Geomorphological assessment, hazard and risk assessments, and mitigation management options for Ōpunakē Bay

A report prepared for the South Taranaki District Council

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EXECUTIVE SUMMARY

The Report Summary in Section 7 has been written so as to also suffice as the Executive Summary

GLOSSARY

Accretion: the seaward displacement of the shoreline as beach sand volume increases.

Andesite: a volcanic rock of moderate viscosity that forms thick lava flows.

Anthropogenic: change resulting from human activity c.f. natural processes.

Annual Recurrent Interval (ARI) or Return Period (RP): refer to section 5.1.

Astronomical tide: the sea-level variation controlled by lunar cycles (moon orbits).

Attenuation: following shoreline overtopping by storm waves, the landward flow diminishes as it spreads out, through ground friction and interaction with other obstructions.

Backshore: that areas landward of the foreshore and typically bounded by sand dune or cliff.

Barrier beach: where the beach/dune acts as a barrier to freshwater drainage reaching the sea.

Bathymetry: sea-bed form typically defined by depth measurement.

Cadastral plan: land survey depicting boundaries and other features primarily for the purpose of ownership.

Chart datum: the lowest level that the sea will seldom fall below.

Conglomerate: Course grained sedimentary rock composed of rounded to subangular fragments surrounded by finer sediment that is often cemented.

Co-ordinates: see **New Zealand Transverse Mercator (NZTM) coordinates**.

Digital elevation model (DEM): data which depict a surface in three-dimensions.

Dynamic water level: refer to Section 5.1

Empirical-based formula: based on statistical analysis of field measurements.

ERB: permanent Emergency Response Beacons.

Escarpment: a steep slope separating areas of relatively flat ground.

Fluvial: processes are associated with rivers and streams and the deposits and resulting landforms.

Foredune: A sand dune located immediately landward of the beach and aligned parallel to the shoreline at the time of formation.

Geometric equilibrium model: refer to Section 4.2.4 and Figure 13.

Geomorphology: the study of landforms – their description, how they form and how they may behave in the future.

Georeferencing: plans, photographs and other images are digitized then transformed to a common set of **co-ordinates** so images can be exactly overlaid for comparison and measurement.

Gyre: currents that horizontally move in a circular pattern.

Hazard: a natural or man-made phenomenon with the potential to cause harm to persons or property.

Hindcasting: a way of calibrating a predictive mathematical model by inputting values for past events. The longer the past record, the more accurate the models predictive power.

Hydrodynamics: the study of water movement.

Intertidal beach: that area between low and high tide.

Joint-probability: the likelihood of events occurring concurrently.

IPCC: International Panel on Climate Change is the international panel of scientists which prepare reports on the possible effects of greenhouse gas-induced climate change.

IRB: Inflatable Rescue Boat as used by surf lifesavers.

LIDAR: Light Detection and Ranging, is a high resolution remote sensing method that uses light in the form of a pulsed laser to measure the earth surface.

Linear regression modelling: a statistical technique for identifying associations and relationships between variables.

Littoral: A zone extending from the high tide mark to the offshore limit of wave and current-driven sediment transport. Littoral drift refers to sediment transported alongshore within this zone.

Lag: heavier/coarser material remaining after finer/lighter material has been (preferentially) eroded away.

Lahar: a violent type of mudflow or debris flow composed of a slurry of volcanic material, rocky debris and water.

Matrix (geological): fine-grained material in which larger materials such as pebbles or fossils, are embedded.

Mitigation: actions to reduce a hazard impact or effect.

Neap tide levels: the minimum upper and lower sea level driven by moon orbit.

New Zealand Transverse Mercator (NZTM) coordinates: the current standard method in New Zealand of assigning every point on the earth surface a unique pair of numbers (co-ordinates) measured to the east and north of a particular base position (spatial datum).

Numerically-based formula: based on theoretical concepts, ideally calibrated using field or laboratory measurements.

Overtopping: where an extreme water level exceeds the shoreline height and flows inland.

Parabolic dune: typically U, or V-shaped sand dune with an elevated convex nose and lower trailing arms. This landform often originates as instabilities within the foredune and can migrate considerable distances inland.

Point cloud: numerous sets of data points defining the ground surface in two or three dimensions.

Proactive: actions to reduce impact before a hazardous event strikes.

Radiative forcing or climate forcing: refers to the difference between sunlight absorbed by the Earth and energy radiated back to space.

Revetment: a lower angle seawall typically constructed of rock or concrete.

Repose (angle of): this is the steepest angle a material can attain without moving down-slope under gravity.

Representative concentration pathway (RCP): a greenhouse gas concentration trajectory adopted by the **IPCC** for its fifth Assessment Report in 2014. Four pathways have been selected for climate modelling and defining associated **SLR.**

Return Period (RP): also referred to as Annual Recurrent Interval (ARI): refer to Section 5.1

Rip channel: channel formed on the intertidal or subtidal beach in conjunction with wave breaking and water retuning seaward as a concentrated flow.

Risk: The potential for losing something of value. In risk management, risk is expressed in terms of the combination of the likelihood of occurrence of a hazardous event with the consequence of the event.

Risk (assessment) matrix: a table detailing combinations of event likelihood categories and consequence categories – refer to Table 10.

Sand dune (coastal): a mound or hill of sand that forms when air flow characteristics change – typically in association with driftwood or vegetation.

Sediment budget: refers to sources and volumes of sediment at a particular location.

Shoreline: the fringe of a water body. Where that water body is the ocean the shoreline is also called the coastline.

Shoreline indicators: features used to define the shoreline such as an elevation (e.g. the mean high water mark), the vegetation-front or base of a cliff.

Semi-diurnal tides: where two tidal cycles occur every day.

Significant wave height: the average of the upper one third of wave heights.

SLR: sea-level rise.

Slumping: the mass movement of (hillside) material involving an element of backward rotation.

Spring tide levels: the maximum upper and lower sea level driven by moon orbit.

Standard error of estimate: the statistical error measured by a **regression analysis**. Refer to Section 4.2.1 and 4.2.3.

Static water level: refer to Section 5.1

Stereo analysis: overlapping vertical images viewed so-as to produce a three-dimensional image.

Still Water Level (SWL), also referred to as Storm Tide (ST): see section 5.1

Storm surge (SS): refer to Section 5.1

Storm tide (ST) also referred to as Still Water Level (SWL): see Section 5.1

Subtidal: seaward of, or below, the low tide mark.

Transect: a line marking the length and orientation of a survey.

Vertical datum. These relate to mean sea level (MSL) based on tide gauge measurement data at 13 ports around the New Zealand coast. As sea-level changes over time and between these ports, it is necessary to specify the datum location and the year the datum was established. New Zealand Vertical Datum 2016 (NZVD16) is the vertical datum presently being adopted throughout the country.

Wave deformation: the change in shape and size of a wave as it moves over changing bathymetry.

Wave period: the time for successive wave crests to pass a common location.

Wave run-up: refer to section 5.1

Wave set-up: refer to Section 5.1

Wind set-up: refer to Section 5.1

1 INTRODUCTION

1.1 Background

Ōpunakē Bay is the main public recreational beach in South Taranaki (Figure 1) and is currently facing several operational issues described in the 2016 Ōpunakē Beach Master Plan prepared by Boffa Miskell for the District Council (STDC). In particular the Plan outlines drainage constraints making the Holiday Park boggy, wind-blown sand, dunes height restricting views and sand accumulation on the beach. Issues of escarpment (the surrounding cliff) stability, drainage on the flat below, and the possibility of managed retreat of Holiday Park utilities were then addressed in the Opus (2017) report assessing cliff stability. Aging infrastructure is also a concern for council along with the potential impacts of climate change and the statutory requirements to address coastal hazards and associated risk, and mitigation options for risk reduction. Once these assessments are complete council can plan for future management of Ōpunakē Bay with confidence.

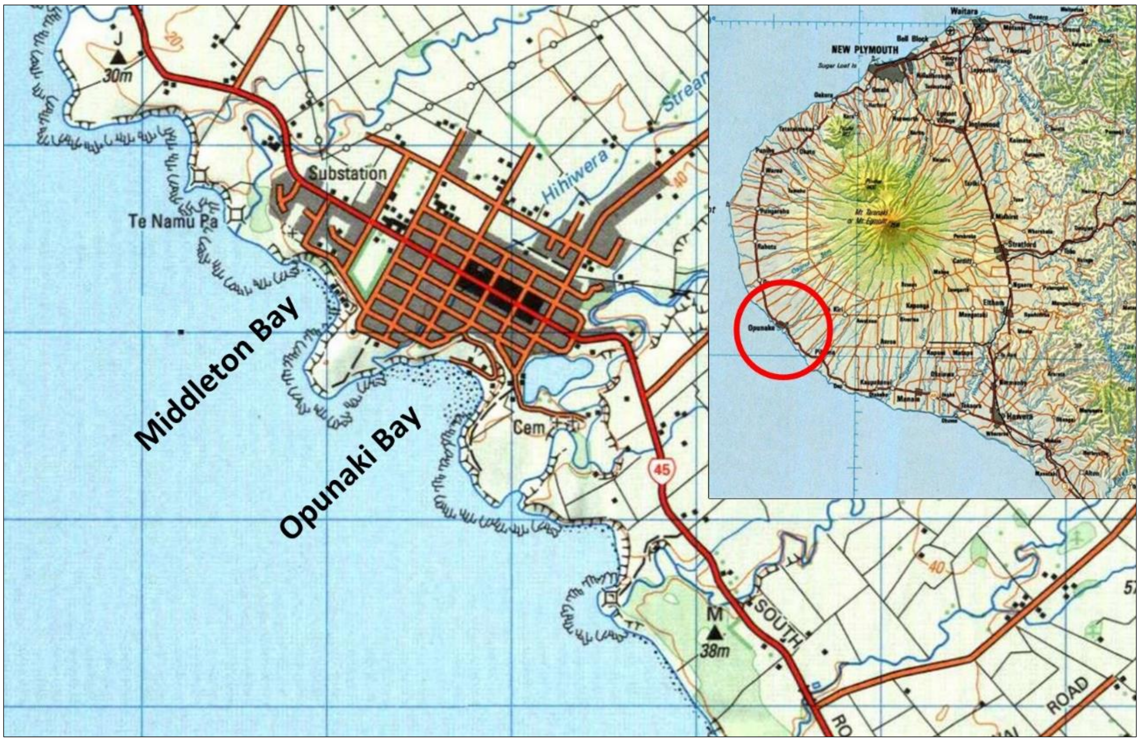


Figure 1 Ōpunakē Bay location map

1.2 Statutory considerations

The Resource Management Act, 1991 (RMA) planning process for the consideration of natural hazards require technical assessment of hazard susceptibility, the risk posed by any such identified hazards, and the means to manage/reduce the hazard risk to suit the needs of the community.

The New Zealand Coastal Policy Statement, 2010 (NZCPS), Policy 24 addresses coastal hazard assessments and hazard risk and requires the identification of areas that are potentially affected by coastal hazard risk. In particular: identify areas in the coastal environment that are potentially affected by coastal hazards, giving priority to the identification of areas at high risk of being affected. A geomorphological assessment underpins the hazard assessment process (Policy 24 [1c]), the effects of predicted/projected climate change are to be incorporated (Policy 24 [1h]), and assessment should span at least 100 years (Policy 24 [1]).

Policy 25 - 27 concern risk reduction by hazard avoidance, adaptation and protection.

Best practice guidance giving effect to the RMA and NZCPS can be found in NIWA (2012), MFE (2017) and DOC (2017)

1.3 Study scope

The STDC has engaged Coastal Systems Ltd (CSL) to undertake a comprehensive study of the beach and reserve geomorphology, undertake erosion and inundation hazard assessments using best practice methods, and incorporate stakeholder consultation. Management mitigation options are to be identified for the beach, reserve, assets and sand dunes which are to include risk and safety issues as well as future monitoring requirements.

1.4 Report layout

The report begins (Section 2) with a review of available information relating to the Ōpunakē Bay coastal environment, then goes on to describe the contemporary geomorphology and sediment and hydrodynamics. Section 3 describes how Ōpunakē Bay has changed over time including bathymetric change, shoreline, sand dune change, and anthropogenic influences such as the breakwater, seawalls, and sand control fencing. Section 4 assesses current and future erosion hazard using a standard component-based model and sea-level rise projections out to 100 years based on the most recent New Zealand official guidance. Section 5 assesses the current and future inundation hazard using standard components, a 100 year time frame and incorporates a joint-probability-based approach. Section 6 assesses the risks associated with erosion and inundation as well as other associated hazards such as foredune erosion escarpment collapse, wind-blown sand, the water table levels and beach currents. Section then outlines a range of mitigation options. Section 7 summarizes the study findings.

2 COASTAL SETTING

2.1 Previous studies

The most comprehensive historical documentation of Ōpunakē is that of de Jardine (1992). De Jardine's work details the arrival of the first settlers, use of the Bay by trading vessels, development of recreational and business utilities, and the Ōpunakē Harbour Board (1913 to 1938). The report references local and central government records as well as local personalities and politics and provided a basis for the information search in the present study given that early council and harbour board archives could not be located in spite of an extensive search. Other descriptive histories referencing the port tend to refer to de Jardine's material.

The earliest technical documentation discovered during our investigation is that printed on the 1882 bathymetric map by Hursthouse. Shortly after in 1987, the Thompson Report proposed harbour development based on a 1886 survey plan by Henderson which included wind, wave, current and tide observations along with costings for a concrete breakwater and associated utilities. Copies of the 1882 and 1886 surveys are included in Appendix A.

According to de Jardine (1992), several other marine engineers prepared subsequent reports for the council and/or harbor board and/or government departments.
De Jardine includes a useful description of beach development in the 1920 and 30s, breakwater construction between 1924-8 out to 600 feet (182 m), various wharf constructions (1891 to 1928), and the power station at the southern end of the bay (1921).

The next technical contributions were the 1974 and 1882 environmental impact reports for Maui gas developments. Chapter 6 covers coastal geology by Gregory (1982) and provides information on hard geology, beach form and behavior, sediment and the sediment budget. However, Ōpunakē was a late addition to this study and only contains limited data.

Morris and Associates (1985) prepared an environmental impact report on a proposal by the Egmont County Council to double the length of the breakwater. However, this was a desktop study based primarily on the Maui investigation material as well as theoretical considerations and local interviews.

In 2001, Tonkin and Taylor Ltd. produced a report for the Taranaki Regional Council (TRC) on compliance monitoring for coastal structures which included a background description of Ōpunakē Bay. The TRC has subsequently produced annual reports on STDC consented coastal structures which notes visual change relevant to the consents.

The next technical contribution came with the ASR artificial surf reef investigation between 2001 and 2004 which was based on numerical modelling using new sediment and bathymetric data, the latter from 2000 and 2009 are reproduced in Appendix A. Sand dune management has also been a feature of the Bay's history, but records of schemes alluded our search with the exception of the Wildlands (2009) report on Dune Restoration which resulted in localised dune grass planting within the centre of the bay.

In 2017, Opus produced a report on Cliff Stability based on drone-based topography (Appendix A) collected for their study..

The STDC produced an Ōpunakē Reserve Management Plan in 1996. And in 2016 Boffa Miskell produced the Ōpunakē Beach Masterplan to guide future management and development. The present study provides a range of information relevant to the Masterplan's operation.

Surf Lifesaving New Zealand have recently been involved in compiling a Coastal Public Safety Assessment and we have been provided with a summary of this work.

Other studies provide support information but don't specifically address the geomorphology or hazards at Ōpunakē Bay.

Several significant features referred to in Section 2 are depicted in Figure 2.

2.2 Contemporary geomorphology

General coverage of the Ōpunakē coast is given in the topographic map series (Topo50) sheet BJ28 (1:50,000), geological map N118 P20 (1:50,000) and bathymetric chart NZ45 (1:200,000). However, the following description of the contemporary geomorphology focuses on the 2000 bathymetry surveyed by DML for the ARS surf reef investigation and the November 2019 drone-based survey of the beach and camp ground by Taylor Patrick Ltd (TPL), both of which are mapped in Appendix C.

Ōpunakē Bay has a sandy (pocket) beach with an inter-tidal width of ~200 m and a 300 m long (high tide) shoreline running east to west. The beach is composed of fine sand. Historical photography and satellite imagery (a selection of which are included as Appendices B and C) show the inter-tidal beach is typically non-uniform alongshore; protruding seaward in the centre-west and landward in the east accompanied by a widened saturation (damp) area adjacent to the drainage outlets (see Figure 2).

The lower beach is relatively uniform with no evidence of inter-tidal rip channels apart from a topographically constrained channel at the eastern end (described later) which extends out toward the headland (see Figure 2). It is noted that at over the past year the eastern beach has accreted and this may be associated with non-operation of the power station tail race over the past 18 months (see images in Appendix C).

While no sequential profile data are available, 8 years of profiling at 2 to 3 monthly intervals at Oaonui Beach some 10 km to the northwest, demonstrated seasonal behavior with upper beach accretion during the summer and lowering during the winter (Gregory, 1985). Elevation change for the upper beach was typically 2 metres. Some seasonality can therefore be expected at Ōpunakē.

Anecdotal evidence at Ōpunakē from Mr Brian Vincent suggests vertical change in the order of 1 to 1.5 m can occur here. The only recent measured change comes from a comparison of Opus February 2017 and TPL November 2019 drone data which showed a difference of 0.5 m along the blue transect line marked in Figure 18. A future monitoring program is required to better define such behavior at Ōpunakē.

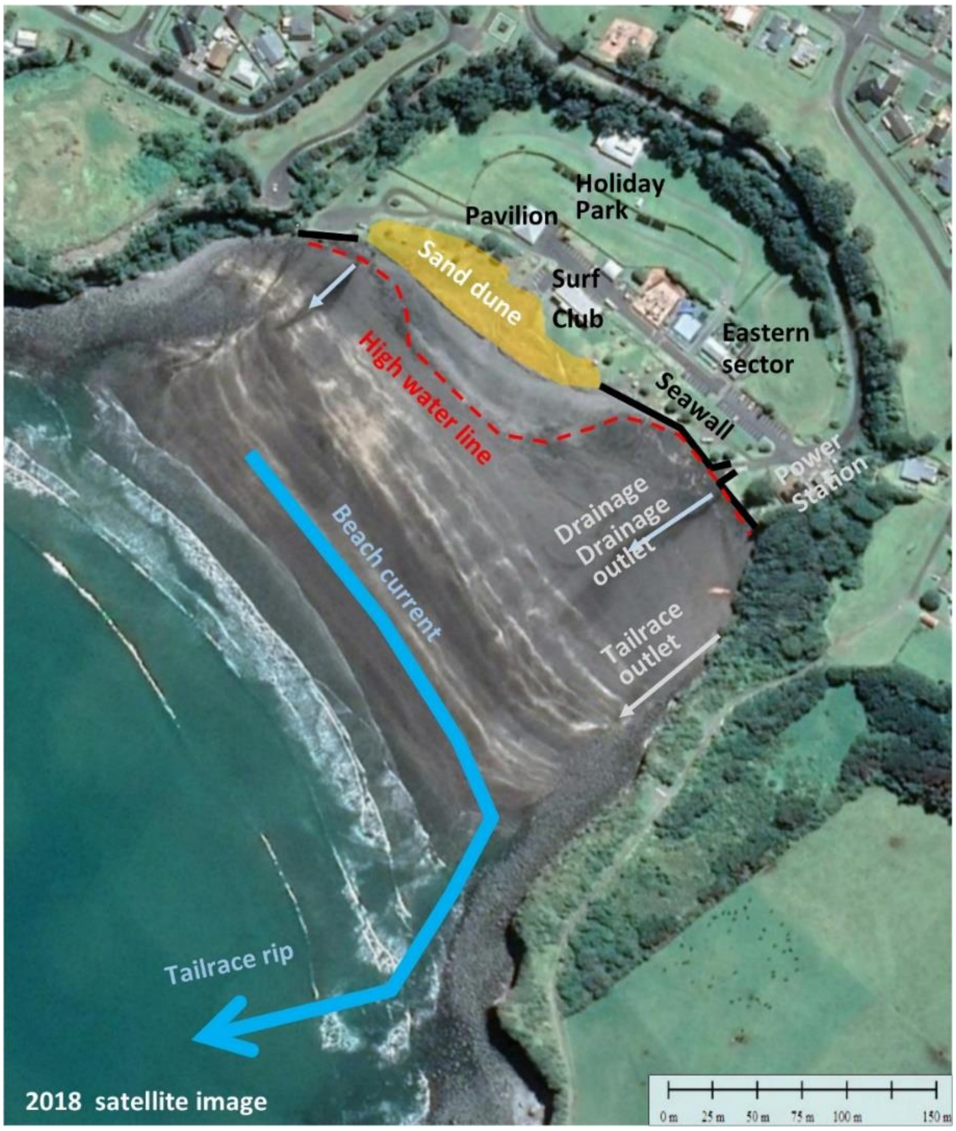


Figure 2 Ōpunakē Bay with marked features referred to in the text.

The central-western beach is backed by 3 to 5 m high sand dunes (the dune toe is approximately 3 m above MSL) with a boulder revetment at the far western end and a concrete retaining wall defining the back of the eastern beach. The backshore then extends landward for some 100 m and is occupied by the Holiday Park/Camping Ground, Surf Club and various infrastructure. This land is relatively uniform low lying at 4 to 5 m above MSL (see Figure 2); it is particularly damp and boggy in the eastern sector and around the base of the escarpment. The drainage is described in Opus (2017) which notes that infilling of the original swamp was not completed in this area. This conclusion is supported by the analysis of historical/aerial photographs carried out in the present study.

The beach and backshore is surrounded by a 15 to 20 m high cliff which extends seaward to a western headland some 700 m distant and the southern headland some 500 m distant. The cliffs are composed of laharic materials: andesitic blocks and boulders in a clay matrix (Opua Formation) characterize the upper cliff; while andesitic conglomerate and sandstone in a silt/mud matrix (Ōpunakē Formation) characterize the lower cliff (Neall, 1979). Boulder reefs extend seaward from each headland. The cliff morphology and stability is described in Opus (2017).

The breakwater extends eastward into the Bay from the western headland. The recent survey by Taylor Patrick Ltd produced a 3D digital model (Appendix C) that shows it to be about 179 m long hence only marginally shorter than when constructed (600 feet ~182 m) in the 1920s. However, some maintenance was carried out in the early 2000s as preparation for constructing the artificial surf reef and this may have distorted this apparent resilience. It's crest reduces in elevation from about 3 m above MSL at the landward end to about 1.5 m below MSL at the distal end.

