Mangawhai Harbour and Spit

Coastal physical processes and management

Prepared for Mangawhai Matters Inc

19 July 2023

HCL

Hume Consulting Ltd

Prepared by:

Terry Hume (Hume Consulting Ltd)

For information regarding this report contact:

Dr Terry Hume

Managing Director Hume Consulting Ltd

027 226 7263

terryhume6@gmail.com

Client report for: Mangawhai Matters Inc

Date: 19 July 2023

Cover Image: Google imagery 4 November 2019

Foreword

Mangawhai Matters Inc is undertaking the Sustainable Mangawhai project to develop an information base to support decision making for the future of our harbour. We see this as necessary in the face of increasing climate volatility, sea level rise, and continuing catchment development. The reason that Mangawhai Matters is taking this on is that, until now, no one organisation has championed the total harbour environment: the distal spit, the estuary, the wildlife, and the community that surrounds and, to a considerable extent, depends on it.

It is time to consider the future using a comprehensive approach so that those charged with managing it are aware of the risks facing Mangawhai's coastal environment and the consequences if the spit and harbour are degraded. We know from past events that serious damage to the spit can have a major impact on the harbour with far-reaching consequences for environmental and community well-being.

A comprehensive approach to future threats is in the interests of all stakeholders. These include the residents and visitors who together make up the Mangawhai community, local and central government agencies, and the volunteer groups, each with its particular interest in the harbour and environment. While different parties may have different objectives, all of them will be impacted if the spit is severely damaged or the quality of the harbour diminished. In our view, well-founded information based on expert analysis will enable stakeholders to align management policies and practices. Differences among them are most likely to be resolved through sharing scientifically sound evidence about the risks the environment faces and understanding the consequences.

It was with this in mind that we commissioned Dr Terry Hume, a recognised expert, to review the evidence on coastal physical processes impacting on the spit and the harbour, the threats that they pose, and how the risks of damage might be mitigated. We also asked him to consider what gaps there might be in our knowledge. We anticipate addressing such gaps in future reports.

Local donations funded this commission, indicating that the community recognises the significance of the matters it covers, and the approach Mangawhai Matters is taking. We are pleased to be able to share the resulting report, *Mangawhai Harbour and Spit - Coastal physical processes and management*.

Dr Hume has drawn together material explaining the processes affecting the coast and harbour as well a wide range of local evidential material from a variety of sources. He has also addressed issues currently preoccupying the community, providing a basis for deliberation on management options.

The report should prove a very useful reference work for any consideration of matters affecting the state of the harbour. It gives us a well-informed view of the challenges we are facing and the options available. We offer it as a valuable resource for the community.

Doug Lloyd
Chairman
Mangawhai Matters Inc.
July 2023

Executive Summary

This report was commissioned by Mangawhai Matters Inc to assesses the threats to the Mangawhai Harbour. It draws on the science associated with coastal processes and existing knowledge about the Mangawhai harbour and spit (Section 3). It describes the drivers of coastal processes under conditions associated with climate change, sea level rise, and increasing human activity (Section 4). Section 5 summarises potential threats, and the risks they pose. It identifies mitigation and monitoring strategies that might reduce them. Gaps in our knowledge that may need to be addressed to help develop and refine management policies are also identified.

This summary highlights key issues arising from the study.

Protecting the integrity of the spit

Protecting the stability of the spit and its shorelines is the key to maintaining the integrity of the harbour because the consequences of a breach would be far-reaching. The 1978 breach saw the loss of a safe entrance and shelter for vessels, erosion of the western shore, and eutrophication of the lagoon. Should a similar breach occur in the future, closing the breach to restore the harbour will face major hurdles around consenting and costs. Under those circumstances, prevention through appropriate harbour and spit management appears the best way to protect the environmental and community benefits they provide.

The weak point of the spit today is the narrow neck 1.5 km south of the entrance. In March 2023 Cyclone Gabrielle also left severely eroded dunes along much of the ocean edge. Today, there are areas of very low or non-existent dunes through which the sea can potentially penetrate the spit. Further storms of similar magnitude could exacerbate this situation. It is critical that stability of the ocean coast shoreline continues to be monitored to identify hot spots where erosion and inundation require the volume of sand and height of the dunes need to be built up.

