An Overview of Coastal Processes and Drivers of Coastal Hazards: Port Waikato

Prepared for:

Waikato Regional Council
Te Kaunihera ā Rohe o Waikato

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Executive Summary

This report reviews existing literature and data relevant to the coastal processes and morphology of the west coast, the Port Waikato Harbour entrance, the Port Waikato spit, and the Maraetai bay/Cobourne Reserve area. The findings of this coastal processes study form the basis and a source of information to inform future management options along this part of the coastline at Port Waikato.

The west coast of the North Island of New Zealand has a high-energy wave climate and is exposed to waves approaching from the south-west through to the north-north-west. Westerly and south-westerly wind components make a significant contribution to the wave climate on the West Coast. The sediment transport is predominantly northward on the West Coast of the North Island at an annual rate of ~150,000 m^3 and significant exchange occurs between the littoral cells of the west coast as compared to New Zealand's east coast, owing largely to the more energetic wave climate and the relatively smaller scale of the control features.

The morphology of the spit and Waikato River mouth has undergone large changes over the past 140 or so years. The spit has migrated northward and varied extensively in shape. It has been estimated that the spit has increased by ~1,900 m to the north, while the northern side of the river mouth has moved some 3.5 km north from the 1853 position, i.e., the river mouth is now far wider (and shallower, sometimes with sand islands present) between the spit and the north head. Whether this continued spit growth is due to the slump block that occurred in the first half of the 19th century and associated human influences, or a long-term cycle where the spit will breach sometime in the future and reset further south, is unknown.

Sunset Beach at the southern end of the Waikato Spit is typical of many on the west coast of the North Island, in that it is dissipative and gently sloping due to the fine-grained and dense titanomagnetite sand. Large fluctuations in beach levels are a feature of the Waikato west coast, including at Port Waikato. Following a long period of accretion since at least 1942, aggressive erosion has occurred since the mid-2000's, especially at Sunset Beach where infrastructure and property has become very vulnerable, and is an ongoing concern. The current erosion scarp is trending towards its most seaward recorded position in 1942.

The spit and township are very low-lying, especially to the east, which has serious implications for inundation hazards due to sea level rise (SLR) and climate change (CC). Even at present day sea levels, inundation of the central township and Maraetai Bay has the potential to occur. In 100 years', time with sea level rise of 1 m, a 1 in 100-year extreme water level event will result in most of the township and spit being inundated. In addition, due to the layer of sand (3-5 m) on consolidated siltstone that comprises Port Waikato and the spit, the groundwater

table is relatively high, which has the potential to exacerbate erosional processes. A high groundwater level also impedes drainage of rainwater during storm events and can contribute to and exacerbate surface or pluvial flooding, which will be made worse with SLR. Therefore, continued efforts to restore and increase resilience to the impacts of SLR and CC for Port Waikato are required.

The west coast has a lower tsunami hazard than the east coast since the primary source for locally generated tsunamis lies on the east side of New Zealand, and so it at low risk of tsunami inundation.

In summary, the coastline of Port Waikato including the spit, Sunset Beach, Maraetai Beach and the township is very dynamic, and affected by a range of coastal drivers and processes. There continues to be a long-term trend of spit extension/accretion, and there is uncertainty with respect to the process of breaching. Recent trends (since the mid-2000's) include continued erosion of Sunset Beach (likely due to intermittent sediment supply up the coast and around the headland), which has resulted in removal of buildings and loss of part of the carpark, with several private dwellings only some 10-15 m from the top of the erosion scarp.

The final section of this report provides a summary of potential management options, with recommendations of the types of interventions and the areas where these can be applied to the management of Port Waikato.

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1 Introduction

This report provides a review of the coastal processes and drivers of coastal hazards affecting Port Waikato, New Zealand. Specifically, this report considers the entire Port Waikato spit (PWS) including Sunset Beach and the settlement, as shown in Figure 1.1.

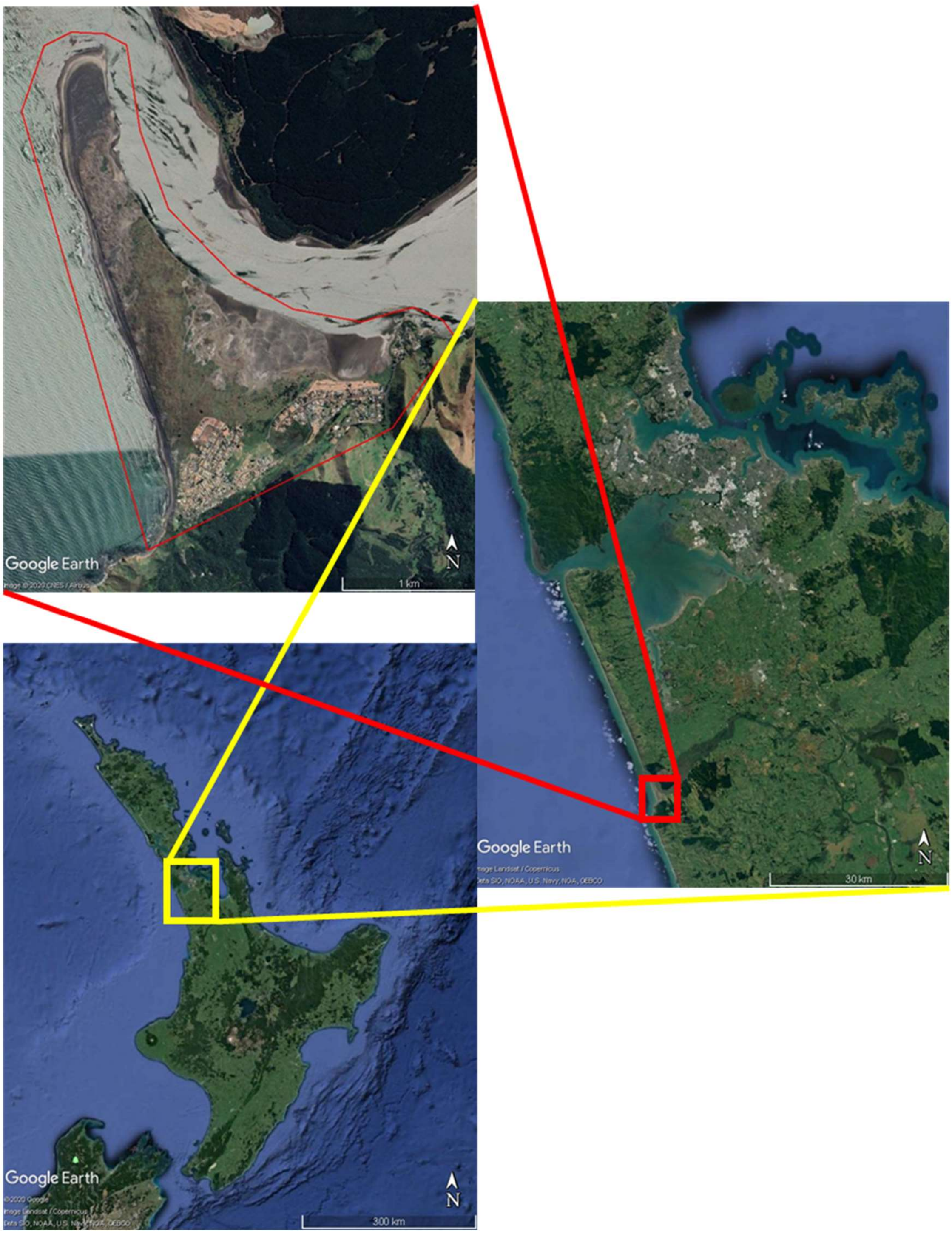


Figure 1.1 Location map of Port Waikato relative to the North Island of New Zealand. Top image depicts Area of Interest (AOI - highlight by the red polygon), the entire Port Waikato spit and settlement (Images sourced from Google Earth, 2020).

1.1 Purpose

In order to better understand the shoreline dynamics in the area of interest (AOI) from Sunset Beach to the end of the spit and around to and including the Cobourne Reserve area (Figure 1.2), a thorough and quantitative understanding of the coastal processes must first be considered. This report reviews existing literature and data relevant to the coastal processes and morphology of the west coast, the Port Waikato Harbour entrance, the Port Waikato spit, and the Maraetai bay/Cobourne Reserve area. The findings of this coastal processes study will form the basis and a source of information to inform future management options along this part of the coastline at Port Waikato. The final Section of the report describes future management options and provides a preliminary catalogue of potential coastal adaptation options.

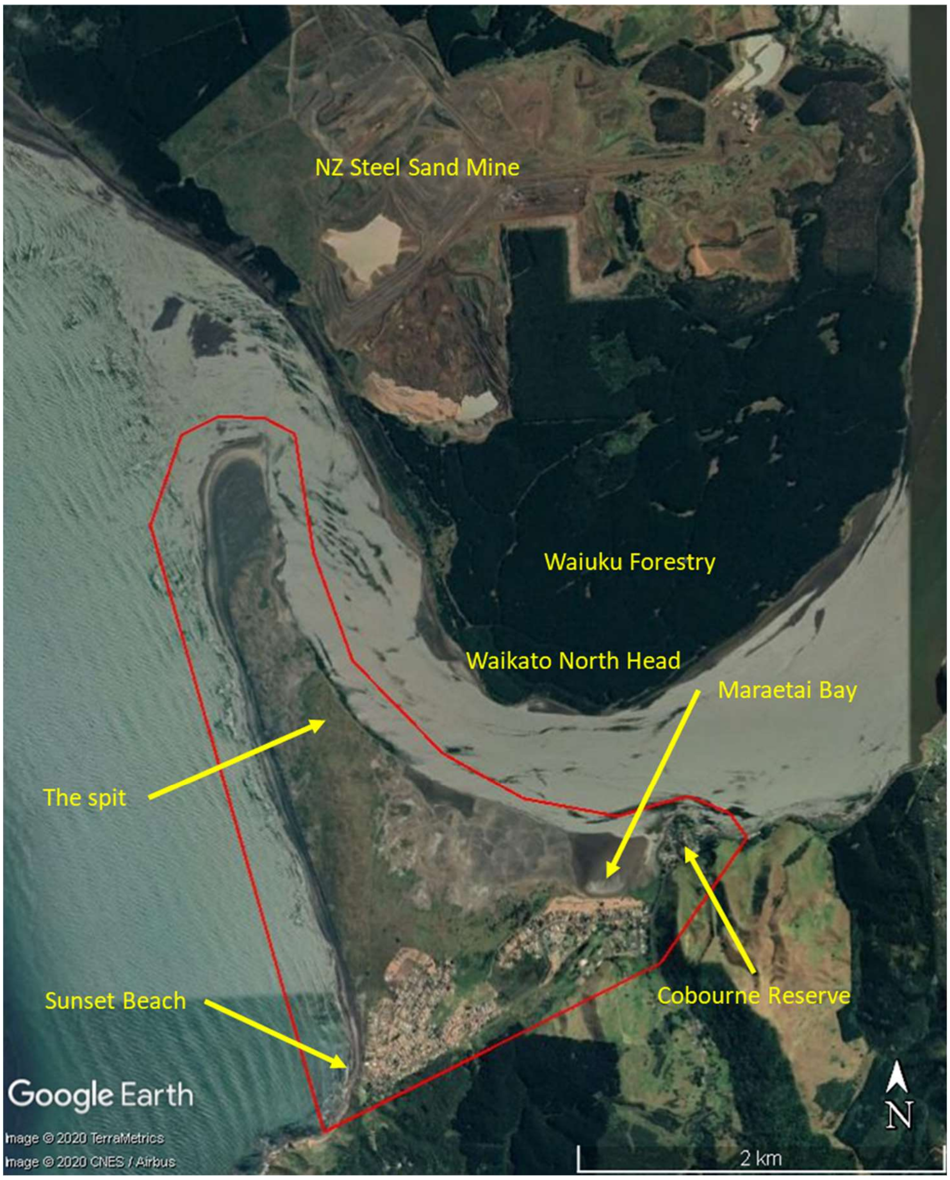


Figure 1.2 The Area of Interest (AOI) at Port Waikato (Image sourced from Google Earth, 2020).

2 Background

Located ~60 km south-south-west of Auckland and ~65 km north-east of Hamilton on the south bank of the Waikato River at the base of Putataka hill, is the settlement of Port Waikato (Figure 1.1). Port Waikato has of population of around 800 (Census 2018), which significantly increases during the summer months.

Port Waikato is where the Waikato River discharges to the Tasman Sea after its 425 km long journey from the slopes of Mount Ruapehu. On the southern bank, at the mouth of the Waikato River, a 3.5 km spit extends from the base of Putataka Hill northward. Waikato North Head and Waiuku Forestry Block is located on the northern side of the Waikato River mouth, behind which the NZ Steel sand mine resides (Figure 1.2).

Port Waikato is of particular importance to local iwi, local residents and visitors, and includes the dynamic west coast, the township, a holiday park, playing fields, a boat access to the beach, surfing on the southern reef and beach, fishing/ whitebaiting, swimming, walking/running/horse-riding tracks through the extensive dune field of the spit and the sheltered reserve on the eastern side of the spit. Okariha is the name used by Ngati Tipa and Ngati Tahinga to represent the spit. The name Okariha is also associated with Sunset beach at the southern end, where a whale by the same name once frequented (WDC. 2014).

Port Waikato has a rich history and was an important port during the New Zealand Wars of the 19th century. It was the first of the colonial settlements to be constructed after the wars began in 1863. Initially, the town was known by its Māori name Putataka, the name of the hill that overlooks the settlement (Swarbrick, 2020).

To Māori living along its banks, the Waikato River provided, and still provides, physical and spiritual sustenance. The spirits of ancestors were said to mingle with its waters, which were used in rituals. Orators addressed it as having a life force of its own. It was a source of food, including eels, mullet, smelt and whitebait, as well as plants such as watercress. Furthermore, the Waikato River was an important trading route for waka taking produce to distant markets, especially in the mid-18th century. In 1993, the Waitangi Tribunal acknowledged that the river was a taonga of the Tainui and Ngāti Tūwharetoa Iwi (Swarbrick, 2020).

Over the years farming has adversely affected the Waikato River. Swamp drainage reduced ponding areas for flood waters and removal of vegetation increased runoff into the river. In the late 19th century, the Waikato-Waipā drainage system became overloaded and there were floods in the lower reaches. Set up in 1956, the Waikato Valley Authority set out to tackle the problem by constructing flood-control works during the 1960's. Revegetation and creation of reserves in the upper reaches helped reduce erosion and silting of the river from adjacent pumice land (Swarbrick, 2020).

Stormwater, phosphate runoff, and effluent are discharged into the river from a catchment area of around 8,800 km^2. The average river flow of 233 m^3/s dilutes this pollution. The pollution, however, has hastened the decline in native fish numbers over the past 100 years with one species, the grayling, becoming extinct. Most aquatic plants are now introduced species. Naturally, the health of the Waikato River is of concern to Māori, conservationists, and also to recreational users such as swimmers, kayakers and water skiers (Swarbrick, 2020).

In 2008, Waikato-Tainui Iwi signed an agreement with the government to protect the Waikato River for future generations and this was made law under the Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010. Waikato-Tainui has kaitiakitanga (guardianship) of the river and works in partnership with the government and local government agencies, such as the Waikato Regional Council, to manage it (Swarbrick, 2020).

The estuary at Port Waikato is tidal, containing a mixture of fresh and saltwater, which is a function of the rising and falling tides. This estuary is home to an array to fresh and saltwater fish, which take advantage of the rich resources of the Waikato River Delta. Exotic pest fish, such as koi carp, are deterred by the higher salt concentration present at the Waikato River mouth. Estuarine vegetation is restricted to the fringes, within which rush and sea meadow bands are observed. Here, native species are threatened by invasive species, such as saltwater Paspalum and alligator weed. Seagrass beds of ecological estuarine significance are located in the intertidal zone (Graeme, 2005; cited in Lealand & Hare, 2018).

The Waikato River Delta is home to various exotic and native waterfowl, marsh- and shorebirds, which utilise the variety of sandflat, saltmarsh, mudflat, and wetland habitats on offer for breeding and feeding (Ryder *et al.,* 2016; cited in Lealand & Hare, 2018). Inanga take advantage of the tidal effects, which are evident to at least the town of Mercer, and spawn along the banks. Importantly, Māui dolphins frequent the coastal waters near Port Waikato (Lealand & Hare, 2018).

In more recent times, coastal erosion has impacted the open coastline, which has seen the carpark and surf lifesaving tower implicated, as well as the community hall and one dwelling, with significant erosion occurring at Sunset Beach. The extensive sand dune system is an important natural buffer and includes several lakes, unique to the rest of the Waikato River catchment. Some believe that sand mining is affecting the sand reserves in the beaches and dunes, as well as the dune ecosystem and habitats (Lealand & Hare, 2018). Furthermore, some argue that sand mining near the coastline creates environments which are more vulnerable to storms, as buffering capacities are reduced (Lealand & Hare, 2018).

3 Overview of Environmental Setting

3.1 Geology

Port Waikato geology was first observed by Ferdinand and Hochstetter, who visited the area near the mouth of the Waikato River in 1859 and were first to recognise Mesozoic strata in New Zealand (Hochstetter, 1864). The first comprehensive study was conducted by Purser (1961) with publications by Rodgers & Grant-Mackie (1978) and followed by Waterhouse (1987), who remapped the area. Purser (1961) mapped the Jurassic formations in terms of biostratigraphy units but, apart from the Huriwai Formation, did not recognise individual rock units (Challinor, 2001). Waterhouse (1987) subsequently named the individual rock formations (Takatahi Formation, Kinohaku Siltstone, Waiharakeke Conglomerate, and Puti Siltstone). These units were originally observed in Kawhia by Fleming and Kear (1960). The younger formations (Coleman Conglomerate and Waikorea Siltstone) were first recognised by Kear (1966) south of Port Waikato in the Te Akau district.

The following only describes the local geology in the upper north-western area of Port Waikato as well as Waikato North Head, as these are the areas nearest the Area of Interest (AOI) i.e. close to the Port Waikato settlement and spit.

3.1.1 Mesozoic: Jurassic

Rocks of the Jurassic extend from near Awakino northwards for ~140 km into the Port Waikato region, where they are downfaulted 2-3 km by the Waikato Fault (Challinor, 2001). These Jurassic rocks form the core of the Kawhia Syncline (Fleming and Kear, 1960; cited in Challinor, 2001). The Kaimango Syncline and Kawaroa Anticline (Figure 3.1 and Figure 3.2) are regarded as slightly asymmetric folds on the western limb of the Kawhia Syncline and can be traced northward to Port Waikato (Figure 3.1 and Figure 3.2) (Fleming and Kear, 1960; Purser, 1961; Waterhouse 1978, cited in Challinor, 2001). The upper Jurassic rocks of interest include (bottom upwards) the Upper Puti Formation, Coleman Conglomerate, Waikorea Siltstone, and the Huriwai Formation.

3.1.1.1 Upper Puti Siltstone

The Upper Puti Siltstone occupies the core of the Kawaroa Anticline. The layer is mostly comprised of siltstones and mudstones with thin sandstones particularly near the top. This sequence is moderately well exposed in the Huriwai Valley and at Maraetai Stream (Challinor, 2001).

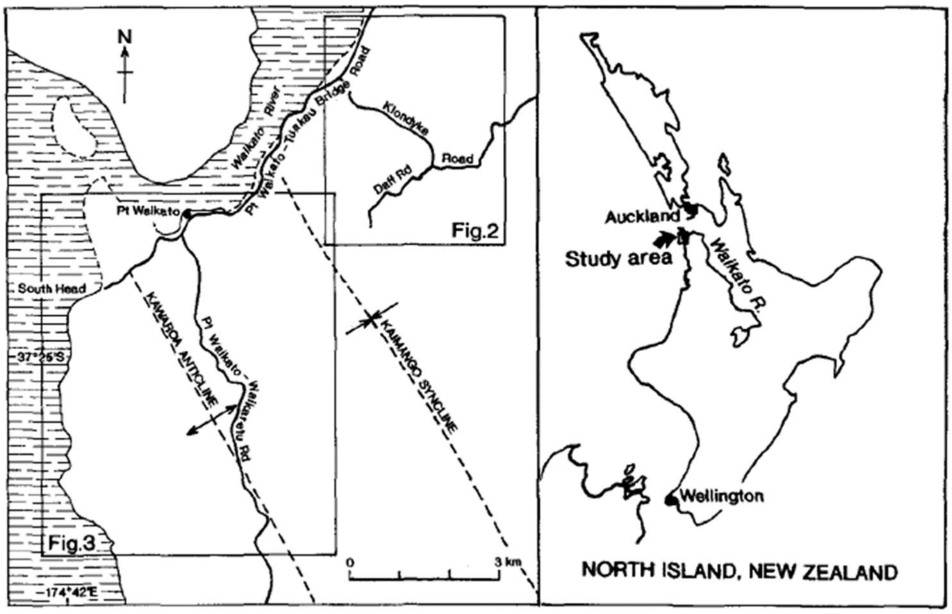


Figure 3.1 Port Waikato region and location in the North Island of New Zealand. The Fig.3 box denotes the location of the local geology presented in Figure 3.2. Basement rocks are folded sequences of the Murihiku Supergroup. The locations of major fold axes are indicated (Challinor, 2001).

3.1.1.2 Coleman Conglomerate

The Coleman Conglomerate (CC) overlies the Upper Puti Sequence and comprises thick sandstones, siltstones, minor conglomerate. The CC is well exposed in the cliffs at the southern end of Sunset Beach at Port Waikato (Figure 3.2). The entire layer is ~220 m thick. The majority of CC, and overlying formations, are concealed on the western limb of Kawaroa Anticline by Quaternary Kaihu Group sands. On the eastern limb of the anticline, CC is present above the Port Waikato Wharf, the outcrops of which are correlated with those at Sunset Beach (Purser, 1961).

3.1.1.3 Waikorea Siltstone

Overlying the Coleman Conglomerate is the Waikorea Siltstone. This siltstone is well exposed in the shore platform and cliffs south and west of South Head (Figure 3.2). The layer is ~275 m thick and consists of blue-grey siltstone, grey sandstone, and siltstone with hard carbonaceous sandstone in the upper part (Challinor, 2001).

3.1.1.4 Huriwai Formation

Above the Waikorea Siltstone and Coleman Conglomerate lies the Huriwai Formation, which is indicated by the appearance of non-marine, well preserved plant fossils. The plant fossils, or fragments thereof, are often observed within the Coleman Conglomerate and the Waikorea Formation (Challinor, 2001).

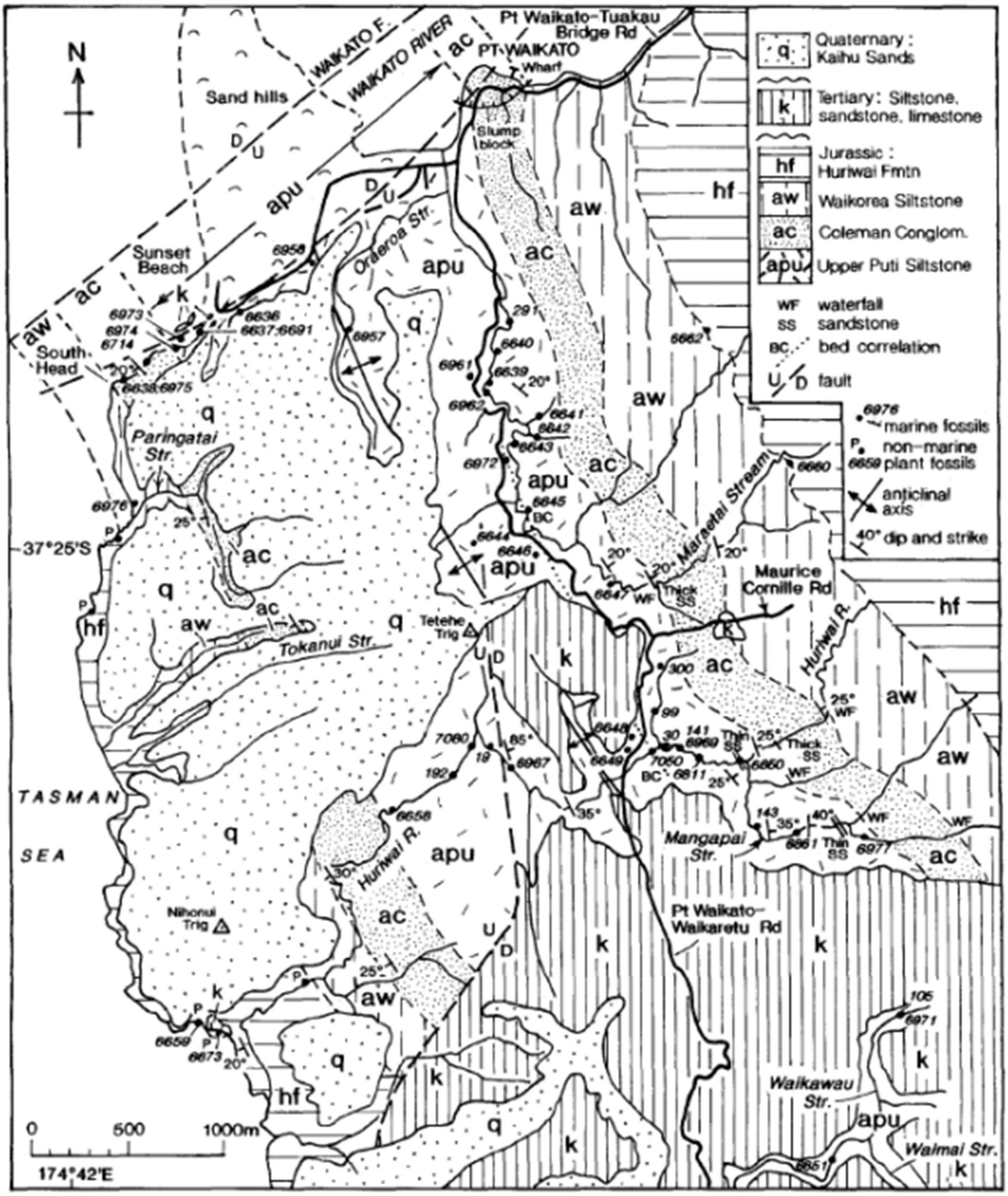


Figure 3.2 Geology and fossil localities south and west of Port Waikato. Base map from Purser (1961, map 3). Map based on Purser (1961), Waterhouse (1978), unpublished maps by R. M. Briggs, C. S. Nelson and J. Gillespie (University of Waikato), and additional fieldwork by A.B.C. All localities containing belemnites and ammonites are shown; many also contain Buchia spp (cited in Challinor, 2001).

3.1.2 Cenozoic: Paleogene Neogene and Quaternary

The Jurassic period is overlain by the Cretaceous (Upper and Lower Epoch), followed by the Paleogene (Palaeocene, Eocene, and Oligocene Epoch) and Neogene Periods (Miocene and Pliocene Epoch) (previously referred to as the Tertiary Period), and then the Quaternary Period (Pleistocene and Holocene Epoch).

At Port Waikato, the Jurassic Murihiku terrain is unconformably overlain by Oligocene and Miocene marine sedimentary rocks of the Te Kuiti and Waitemata Groups, respectively (Figure 3.3 and Figure 3.4) (Waterhouse, 1978; cited in Brathwaite, 2020). These Oligocene and Miocene marine sediments form the base of the Port Waikato spit.

These sedimentary rocks are overlain by a pumiceous sandstone with a basal shell bed known as the Kaawa Formation from the Pliocene (Waterhouse, 1978). An erosion surface separates the Kaawa Formation from the overlying Awhitu Formation, which is the lower sequence of the Kaihu Group from the Pleistocene in the Quaternary (Figure 3.5). The erosion surface has local occurrences of basaltic flows and breccia of the early Pleistocene Ngatutura Basalt (Briggs *et al.,* 1989; Nelson *et al.,* 1989; cited in Brathwaite *et al.,* 2020).

The Kaihu Group (Figure 3.2) (Kear 1965; 1979; Waterhouse, 1978) or more recently defined and identified as the Awhitu and Kariotahi Groups (Figure 3.3) (Issac *et al*., 1994; cited in Brathwaite *et al.,* 2020), consists of three main formations, the Awhitu sands, Hood Sands and the Mitiwai Sands.

3.1.2.1 Awhitu Group

Isaac *et al.* (1994) defines the early Awhitu Group as predominantly moderately to poorly consolidated, large scale, cross bedded sands, with less common plan-parallel and ripple laminated sands, paleosols, lignites, and carbonaceous mud. Locally, conglomerate, rhyolitic ignimbrite and tephra are present (Figure 3.5).

3.1.2.2 Kariotahi Group

The overlying mid-Pleistocene to Holocene Kariotahi Group is defined by Isaac *et al*. (1994) as consisting of moderately consolidated to unconsolidated, titanomagnetite-rich coastal dune sands, with intercalated swamp, fluviatile and lacustrine deposits. The Kariotahi Group is comprised of the Kariotahi, Hood, Bothwell, and Mitiwai Formations (Figure 3.5) of Kear (1965;1979) and Waterhouse (1978) (cited in Brathwaite *et al.,* 2020).

These coastal and river sands at the north head of Port Waikato River are ~80 m thick. Members of the Hood Sand and Mitiwai Sand Formations are currently mined for their titanomagnetite rich properties by New Zealand Steel and constitute a giant placer deposit of ~90 Mt Fe (Figure 3.3 and Figure 3.6) (Brathwaite *et al.,* 2020).

The superficial layers of the Port Waikato spit are largely comprised of the Awhitu and Kariotahi Group Formations overlying Murihiku terrane (basement).

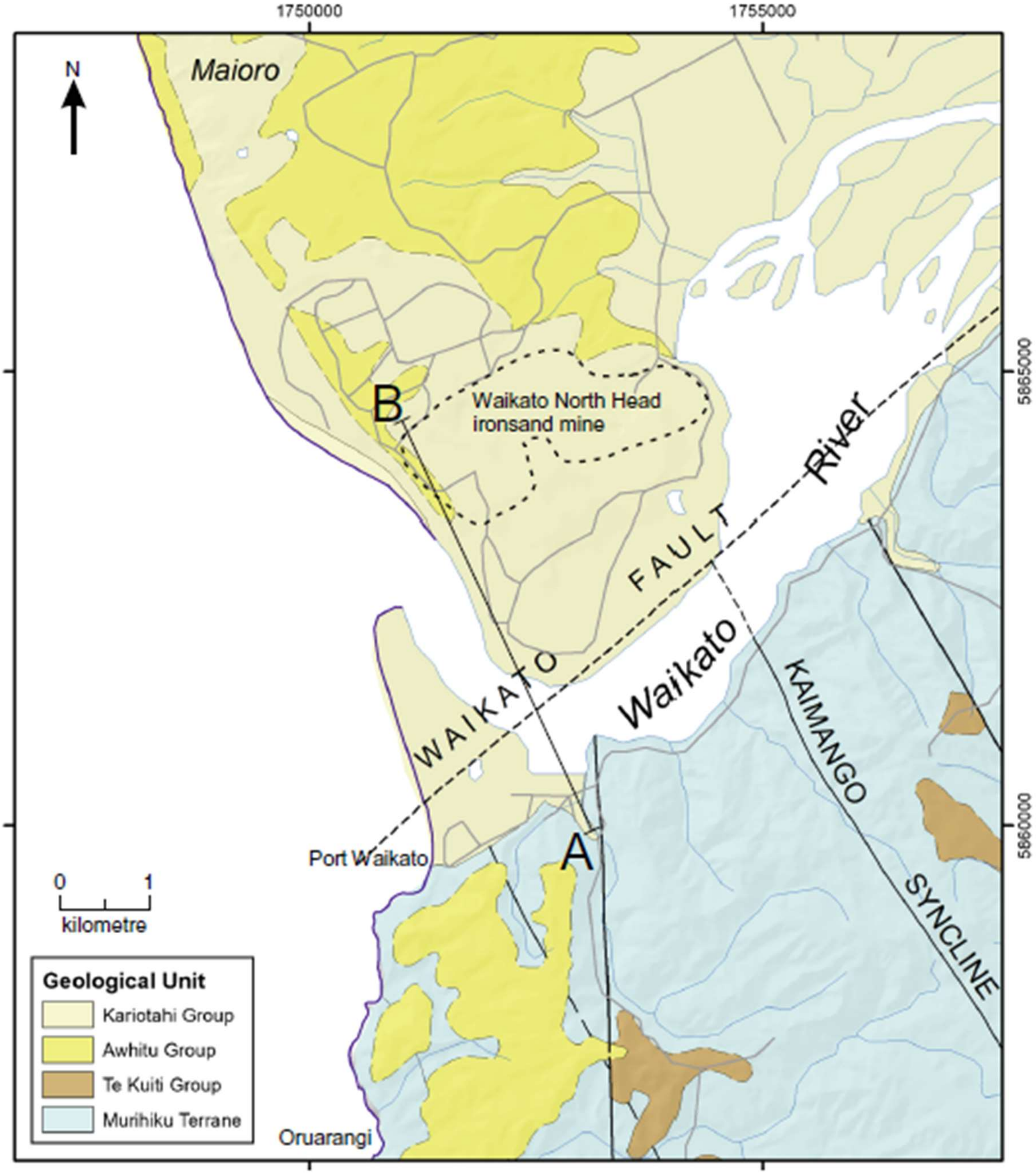


Figure 3.3 Geological map of the Waikato River mouth area, which also shows the location of the Waikato North Head ironsand mine (modified from Waterhouse 1978, and QMAP Auckland, Edbrooke 2001; cited in Brathwaite *et al.,* 2020). Grid is New Zealand map grid

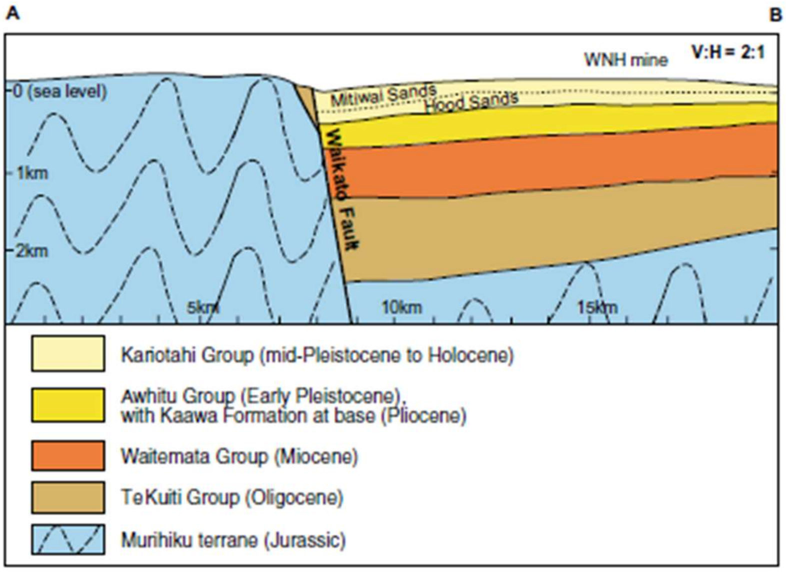


Figure 3.4 Cross section (A–B on Figure 3.3) through Waikato North Head ironsand mine illustrating fault-angle setting of the Awhitu- Kariotahi group sands. Structure from interpretation of gravity survey by Hochstein and Nunns (1976); stratigraphy modified from Waterhouse (1978), and QMAP Auckland (Edbrooke 2001).