Subtidal bathymetry consists of arcuate contours with the maximum depth between the headlands of about 6 m below low water. A thin cover of sand mantles the seabed out to about the -4 m contour with boulders thereafter (ASR, 2004). While the subtidal sand cover fluctuates (Mead, 2019, pers comm), there is no evidence of subtidal sand bar formation as is common on open (c.f. embayed) west coast sandy beaches.

2.3 Waves and sediment

Tides at Ōpunakē are semi-diurnal (two cycles per day) with the second having a slightly higher elevation. The mean spring range is 3 m and the mean neap range is 1.7 m.

The following wave statistics were provided by MetOceans (2019) as background for the present study. At 40 m depth (approximately 4 km offshore), the mean significant wave height is 2.12 m (0.41 to 8.31) and the mean period is 12.8 seconds (5 to 21). The annual mean significant wave height is 5.9 m. As these waves propagate shoreward they lose energy from friction and deformation associated with sea-bed irregularities and the mean annual wave height reduces to 3.8 m just beyond the headlands. Wave climate statistics demonstrate some seasonality with the summer mean significant height if 1.85 m increasing to 2.29 m in the winter.

Waves predominantly approach Ōpunakē from the west south west. Waves do also approach Ōpunakē from the SE quarter; however, these are locally generated, of lesser height and typically superimposed upon the longer period swell from the southern ocean.

Coarse sediment (boulders) along the cliff-base headland reefs are likely a lag following cliff erosion of boulder lahars. Sand is transported to Ōpunakē Bay from more distant sources under wave and wind-driven, net west to eastly directed, longshore current (littoral drift). According to Gregory (1982), the main origin of sand along the Cape Egmont to Ōpunakē coast is from fluvial input followed by cliff erosion, with approximately 30,000 to 60,000 m^3 being transported annually.

Both anecdotal and measured current within Ōpunakē Bay has a clockwise gyre with current strength showing an association with wave height but little with tide or wind (ASR, 2001). A rip-like current is permanently located along the southern sand/rock boundary. While flow from the power station tailrace is also aligned with this rip (which surfers call the tailrace rip), no current correlation was found with the power station operation indicating the general circulation pattern and rock/sand configuration control this rip.   Within the bay itself sediment in transported in response to wave-driven currents and may reach the intertidal beach under fairweather conditions before either being swept seaward to rejoin the southward directed littoral stream under subsequent storm conditions, stored as beach accretion, or blown landward.

It is noted that beach scraping was carried out by the Egmont Borough Council in the 1980s (Morris and Associates, 1985). And in the 1990s by Mr Brian Vincent removed an estimated annual volume at 2000 m^3 from the upper beach and deposited it along the low tide mark.

Lack of profile monitoring in Ōpunakē Bay prevents further refinement of Gregory's (1982) and Mr Vincent's sediment transport/budget estimates.

3 GEOMORPHOLOGICAL BEHAVIOUR

3.1 Anthropogenic influences

The following description is based primarily on historical surveys (Appendix A), historical photographs (a selection is reproduced in the text and in Appendix B), and georeferenced aerial photographs (see Appendix C). Early imagery (Figure 3) shows a uniform and relatively (compared with post 1920s) narrow beach backed by a low sand dune centre/west fronting a swamp. The swamp drains to the sea at the eastern end of the beach and mantling the lower cliff behind is has what appears to be sand dunes.

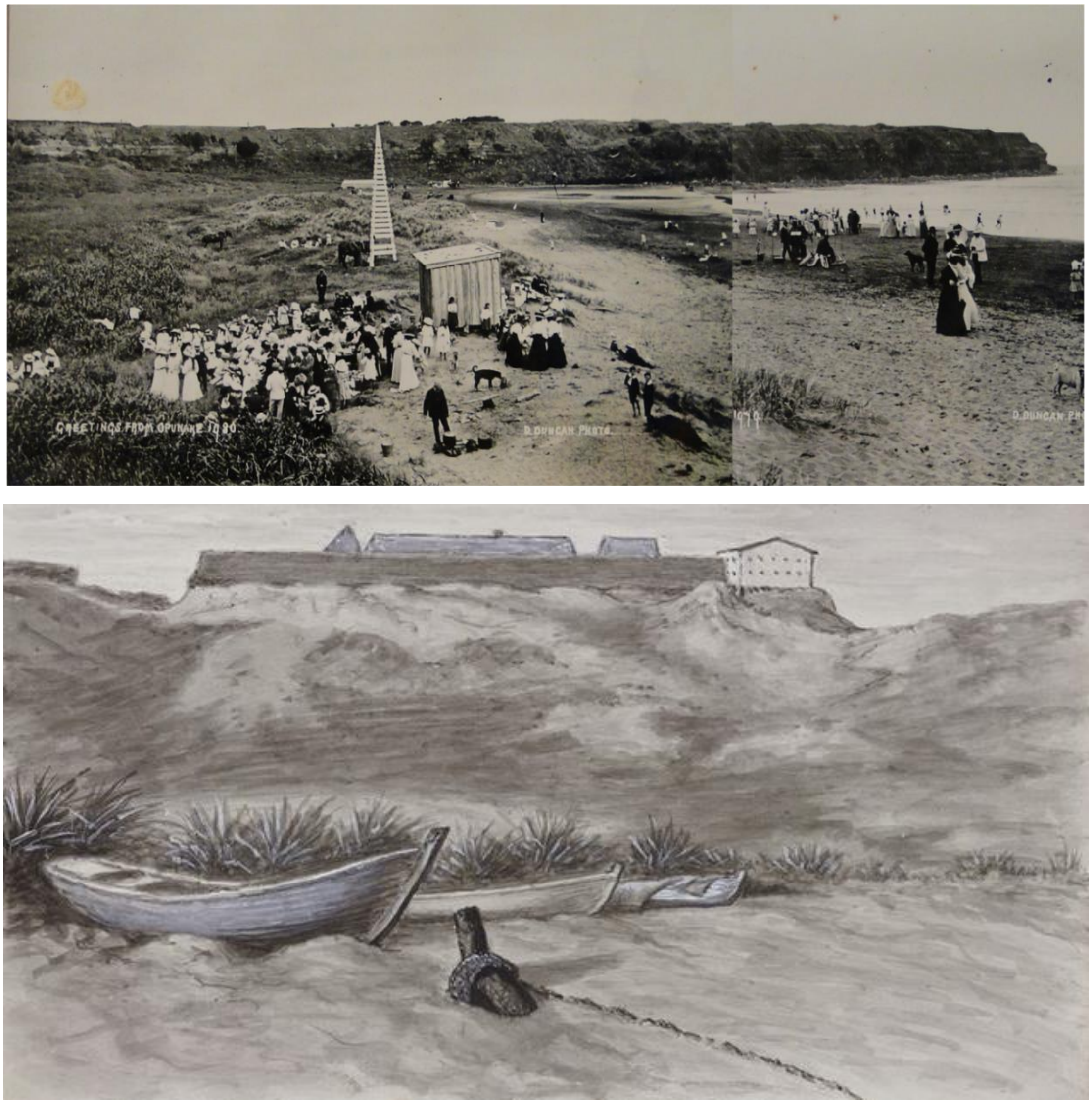


Figure 3 Early imagery of Ōpunakē Beach and environment. Upper: 1908 (merged) photos of D. Duncan shows the beach and landward swamp. The tall structure is the forward navigation beacon, the shed in the foreground is the first changing room and the far building houses the surf boat. Lower: 1882 painting by S. George showing the north eastern corner of the bay, backing cliff and Redoubt. The boats were for negotiating the surf to ships anchored in the roadstead.

The Feaver photographic collection of Ōpunakē Bay spans the period 1913 to 1937 and comprise over 50 photographs showing how recreational beach development proceeded during this time interval - appearing to have peaked in the late 1920s and early 1930s. A variety of structures can be identified for erosion and accretion control, fencing and planting for wind-blown sand control, and the breakwater originally extending some 600 feet into the bay. Swamp infill began at the western end and progressed eastward during the 1930s, but was not completed (see Section 3.3). Table 1 lists the various anthropogenic works and Figure 4 locates their positions.

Table 1 Details of anthropogenic works at Ōpunakē Bay

1912-1930	Dune removal/flattening for recreation	West and centre
1917-1938	Seawall construction for erosion control	West and centre
1924-1928	Breakwater construction	Western headland
1935-	Swamp infill	West-centre
1935-1990	Dune fencing to control wind-blown sand	West-centre
1950s/80s/90s	Shoreline retaining walls to define accretion	Centre-east
1980s/90s, 2011	Planting to control wind-blown sand	West-centre
1950s, 2000s	Rock revetment	Western end
2007	Artificial surfing reef	Lee of breakwater

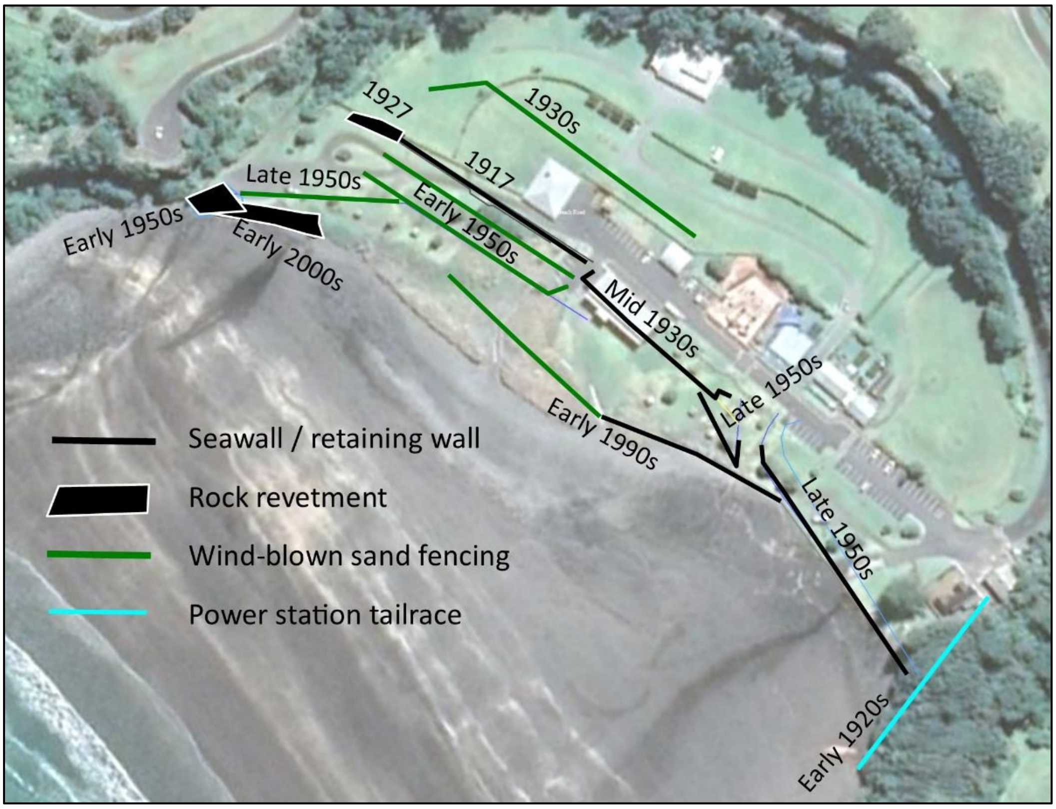


Figure 4 Location of anthropogenic works in Ōpunakē Bay

Ōpunakē Bay is clearly a product of man-made interventions: seawalls initially to control erosion and later to define the shoreline during periods of accretion, and also a variety of controls to catch wind-blown sand which resulted in the present dunes backing the centre-west of the beach. A current abundance of sand is indicated by buried drainage outlets along the eastern beach and recent lowering (topping) of the foredunes to enable surf lifesavers to view beach users (discussed later).

3.2 Bathymetric change

3.2.1 Data

Detailed survey coverage of Ōpunakē Bay began in 1882 with the Hursthouse plan that carried out subtidal and terrestrial measurements as well as sketching natural and anthropogenic features on his map. Four years later in 1886, J. A. Henderson resurveyed the subtidal areas, as well as the inter-tidal beach, the backing swamp and surrounding cliffs. Both maps are reproduced in Appendix A

The bathymetry was not comprehensively reconsidered again until November 2000 when DML carried out a survey in preparation for the ASR surf reef design. ASR carried out an as-built survey in September 2009. The inter-tidal beach was not included in any of these surveys. The DML and ASR charts are also included in Appendix A.

The 1882 and 1886 charts were located in the Auckland Library Heritage Collection and the Puki Ariki museum in New Plymouth respectively. They were scanned at high resolution and georeferenced by CSL to the NZTM (New Zealand Transverse Mercator 2000) co-ordinate system, this being the current standard. Digital data for the 2000 and 2009 surveys were provided by ECoast and converted to NZTM, thus enabling direct comparison of all charts. The 1886 data were used in the present study in preference to the 1882 as the former had more dense sampling. The 1882/86 elevation datum was extreme low tide, and chart datum was used for the 2000 survey – these being approximately equivalent.

To define change during the intervening 114 years, depths along two representative transects were abstracted. One transect is located along the western side of the bay and includes the breakwater and site of the artificial surf reef. The other transect runs out through the centre of the Bay. In addition, the artificial reef's early environmental impact was assessed using along and across-reef transects. All sampling transects are marked in Figure 5 which is underlain by the 2000 DML bathymetry.

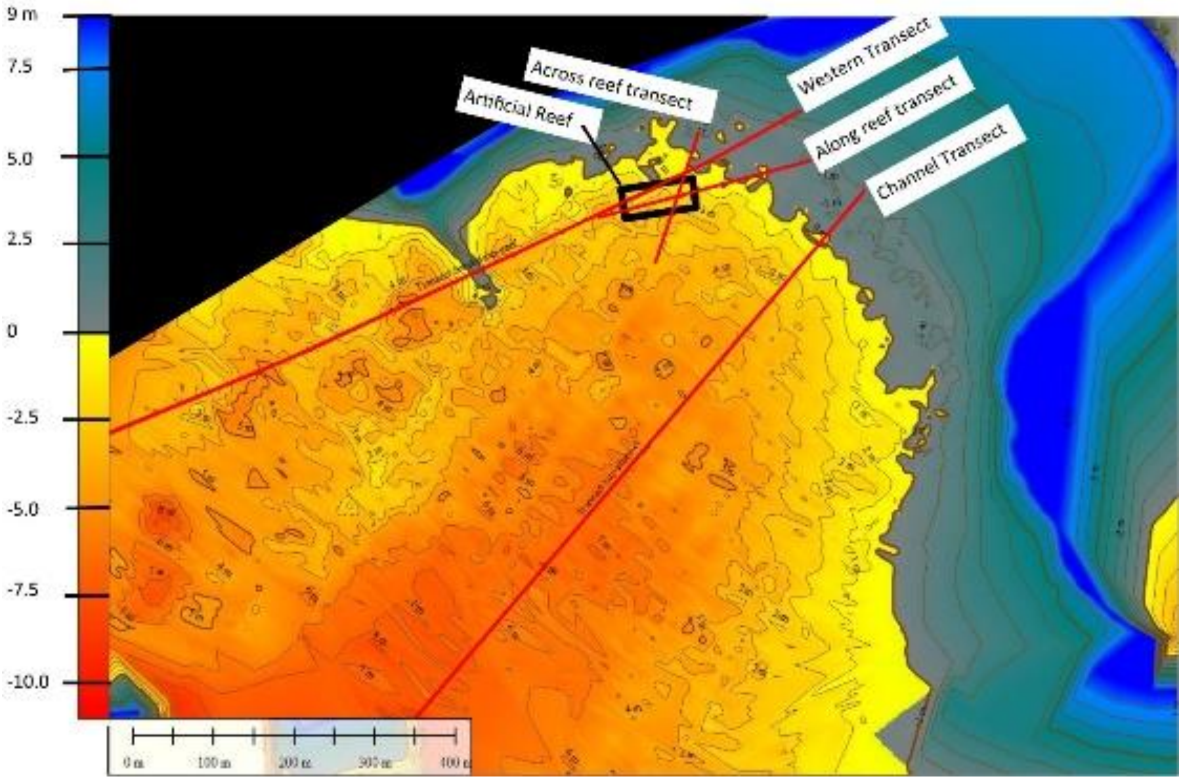


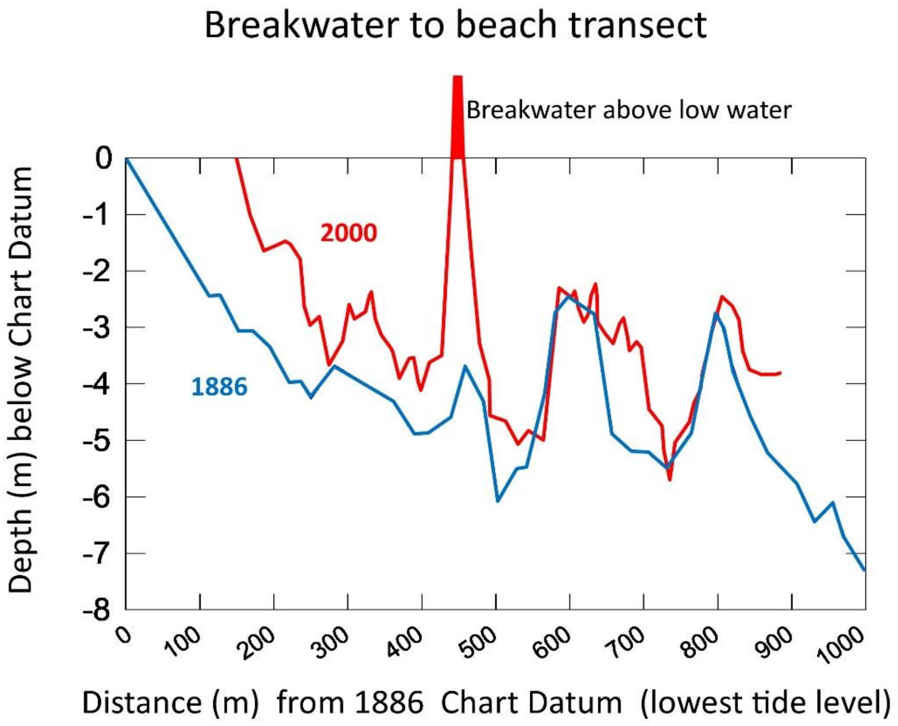
Figure 5 2000 bathymetry with sampling transects marked

3.2.2 Results

Long-term (1886 to 2000) bathymetric changes for the Western and Channel transects are depicted in Figure 6A. In the centre of the B ay, the elevation datum (extreme low tide) has migrated seaward some 140 m resulting in the seabed raising some 2.6 m. By comparison, the western side of the bay has migrated seaward some 155 m and infilled 3 m. These results suggest the breakwater (1924-28) may have a sheltering effect which has induced greater sedimentation on the western side where wave shadowing would be greater.

The artificial reef profile results (Figure 6B) show erosion occurred immediately landward on both transects – this would be associated with the increase in wave breaking and turbulence. There is an indication of intertidal sedimentation within the bay – a consequence of the reef as predicted in ASR (2004).

The Taranaki Regional Council is removing the reef at the time of writing and we understand pre and post-removal surveys are part of this process.



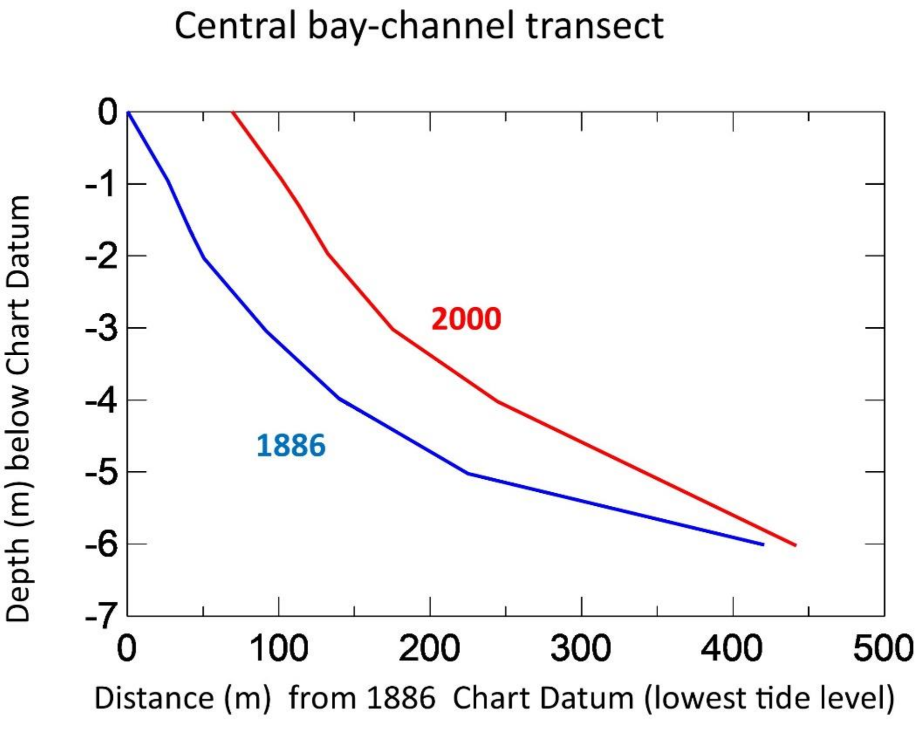
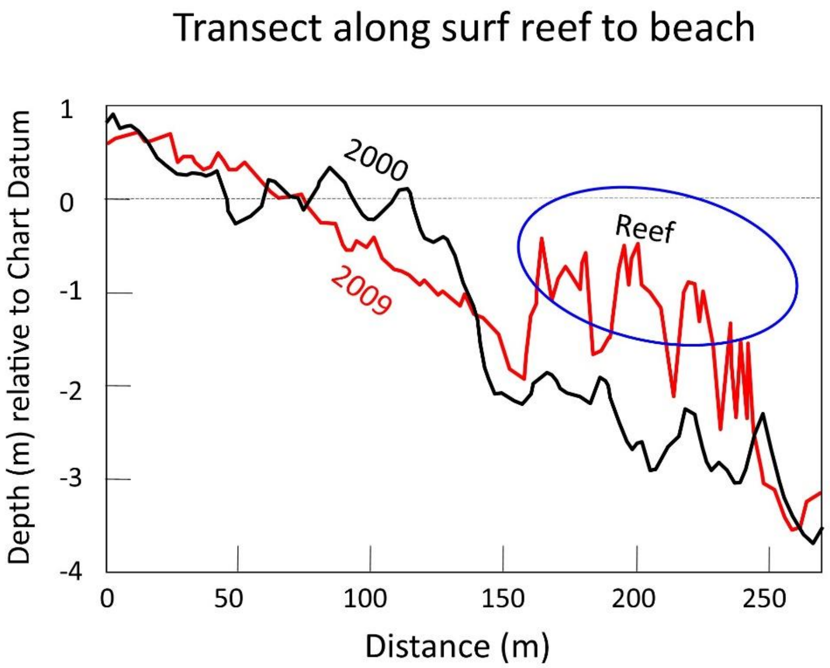


Figure 6A Western and central transect profile comparison 1886 with 2000.