While a breach remains a long-term risk. the severity of potential impacts calls for the avoidance of actions that will increase that risk, and for a sound understanding of the forces behind it. Discontinuing current measures for spit management, for example, could place the protective role of the spit in jeopardy. These measures involve using sand dredged from sand traps in the harbour to nourish the neck area, maintaining and planting sand binding vegetation, and building up the dunes on the ocean shoreline. Moving forward, the effectiveness of dredging should be monitored by recording quantities and placement on the spit with a view to maximising its protective role.

In the event of an increase in the risk of a spit breach, it would be appropriate to ensure that emergency dredging and sand placement can take place, although this will face constraints around cost, rate of delivery, and available volume. An alternative is to provide for earth moving machinery to repair and speed up recovery of protective dunes should extreme conditions call for it.

It is also important to take preventative measures to manage risk by averting undue loss of foreshore dunes on an ongoing basis. This can be done through continuing sand trap fencing and planting until such time as more extreme conditions call for a more definitive response.

On the harbour shore sand dredging and placement, wind break fencing, and planting need to continue to counter the threat of erosion from channel meander and higher water levels during storm surge events. An alternative to such "soft" management techniques is to build protective structures such as groynes or revetments in the vicinity of the neck to stabilise the channel meander and the shore.

Sand mining on the open coast

Sand mining on the open coast reduces the coastal sand budget, potentially increasing coastal erosion and, consequently, the risks to the spit. While the annual removal of sand provided for in the resource consent applications before the Environment Court is small relative to total sand in the embayment, the cumulative effect of extraction since the 1920’s needs to be considered, especially as there is considerable doubt as to whether the sand extracted is replenished by that from streams, cliff erosion, shell production and offshore sources.

Because the effects of extraction are spread over a wide area, the relationship between mining and shoreline erosion is difficult to prove. Net erosion of the Mangawhai-Pakiri embayment shoreline, including the spit, is gradual, small, and obscured by variations in the distribution of sand by storms. However, it can be expected to accelerate in the face of climate change and sea level rise. Under these circumstances, ocean mining can be seen as increasing the threat of damage to the spit.

While evidence presented to and decisions from the current Environment Court hearings will decide the future of oceanic sand mining off the spit, the applications for sand extraction in the nearshore and mid shore can be opposed on precautionary grounds.

Managing water quality

Over-development and intensification of land use in the catchment lower water quality through inputs of sediments, nutrients, and bacterial contamination via runoff during rain events resulting in the sandy harbour substrate being overlaid by mud. These inputs can also change the benthic ecology and food availability for fish and bird life. In the longer-term climate change will be accompanied by more and more intensive La Nina and El Nino oscillation. This will mean more frequent, intensive and longer rainstorms and flooding leading to increased catchment erosion and runoff.

The potential effects in Mangawhai Harbour will be greatest in the headwaters and the tidal creeks closest to the source and where flushing is relatively poor. This will change the ecology where sandy substrate becomes muddy and waters more turbid. While the effects can cascade down the harbour, the risks are less in the middle and lower reaches where wind waves and better tidal flushing can resuspend and transport the mud from the sandy substrate. In these areas, the effects of effects of heavy runoff events currently last for short periods only (days).

It is very difficult to remediate water quality once the nutrients and sediments have entered the harbour. The only practical solution is to control activities at source through initiatives such as riparian planting of stream margins to reduce sediments, nutrients and bacterial contamination entering streams, and land use policies. While there is some monitoring of catchment inflows and some of harbour waters there do not appear to be any triggers or thresholds set to initiate action should water quality levels exceed guidelines. It is important that the monitoring continue, and that management strategies are drafted given that catchment development is intensifying and issues associated with runoff are like to be accentuated with climate change.

Coastal inundation

Land and infrastructure bordering Mangawhai Harbour are at threat from coastal inundation (flooding from the sea). While small inundation events are common, extreme and damaging coastal inundation currently are infrequent. Major events require convergence of particular meteorological and oceanographic conditions: a high or king tide, low atmospheric pressure, strong onshore winds, large waves, and stream flooding. Climate change and sea level rise will increase the potential for more frequent and far-reaching such events.

While a little can be done to mitigate effects when coastal inundation occurs, a lot can be done beforehand. Strategies to mitigate inundation and limit coastal erosion include such things as monitoring warnings for extreme meteorological and oceanographic events, modelling the extent and severity of inundation based on predictions of return frequencies and water levels.

Mangroves

Mangroves colonise the intertidal flats from the high tide level down to about mid tide level. Their spread is widely attributed to increased sediment and nutrient inputs from land development and changes in hydrodynamics brought about by things like causeway construction. In turn, mangroves modify the physical environment, most notably by increasing the muddiness of former sandy substrate, sustaining a process of cumulative extension.