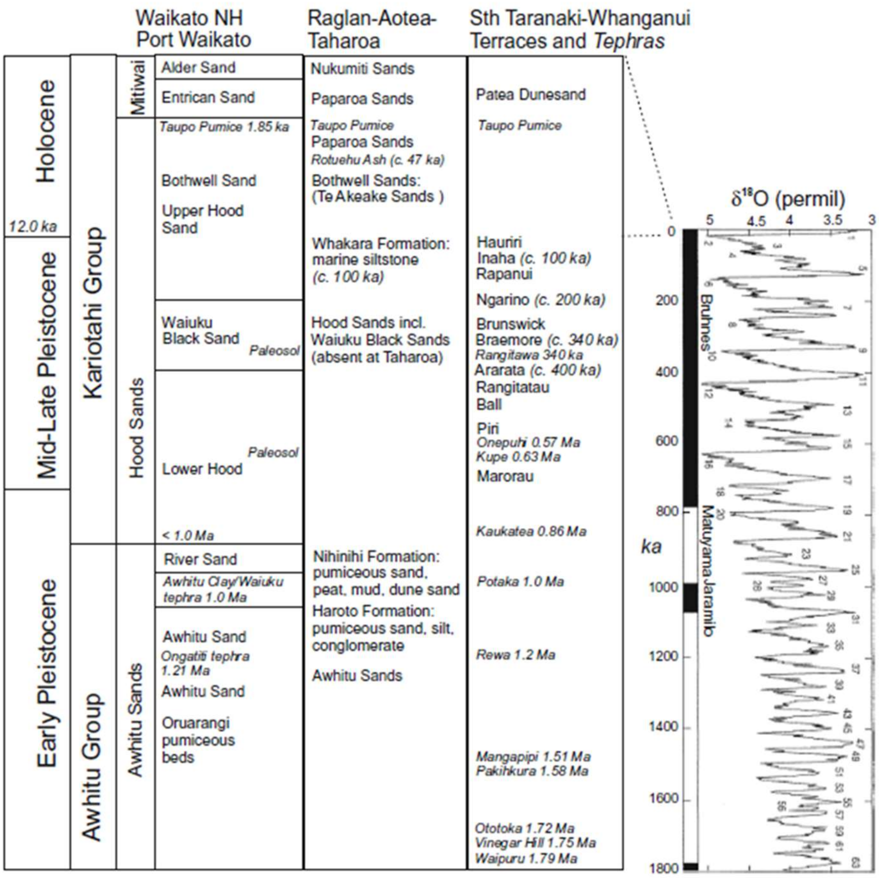


Figure 3.5 Correlation diagram for the sequences at Waikato North Head-Port Waikato, Raglan-Aotea-Taharoa (Pain 1976; Stokes *et al.,* 1989;Waterhouse and White 1994; Alloway *et al*., 2004; Wood *et al*., 2016), South Taranaki-Whanganui (Pillans 1983, 1990, 1994; Pillans *et al.,* 2005), and the stacked marine oxygen-isotope (astronomically calibrated) record and magnetic polarity timescale since 1.8 Ma from Lisiecki and Raymo (2005). Even numbered stages in the record represent ocean cooling with lowered sea levels (i.e. glacial intervals), whereas odd numbered stages represent ocean warming with rising sea levels (i.e. interglacials). Note expanded time scale for Holocene (cited in Brathwaite *et al*., 2020).

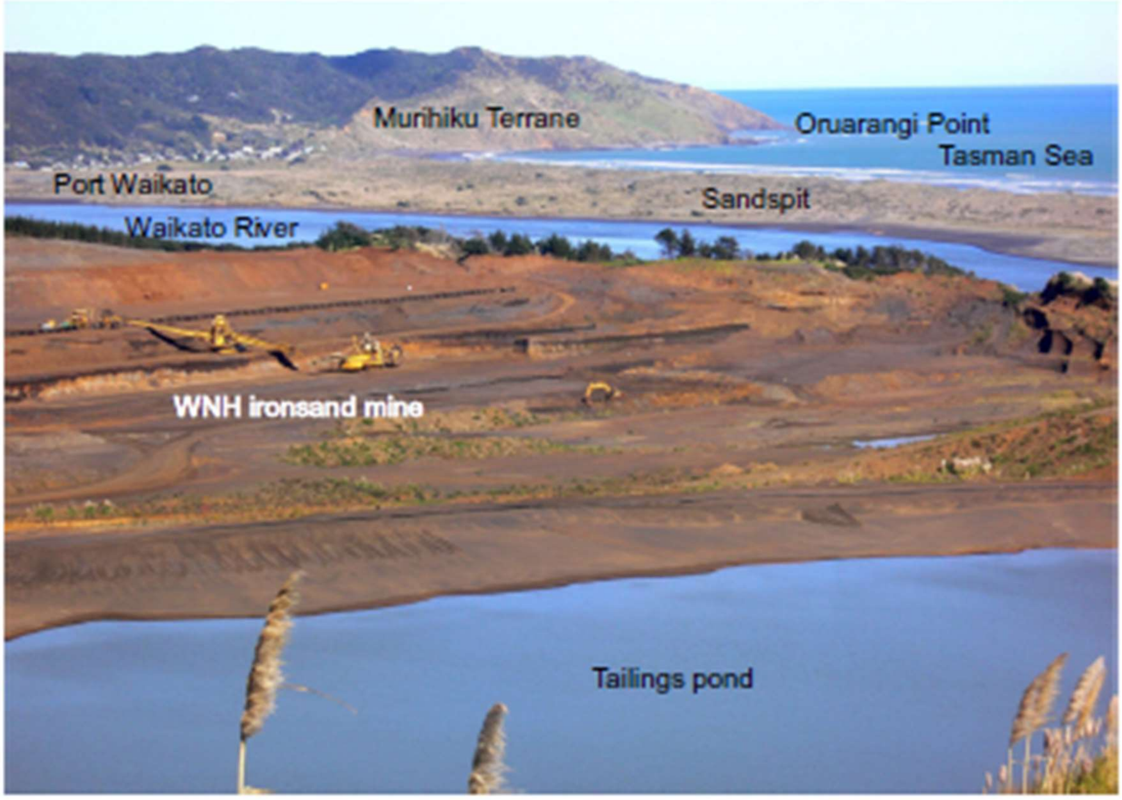


Figure 3.6 Photo of Waikato North Head ironsand mine looking south in 2010. Waikato River in middle distance and a former tailings pond in foreground (Brathwaite *et al.,* 2020).

3.1.3 Vertical Land Movement

Subsidence, or uplift, of the land can have a significant effect in either making worse or compensating the effects of sea level rise (SLR – Section 4.1)) and associated hazards. Beavan and Litchfield (2012) assessed vertical land movement (VLM) (uplift and subsidence) around New Zealand's coastline using geological methods for long term (up to 125,000 years) rates and geodetic methods for present day short term (c.10 year) rates.

Beavan and Litchfield (2012) state that the elevation of the land may change in response to a number of causes:

- Isostatic adjustment caused by flow of the rock in the Earth's mantle due to changes in mass loading on the Earth's surface (in particular, changes of mass due to continental ice sheets growing and melting, when it is known as Glacial Isostatic Adjustment, or GIA);
- Long-term changes due to plate tectonics;
- Subsidence due to withdrawal of fluids (e.g., water, oil) by pumping;
- In sedimentary environments, subsidence due to natural compaction of the sediments (which may be enhanced by earthquake shaking).

The long-term plate tectonic rate may be modulated by:

- Sudden changes due to nearby earthquakes;
- Gradual “postseismic” changes in the years immediately following earthquakes;
- In subduction environments, slow changes of weeks to years duration (“slow slip events”) which result from slip at depth on the subduction interface.

Current GIA effects are estimated to be about -0.3 mm/yr RSL (relative sea level) in the New Zealand region and they are not predicted to change by more than about 0.1 mm/yr over the next hundred years (Beavan and Litchfield, 2012). This means that the New Zealand coastline is rising at about 0.3 mm/yr relative to sea level, as a result of flow in the Earth’s mantle due to melting of the ice sheets over the last 20,000 years (Beavan and Litchfield, 2012).

Rates of vertical movement over the past 125,000 years are broken down further, with the North Island West Coast between Port Waikato and Wellington having an uplift rate of 0-1 mm/yr (Figure 3.7). Beavan and Litchfield (2012) estimate that present day rates of vertical movement sites in Northland, Auckland, Waikato, Otago and Southland have vertical rates that average close to zero (Figure 3.8).

With respect to vertical land movements and how this affects SLR in the Raglan area, it means that the rate of SLR is very slightly compensated for, since the land is moving upwards. It is notable that the West Coast of the Waikato is relatively stable tectonically, which means violent uplift events such as occurred in Kaikoura in 2016 (0.5-2.0 m) will not result in ‘re-setting’ SLR.

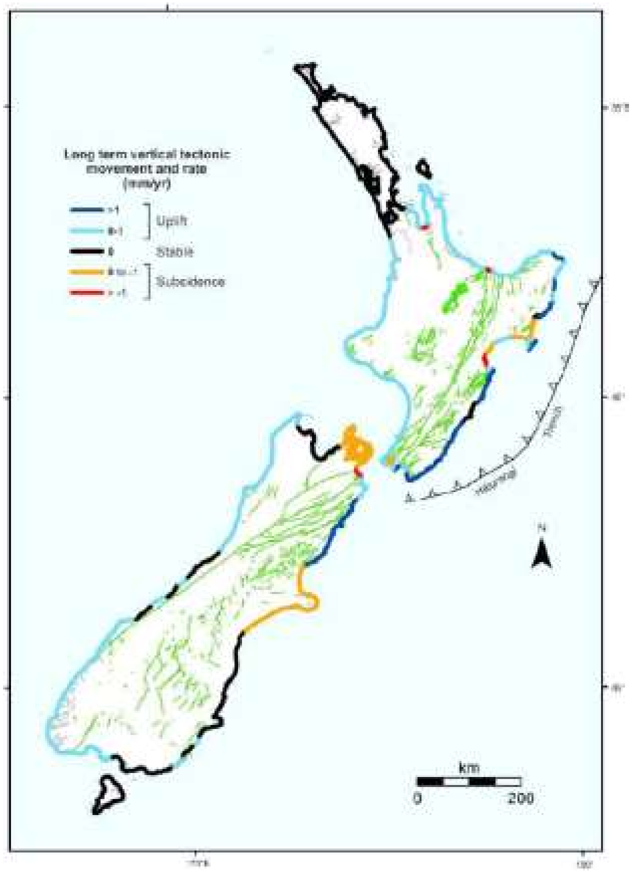


Figure 3.7. Long-term vertical tectonic movements of the New Zealand coastline, compiled primarily from 125,000-year marine geological markers (Beavan and Litchfield, 2012).

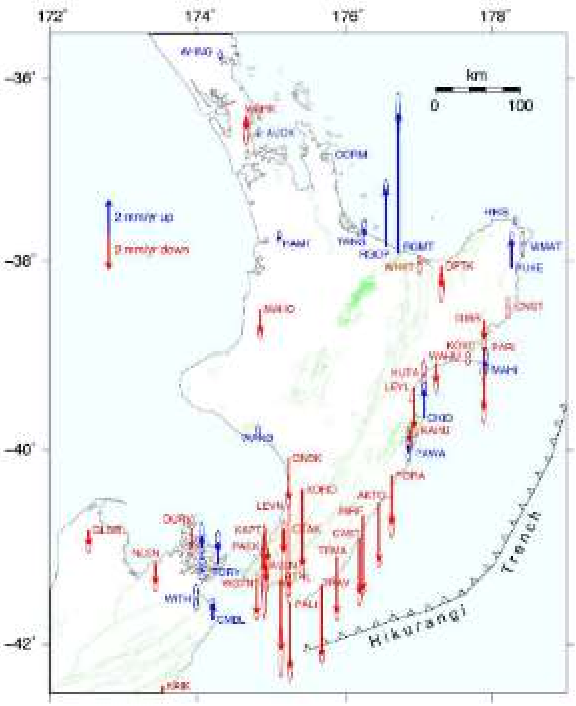


Figure 3.8. Present-day vertical rates estimated at near-coastal GPS sites in the North Island and northern South Island. These show rates of land elevation change per year.

3.2 River Process

3.2.1 Human Intervention and Flood Risk

The Waikato River is the longest river in New Zealand and has a series of eight hydroelectric power stations built between 1929 and 1971. The discharge is regulated first by a control gate at the Waikato River outlet from Lake Taupo. The river has a flood control scheme at Rangiriri with a spillway to Lake Waikere and Whangamarino Wetland, which is designed for a rainfall frequency of 200-250 mm over three days (Lower Waikato Waipā Control Scheme).

Dams on the Waikato River are also used to control flood events; they flush water quicker to reduce flooding of lowlands and can delay flood peaks so they do not coincide with the uncontrolled Waipā River peak flow at the confluence with the Waikato River at Ngāruawāhia. Flood risk areas have been determined by Waikato Regional Council on the Waikato River and indicate risk on low lying land near the river on the lower part of the Waikato River from Ngāruawāhia north (i.e. after the confluence of the Waipā River, which carries large volumes of water). Even so, the Waikato Regional Council assessment indicates that the Port Waikato township is protected by flood control schemes and so is in a low-risk zone i.e., during a 1% AEP flood event, the flood extent does not penetrate into the township (Figure 3.9).

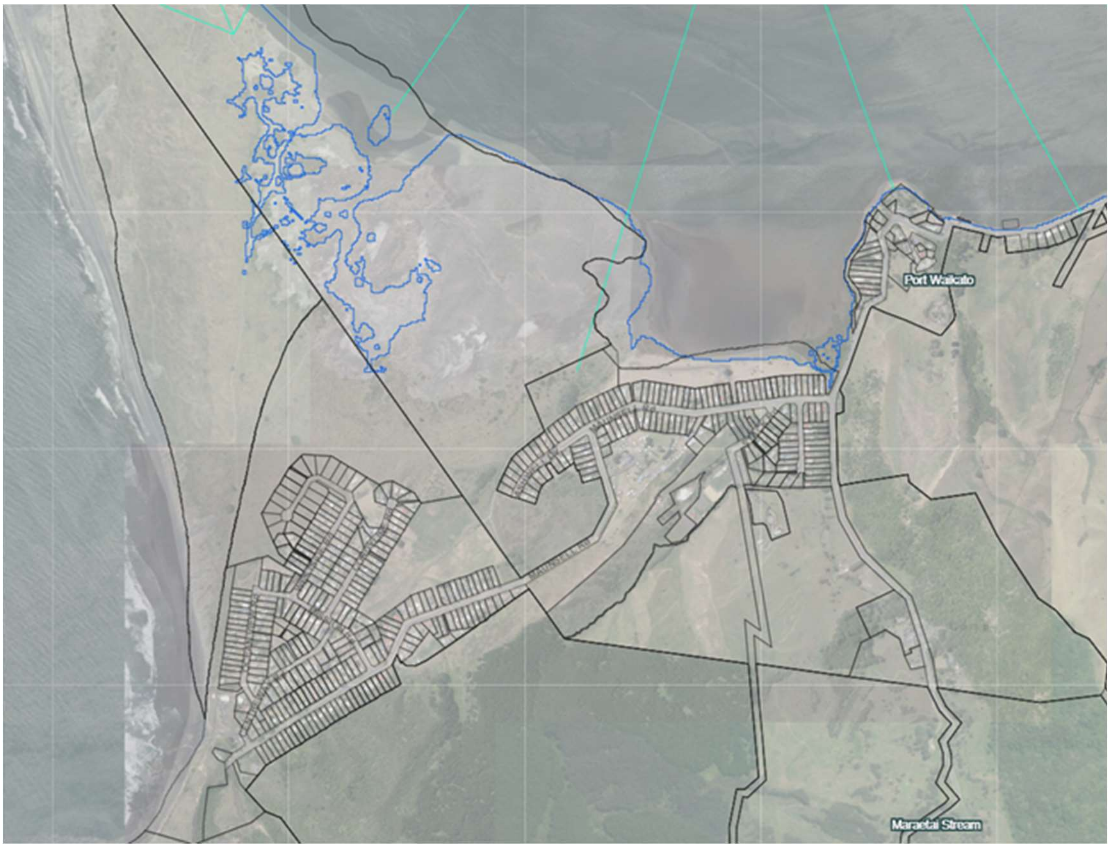


Figure 3.9 Shows the Waipā and Waikato River 1% AEP flood extend (blue line) (retrieved from the Waikato Regional Council Hazards Portal, 2020).

3.2.2 Residence Times of the Waikato River Estuary

Greer *et al.* (2016) mapped residency times of West Coast estuaries, including the Waikato River Estuary. Miller and McPherson (1991) define estuarine residence time as "*the required time to flush a given fraction (e.g. 95%) of a conservative constituent from the modelled part of an estuary*". Residence times are expected to change under different meteorological and oceanographic conditions. Among these, river flow conditions are expected to change the rate at which estuary water is replaced. The residence times were investigated under different flow rates corresponding to low, medium, and high river flow taken to be the 90th (Q10), 50th (Q50 or median), and 10th (Q90) percentile flows, respectively. Flow rates were calculated from complete years of data. Calculations of low, medium, and high flows used gauged river flow scaled to account for inflow from the entire catchment. The flow rates are summarised in Table 3.1. The flows were applied as uniform river flow in the models, which were used to calculate residence times.

Greer *et al.* (2016) stated that while this is not an entirely realistic representation of river flow, particularly for estuaries with longer residence times, it serves the purpose of illustrating the effect of different flow conditions on residence time. For the Waikato River Estuary, flow conditions were estimated from data recorded by the Mercer flow gauge, which was also used to create model boundary conditions. Flow rates were established by analysis of flow rates between 1 January 2002 and 1 January 2015.

Table 3.1 Total riverine discharge (m^3/s) used in scenarios for each estuary. (Greer *et al.,* 2016)

Estuary	Low (Q90) Flow	Medium (Q50) Flow	High (Q10) Flow
Waikato River estuary	219	339	628
Whaingaroa (Raglan) Harbour	1.2	5.3	25.7
Aotea harbour	0.9	4.4	15.4
Kawhia Harbour	4.1	11.8	39.89
Marokopa River estuary	4.4	13.0	56.8
Awakino River estuary	3.8	11.2	49
Mokau River estuary	9.2	27.2	119.1

Greer *et al.* (2016) reported that although the estuary is tidal, the tidal influence of the river extends beyond the upstream model boundary and was observed in the flow gauge record at the Mercer tide gauge some 43 km from the estuary mouth. The authors produced residence time maps for each flow condition for (Figure 3.10 low, Figure 3.11 medium, and Figure 3.12 high flow). It was found that at a constant low flow, the residence time was at its maximum of approximately 4.5 days at the mouth of the harbour and less than 0.5 days at the upstream boundary of the river. For the medium and high flow cases the residence times reduced such that for high flows almost all cells in the estuary had a residence time of <2.5 days.

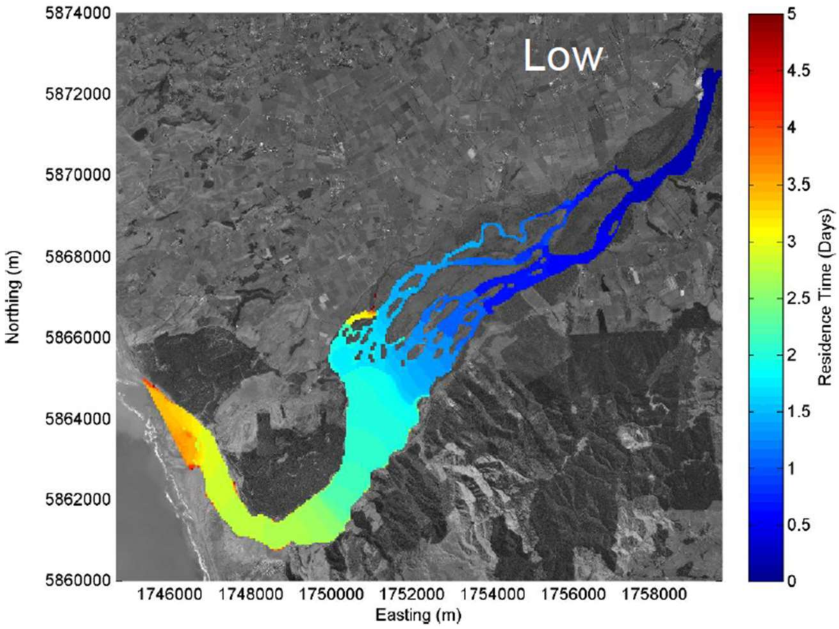


Figure 3.10 Residence time for the Waikato River Estuary calculated using low flow. The tracer was released at high tide during mid-range tides (Greer *et al.,* 2016).

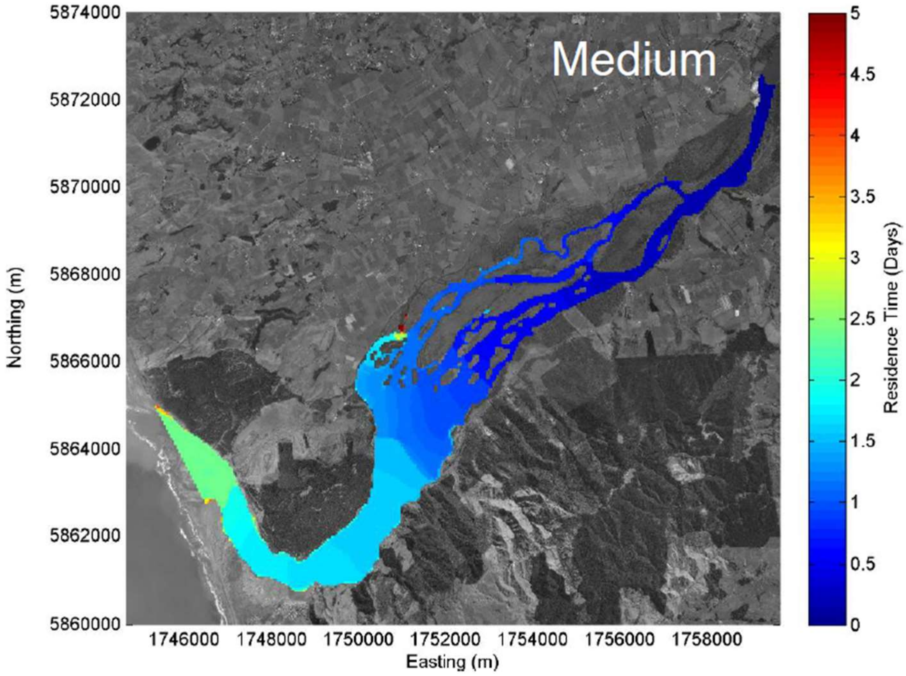


Figure 3.11 Residence time for the Waikato River Estuary calculated using medium flow. The tracer was released at high tide during mid-range tides (Greer *et al.,* 2016).

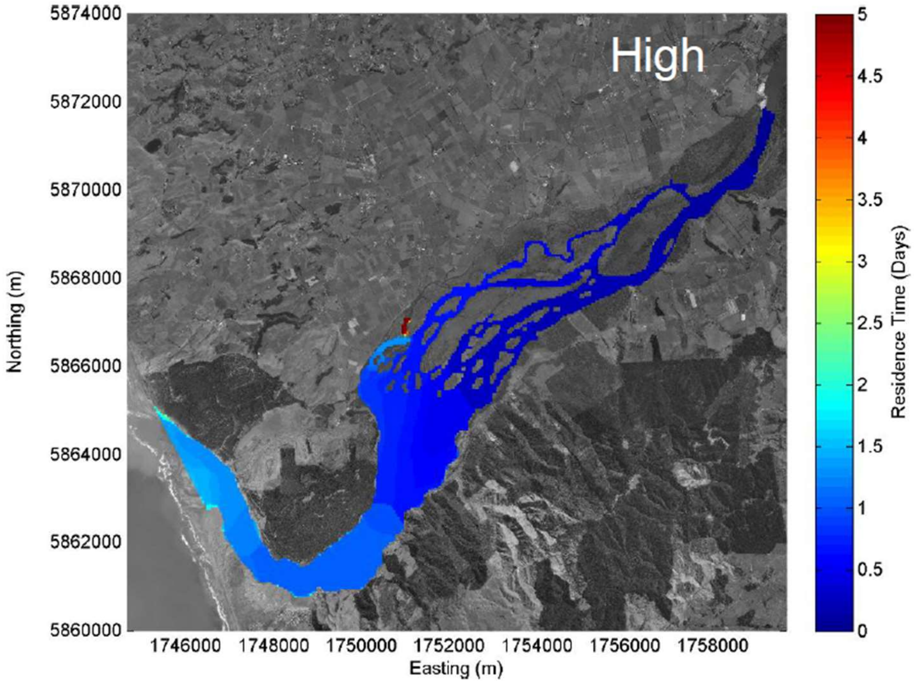


Figure 3.12 Residence time for the Waikato River Estuary calculated using high flow. The tracer was released at high tide during mid-range tides (Greer *et al.,* 2016).

3.2.3 Bathymetry and Tidal Influence

Atkin *et al.* (2016) carried out a bathymetric survey of the Waikato River mouth/Estuary as part of the development of the Waikato River model. A Real Time Kinematic (RTK) Global Positioning System (GPS) device collected horizontal position (WGS84) and elevation (Ellipsoidal) data at 1 Hz for the bathymetric survey and every metre for the topographic survey. Before the survey, a base station was established above a Land Information New Zealand (LINZ) geodetic mark. The base station provided real time corrections of horizontal and vertical position to a roving GPS receiver used in the field to collect data points. Data points were collected in World Geodetic System 1984 (WGS84).

The bathymetry survey carried out by Atkin *et al.,* (2016) was designed to complement existing data (Figure 3.13) for the Waikato River estuary, collected by Jones & Hamilton (2014) for the lower reaches up to the now decommissioned Elbow Road aggregate processing site. The survey work undertaken was, therefore, done in two areas (Figure 3.14) to complement the existing data.

Atkin *et al.* (2016) generated a bathymetry dataset for model development, which includes the first ever survey of the river entrance (Figure 3.15).

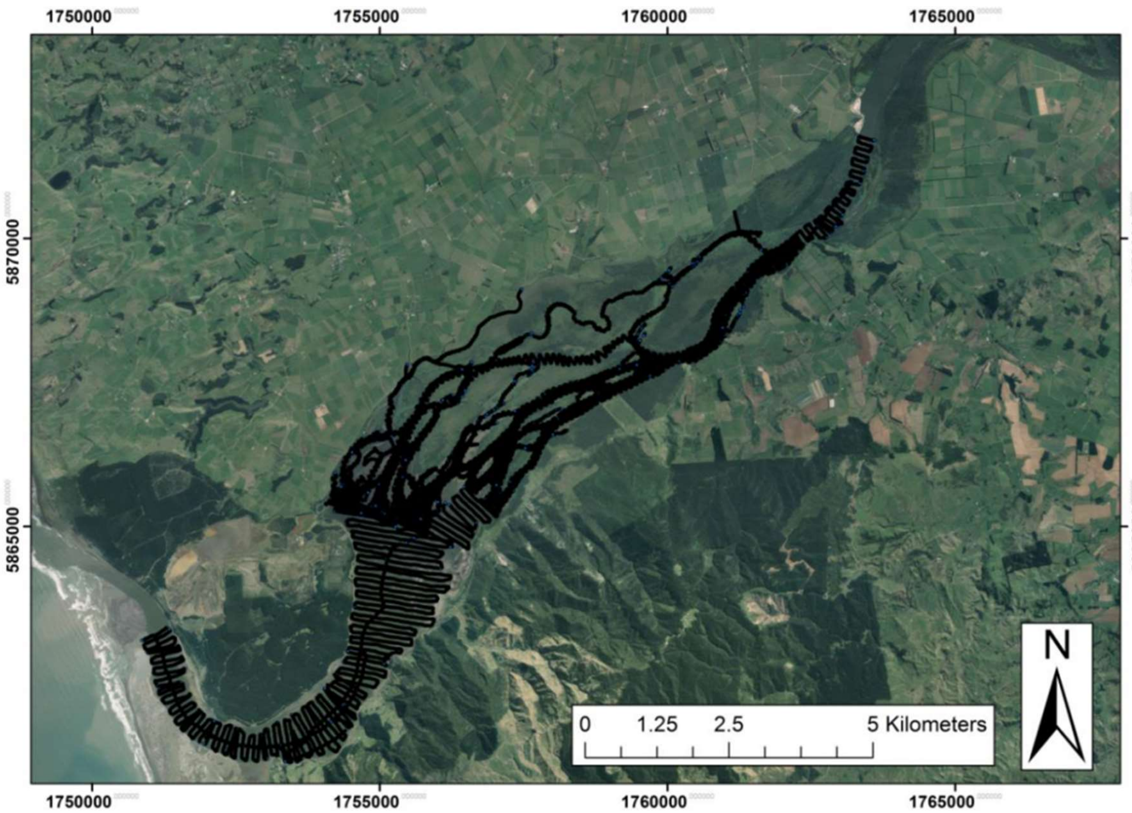


Figure 3.13 Bathymetry survey coverage of Waikato River Estuary and Delta (Jones & Hamilton, 2014).

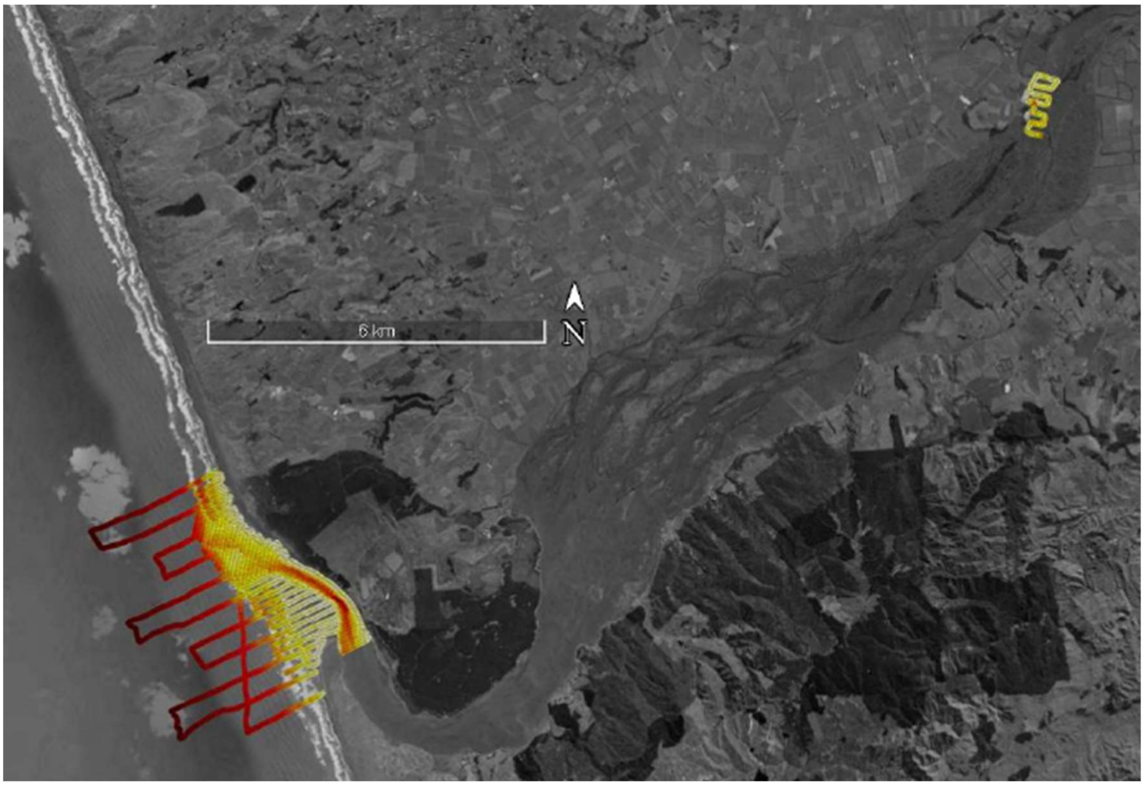


Figure 3.14 Overview of the two survey areas in Waikato River Estuary: the bar and entrance area (left side) and the Elbow Road water ski area (right side) (Atkin *et al.,* 2016).

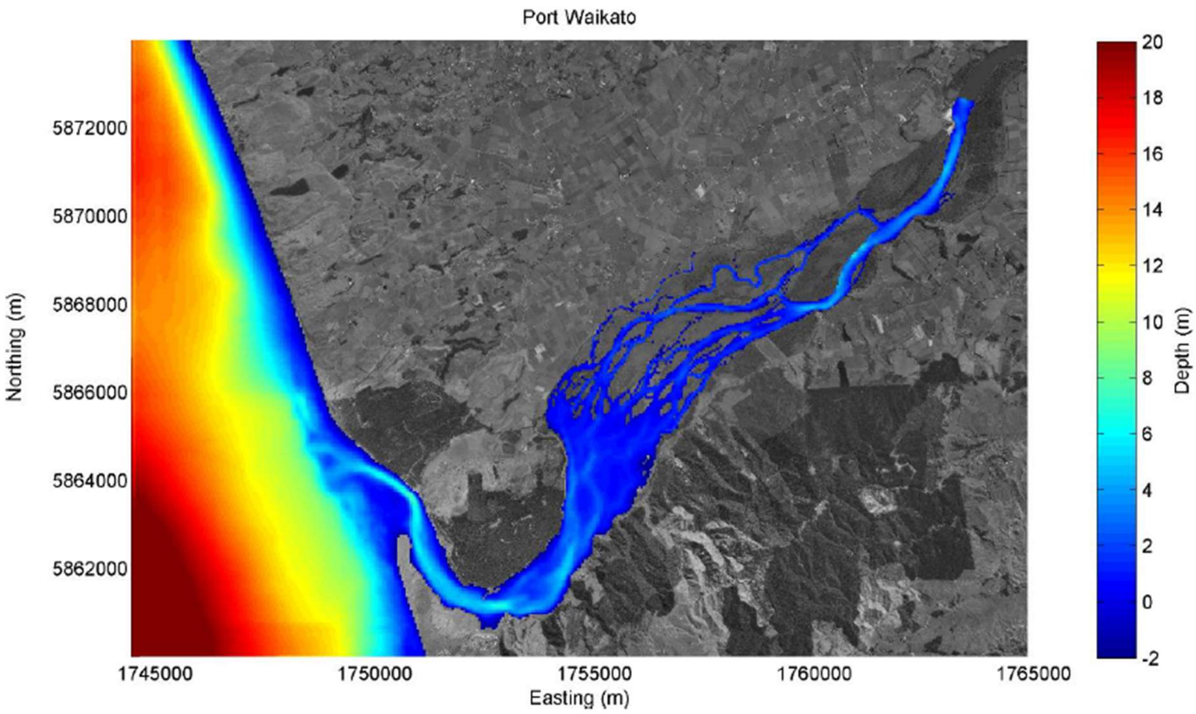


Figure 3.15 Waikato River Estuary bathymetry (Atkin *et al.,* 2016).

The field work carried out by Atkin *et al.* (2016) also provided sea level, current, and salinity data at two locations in the estuary ('Lower') in the lower reaches of the estuary and ('Upper') in the upper reaches of the estuary. Current data was used to calibrate the numerical model of the lower Waikato River. Model simulations of peak flood and ebb currents are shown in Figure 3.16 and Figure 3.17, respectively. The results indicate that the estuary is ebb-dominant, with ebb currents speeds far greater near the entrance compared to those during flood tide.

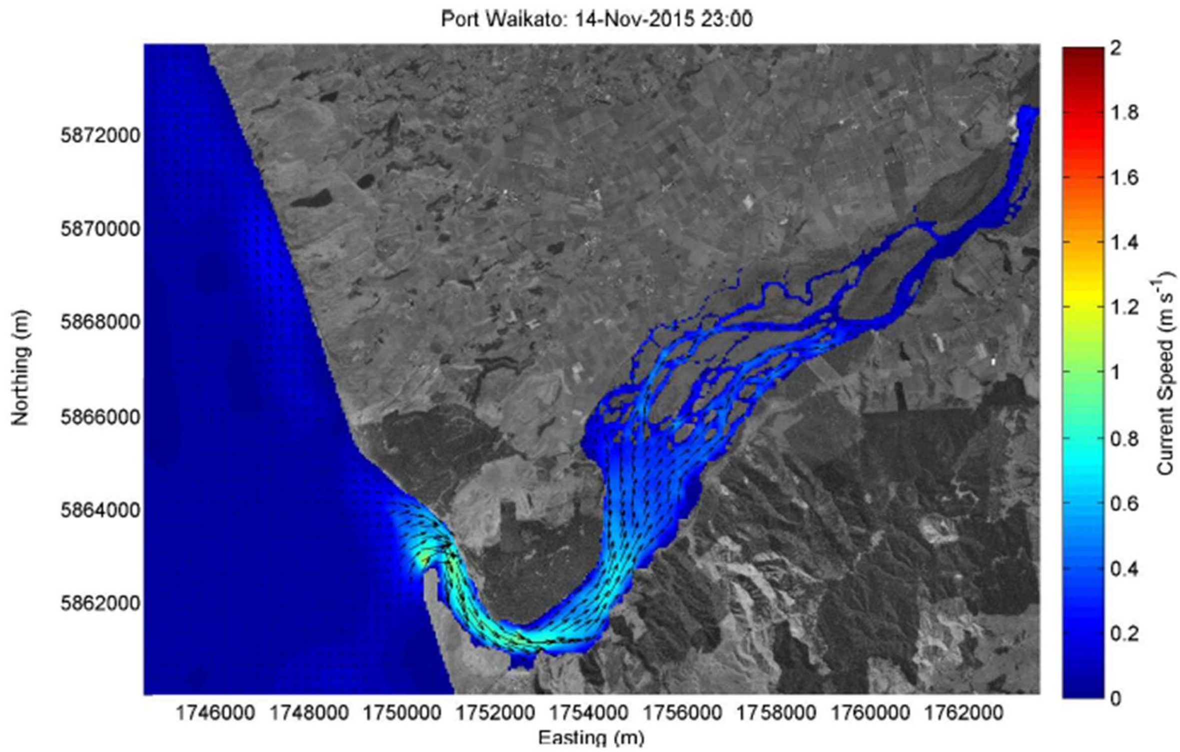


Figure 3.16 Waikato River Estuary showing current speeds (m/s) during peak flood.