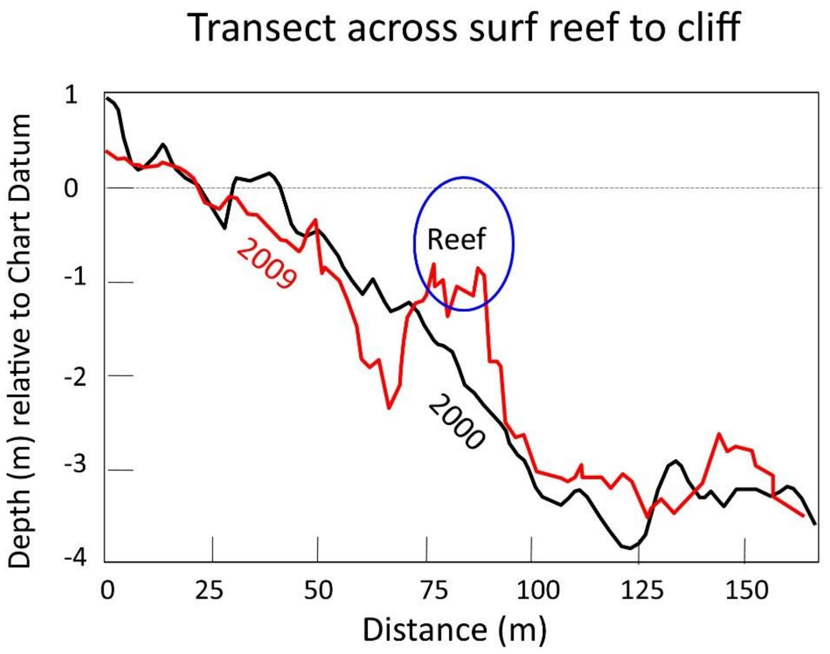


Figure 6B Along and across-reef profile comparison between 2000 (pre-construction) and 2009 (post construction). Transect locations as shown in Figure 5.

3.3 Shoreline change

3.3.1 Data

Shorelines are typically used to define coastal change and are themselves defined using a range of "indicators" including elevation such as the mean high water mark (MWHM) or features such as the vegetation-front which approximates the toe of the foredune. The earliest surveyed shorelines are found on bathymetric and land survey plans which, in New Zealand, typically date from the mid 19th century and map the high water mark (HWM) at the time of the survey. Vertical aerial photography in most parts of New Zealand began in the 1940s in association with WW2, and high tide lines, cliff edges or the vegetation front are typically used as shoreline indicators in associated coastal studies. From the 1990s, LIDAR (lazer surface detection) became available and this provides point clouds enabling the generation of a three-dimensional (3D) digital elevation model (DEM). When overlain with the corresponding aerial photograph, a range of elevation and feature-based shoreline indicators may be defined. More recently drone-based photography has been used to generate the DEMs using photo-overlap stereo analysis.

While cadastral land surveys for Ōpunakē date from 1867, the Hursthouse and Henderson surveys of the 1880s provide the first reliable shoreline data (HWMSpring). Unfortunately, subsequent survey plans in 1938 and 1963 plotted the 1880s shoreline rather resurveying this feature.

Vertical aerial photography is available from 1953, 1959, 1970, 1977, 1982, 1994, 1996, 2007, 2012, 2017 and 2019. Vertical satellite imagery is available from 2001, 2004, 2007, 2012, 2013 (2), 2015, 2016, 2017, 2018 (2) and 2019. Oblique aerial photographs are available from 1947 and 1958. All images were transformed to New Zealand Transverse Mercator (NZTM) coordinates to allow direct overlay and comparison. Oblique terrestrial photography is available from 1908 with the Feaver collection being particularly useful in early defining shorelines.

For the present study, the high water mark delineated by a dark-light boundary (signaling the pervious spring high tide line) and the vegetation front were digitized from aerial photographic and satellite images, while the spring high water (HWMSpring) line was similarly abstracted from the terrestrial photos.

3.3.2 Results

The set of HWMSpring shorelines are overlaid in Figure 7A with their envelope shaded blue and five cross-shore transects marked T1 to T5. These data show the shoreline extends further seaward in the centre of the bay, narrows slightly in the west and narrows more extensively at the eastern end of the Bay. In addition, the dashed black line depicts an average shoreline shape – a shape that infers the direction of sediment transport is eastward (arrowed). This result being consistent with other observations of net current direction mentioned earlier in Section 2.3.

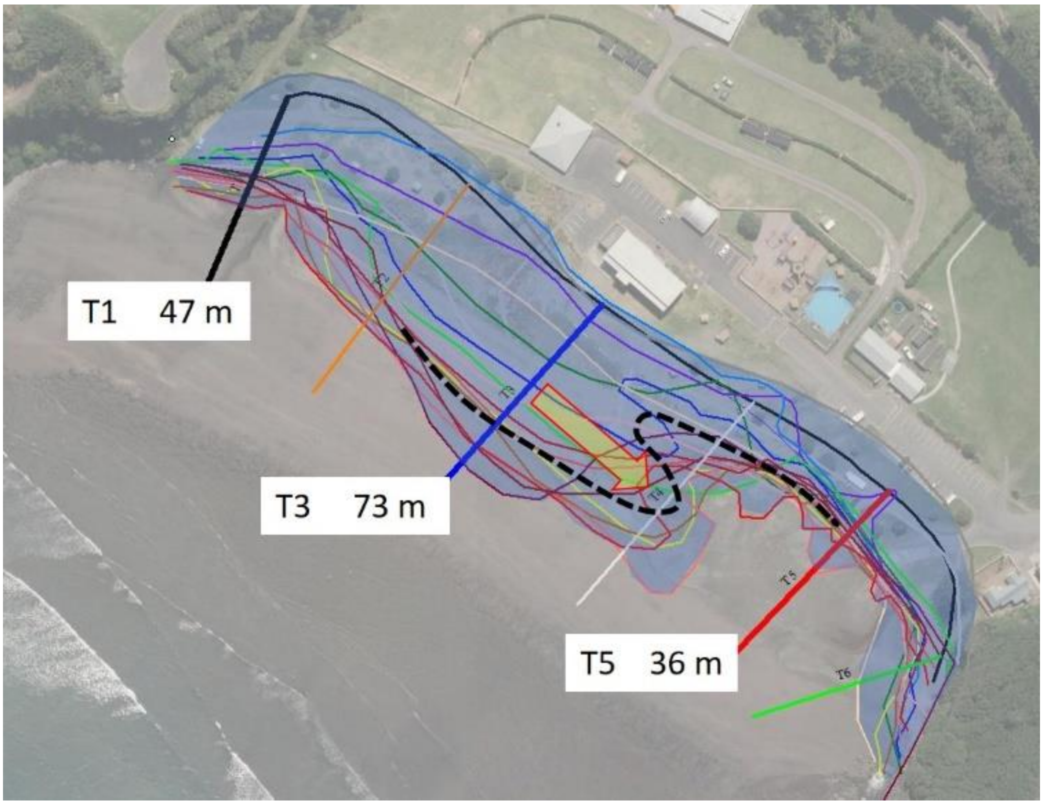


Figure 7 Superimposed HWMSpring shorelines with their envelop shaded blue and envelop widths marked for three transects (1, 3 and 5). The dashed black line locates an overall shoreline shape and the arrow shows the direction of inferred sediment transport.

As noted earlier in Section 2.2, the alongshore variation in shoreline shape is broadly related to the location of drainage outlets onto the beach (Figure 8), with the shoreline being landward where the outlets occur and seaward where they are absent. The beach water table water is raised in the vicinity of drainage outlets thereby increasing the water content in the beach sand which reduces inter-grain resistance and facilitates erosion.

Shoreline behaviour through time is depicted in Figure 9. Only graphs for transects 1, 3 and 5 are included as these were found to adequately represent the beach system. The construction of the breakwater (1924-8) is marked by the vertical bar. While early data points are sparce, the graph indicates a stable/eroding shoreline before breakwater construction, and systematic accretion thereafter. The subdued foredune morphology in the 1882 and 1908 imagery (Figure 3) supports such early shoreline behaviour with the dune possibly being a temporaryl feature.

Linear regression models have been fitted to the post-breakwater data points (dashed lines in Figure 9) and show average rates of shoreline advance ranged between 0.53 m/yr at Transect 2 in the centre of the bay down to 0.27 and 0.23 m/y at the west and eastern ends respectively.

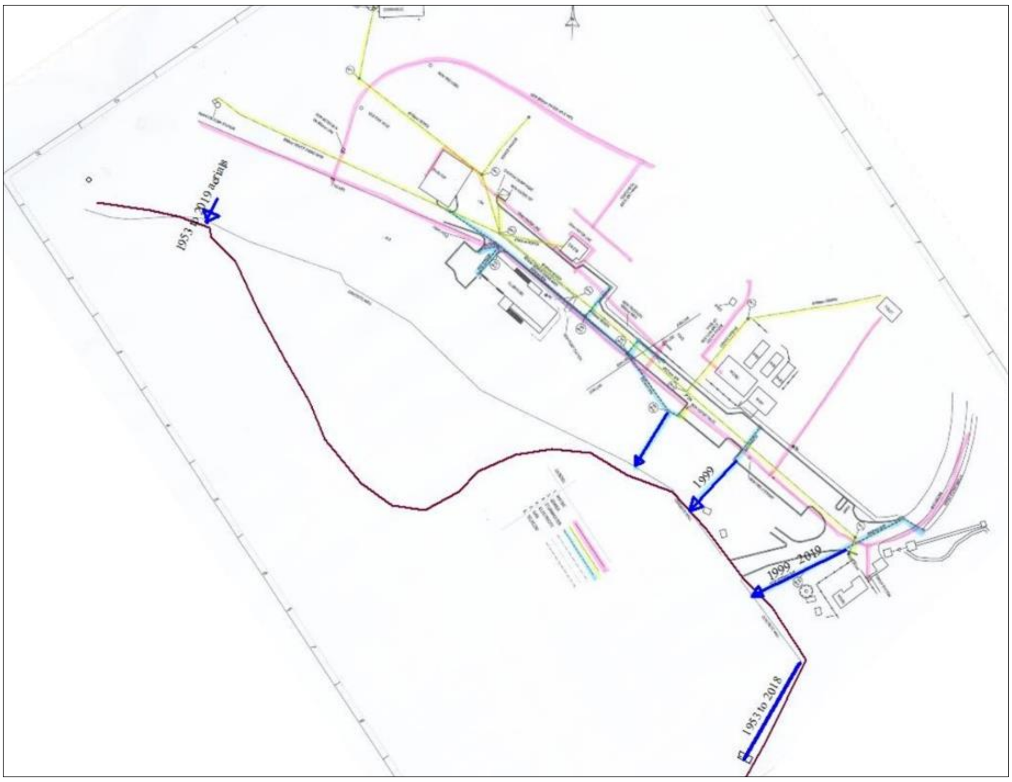


Figure 8 STDC Ōpunakē Beach infrastructure with beach drainage outlets marked by arrows along the (2019) spring high water shoreline.

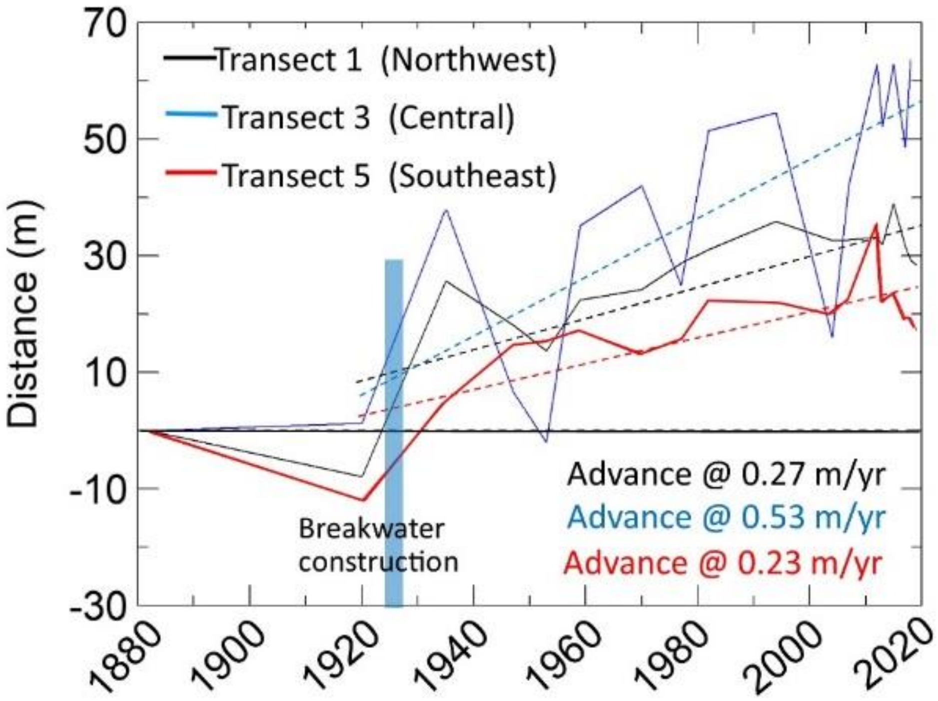


Figure 9 Shoreline time-series graphs for Transects 1 ,3 and 5, with linear regression models fitted (dashed lines). The Breakwater construction period is marked by the vertical blue bar

The post-1920s shoreline accretion trend is also consistent with the breakwater wave shaddowing effect sugested by the bathymetric analysis. Such structure effects on shoreline change have been observed elsewhere; for example, at Timaru the 1.3 km breakwater resulted in the adjacent bay (Caroline Bay) accreting 500 m seaward in 140 years (Tierney, 1977).

The graphs also depict the shoreline fluctuating in its cross-shore location with a periodicity of about 30 years. Such fluctuations likely relate to variation in littoral sediment supply quite possibly associated with changing fluvial input as suggested by Gregory (1982).

3.4 Sand dunes

As described in Section 3.1, the natural beach was backed by a low foredune in the central-west and minimal, if any, dune in the east where the swamp drained onto the beach. This is known as a barrier beach system where the beach/dune acts as a barrier to freshwater drainage reaching the sea. It seems quite plausible that the dune may, at times, have been eroded away entirely by storm waves during periods of lower sediment supply.

It was also noted in Section 3.1 that early images suggest sand dunes at the base of the cliff. This is a common occurrence when a foredune has become unstable and sand streams landward to form a "tongues" of sand known as a parabolic dune which migrates landward overcoming obstacles in its path – including climbing cliffs. In Section 6.2 (Figure 20), recent photographs of the foredune fronting the Surf Club show the initial stages of parabolic dune development. There are several reasons why a foredune becomes unstable and all involve loss of vegetation cover. Most relevant at Ōpunakē are wave cut of the foredune toe exposing bare sand and/or dune height increasing such that increased wind speed desiccates vegetation and facilitate wind funneling. Ensuring adequate vegetation cover and control of foredune height become integral parts of managing developed beach environments.

As listed in Table 1, the foredune was flattened/removed to facilitate beach development between about 1913 and the mid 1930s. The low seawall along the western beach constructed about 1917 (Appendix B) suggests upper beach erosion was a problem at the time.

The western/central swamp was infilled during the 1930s; however, the photo record and recent topographical surveys suggesting the eastern sector infill was not completed and seemed only to receive some infill by wind-blown sand and dewatering by the drainage infrastructure which Opus (2017) describes as now being inadequate and dysfunctional.

Since 1935, dune fencing and/or planting has been used to trap wind-blown sand (examples in Figure 10). Substantial mechanical effort has also been used to control the abundant sand supply (examples in Figure 11) with sand from the upper beach and dunes often being returned to the beach at low tide as noted in Section 2.3.

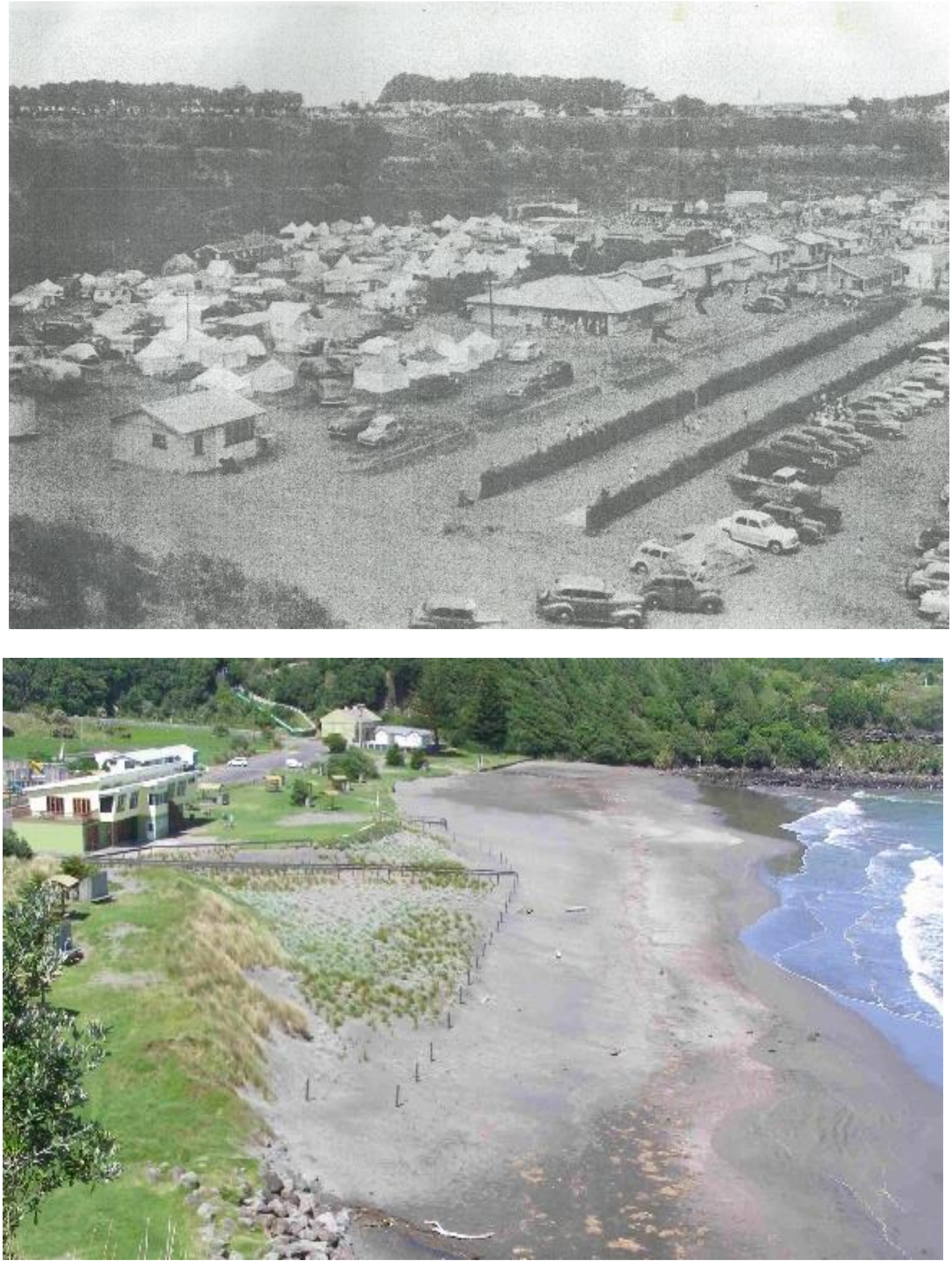


Figure 10 Conservation works to control wind-blown sand. Upper photo: brush fences in the mid 1950s (1917 seawall evident immediately to landward). Lower photo taken in 2011 showing the 2009 planting.

Figure 11 Mechanical sand removal. Top photo: beach scraping 1990s; middle photo: dune removal 1987, and bottom photo: dune removal 1996-1997

Presently, the highest dunes (about 5 m above the dune toe which is about 3 metres above MSL) are located to the west of the Surf Club and correspond with early sand fencing (Figure 10, upper photo) and areas which avoided sand clearance (Figure 11, lower photo). The most recent dune growth along the central-sector shoreline results from planting in 2009 (Figure 10, lower photo) which appears to have been carried out to control an episode of severe wind-blown sand. Figure 9 shows this period corresponds with the current fluctuation peak, i.e. the shoreline undergoing a seaward excursion. However, the ongoing positive sand supply has enabled the dune to continue to grow in elevation to the point where it was blocking surf lifesavers view of beach so was “topped” in November, 2018. The bare sand has yet to be replanted and now wind-blown sand is again causing a nuisance hazard; this situation is illustrated and considered further from a hazard risk perspective in Section 6.2.3.

3.5 Future change

Future geomorphology depends on the energy drivers and sediment supply controls: wind and wave regime, sea-level/climate change and the extent to which any sedimentation associated with the breakwater-effect continues into the future.

In addition, the evidence presented earlier shows how Ōpunakē Beach and environment are very much a product of anthropogenic activity interacting with, and modifying, coastal processes, and as such, alternative future interventions can be expected to modify the beach environment. The following sections on erosion and inundation hazard will identify and quantify how the environment may respond in the future, thereby providing a basis for outlining hazard mitigation (risk reduction) options.

4 EROSION HAZARD ASSESSMENT

4.1 Conceptual model

Best practice methodology for assessing the coastal erosion hazard for a sandy shoreline involves additively combining 4 essentially independent components (MFE 2008, NIWA 2012, MFE 2017) which are diagrammatically illustrated in Figure 12

ST = Short-term cross-shore fluctuation in shoreline position associated with storm erosion;

DS = Dune stability adjustment. Following storm-wave erosion (cut) the dune has a near-vertical face that subsequently adjusts by slumping and sliding to achieve the stable slope angle – the angle of "repose";

LT = Long-term retreat of the shoreline (annual rate * prediction period): this occurs on coasts where there is a long-term sediment deficit, and

RSLR = Shoreline retreat due to the effects of projected sea level rise (SLR). A rise in sea-level enables wave energy to attack and erode higher up the profile and this sediment is then deposited seaward.