A clearance of c.16 ha of mangroves was undertaken in the upper reaches of Mangawhai Harbour below the causeways. Observations suggest that the substrate is reverting to its former sandy nature as the orbital currents from small wind waves resuspend mud which is then flushed from the area.

With rising sea level mangroves are expected to retreat unless sea level rise is offset by increased sediment supply and accumulation and buildup of bed level of intertidal areas. Importantly, mangrove removal is a temporary fix unless further catchment management decisions are taken to minimise the input of land-based sediments and nutrients entering waterways.

Causeways

Causeways are commonly cited as reducing flushing and causing an accumulation of muds and mangrove proliferation upstream of the structure. Historical images show that since causeway construction (post 1963) there have been marked changes in channel and shoal configuration in their vicinity. Comparing the 2015 and the 2023 images shows little change in shoal and channel configurations, indicating that the system had probably reached a state of dynamic equilibrium by 2015 with respect to flows and sediment transport. Mangroves have colonised the tidal flats up- and down-stream of the causeways. However, the degree to which mangrove growth upstream is due to increased sediment accumulation upstream of the causeways is not clear.

The causeway openings may be too small to accommodate any increased discharge associated with tidal prism from sea level rise or floods unless they can scour the bed to increase the cross-sectional area of the throat. Adding culverts to improve the throat capacity would help address this issue.

A numerical model of the harbour could be used to test how mangrove removal and adding culverts to the causeways might change tidal prism, current flows, and sedimentation and provide information to advise removal and engineering strategy and outcomes.

Conclusion

The greatest threat to Mangawhai Harbour lies with the potential loss of protection from the ocean by overtopping or, in the extreme, breach of the spit. The effects of a breach would be severe, heightening the risk and likely scale of erosion of the western shoreline, blocking off the northern entrance leading to eutrophication, and increasing the risk of inundation of low-lying properties. The impacts on biodiversity and community of a breach would be far-reaching.

A decline in water quality is seen as a more modest risk with more limited impacts. Nevertheless, more volatile weather and increasing development calls for a vigilant approach if the harbour's quality is to be sustained. This means stepping up monitoring of the quality of discharges, especially into the upper harbour, and maintaining high standards of land use, riparian, and stormwater management within the catchment.

Contents

Preface

Executive Summary

1 Introduction and background ... 1
1.1 Mangawhai matters ... 1
1.2 Context for this study ... 2
1.3 Study objectives ... 3
1.4 Report outline ... 3
2 Knowledge base ... 4
3 Current understanding of coastal physical processes ... 7
3.1 Evolution of the estuary and spit ... 7
3.2 Mangawhai harbour and spit physical characteristics ... 11
3.3 Harbour hydrodynamics ... 13
3.4 Harbour sediments and their formation ... 14
3.5 Catchment and harbour water quality ... 15
3.6 Drivers of shoreline change – water levels ... 18
3.7 Drivers of shoreline change –Wave climate and storm climatology ... 21
3.8 Shoreline change and coastal erosion ... 25
3.9 Coastal inundation ... 30
3.10 Potential effects of climate change and sea level rise ... 30
3.11 Human influences on coastal processes ... 36
4 A coastal physical process lens on issues and threats ... 39
4.1 Catchment development and runoff ... 39
4.2 Mangroves ... 40
4.3 Causeways ... 44
4.4 Stability of the spit and its shorelines ... 46
4.5 Vegetating the spit ... 50
4.6 Dredging to build up the spit and its shorelines ... 51
4.7 Coastal erosion hazard on the harbour’s western shoreline ... 53
4.8 Coastal inundation hazard ... 55
4.9 Sand mining in the Mangawhai-Pakiri embayment ... 57
4.10 Water recreation and associated infrastructure ... 59
5 Looking ahead ... 61

5.1 Issues, threats, risk and mitigation 61
5.2 Identifying the risk and adverse impacts 66
5.3 Conclusion 70
6 Acknowledgements 71
7 References and information sources 72

Appendix A: Monitoring and information gaps

Appendix B: Peer review of report

1 Introduction and background

1.1 Mangawhai matters

Mangawhai Harbour is located on the east coast of Northland south of Whangārei where an estuarine lagoon is separated from the ocean by a sandy barrier spit (Fig 1-1). The spit has extensive dune fields with sparse vegetation and ephemeral damp sand plain lakes overlooked by a dune reaching 50 m elevation in the south. The spit is home to Caspian terns, variable oystercatchers, godwits, New Zealand dotterels and is the summer nesting site of a small population of endangered fairy terns.