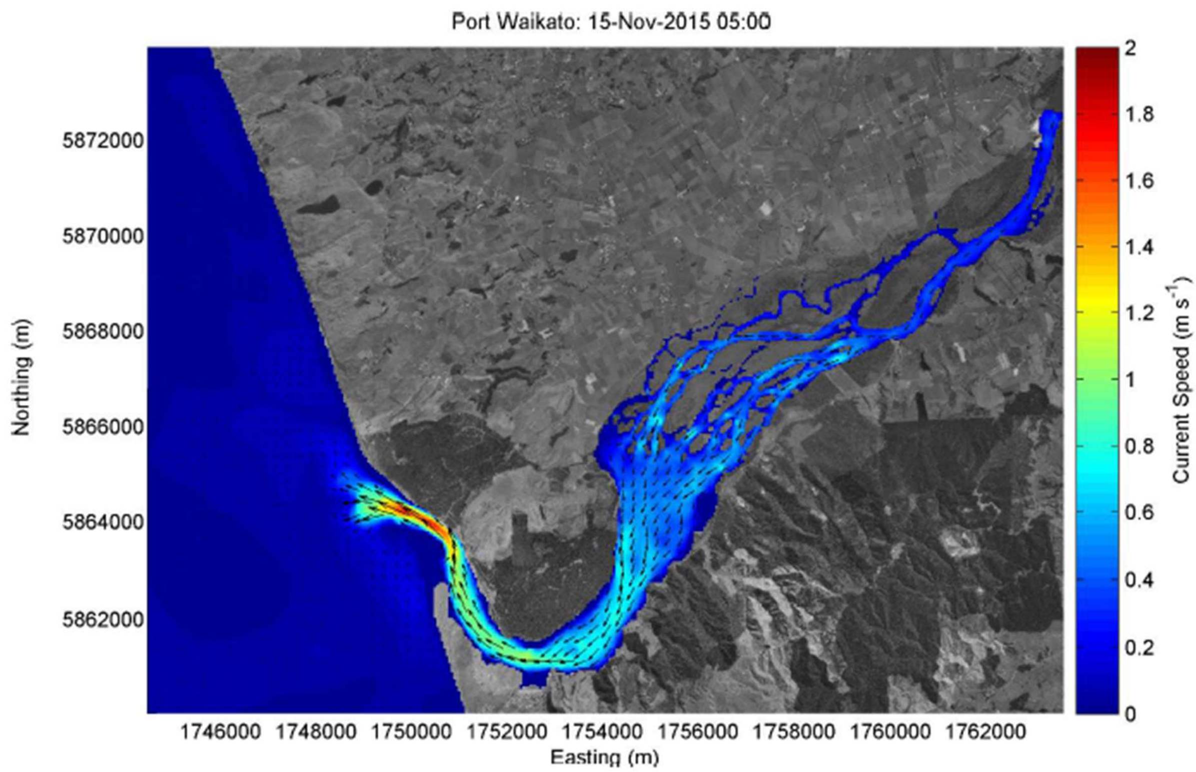


Figure 3.17 Waikato River Estuary showing current speeds (m/s) during peak ebb.

3.2.4 Ebb and Flood Tidal Deltas

Harrison (2015) describes ebb tidal deltas (ETDs), as large sedimentary accumulations on the seaward side of tidal inlets that play a significant role in moving sediment around the coastal littoral cells. In contrast, flood tidal deltas (FTDs) are large sedimentary accumulations on the landward side of an inlet. Deltas typically shelter inlets by dissipating and redirecting energy offshore and on to adjacent beaches, respectively (Fitzgerald, 1984). ETDs provide a mechanism for sediment to bypass inlets (Syvitski and Saito, 2007).

Both ETDs and FTDs provide storage, exchanging sediment between adjacent beaches, nearshore, and inlet mouths (Fitzgerald, 1984). Deltas are formed in response to tidal forcing through an inlet (van der Vegt *et al.,* 2006), with modal size and shape determined by the tidal prism (Walton and Adams, 1976), wave energy, and available sediment (Hicks and Hume, 1996). Sediment that is transported into an inlet by either waves or flood currents is either deposited onto the FTD or is transported further into the inlet where it could be deposited or recirculated out of the inlet and potentially deposited on the ETD.

The geomorphology of deltas is classified by Galloway (1975) based only on the relative influence of fluvial, wave or tidal processes. Harrison (2015) points out however, that when short-term conditions deviate from the long-term average, 'a local morphodynamic response occurs', whereby mobile bedforms or sandbars migrate along the delta toward the nearshore and adjacent beaches (Sha, 1989; Hicks *et al.,* 1999; Sherwood *et al.,* 2001; Ruggiero *et al.,* 2003; Ruggiero *et al.,* 2009). This can result in hydrodynamic shifts whereby channels are moved and/or realigned.

Due to the dominance of the river flow, these classification of ebb and flood tidal deltas do not apply well to the Waikato River mouth. The sediment deposition ('the island') sometimes observed within Waikato River Estuary (Figure 3.18) entrance does not fit the definitions presented by Harrison (2015) for flood and ebb deltas on the Waikato west coast. The sediment accumulation in the middle of the entrance is likely an extension of the spit that that is repeatedly breached, thus producing the 'island' observed. The absence of an ebb tidal delta is also noted in the bathymetry survey (Figure 3.15), as well as in comparison to other Waikato Region west coast estuaries (Greer *et al*., 2016). In fact, while the morphology of the Waikato River Delta is similar to classic river deltas (i.e., the thin dendritic delta of the river as it passes through low-lying swampy land between Meremere and some 9 km to the coast), it does not fit into the classic categories of river deltas, as it then narrows and deepens and there are no significant bar features extending into the open water (Figure 3.15).

As described above, the Waikato River mouth system to a tidal inlet does not quite fit the classification criteria. However, the reason that it is hard to fit in with the FitzGerald *et al.*

(2001) model, is that the Waikato River mouth complex is a type of Tidal River Mouth system the general properties of which are described in Hume *et al*. (2016); i.e., seawater can intrude kilometres up the estuary via low-gradient coastal plains, it has a narrow inlet restricted by the sandy spit with a lagoon, and emerges on a coast with sufficiently high wave energy where littoral drift has builds a spit to the north. There is usually only a relatively small bar at the entrance in comparison to other west coast estuaries (e.g., Aotea or Raglan Harbours which have very large tidal prisms compared to river input) because of the predominance of ebb flow, the small load of sand and gravel reaching the coast and the fact that sand/gravel deposits get clipped off by the energetic wave climate. It is more similar to the Whakatane River entrance on the on the east coast (T. Hume, pers. comm.).

Figure 3.18. An example of the sediment accumulation that occasionally manifests at entrance of Waikato River Estuary.

3.3 Coastal Processes

The west coast of the North Island faces directly into the circumpolar westerly winds and is subject to persistent, and on occasion, extreme, wind and wave energy emanating from the Southern Ocean and the Tasman Sea. In the offshore bathymetry, a clear slope break can be seen at approximately 200 m depth, which delineates the continental shelf from the continental slope and the abyssal depths (Figure 3.19). The width of the continental shelf along the west coast varies considerably from 25 km in the northern reaches near the Kaipara Harbour entrance to more than 150 km offshore of Taranaki. Along this stretch of coast there are 19 significant river mouths or harbour systems, including Port Waikato Harbour. The offshore geology consists of an almost continuous sequence of sedimentary and volcanic rocks up to 8,000 m thick. This sequence fills the northern part of the Taranaki Basin and sub-basins, which are well known for oil and gas deposits.

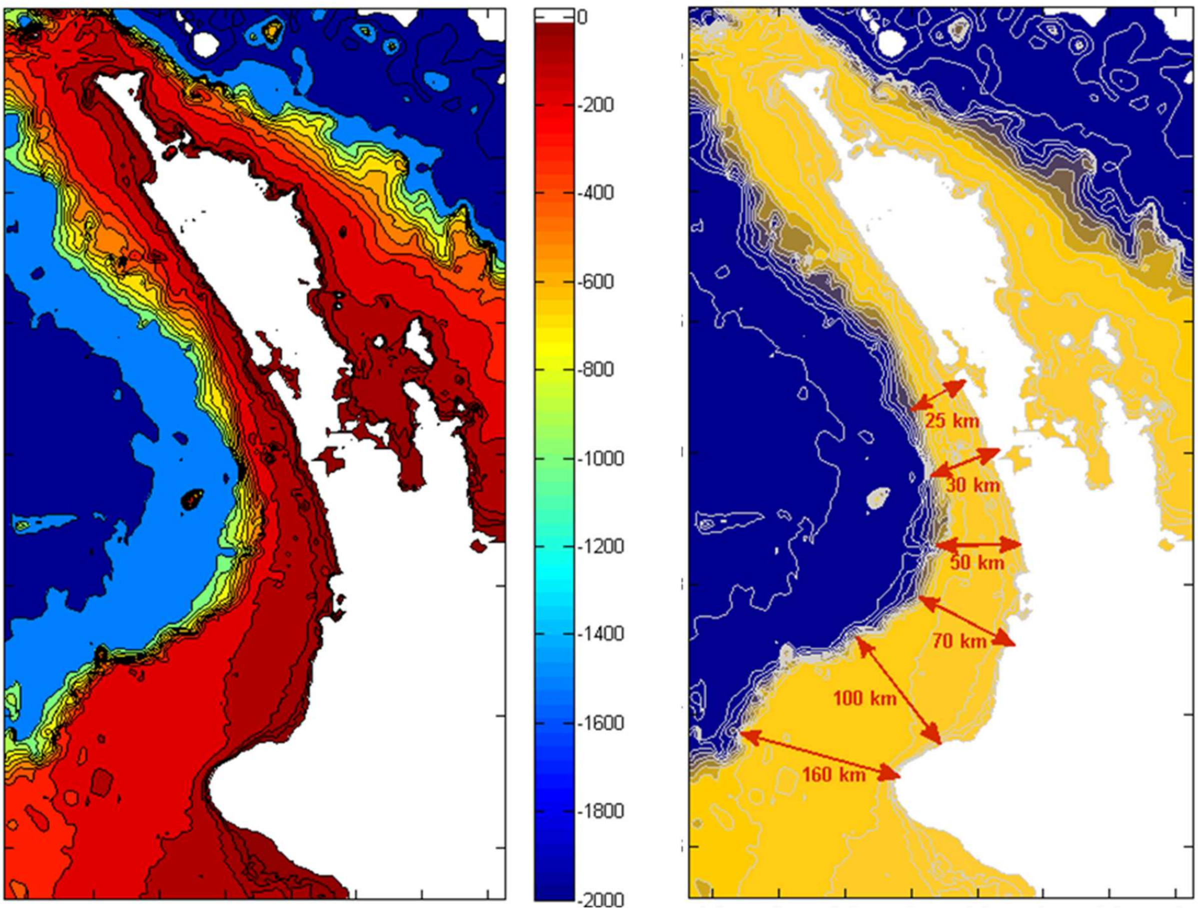


Figure 3.19 (left) Bathymetry of the west coast of the North Island. (right) Depths less than 200 m are shown in yellow indicating the width of the continental shelf.

3.3.1 Wind and Wave Climate

The west coast of the North Island of New Zealand has a high-energy wave climate and is exposed to waves approaching from the south-west through to the north. The longest available record of measured wave data relevant to this part of the West Coast is the dataset from the offshore drilling platforms of the Maui gas field located some 35 km offshore of Taranaki south of Port Waikato. The data, collected over a ten-year period from September 1976 through April 1987, includes directional wave information only in the last year of the record. Despite the relatively short record, these data are generally representative of wave conditions along the west coast of central New Zealand, except for local features (Laing, 1993). Kibblewhite *et al.* (1982) produced a wave climate based on 5 years (1977 – 1981) of these data and their analysis of seasonal variations indicated a higher wave climate in the winter months. In a spectral analysis of the Maui wave data by Ewans and Kibblewhite (1992), the measurements demonstrate the importance of the south-west swell component (with an average wave period of ~12 seconds) arriving from distant sources in the south of the Tasman Sea and the Southern Ocean. They suggest that the westerly and south-westerly wind components also make a significant contribution to the wave climate on the West Coast.

In addition to the measured data discussed above, longer-term records of modelled hindcast wind and wave data are also available. This includes data from NOAA (the US National and Oceanic and Atmospheric Administration) and the ECMWF (the European Centre for Medium-Range Weather Forecasting). Below we present summary rose plots of wind and wave data extracted from the NOAA archive at the location -37.5.0° latitude and 174.5° longitude approximately 22 km south-west of Raglan (Figure 3.20) with data covering the period from 1979 through to 2019. The wind rose plot presented in Figure 3.21 clearly indicates the dominance of south-westerly winds, however there is a significant fraction of winds from other directions. In terms of waves (Figure 3.22), again the southwest direction is clearly dominant, and the data is suggestive of a highly energetic wave climate with heights in excess of 2 m and periods greater than 12 seconds for the majority of the record.

NIWA analysed hindcast wave data for a location 5 km off the coast near Raglan (38.001°S, 174.737°E, R. Gorman, pers. comm.) ~44 km south of Port Waikato. Summary statistics for their 15-year (1979 – 1993) record are presented in Table 3.2, while the joint probability of significant wave height and direction is given in Table 3.3. Although this record is from a different data set, the results are in line with the longer-term hindcast data, clearly showing that most waves approach from the WSW quarter. The joint probability table also indicates that a significant amount of wave energy come from the west and north-west.

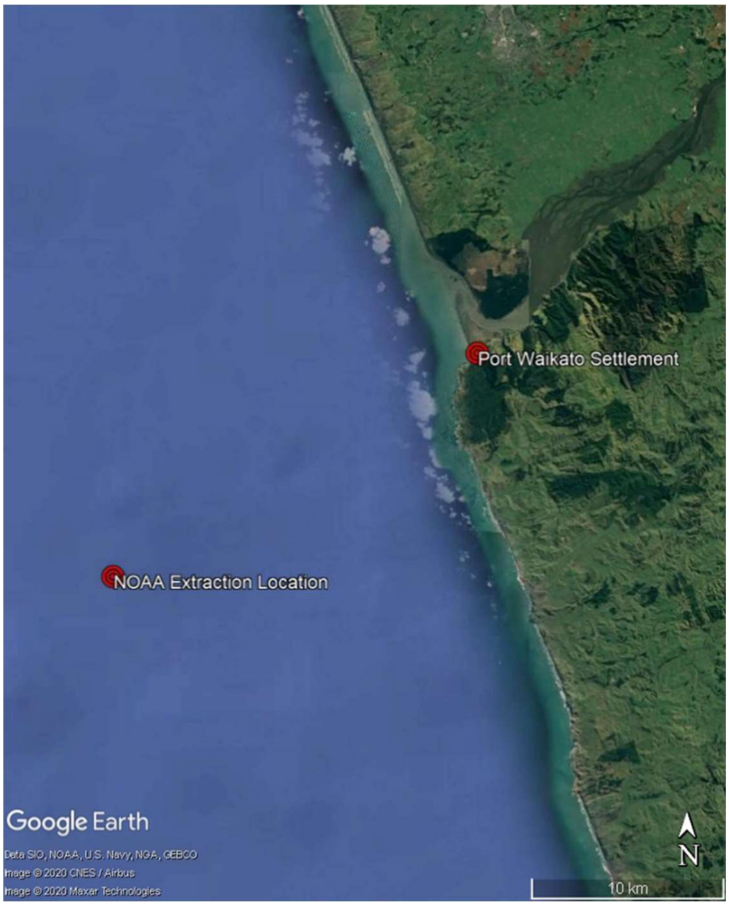


Figure 3.20 Location of the NOAA data extraction point (Image sourced from Google Earth, 2020).

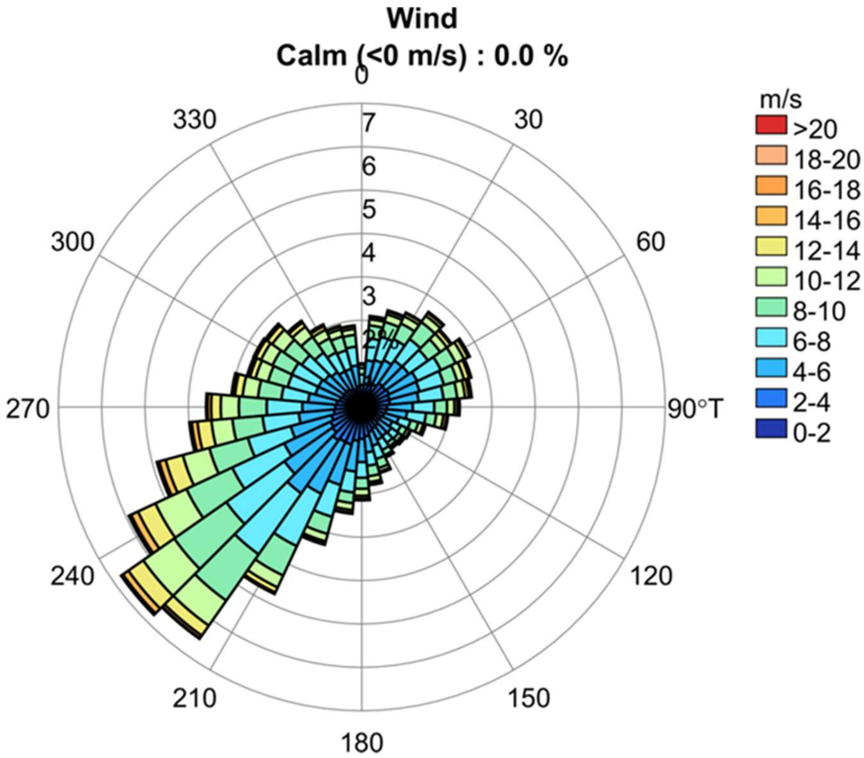


Figure 3.21 Rose plot of wind climate from the NOAA hindcast data set.

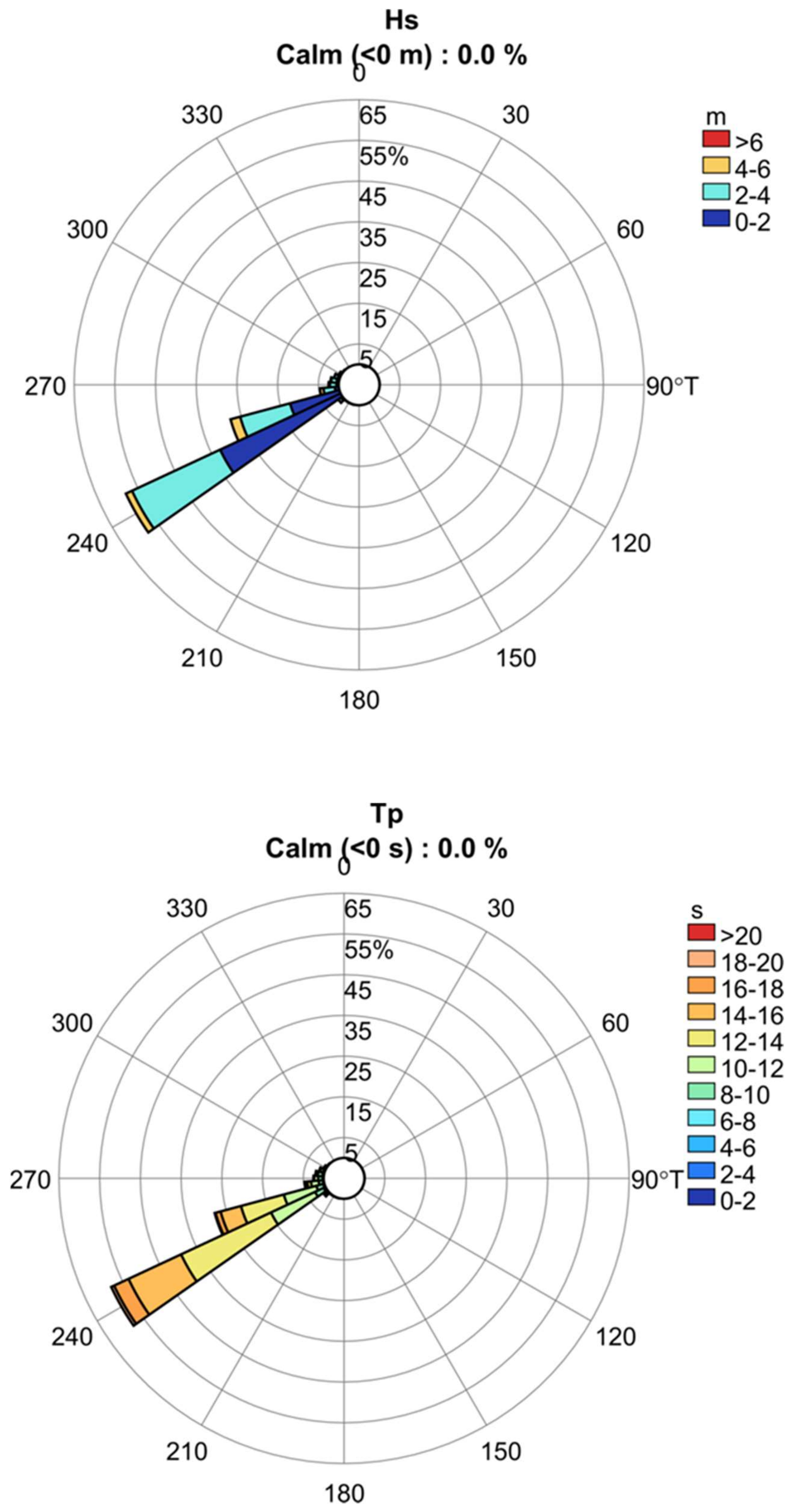


Figure 3.22 Rose plots of wave height (top) and period (bottom) from the NOAA hindcast data set.

Table 3.2 Mean statistics of significant wave height, peak spectral wave period, and mean wave direction for the WAM 15-year numerical hindcast for a site 5 km offshore of Raglan (data source: R. Gorman, NIWA, Hamilton; cited in ASR, 2010).

	Average	Standard Deviation	Minimum	Maximum
Significant wave height (m)	1.66	0.79	0.23	9.15
Peak spectral wave period (s)	11.2	2.2	3.2	19.8
Mean wave direction (deg)	251	22.6	-	-

Table 3.3 Joint probability of occurrence of significant wave height (m) and mean wave direction (from) for the WAM hindcast data 5 km offshore of Raglan (38.001°S, 174.737°E) (data source: R. Gorman, NIWA, Hamilton; cited in ASR, 2010).

	< 0.2	< 0.5	< 1.0	< 1.5	< 2.0	< 2.5	< 3.0	< 3.5	< 4.0	< 5.0	<10.0	TOTAL
NNE	0	0	0.01	0	0	0	0	0	0	0	0	0.01
NE	0	0	0.01	0	0	0	0	0	0	0	0	0.01
ENE	0	0	0.01	0	0	0	0	0	0	0	0	0.01
E	0	0	0.01	0	0	0	0	0	0	0	0	0.01
ESE	0	0	0.01	0	0	0	0	0	0	0	0	0.01
SE	0	0	0.02	0	0	0	0	0	0	0	0	0.02
SSE	0	0	0.01	0	0	0	0	0	0	0	0	0.01
S	0	0.01	0.02	0	0	0	0	0	0	0	0	0.03
SSW	0	0.03	0.16	0.07	0	0	0	0	0	0	0	0.27
SW	0	0.42	7.52	9.12	4.54	1.91	0.9	0.26	0.14	0.08	0.01	24.93
WSW	0	0.22	7.78	13.58	11.1	7.25	4.61	2.46	1.1	0.66	0.11	48.87
W	0	0.06	1.99	4.39	3.8	2.39	1.41	0.82	0.31	0.25	0.04	15.46
WNW	0	0	1	1.83	1.76	1.29	0.49	0.24	0.07	0.05	0	6.75
NW	0	0.01	0.42	0.85	0.72	0.45	0.14	0.07	0.03	0.01	0	2.69
NNW	0	0.01	0.24	0.36	0.17	0.03	0.01	0	0	0	0	0.81
N	0	0	0.08	0.03	0	0	0	0	0	0	0	0.12
SUM	0	0.78	19.27	30.23	22.1	13.32	7.57	3.85	1.65	1.06	0.16	100

Infra-gravity waves are also likely to occur through the river entrance and south into the lower Waikato River, as they do in most rivers and estuaries on the West Coast during long period swell events. However, the effects of infra-gravity waves on the coastal processes at this location are largely unknown.

3.3.2 Tides and Extreme Water Levels

According to the Land Information New Zealand (LINZ) Secondary Ports Tide Levels data set (LINZ, 2019) the tidal range at the Waikato River Entrance (37°24’ S, 174°45’ E) is approximately 3.2 m and 1.8 m for spring and neap tides, respectively, with a highest astronomical tide of approximately 4.2 m (Table 3.4).

Table 3.4 Tide levels at Waikato River Entrance (37°48' S, I74°53 E'), obtained from LINZ (2019).

HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT/CD
4.2	3.7	3.0	2.1	1.2	0.5	0

Astronomical tides, however, are only one component of several that contribute the overall water level at any location. In addition to the tide, wind, wave, and pressure set-up (collectively known as 'storm surge') contribute to the total water level observed at any point in time. This is depicted schematically in Figure 3.23.

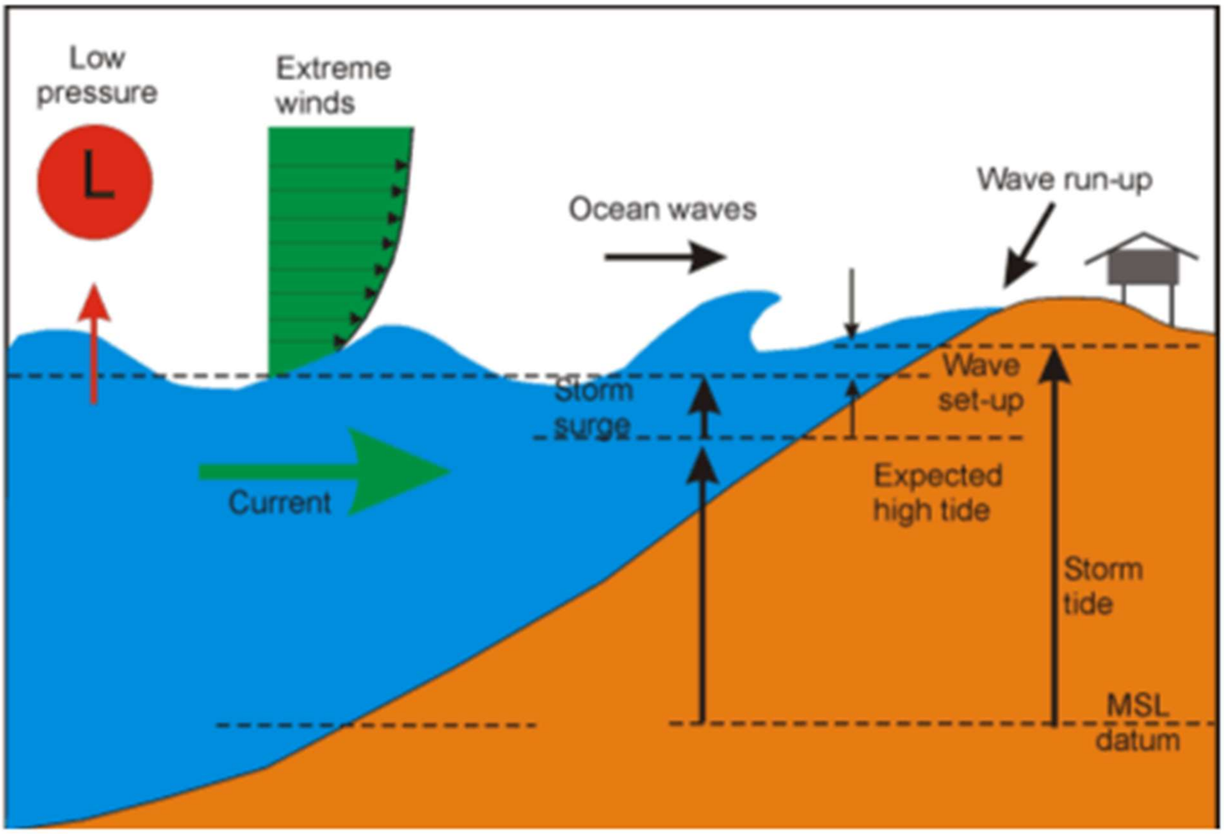


Figure 3.23 Factors contributing to total water level and coastal inundation (MfE, 2003).

Extreme events occur when a series of factors occur coincidentally, which often drive aggressive erosion on the Waikato west coast. That is, a combination of:

- High tide (spring or King tides will exacerbate the event);
- Storm surge due to low atmospheric pressure (1 cm of increased water level for every millibar below average pressure);

- Onshore winds causing wind set-up and short-period erosive waves (northwest winds for Sunset Beach/Port Waikato);
- Wave set-up, with longer period waves increasing the amount of set-up, and;
- Large waves.

The impacts of this on Port Waikato, including due to sea level rise (SLR) are discussed further in Section 4.2.

3.3.3 Sediment Transport Regime

It is commonly accepted that sediment transport is predominantly northward on the West Coast of the North Island (Gibb, 1979; Stokes and Nelson, 1991; Phillips *et al.*, 1999) at an annual rate of ~150,000 m^3 which originates from Taranaki (Figure 3.24), and that significant exchange occurs between the littoral cells of the west coast as compared to New Zealand's east coast, owing largely to the more energetic wave climate and the relatively smaller scale of the control features such as headlands (Hart and Bryan, 2008). Phillips *et al.* (1999) concluded in their study that the presence of sand on the Karioi headland may not be strongly dependent on supply of sediment by longshore drift and instead that local re-circulation sediment pathways may be primarily responsible. However, supply to the beaches north of the Karioi headland requires large volumes of sand bypassing during extreme events to occur periodically (Mead and Phillips, 2007). By comparison the Port Waikato headland is far more subtle and shallow (<8 m deep), meaning that significant exchange from the coast to the south is likely to occur whenever sediment is available (Figure 3.25).

Large fluctuations in beach levels are also well known on west coast beaches (from both anecdotal and scientific information) and have been recorded at Mokau, Raglan, Port Waikato, Karioitahi, Whatipu, Karekare, Piha, and Muriwai. The extent and timing of these fluctuations are dependent on pulses of sand moving up the coast, which vary on a range of time scales. For example, Piha was severely eroded in the early 1990's leading to concerns about the coastal road/parking lot and properties. The beach recovered naturally with a pulse of sand moving northward from the Manukau Heads, however, in recent years there have been concerns that there is too much sand in the system, and that it was negatively impacting on the surfing wave quality (Mead and O'Neill, 2015). Historical analysis of beach fluctuations at Ngarunui Beach in Raglan found that the beach was extremely eroded to its most landward position in 1974 and again in 2015, although today it has mostly recovered at the southern end and extreme erosion has recently (over the past 6 months) occurred at the northern end adjacent to the harbour entrance. Similar cycles of erosion and accretion along the Waikato west coast have also been attributed to northward moving pulses of sand (Gibberd and Dahm, 2019).

Review of satellite images of the open coast to the south of the Port Waikato headland (i.e. where Huriwai River discharges) indicate ongoing erosion since the first available image in 2010, to the last available suitable image in early 2019. This suggests that up until at least 2 years ago, there has not been an influx of sand from the south that will nourish Sunset Beach and the spit.

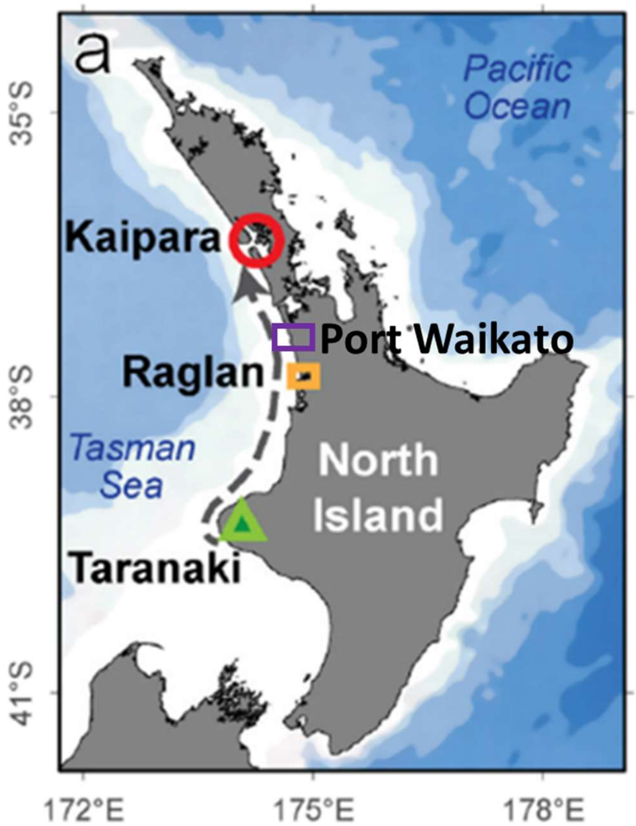


Figure 3.24 Illustration of the northward sediment transport regime, which originates from Taranaki and drifts to Kaipara (modified from Harrison, 2015).

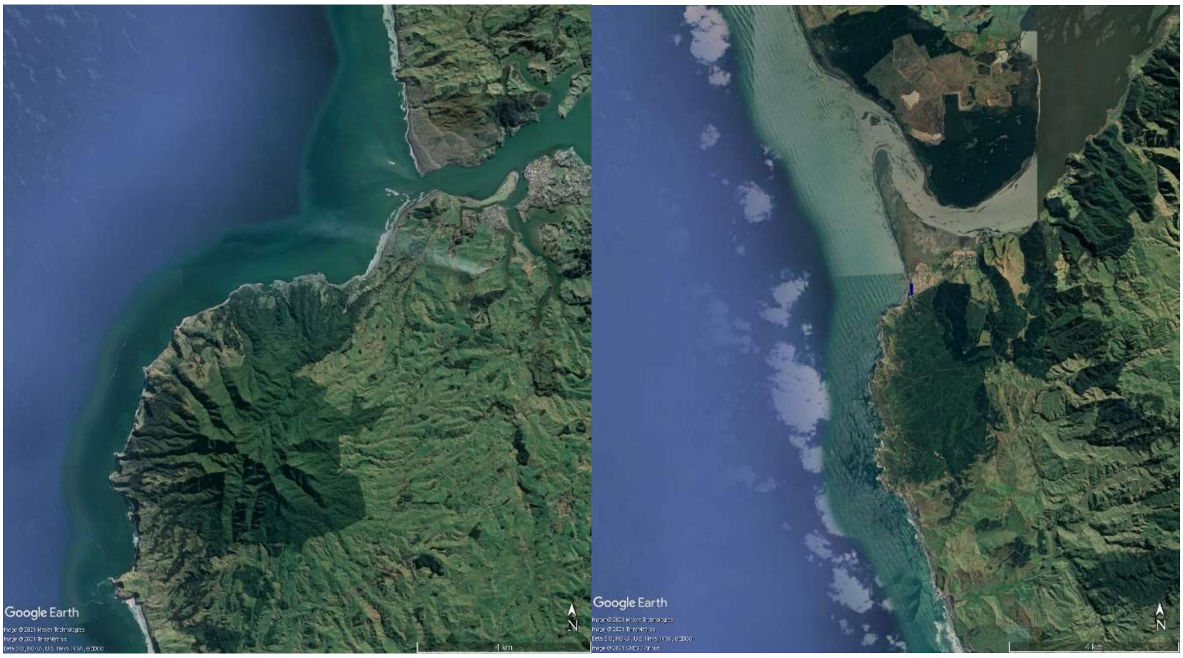


Figure 3.25 Left – The Karioi Headland at Raglan is a significant feature that requires extreme events to deliver sand from the southern side to the northern beaches at Raglan. Right – by comparison, the Port Waikato headland is far more subtle and relatively shallow, meaning that significant exchange from the coast to the south is likely to occur whenever sediment is available.