The **current erosion hazard distance** (EHD) is represented by equation 1.

$$EHD_{2020} = ST + DS \qquad (1)$$

The **future erosion hazard distance** for a 100 year prediction period is represented by equation 2:

$$EHD_{2120} = ST + DS + LT + RSLR \qquad (2)$$

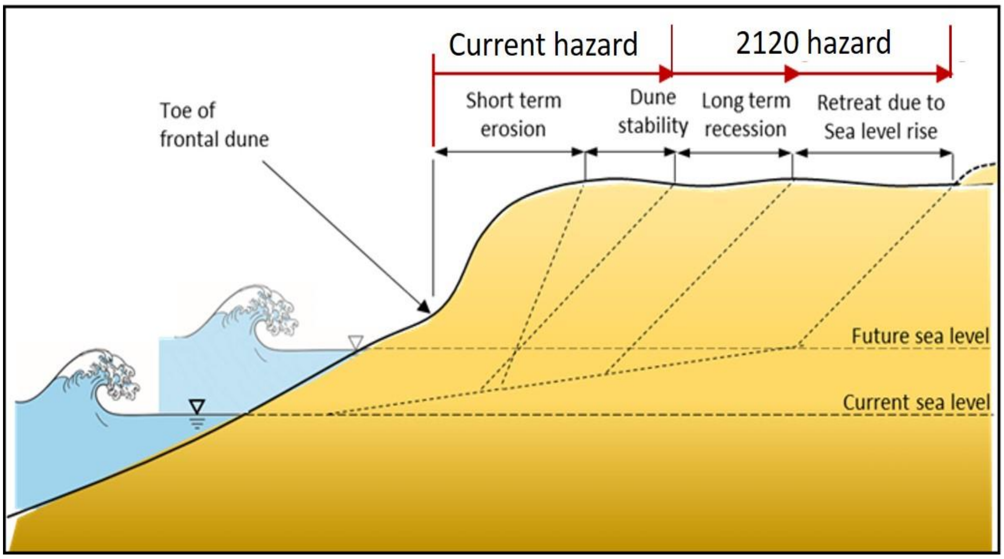


Figure 12 Definition sketch of erosion hazard assessment components for current and future scenarios

Conservative values are selected for the components as the NZCPS (2010) requires the identification of sections of coast potentially susceptible to erosion hazard risk. Where highly accurate assessments are required a more expensive probabilistic approach is used (Shand et al., 2015). While a factor of safety was included in the earlier assessments, this now omitted due to the improved quality of data and methodologies. In the present study hazard ranges are defined to assist in planning so a component-based summation approach was considered adequate.

4.2 Component derivation

4.2.1 ST

Short-term shoreline fluctuations are typically derived from surveyed profiles; however, as no such monitoring had been carried out at Ōpunakē, ST was based on statistical analysis of the foredune toe (vegetation-front) identified on aerial photo and satellite images representing discrete periods of natural behavior. In particular, the standard error of estimate (SEE) was derived from a linear regression analysis (see LT derivation below) and when multiplied by 2 this parameter provides 95% certainty of encompassing that the range of possible shoreline locations.

For our Ōpunakē data, SEE = 3 m so ST = 6 m (see Table 3)

4.2.2 DS

The dune stability (DS) component is computed using equation 3.

$$\mathrm{DS} = \frac{\mathrm{h_{dune}}}{2(\tan \alpha_{\mathrm{sand}})} \qquad (3)$$

Where h_{dune} is the dune height from the eroded base to the crest and α_{sand} is the stable angle of repose, typically 34 degrees for dry sand.

The dune retreat values ranged between 1.6 and 8.2 m (see Table 3) with the largest values corresponding to the highest dunes

4.2.3 LT

Long-term retreat was derived from a linear regression analysis of the HWMSpring shoreline data-set (depicted in Figure 7), using equation 4.

$$\text{Dis} = a + r{*}\text{Chron} + SEE \qquad (4)$$

Where r is the mean rate of shoreline change, which when multiplied by the prediction period to give LT; Dis is the cross-shore distance, Chron = the number of years since the first sample, a = the intercept on the Dis axis, and SEE = fitting error.

LT values range between 0.23 m/yr and 0.53 m/yr (see Table 3) with the higher rate occurring along the central shoreline

4.2.4 RSLR

The most widely used approach to defining shoreline retreat from sea-level rise on sandy coasts is by the geometric equilibrium model (Shand et al., 2013) as conceptually illustrated in Figure 13. The model essentially translates the profile along the average slope by an amount determined by SLR and this can be defined using equation 5.

$$RSLR = SLR/\tan \beta \qquad (5)$$

Where tan β is the average profile of the depositional slope. In cases where there is either limited sand cover or barriers to littoral drift, the boundaries of the depositional area are defined by the inter-tidal slope (T&T, 2018). For Ōpunakē, this average slope was defined from the 1977 profile reproduced in Gregory (1982), and the recent TPL (November, 2019) survey. These data gave slopes of 0.0167 and 0.0162 respectively, so the average value of 0.0165 was used in the present erosion analysis.

Sea-level rise (SLR) scenarios for the New Zealand coast are provided by MFE (2017). These guidelines define the following representative concentration pathway (RCP) scenarios of future radiative forcing, with the average SLR for each RCP listed in Table 2:

- RCP 2.6 the peak and decline in global emissions occurs soon;
- RPC 4.5 emission peak around 2050;
- RPC 8.5 no effective emissions reduction, and
- RPC 8.5H+ as for RPC 8.5 with faster polar ice sheet melt later in this century.

RSLR component values to 2120 are as follows: 18.1 m for RCP 2.6; 25.4 m for RCP 4.5; 48.5 m for RCP 8.5, and 65.5 m for RCP 8.5H+ .

Table 2 Mean SLR (m) projections[1,2]

Time frame	RCP 2.6	RCP 4.5	RCP 8.5	RCP 8.5H+
2020	0	0	0	0
2070	0.16	0.20	0.28	0.42
2120	0.30	0.42	0.80	1.08

1. Adjusted to 2020 base as MFE (2017) guidance is based on 1996 base
2. Subtracts historic rate of 1.7 mm/year to avoid double-counting erosion from SLR already incorporated within the historically-based LT values.

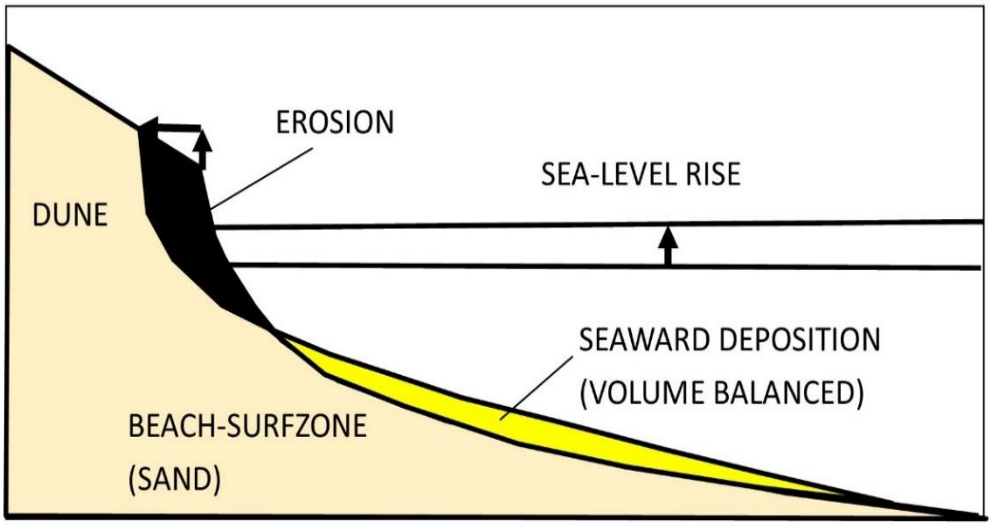


Figure 13 Geometric translation model concept of shoreline response to sea-level rise

4.3 Coastal erosion hazard distances

4.3.1 Computation and assumptions

Two scenarios are used for LT inclusion:

1) Where no future LT contribution occurs (LT = 0). This is typically used in higher level potential erosion hazard calculations where coasts have undergone long-term accretion, and

2) Where LT continues into the future the historical values are used. This scenario is also included here as historical accretion has been consistent and it seem reasonable to assume at least some accretion will continue during the planning period.

The assessment uses lower and upper SLR scenarios (RCP 2.6 and RCP 8.5H+) to define the range of possible RSLR values.

Potential coastal erosion assessments assume no shoreline structures are present. This assumption is due to their typically limited design life and the potential for structures to not be renewed in the future. If existing protection structures are robustly upgraded to account for climate change then this becomes a type of hazard mitigation and contributes to risk reduction.

Hazard retreat distances are measured landward of a reference shoreline which is typically the dune vegetation front or hard structures as identified on the most recent imagery.

4.3.2 Results

Potential erosion hazard distances at 2120 are summarized in Table 3 and the resulting hazard lines are plotted in Figure 14 where the offsets are measured from the 2019 (reference) shoreline.

TABLE 3 Summary of erosion component values and erosion hazard line distances (EHD) for different scenarios to 2120

Transect	ST (m)	LT (m) excluded	LT (m) from model	RSLR (m) RCP 2.6	RSLR (m) RCP 8.5H+	DS (m)	EHD (m)
1	6	0	-	-18.1	-65.5	-3.8 -3.8	-29.1 -75.3
1	6	-	26.7	-18.1	-65.5	-1.9 -3.9	0 -48.4
2	6	0	-	-18.1	-65.5	-5.9 -3.4	-30.0 -74.9
2	6	-	50.1	-18.1	-65.5	-1.6 -6.1	+24.4 -27.5
3	6	0	-	-18.1	-65.5	-3.7 -3.1	-27.8 -74.6
3	6	-	52.8	-18.1	-65.5	-1.6 -4.2	+26.8 -22.7
4	6	0	-	-18.1	-65.5	-3.2 -3.3	-27.3 -74.8
4	6	-	43.9	-18.1	-65.5	-2.2 -3.2	+17.6 -30.8
5	6	0	-	-18.1	-65.5	-3.1 -3.4	-27.2 -74.9
5	6	-	23.2	-18.1	-65.5	-2.8 -3.3	-3.7 -51.8
6	6	0	-	-18.1	-65.5	-3.5 -3.4	-27.6 -74.9
6	6	-	12.4	-18.1	-65.5	-3.3 -3.6	-15.0 -62.7

For RPC 2.6 with historical LT continuing, the hazard line is seaward of the present shoreline for all but the eastward most 30 m. The greatest seaward offset is 26.6 m in the centre of the bay. For RPC 2.6 with no future LT, the shoreline will retreat approximately 28 m along the entire bay.

At the other SLR extreme (RPC 8.5H+), with historical LT continuing, there is retreat of 20 to 30 m in the centre of the bay and about 50 m at the ends. The most extreme erosive scenario occurs under 8.5H+ when no allowance is made for future accretion (a somewhat unlikely situation), with the resulting shoreline being about 75 m to landward.

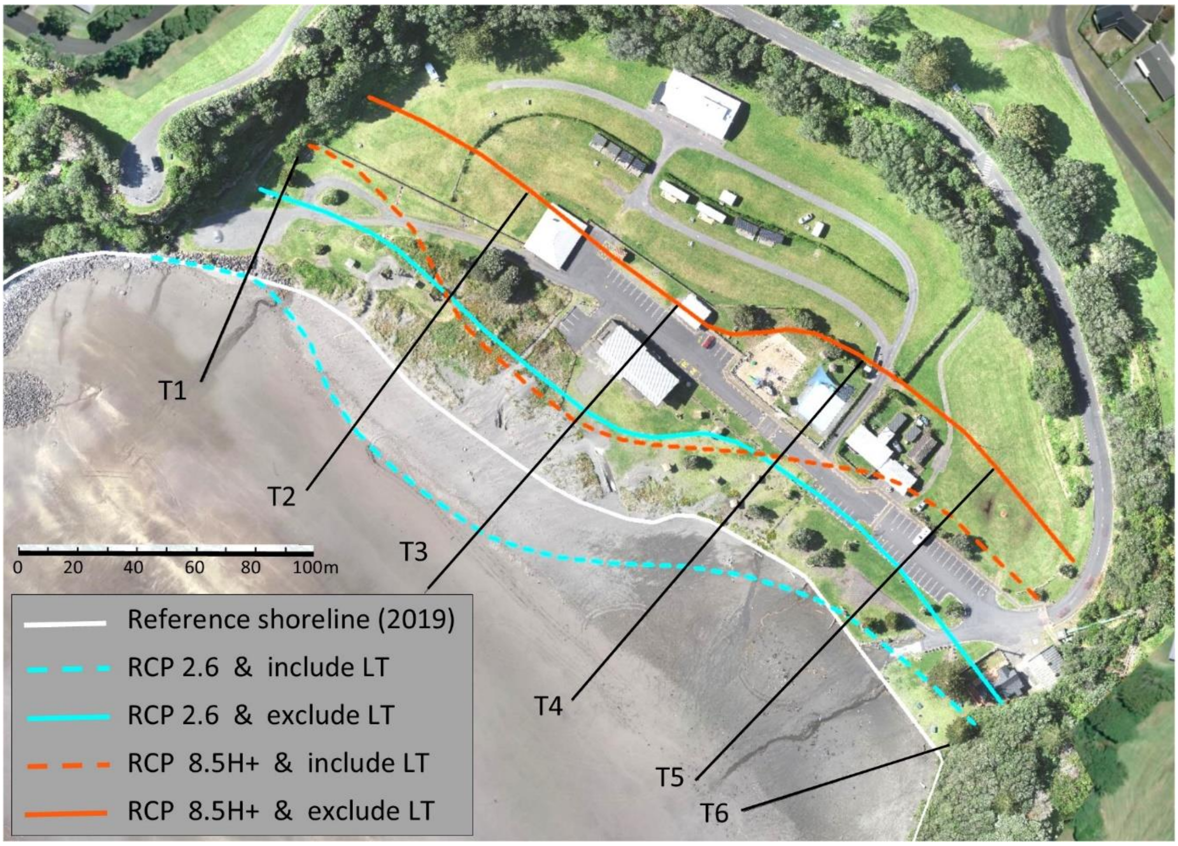


Figure 14 Erosion hazard lines at 2120 – derived by summing values for ST, DS and scenarios for both LT (inclusion and exclusion), and RSLR for the range of RCPs (2.6 and RCP 8.5H+). Component values for each transect are listed in Table 3, and the hazard lines are measured from the 2019 reference shoreline (white): positive values to seaward and negative to landward. The underlying aerial photo is from the November 2019 TPL survey.

5 INUNDATION HAZARD ASSESSMENT

5.1 Conceptual model

Best practice methodology for assessing coastal inundation is described in NIWA 2012, MFE 2017, T&T 2017 and involves deriving the following list components which are diagrammatically illustrated in Figure 15

SWL = Still Water Level, also referred to as Storm Tide, is defined by the combination of:
-Astronomical tide, PLUS
-Storm surge (SS) which is itself the combination of:
-Wind set-up against the coast PLUS
-Low barometric pressure PLUS
-Mean sea level fluctuations (seasonality, ENSO etc).

SU = Wave set-up where the elevation of the mean water surface caused by wave breaking and subsequent momentum across the surf zone .

RU = Wave run-up is the shoreline elevation reached by individual waves. This component includes wave set-up.

SLR = Sea-level rise over planning time frames up to 100 years, using the RCP-based values discussed earlier in Section 4.2.4.

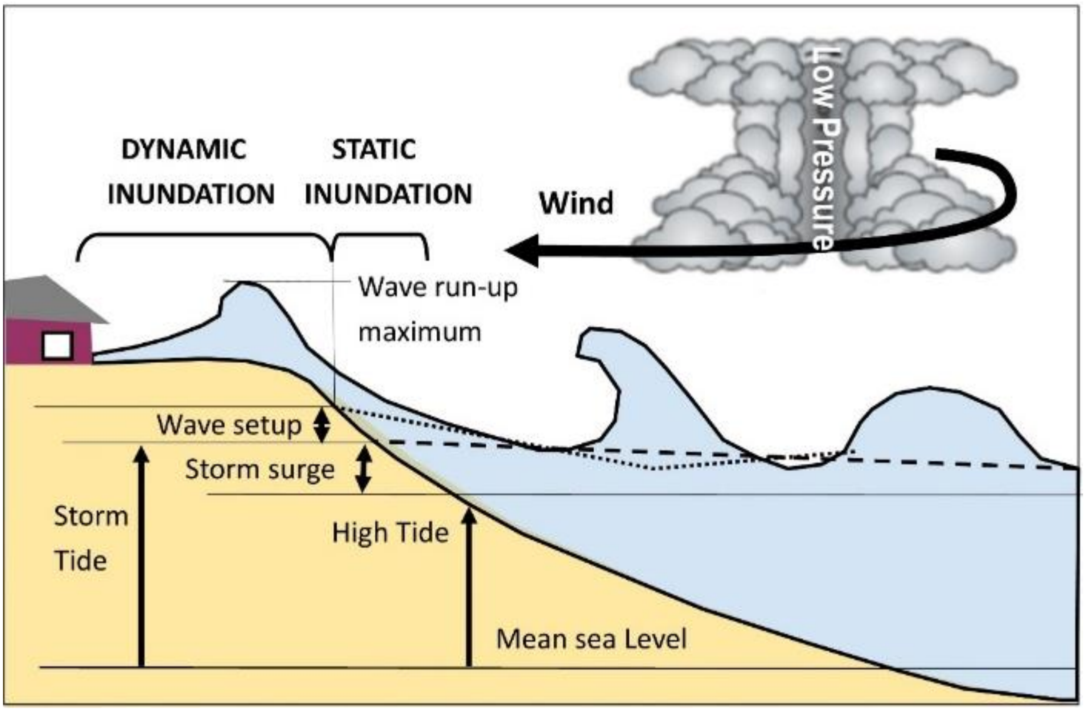


Figure 15 Schematic diagram of tide, wave and atmospheric components driving extreme sea-levels and storm-induced inundation at the coastal margin.

The **static extreme water level** (Stat_EWL) is represented by equation 6:

$$\text{Stat\_EWL} = ST + SU + SLR \qquad (6)$$

Stat_EWL is a constant level and has the greatest inundation impact along low-lying beaches and inlets.

The **dynamic extreme water level** (Dyn_EWL) is a time-varying level controlled by wave run-up and is represented by equation 7.

$$\text{Dyn\_EWL} = ST + RU + SLR \qquad (7)$$

Dyn_EWL maximizes at or about the shoreline and as this pulse of water progresses inland it dissipates from ground friction, obstacles and ground slope. The attenuation vs distance relationship is critical to identifying the Dyn_EWL inundation hazard and is described further in Section 5.2.6.

As not all inundation components are independent, joint probability considerations are necessary (CIRIA, 1996) to derive the required inundation Return Period (RP) , also referred to as Annual Recurrent Interval (ARI). Put another way, if all component values were derived for the required RP and simply added together, then the result will be overly conservative (high).

As with the erosion hazard assessment in Section 4, a factor of safety is also omitted from current inundation assessments.

5.2 Component derivation

5.2.1 Tide

The mean spring tide level (MHWS) is include in coastal inundation assessments.
The MHWS for Port Taranaki (the closest port) is 1.33 m in New Zealand Vertical Datum 2016 (NZVD16) which increases to 1.48 m once adjusted to the current mean level of the sea (LINZ 2019-20). LINZ Secondary Port tables show the Ōpunakē tide range is slightly less than Port Taranaki value, so its adoption will provide a conservative base level.

5.2.2 Storm Surge

Metocean Solutions Ltd. undertook an extreme value analysis of measured sea-level data at Port Taranaki for the period 2002-2016 (Tonkin and Taylor, 2016). Extreme still water level (SWL) for different return periods are listed in Table 4. The elevation datum used in this report is New Zealand Vertical Datum 2016, or NZVD16, which is the standard presently being adopted throughout New Zealand. By subtracting the tidal component from the SWL, the corresponding storm surges were derived and the resulting extreme values are also listed in Table 4. While Port Taranaki and Ōpunakē are exposed to slightly different wind regimes some variation in SS can be expected; however, this is the best information available at the present time.

Table 4 Extreme storm surge and still water level 2002 to 2016 for Port Taranaki

RP (years)	Storm Surge (m)	SWL (m NZVD16)
1	0.52	1.75
10	0.69	1.91
50	0.81	2.00
100	0.86	2.04

Source: MetOceans for Tonkin and Taylor (2016)

5.2.3 Extreme wave data

Wave information are required to determine both Set-Up (SU) and Run-Up (RU).
In particular, significant wave height (average of the upper 1/3 of wave heights) at the breakpoint (Hb) is required for computing setup, while deep water wave height (Ho) is used for computing runup.

For this study, Metocean Solutions Ltd. undertook a detailed analysis of wave hindcast data using a 38 year hindcast record (1978 to 2016) to provide extreme values and ambient wave statistics for an inshore site just seaward of the Ōpunakē headlands (173.85E, 39.465S), and also at a site some 3.7 km offshore (173.82E, 39.48S) where water depth is ~40 m. Extreme significant wave height values are listed in Table 5 for RPs ranging from about 1 month to 1000 years. Note the smaller RPs values (0.1, 0.2, 0.5, 1.0) are used when computing SU and RU so when combined with SWL values the combined component calculation gives 1, 10, 50 and 100 year return period extreme inundation values (CIRIA, 1996).

5.2.4 Wave set-up

There are a range of methods available to calculate wave set-up including both numerical and empirical. While empirical approaches are straightforward, the numerical method is preferred as it incorporates continuous seabed slope. But it is a more complex computation involving the continual change in height and period values as waves propagate shoreward – information that was not readily available for this Ōpunakē study. However, in their recent inundation assessment of the North Taranaki coast, Tonkin and Taylor (2016) calibrated the empirical approach of CEM (2006) to the numerical approach of Larsen and Kraus (1989) and identified a calibration coefficient of 0.59. The present assessment will therefore compute SU using the empirical CEM (2006) method then apply the 0.59 reduction. Input parameters are inshore breaking wave height (Hb), peak period (Tp) and beach slope (tan β) from breakpoint to set-up intersect with the beach profile. These parameter values together with resulting set-up values are shown in Table 6A to range between 0.56 and 0.62 m.