The harbour is a narrow, shallow body of water. In the upper reaches the narrow channels are lined with muddy tidal flats and mangroves. In lower reaches extensive intertidal sands flats and shoals are exposed at low tide and small sandy beaches flank the margins. The harbour waters exit to the sea via a narrow entrance between the tip of the spit and a rock headland.

Figure 1.1. Mangawhai Harbour and spit (C indicates location of causeways).

Mangawhai Heads township and associated urban area are located on the Mangawhai Peninsula, a 4 km long ridge of high ground bordering the western shore of the harbour. Mangawhai Village is located on low lying ground to the south of the estuary. The two areas are linked by road and causeways crossing the upper reaches of the estuary. Mangawhai is a popular summertime destination being close to Auckland and Whangarei, with much of the coast developed with homes, holiday homes, camping and other tourist accommodation. The area provides for a wide range of activities including boat launching facilities, safe anchorage and moorings, sailboarding, kayaking, fishing, surfing, diving, coastal and bush walks, and golf courses.

Mangawhai Harbour is classified as Marine 1 (Protection) Management Area (MM1A) in the Regional Coastal Plan (RCP) and General Marine Zone in the Proposed Regional Plan for Northland (PRP). Within the General Marine Zone there are significant surf breaks at the inlet, a Significant Ecological Area (SEA), a Significant Bird Area (SBA) and a Significant Marine Mammal and Seabird Area (SMMSA). The Mangawhai Sand Spit is administered by the Department of Conservation and classified as an Outstanding Natural Feature (ONF).

Mangawhai Harbour and spit are central to the amenity and values that define Mangawhai locality and community. Their significant cultural, social, and economic value, and provision of environmental services by way of marine and terrestrial habitat and biodiversity are under threat given ongoing and increasing development and the potential impacts of climate change.

Threats to the coastal physical environment come from catchment, harbour, open coast and global sources. More specifically, threats are seen as catchment development and silt runoff degrading the water quality and causing a build-up of muddy substrate, ongoing deflation of the sand spit by wind causing shallowing of harbour channels and shoaling, the spread of mangroves in the upper reaches of the harbour and associated siltation and reduction in tidal prism and flushing, erosion of harbour shorelines, sand mining on the open coast causing shoreline erosion on the spit, and coastal inundation and erosion of the shorelines during storms.

A spit breach is seen as a major threat and risk. In 1978 the spit was overwashed and breached by the sea in a storm opening a second entrance to the sea and eventually causing the northern entrance to fill with sand and close off (McCabe 1985; McCabe et al. 1985). The new southern entrance developed multiple shifting channels and shoals and proved dangerous for boat passage, it allowed ocean waves to attack and erode the inner shore of the estuary, it caused stagnation/eutrophication of the dead arm of water between the north and south entrances, and the closed off northern inlet provided an easy access land bridge for people, vehicles and predators to endangered birds nesting on the spit (Parnell 1992, LaBonté 1994, Blackett and Hume 2006). The south entrance was eventually closed, and the north entrance opened in 1996 only after several failed attempts at considerable cost and effort by the community (Ross 2007). Climate change and associated increasing intensity and occurrence of storms and rise in sea level are envisaged as exacerbating these threats.

1.2 Context for this study

Mangawhai Matters Inc[1]. is leading the Sustainable Mangawhai Project, a study on the future of the Harbour given ongoing development and the potential impacts of climate change. The objective is to establish harbour management guidelines for the foreseeable future. Two scoping studies comprise Stage 1. The first (this study) reviews existing information and assesses the threats to the coastal physical environment and how they might change with climate change and sea level rise. The second study reviews the possible social, cultural, and economic impacts of any future degradation of the harbour. Following the scoping studies more focused scientific studies may be needed to address any knowledge gaps identified in the scoping studies and evaluate the best ways to protect the integrity of the spit and harbour.

[1] Mangawhai Matters Inc. is an incorporated society representing the residents of Mangawhai. Its mission is to examine long-term threats to the harbour and coast, and their potential impact on the community to protect the future of Mangawhai. It has a track record of effective engagement with the district and regional councils on a range of matters and is widely supported within the community.