3.3.4 General Spit Mechanics

In general, spits are formed when the dominant alongshore waves or currents carry the sediment into an elongated depositional feature extending away from a headland; in this case to the north. Sand transported along the trunk of the spit is deposited at its end in deeper water, allowing the spit to grow longer, while terrestrial derived materials deposit in the relatively quiescent waters inside the spit making it wider. The growth (and loss) rate of a spit is related to many different factors such as the sediment supply and transport rate, the depth of water into which the spit is growing, the hydrodynamics of the water body behind the spit, the wave climate on the open side of the spit and so on, with changes in any factors resulting in changes to the spit, or a continual cycle of growth and decay of the spit driven by the different factors. Thus, spits are dynamic coastal structures that are constantly changing at a range of different timescales. Commonly, spits may accrete and erode at their distal end, fluctuate in width along their length, or form longer and longer until they breach and begin the process again.

FitzGerald (2001) developed 6 conceptual models for spit formation, breaching and sand-bypassing (Figure 3.26). As noted in Section 3.2.4 above, the Waikato River entrance does not have a delta. Even so, based on FitzGerald's models, we would expect the Waikato River spit to conform to model 1 and/or 5. However, it has continued to extend north for at least 170 years, with some small retreats resulting in ‘islands’ in the entrance channel (similar to model 5 in Figure 3.26).

While there is some inference that the southern Waikato River spit will at some time reach a new equilibrium with the river mouth further to the north due to the human induced impacts on river flow, sediment inputs and possible land slide diversion, equilibrium is not the common state for a river mouth spit and delta. Mead *et al.* (2007) points out that the contrary is usually the case, with constantly shifting sand banks and entrance channels due to both coastal and riverine processes, as demonstrated by FitzGerald’s (2001) conceptual models. A common cycle of river mouth and associated spit variation on coasts with a predominant uni-directional alongshore sediment transport regime (such as the North Island West Coast) is the growth of spit until it is breached near or at the base. Following a breach the spit begins to prograde again (Figure 3.26).

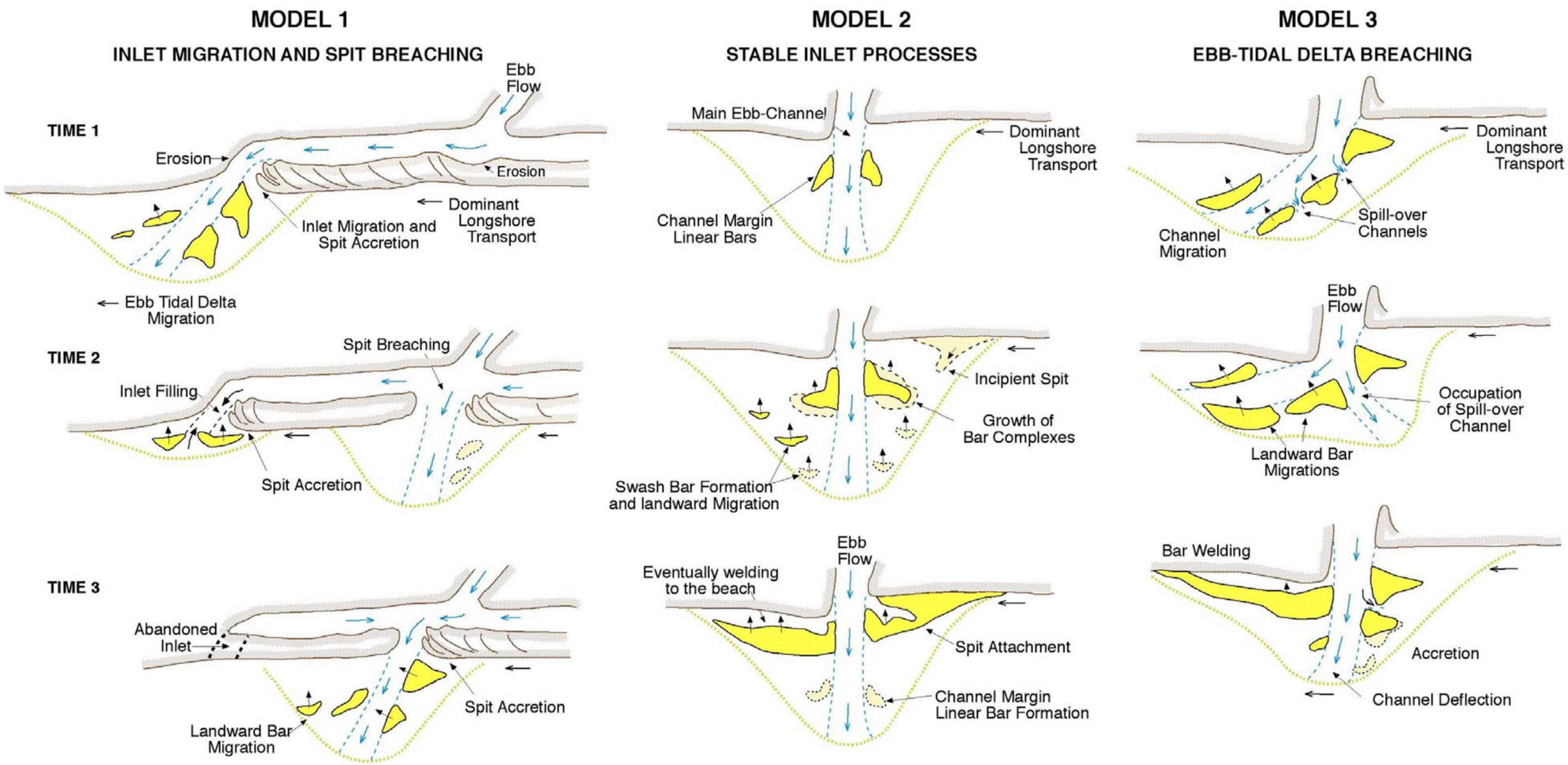


Figure 3.26. Spit formation, breaching and sediment bypassing mechanisms (from FitzGerald 2001)

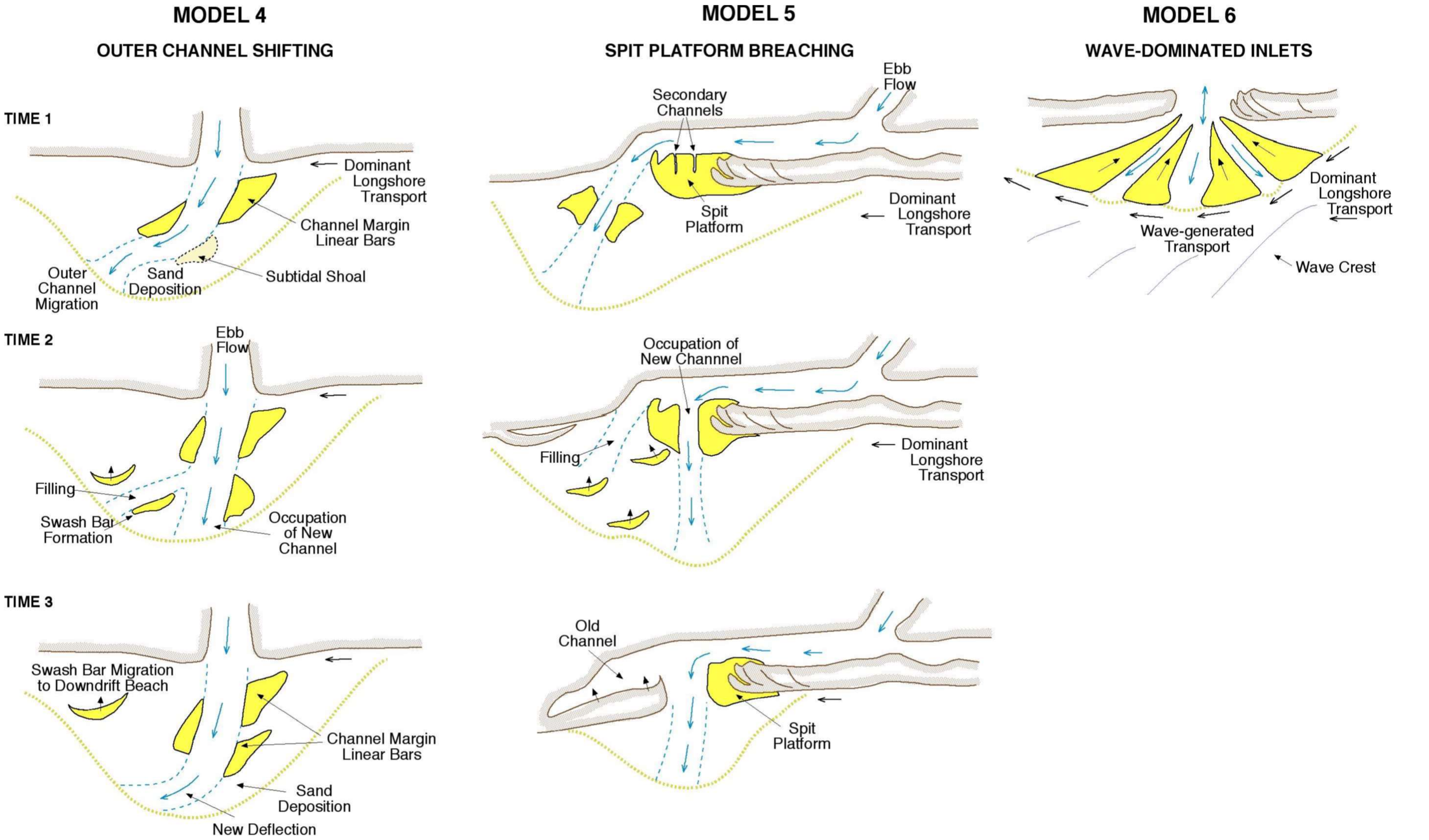


Figure 3.36. Spit formation, breaching and sediment bypassing mechanisms (from FitzGerald 2001)

A breach can occur if the water level on one side of the spit exceeds some critical elevation. Breaching can happen by overtopping, which means that running surface water can generate a channel between the sea and an estuary. An extended duration of inundation is required, as well as a strong flow, and breaching is promoted by wave action and the presence of a pre-existing localised area of low elevation in the spit that can confine and intensify the flow (Kraus and Wamsley, 2003). The inundation can proceed either from the seaward side and/or from the estuary side.

The causes of a breach may be due to:

- a flood event, or series of events, greatly increasing river flows and breaking through the spit at the 'point of least resistance';
- the widening and shallowing of the river mouth at the tip of the spit resulting in either partial or total closure at the mouth and the consequent breach along the spit at the 'point of least resistance';
- a major storm event, or series of events, eroding the open side of the spit and creating a breach at the narrowest point, or;
- a combination of any of the above.

The cycle of spit formation and breaching can occur over a variety of time scales, a few years to several centuries, or in some cases not at all, depending on the conditions specific to the site.

In the present situation, the time scale of the Port Waikato spit formation is unknown; the river has been in its current location for ~17,000 years. Furthermore, the time scales of a breach are also unknown, and if it does occur, the location of which is also unknown. The human intervention along the rivers course, as well as the possible landslide re-directing the river flow (refer to Section 3.4.1) may have led to a situation that did not previously exist at the Waikato River entrance. It is possible that the entrance may have previously exited closer to South Head and remained relatively stable due to the magnitude of the flow and flood events and the absence of a partial blockage (i.e. the orally recorded landslide) for the past ~6,000 years.

The very fact that the entrance is still tracking north, the northern side of the river is still eroding, and that the river entrance is now so much wider and shallower, however, all indicate that the river has not reached a new equilibrium and that the present cycle of spit formation may be followed by a breach in the future.

Potential breaching is minimized if the spit is high and wide. The southern part of Port Waikato spit is large (>1 km). Despite this, much of the spit has low elevations, especially on the estuary side and northern section, which is relatively narrow and low. Higher elevations occur on the coastal side (coastal dunes). Therefore, the risk of a breach could be considered to be greater moving northward along the for the Port Waikato spit (Mead *et al.,* 2007).

International work in spit evolution and breaching has shown that these processes are cyclic, although dynamic equilibrium of channel configurations may persist for long periods of time. For example, Tomlinson and McCauley (2001) found that the Jumpinpin Inlet in Queensland has a 20-year cycle of formation and breaching due to the northwards littoral drift. Prior to the 1940's, the spit would migrate further and further to the north until the entrance closed up and a breach occurred in the southern part of the spit, after which the entrance would begin to migrate northwards again. Post the 1940's, the northern spit entrance has remained permanently open while every 20 years or so a second entrance opens through a breach in the spit to the south, before closing off again. It has been concluded that the changes to the spit cycle mechanics are a natural process (severe cyclones in the 1930's), although anthropogenic influences may have been acting on the spit since the 1980's (Mead *et al.,* 2007).

There is a lot of evidence that changes to spit systems (natural (e.g. the slump block) and anthropogenic (e.g. changes to the flow regime, sediment control structures built on spits, etc.)) can radically change spit morphodynamics through positive feedback. On sandy shorelines subject to longshore sediment transport, small shoreline perturbations can evolve into large scale morphological features, which can merge and contribute to even larger features (Ashton *et al* 2001; Ashton and Murray 2006; Coco and Murray, 2007; Mead and Lebreton, 2010). The small perturbations lead to modification of the flow, this positively feeds back into modification to the morphological setting, which again modifies the driving forces. Over time the positive feedback mechanisms continue to evolve the morphology and flow regime. Thus, even small perturbations in any coastal feature may lead to only small initial changes in terms of the response of the system. In the context of the Waikato River and spit, the slump block could be considered a small perturbation that, potentially along with other changes, has led to the continued northward extension of the spit. Mead (2016) found that due to the installation of a geotube groyne on the Motueka Spit, the 10–15-year breaching cycle was extended to at least 35 years (it has still not breached since the mid 1980's) and led to spit extension of over 1.5 km beyond recorded history (1881).

The mechanisms driving the continued northwards spit movement remain uncertain (Mead *et al*., 2007), as is whether or not this is due to other factors (i.e., modifications to river flow, sediment inputs and landslide diversion) or is a long-term natural cycle. Spits are constantly changing at a range of different timescales, and so there remains the potential that the Port Waikato Spit will breach sometime in the future, resetting its distal end in the vicinity of where it was mapped in 1853 (Section 3.4.1 below, Figure 3.33) and beginning the growth cycle again.

3.4 Geomorphology and Coastal Erosion

3.4.1 Morphology of the Waikato River mouth and Port Waikato spit

At Port Waikato, alongshore sediment transport on the coast is predominantly from south to north (due to the predominant south-westerly wind and swell direction) – sediment transport rates along the North Island's west coast have been estimated at between 140,000 and 180,000 m^3 per year (e.g. McComb, 2001; Phillips, 2004). As a result, the Port Waikato spit extends northwards (Figure 3.27). Currently, the river flow at the mouth is deflected to the north by the presence of the spit.

The morphology of the spit and Waikato River mouth has undergone large changes over the past 140 or so years. The northward migration of the spit and variability of its shape are clearly demonstrated by the analysis presented in Figure 3.27 and Figure 3.28. It has been estimated that the spit has increased by ~1,900 m to the north, while the northern side of the river mouth has moved some 3.5 km north from the 1853 position, i.e. the river mouth is now far wider (and shallower, sometimes with sand islands present) between the spit and the north head. As a result, the northern coastline of Port Waikato has eroded greatly over this period – erosion in this area is presently continuing along the north head of the Waikato River (Figure 3.27).

Mead *et al.* (2007) reported that the mechanisms driving the continued northwards spit movement remain uncertain, since the spit has been extending northward since at least 1853. Māori oral history indicates a landslide which may have diverted the river channel northward of the existing headland formation (Wily and Maunsell, 1938 – cited Weatherall, 2007), although no clear geological evidence has been provided (Figure 3.30). A geological map of the area (Figure 3.2) denotes the headland at the Port Waikato wharf as a "slump block" (Purser, 1961; Waterhouse 1978; cited in Challinor, 2001), which EW denoted as a landslide of historic significance, and could potentially deflect river flows. The extent of the influence of this slump block on the course of the Waikato River and whether it is a relatively recent feature or not, however, is unknown. It has been noted that a landslide, in itself, would have been unlikely to have caused a permanent blockage and diversion of the river due to the nature of the material comprised (i.e. easily erodible materials) (Mead *et al.,* 2007). However, it is likely to have contributed to the growth of the spit, since its presence diverts the river flow northward and blocks the potential for the spit to be 'blown-out' during extreme river flow events (Figure 3.30); this would support extension of the spit since the earliest records in 1856.

With respect to the shoreline position of the spit, on the river/eastern side of the spit, the shoreline was in a more eastern position in the central part of the spit than it is today (most easterly in the late 1960's), while the southern area of the spit including Maraetai Bay has accreted and is significantly more eastward today than in the past (Figure 3.27). The northern part of the spit cannot be compared to historical locations, since it was not present, however, the northern back of the river has eroded dramatically since 1942 due to the continual northern extension of the spit (Figure 3.27).

On the ocean/western side, the spit significantly accreted from its most landward/eastward location in 1942 to the late 1960's, with a breach occurring sometime in the 1950's (Figure 3.28 and Figure 3.29), and remained relatively stable until 2007, and has since been rapidly eroded to the present day (Figure 3.27). The fluctuations in beach position are discussed further in Section 3.4.2.

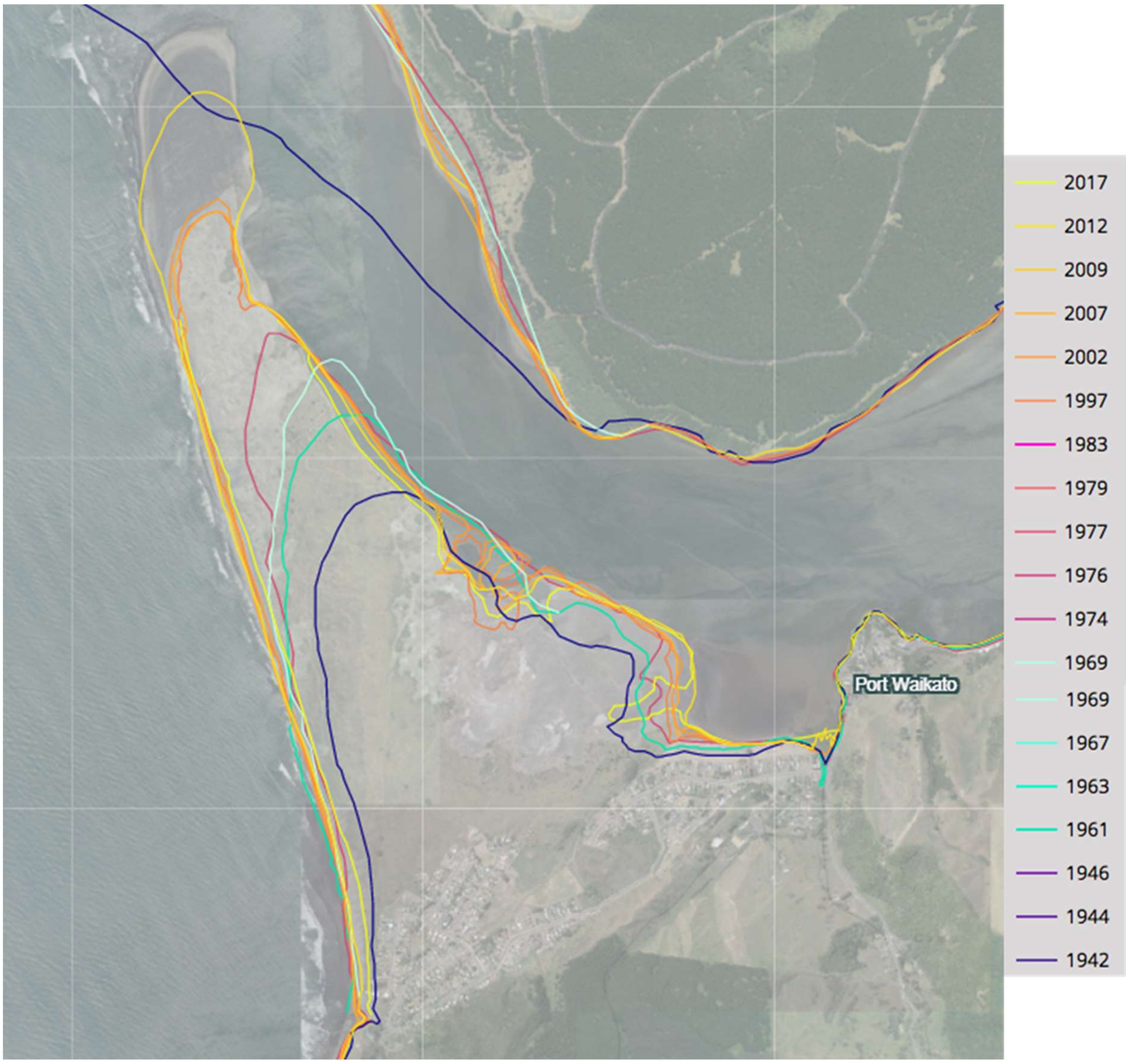


Figure 3.27 The northward migration of the Waikato River mouth from 1942 to 2012, as the sand spit grows northward. The complementary erosion on the northern side of the Waikato River mouth is also evident. Retrieved from the Waikato Regional Hazards Portal.

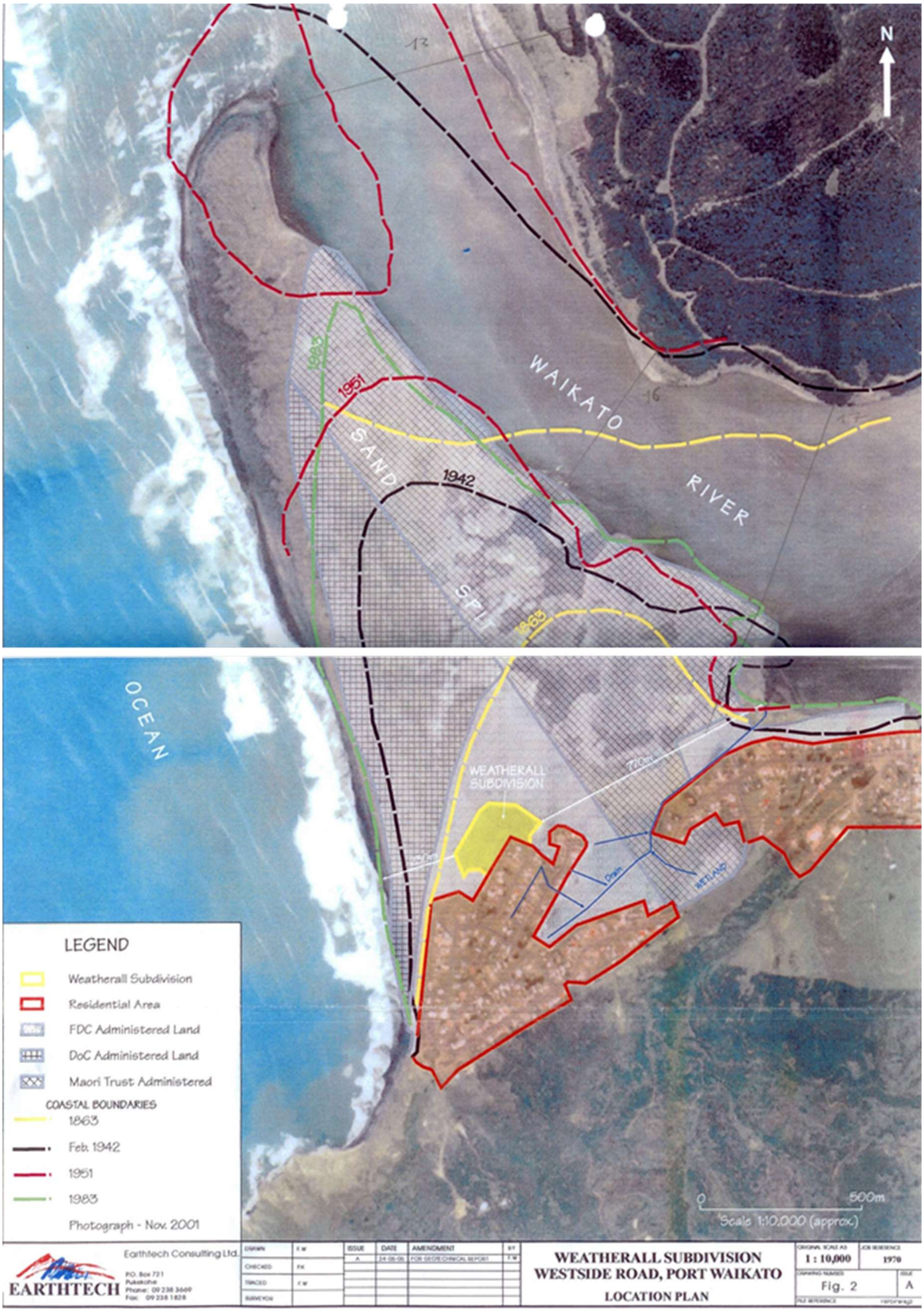


Figure 3.28 The northward migration of the Waikato River mouth from 1863 to 1983, as the sand spit grows northward. The figure also shows the erosion on the northern side of the Waikato River mouth over time (modified from Earthtech, 2006; cited in Mead *et al.*, 2007).

Figure 3.29. The spit breach from the 1950's (Figure 3.28), as seen in October 1960 (Imaged sourced from Port Waikato Dairy; cited in WDC, 2014)

Figure 3.30 Aerial photo of Port Waikato showing location of "slump bock" (Image sourced from LINZ-R13, 1996-1997; cited in Mead *et al.,* 2007).

Changes to land use in the late 19th century included the removal of vegetation and swamp drainage and led to increased sediment inputs into the river, potentially adding to the northward growth of the spit. The Waikato-Waipā drainage system also became overloaded and there were floods in the lower reaches in the first half of the 20th century. This led to the creation of the Waikato Valley Authority, which set out to tackle the problem by constructing flood-control works during the 1960's. The flood-controls effectively reduce peak flows and flooding at Port Waikato, a further mechanism that has the potential to drive spit growth.

It has been assumed that the Waikato River spit remained reasonably unchanged (with the exception of seasonal variations) until the 20th century, when changes to the river's flow rates due to human intervention led to the growth of the southern river mouth spit (Earthtech, 2006; T&T, 2007). The assumption is that the controlled flow of the Waikato River due to dam construction, irrigation, and flood-control measures possibly allowed an increased dominance of the alongshore sediment transport inducing the northward migration of the river mouth (until it eventually reaches a new equilibrium), i.e. the flow rates were lower during flood events and due to this decreased velocity and volume the coastal processes have more dominance compared to before human intervention (Mead *et al*., 2007). Mead *et al.* (2007) state that there is no doubt that the Waikato River spit has accreted a large volume of sediment since the first survey in 1863, with basic estimates indicating an increase of ~8 M m^3 of extra sediment during this period (i.e., up to 2007). The authors also noted that no relationship between river flow or dam construction with morphological changes to the spit nor river mouth have been demonstrated with the available data. Indeed, the Port Waikato spit continues to extend northwards to this day.

Mead *et al.* (2007) found that changes to river discharge may have had little impact on the formation of the southern spit, noting that the longest water level and flow record of the Waikato River (1958 to 2015 and 1957 to 2020; Figure 3.31 and Figure 3.32) at Ngāruawāhia shows the annual mean and minimum flows have remained relatively stable for 63 years (Figure 3.32), even though there have been significant modifications to the river during this time period. Five hydroelectric power stations have been built since 1958 - Atiamuri and Waipapa: 1958, Ohakuri: 1960, Aratiatia: 1964 and Maraetai: 1971, although no obvious impact on river flow has been observed; the reduced flows from 2018 indicate the drought conditions that much of New Zealand has experienced (Figure 3.32). This is attributed to the river management regime, which again indicates that extreme events that have been managed for more than half a century have likely reduced the potential for spit erosion/blow-out/reset and assisted the continued northward growth.

In the biography of Robert Maunsell (Wily and Maunsell, 1938 – cited Weatherall, 2007 & Mead *et al.,* 2007), there is reference to great changes on the river's navigable channel due to the actions of the River Board, “which undertook to defy gravitation and lower the surface of the river below the level of the Tasman Sea” at some time in the early 20th century. Unfortunately, there is no detailed information provided as to what changes occurred on the Waikato River after 1863 (both morphologically and hydrologically), and there is a gap of some 80 years between the 1863 chart and the 1942 aerial photograph. If such data are available, provision of detailed description of the changes to the river’s flow and associated land use of the catchment would be especially useful in determining the extent of river flow modifications and hence the ‘new’ stability of the spit due to human intervention. At present the 1958-2014 flow data available show no evidence of changes to flow despite the construction of 5 dams and other modifications (e.g. the lowering and control of Lake Waikare levels in 1965).

Discussion by Mead *et al.* (2007) with Environment Waikato (EW) engineers supported these data, i.e. that the dams have had little effect and flush water from the river quicker (M. Mulholland, pers. comm.). Thus, with the present level of information available, it cannot confidently concluded that human intervention along the length of the river has influenced the formation of the spit over the past 140 years. However, it is very likely that land-use changes, river management and the historical landslide have all contributed to the continued growth of the Port Waikato spit over the past 170 years.

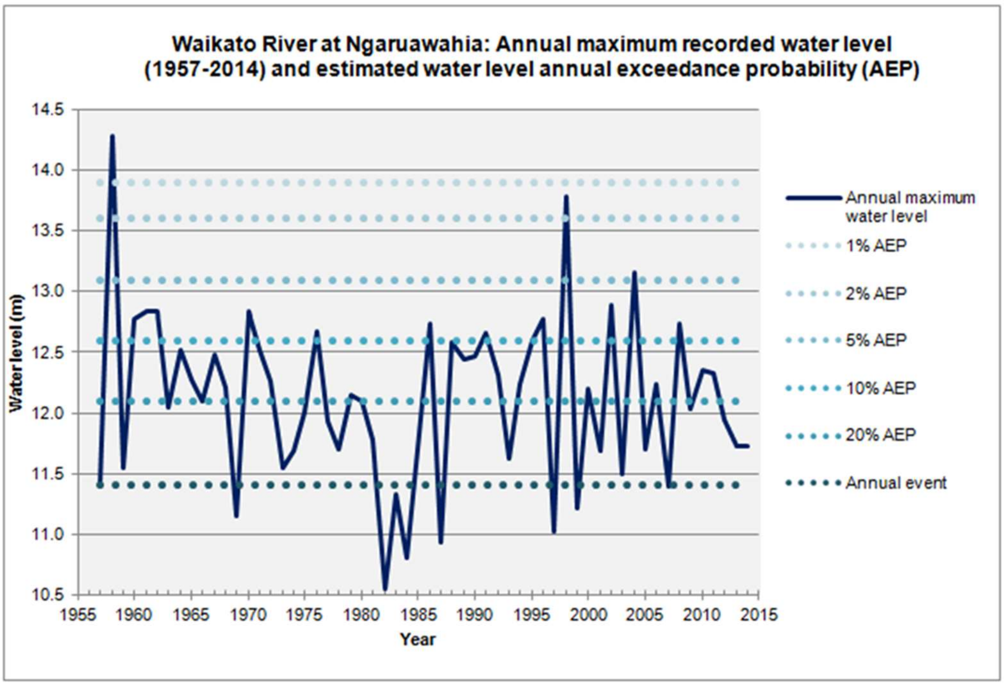


Figure 3.31 The annual maximum recorded water levels on the Waikato River recorded at NgCruawāhia between 1957 and 2014, as well as the estimated water level annual exceedance probability (AEP).

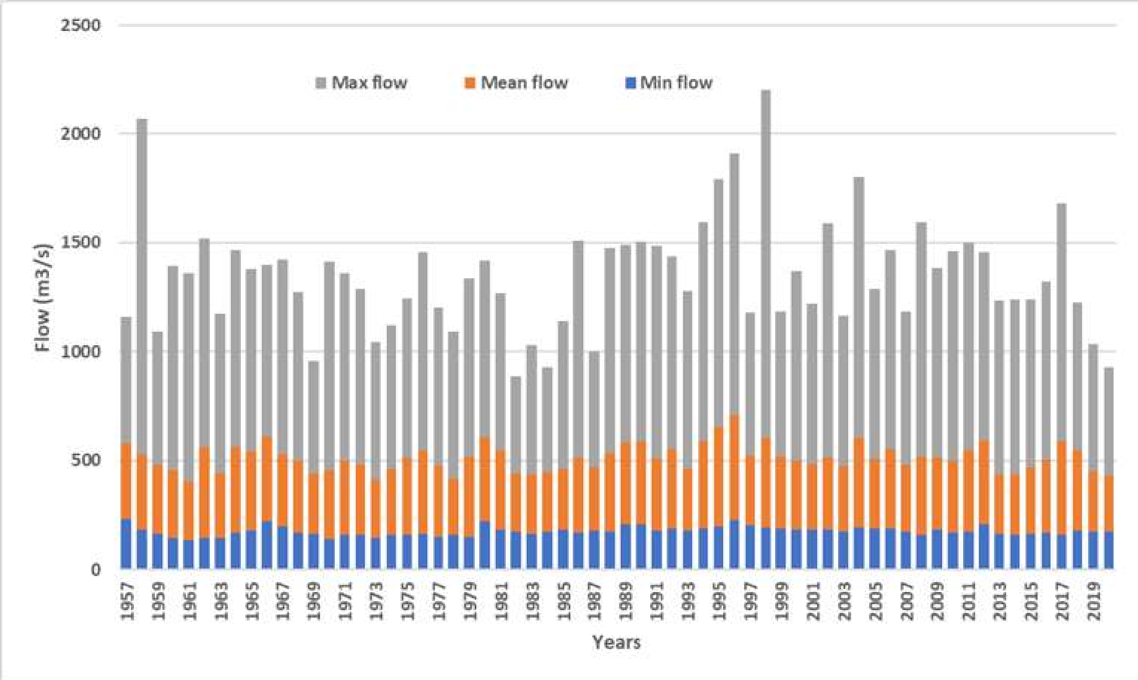


Figure 3.32 The annual mean, minimum and maximum flow of the Waikato River at Ngāruawāhia from 1958 to 2020 (Source data: EW, Waikato River-Ngaruawahia Cableway).

Mead *et al.* (2007) collated Waikato River channel data from EW; a series of cross-sections from 1962 to 2006 (refer to Appendix A). Apart from cross-section M13 located near the northern end of the spit, which showed large fluctuations (e.g. the spit retreated, and the river widened (~240 m) and shallowed between 1965 and 1989, and then returned to its former position), there was little to indicate that the river channel was trending towards one bank or the other. Mead *et al.* (2007) concluded that the banks had changed little, and that the depths of the channels and flats of the river had fluctuated back and forth over the period of data collection. The authors stressed that the channel cross-section data was relatively recent (some 40 years of data in total), and that the position had changed radically over a longer period (i.e. ~160 years).