Table 5 Extreme wave values for the inshore and offshore sites

Return Period yr	Inshore Hb (m)	Inshore Tp (sec)	Offshore Ho (m)	Offshore Tp sec
0.1	3.43	13.68	4.42	11.63
0.2	3.58	14.05	4.93	12.18
0.5	3.73	14.43	5.53	12.77
1.0	3.82	14.67	5.94	13.16
10	4.09	15.33	7.22	14.22
50	4.24	15.71	8.03	14.83
100	4.30	15.87	8.37	15.06
1000	4.49	16.34	9.46	15.76

Source MetOceans (2019)

Table 6A Extreme wave set-up

Return Period	0.1 year	0.2 year	0.5 year	1 year
Wave (Hb)	3.43	3.58	3.73	3.82
Period (Tp)	13.7	14.1	14.4	14.7
Slope	0.016	0.016	0.016	0.016
Empirical	0.94	0.98	1.03	1.05
Calibrated SU	0.56	0.58	0.61	0.62

5.2.5 Wave run-up

A range of empirical-based formula to predict run-up have been developed over the past 50 years using the results of field and laboratory studies. Shand et al. (2011) reviewed these methods using field data of run-up height measured during extreme events and found the method of Mase (1989) to be the most accurate predictor so this will be used in the present assessment. Input parameters are offshore significant wave height (Ho) and peak wave period (Tp) and these are listed in Table 6B together with resulting maximum run-up levels which range between 2.36 m and 3.13 m (above the still water levels in Table 4) .

Table 6B Extreme wave run-up

Return Period	**0.1 year**	**0.2 year**	**0.5 year**	**1 year**
Wave (Ho)	4.42	4.93	5.53	5.94
Period (Tp)	11.6	12.2	12.8	13.2
Slope	0.027	0.027	0.027	0.027
Run-up	2.36	2.62	2.92	3.13

5.2.6 Overtopping height attenuation

Maximum runup occurs about the shoreline and if it overtops this level then the subsequent landward flow is attenuated as water contained within the wave spreads out under gravity and its energy dissipated by obstacles, ground friction and ground slope. This process is illustrated in Figure 16 and the wave attenuation distance is calculated using the original method of Cox and Machemehl (1986) and adjusted by FEMA (2005) to derive equation 9.

$$d = \left[\sqrt{RU - Y_0} - \frac{5X}{A(1-2m)\sqrt{gT^2}}\right]^2 \qquad (9)$$

Where:

d = Flow depth (in meters) at certain wave run-up attenuation distance (X)

X = Wave run-up attenuation distance (m)

RU = Wave run-up level including the storm tide (m RL)

Y_0 = Dune crest elevation (m RL)

T = Wave period

G = 9.81 m/s^2

A = Friction/resistance factor

M = Positive upward inland slope

Landward attenuation distances for a range of runup (RU) and overtopping heights (h) were calculated using equation 9. Results for the different shoreline sectors (rock revetment at western end, foredune in centre and the retaining wall at the eastern end) are shown in Table 7. For comparison, both high and low friction surfaces were considered for the eastern sector (Table 7A), with the present cover corresponding to the lower resistance option (grass and pavement). The higher resistance option consisting of driftwood and other obstacles. Only the current cover is included for the central and western sectors (Tables 7B and C respectively).

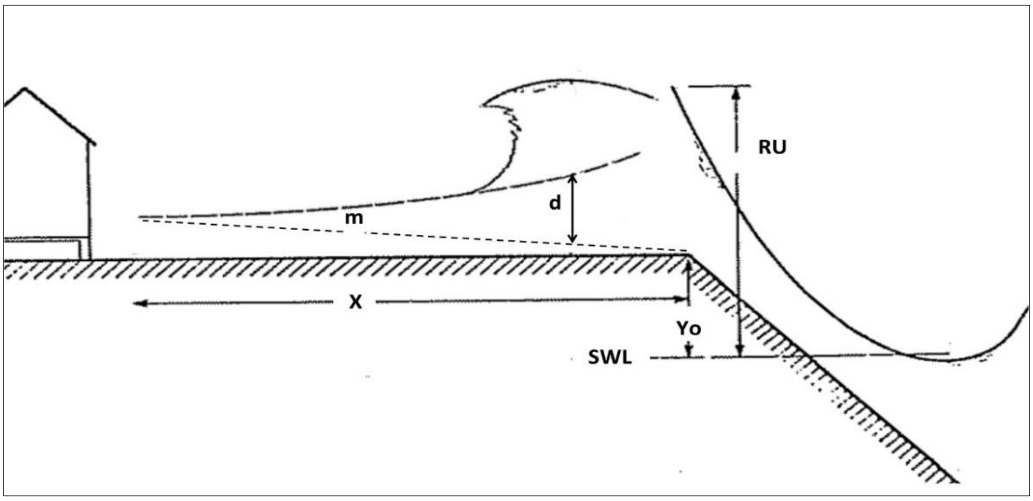


Figure 16 Schematic diagram of overland flow attenuation and illustration of listed parameters used for the computation of equation 9.

TABLE 7 Landward attenuation distance (marked x in Figure 16) at different shore-line locations and run-up elevations. All dimensions in metres with heights relative to NZVD16.

A. Eastern sector (retaining wall)

Crest elevation	4	4	4	4	4
RU	4.5	5.0	5.5	6.0	6.5
h	0.5	1.0	1.5	2.0	2.5
X high resistance	9	15	21	25	29
X low resistance	25	42	57	68	79

B. Central sector (sand dunes)

Crest elevation	5	5	5	5	5
RU	4.5	5.0	5.5	6.0	6.5
h	-0.5	0	0.5	1.0	1.5
X	-2.5	0	9	15	21

C. Western sector (revetment)

Crest elevation	5	5	5	5	5
RU	4.5	5.0	5.5	6.0	6.5
h	-0.5	0	0.5	1	1.5
X	-1.5	0	24	42	57

5.2.7 Sea-level rise

Future sea-level rise (SLR) values for an inundation assessment using the representative concentration pathway (RCP) approach recommended in MFE (2017) and using with a 2020 base, are shown in Table 8 to range between 0.3 and 1.08 m out to 2120.

Table 8 Mean SLR projections using a 2020 base

Time frame	RCP 2.6	RCP 4.5	RCP 8.5	RCP 8.5H+
2020	0	0	0	0
2070	0.16	0.20	0.28	0.42
2120	0.30	0.42	0.80	1.08

5.3 Extreme water levels and inundation extents

5.3.1 Extreme water levels

Extreme static and dynamic water levels (Section 5.1, Figure 15) for both the present (2020) and 100 year (2120) time fames and using the recommended RCP-based SLRs are shown in Table 9. In addition, MHWS and SWL are also listed. Results for both 1 and 100 year return periods are given and all levels are based on NZVD16.

Table 9 Extreme water level summary for 2020 and 2120

Planning horizon	Return Period (yrs)	2020	2120	2120	2120	2120
SLR (m)		- 0	RCP 2.6 0.44	RCP 4.5 0.56	RCP 8.5 0.95	RCP 8.5H+ 1.25
MHWS (m)		1.48	1.92	2.04	2.43	2.73
SWL (m)	1 year RP 100 year RP	1.75 2.30	2.19 2.48	2.31 2.60	2.70 2.99	3.00 3.29
Stat_EWL(m)	1 year RP 100 year RP	2.31 2.92	2.75 3.10	2.87 3.22	3.26 3.61	3.56 3.91
Dyn_EWL	1 year RP 100 year RP	4.48 5.60	4.92 5.78	5.04 5.90	5.43 6.29	5.73 6.59

SLR = sea-level rise. MWHS = mean high water spring. SWL = still water level, also knows as ST= storm tide level. Stat_EWL = extreme static water level. Dyn_EWL = extreme dynamic water level. Vertical datum is NZVD16.

5.3.2 Static extreme water level inundation

The inundation extents of the extreme static water levels are depicted graphically in Figure 17 which shows a cross section at the eastern end of the beach (transect line is marked blue in Figure 18), this being the most vulnerable location. Overtopping occurs a little under 4 m, but only under the most extreme SLR scenario and highest return period is this level reached.

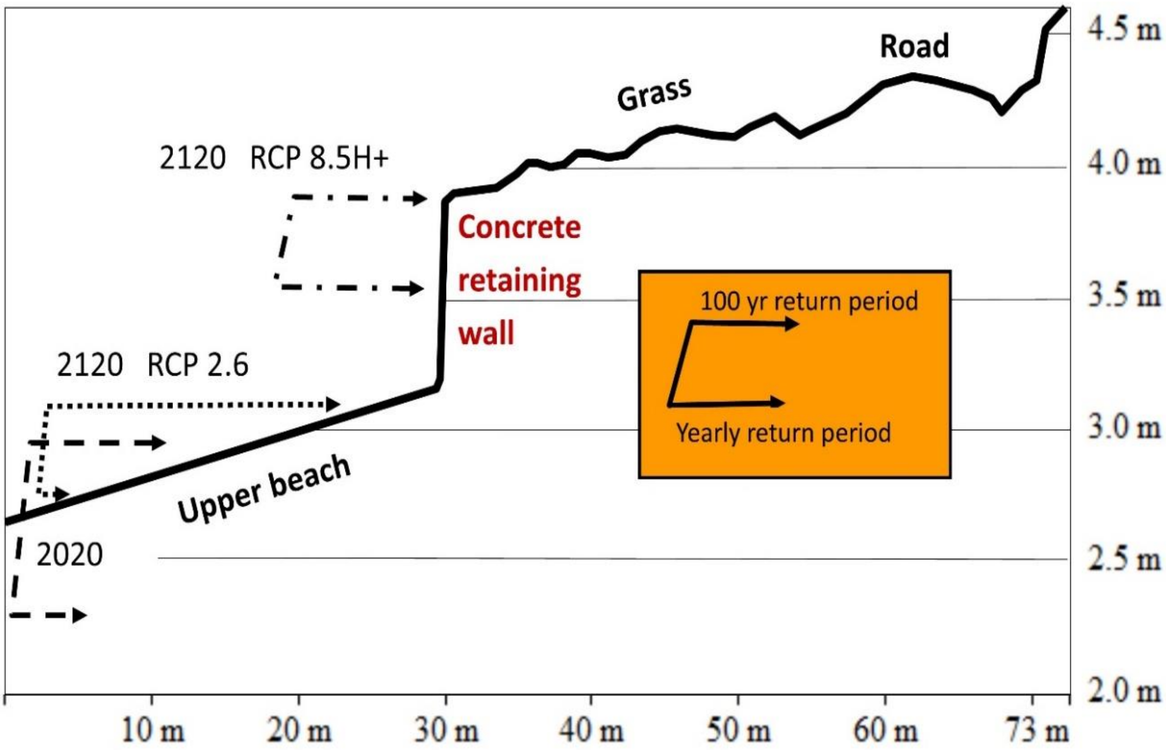


Figure 17 Static extreme water levels (still water level plus storm surge) for bracketing scenarios along the transect marked in Figure 18.

5.3.3 Dynamic extreme water level inundation

The inundation extents of extreme dynamic water levels are depicted in Figure 18 which maps the overland flow limits (to 0.1 m depth which is considered "tolerable") for present (2020) and future (2120) time frames. Values are based on Table 7 (modelled attenuation distances for existing ground cover), and then adjusted for topography using the 2019 TPL 3D digital elevation model. Of particular note is the effectiveness of sand dunes along the central sector in mitigating run-up extent.

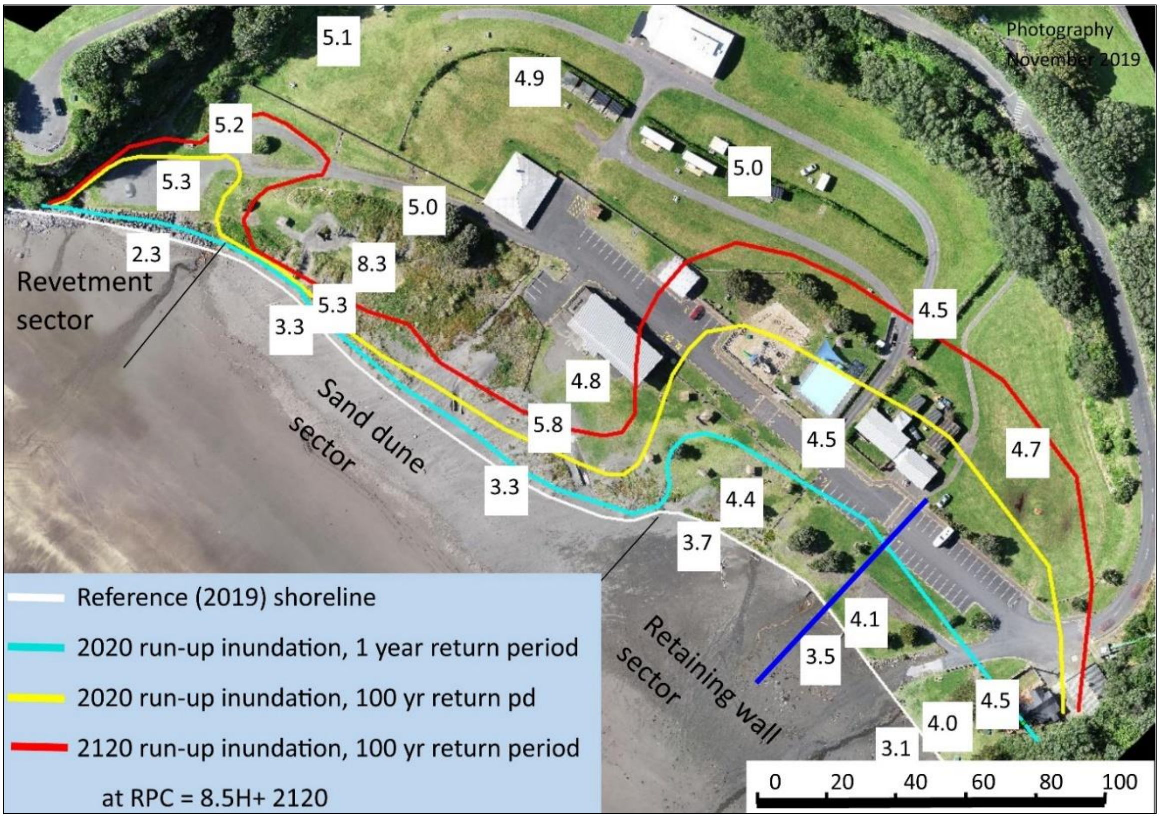


Figure 18 Dynamic extreme water level inundation extents depicting 2020 for 1 and 100 year return periods, and 2120 for the RPC 8.5H+ option with a 100 year return period.
Spot levels are in NZVD16 and the aerial photo is from the November 2019 TPL drone survey. The blue line defines the transect used in the set-up profile shown in Figure 17.

6 Hazard risk assessment and management options

6.1 Concepts and definitions

In order to select an appropriate response to a hazardous event, both the likelihood of the event and the consequences to human values must be considered. Risk (R) is defined as the combination of the likelihood or probability (P) of an event occurring and the consequence (C) of that event and is represented by equation 1O (AGS, 2000).

$$R – P * C \qquad (10)$$

Likelihood is typically assigned the following classes (MFE 2008):
-Very unlikely: occurs 1 to 10% of time;
-Unlikely 10 to 33%;
-Possible or "as likely as not" 33 to 66%;
-Likely 66 to 90%, and
-Very likely 90 to 99%.

Consequence is typically classed as follows:
-Insignificant: minor inconvenience;
-Minor: some damage, isolated injury possible;
-Medium: moderate property damage and injuries probable;
-Major: extensive damage and serious injuries even a fatality, and
-Catastrophic: complete destruction and numerous fatalities.

Risk. Once likelihood and consequence are defined then risk can be determined using a risk matrix (Table 10) where risk classes comprise the following (PRIF, 2017):
-Very low;
-Low;
-Moderate;
-High, and
-Very high.

Table 10 Risk matrix based on likelihood and consequence combinations

Consequences

Likelihood (% occurrence)	Catastrophic	Major	Medium	Minor	Insignificant
Very Likely (90 to 99%)	Very High	High	High	Moderate	Low
Likely (66 to 90%)		High	Moderate	Low	Low
Possible (33 to 66%)	High	High	Low	Low	Very Low
Unlikely (10 to 33%)	High	Moderate	Low	Very Low	Very Low
Very unlikely (1 to 10%)	Moderate	Low	Very Low	Very Low	Very Low

Response and mitigation depend upon the type of activity and the authorizing agency's responsibilities, but in general, moderate risk and above require a risk-reduction mitigation or treatment plan to be implemented to reduce the risk to acceptable levels, while lower risks require monitoring and ongoing reassessments (PRIF, 2017).

Response to different levels of risk can be summarized as follows:
- Very Low Risk: acceptable with day to day management;
- Low Risk: tolerable for now, but monitoring for longer term ongoing assessment;
- Moderate Risk: broadly tolerable, but a treatment plan and its implementation is Required;
- High Risk: not acceptable and a short-term solution required, and
- Very High Risk: not tolerable and an immediate solution is required.

Present and future risk may vary so the present hazard assessment considers both scenarios.

6.2 Risk Assessment

The following hazards were identified or implied in Sections 3 to 5 and their risks are assessed below and summarized in Table 11.

6.2.1 Erosion of foredune

Collapse of a freshly eroded (overly steepened) or cliffed foredune onto beach users – typically children jumping down (Figure 19), or tunneling into, the face. Cliffing is an episodic event and of relatively low occurrence (unlikely). However, the consequence is major with fatalities possible thereby resulting a moderate risk.

This risk will increase to high in the future under climate-driven sea-level rise and potentially increasingly energetic wind and wave regimes.

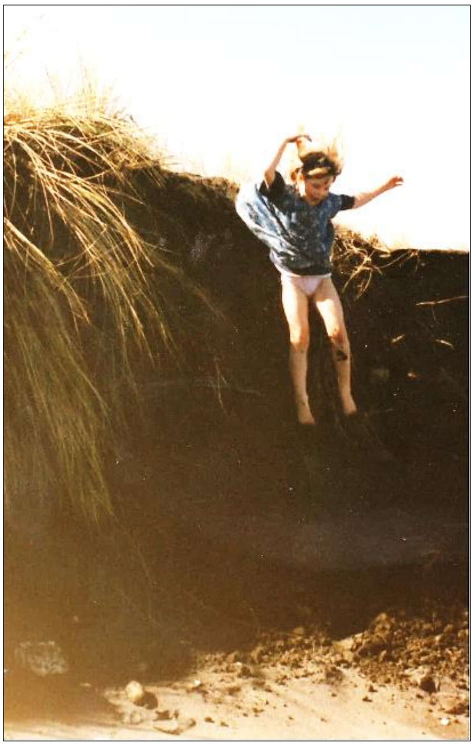


Figure 19 Foredune escarpment (post-storm) with potential collapse and burial hazard

Table 11 Risk assessment summary for present and future scenarios

Hazardous Event	Affected Object	Time Frame	Likelihood	Consequence	Risk
Foredune erosion	People	Current	Unlikely	Major	Moderate
		2120	Possible	Major	High
Shoreline Erosion	Property[1]	Current	Unlikely	Minor	Very low
		2120	Unlikely	Major	Moderate
Wind-blown Sand	People and Property	Current	Unlikely	Medium	Low
		2120	Possible	Major	High
Water table	Property	Current	Likely	Medium	Moderate
		2120	V. Unlikely	Major	High
Dynamic inundation	People	Current	V. Unlikely	Minor	Very Low
		2120	V. Unlikely	Medium	Low
Dynamic inundation	Property	Current	V. Unlikely	Medium	Low
		2120	V. Unlikely	Major	Moderate
Beach-surfzone current	People	Current	Likely	Medium	Moderate
		2120	Likely	Major	High

1. Property can include cars, buildings, infrastructure and other assets

6.2.2 Erosion of shoreline excluding foredune

Destabilizing of property (undermining structures) is a very unlikely event at present (with any damage being minor (once the retaining walls are maintained) making the risk very low. (Such structure destruction also presents a subsequent minor risk to personal safety). Under future climate change (using a midrange RCP scenario), this risk increases to moderate as major damage may occur to infrastructure.

6.2.3 Wind-blown sand

Vision impairment and/or skin burn to people can occur during periods when bare sand is exposed on the beach, (vulnerability increasing during times of sediment surplus) and/or devegetation of the dunes (because of cliffing or artificial reshaping if carried out periodically for surf lifesavers) are coupled with strong wind (> 25 knots). Property burial and sandblast (including vegetation desiccation) also occur during these conditions. The unlikely occurrence of these events results in a low risk at the present time. However, the risk will increase to high under climate change as both extreme wind and dune cliffing (bare sand exposure) are expected to occur more often.

Figure 20 Extreme episode of wind-blown sand on 2 October, 2019. At this time it was not possible to be outside and this photo was taken from the upper story of the Surf Club. The foredune had been lowered (topped) in November 2018 and not replanted. As evident in the upper photo (12 November 2019), gutting is now occurring on the bare dune face and sand has overwhelmed rear dune vegetation with parabolic dune formation occurring.

6.2.3 Water table

The landward water table is near (or at times above) the surface and is a nuisance to people, affects the foundation of infrastructure and buildings and prevents effective drainage. These events occur much of the time in the eastern sector and around the perimeter base of the cliffs making it a likely event. With medium level consequences the current risk is moderate and increases to high under future SLR scenarios as likelihood and consequences increase.

6.2.4 Inundation

At Ōpunakē Bay, inundation from extreme static water levels will have nil to minimal effect landward of the shoreline/seawalls even under the most extreme climate change scenarios. By contrast, landward wave-driven flows from dynamic extreme water levels can present more substantial hazard risk.

A. Personal hazard risk

Once wave-driven flow depths exceed about 0.5 m for children and 1 m for adults they susceptible to destabilization (Figure 21) and injury (Shand et al., 2010). At present, under extreme (very unlikely) conditions in the eastern sector these depths can be exceeded for about 30 m inland resulting in minor injuries and present a very low hazard risk to people. Under future SLR scenarios the distance inland experiencing critical depths and flows approximately doubles making for medium consequences and low risk.