Together these studies are intended to provide a well-researched platform to enable agencies and the community to coordinate plans for long-term management of the harbour, clarifying where responsibilities should lie and how they might be funded. Stakeholders include the local and visitor communities, a range of interest and recreational groups, the Department of Conservation, Northland Regional Council, and Kaipara District Council.

1.3 Study objectives

This study of coastal physical processes will identify the factors most likely to affect the integrity of Mangawhai Harbour in the future and highlight issues that require more intensive study. It will inform and underpin a community strategy so that discussions and adaptive planning options are based on a common understanding of coastal processes and drivers. It is based on reviews of previous studies, new information, popular press, site visits, the author's experience in coastal processes, and discussions with residents. Where there is no site-specific information, this assessment draws on coastal processes theory. It does not provide specific advice on solutions to issues at specific sites. This study does not review information in respect to te ao Māori and mātauranga Māori.

Specific objectives are to:

- Identify and describe existing information relevant to coastal physical processes.
- Identify and evaluate the drivers of changes to Mangawhai Harbour and its physical environment. This includes the harbour's shoreline, channels and banks, water volume and quality and sediment, the protective spit and dune system, and the ocean coastline.
- Consider potential changes to the harbour arising from climate change and development within the harbour catchment and coastal zone.
- Highlight those changes which most threaten the integrity of the harbour or those about which more information is required.
- Identify the range of potential management options to address the changes.

1.4 Report outline

Section 2 describes the varied knowledge base for this study comprising scientific literature and technical articles, books, consultant reports, evidence from consent hearings, various maps and charts, brochures, planning documents and popular press/newspaper articles.

Section 3 provides a summary of the evolution of the harbour and spit, the human activities that have the potential to impact the system and the nature of the key drivers of coastal processes both now and in the future under climate change and sea level rise.

Section 4 discusses issues and threats facing Mangawhai Harbour and spit from a coastal physical perspective along with potential mitigation actions (some of which are already being progressed) and what can be done going forward to strengthen the response.

Section 5 summarises potential threats, effects and risk to elements and activities in the Mangawhai Harbour and spit environments. Mitigation options and monitoring strategies are suggested and gaps in information identified that can be used to develop research, monitoring, and management policies. Consideration of risk and an assessment of probable effects on the environment of different events has enabled some ordering of priorities of potential policies for avoidance and mitigation.

2 Knowledge base

The knowledge base for this study is varied, comprising scientific literature and technical articles, books, consultant reports, evidence from consent hearings, various maps and charts, brochures, planning documents and popular press/newspaper articles. The Mangawhai Museum archives were a rich source of reports and newspaper articles. Where there was no site-specific information, the study draws on coastal processes theory and the authors knowledge of coastal processes.

A search of existing information showed that there is no single comprehensive study of harbour or spit coastal physical processes. Much of the available information relates to reviews addressing specific issues and coastal processes at specific locations. There are few papers in the scientific literature. Technical reports are more abundant. Some works are based on field studies while others rely on application of coastal processes theory. There are a substantial number of articles in newsletters/newspapers (e.g., Mangawhai Focus and the Northern Advocate) much of it devoted to community concerns relating to the spit breach, mangrove clearance and sand mining in the Mangawhai-Pakiri embayment. Some works are based on field studies while others rely on application of coastal processes theory.

Some of the more relevant technical works include:

- The MSc thesis work of McCabe (1985 and McCabe et al. 1985) documented the development of the dual inlet system based on field studies, aerial imagery and consideration of tidal inlet theory.
- Enright and Anderson (1988) described the evolution of the spit dune field since about 800 years B.P. based on field work and reconstruction using palaeo-environmental evidence and dating of woody material, shells, and volcanic ash.
- Hume and Herdendorf (1992) surveyed the inlet throat characteristics and gauged tidal discharge through the Mangawhai entrance as part of a study of factors controlling tidal inlet characteristics on low drift coasts on the northeast coast of the North Island.
- Parnell (1992) described the physical state of the harbour pre- and post-spit breach, the engineering works to close the breach and their associated impacts and made recommendations for a baseline monitoring programme.
- Flood et al. (1993) describe conflicts between coastal resource management requirements and community action following the spit breach at Mangawhai to demonstrate the need for closer interaction between local communities and state authorities, to avoid unnecessary conflicts.
- Lawson (1994) undertook a theoretical examination of the way in which the process of natural channel meandering may affect the western shore of the spit and the modes of movement of the shoreline as the flow at the outside of a bend cuts into the shore.
- Hilton (1995) and Hesp and Hilton (1996) describe and offer an interpretation of the sediments of the subtidal environments of the Mangawhai-Pakiri sand body and address the sustainability of nearshore coastal sand mining in the Mangawhai-Pakiri embayment.
- LaBonté 1994 prepared a technical report in support of consent for a restricted coastal activity for substantial engineering and related works (planting to revegetate the spit and stabilise the dunes) to close the spit breach and restore flows to the northern inlet.
- Hume et al. (1998) in a final report from the Mangawhai-Pakiri Sand Study, address the issue of sand extraction in the Mangawhai-Pakiri embayment. The report summarises the results of field investigations of sand storage in the dunes and offshore seabed, coastal tides and currents and sediment transport and modelling of currents and wave processes. It is underpinned by a series of technical reports (e.g., Nichol et al. 1996; Healy et al. 1996; Hume et al. 1998; Bell et al. 1997; Black et al. 1998). Numerous other studies have followed as part