Apart from the other factors that influence spit dynamics (refer to Section 3.3.4), Mead *et al.* (2007) reported that there are two pieces of information that suggest the river exited further south than shown on the 1853/63 chart (Figure 3.33). The first is the presence of alluvial deposits at the base of South Head, while the second is the presence of the freshwater lake. The authors suggested that this lake may have been impounded by coastal and/or river processes (i.e. spit formation), having previously been the location of the river channel and entrance, since the rock of the South Head is well south of this feature, i.e. this area of the spit is erodible substrate (refer to Sections 3.1.2.1 and 3.1.2.2). Considering the location of the river mouth in relation to the slump block (Putataka) (Figure 3.30), Mead *et al.* (2007) reported that it is conceivable that the slump block could have caused the river mouth to be diverted northward, but stresses that no data has been presented to support this.

To provide these data, Mead *et al.* (2007) highlighted the need for an investigation to determine how old the slump block is in comparison to river flow and spit morphology data. This would incorporate a geological survey of the slump block and bore holes at the subdivision to determine the presence and age of river materials in the subdivision location. References had been made to the findings of an archaeological survey; however, this was not directed at finding the soil types and their ages; a cycle of growth and decay of the spit may operate over scales of several centuries. Test pits were subsequently investigated, which indicated that the spit had been present in the location of the proposed subdivision (Figure 3.28) for at least 6,000 years (R. Liefting, pers. comm.).

An additional activity that was considered in order to determine its influence on the continued northward extension of the Port Waikato spit is water extraction for Auckland City drinking water. In 2002 around 75 million litres/day was being extracted, which was doubled to 150 million litres/day in 2013. The average discharge rate of the Waikato River is 293 billion litres/day, which means the extraction represents ~0.05% of the average discharge rate. It is unlikely that this has any significant impact with respect to continued deposition on the spit and reduced capacity to breach.

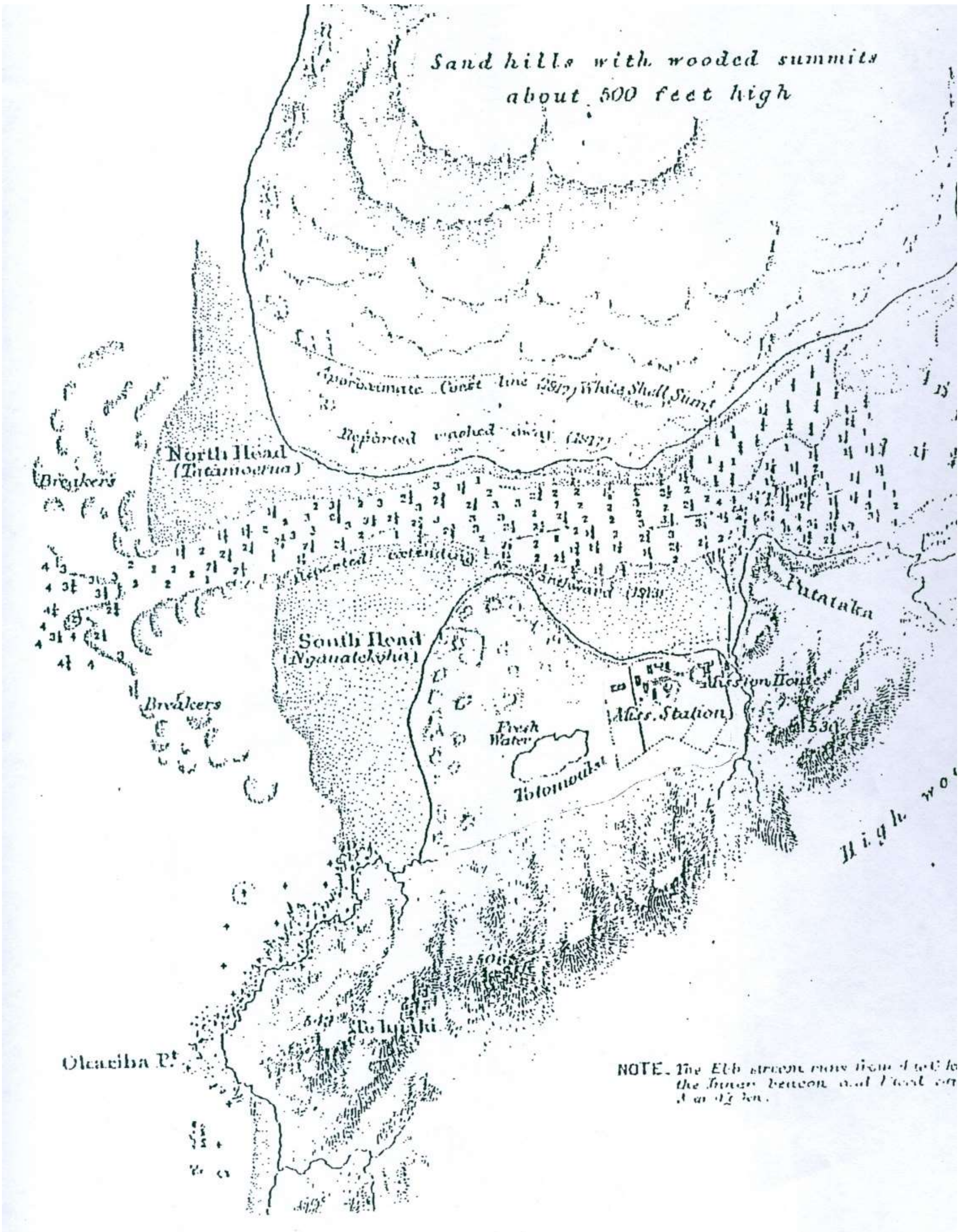


Figure 3.33 The 1853 nautical chart of the Waikato River mouth. Note the location of a freshwater lake and the indented shoreline west of the lake (Mead *et al.,* 2007).

3.4.2 Morphology of Sunset Beach

Sunset Beach is located adjacent to the western section of the Port Waikato Settlement. The medium to fine grain sand of Port Waikato's open beach and spit is moderately well sorted, and in combination with the dense fraction of titanomagnetite results in a relatively low gradient/dissipative beach profile. The morphology of Sunset Beach in front of the surf lifesaving club has changed significantly since 1942 (Figure 3.34 and Figure 3.35). The historical aerial photographs indicated that the beach in 1942 was the most eroded on record, with the 1942 image being the first available (Figure 3.36). Between 1942 and 1961, the beach prograded ~80 m, after which the beach retreated ~25 m to 1969. Between 1969 and 2007 the beach remained relatively stable and prograded only ~10 m. From 2007, however, the beach was observed to undergo an aggressive erosional phase. Between 2007 and 2012, the beach eroded ~30 m and eroded a further 20 m to 2017.

Shoreline data between 2017 and 2021 is not available on the Waikato Regional Council coastal hazards portal, and it is unclear from available satellite images with respect to quantifying retreat. However, the old surf life-saving club house has been demolished and rebuilt slightly to the south-east since 2017 (Figure 3.37). Today, Sunset Beach remains in a state of severe erosion, as does seaward side of the spit to the north (Figure 3.38).

Figure 3.34 The morphological shoreline changes at Sunset Beach, Port Waikato. Retrieved from the Waikato Regional Hazards Portal.

Figure 3.35 The morphological shoreline changes at Sunset Beach, Port Waikato. These are kml files which were reproduced from the Waikato Regional Council Coastal Hazards Portal shoreline data.

Figure 3.36. Top) The shoreline at Sunset Beach was more shoreward in 1942 than it is today. Bottom) The location of the rock at the bottom of the beach access in 2021 and its position in 1942 (red arrow).

Figure 3.37 Top) Port Waikato in 1970 looking north towards Port Waikato Township and the Surf Life Saving club (left of photo) (Source: Sunset Surf Life Saving Club). Recent collage of images) The eroding Sunset Beach in front of the old Port Waikato surf lifesaving club. The top image date of the recent collage unknown but is prior to 2017 (Image sourced from WRC website). The middle images are dated December 2017 (Dahm & Gibberd, presentation). The bottom image date is unknown but is after March 2019 (Image sourced from WRC website).

Figure 3.38. Top) looking north along the eroding spit. Bottom) the erosion scarp in front of the carpark.

Recent satellite imagery indicates that up to early 2019, the coast to the south of the Port Waikato headland has also continued to erode. This suggests that up until at least 2 years ago, there had not been an influx of sand from the south that will be moved north to nourish Sunset Beach and the spit.

3.4.3 Morphology of Maraetai Bay and Cobourne Reserve

Maraetai Bay and Cobourne Reserve are located within the Port Waikato Estuary on the eastern side of the spit (Figure 1.2). Despite these two locations being adjacent to one another, the morphological shoreline change between them differs greatly. At Maraetai Bay, the shoreline appears to have retreated ~500 m from the headland of Cobourne Reserve, southward. Since consistent records began in 1942, however, the shoreline appears to have reached somewhat of an equilibrium after a brief period of accretion. Between 1942 and 1977 the shoreline prograded ~43 m, after which the shoreline has remained relatively stable, retreating ~5 m through to 2017 (Figure 3.39). In contrast, the shoreline morphology at Cobourne Reserve has remained relatively unchanged since records began in 1942 (Figure 3.39).

The morphological shoreline differences between these locations, despite being adjacent to one another, is a function of the local geological differences. Cobourne Reserve is situated on Coleman Conglomerate, part of the Murihiku Terrane (Jurassic Period) (refer to Section 3.1.1.2), which comprises thick sequences of sandstones, siltstone, and minor conglomerate. These layers are significantly more consolidated than the younger Kariotahi Group formations located in Maraetai Bay (Figure 3.3), which comprise moderately consolidated to unconsolidated dune sands with intercalated swamp, fluviatile and lacustrine deposits. Thus, the younger weaker formation is eroding at a greater rate while the older stronger formation resists.

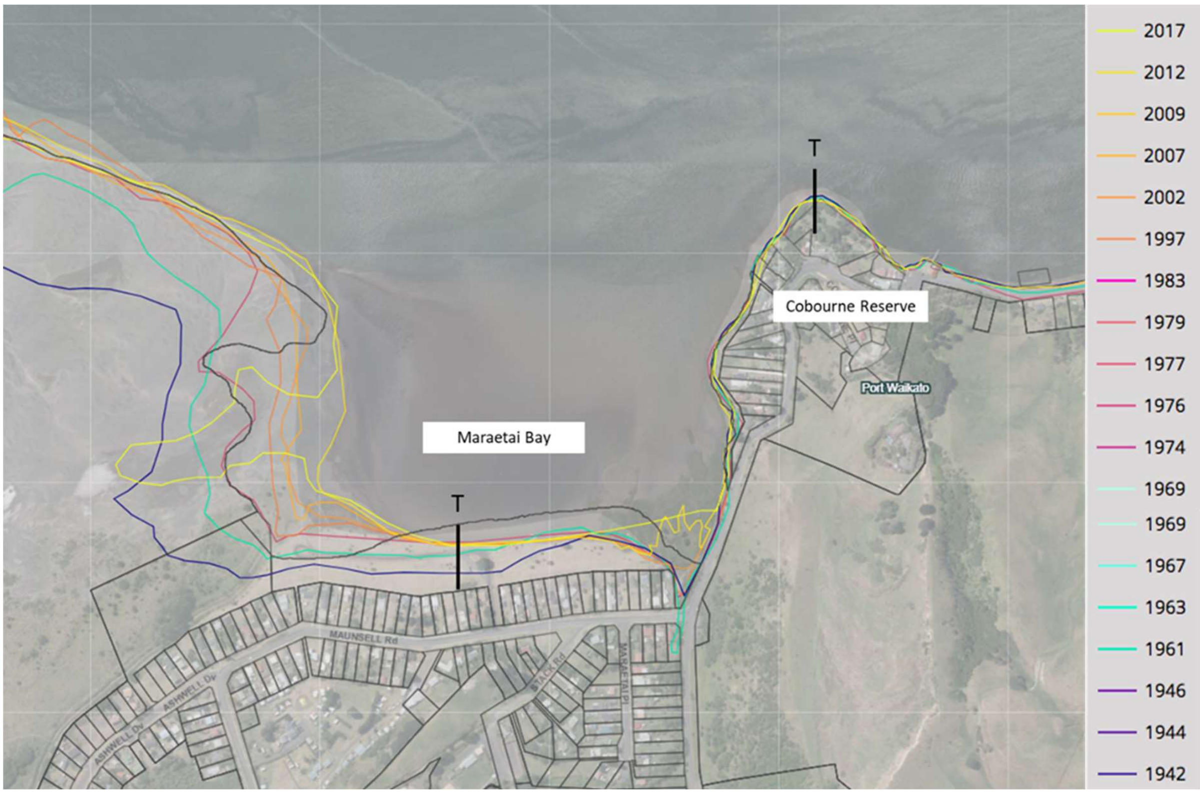


Figure 3.39 Morphological shoreline change at Maraetai Bay and Cobourne Reserve, Port Waikato. Retrieved from the Waikato Regional Hazards Portal. The T's represent the transects where the shoreline change has been observed for reporting purposes.

4 Hazard Drivers

4.1 Climate Change and Sea Level Rise

Sea level rise estimates are generally presented in the context of RCP (Representative Concentration Pathway) scenarios. RCPs are scenarios of greenhouse gas concentrations trajectories into the future and each RCP is associated with a different rate of sea level rise derived from the median projections of global sea-level rise by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) (Church *et al.*, 2013). Figure 4.1 illustrates four sea level rise scenarios for New Zealand through the year 2150 based on the four RCPs from the IPCC AR5 report (Bell *et al.*, 2017). The most extreme scenario (NZ RCP8.5 H+) indicates that in 50 years the sea level will rise by 0.61 m. 50-year SLR amounts of 0.32, 0.36, and 0.45 m are predicted for the other RCP scenarios. The projections include a New Zealand-wide regional offset, with a small additional SLR above the global mean projections. These have been extended to 2120, to meet the minimum requirement of assessing risk over at least 100 years, as required by the NZCPS 2010. A further extension to 2150, using the rates of rise from Kopp *et al.* (2014), provides a longer view over 130 years (with a gap shown in Figure 4.1 between the two sets of projections). It is also a reminder that sea level will keep rising after 100 years, irrespective of actual future greenhouse gas emissions (Bell *et al.,* 2017).

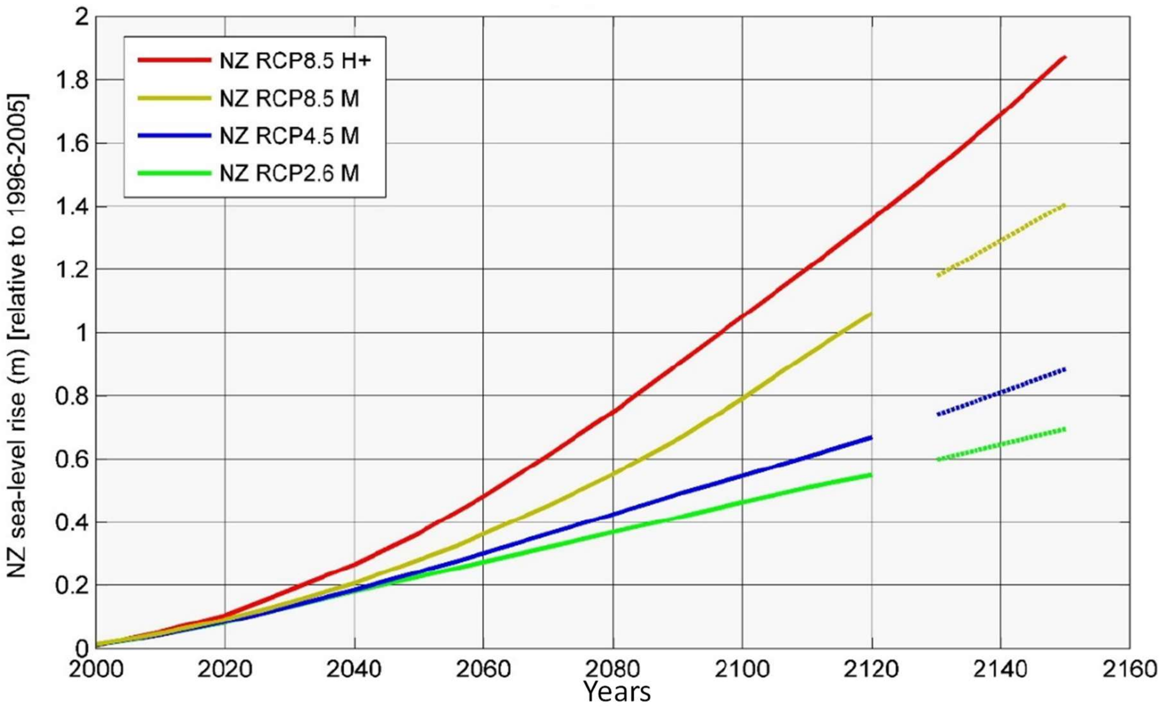


Figure 4.1 Four scenarios of New Zealand-wide regional sea level rise projections to 2150 based on Kopp *et al.* (2014) cited in Bell *et al*. (2017).

The IPCC AR5 report states that coastal systems and low-lying areas will increasingly experience submergence, flooding, and erosion throughout the 21st century and beyond, due to sea level rise. Bell *et al.* (2017) state that besides sea level rise, coastal and estuarine environments will also be affected by changes in weather-related coastal hazard drivers, such as storm surges, waves, winds, and the frequency and intensity of storms. Any changes in impacts from these drivers will have implications for coastal erosion, storm inundation, and groundwater and drainage levels.

4.2 Coastal Inundation

With sea levels projected to rise between 0.32 m and 0.61 m in the next 50-years and between 0.55 m and 1.36 m in the next 100-years (Bell *et al.,* 2017), the Port Waikato settlement and spit are vulnerable to coastal inundation. Gibberd and Dahm (2019) suggest that for a 1% AEP storm surge event (Figure 4.2), a considerable area of the Port Waikato settlement (town) could become inundated, as well as northward areas of the spit on the harbour (Figure 4.3 and Figure 4.4). If sea levels were to rise by 1.0 m (Figure 4.5 and Figure 4.6) then a greater portion of the spit and settlement could become inundated under the same storm surge conditions.

In order to quantify the areas inundated within the settlement of Port Waikato, the settlement has been divided into eastern and western settlements. During a present-day sea-level scenario with an upper storm tide range estimate of 3.1 m above sea level (Moturiki Datum (MVD-53)), the total area inundated in the western and eastern settlements would be 49% and 27%, respectively (Figure 4.7 and Figure 4.8). Under the same scenario with an additional 1.0 m sea level rise then the total area inundated in the western and eastern settlements would be ~63% and ~51%, respectively (Figure 4.7 and Figure 4.8). Thus, greater portions of each settlement will be inundated, and the depths of inundation will be greater as SLR proceeds.

Waikato River

Sea Level Scenario		Sea Level (MVD-53)
Present Day	MHWS	1.7m
	Max Tide	2.0m
	Lower Storm Tide Range (Estimate)	2.2m
	Upper Storm Tide Range (Estimate)	3.1m
Future Projected 0.5m Sea Level Rise	MHWS	2.2m
	Max Tide	2.5m
	Lower Storm Tide Range (Estimate)	2.7m
	Upper Storm Tide Range (Estimate)	3.6m
Future Projected 1.0m Sea Level Rise	MHWS	2.7m
	Max Tide	3.0m
	Lower Storm Tide Range (Estimate)	3.2m
	Upper Storm Tide Range (Estimate)	4.1m

The above projections are simply indicators. For detailed future projections of sea level rise, refer to these tables, sourced from the latest national guidance.

Figure 4.2 Present day and future projected sea level rise scenarios including upper storm tide ranges. Retrieved from https://coastalinundation.waikatoregion.govt.nz/

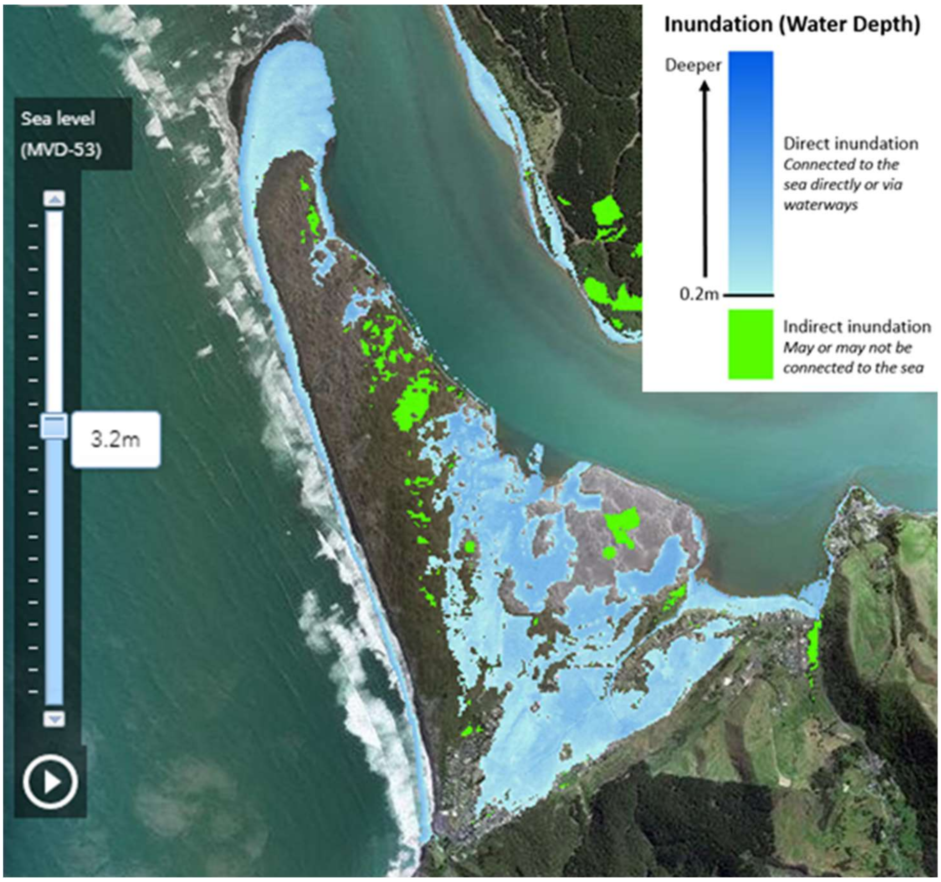


Figure 4.3 Areas likely to be inundated by a 1% AEP storm surge event at existing sea levels. Retrieved from https://coastalinundation.waikatoregion.govt.nz/

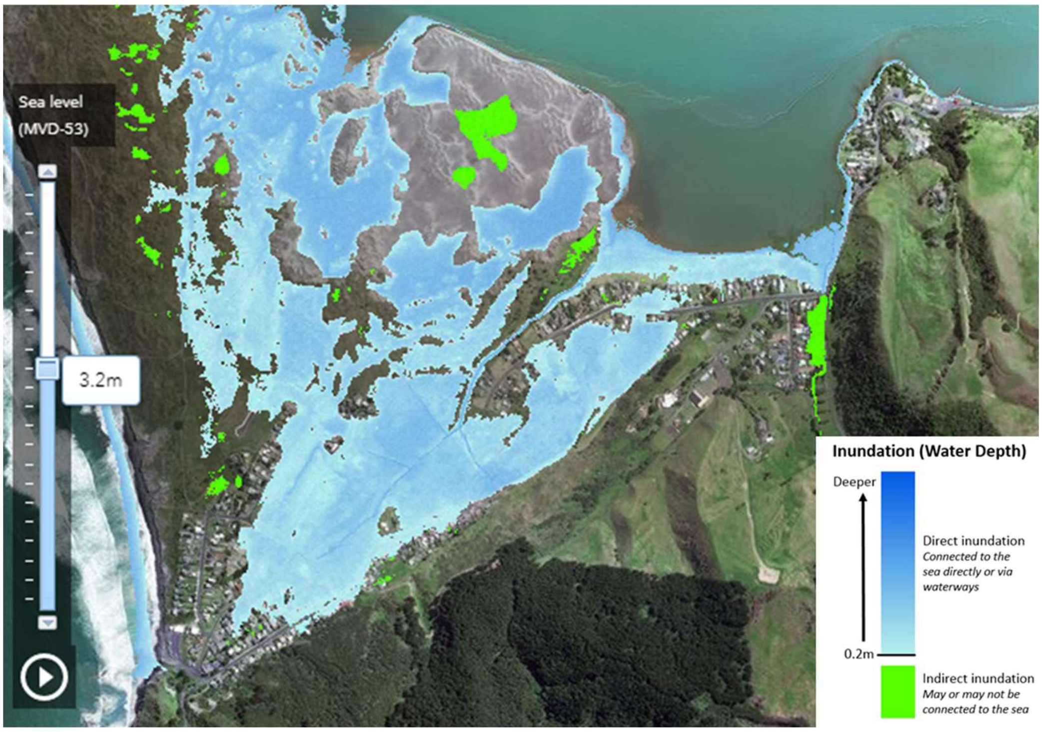


Figure 4.4 Areas likely to be inundated in the Port Waikato Settlement by a 1% AEP storm surge event at existing sea levels. Retrieved from https://coastalinundation.waikatoregion.govt.nz/

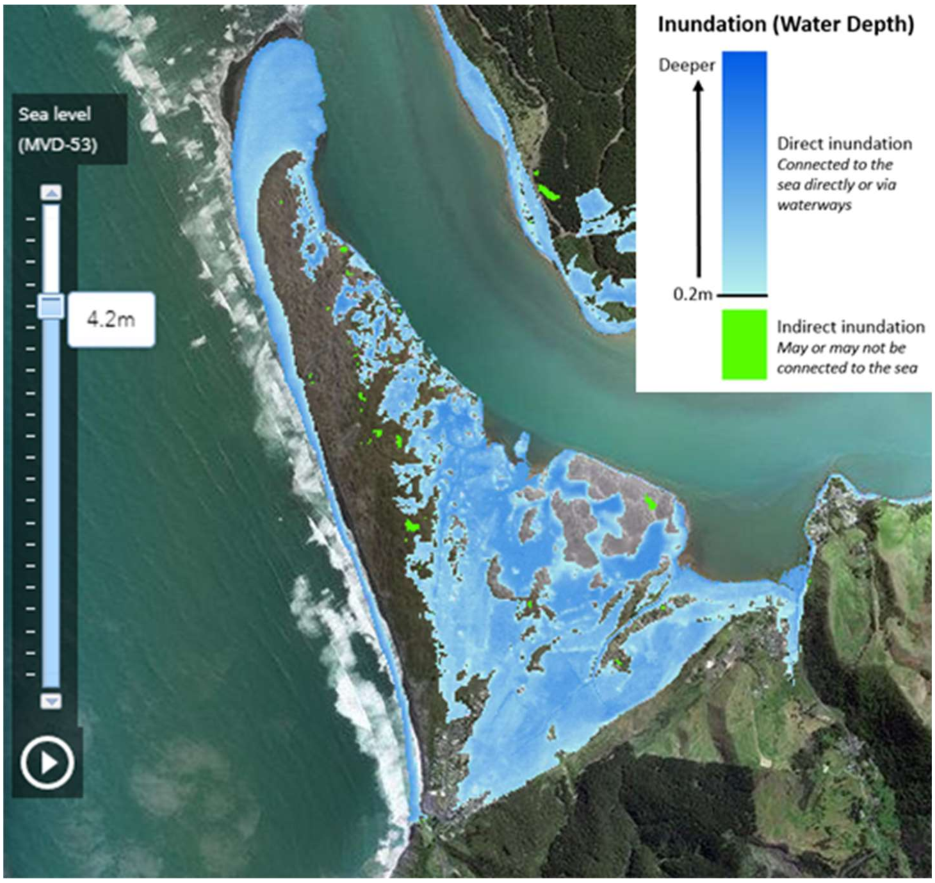


Figure 4.5 Areas likely to be inundated by a 1% AEP storm surge event with 1.0 m of sea level rise. Retrieved from https://coastalinundation.waikatoregion.govt.nz/

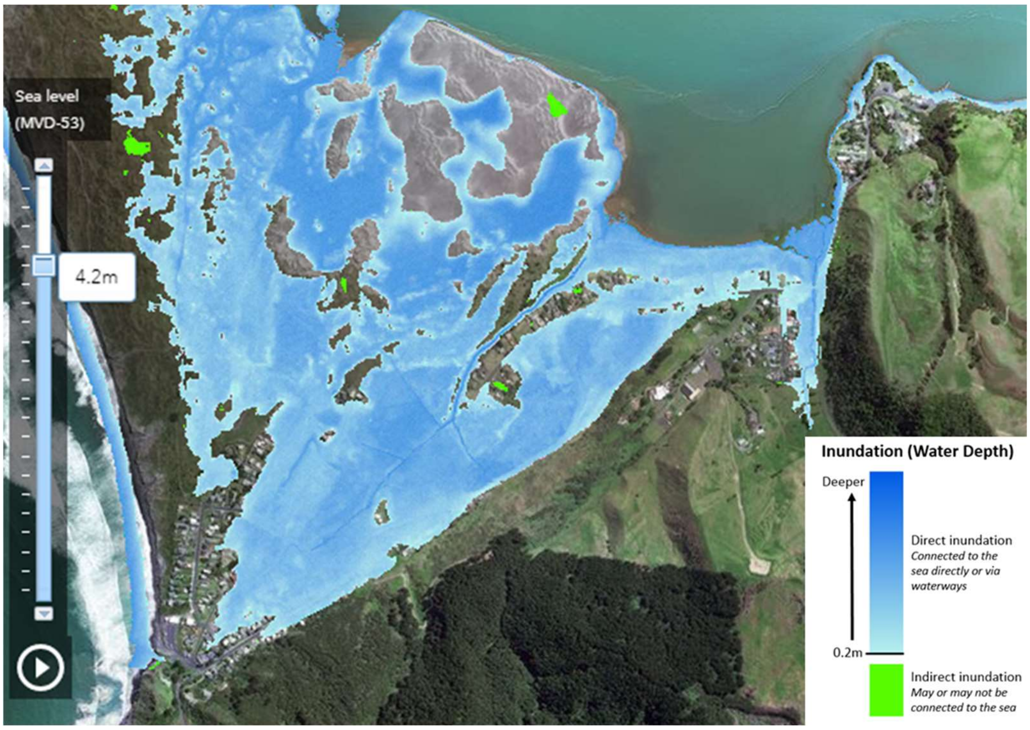


Figure 4.6 Areas likely to be inundated in the Port Waikato Settlement by a 1% AEP storm surge event with 1.0 m of sea level rise. Retrieved from https://coastalinundation.waikatoregion.govt.nz/

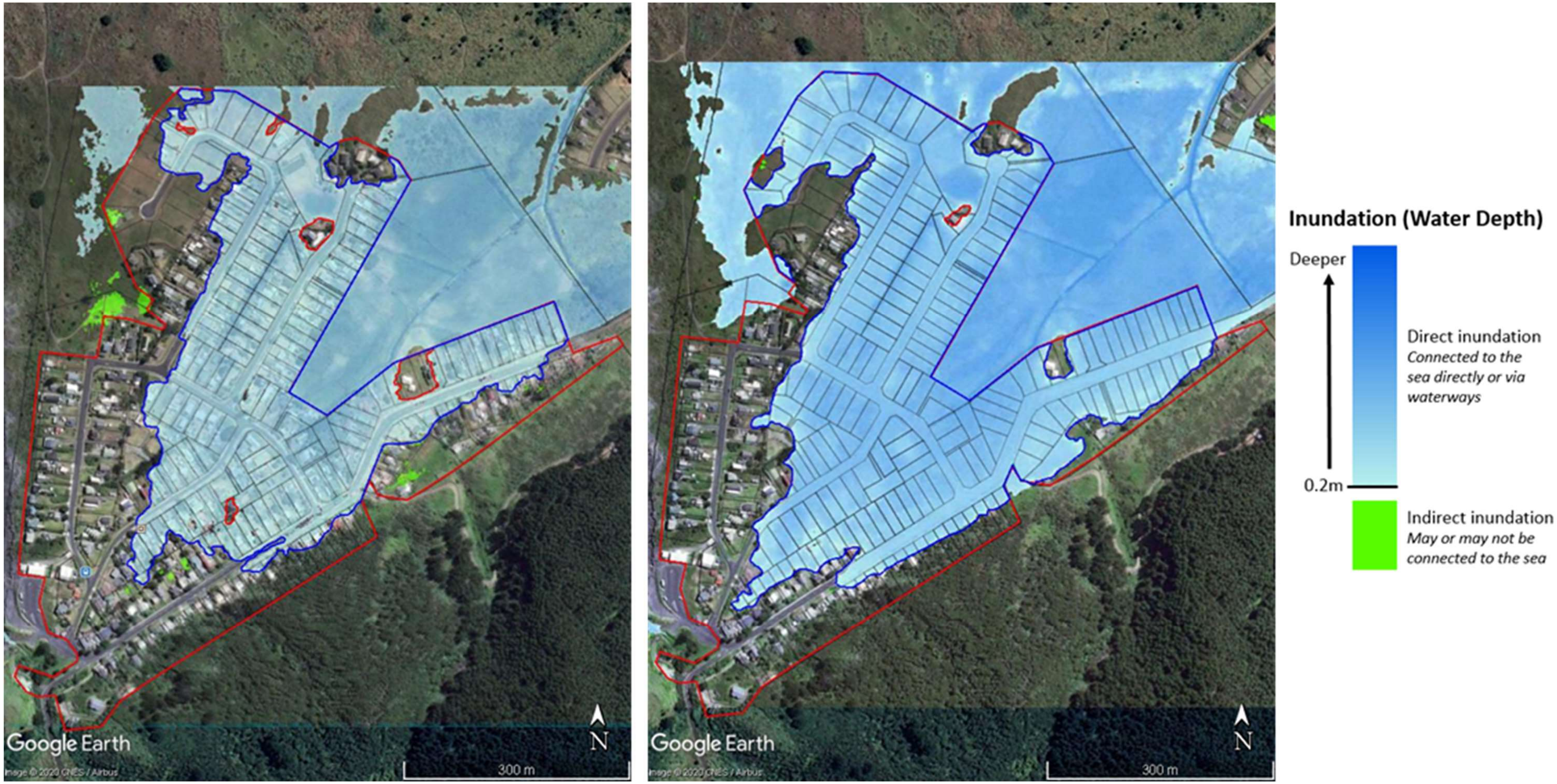


Figure 4.7 The areas inundated in the western Port Waikato settlement (left) during present day sea levels with an upper storm tide range estimate of 3.1 m and (right) under the same conditions but with 1.0 m of sea level rise (i.e. 4.1 m above present-day sea level (MVD-53)). Note, the red line presents the approximate perimeter of settlement, the blue line represents the areas inundated. The small red polygons represent high spots within the inundated areas (Images sourced from Google Earth, 2020).