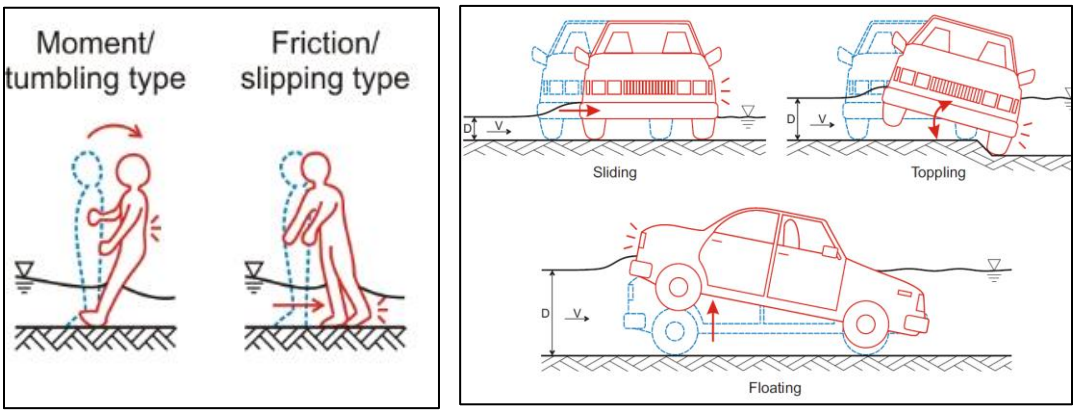


Figure 21 Typical modes of human and vehicle instability (Shand et al., 2010).

B. Property hazard risk

Once wave-driven flow depths exceed 0.3 to 0.5 m vehicles become unstable and paving can delaminate. Under the current regime the likelihood of such inundation extending far enough inland for this to occur is very low, consequences medium and the associated risk is very low. However, under SLR scenarios dynamic inundation the consequences increase to major as virtually all the infrastructure, buildings and vehicles may be impacted, making for a moderate hazard risk.

Figure 22 Delamination of road paving by dynamic inundation flow.

6.2.5 Currents

Wave-driven currents can carry swimmers and novice surfers eastward along the beach where they can then be carried seaward in the "tailrace rip" (Figure 2). A Coastal Public Safety Assessment (CPSA) has been carried out for Ōpunakē Bay in association with Surf Life Saving New Zealand, and the summary report states that that there is a moderate level of risk of drowning and injury with 16 people saved, 15 injured and about 1000 preventative/warning actions on average each year at Ōpunakē and Ohawe Beaches. Climate change scenarios could increase water depths and current strength thereby increasing occurrence and making for more serious consequences thereby increasing the risk to high.

6.2.6 Risk assessment summary

From the risk summary Table (11), it is evident that hazard risks at the present time range between very low (2 cases), low (2 cases) and moderate (3 cases), while future (2120) risk increases by one, and in some cases by two levels, making 1 low case and 2 moderate cases and 4 high risk cases.

6.3 Mitigation Options

6.3.1 Erosion of foredune

The hazard is escarpment collapse and burial.

Proactive approaches:

- Limit foredune growth by upper beach scraping to reduce the sand supply. The volumes involved will vary year to year. The management regime will need to be defined by trial and error aided by the proposed profile monitoring program (see Section 6.5 below). Trigger conditions will need to be defined and the TRC determine whether changes to the existing consent is required.

- Control height and shape of the foredune by mechanical digger (and planting to control wind-blown sand…see 6.6.3 below) to limit height of potential (storm wave) erosion scarp (which exposes bare sand that is then vulnerable to wind erosion). Profile monitoring will be required to define the management regime. The existing consent is too restrictive and will need modifying.

Post-event responses:

- Reduce slope angle by mechanical excavator (consent attention required);

- Hazard fencing as required,
- Warning signage as required.

6.3.2 Erosion of shoreline excluding foredune

The hazards are destabilizing people and property

Proactive approaches:

- Maintain protection structures (seawalls), or
- Establishment of a low dune fronting existing protection structures could buffer storm erosion. Drainage outlets would first need to be extended seaward…this extension would then be buried by the new dune. Dune height/shape and vegetation control and guiding monitoring would be required and a consent could be required, or
- Relocation of vulnerable property if other options fail or are not implemented

Post event responses:

- Repair infrastructure;
- Infill localized erosion areas;
- Hazard fencing as required,
- Warning signage as required.

6.3.3 Wind-blown sand

The hazards are to eyes, skin burn, plant desiccation, property sand blast and burial.

Proactive approaches:

- If there is a surplus of sand on the upper beach, then carry out scraping (monitoring and consent requirements);
- Maintain and protect vegetation (planting, fencing, signs and accessway control);
- Control foredune shape and height (monitoring and consent requirements);
- The low dune proposal in 6.3.2 above would also intercept wind-blown sand.

Post-event responses:

- Re-establish vegetation cover (reshaping/planting/fencing/signs),
- Mechanical removal of sand as required.

6.3.4 Water table

The hazards are wet/soggy/unstable underfoot, loss of vehicle and foundation support, drainage impediment.

Proactive approaches:

- Raise ground surface using upper beach scrapings when beach has sand surplus (monitoring and consent requirements);
- Raise drainage pipe network once ground surface raised;
- Extend drainage outlets seaward: this occurs elsewhere on open coast beaches; however, such obstacles in a pocked beach could present health and safety issues (consenting requirements), or
-
- Collect existing outlets and redirect to ends of bay (cliffs) and thence seaward new outlet (consenting requirements).

Post event response:

- Mechanical clearance of drainage outlets (existing consent?);
- Relocate property to avoid this hazard if other options fail or are not implemented.

6.3.5 Dynamic extreme water-level inundation

The hazards: destabilization of persons, vehicles and property by wave surges and debris.

Proactive approaches:

- Raise ground level along and immediately landward of the shoreline seawall
- structures;
- Redesign seawalls/revetments to prevent/minimize overtopping;
- Incorporate structures, obstacles and vegetation to dissipate overtopping flow, and
- Ensure structures and other items (e.g. picnic tables) are secure.

Post-event response:

- Clearance of debris and other damage.

6.3.6 Currents

The hazards are destabilization of swimmers and novice surfers, carried eastward along the beach and then seaward out the Tailrace Rip.

The surf lifeguard service has made several recommends to reduce the risk of drowning and injury at Ōpunakē Beach in the Coastal Public Safety Assessment summary document. This document states that “provision of these [listed below] safety interventions is built into future plans for the coastal environment by the STDC”.

Proactive interventions:

- Water safety and daily information signage at key locations;
- Maintain volunteers and professional staff, and rescue craft (IRBs) at the required levels;
- Install a network of permanent emergency response beacons (ERBs);
- Ensure beach safety information is available at tourist and accommodation locations and on local authority, tourism and Surf Life Saving websites;
- We add that the local surf shop, where surfboards are hired, presently provides verbal safety information; perhaps they could be provide with written information/safety material to hand to their customers.

During a hazardous encounter:

- If it doesn’t already, then the beach information and signage needs to also provide basic instruction on what to do when encountering hazardous current.

6.4 Preferred options

A range of mitigation options have been identified to reduce the risk associated with each hazard. When identifying the preferred management option for each hazard, both now and in future reviews, the underlying issue is whether an incremental adaptation approach involving hard structures and mechanical interventions is favoured over a strategic withdrawal that ultimately allows natural processes to prevail.

The identification of the preferred risk reduction option for each hazard will need to be cognizant of the council’s Asset Management Plan, the Ōpunakē Bay Master Plan and further community feedback.

6.5 Monitoring Programme

To better understand and define future changes to the geomorphological system, associated hazards and risk, and to develop/refine mitigation approaches, the following measurement-based monitoring programme is proposed.

6.5.1 Beach and dune profiling

Repeat cross-shore profiling is the standard method of quantifying beach change in the shorter term. As part of the recent TPL survey, 3 cross-shore transects have been established extending from the rear of the dune to the spring low tide mark. These transects have been marked on the 3D image in Appendix C, dated 12 November 2019. Normal practice is to repeat surveys at 6 monthly intervals to define the extent of seasonal change, then, upon the recommendation of a coastal expert, revert to longer sampling intervals if deemed appropriate. Cost estimate as at 2020: survey $3000 plus interpretive reporting[1].

6.5.2 Topographic (3-D) survey (drone-based or as part of a regional LIDAR survey):

This monitoring is to define changes between and beyond the profile transects. Following on from the recent TPL survey, this should be repeated at say 5 yearly intervals. The backshore/reserve/camping ground, and bordering cliffs should all be included. Cost estimate at 2020: survey $7000 plus reporting[1].

6.5.3 Breakwater survey

This study indicates the breakwater may contribute to sediment behavior and long-term accretion within the Bay. Its effectiveness under climate change may also change. It is important to identify any settlement/lowing of the structure and the need for maintenance/raising. A very high resolution point cloud (to define individual rocks) should be carried out at time of maximum exposure (spring low tide, high pressure and low waves. The recent TPL survey serves as a guide, and a 3D output image is included in Appendix C . Repeat every 10 years. Cost estimate as at 2020: survey $1200 plus reporting.

6.5.4 Bathymetric survey

It is helpful to identify any trends in sediment change within the outer bay as this may well be indicative of subsequent sediment supply change and response in the beach system and the extent of such a response. This becomes more important given the uncertainties in climate change and littoral sediment supply. The last survey was carried out by DML in 2000. We recommend surveys at 10 year intervals. Cost estimate as at 2020: survey $7000 plus interpretive reporting.

6.5.6 Structures within the bay.

The TRC annually monitor and report on consented coastal structures based on a visual inspection. The TRC is considering measurement-based monitoring to better define longer term change. We recommend the STDC be proactive in this regard.

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1. Reporting for all types of monitoring should be carried out by an expert who will analyse new data, compare these with previous surveys, interpret any change and, if necessary, make recommendations on future surveys and management. The reporting cost can be about the same as the survey, but it is often less

7 Summary

Ōpunakē Bay is currently facing several operational issues described in the 2016 Ōpunakē Beach Master Plan prepared by Boffa Miskell including drainage constraints, wind-blown sand and dunes height restricting views. In 2017 Opus investigated the stability of the surrounding cliff, drainage on the flat below, and the possibility of managed retreat of Holiday Park utilities. Aging infrastructure is also of concern to council along with the potential impacts of climate change and the statutory requirements to address coastal hazards and associated risk and mitigation options to reduce that risk.

The present study continues the investigation into these issues by firstly assessing the geomorphology of Ōpunakē Bay then, based on those findings, carried out erosion and inundation hazard assessments for the purpose of identifying hazard risks and mitigation options.

The geomorphological and hazard assessments identified the following matters as having hazard risk and management implications:

Anthropogenic influences (breakwater, seawalls, drainage, sand management) have significantly affected past geomorphology and have the potential to affect future processes and hazard mitigation;

The shoreline has been systematically accreting (moving seaward) since the 1930s with maximum rates in the centre of the Bay (0.53m/year or 53 m in 100 years) and less at the ends (0.23 m/year or 23 m in 100 years). This trend is superimposed upon medium-term fluctuations at about 30 year intervals;

The present positive sediment budget, and its potential to facilitate wind-blown sand and dune growth, both of which can present hazards, seems likely to continue into the foreseeable future;

Areas where beach accretion or erosion occur relate to drainage outlets onto the beach as such drainage raises the beach water table and facilitates surface erosion. Projected future climate change is likely to raise the water table and compound drainage issues both landward and seaward of the shoreline;

Episodic erosion causes foredune cliffing which is a potential burial hazard to children in particular, and future climate change will likely increase its frequency and severity.

Projected rise in sea-level will in itself cause shoreline erosion with calculated retreat over 100 years varying between 18 m and 65.5 m depending on the scenario. However, the actual effect must be balanced against the future littoral sediment supply and if historical accretion continues then this may compensate for SLR-based retreat. The range of possibilities are detailed within the report.

Static extreme water level (excludes wave run-up) may reach just the top of the eastern retaining wall under most extreme future SLR scenario; as such this is not considered to be a hazard;

Dynamic extreme water level (includes wave run-up, overtopping the shoreline and propagation inland) already affects the eastern sector. Under future SLR scenarios such inundation will increase with the risk being greater where there is a lack of obstacles and rough vegetation to dissipate wave surges. Accordingly, dynamic inundation is least where sand dunes front the shoreline.

Using a coastal hazard risk matrix, which combines the likelihood of a potentially hazardous event with the consequences to person and/or property, foredune erosion, shoreline erosion, wind-blown sand, water table effects, dynamic inundation and beach and surf zone currents were found to be hazard risks and that risk is predicted to increase in the future by at least one level (e.g. medium to high).

A range of proactive mitigation and post-event response options have been identified to reduce the risk associated with each hazard.

Such options broadly relate to either an incremental adaptation approach involving hard structures and mechanical interventions, or a strategic withdrawal approach in which natural processes ultimately prevail.

Identification of the preferred risk reduction options will need to be cognizant of the council's Asset Management Plan, the Ōpunakē Bay Master Plan, and public feedback. Any specialist investigations thus required, such as engineering redesign of the eastern sector retaining wall, will then need to be undertaken.

To better understand and define future changes to the geomorphological system, associated hazards and risk, and to develop/refine mitigation approaches to risk reduction, a measurement-based monitoring programme has been outlined which includes profile surveys, 3D terrestrial and sea-bed surveys, and structure surveys.

Several of the proposed mitigation options will require new or modified resource consents.

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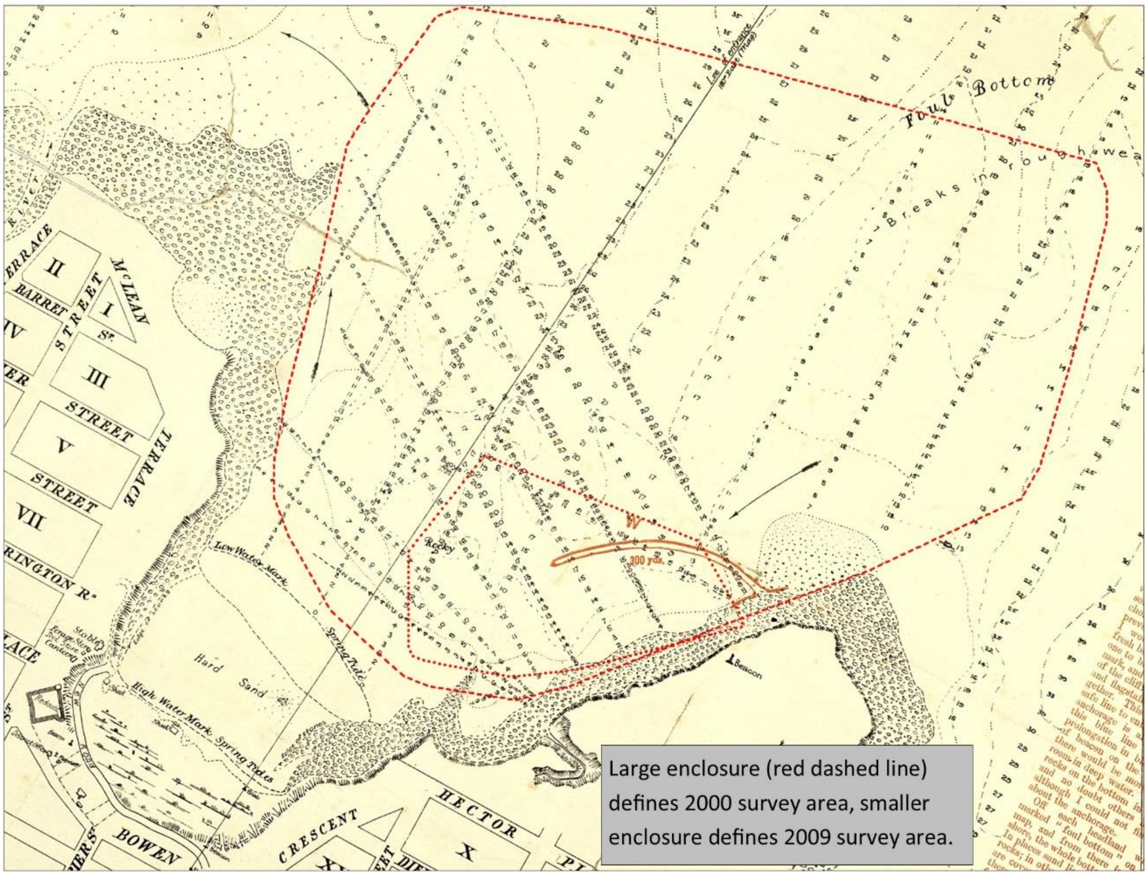
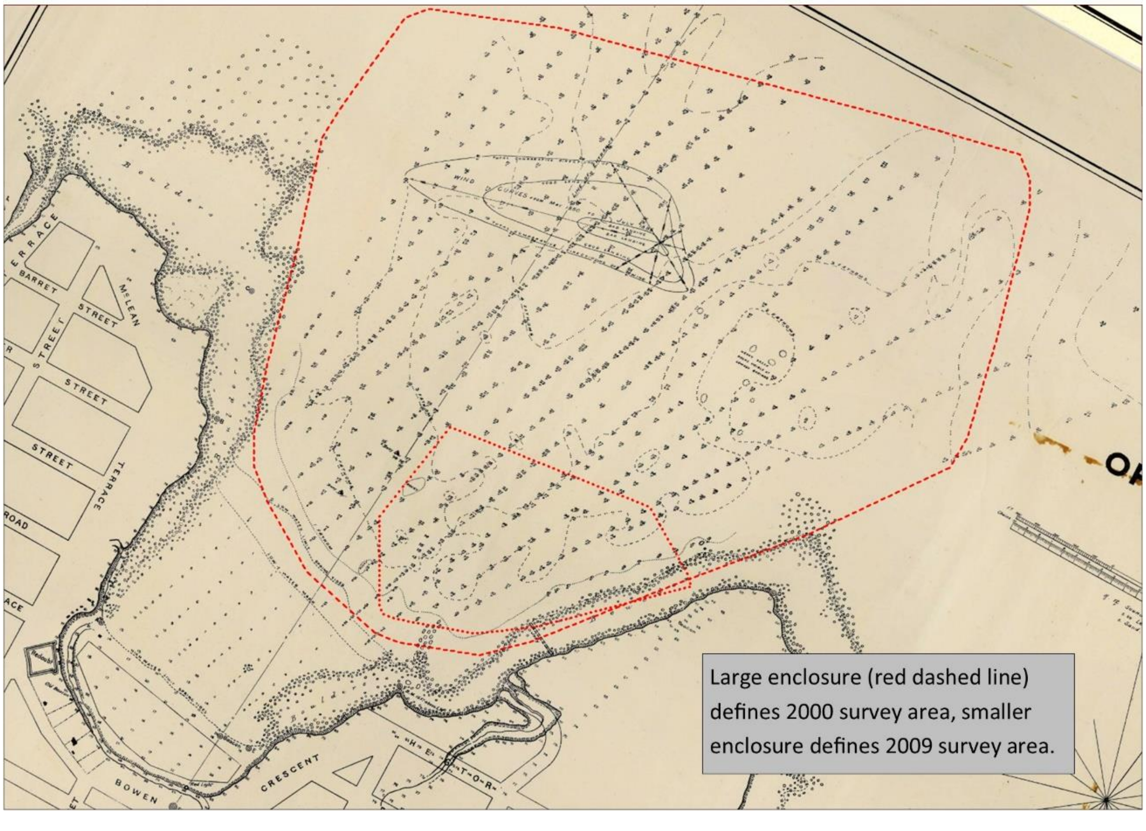
APPENDIX A Surveys

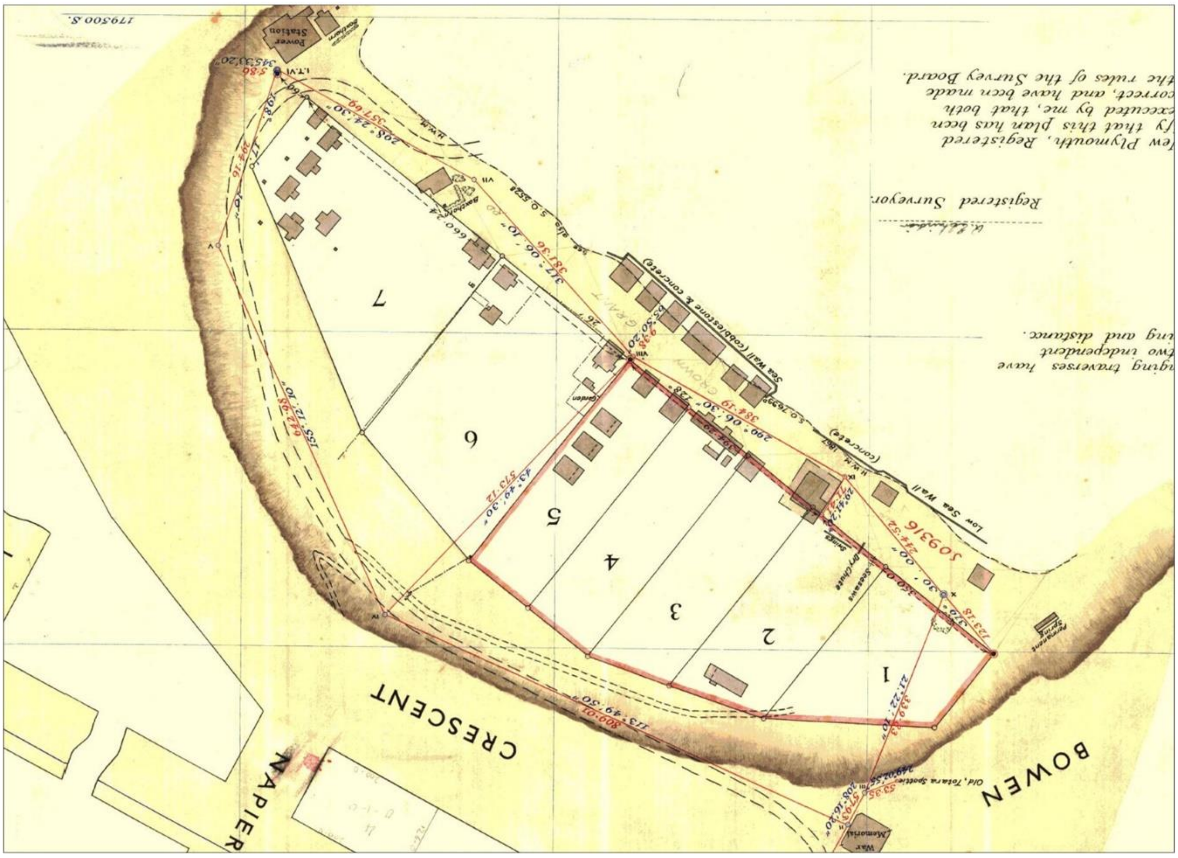
1882 Chart of Opunaki Bay and Roadstead by C .W. Hursthouse. Auckland Library.