of consent processes related to sand extraction.

- Hicks and Hume (1996) as part of a study of 17 ebb tidal deltas on the east coast of North Island measured the volume of sand in the Mangawhai ebb tide delta to determine the factors controlling delta size and shape and to explore the implications for coastal management.
- Hume et al. (2000) describe field measurements by sonar instruments and SCUBA diving of the distributions of surficial sediments and sand transfers around the Cape Rodney headland.
- Hicks et al. (2002) describe instrument measurements of sand volume change and cross-shore transfers off Mangawhai Beach.
- Mangawhai Harbour Restoration Society (MRHS) (2003) prepared a Mangawhai Harbour draft sustainable management plan.
- Ramsay (2004) reviewed consent applications for continuation of sand mining from the mouth of the Mangawhai Harbour for construction aggregate based on an understanding of tidal inlet processes.
- Ross (2007) produced a book describing the story of the restoration of the Mangawhai Estuary following the spit breach and how a small and dedicated group took on the powers of nature and bureaucratic red tape to restore the system. The Mangawhai Harbour Restoration Society was formed from this endeavour.
- Dahm and Bergen (2016) report on a draft strategy to guide dune restoration and management while maintaining critical shore bird habitat in the Mangawhai Government Purpose Wildlife Refuge Reserve (the spit).
- The Mangawhai Harbour Water Quality Project Team (2018) initiated a project to characterise and compare water quality from the inflows from the major sub-catchments describing testing at 5 sites.
- Jacobs (2020) provides a comprehensive account of the coastal processes (tides waves, currents, shoreline movements) operating within the Mangawhai-Pakiri embayment and identifies the scale of any effects to these processes from the past or continued inshore extraction of sand from the embayment.
- Tonkin & Taylor (2020) reported coastal erosion hazard assessment along the eastern facing shoreline of the lower harbour as part of a wider study of 31 selected sites in Northland.
- Northland Regional Council (2022) is the Proposed Regional Plan for Northland combining regional air, land, water and coastal plans.

Following the 1978 spit breach and its study by McCabe (1985) there has been a huge body of literature describing the breach and subsequent shoreline and channel movements and remedial work, including planting to stabilise the dunes and the dredging of sand to nourish the spit. Following unsuccessful attempts by the community to close the breach and reopen the northern entrance LaBonté 1994 prepared a comprehensive technical report in support of consent for substantial engineering and related works, a restricted coastal activity, to address the issues. This followed a pilot study and involved phase one engineering works to restore flows to the northern inlet and close the breach and a subsequent phase two of planting for dune stabilisation and revegetation of the spit. This initiative was ultimately successful and led to the closure of the breach.

The work has also resulted in data capture in the form of monitoring of spit profiles, surveys of harbour bathymetry and LiDAR surveys of the spit topography. Numerous works have documented the journey from breach to closure in terms of community response, performance of government agencies, and consenting issues e.g., Parnell (1992), Flood et al. (1993), MHRS (2003), Blackett and Hume (2006), Ross (2007) and Blackett et al. (2010).

There is a substantial body of work relating to sand mining in the Mangawhai-Pakiri embayment in the form of scientific studies, technical reports, hearings evidence and popular press (e.g., Hilton 1989, 1990 and 1995; reports from the Mangawhai-Pakiri Sand Study 1996-98; Jacobs 2020). Applications for renewal of consents for sand extraction in the nearshore, middle and offshore of the Mangawhai-Pakiri embayment are currently progressing through Environment Court hearings.