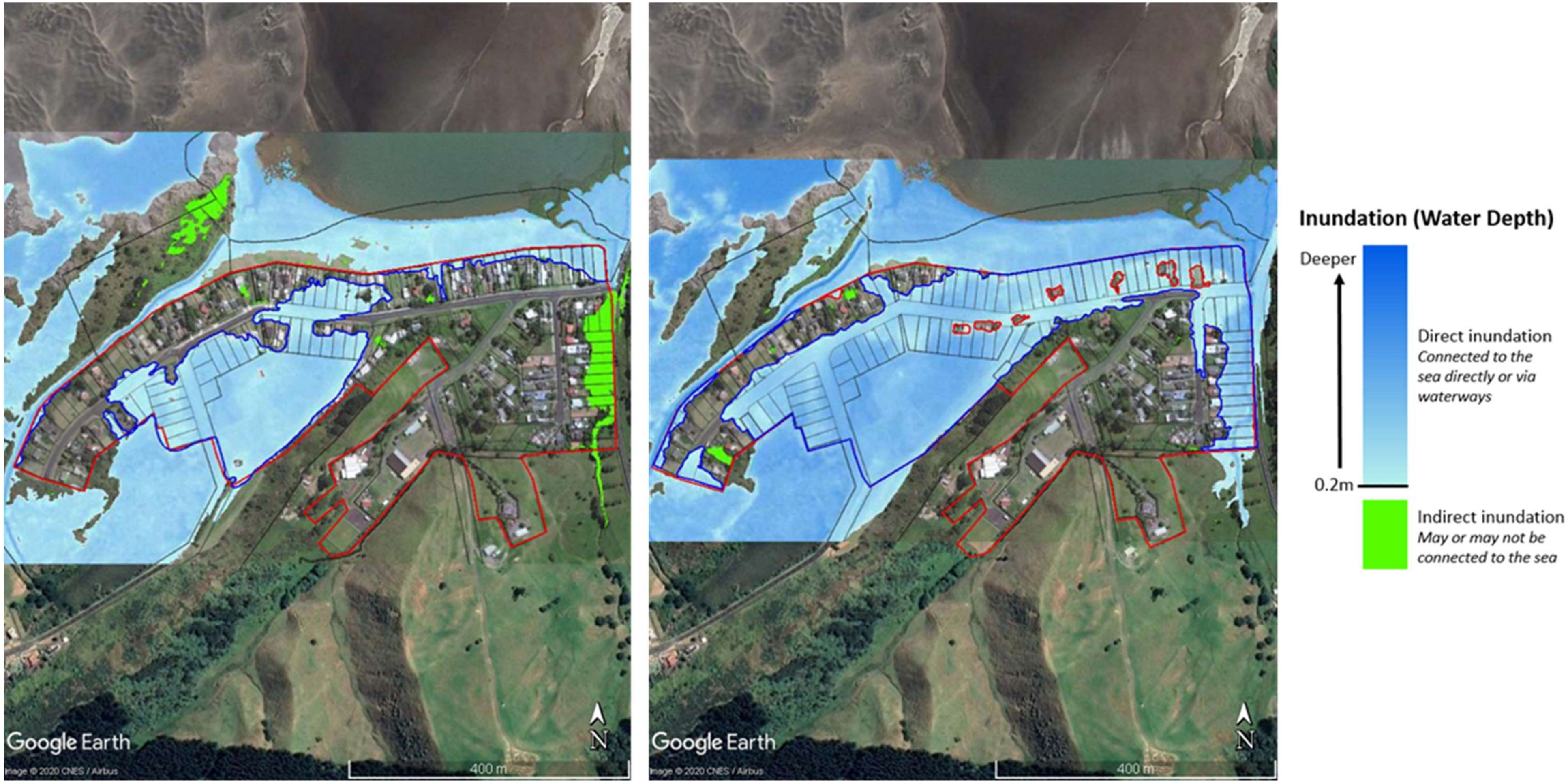


Figure 4.8 The areas inundated in the eastern Port Waikato settlement during (left) present day sea levels with an upper storm tide range estimate of 3.1 m and (right) under the same conditions but with 1.0 m of sea level rise (i.e. 4.1 m above present-day sea level (MVD-53)). Note, the red line presents the perimeter of settlement, the blue line represents the areas inundated. The small red polygons represent high spots within the inundated areas (Images sourced from Google Earth, 2020).

It is important to be cognizant that while we can consider the inundation effects of 1.0 m of SLR (e.g. Figure 4.5 and Figure 4.6), SLR will also dramatically increase the frequency of occurrence of coastal erosion and particularly inundation events. That is, events that are rare today will be increasingly common in the future as the mean level of the sea (MLOS) increases due to SLR. For example, an extreme inundation event that presently occurs every 50 years will have the potential to occur every few years by the year 2050 after approximately 0.3 m of SLR has increased the MLOS.

This also means that more erosion of the beach and dunes can occur, since the increase MLOS will 'push' the water level higher/more shoreward and allow the higher parts of the beach to be attacked by wave action more frequently. In addition, higher waves can reach further up the beach (since wave breaking is depth-limited and SLR results in deeper water) resulting in increasing erosion/retreat.

These increasing erosional and inundation events on the West Coast will be further compounded by increased storminess and increases to the average wave height for this part of New Zealand due to climate change (CC), meaning that more energy is delivered to the coast. Although there remains uncertainty with respect to the rates of SLR and how CC will manifest (mainly based on how humans respond to reducing CO_2 emissions in the coming decade), both SLR and CC will result in increased erosion and inundation events along the coastline of Port Waikato. Therefore, continued efforts to restore and increase resilience to the impacts of SLR and CC for this area are required.

4.3 Tsunami

Borrero and O'Neill (2016) evaluated the tsunami hazards at three locations on the west coast of North Island New Zealand: Port Waikato, Raglan (Whaingaroa) Harbour and Aotea Harbour for several regional and far-field tsunami sources. The assessment included maximum tsunami wave heights, tsunami inundation and tsunami induced current speeds. Also assessed were the nearshore tsunami heights along the west coast due to possible near field landslide or slump sources.

The study showed that the west coast of the North Island has a much lower tsunami hazard relative to the east coasts of the North Island. This is due to the fact that the principal hazard driver for tsunami is the Tonga-Kermadec (TK) Trench, a subduction zone that runs just offshore of the east coast of the South Island and extends northward to Tonga (Figure 4.9). Model results of tsunami generated along this fault line show that the west coast is sheltered, since the tsunami is generated along the east coast (Figure 4.10).

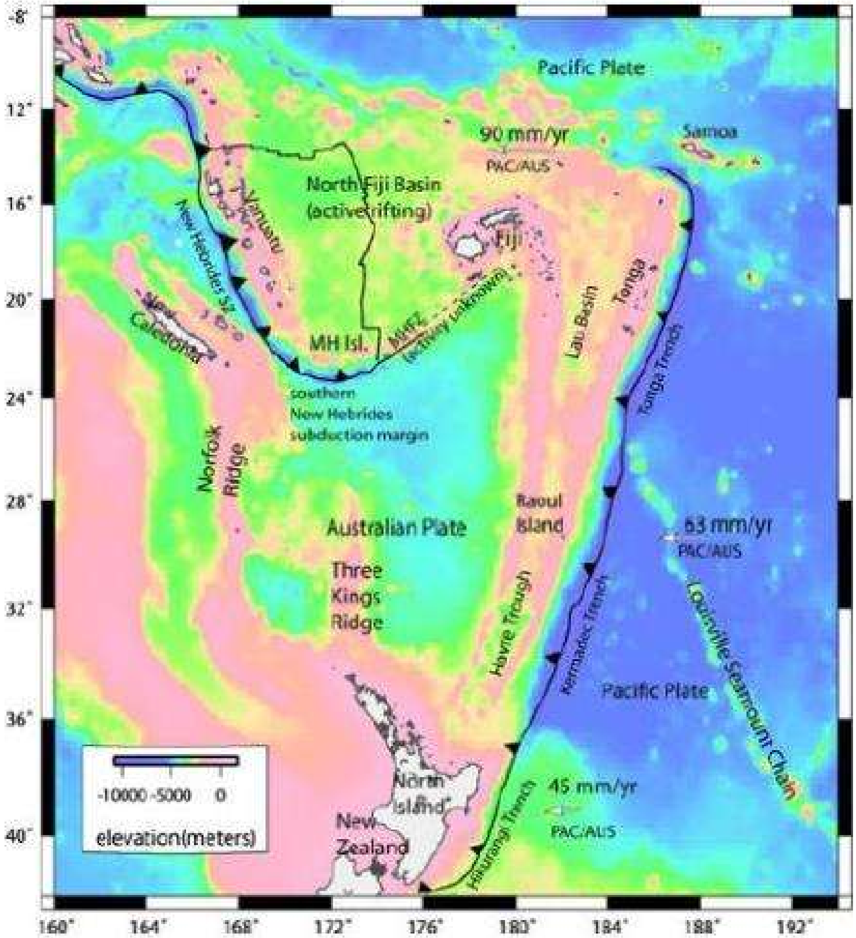


Figure 4.9 Tectonic setting of the Kermadec and New Hebrides plate margins. Black triangles signify the over-riding plate at the regions' subduction margins. White arrows show predicted motion of the Pacific Plate relative to the Australian Plate (Power *et al.,* 2012).

In addition to the TK Trench scenarios, the Borrero and O'Neill (2016) study also looked at tsunamis generated by large (M~9) subduction zone earthquake scenarios occurring on the Puysegur Trench (located on the extreme SW corner of the South Island) and along segments of the Southern New Hebrides and Solomon Islands Subduction Zones. These scenarios produced much stronger tsunami effects in Port Waikato Harbour with the Puysegur source producing tsunami amplitudes of up to 3.0 m just north of the river mouth at Port Waikato Estuary entrance. Inside Port Waikato, this scenario resulted in some inundation of the low-lying areas of the spit and Maraetai Bay, and other small embayments on the northern and southern banks as shown in Figure 4.11. It should be stressed however, that events of this nature have a very low probability of occurrence with annual occurrence probabilities in the order of 0.04% (i.e. events with recurrence intervals of ~2500 years).

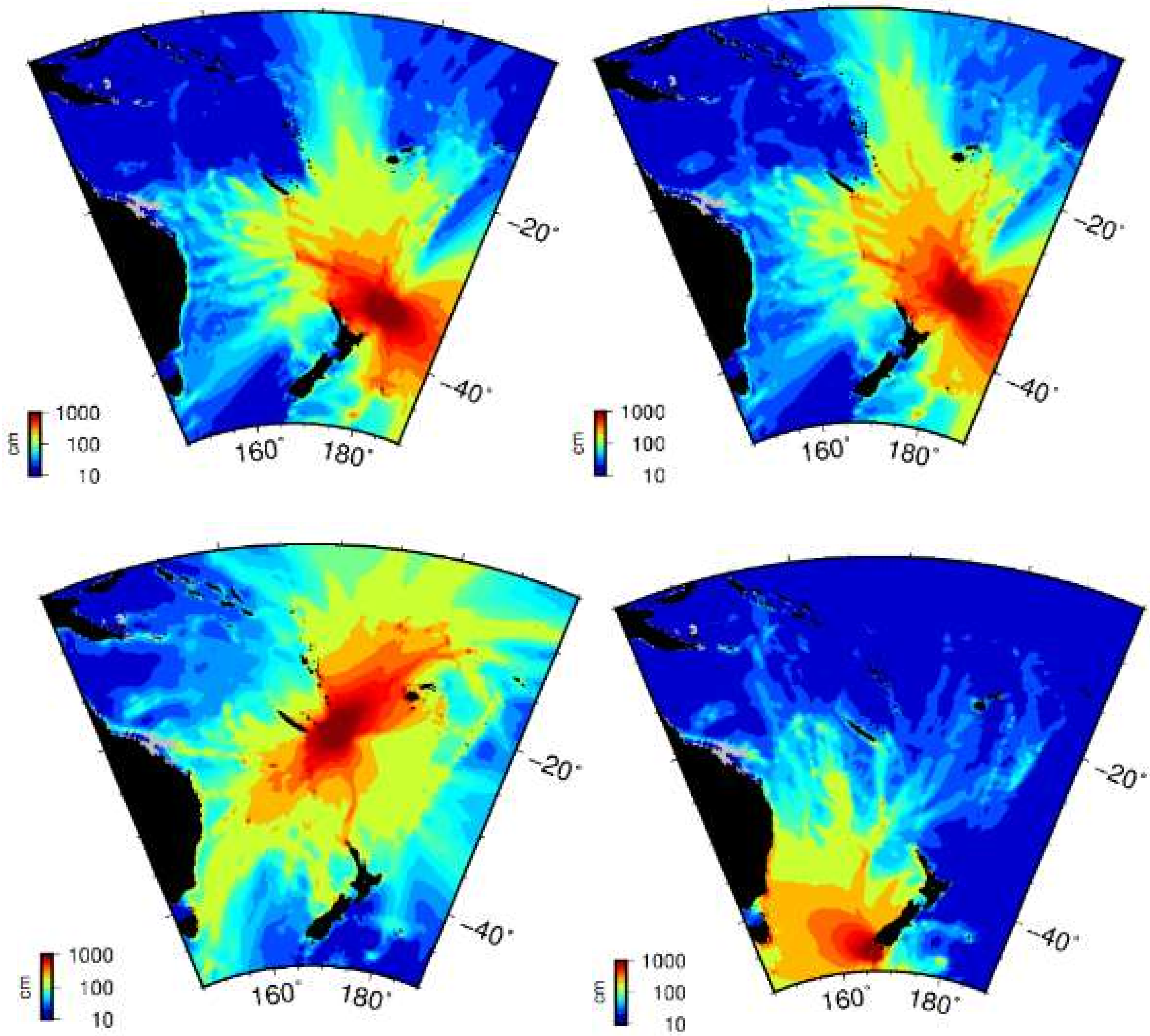


Figure 4.10 (top row) Maximum computed tsunami amplitudes around New Zealand from Magnitude 9 earthquakes along the Tonga-Kermadec Trench. Note the significantly smaller values along the west coast of the North Island. (bottom row) Maximum computed tsunami amplitudes around New Zealand from Magnitude 9 earthquakes along the southern New Hebrides Trench (left) and the Puysegur Subduction Zone (right). These sources have a stronger effect on the West Coast of New Zealand.

The results of the Borrero and O'Neill (2016) study also showed that for the regional source events, tsunami waves did not begin affecting Port Waikato until at least 3 hours after the earthquake scenario, however the strongest tsunami effects might not occur for several hours after the arrival of the first waves (Table 4.1). While this is good in the sense that there would be time to initiate an orderly evacuation of any potentially affected areas, these areas might need to remain evacuated or have activities restricted for a relatively long time as the tsunami effects may persist for several hours.

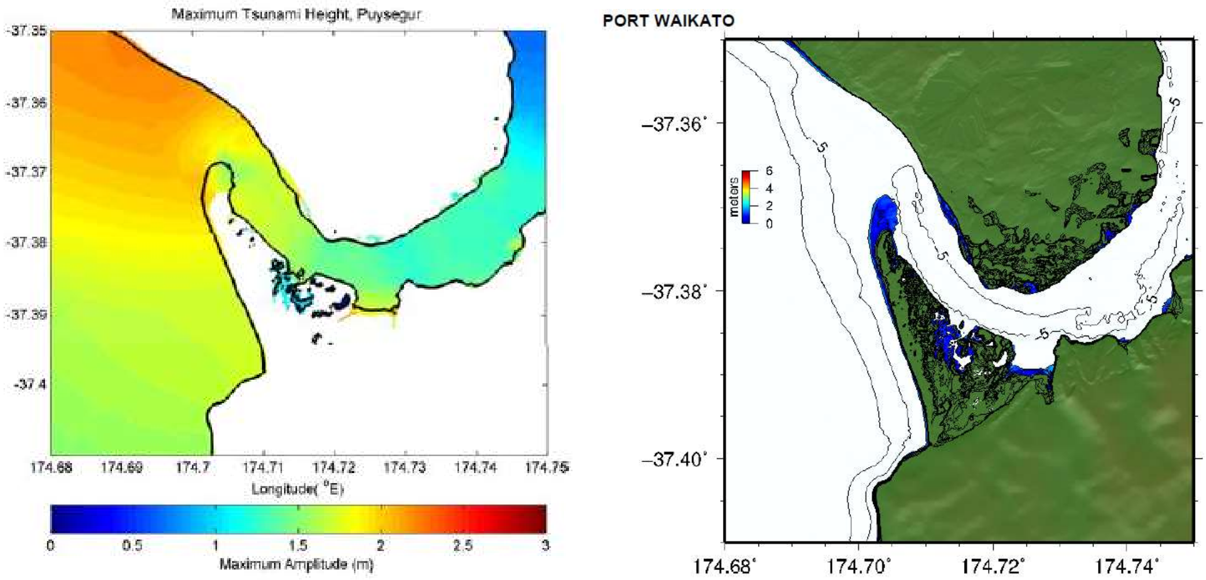


Figure 4.11 Maximum computed tsunami amplitudes (top) and maximum flow depths for inundated areas (bottom) from the Puysegur scenario at high tide at Port Waikato.

Table 4.1 Summary of Tsunami arrival and timing of peak tsunami activity for regional sources. All times are approximate and determined through visual inspection of the time series plots.

	First Arrival (hrs)	Peak Activity (hrs)	Largest Surge (hrs)
Port Waikato			
HEB	3.5	3.5-4	9
PUY	3	3-9	4.8
TK 1	3	3-12	6.5
TK 2	3	3-16	6.5
SOL 1	6	6-16	14
SOL 2	6	6-16	11
SOL 3	6	6-18	13

The Borrero and O'Neill (2016) study also looked at tsunami generated by large magnitude earthquakes around the Pacific Rim including South America and Japan. The study concluded that these sources did not pose an appreciable hazard in terms of overland flooding in Port Waikato. There was, however, the possibility of long-lasting current speeds in excess of 2 knots at the estuary entrance.

Finally, the Borrero and O'Neill (2016) study looked at tsunami caused by submarine landslides occurring offshore of the west coast. This was done in response to a study by Goff and Chagué-Goff (2015) who suggested that geological evidence of 30-60 m tsunami heights (including a 20 m height at Ruapuke) existed. They did not, however, propose any plausible mechanism for tsunami of this size. Borrero and O'Neill (2016) modelled several potential submarine landslide scenarios and concluded that it was highly unlikely that a tsunami was responsible for the geological evidence put forth by Goff and Chagué-Goff (2015).

4.4 Groundwater and Stormwater

Groundwater inundation, which is the localised coastal plain flooding due to a rise of groundwater level with sea level, is a concern with rising sea levels. A rise in groundwater level also impedes drainage of rainwater during storm events and can contribute to and exacerbate surface or pluvial flooding (Bell *et al.,* 2017).

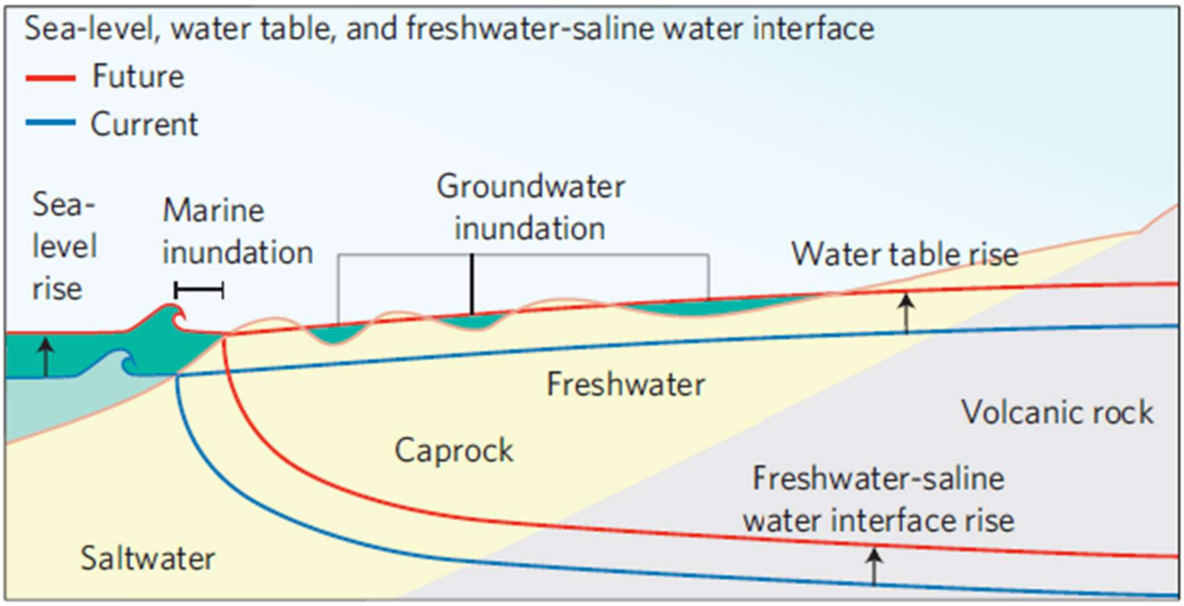


Figure 4.12 Sea level influence on groundwater (Rotzoll and Fletcher, 2013; cited in Bell *et al.,* 2017).

4.4.1 Drainage and Flooding

In a report prepared by City Design Ltd (2004) titled *"Stormwater Catchment Management Plan: Port Waikato Township (Final Report)"* prepared for Franklin District Council, the geological structure hazard profile was addressed. Bore logs from Environmental Waikato (now WRC) and Franklin District Council were obtained and analysed. These bore logs illustrated that across most of the low-lying area of Port Waikato, it is expected that unconsolidated iron sands in the order of 3 – 5 m thick overlie consolidated siltstones of the Apotu Group (youngest and most northerly marine strata of the Murihiku Supergroup (Campbell & Coombs, 1966)). The authors identify these siltstones as representing horizontal shore platforms from an erosional period that are impermeable.

Groundwater movement within the iron sands can be expected due to the lack of permeability of the underlying siltstone. Furthermore, saturation of these iron sands during extreme rainfall events is expected due to the limited thickness of the iron sands.

Early geological maps of the area indicate that the area was extremely swampy with a lake system existing within the central area (Figure 3.33), which now forms the current wetland drainage area (City Design Ltd, 2004). City Design ltd (2004) reported that the standing water level appears to lie within the thinnest areas of unconsolidated iron sands, which reflects the impermeable siltstones below. Flooding, therefore, would be expected to occur in those zones where the previous lake feature existed.

It is noted from WDC (2014), that a storm water pipe connecting the culvert at the base of the vehicle access way with the stream has been removed or covered in sand. The culvert appeared to be operating with no records or information available on where stormwater is derived. In the past the pipe has been exposed, preventing vehicle access. It was recommended that the culvert and storm water pipe under the Sunset Beach carpark would need to be removed or reinstated to discharge into the stream in the future (WDC, 2014).

4.4.2 Catchment Hydrology

City Design Ltd (2004) also discussed the catchment hydrology of the Port Waikato Township, which consisted of rainwater tanks, for potable water, septic tanks, and ground soakage trenches for wastewater disposal with a combination of ground soakage and drainage reticulation networks for stormwater. The authors note that there are a number of groundwater bores that are utilised for emergency potable and irrigation supplies. Furthermore, it was recognised that a number of sewage systems were vulnerable to flooding, while others had failed as a result of being located in an area with high groundwater.

City Design Ltd (2004) report that Port Waikato maintains a northerly aspect with regards to its catchment. The catchment is comprised of a three-valley system, which slope steeply down from the southern boundary to flat areas, which in turn gently slope towards the receiving environment. The two main watercourses, Maraetai Stream (from the south) and the main drain running eastwards, discharge into the Waikato River at Maraetai Bay (Figure 4.13).

The main stormwater drainage system comprises ephemeral streams within the valleys in the upper catchment leading to engineered watercourses and pipe networks in the flat parts of the catchment. The low-lying flat areas of the catchment have high water tables and poor drainage, which has resulted in engineered designed water courses being constructed to assist in drainage (City Design Ltd, 2004).

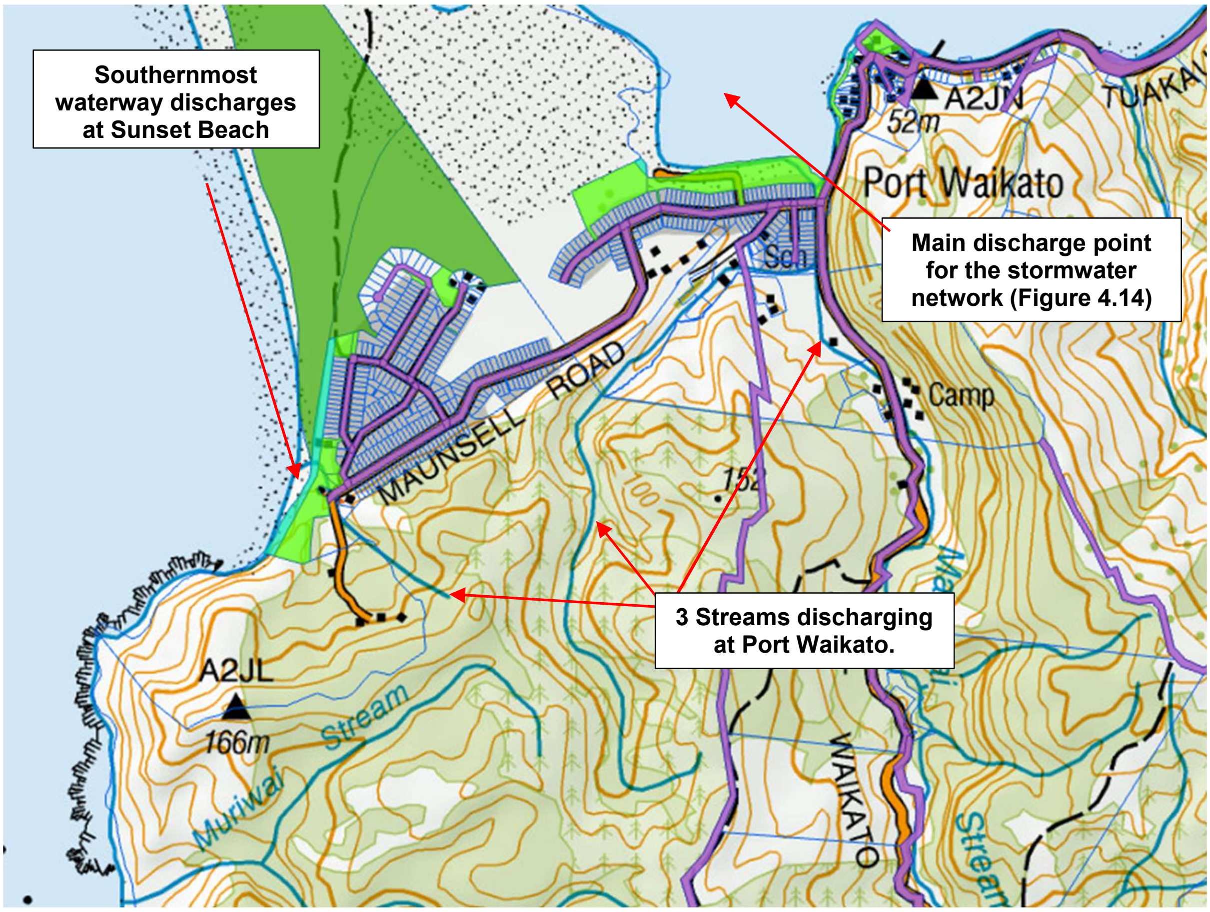


Figure 4.13. There are 3 catchments/streams discharging to Port Waikato. The northern 2 discharge to Maraetai Bay, the southern at Sunset Beach.

City Design Ltd (2004) note that engineered watercourses can be characterised as straight, unlined trapezoidal shaped channels with flat, soft sedimented bottoms, slow flow and no riparian vegetation. The drainage capacity of the watercourses was regarded as being generally well maintained. There was, however, aquatic weeds and algae present during a site visit (City Design Ltd, 2004). The authors note that the lateral systems were comprised of small v-drains and pipes. There were several ponding areas located within the network. Pipe systems within the network generally consisted of concrete pipes, which ranged between 225 mm and 600 mm in diameter. The pipes connected sections of open channels and acted as culverts to allow traffic access across the roadside v-drain/channel system. V-drains are typically shallow, grass covered and are normally located in the road reserve (City Design Ltd, 2004).

City Design Ltd (2004) describes the wetland as consisting of a large area of raupo and with the more open areas containing a mixture of grasses, sedges, and muehlenbeckia. Within the wetland, the watercourse flows south-west to meet the main channel. The main watercourse then flows west of Ashwell Drive at the base of the rear of the sand dunes towards Maraetai Bay.

The main drainage system leads to a pump station. This station has two pumps discharging to an outlet channel, which flows a short distance to the Waikato River. The pump station is at a level above the general range of the Waikato River tidal and flood levels.

City Design Ltd (2004) notes that the southernmost waterway in Port Waikato township discharges directly to the West Coast at Sunset Beach (Figure 4.13). The main watercourse is pumped to the Waikato River and discharges at the west end of Phillips Reserve at the western end extent of Maraetai Bay (Figure 4.14 and Figure 4.15). Maraetai Stream discharges to the east of the bay (Figure 4.16).

Figure 4.14. Left) the main v-channel of the stormwater drainage system. Right) The pump station that pumps Port Waikato stormwater into Maraetai Bay.

Figure 4.15. The southern stream discharges to the west at Sunset Beach; note, this catchment is relatively small.

Figure 4.16. Locations of discharge points in Maraetai Bay.

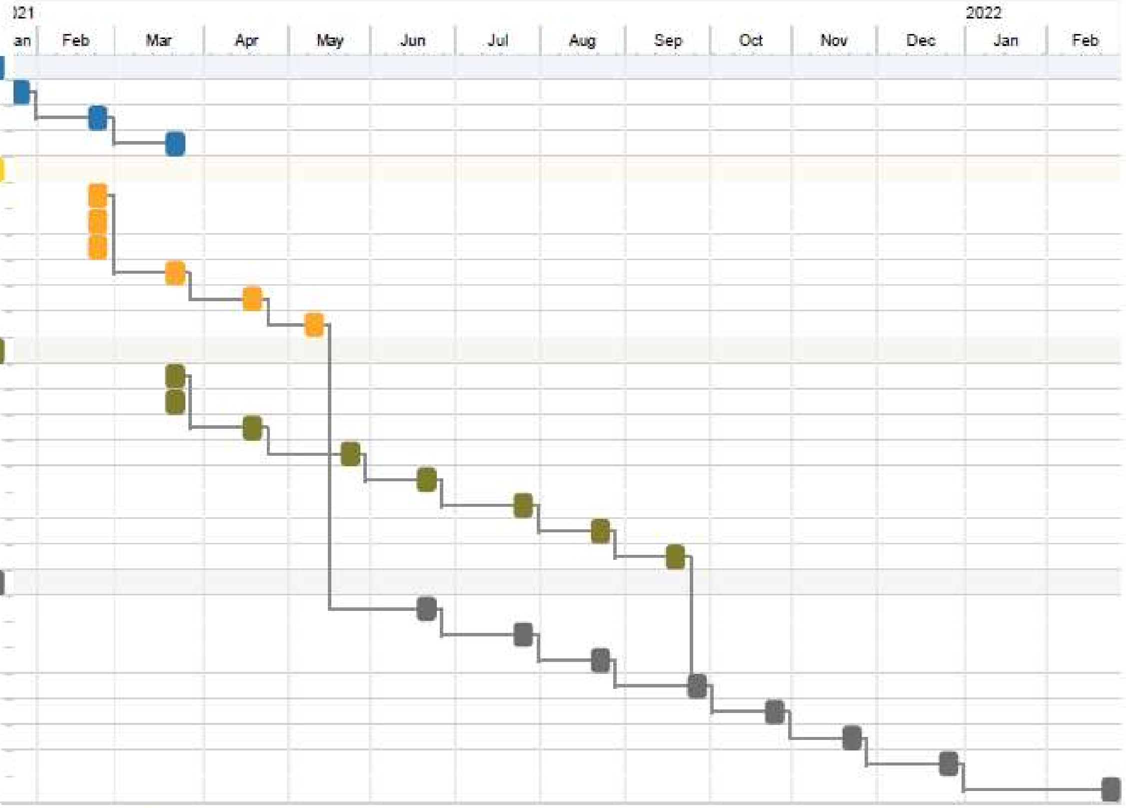
5 Port Waikato Community Resilience Strategy

Due to the progressive erosion since the mid-2000's, the Port Waikato Resilience Group are developing a Work Plan to respond to the erosion and develop a resilience strategy for Port Waikato. The Draft Plan is presented in Table 5.1 and Appendix B. As can be seen in Table 5.1 and Appendix B, the plan is currently a draft plan for discussion and is being developed through 2021.

Table 5.1. The Port Waikato Resilience Group's Draft Work Plan.

DRAFT FOR DISCUSSION: Port Waikato Resilience Group Work Plan

Activity	Start
PWRG Action Plan	**21-01-21**
Confirm scope, brainstorm and prioritise list of potential projects/actions	21-01-21
Review draft Action Plan and provide feedback	18-02-21
PWRG Action Plan FINALISED	18-03-21
Port Waikato Natural Hazards Planning Co-design Process Report	**18-02-21**
Identify Co-design Report Outcomes	18-02-21
Identify Co-design Report Scope	18-02-21
Identify Co-design Report Objectives	18-02-21
Review Draft Co-design report and provide feedback	18-03-21
Port Waikato Natural Hazards Planning Co-design Report FINALISED	15-04-21
WDC / WRC consideration / adoption of Co-design Report	07-05-21
Sunset Beach Erosion Response Plan	**18-03-21**
Confirm expertise and process for developing Erosion Response Plan	18-03-21
Workshop/site visit with consultants	18-03-21
Erosion Response Plan Workshop 1	15-04-21
Erosion Response Plan Workshop 2	20-05-21
Erosion Response Plan Workshop 3	17-06-21
Erosion Response Plan Workshop 4	22-07-21
Sunset Beach Erosion Response Plan FINALISED	19-08-21
WDC / WRC consideration / adoption of Erosion Response Plan	15-09-21
Port Waikato Resilience Strategy	**17-06-21**
Resilience Strategy Workshop 1	17-06-21
Resilience Strategy Workshop 2	22-07-21
Resilience Strategy Workshop 3	19-08-21
Resilience Strategy Workshop 4	23-09-21
Resilience Strategy Workshop 5	21-10-21
Resilience Strategy Workshop 6	18-11-21
Port Waikato Resilience Strategy FINALISED	23-12-21
WDC / WRC consideration / adoption of Resilience Strategy	21-02-22



project: Port Waikato Resilience Strategy

date: 2021

PWRG Action Plan · Co-design Report · Resilience Strategy · Erosion Response Plan

6 Summary of Coastal Processes at Port Waikato

The above Sections have provided a review of the coastal processes and drivers of coastal hazards affecting Port Waikato; including the spit, Sunset Beach, Maraetai Beach and the township (Figure 1.2). Port Waikato is located on the west coast of the North Island, which faces directly into the circumpolar westerly winds and is subject to persistent, and on occasion, extreme, wind and wave energy emanating from the Southern Ocean and the Tasman Sea, meaning the open coast is a very dynamic place. In addition, New Zealand's largest river runs along the eastern side of the Port Waikato spit and discharges at the northern end adding further complexity to the coastal processes of the area.

The following points summarise the coastal processes and drivers of coastal hazards affecting Port Waikato; including the spit, Sunset Beach, Maraetai Beach and the township:

1. The area of interest is of particular importance to local iwi, local residents and visitors, and includes the dynamic west coast, the township, a holiday park, playing fields, a boat access to the beach, surfing on the southern reef and beach, fishing, swimming, walking/running/horse-riding tracks through the extensive dune field of the spit and the sheltered reserve on the eastern side of the spit. Aggressive erosion since the mid-2000s, especially at Sunset Beach where infrastructure and property has become very vulnerable, is an ongoing concern. Recent satellite imagery indicates that up to early 2019, the coast to the south of the Port Waikato headland has also continued to erode. This suggests that up until at least 2 years ago, there had not been an influx of sand from the south that will be moved north to nourish Sunset Beach and the spit.
2. Due to the predominance of south-westerly winds and waves, sediment transport is generally in a northward direction, with ~150,000 m^3 of net northerly sediment transport annually a common figure quoted. Large fluctuations in beach levels are also a feature of the Waikato west coast; at Port Waikato, the current extensive erosion is trending towards its most seaward recorded position in 1942. Pulses in sediment moving up the coast are associated with the large fluctuations in beach levels on the Waikato Region's west coast, with significant exchange occurring around the Port Waikato headland due to the energetic wave climate and the relatively small scale of the headland control feature.
3. The medium to fine grain sand of Port Waikato's open beach and spit is moderately well sorted, and in combination with the dense fraction of titanomagnetite results in a relatively low gradient/dissipative beach profile. The geology of the site is complex with high rocky relief to the south of the township and spit, and the township and spit

being located on much lower ground comprised of a layer of unconsolidated iron sands of the order of 3-5 m thick overlying consolidated siltstones.