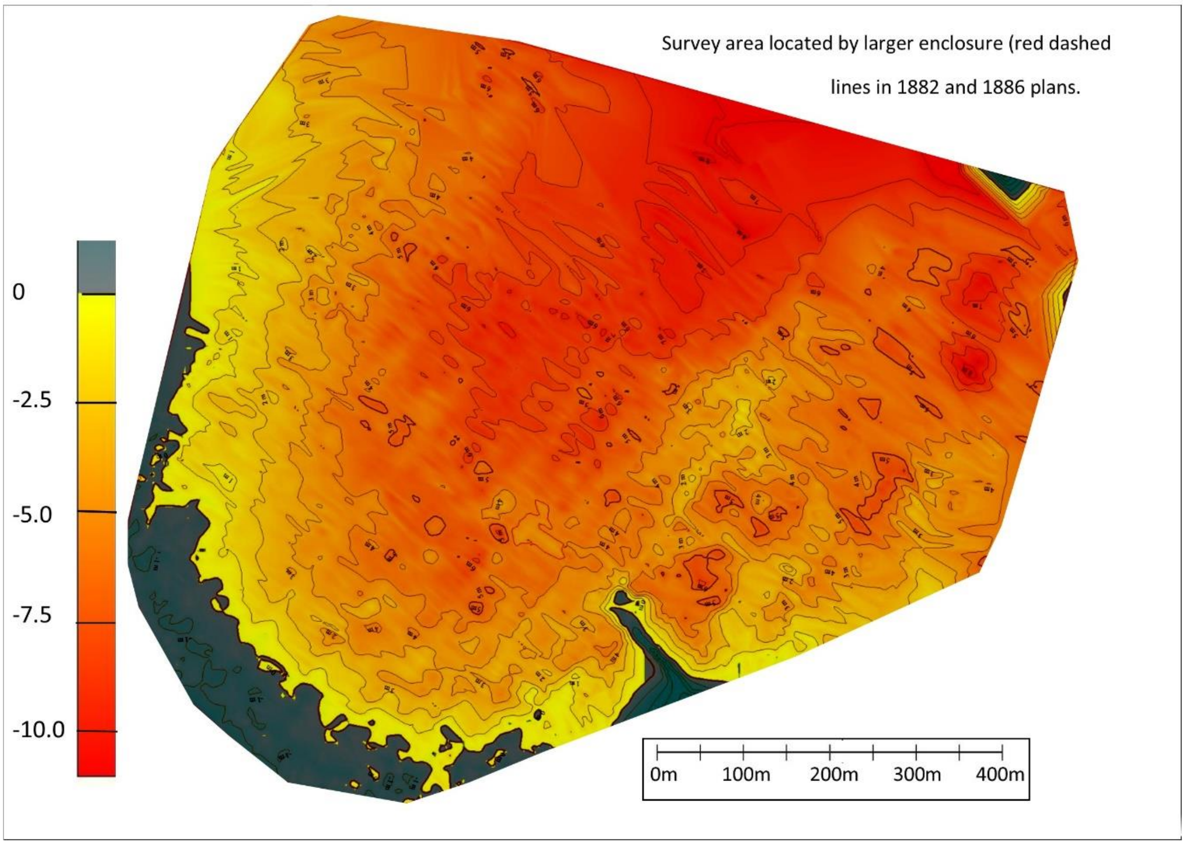
1886 Plan of Opunaki Bay by J.A Henderson Source: Puke Ariki, New Plymouth



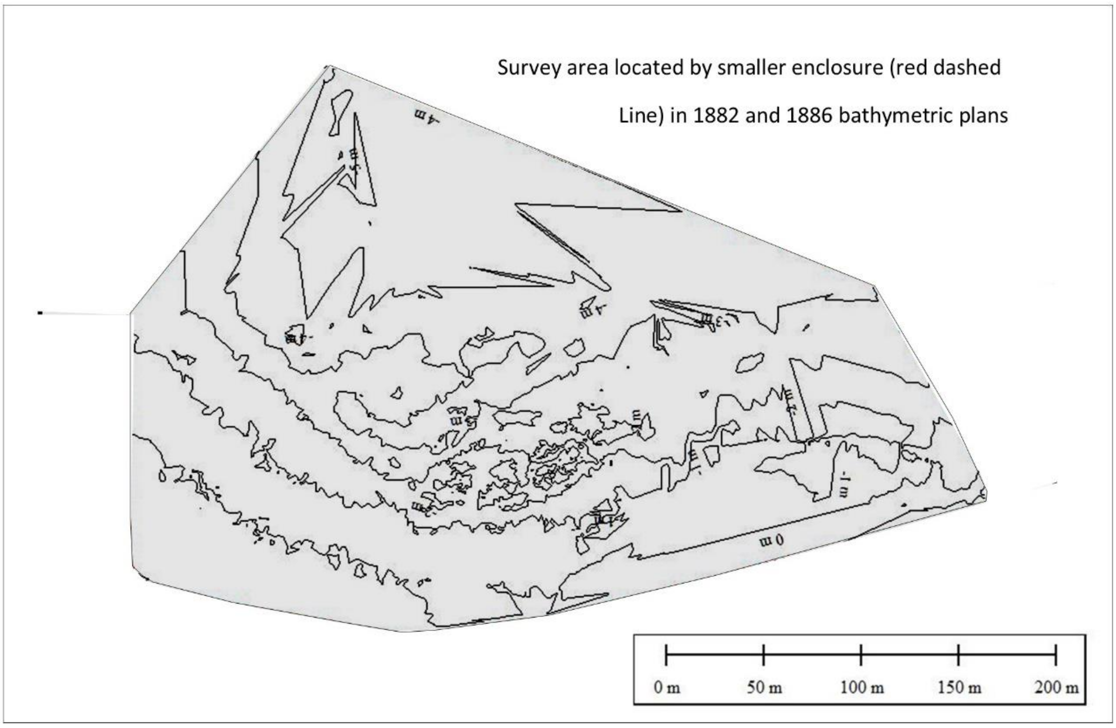
1938 Survey Plan SO 7668. A. E. Christian surveyor Source: LINZ



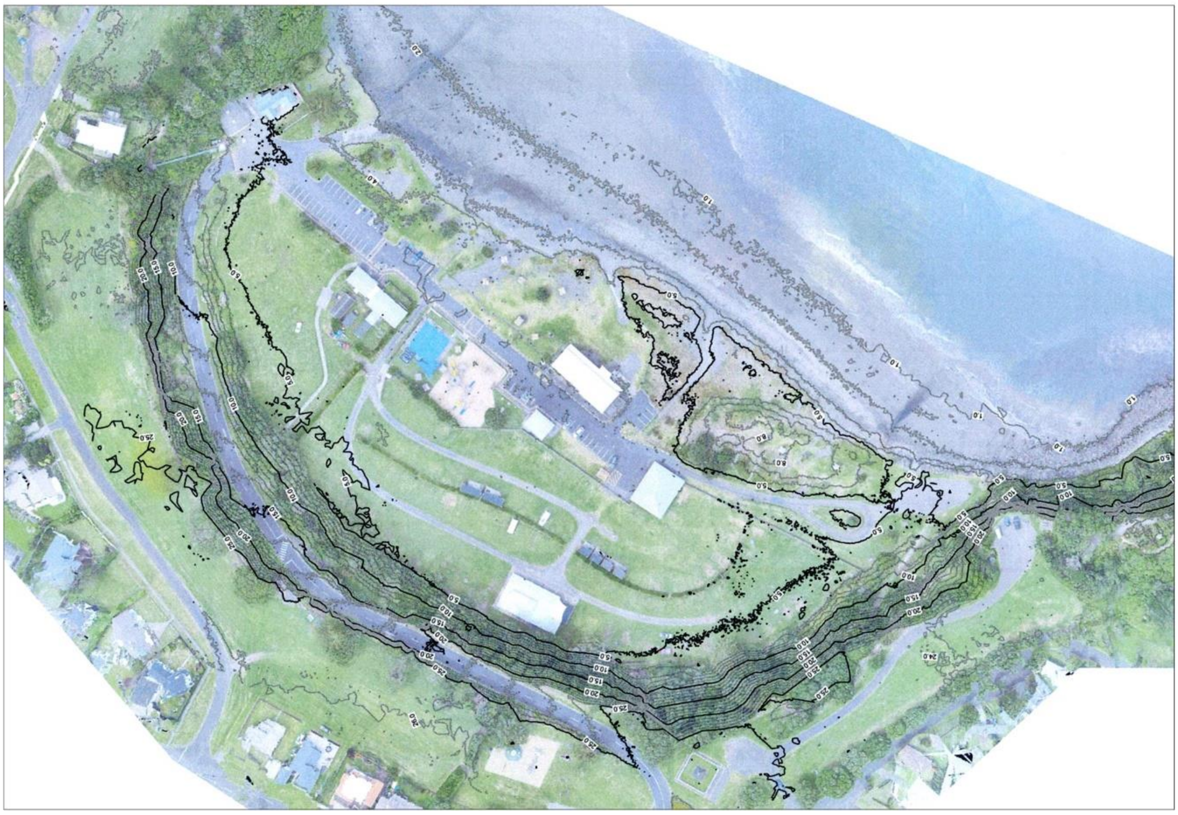
2000 Bathymetric survey of Opunaki Bay. DML surveyor CSL mapping



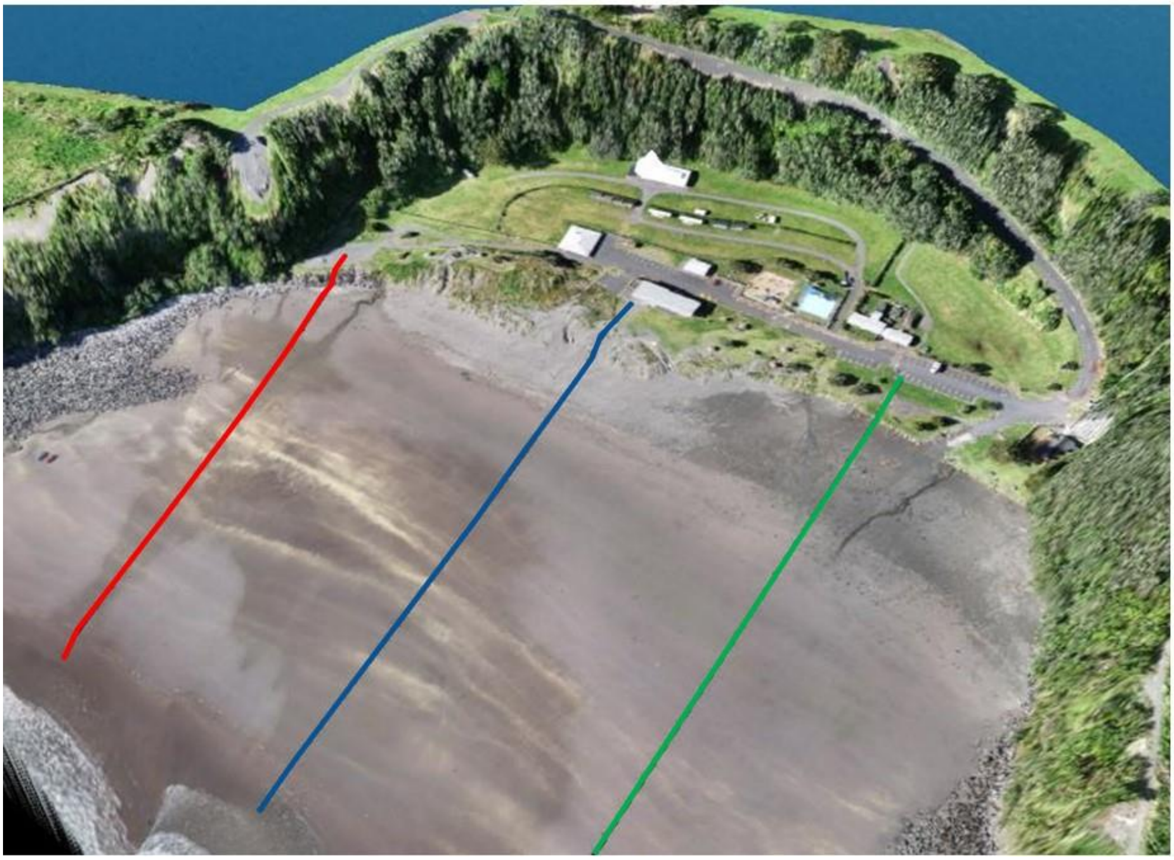
2009 Bathymetric survey of western Opunaki Bay area. ASR survey. CSL mapping



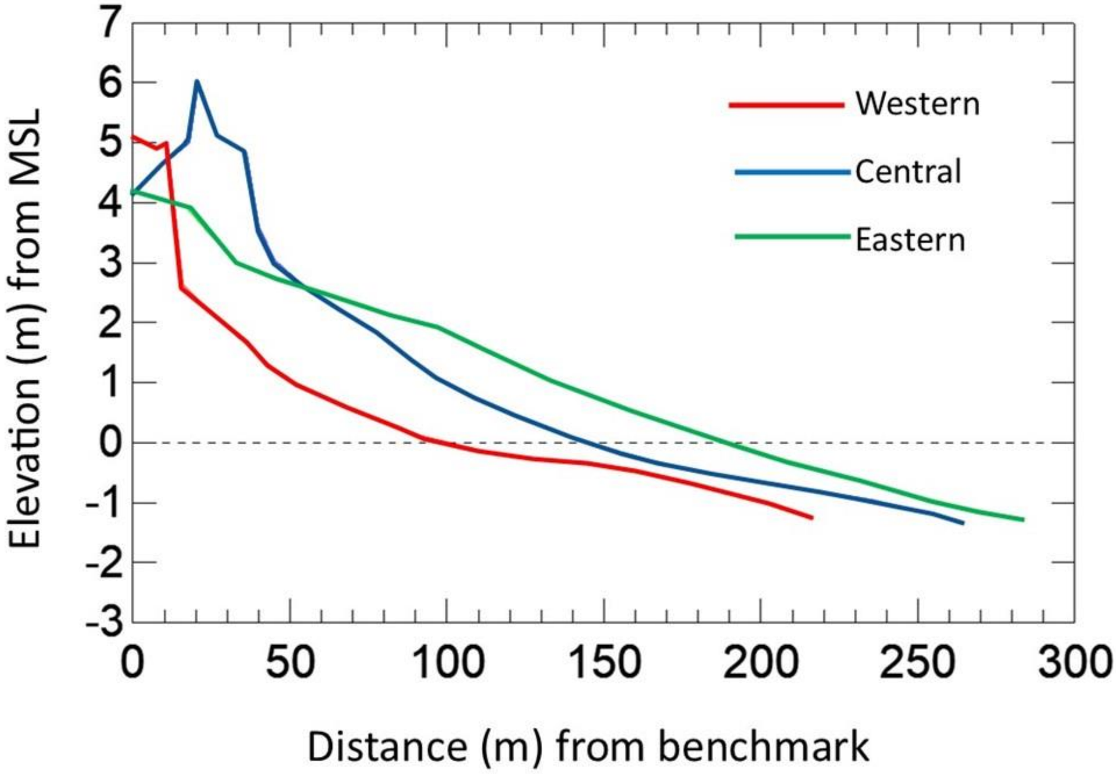
2017 Drone-based 3D survey Opus



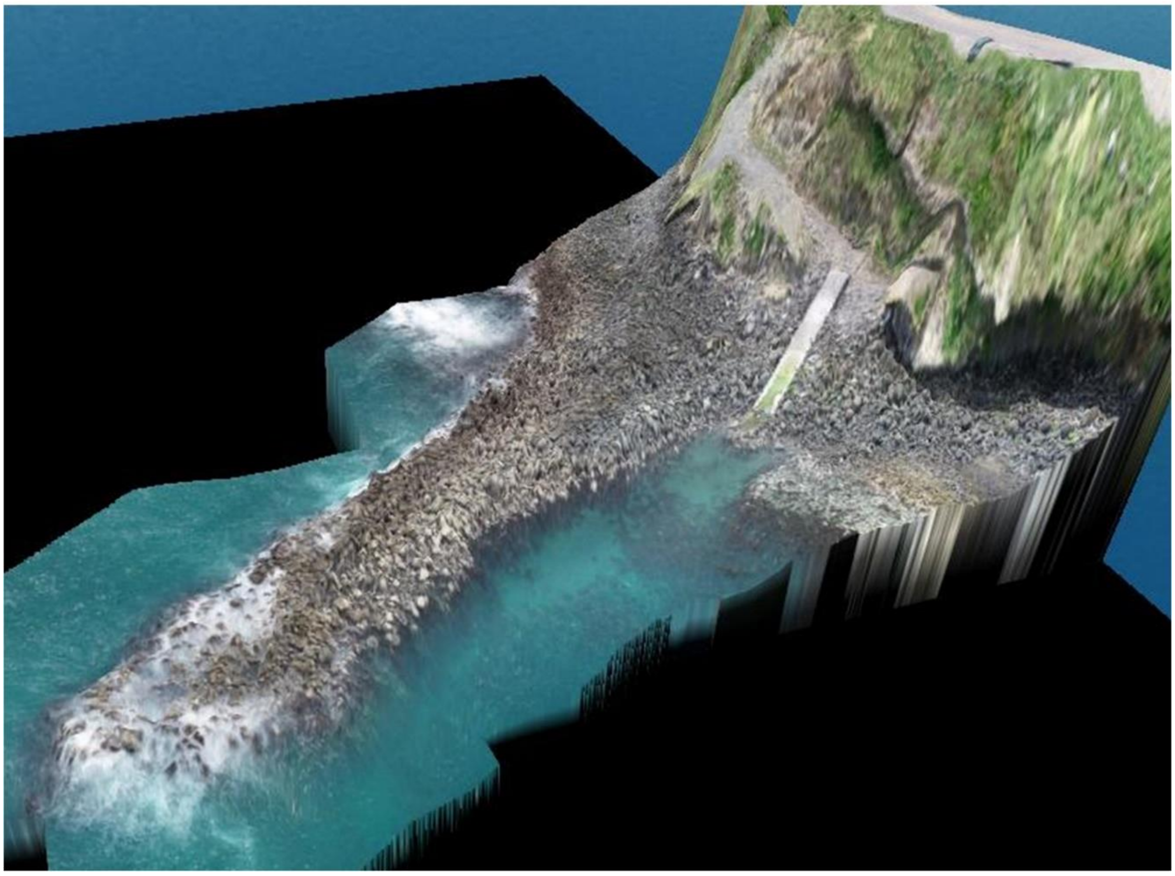
2019-11-12 Drone-based 3D and survey transects Taylor Patrick Ltd