An analysis of the tsunami hazard for Mangawhai was not part of this study. However, Northland has been affected by numerous tsunamis in historical times and there is evidence of tsunami affecting the area in prehistoric times presenting it with a high to moderate hazard risk (depending on location) (Borrero and O'Neill 2019). There has not been a study of the tsunami threat for Mangawhai. However, Borrero and O'Neill (2019) provide a comprehensive account of studies of the tsunami hazard for Northland. They describe the history of tsunami in Northland, tsunami effects resulting from local, regional and distant source earthquakes and also model tsunamis generated by large earthquakes that have affected Northland in the past. One of the six sites they selected for detailed analysis is Marsden Point. The report describes the development of planning and response products for the mitigation of tsunami hazards from distant and regional source tsunamis affecting maritime facilities in the Northland region. The products are a series of hazard maps and decision-making worksheets (i.e., 'playbooks') designed for use by local emergency management officials and harbourmasters during a tsunami event to guide their response activities as the event unfolds.

3 Current understanding of coastal physical processes

This section provides a summary of the evolution of the harbour and spit, the human activities that have the potential to impact the system and the nature of the key physical drivers of coastal processes both now and in the future under climate change and sea level rise.

3.1 Evolution of the estuary and spit

Estuaries and spits like Mangawhai owe much of their existing form to events that have taken place in the last 20,000 years or so. At the time of the Last Glacial Maximum some 16-18,000 years B.P. (in the Late Pleistocene) the sea was approximately 120 m below its present level (Gibb 1986). During the marine transgression that followed, the ancestral valleys and bays of the coastal landscape were flooded by the rising sea. The rise continued through the Holocene (10,000 yrs B.P. to present). In the North Island the early-Holocene sea-level high-stand commenced about 8,100 to 7,240 yrs B.P. when present relative sea-level was obtained (Clement et al. 2016). Studies of chenier shell ridges[2] at Kaiaua in the Firth of Thames (Dougherty and Dickson 2012) indicate that from this point sea level rose to more than 2.0 m higher than at present. Following this sea-level then fell about 2 m from 4,000 years B.P. until reaching its present level about 1,000 years B.P. At Kaiaua the fall in sea level caused rapid progradation of the chenier ridges and influenced the spacing of sequential ridges. The ridges are now stranded in farmland on the coastal plain (Dougherty and Dickson 2012).

On an open coast situation like Mangawhai the changes in sea level and waves transported sand ashore building sandy barriers and spits across the entrance to bays. This sand from the sea along with catchment runoff accumulated in the newly formed estuaries. While there are no studies to provide detail as to how the Mangawhai spit barrier developed over the Holocene, studies in Australia offer some insight. In Australia patterns of Holocene shoreline progradation were initially inferred from radiocarbon ages. For the coastal plain at Moruya in southeastern Australia, Thom et al. (1981) reported that the radiocarbon chronology suggested barrier development began about 7,220 years ago, followed by an initially rapid phase of sediment accretion, which then slowed until eventually ceasing ~2,500 cal. yr BP. After this time, the last 10% of the barrier was formed, mostly comprising the large foredune which is adjacent to the present-day beach (Roy et al., 1994).

More recent studies using optically stimulated luminescence (OSL) dating of the Moruya barrier ridges (Oliver et al. 2015) provide a different story. The OSL chronology shows a linear rate of seaward shoreline progradation from 7,220 ± 390 years ago to 390 ± 50 years ago at an average linear rate of 0.27 m/yr. The linearity of the ages, especially in the seaward 40% of the barrier, indicates neither cessation, nor slowing, of shoreline progradation over the past 3,000 years. There does not appear to be evidence for an 'adjustment phase' where shoreline progradation is initially more rapid following culmination of the rapid post-glacial sea-level rise around 7,400 cal. yr B.P. The dating suggests that progradation of the barrier commenced once sea level reached its present position and continued at a similar rate thereafter.

Early considerations of barrier development in New Zealand have generally followed the early Australian model. They considered that barrier progradation went through an 'adjustment phase' where shoreline progradation was initially more rapid following culmination of the rapid post-glacial sea-level rise around 7,400 cal. yr B.P. Sea level has been stable for about the last 6,000 years, however the only curve published for New Zealand is has little resolution in the latter part of the Holocene (Gibb, 1986). This early thinking has been recently challenged by studies by Dougherty and Dickson (2012) where chenier ridges on the Miranda plain in the Firth of Thames provide evidence that sea

[2] Chenier ridges which are shelly, low, shore-parallel chenier ridges lying atop muddy sediment.

level rose to more than 2.0 m higher than at present, and then fell about 2 m from 4,000 years B.P. until reaching its present level about 1,000 years B.P. This fall in sea level caused rapid progradation of the chenier ridges and a seaward building of the coastal plain.