4. Due to the northward sediment transport, the Port Waikato spit extends northwards and is presently approximately 3.5 km long from the southern end of Sunset Beach. The Waikato River entrance is deflected to the north by the presence of the spit and is currently >1.5 km wide. The tidal range at the entrance to Waikato River is over 4 m, with a spring tidal range of 3.2 m. Periodically, shallow islands form in the river entrance as the distal tip of the spit is breached and remnant parts are left in place. The lower Waikato River is tidally influenced, with the ebb tide dominating current speeds.
5. The spit has continued to extend northward since at least 1853. Whether this continued spit growth is due to the slump block that occurred in the first half of the 19th century and associated human influences (i.e. flood control that reduces peak flows during flood events, and consequently prevents spit breaching, and land-use changes delivering large quantities of sediment to the coast adding to the spit's volume), or a long-term cycle where the spit will breach sometime in the future and reset further south, is unknown. It is noted that a significant breach occurred sometime in the 1950s, although the Spit has continued its northward extension since this last breach. Long-term erosion on the northern bank of the river is associated with the continued northward extension of the spit.
6. Infra-gravity waves are likely to occur through the river entrance and south into the lower Waikato River, as they do in most rivers and estuaries on the West Coast during long period swell events. However, the effects of infra-gravity waves on the coastal processes at this location are largely unknown.
7. The spit and township are very low-lying, especially to the east, which has serious implications for inundation hazards due to sea level rise (SLR) and climate change (CC). Even at present day sea levels, inundation of the central township and Maraetai Bay has the potential to occur. In 100 years' time with sea level rise of 1 m, during a 1 in 100-year extreme water level event most of the township and spit will be inundated.
8. Tsunami risk is considered relatively low for this part of New Zealand's west coast and the area of interest. However, a large (M~9) subduction zone earthquake scenario occurring on the Puysegur Trench (located on the extreme south-western corner of the South Island) has the potential to produce tsunami amplitudes of up to 3.0 m at the entrance to the Waikato River. This scenario results in some inundation of the low-lying areas of the spit and Maraetai Bay, although its likelihood of occurrence is on the order of 0.04% per year (i.e. a recurrence interval of 2500 years).

9. Due to the layer of sand (3-5 m) on consolidated siltstone which comprises Port Waikato and the spit, the groundwater table is relatively high. This has the potential to exacerbate erosional processes. A high groundwater level also impedes drainage of rainwater during storm events and can contribute to and exacerbate surface or pluvial flooding, which will be made worse with SLR.
10. Figure 6.1 provides a schematic representation of the coastal processes at Port Waikato.

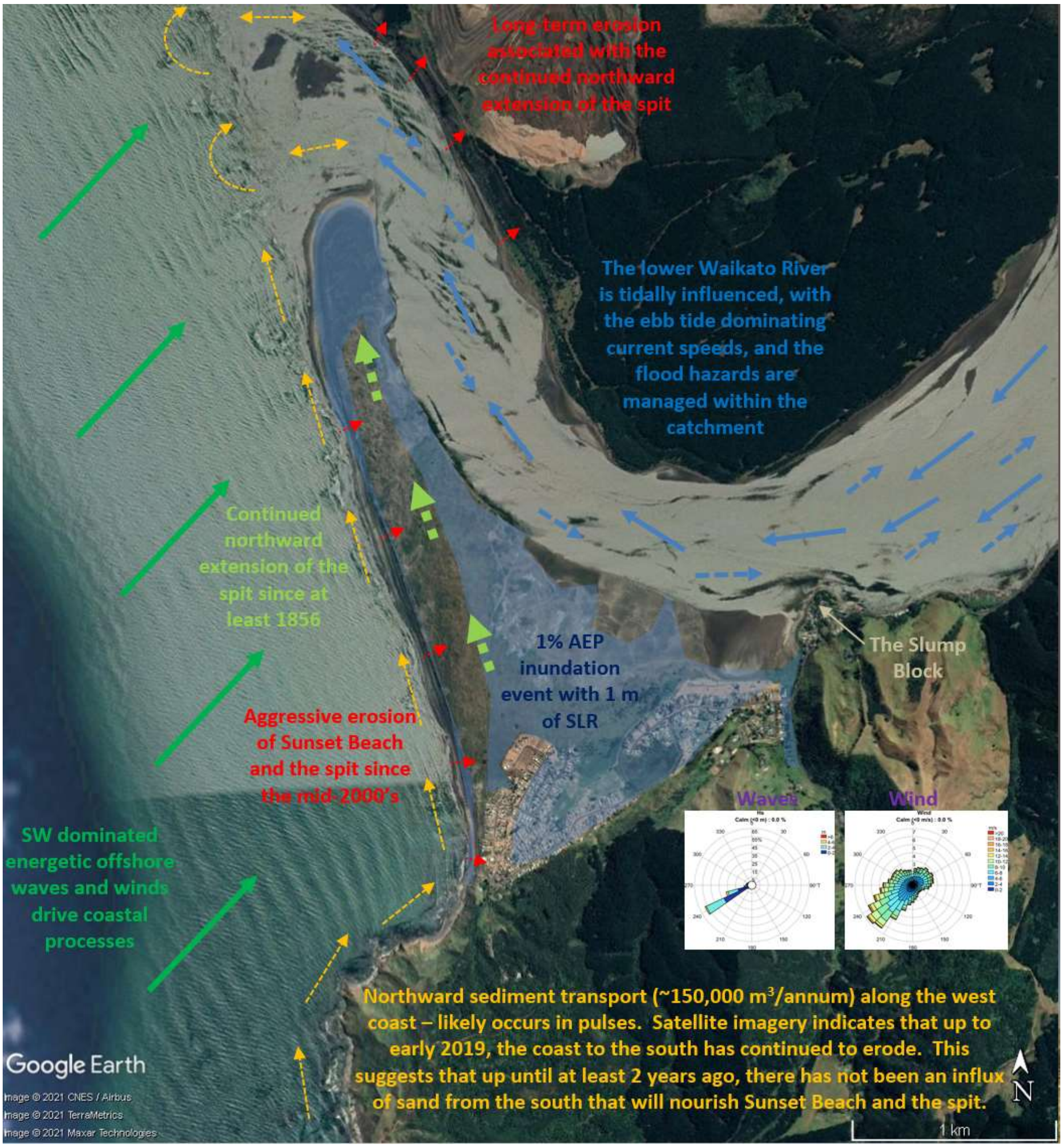


Figure 6.1 Coastal processes summary at Port Waikato.

7 Knowledge Gaps

Beach profile monitoring

Table 7.1. Current knowledge and gaps in knowledge.

	Knowledge	Gaps
Waves	• Long data sets are available for the study area from hindcast global wave models. • The wave climate in the study area has been well studied and is widely described in the literature.	• Limited availability of data sets from field measurements. • Long (infragravity) waves have never been studied or analysed
Water levels	• A relatively long water level gauge record is available Hoods Landing (from 1962). • High water levels during some storm events have been quantified and reported.	• Hoods Landing is some 11 km from the river mouth and does not represent Port Waikato • Effect of infragravity waves on storm water levels.
Wind	• Time series are available for the whole study area from hindcast global atmospheric models.	• Dataset from weather station are missing for most of the study area and through time. • No source of good wind data inside the estuary/lower river.
Coastal Morphology and Shoreline Mapping	• Descriptions of the study area's beaches are available. • Geology of the region is well described. • Historic shoreline mapping has been done. • Monthly beach monitoring is currently undertaken	• Development of a comprehensive integrated topo/bathy data set that is regularly updated. • Further investigations into the historical beach changes should be undertaken to consider the potential for spit breaching.
Sediment Flux	• The northward drift trend in the nearshore zone is commonly accepted and has been estimated in several studies.	• Rate of sediment transport between Huriwai and Sunset Beach not quantified. • Sediment entering and bypassing the river entrance not quantified (does this influence spit growth?).
Hydrodynamics	• Some hydrodynamic modelling exists i.e. Greer *et al.* (2016) characterising the spring/neap tidal currents.	• Detailed hydrodynamic models for the application of shoreline morphological assessment, real time water quality assessment, and potential effects of water extraction on spit morphology.
Bathymetry	• Bathymetric survey carried out for Atkin *et al.,* (2016) model application.	• Little information exists at the entrance to the river. Bathymetric surveys at regular intervals would provide useful information
Climate Change Effects	• Inundation information has been compiled.	• Keep revising as IPCC info changes – how CC and SLR affect all of the above
River Inputs	• This information is available, although has not been compiled	• how have changes in the flow regime and sediment transport of the river affected the mouth
Extreme water levels and inundation	• This has been considered at a large scale	• Site specific calculations made on how the frequency of occurrence change with climate change would be useful

Ground water effect on coastal erosion	• This has been flagged, although not investigated in detail	• How dependent on beach height/sand levels is this ,and does water flow thru the barrier?

8 Management Options for Port Waikato

The findings of this coastal processes study form the basis, and a provide a source of information, to inform any future management options along the coastline of Port Waikato.

A range of management options are presented for discussion/consideration. In order for these options to be meaningful, we first need to consider the aims of the Stakeholders and the physical aspects and constraints of the area.

These include:

- The aims to enhance natural character (i.e. make the coastal margin more attractive), increase cultural value (i.e. planting harakeke and pingao for weaving), and increase native biodiversity (i.e. plant a variety of species). (Policy 14, NZCPS 2010).
- Restoration of natural defences (Policy 26, NZCPS 2010) – capture sand to restore the foredunes. Create a functional and sustainable dune along the coastal margin that will allow recovery of the beach and may also be effective at addressing the future impacts of SLR (e.g. de Lange and Jenks, 2007).
- The need to weigh up management responses with public use – it is a popular area for beach walking, and public usage poses a potential threat to the integrity of the dunes (access, protection, education is required).
- Taking a holistic approach for the whole spit and recognise that this natural feature has been highly modified by human activities.
- This coastline and the spit itself are very dynamic and affected by a range of coastal processes and drivers.
- There is an intermittent sediment supply along the West Coast and around the headland and into Sunset Beach.
- The Spit and river entrance are likely affected by greater then decadal time scales, it has been generally extending northwards since 1853, with consequent erosion of the northern bank.
- There is presently a very restricted area to work with at Sunset Beach due to the carpark and private properties. This means that options like beach reshaping cannot presently be applied, especially while the beach is still in an erosive phase.
- Much of the area is low-lying – with sea levels projected to rise between 0.32 m and 0.61 m in the next 50-years and between 0.55 m and 1.36 m in the next 100-years. Port Waikato and the Spit will become much more vulnerable to coastal inundation, especially on the lower-lying eastern side, and most of the township will also be

impacted. This indicates a need to begin the development of a dynamic adaptive planning pathway (DAPP) process (Bell *et al.*, 2017).

- An example of a DAPP approach would involve planning for the possible need to relocate vulnerable buildings. A common approach is to establish a sentinel marker/trigger point for the time when the building will need to be moved if/when that pole falls over due to erosion (e.g., Figure 8.1). Planning and permitting activities for these events should begin now, even if it never becomes necessary. Permitting or consents should be sought now that would allow for a future relocation of buildings at the time when it is necessary so that action is not delayed by the need to obtain additional consents.

Figure 8.1 Discussing the Te Kōpua plan in front of the Kokiri Centre stage building at Raglan. The sentinel wooden poles can be seen between the building and the dune scarp as triggers to indicate the need to relocate the building.

The spit and township is very low-lying, especially to the east, which has serious implications for inundation hazards due to sea level rise (SLR) and climate change (CC). Even at present day sea levels, inundation of the central township and Maraetai Bay has the potential to occur. In 100 years' time with sea level rise of 1 m a 1, in 100-year extreme water level event most of the township and spit will be inundated. Therefore, continued efforts to restore and increase resilience to the impacts of SLR and CC for Port Waikato are required.

In summary, the coastline of Port Waikato including the spit, Sunset Beach, Maraetai Beach and the township is very dynamic, and affected by a range of coastal drivers and processes. There continues to be a long-term trend of spit extension/accretion, and there is uncertainty with respect to the process of breaching. Recent trends (since the mid-2000's) include continued erosion of Sunset Beach (likely due to intermittent sediment supply up the coast and around the headland), which has resulted in removal of buildings and loss of part of the carpark, with several private dwellings only some 10-15 m from the top of the erosion scarp.

The following management options can be weighed against the 'do nothing' option and can be considered as components to a holistic adaptive management plan. That is, there are a range of different issues and physical settings at Port Waikato that require a range and combinations of interventions including:

1. Re-establishing native dune species (i.e., spinifex and pingao), once an accretionary phase begins.
2. Building brush fascines to capture wind-blown sand to increase the sand reservoir and create a wider beach/buffer; once an accretionary phase begins.
3. Providing for stormwater management and relocation of stormwater infrastructure.
4. Undertaking sand management in the form of transferring sand from one part of the spit to another. For example, back-passing material from inside the spit north of Sunset Beach to renourish the beach.
5. Creating a raised buffer zone along the northern and eastern parts of the township to increase resilience to inundation due to SLR and CC.
6. Increase beach space for coastal processes – e.g. naturalization of the carpark to provide a wider buffer zone.

Further options are included in Table 8.1 below, which also includes some comments with respect to the pros/opportunities and cons/risks, and a 'traffic light' (red/amber/green) scoring system with respect to their applicability to the future management of Port Waikato in response to the existing coastal hazards. A numbering system is also included to denote the areas where the green (and some amber) options can be applied to Port Waikato, with reference to these locations in Figure 8.2.

When considering appropriate interventions, it is important to be cognizant that some options can be considered 'no regrets', which are low cost and unlikely to have knock-on impacts, while others may have substantial risks that would require thorough consideration; e.g. moving sand from accumulations in the intertidal to other areas has the potential to impact on the local ecology, the local hydrodynamics (and consequently sediment transport), and may fail (e.g. sand push-ups on a very exposed coast like at Port Waikato can allow larger waves to approach closer to the shore and cause more erosion during an extreme event.).

Table 8.1. Preliminary Catalogue of Potential Coastal Adaptation Options (not exhaustive) to be Weighed Against the ‘Do Nothing’ Option. Struck-through options are considered not applicable to the Port Waikato Area. Note some options may be applicable to several categories (e.g. beach recharge can be considered both accommodate/advance and protect, as can dune planting). The last column refers to numbers on Figure 8.2 to denote the approximate areas where these options could be applied – the zeros indicate that these options are not being considered at present.

KEY:

Advisable, can/should be acted upon.	(green)
Possible, but more information and/or investigation are needed.	(yellow)
Not Recommended or Not Applicable.	(orange)

	Option Description		Risks	Opportunities	Timeframe	Map
Accommodate/Advance						
1	**Modification of assets at risk due to erosion**	This option can include a range of actions such as relocation of assets and or modifying assets so that they can be relocated if required.	Some structures cannot be modified, and retrofitting can be relatively expensive. However, this can be compared against construction costs for hard defenses. Land ownership issues.	Can integrate into rethinking for new assets for landowners and the community. Avoids overbuild of coastal defenses over long-term.	LONG	1
2	**Improved drainage**	Improving drainage can help to reduce structural and dune loads. A common cause of dune failure along the coast is a combination of wave action, soil saturation and water run-off. By improving drainage, the likelihood of beach/dune failure may be reduced.	Unlikely to be a long-term protection measure since it addresses only a particular aspect of the system (i.e., erosion may still be occurring, reducing stormwater run-off to the beach/dune will only reduce the impact).	Improve geotechnical stability of areas of the spit. Reduce risk of slope failure and direct impact or encroachment on coastal assets and property.	SHORT - MEDIUM	2
3	**Banks and insurance determining habitation**	To allow banks and/or insurance companies to determine habitation viability.	This approach does not address the direct risks and can result in un-directed and maladaptive responses. Does not yield an aspirational outcome aligned with community desires.	Would send signal to community that action is required. Insurance could be parametric or conditional upon adaptive measures being in place.	LONG	0
4	**Dune rehabilitation and/or reshaping**	Some areas of the coastal dunes have been modified and/or removed (e.g., flattened and clay-capped). By re-creating, reshaping, or rehabilitating these dunes, a more resilient natural defense could be achieved to accommodate storm events, changes in sediment supply and to prepare the dune for upcoming coastal changes (i.e., SLR).	Reliance on a soft protection measure for coastal erosion. New dune shape capability to withstand energetic events and maintain level of protection within a restricted beach space.	Increase dune stability. Increase ecological value/biodiversity by dune planting. Improve dune resilience to aeolian processes. Increase resilience to flood inundation on the eastern side of the spit.	SHORT - MEDIUM	3
Protect						
5	**Do minimum**	The do minimum option implies to *hold the line* by maintaining current protection measures including both hard structures and soft protection such as vegetated dunes. This option may require reactive measures against storm events damage, as well as maintenance of the existing soft and/or hard protection measures	By holding the line, different risks can apply depending on the coastal system. Some of these can include the increased risk of structural failure, increased maintenance costs over time. Furthermore, this a management approach likely to not be feasible long-term.	Holding the line may include short-term benefits like the maintenance of the current levels of service and erosion protection. Benefits of the do minimum management approach will decrease with time.	SHORT	4
6a	**Beach recharge or nourishment below high-water mark**	Beach or foreshore nourishment serves to compensate the eroded or lost sand without big impacts in the sediment transport patterns. The latter implies that if erosion is present, the natural erosion processes will continue. Beach nourishment requires a sediment source: ideally, the eroded material is replaced on a regular basis with sand from somewhere else. Sand could be supplied from local borrow areas (e.g., areas of accumulation/accretion), or from offsite sources (e.g., the flood or ebb tidal delta).	Beach nourishment is likely to require maintenance, i.e., repeated beach recharge. Sediment needs to be suitable/like the natural beach sediment. Nearshore ecological value may be compromised. Maintenance costs and recharges can be difficult to plan/forecast. High risk of nourished sediment removal after storm events or other natural processes (e.g., tidal currents at the entrance).	Beach accretion/basis for dune re-establishment. Increased beach amenity value. Increase beach sediment budget. Increased beach widths providing buffer sediment to be eroded during storm events. Can add natural landscape value.	MEDIUM	5a
6b	**Beach recharge or nourishment above high-water mark**	As above, however if all activity takes place above the highwater mark, i.e., sand redistribution on land, then consenting issues can be avoided. Beach scraping or dune ‘push up’ activities can be part of this action, but resource consenting may be required.	Sediment should be similar to the natural beach and/or other nearby back dune areas. Dis-similar sediment characteristic can lead to future problems if erosion reached the re-charged areas. The spit represents a large reservoir of suitable material	Can provide a preemptive buffer or supply of sediment and an enhanced back dune area in anticipation of future erosion event. Will be a step towards restoring native plants, increasing biodiversity and improving amenity value.	MEDIUM – LONG (If not impacted by high water)	5b

	Option Description		Risks	Opportunities	Timeframe	Map
7	**Groyne(s)**	Groynes are shore perpendicular structures that influence the rate of longshore sediment transport under both normal and extreme conditions. Groynes can be permeable, allowing water flow through at reduced velocities, or impermeable, blocking and deflecting the current. There is also the option of considering a single groyne or a series of groynes. Careful analysis should be undertaken to avoid side effects such as erosion of the downdrift side or rip current generation. Groynes are often complemented with nourishment to mitigated adverse side effects.	High visual impact and intrusion onto the beach area. Incomplete understanding of the coastal dynamics may lead to negative side effects such as downdrift erosion and/or rip current generation (e.g., performance with infra-gravity waves; negative impacts at Maraetai Park). Creation of erosion hot spots during storm events. Nearshore structure influencing current coastal dynamics. Potential health and safety concerns for beach users. Loss/Influence on local hydrodynamics. Unlikely to be successful without input of new sediment.	Potential for beach accretion. Platform for beach users like fishing enthusiasts or bathers. Enhance ecology and biodiversity by creating new dune systems.	MEDIUM-LONG	0
8	**Offshore breakwater(s)**	Breakwaters are a type of hard coastal protection which interferes primarily with cross-shore sediment transport and provides wave action sheltering to the beach foreshore. These structures have the potential to accrete sand by forming a salient and/or tombolo landwards their location. Offshore or detached breakwaters can be considered submerged or emerged. Careful consideration of the potential side effects and risks should be given during the planning phase. Offshore breakwaters are often complemented with nourishment to mitigated adverse side effects.	High visual impact and intrusion in the beach area. Incomplete understanding of the coastal dynamics may lead to negative side effects such as adjacent beach erosion and/or rip current generation. Potential creation of erosion hot spots during storm events. Offshore structure influencing current coastal dynamics. Potential health and safety concerns for beach users. Extremely expensive at this site.	Potential for beach accretion to address erosion hotspots. Platform for beach users like fishing enthusiasts or bathers. Enhance ecology and biodiversity by creating Living Breakwaters type of structure (i.e., substrate for colonization). Wave action sheltering: decreased wave impact at beach dunes or seawall.	MEDIUM-LONG	0
9	**Attached breakwater**	Attached breakwaters are type of nearshore structures which combines characteristics of groynes and offshore breakwaters. Primarily designed to reduce wave action but can also retain or block sediment transport depending on the coastal system dynamics. Careful consideration of the potential side effects and risks should be given during the planning phase. Attached breakwaters are often complemented with nourishment to mitigated adverse side effects.	High visual impact and intrusion in the beach surf zone. Incomplete understanding of the coastal dynamics may lead to negative side effects such as sediment blockage or beach erosion. Creation of erosion hot spots during storm events. Offshore structure influencing current coastal dynamics. Potential health and safety concerns for beach users. Extremely expensive at this site.	Potential for beach accretion. Platform for beach users like surfers, fishing enthusiasts or bathers. Enhance ecology and biodiversity by creating Living Breakwaters type of structure (i.e., substrate for colonization). Wave action sheltering: decreased wave impact at beach dunes or seawall.	MEDIUM-LONG	0
10	**Revetment - Rock or concrete units**	Coastal revetments fall in the category of hard protection structures: they consist of sloping structures and are constructed as permeable structures using rocks or concrete blocks. When well designed, revetments can be considered one of the more resilient coastal protection structures because of their ability to resist wave energy and reduce run-up. This type of coastal structure requires a source of quality rock or concrete units that complies with appropriate specifications.	High visual impact and large footprint. Hard-structure induced foreshore and beach lowering due to reflection (rocks are far more reflective than a sloping beach) and end-effect erosion. Decreased beach accessibility. Potential health and safety concerns for beach users. Structure influencing nearshore coastal dynamics. Potential long-term loss of sandy beach. Very expensive at this site.	Design the revetment to cope with foreshore bed lowering and scour, thus larger life-span and low maintenance costs. Integrate access facilities to improve beach accessibility. Significantly increase erosion protection.	MEDIUM-LONG	0
11	**Sand bypass or backpass**	Bypass is a form of artificially restore a (human-induced) blockage of the sediment transport. A bypass system could be used to bring sand from an accreting updrift shoreline to an eroding downdrift shoreline. A backpass system can also be used within the spit north of Sunset Beach, this could take the form of a small cutter dredge that is located within a depression in the spit. The spoil is then transported by a pipeline downcoast to the beach.	Sediment suitability for bypassing. Long-term functioning bypassing network Low success rates and very expensive. Risks associated with nourishment. Thin layer of suitable sediment on the spit. Potential to reduce resilience of spit with respect to SLR.	Mitigate beach erosion. Not creating a large environmental impact. Mitigate structural induced erosion.	MEDIUM-LONG	6
12	**Seawall: vertical or recurved**	A seawall is a form of coastal defense constructed where the coastal processes impact upon the coastal landforms. The purpose of a seawall is to protect the coastal land from coastal hazards such as coastal erosion and inundation. It is typically an impermeable structure that impede the exchange of sediment between land and sea, and it induces wave reflection. As with the other hard structures, this option could also be complemented with beach nourishment to mitigate negative side-effects.	High visual impact Hard-structure induced foreshore and beach lowering and end- effects. Structure influencing nearshore coastal dynamics. Potential long-term loss of sandy beach. Exposure to rapid/instant structural failure. Extremely expensive at this site.	Small footprint. Holding the line structure. Provides landward erosion and inundation protection.	MEDIUM-LONG	0

	Option Description		Risks	Opportunities	Timeframe	Map
13	**Salt resistant planting**	It has been shown that vegetated areas can help to reduce erosion risk, especially where native species are used. Planting dunes and foreshore with salt resistant species (e.g., spinifex and pingao) capable to reduce water run-up (through percolation) and withstand storm events can be considered if the coastal area is suitable for planting.	Planting may not withstand wave action or high energetic events. Difficult in an actively eroding situation. The effects on erosion protection may be perceived as negligible.	Increase biodiversity and ecological value. Increase aeolian sedimentation and development of a larger buffer zone.	SHORT-MEDIUM LONG (with continuous maintenance)	7
14	**Wind Blown Sand Capture**	Construction of sand trapping fascines from biodegradable brush. Fascines are built cross shore from the base of the dune to the mid-water line. They work to trap primarily windblown sand and slow erosion.	May not withstand high energy waves or currents. Can be tampered with. May require resource consent. Effectiveness is not guaranteed.	Low cost, low detrimental impact, and low risk. Encourages community involvement.	SHORT - MEDIUM	8
15	**Secondary/set-back raised defense**	This option could be considered as a mitigation measure for rapid failure of current coastal protection strategies. It consists of the construction of a structural coastal protection, i.e., a secondary defense, landwards the existing coastline. This option is considered be under the *protect* approach, although could be considered a *retreat* strategy too.	Loss of current protection if left abandoned. Rapid erosion of the seaward side of the secondary defense once exposed to waves/currents.	Decrease coastal erosion and inundation risks. Reduce emergency works. Decrease maintenance costs on existing coastal structures.	SHORT-MEDIUM	0
Retreat						
16	**Decommissioning of current hard coastal protection structures, short term protection measures or temporary solutions for coastal protection.**	The decommissioning of hard structures, such as seawalls, or temporary/short-term measures, may need to be combined with other options as new exposed areas might be at risk of erosion. Erosion and/or flooding risks need to be addressed and understood, especially if properties are at risk. If the erosion or flooding risk is considered too high, this option could be accompanied with temporary mitigation measures to reduce that risk, e.g., buried toe protection in front of dune faces to accommodate beach extremes. Monitoring of beach evolution may also be required to assess risk exposure of the newly exposed hinterland.	Loss of current level of service, flooding, and erosion protection. Increase in erosion/flooding risks. Loss of current amenity value. Unknown coastal processes response, e.g., potential rapid recession of the beach after structure's removal.	Increase beach space for coastal processes – e.g., naturalization of the carpark to provide a wider buffer zone, as undertaken at Muriwai. Removal of any health and safety hazards/concerns Engineer/design of more suitable waterfront/coastal protection landwards. If maintenance costs of these coastal protection measures are high, this could be eliminated or reduced. Opportunity to relocate and/or improve current amenity value.	SHORT-MEDIUM	0
17	**Compartmentalization - backstop walls**	Compartmentalization is a type of managed retreat. It would consist of creating compartments landwards the current coastline. The created compartments would be designated as protected areas and/or sacrificial land that are to be given to the beach. The landward side of the compartments are intended to withstand erosion and/or episodic flooding during storms.	Loss of amenity value within the seaward compartment. Rapid erosion of the compartment seaward end. Increased discontinuities along the coastline.	Increase ecological value and biodiversity by creating natural buffer zones such as estuaries. Increase beach accommodation space. Opportunity to increase amenity value by increasing landscape naturalness. Improve beach access. Create community activities like planting suitable for the buffer zone.	MEDIUM-LONG	0
18	**Relocation of existing assets along the coastline**	It may be that the coastal edge or hinterland contains assets such as transport infrastructure that may be exposed to coastal erosion and inundation. This option proposes the early relocation of these existing assets along the coastline to avoid emergency works to restore the assets functionality. The relocation of the assets can be seen as a proactive approach to cope with the uncertainties associated with the effects of storm events and future climate change/SLR pressures.	Need available space landwards for the relocation. Potential loss of amenity value along the coastal edge/hinterland. Can result in access issues to properties that depend on road or other infrastructure.	Creation of beach space. Reduce/eliminate coastal hazard risks on assets. Improve resilience of coastal edge/hinterland. Possibility to increase amenity value.	LONG	8
19	**Storm surge/erosion buffer**	This option consists of creating a buffer zone as an area designed to be flooded and/or naturally eroded. This option implies accepting the damage to the current beach coastline, especially during storm conditions. To delimit the flooding area and to protect the landward land not destined to be flooded, the construction of a bund or similar structure may be necessary to avoid future erosion risks.	No assets should be contained within the buffer zone. Rapid erosion of the buffer area. Construction of a backstop wall may be required to avoid future erosion risks.	Increase ecological value and biodiversity by creating natural buffer zones such as estuaries. Increase beach space. Opportunity to increase amenity value by increasing landscape naturalness. Improved beach access. Create community activities like planting suitable for the buffer zone.	LONG	0
20	**Use of PDP provisions**	Will require replacement or relocation of existing buildings in High-Risk Coastal Erosion Area to mitigate risk from erosion through relocatable building design.	Requires triggers and adaptive pathways. Risks - may require future retreat Opportunities	Allows for continued use of land where appropriate, increases resilience of buildings, and provides certainty for possible future scenarios. Similar to option 1, 18 and 21.	Medium/Long	0

	Option Description		Risks	Opportunities	Timeframe	Map
21	**Relocate/buy properties at risk**	This option consists of the relocation/acquisition of residential and commercial properties exposed to erosion and/or flooding risk currently or in the future.	Owners' refusal to sell/relocate their property/business, which may turn into a legal battle.	Own the land at risk. More flexibility to elaborate a long-term plan for the coastal system.	LONG	0
Avoid						
22	**Re-Zoning**	Re-zoning can be done for different purposes: to prevent further development, to prevent re-development/land-use change (unless new use is less vulnerable), to expedite retreat (prevent resale/reoccupation and remove use rights) or to immediately extinguish existing use rights. The re-zoning of the current land-use is to favour the long-term strategy plan of the coastal hinterland. Similar outcomes can be achieved through overlay areas with associated restrictive provisions.	May be unpopular with community and elected members. May require changes to a District Plan that has already been through consultation recently. Any downzoning approach needs to be balanced with ensuring adequate land is available elsewhere for 'resettlement' - including supporting physical and social infrastructure Any imposition of a provision that extinguishes existing use rights is also subject to section 85 of the RMA (financial implications as court can require Council to purchase the land)). http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM233831.html	Could strengthen the controls on development and densification in vulnerable locations. Reduces exposure of property and amenities over time. As an alternative to zoning WDC could designate the land for a purpose aligned to hazard mitigation (as an alternative to re-zoning). This could trigger owner seeking WDC purchase their land by going to the Environment Court. Rezone to expedite retreat (for instance, prevent resale/reoccupation and remove existing use rights) would need to be a rule provision in a Regional Plan (s30(1)(c)(vi) and s20A RMA (so would need to be facilitated either by a private plan change by WDC to a regional plan or somehow convince the WRC to lead one).	LONG	0
23	**Make alternative lower-risk locations favourable**	This consists of facilitating lower risk areas for development.	Potential loss of existing amenity value along the coastline.	Increased flexibility within the coastal zone for a long-term plan. Ability to introduce new amenities and co-benefits of coastal protection, environmental restoration, and public recreation.	LONG	0
24	**Use LIMs to communicate risk and allow community (and banks/insurance) to react/respond**	This option requires and update of the Land Information Memorandum (LIM) report to include coastal hazard and climate change associated risks. The LIM report could be used to inform landowners. Including known Hazard information on LIMS is required by law. Hazard overlays are also likely to be included in the PWDP	Can result in legal challenge from the community. Requires careful and credible assessment of erosion and flood risk in the coastal zone that is robust enough for legal challenge. Unpopular approach.	Clarifies risk and directs market away from at risk locations. Risk is clear to property owners.	LONG	0
25	**Forced land use change/acquisition to lower risk use**	This option implies the negotiation for land procurement	Potentially expensive for Council.	Enables Council to move forward with adaptive management along the shoreline.	LONG	0

Figure 8.2. The numbers refer to the categories/options presented in Table 8.1 for the various parts of around Port Waikato. In some areas there are multiple options, often of which require a sequence to be followed. For example, 7 'wind-blown sand capture' can be undertaken above the mean high water spring tide mark once an accretional phase begins, and following the successful development of foredune (which may require lifting and extending the sand capture devices), salt resistant plants can be established.

