline* shape is characteristic these west coast inlets.

The southern IMC follows the early survey plan channel seaward before curving south to meet the landward aerial shoreline envelope in keeping with the method illustrated in Figure 3. The IMC deviates landward in keeping with the early 20th century inlet breach, and two alternatives are depicted at the inlet's southern extreme to merge with the Waikawa's IMCs which includes a entry at the site of its nineteenth century mouth.

3.5 Erosion Hazard Lines

The EHLs for both the 50 and 100+ yr assessment periods are derived by summing the open coast parameter values (equation 1) and offsetting the resulting distances from the IMC.

Should the Ohau Inlet again become active to the south as last occurred during the late 1970s/early 1980s, then significant wind erosion along the inlet margin could occur. **Consideration should thus be given to deepening the erosion hazard zone when defining the final EHLs in this area, and a suggested setback line is shown in Figure 7 (dashed red line).**

4 HOKIO INLET

4.1 General

The Hokio Inlet has a maximum area of ~23 ha and alongshore length up to ~1450 m based on the aerial photograph record. The channel has a southerly offset throughout the early survey plan and aerial photo records, although geomorphic evidence discussed below indicates an earlier (slight) northerly offset. The catchment area is 7,000 ha (70 km^2) and the mean annual flood flow at the mouth is 35 m^3/s**.** The inlet's adjacent seaward shorelines are undergoing long-term progradation of about 1.6 m/yr on the northern side and 1.0 m on the southern side.

4.2 Past and present morphological behaviour

Past shorelines are overlayed in Figure 8. A large indentations on the 1942 northern open coast shoreline coupled with the adjacent (to landward) curving channel meander (forming dogleg marked in Figure 8) indicate that the earlier inlet may have had a northerly offset, and other morphological indicators in the aerial photographs support this assertion including the depicted deflation area (RL = 3 m). The dogleg channel configuration has remained constant throughout aerial photo record possibly due to the adjacent sand dune (up to 15 m high and possibly formed of sand from the deflation basin) impeding meander development. The prograding northern open coast shoreline has enabled and a 200 m wide foredune complex to develop through the 69 yr aerial photo record.

The Hohio Inlet is characterized by systematic southward migration with the northern shoreline migrating over 100 m during the aerial record, and southern shorelines up to 300 m. This systematic migration is also inferred by the 1887 channel shape which bends (deflected?) southward and suggests that the large sediment influx which played such an important role in the historical evolution of both the Waikawa and Ohau inlets may also have been influential here.

The photogrametric DTM (not shown) defines a low lying area between the channel dogleg (marked in Figure 8) and foredune and this is also indicative of rapid coastal progradation.

A 130 m long groyne orientated ~20 degrees south of shore normal is first evident in the 1983 aerial photo. The groyne was constructed along the northern side of a seaward perturbation which existed throughout the earlier aerial photo record (a similar configuration exists at Waikawa). Note such features typically occur where an approach channel meets an inlet. It appears that the groyne structure was build to contain bank erosion considered a threat to southern end of the settlement. This erosion may be caused by the littoral sand influx during the 1960s (evident in the aerial photo) deflecting the channel landward.