2019-11-12 Profiles surveys Taylor Patrick Ltd

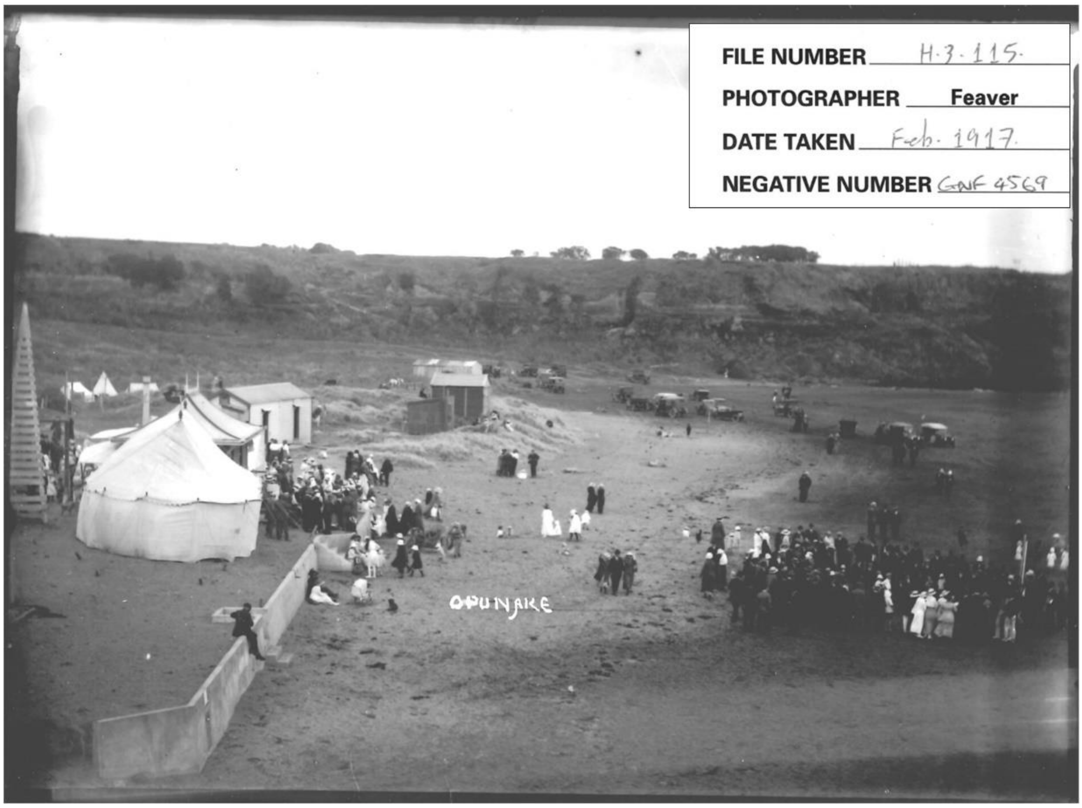


2019-11-12 Drone-based 3D Breakwater survey Taylor Patrick Ltd

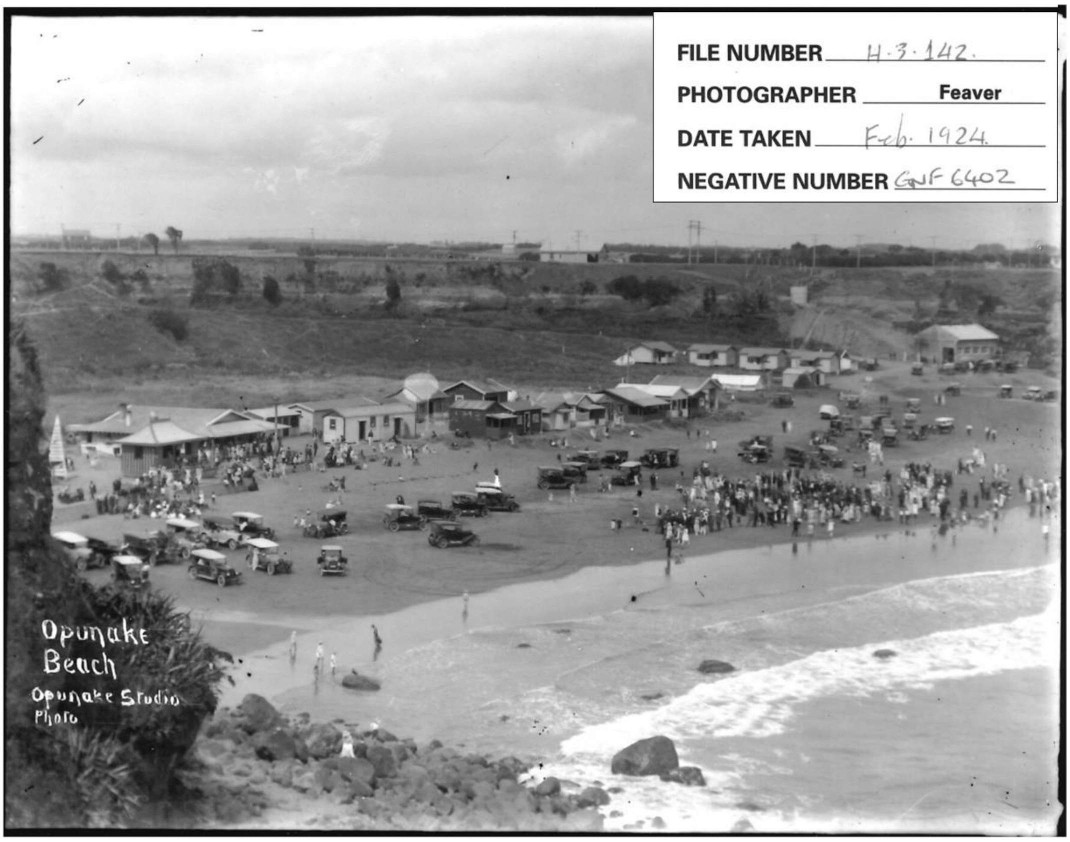


APPENDIX B Historical photographs

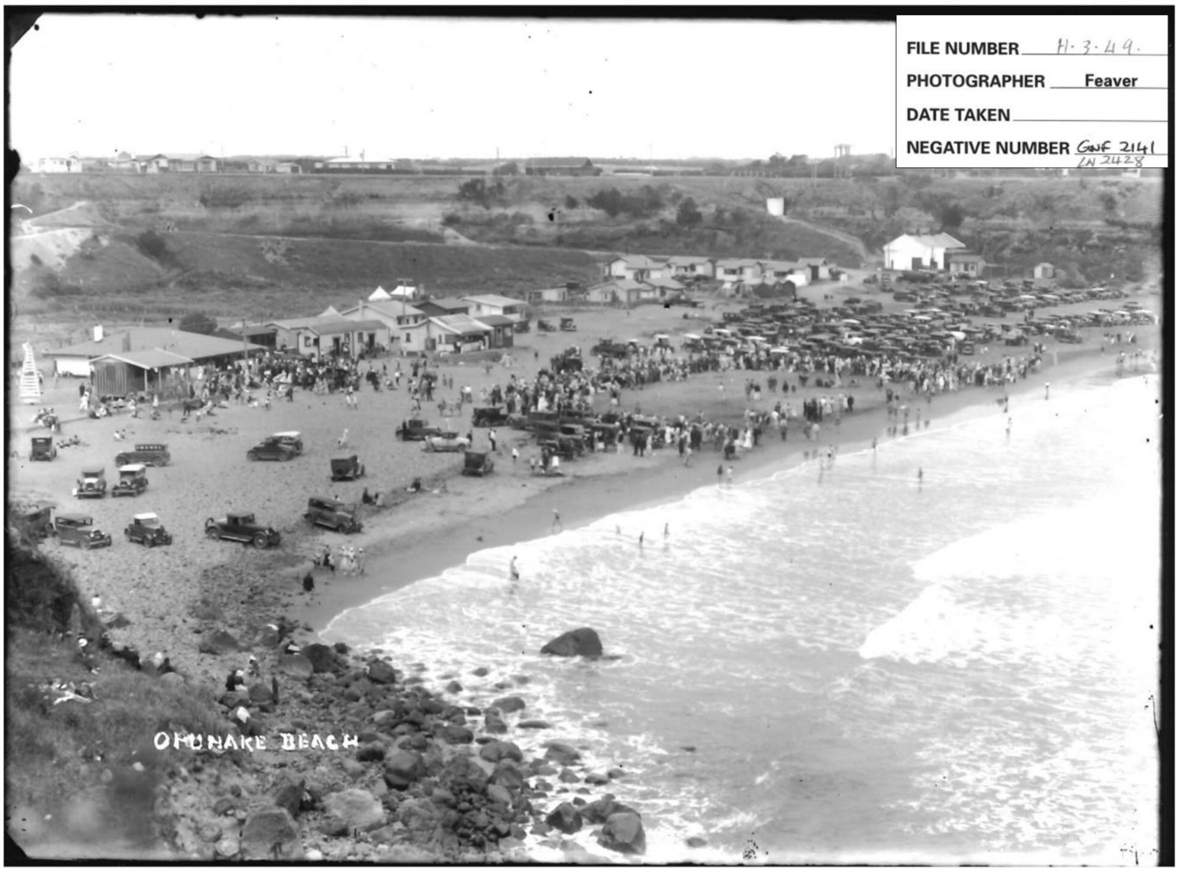
1917 Feaver photographer Source: Puki Ariki, New Plymouth



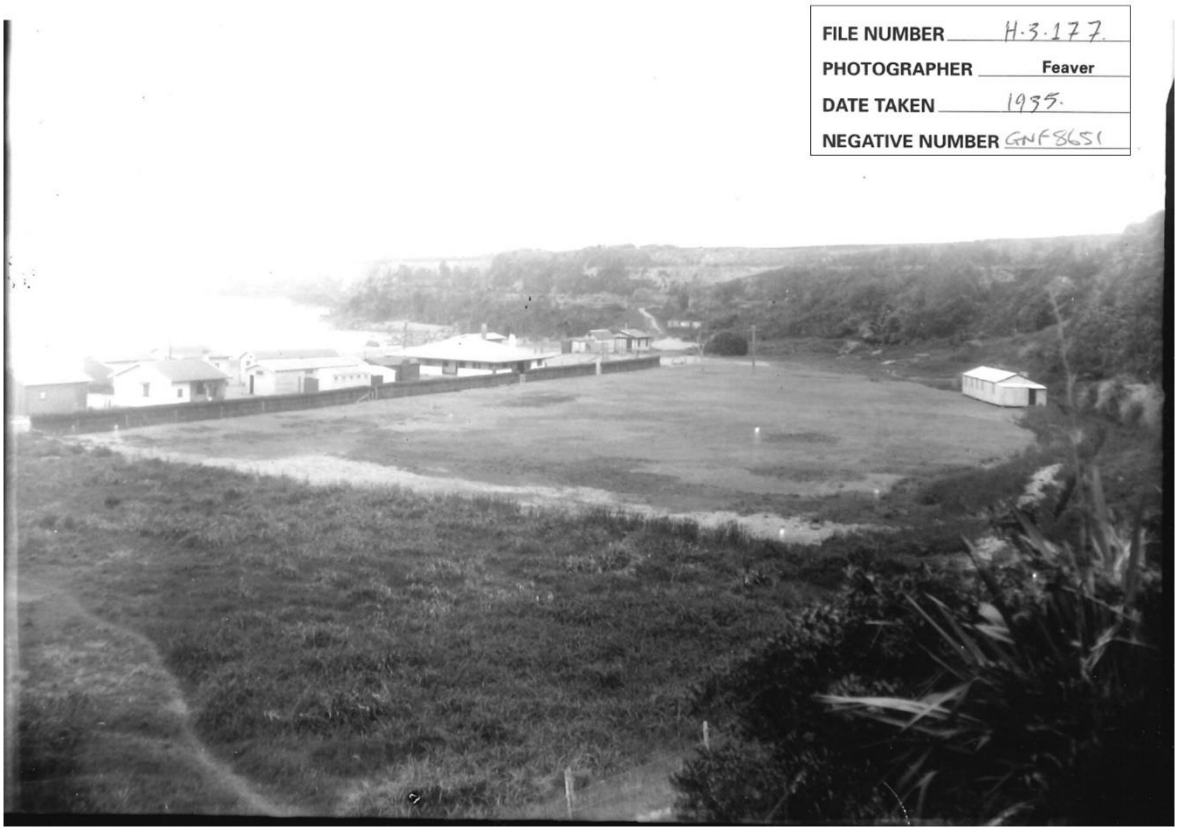
1924 Feaver photographer Source: Puki Ariki, New Plymouth



1933-37 Feaver photographer Source: Puki Ariki, New Plymouth



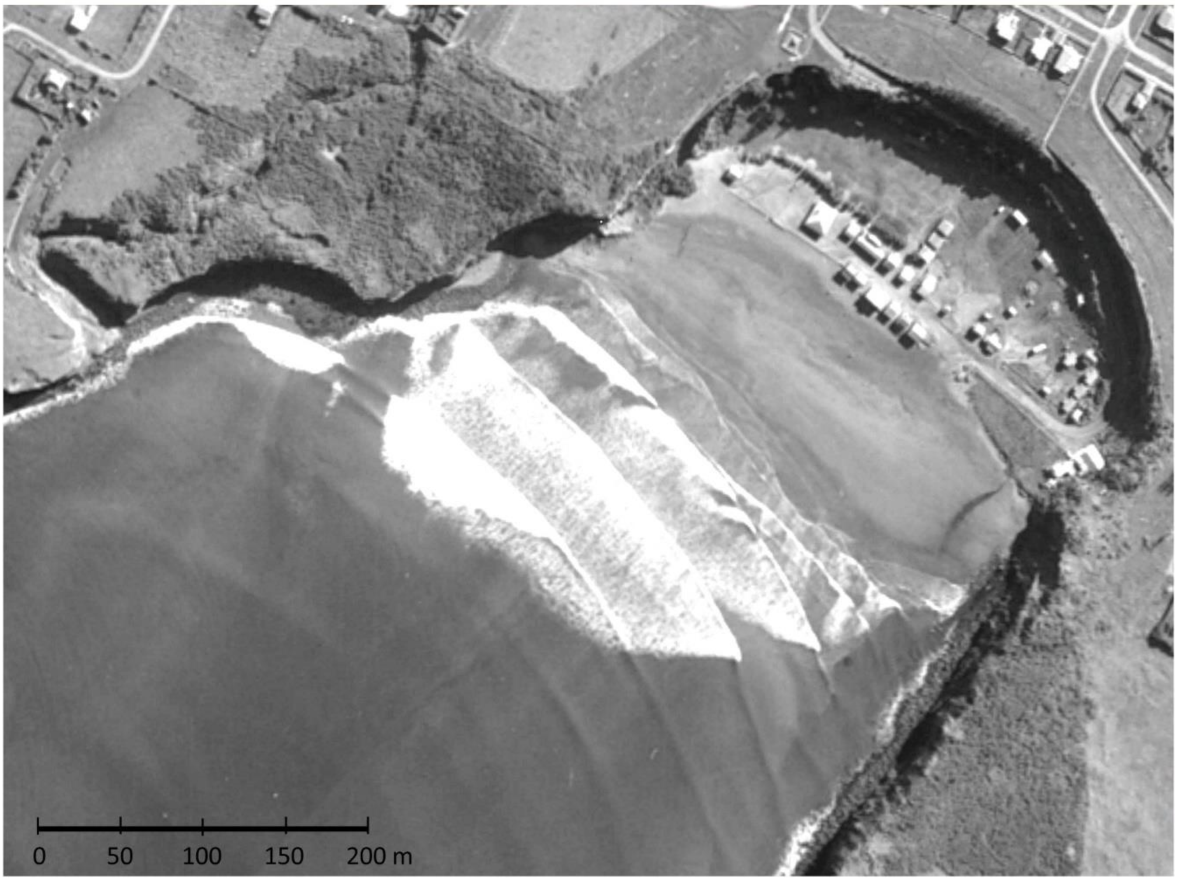
1935 Feaver photographer Source: Puki Ariki, New Plymouth



APPENDIX C Aerial photographs and satellite images

1947 V C Browne and Son (reproduced with permission)

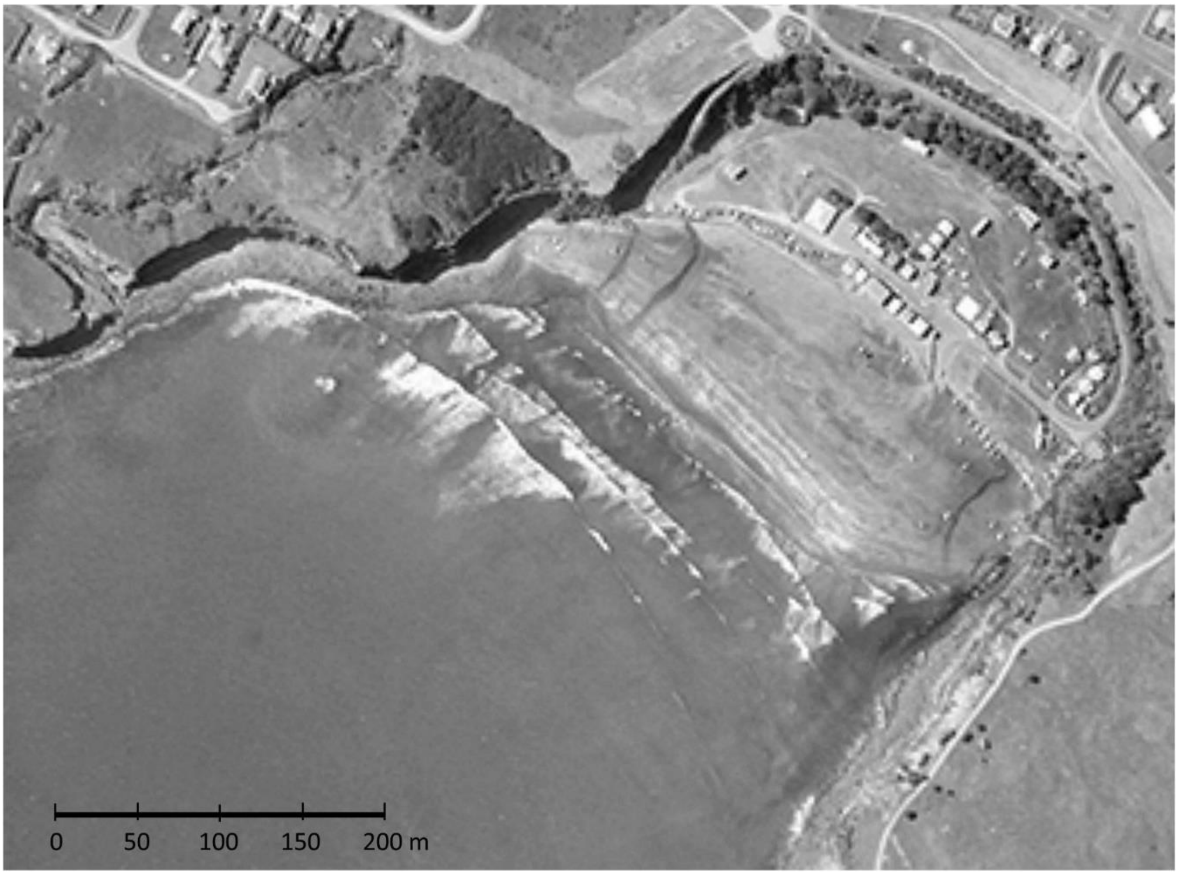
1953 New Zealand Aerial Mapping SN 259_2147



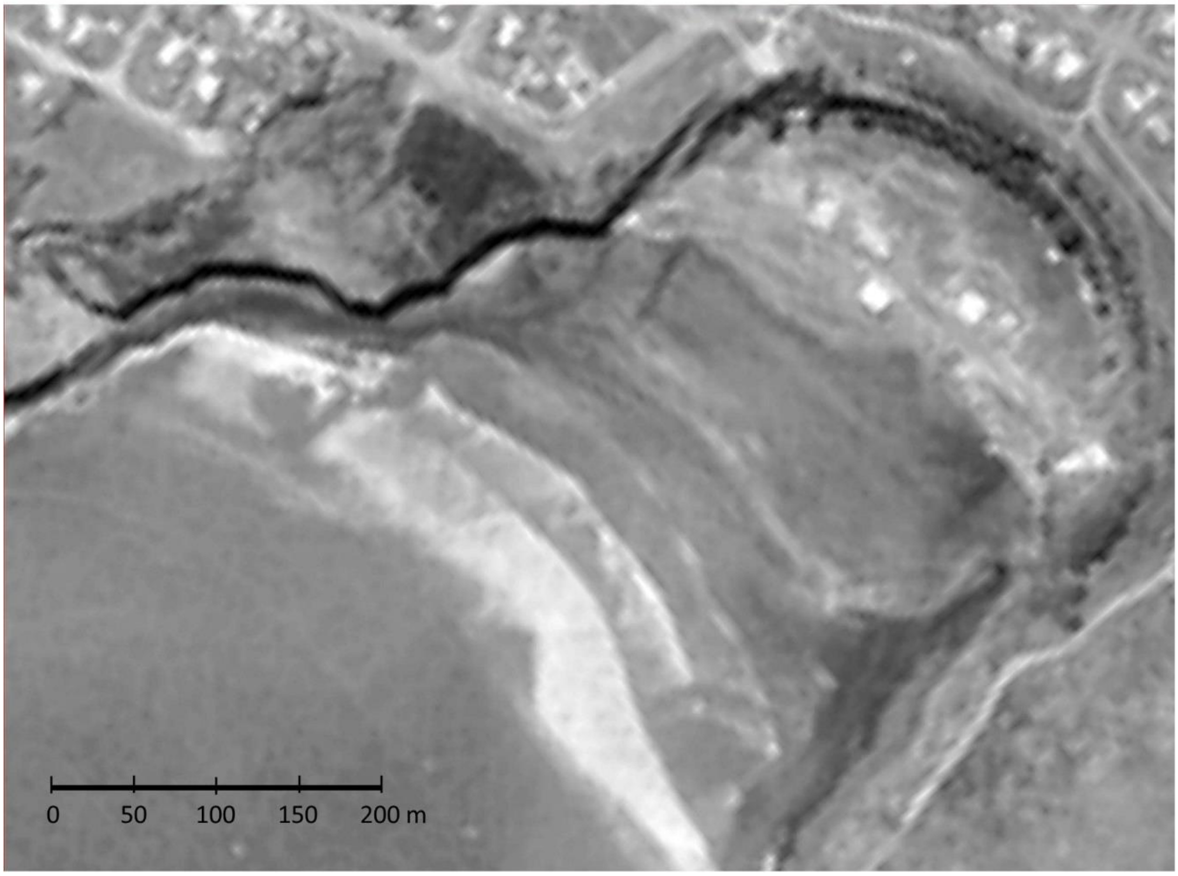
1958 Wrights Aviation National Archives NZ

1959 New Zealand Aerial Mapping SN 1137_A

1970 New Zealand Aerial Mapping SN 3407_4497

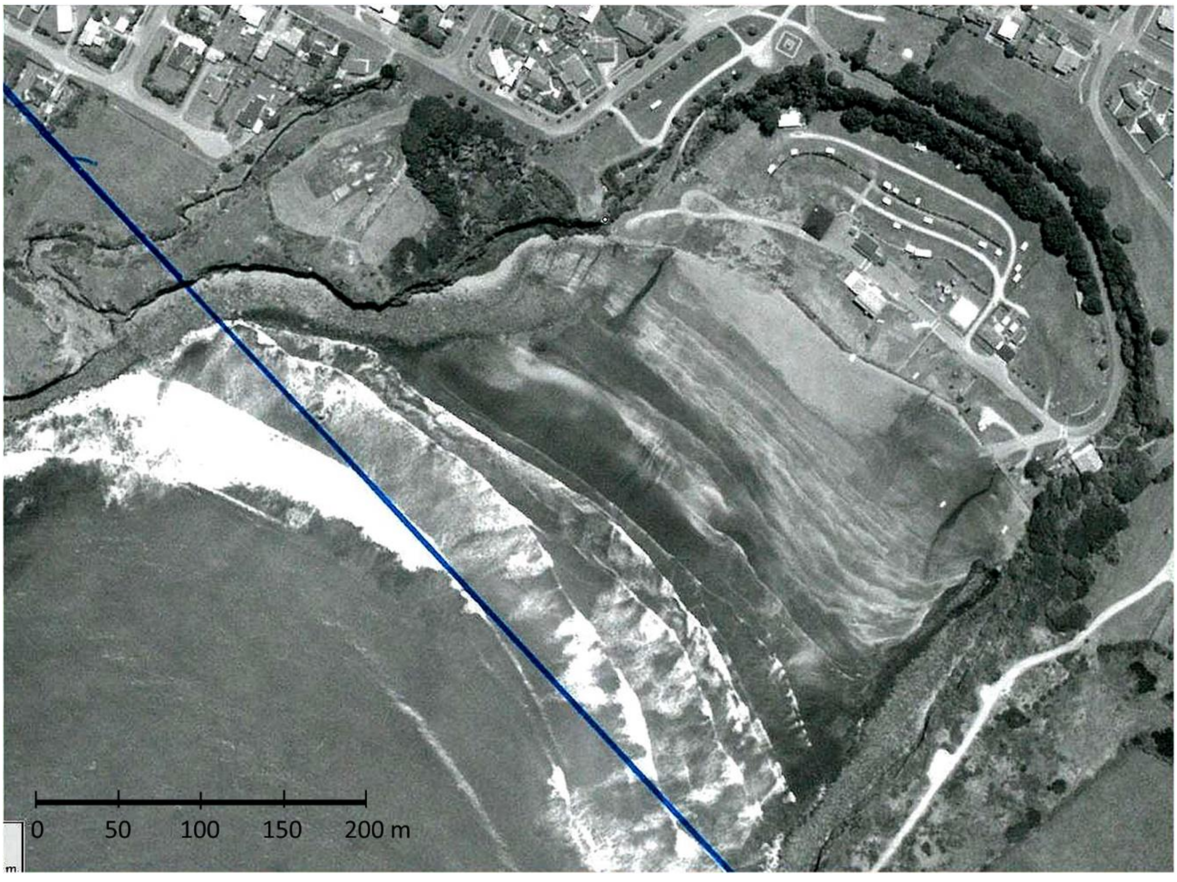


1977 New Zealand Aerial Mapping SN 5131_C



1982 New Zealand Aerial Mapping SN 8008_G

1994 New Zealand Aerial Surveys SN 246281



2001 Digital Globe

2004 Digital Globe

2007 LINZ

2012 LINZ

2017-15-2 Opus

2019-11-12 Taylor Patrick Ltd

2019-11-12 Breakwater Taylor Patrick Ltd