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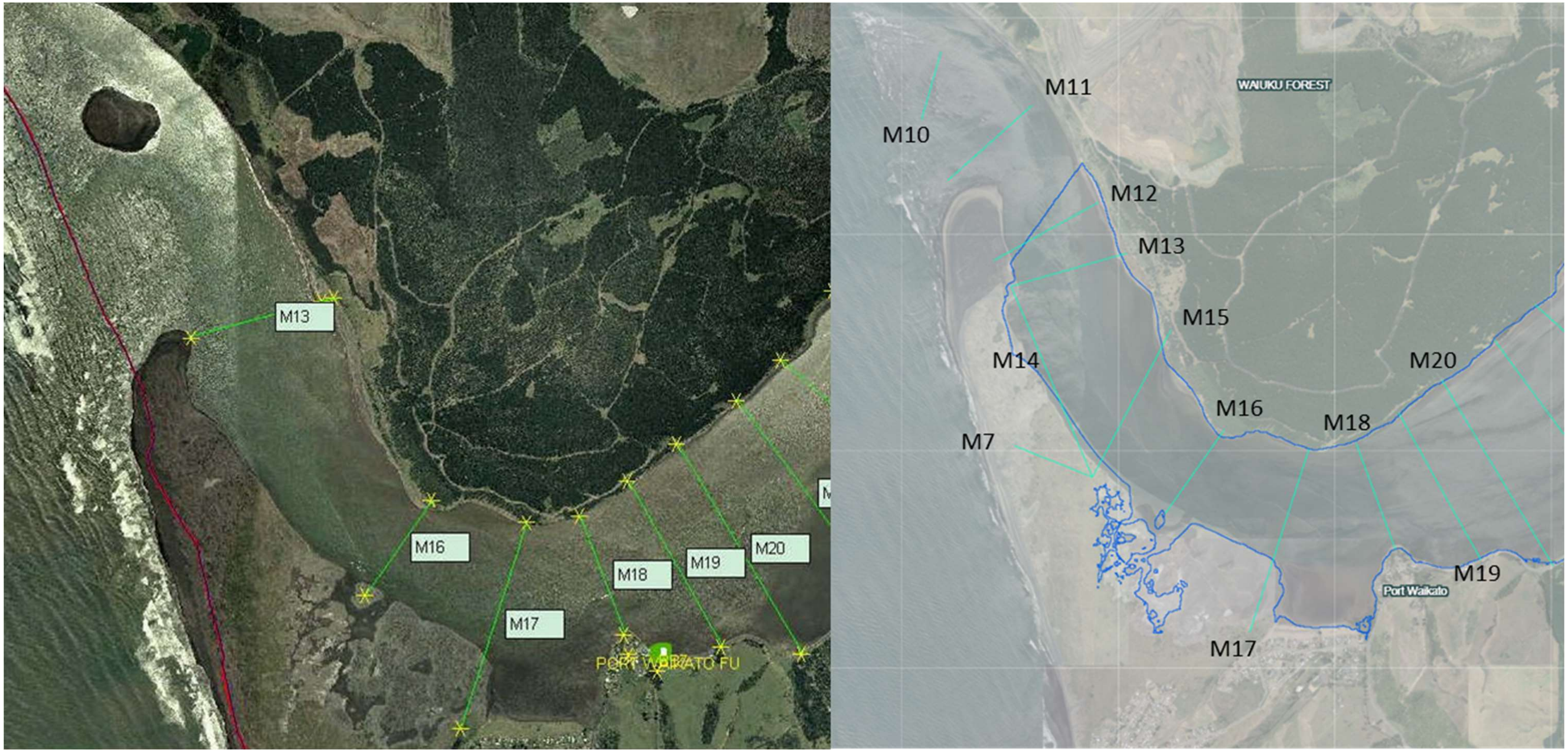
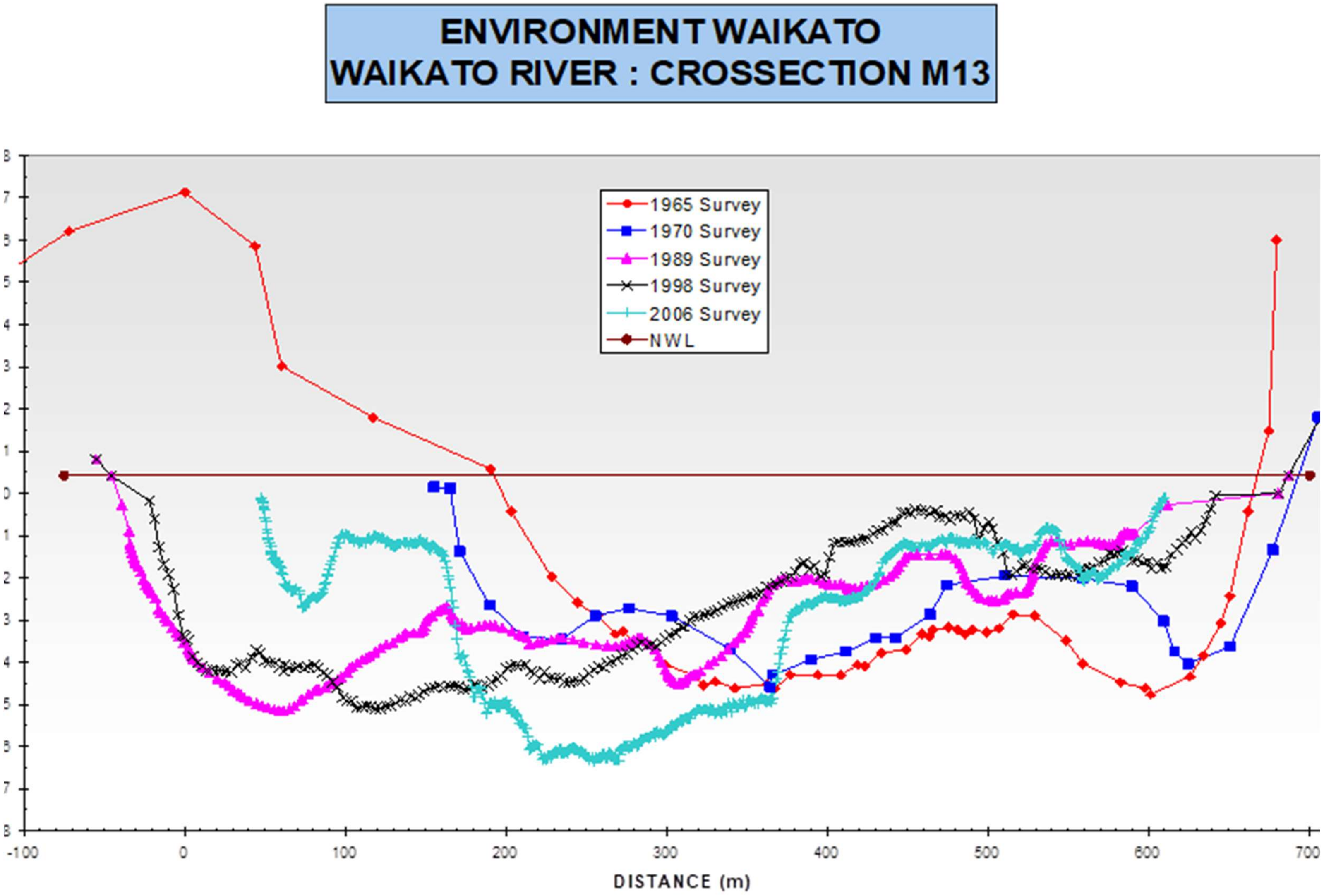
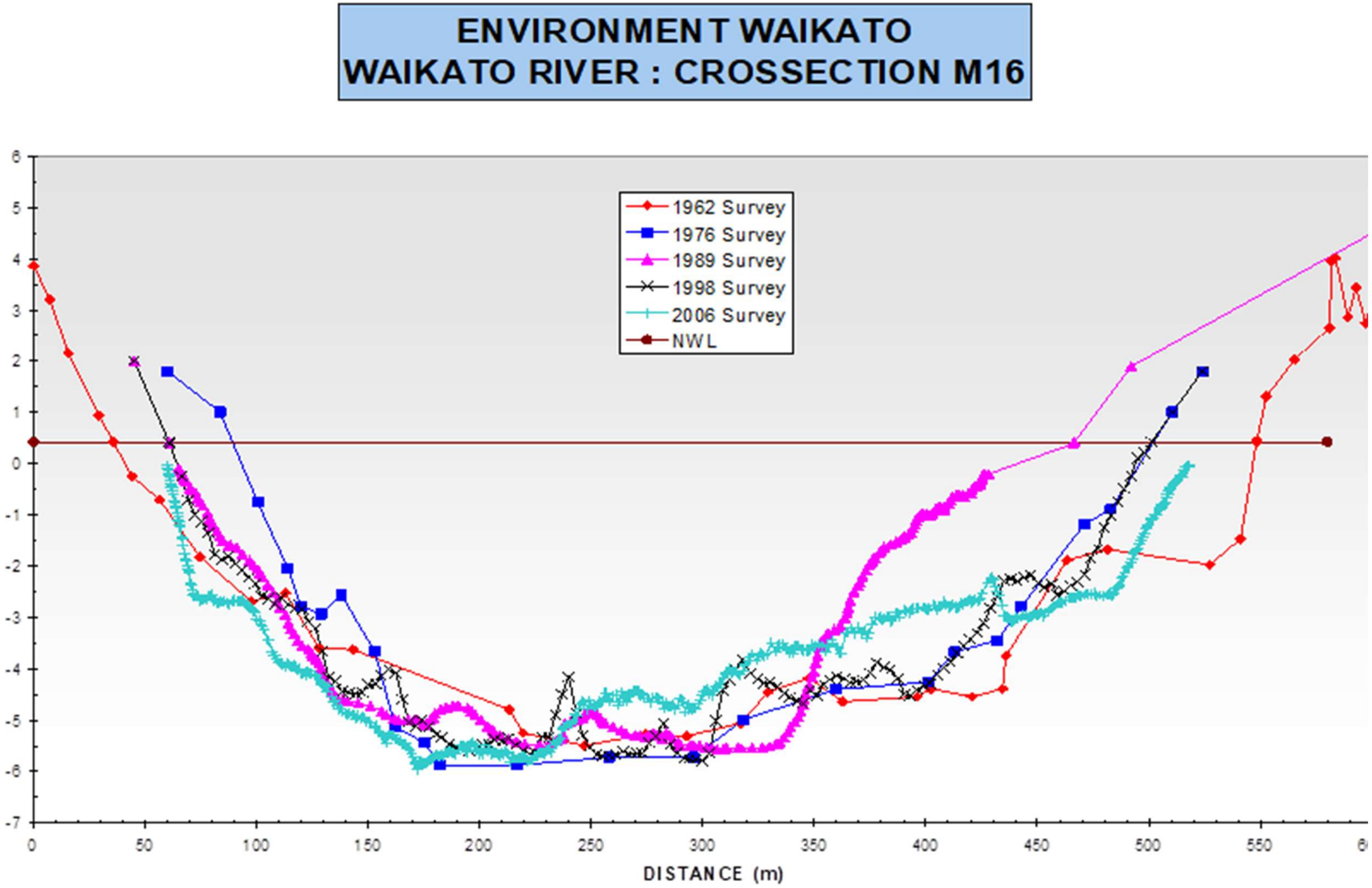
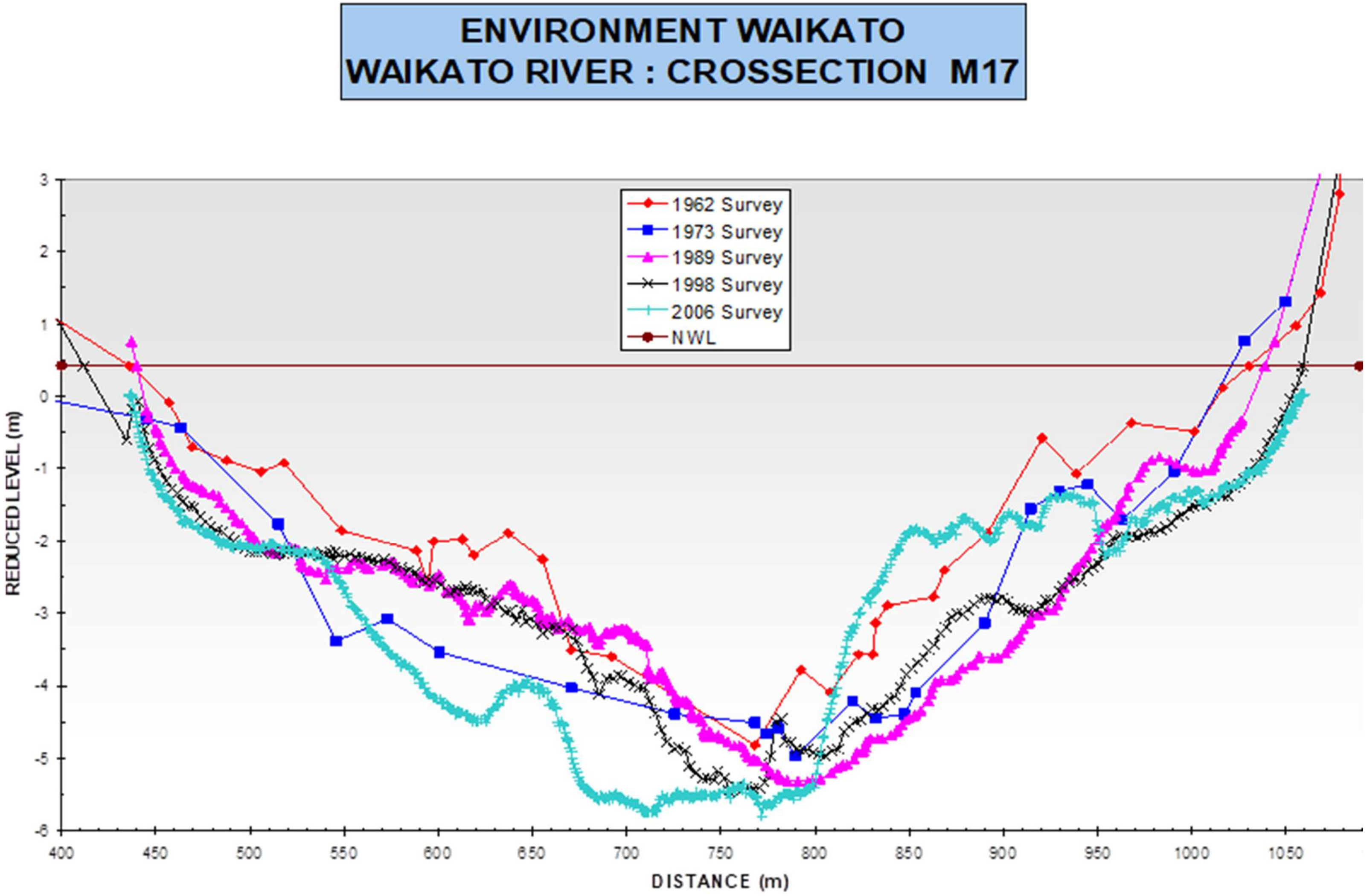
Appendix A. Waikato River Cross Sections from Environment Waikato (Mead *et al.,* 2007) and New Cross Sections from Waikato Regional Council

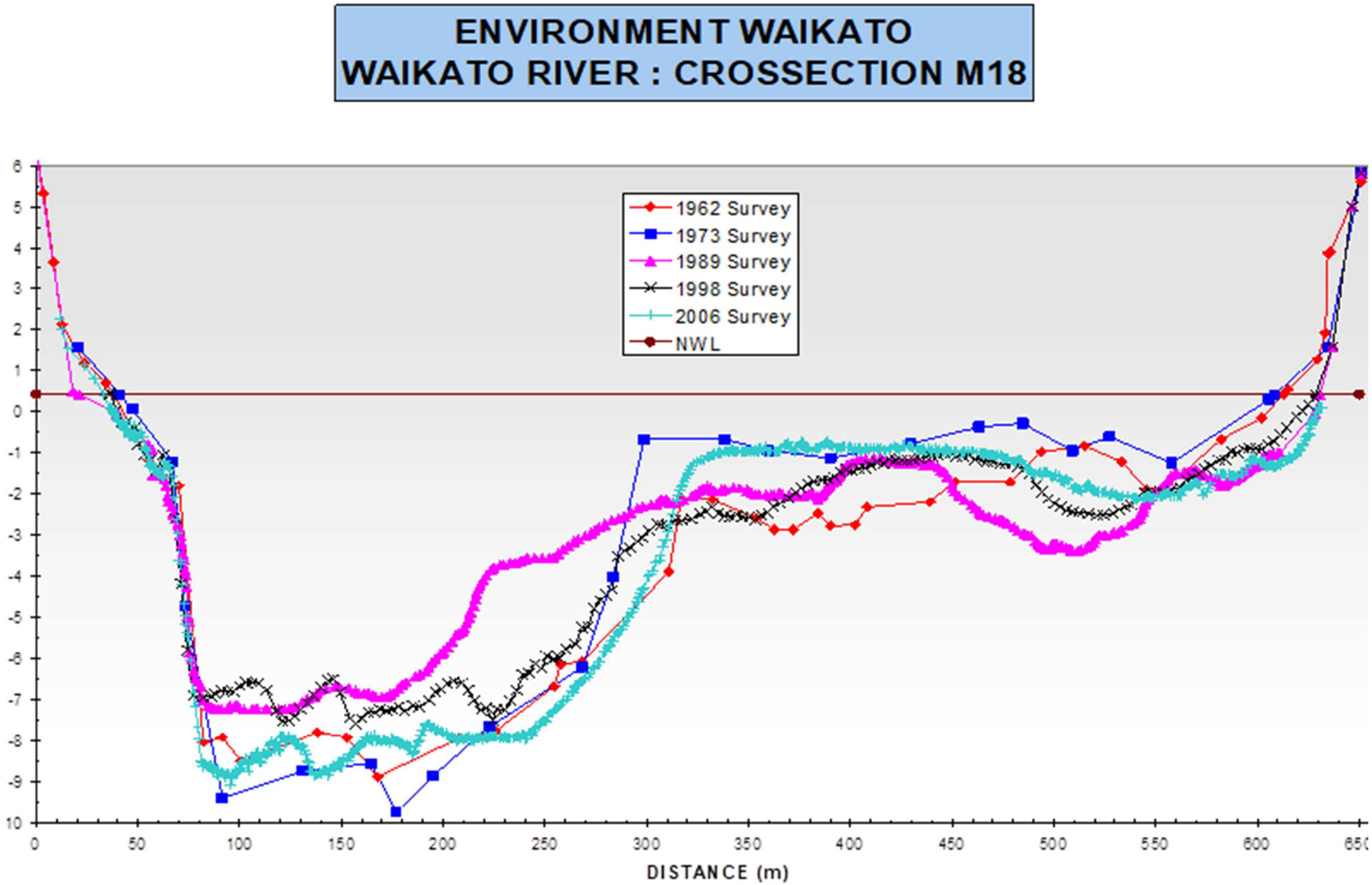


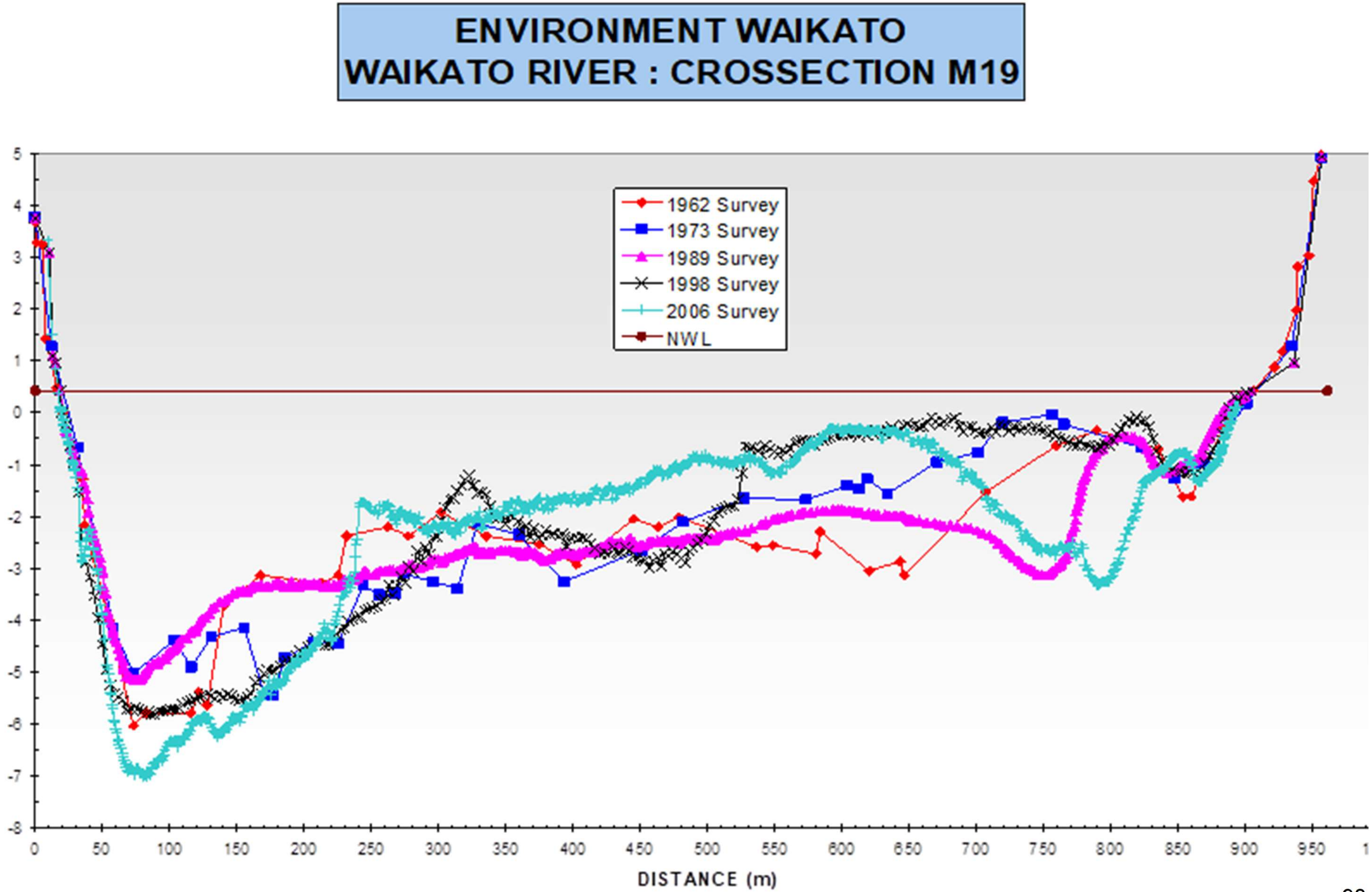
Left -Environment Waikato, Waikato River Cross Sections (Mead *et al*., 2007). Right – Waikato Regional Council, Waikato River Cross Sections. Sections are presented looking downstream.

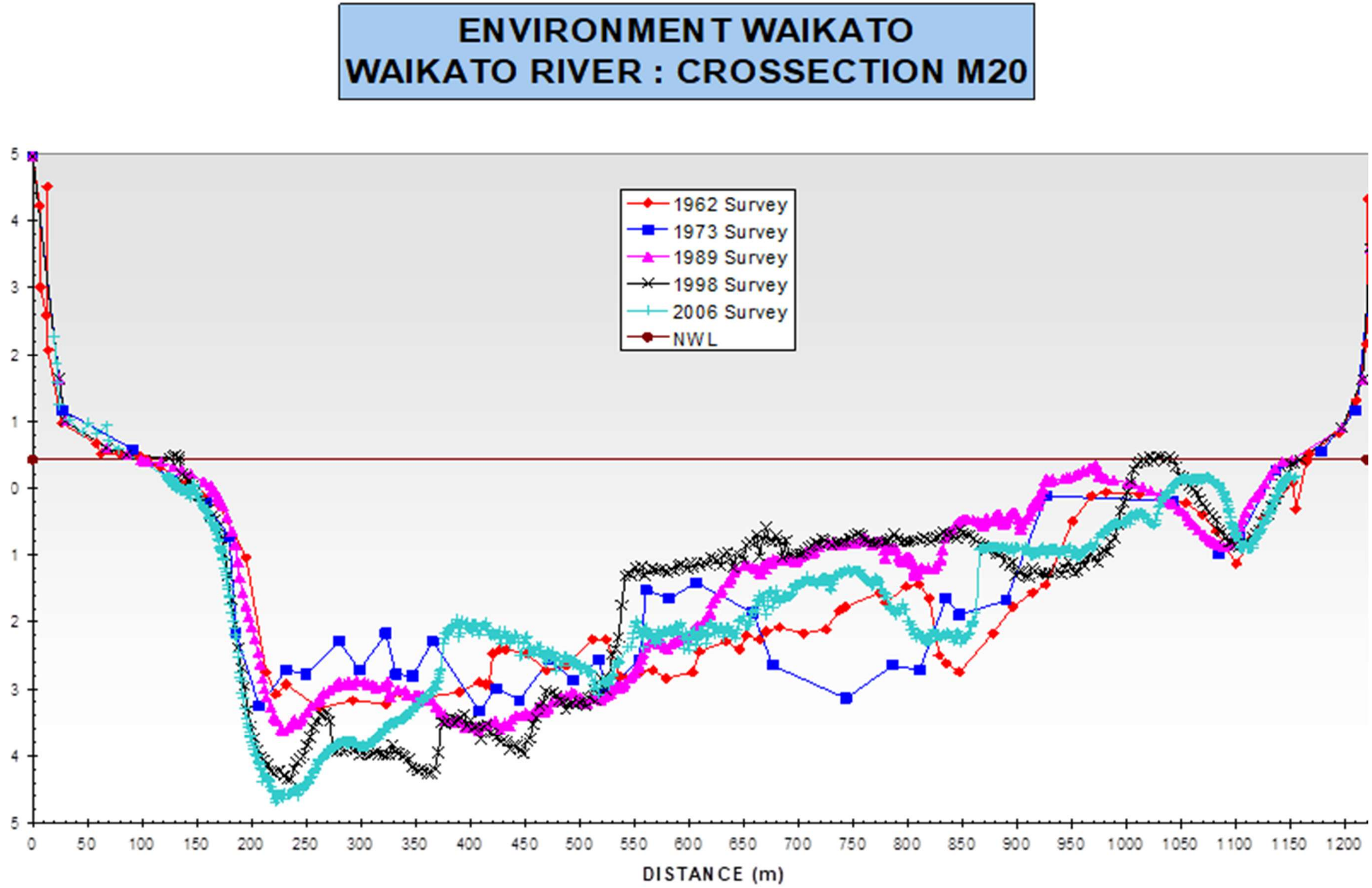

ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M13
1965 Survey
1970 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
DISTANCE (m)
-100
0
100
200
300
400
500
600
700

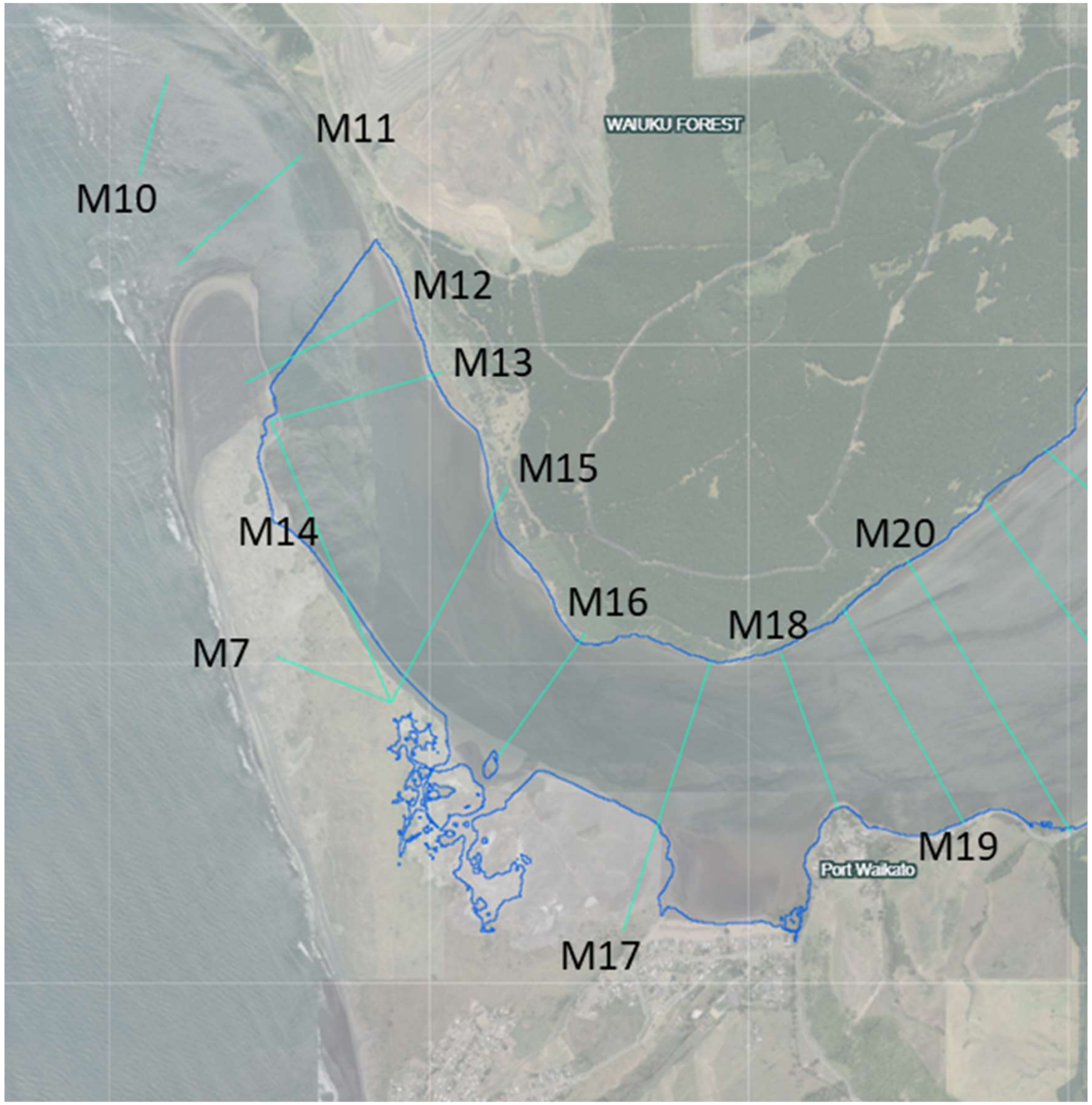

ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M16
1962 Survey
1976 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
DISTANCE (m)


ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M17
1962 Survey
1973 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
3
2
1
0
-1
-2
-3
-4
-5
-6
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050


ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M18
1962 Survey
1973 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
DISTANCE (m)


ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M19
1962 Survey
1973 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1
DISTANCE (m)


ENVIRONMENT WAIKATO
WAIKATO RIVER : CROSSECTION M20
1962 Survey
1973 Survey
1989 Survey
1998 Survey
2006 Survey
NWL
5
4
3
2
1
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
DISTANCE (m)


M11
WAIUKU FOREST
M10
M12
M13
M15
M14
M20
M16
M18
M7
M19
Port Waikato
M17

Appendix B. Port Waikato Resilience Group Action Plan (Draft), and Sunset Beach Erosion Response Plan (Draft)

Action	Description	Action lead	Resourcing	Status	Next step	Action completed (date)
COASTAL PLANTING						
▪ Plant stock	Develop a source of affordable / no cost and locally sourced plants for us in Port Waikato planting project					
▪ Planting advice	Develop an information resource (booklet or similar) to assist residents – information on what species to plant where and when, post planting maintenance requirements, etc.					
▪ Planting Plan	Develop an overall planting plan for the Port Waikato Area defining areas for planting and a programme of works					
DUNE STABILISATION						
▪ Wind Erosion	Investigate cost effective wind erosion solutions (including identifying consenting					

Action	Description	Action lead	Resourcing	Status	Next step	Action completed (date)
	requirements, capital and operational costs etc) and report recommendations to PWRG					
▪ Public access	Install and maintain signs and other devices to restrict / prevent public access to sensitive dune areas					
▪ Erosion repair	Investigate cost effective solutions for repairing erosion damage (including identifying consenting requirements, capital and operational costs etc) and report recommendations to PWRG					
▪ Erosion reduction trial	Investigate a cost effective solution that can be trialled on Sunset Beach to reduce wave erosion (including identifying consenting requirements, capital and operational costs etc) and report recommendations to PWRG					
REGULATORY						

Action	Description	Action lead	Resourcing	Status	Next step	Action completed (date)
▪ RMA Advice	Source advice on consenting requirements for coastal structures / erosion intervention measures					
▪ Building Act Advice	Source advice on Building Act implications for relocating / construction new dwellings in erosion hazard areas					
EMERGENCY RESPONSE						
▪ Erosion Event Emergency Response Plan	Develop an Emergency Response Plan which details who is to respond and how in the event of a significant erosive event at Port Waikato					
PUBLIC ASSETS						
▪ Drain clearance	Clear / reinstate drains along coastal frontage to address unmanaged stormwater issues					

Action	Description	Action lead	Resourcing	Status	Next step	Action completed (date)
▪ Car park works	Install measures to prevent overland stormwater flow from sealed areas exacerbating dune erosion at Sunset Beach					
▪ Public toilets	Resolve sewerage leaks at public toilets					
COMMUNICATIONS						
▪ Communications Plan	Develop a communications plan for the PWRG					

PORT WAIKATO COMMUNITY RESILIENCE STRATEGY

Sunset Beach Erosion Response Plan

Context

The Sunset Beach Erosion Response Plan is developed as part of a suite of deliverables (Table 1) being prepared by the Port Waikato Resilience Group (PWRG).

Table 1: Port Waikato Resilience Group Deliverables

	PWRG Action Plan	Sunset Beach Erosion Response Plan	Port Waikato Resilience Strategy
Planning horizon	0 to 24 months	0 to 5 years	0 - 100 years +
Purpose	Drives projects / actions for responding to immediate natural hazards risks and other community matters in Port Waikato in the short term.	Short-term slowing / halting of erosion losses at Sunset Beach to mitigate further serious damage to infrastructure and property from coastal erosion at Port Waikato while a long-term plan is developed	Long term, adaptive plan for responding to natural hazards risks and impacts including the effects of sea level rise
Pre-requisites	Projects must - Be able to be rapidly deployed. - Respond or be related to a natural hazards issue. - Have minimal or no resource consent requirement. - Be low cost. - Be undertaken on a "no-regrets"" basis. - Complement an adaptive planning approach.	Project must: - Represent the best practicable option for the short-term response to erosion issues at Sunset Beach - Be implemented within reasonable timeframe. - Complement an adaptive planning approach.	Projects must: - Follow the dynamic adaptive pathways planning approach for coastal hazards as set out in the Ministry for the Environments for guidance for local government

Outcome Sought

By December 2022, the Sunset Beach Erosion Response Plan will result in the implementation of physical works to reduce erosion losses at Sunset Beach.

Draft Objectives

The following draft objectives are set for the purposes of undertaking a multi-criteria analysis (MCA) of options for reducing erosion risks at Sunset Beach. Setting clear objectives ensures that the ultimate decisions taken achieve desired outcomes.

Draft Objectives:

1. Meaningfully reduces erosion risks to people and properties along Ocean View Road and Council and community infrastructure at Sunset Beach, for at least 5 years.
2. Complements long-term adaptive planning approach for Port Waikato
3. Preserves the natural character of the Sunset Beach environment
4. Affordable for Council and community

Draft Criteria

The following draft criteria (Table 2) will be used to assess the performance of options being considered for the Sunset Beach Erosion Response Plan. A criterion for cost has not been included. It is proposed that cost is used as a second stage to compare options, with the final option being selected based on a combination of its criteria score and cost, and its ability to achieve the defined objectives.

Table 2: Draft Option Assessment Criteria (MCA) for Sunset Beach Erosion Response Plan

Criteria Type	Criteria	Description	Proposed Scoring Guide
Performance of the option in reducing risk	**1. Manages the risks of coastal erosion**	• Reduces exposure to erosion effects for the build environment • Responds proportionately to the scale and nature of the erosion risk • Proven technology with track record of success	**5** – High / Good **4** – **3** – Mid **2** – **1** – Low / Bad
	2. Potential for exacerbation of risk	• Risk of exacerbation of natural hazards risks affecting others outside of project focus area • Risk of increasing risk to others, including future generations	**5** – Low / Good **4** – **3** – Mid **2** – **1** – High / Bad
Effect of implementing the option	**3. Socio-economic impact**	• Effects on community safety • Loss of amenity value, beach access and use • Decline in recreation values • Loss of community facilities • Indirect economic impacts such as tourism	**5** – Low / Good **4** – **3** – Mid **2** – **1** – High / Bad
	4. Impact on cultural values	• Effects on cultural sites • Impacts on kaimoana abundance / access • Limits access to and/or the carrying out of customary activities	**5** – Low / Good **4** – **3** – Mid **2** – **1** – High / Bad

	5. Impact on the natural environment	• Effects on natural coastal ecosystems • Effects on the natural character of the coastal environment.	**5** – Low / Good **4** – **3** – Mid **2** – **1** – High / Bad

Options for Assessment:

The following options have been sourced / adapted from the 2021 eCoast report "*An Overview of Coastal Processes and Drivers of Coastal Hazards: Port Waikato*", and supplemented with advice and input from members of the Port Waikato Resilience Group, Nature Based Solutions and Dr Terry Hume.

Note that this options list is not intended to be exhaustive – options such as hard defence measures have not been included as these are clearly beyond the scope of this erosion response plan which has a short term (approximately 5 year) focus.

For each option, a recommendation is provided on whether the option should be advanced for assessment under this plan.

Table 3: Options under consideration for Sunset Beah Erosion Response Plan

ID	Option	Description	Recommendation
0	**Do nothing**	Take no further action in response to erosion at Sunset Beach – let nature take its course	Shortlist for assessment
1	**Do minimum**	Minimal intervention, reactive measures against storm events damage, as well as maintenance of the existing erosion response measures	Shortlist for assessment
1	**Planting**	Re-establishing native dune species (i.e., spinifex and pingao), once an accretionary phase begins.	Progress through PWRG Action Plan
2	**Wind-blown sand capture**	Building brush fascines to capture wind-blown sand to increase the sand reservoir and create a wider beach/buffer; once an accretionary phase begins.	Progress through PWRG Action Plan
3	**Stormwater Management**	Providing for stormwater management and relocation of stormwater infrastructure.	Shortlist for assessment
4	**Sand renourishment trial**	Undertaking sand management trial in the form of transferring sand from one part of the spit to another. For example, back-passing material from inside the spit north of Sunset Beach to renourish the beach.	Progress through PWRG Action Plan

5	**Inundation protection**	Creating a raised buffer zone along the northern and eastern parts of the township to increase resilience to inundation due to SLR and CC	Consider for longer term strategy for Port Waikato
6	**Coastal erosion buffer**	Increase beach space for coastal processes – e.g. naturalization of the carpark to provide a wider buffer zone.	Shortlist for assessment
7	**Asset modification**	This option can include a range of actions such as relocation of assets and or modifying assets so that they can be relocated if required.	Consider for longer term strategy for Port Waikato
8	**Improved drainage**	Improving drainage can help to reduce structural and dune loads. A common cause of dune failure along the coast is a combination of wave action, soil saturation and water runoff. By improving drainage, the likelihood of beach/dune failure may be reduced.	Shortlist for assessment
9	**Dune rehabilitation and/or reshaping**	Some areas of the coastal dunes have been modified and/or removed (e.g. flattened and clay-capped). By re-creating, reshaping, or rehabilitating these dunes, a more resilient natural defence could be achieved to accommodate storm events, changes in sediment supply and to prepare the dune for upcoming coastal changes (i.e. SLR).	Shortlist for assessment
10	**Beach recharge or nourishment below high-water mark**	Beach or foreshore nourishment serves to compensate the eroded or lost sand without big impacts in the sediment transport patterns. The latter implies that if erosion is present, the natural erosion processes will continue. Beach nourishment requires a sediment source: ideally, the eroded material is replaced on a regular basis with sand from somewhere else. Sand could be supplied from local borrow areas (e.g. areas of accumulation/accretion), or from offsite sources (e.g. the flood or ebb tidal delta).	Consider for longer term strategy for Port Waikato
11	**Beach recharge or nourishment above**	As above, however if all activity takes place above the highwater mark, i.e.	Shortlist for assessment

	high-water mark	sand redistribution on land, then consenting issues can be avoided. Beach scraping or dune 'push up' activities can be part of this action, but resource consenting may be required.	
12	**Secondary/set-back raised defence**	This option could be considered as a mitigation measure for rapid failure of current coastal protection strategies. It consists of the construction of a structural coastal protection, i.e. a secondary defence, landwards the existing coastline. This option is considered be under the protect approach, although could be considered a retreat strategy too.	Shortlist for assessment