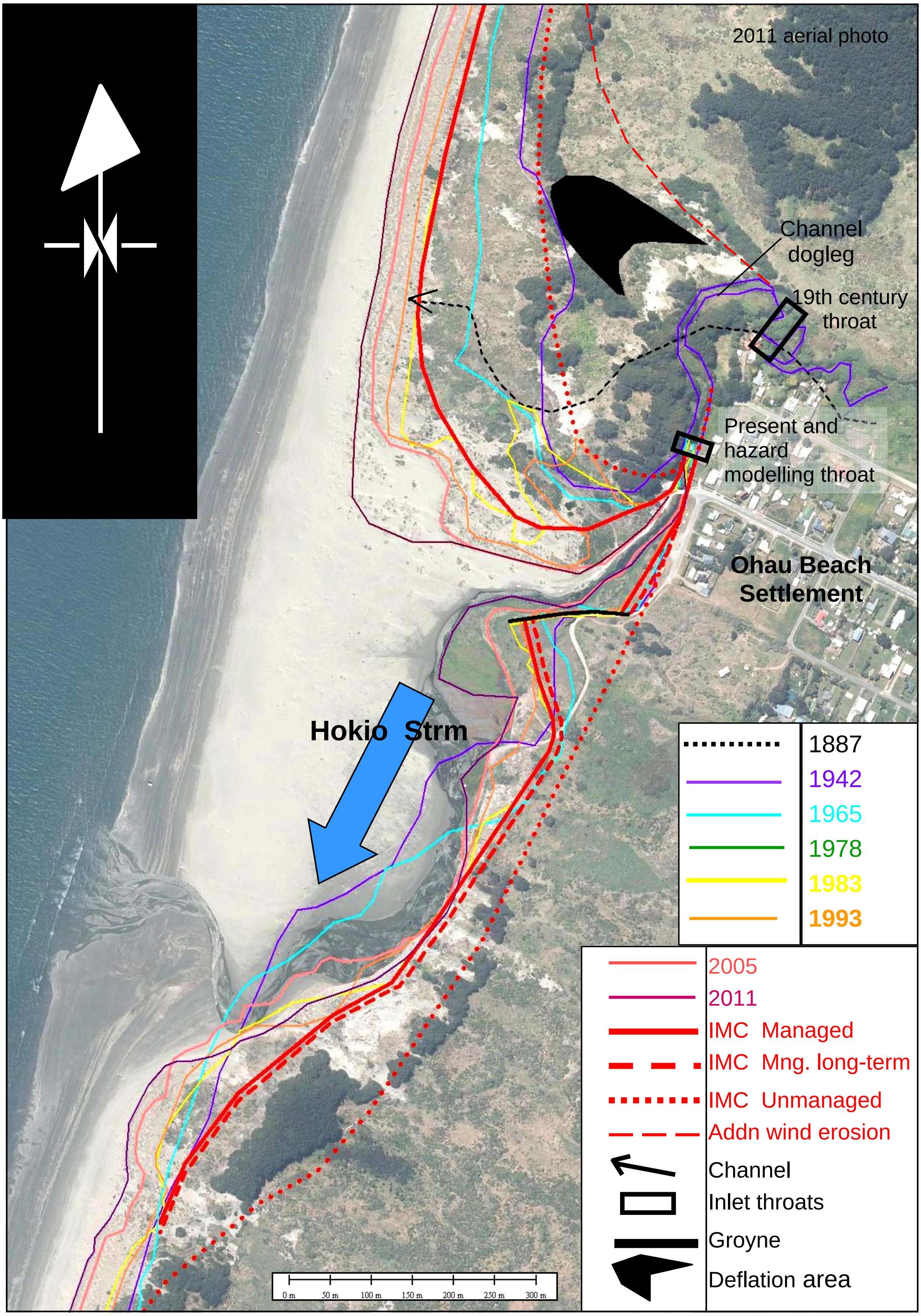

Figure 8 Ohau inlet showing historical shorelines and inlet migration curves (IMCs) for managed and unmanaged scenarios. Where no *Managed long-term IMC is* shown then the *Managed IMC* applies. The marked deflation area has been stable for the past 10 yrs. Note the final erosion hazard lines will be offset landward to account for other influences such as effects from predicted climate change and possibly additional offset for wind erosion hazard (marked).

Under natural conditions, this perturbation may be expected to translate southward as the northern side of the inlet migrates south. However, since groyne construction the perturbation has grown in size especially on the southern side.

The northern shoreline has become relatively stable in the vicinity of the groyne, but further seaward sand accumulation, dune building and inlet shoreline migration (southward) are proceeding.

South of the groyne/perturbation, the channel's point-of-contact (active erosion) with the inlet shoreline results in active erosion and this locus has migrated from 200 m beyond the structure at the time of construction to 400-600 m alongshore, behaviour that suggests a causal affect. Interestingly, the shorelines along the back of the inlet has not receded landward of the 1983 shoreline indicating the groyne is not having a significant effect. Eight to 10 m high active dune scarps occur in this area with associated sand drifts extending inland. However, such processes along the back/southern side of inlet are evident throughout the aerial photo record.

The southern inlet shoreline has migrated ~220 m southward during the aerial record at an average rate = 3.2 m/yr. The rate prior to groyne construction = 5 m/yr to the south, but after construction the shoreline adjusted northward some 23 m (linear regression rate = 0.8 m/yr. While this may reflect the structure influence, some slowing of the pre-groyne southward migration would be expected as the system moves toward equilibrium.

In summary, as at Waikawa, the groyne influence appears to be to constrain and confine inlet migration.

4.3 Future morphological behaviour

The northern side of the inlet will likely behave much as the Waikawa, with the groyne coming under increasing load as the shoreline and dunes encroach. Further into the future, and if open coast progradation continues, the northern inlet shoreline could outflank the groyne and a dogleg channel result with increased likelihood of erosion along the back of the inlet associated with channel meander processes. However, should climate change predictions eventuate, the underlying open coast progradation may be limited and the groyne itself, as well as adjacent rear inlet shorelines, will be more susceptible to erosive precesses.

The future behavour of the southern inlet shoreline is less certain. Given the uncertainty of the groyne effect in slowing the rate of southward inlet migration and the expected enhanced erosion associated with climate change, some ongoing seaward extension of the inlet must be assumed under the longer-term managed scenario and more significant southward migration under the natural scenario.

Finally it is noted that while the deflation area presents a potential weakness in the dune buffer should systematic erosion of the foredune and seaward channel meander at the dogleg occur, it is considered most unlikely in inlet reconfiguration would occur (with associated erosion affecting the settlement) as firstly the channel is historically stable at this location (see Section 4.2) and secondly, sand from an eroding foredune would fill the deflation zone. However, significant open coast erosion, from climate change or natural processes, could facilitate wind erosion and wind-blow sand upwind of the settlement, so incorporating additional capacity when making the EHL selection would be precautionary (Section 4.4).

4.4 Inlet migration curves

The present inlet throat is located ~50 m upstream of the beach access bridge, and given the stability of the upstream channel, the approach orientation into the inlet is likely to remain into the future. The inlet configuration (offset) to the south is long established both before and after the groyne construction, so can be assumed to persist into the future.

Managed IMCs

The post groyne shorelines (1983-2012) are used to define managed inlet behaviour (IMC) using the method illustrated in Figure 2. The managed scenario requires local government agents to maintain the groyne and ensure the approach channel alignment remains essentially unchanged.

Because the post groyne-affected (managed) shorelines are too few to confidently define the managed IMC in the "longer-term" (100+ yrs) given the possible morphological responses already discussed, the following modifications have been applied. No change is required for the northern side of the inlet as this shoreline has become very stable since groyne construction and the underlying tendency for morphological change will be for this shoreline to migrate south (by outflanking the groyne). Some additional shoreline response may occur along the rear and southern sides of the inlet so an additional 10 m offset is applied (as used in the Waikawa assessment). The combination of the northern shoreline outflanking the groyne and the effects of climate change mean that the observed (post groyne) northward migration of the southern shoreline cannot be assured in the longer-term and it is beyond the scope of this assessment to more definitively model any such behaviour. As a precautionary measure, the longer-term managed southern IMC has thus been offset southward by some 11 m, this being 50% of the observed post groyne net shoreline change, the same approach as used for the Waikawa assessment (Section 2)

Unmanaged IMCs

On the northern side of the inlet, the pre-groyne shorelines are used as the basis for defining the IMC. The perturbation immediately south of the groyne has been excluded from the IMC as this feature can be expected to migrate south as the inlet systematically extends in that direction. It is unclear how far south the inlet could migrate to reach equilibrium under an unmanaged regime; however, and there will be a limit thus making the average pre-groyne rate of 5 m/yr unlikely to persist throughout the assessment period. A rate of 50 % of the pre-groyne rate, i.e. 0.5 * 5, will be used, this also approximates the 1942 to 2011 rate of 2.7 m/yr.

4.5 Erosion Hazard Lines

The 50 yr EHL can confidently be based upon the managed IMC, but requires an assurance from local government that alignment upstream of the throat is maintained and the groyne also maintained.

There are two options for the 100+ yr EHL.

1) Based on the managed IMC this again requires local government agencies to ensure the alignment of the river channel at, and upstream of, the throat is maintained and inlet control structure maintained and modified to ensure the channel and inlet sides remain within the defined EHLs for at least 100 yrs.

2) Based on the natural IMC and requires no assurances from councils. The southward migration of the inlet has likely been overestimated by the IMC; however, this is acceptable given the undeveloped nature of the terrain. Furthermore, such an extension helps address the dune erosion and wind-blown issue which this area has been, and will continue to be, subjected toe, especially if climate change predictions eventuate.

   With this high potential for wind erosion and wind-blown sand in mind, **consideration should also be given to extending the landward margin of the EHZ on the northern side of the stream right to the present channel between the beach access bridge and the upstream dogleg, and thence seaward as a precautionary measure.**

Option 2 better meets the purpose of the RMA 1991 in that it more comprehensively promotes the sustainable management of natural and physical resources

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