Further evidence for a fall in sea level contributing to a building of the coastal plain in NewZealand comes from a study at Omaha by Dougherty (2014). Omaha is a 3.5 km long prograded barrier spit (also known as Mangatawhiri Spit) located 30 km south of Mangawhai. Dating analysis on shelly mud deposits underlying the sandy barrier sequence give an age of 6,460 7 60 years B.P., indicating a mid-Holocene time of initial progradation of the spit (Schofield, 1973). Here the offshore and inner shelf deposits are considered to be the primary source for barrier construction (Schofield, 1970) and inputs of sand from the catchment negligible (Hilton and Nichol, 2003). Coring and ground penetrating radar (GPR) surveys by Dougherty (2014) found that a 2 m drop in sea level is thought to have driven barrier progradation by providing access to offshore sediments. The rational for this is that falling sea level corresponds to a drop in wave base in a seaward direction, which in turn taps further into the offshore source of sand. The space available to accommodate this influx of sand to the barrier is similarly regulated by the drop in sea level. Once sea level stabilized at or near the present elevation, progradation ceased and a large foredune complex aggraded. The GPR imagery showed that for at least the past 100 years, sea level has been rising and during this time the barrier has likely been receding.

It is likely that the 2 m fall in sea level from 4,000 years B.P. contributed to the progradation of the Mangawhai spit. It is also likely that during the past 100 years sea level rise has been contributing to spit recession. Rising sea level associated with climate change will see this trend continue.

Under today's conditions beach profile surveys in the Mangawhai-Pakiri embayment show continual shoreline fluctuations back and forth in response to storm events. This makes it very difficult to detect net shoreline change. There is argument between and conflicting evidence from experts as to whether the shoreline of the Mangawhai-Pakiri embayment is undergoing net progadation or retreat and whether sand extraction is affecting this process. If there is any overall net change then it's probably very small at best and hidden in the 'noise' of events.

<u>Waikato River origin of Mangawhai sand</u>

Much of the sand that now forms the Mangawhai-Pakiri embayment, Mangawhai spit and harbour floor, originally came from the ancestral Waikato River (Schofield 1965, 1970 and Hume et al. 1975). Fuelled by intense volcanic activity and storms and runoff in the central North Island the river delivered huge quantities of sand and gravels to the Hauraki Lowlands. On two occasions (220,000 to 65,000 yrs ago and 20,000 to 25,000 yrs ago) the river flowed through to lowlands and into the Hauraki Gulf. Sea level was 120 m below the present level at the height of the Last Glacial maximum (16-18,000 years B.P.) and the river discharged its sediment over an extensive alluvial coastal plain extending seaward from the inner Gulf as far as Great Barrier and the Mokohinau islands. The Waikato River build up its river plain with so much sediment that it switched its drainage to the west coast about 18,000 years ago, essentially cut off sediment supply to the northeast coast when sea level was more than 100 m below present.

Waikato River sediment transported to the east coast was distributed northward by longshore currents (Griffiths and Glasby 1985). The sediment that migrated landward from the continental shelf during the post-glacial marine transgression/sea level rise (12,000–6,000 years ago) is thought to have been reworked to infill the shoreline of the Mangawhai-Pakiri embayment and form barrier spits such as Mangawhai and Omaha, during the ensuing relative sea level 'stillstand' (Schofield 1985). Evidence that the original source of sands in the Mangawhai-Pakiri embayment and Mangawhai spit came from the Waikato River lies in the quartzo-felspathic rich nature of the sands which are very similar to those of the Hamilton and Hauraki lowlands.

Today the Waikato River flows out to the west coast and no longer supplies sand to the east coast. Consequently, sand replenishment to the Mangawhai-Pakiri embayment from rivers and cliffs is small and was estimated at about 8,000 m^3/yr (Hume et al. 1998). The quantity of sand coming from offshore via diabathic (cross shelf) transport to nourish the beaches is under debate (see section 4.9). So, the key question is whether enough sand is being brought ashore from the seabed to offset beach erosion from natural causes and sand mining.

Sand stores in the Mangawhai-Pakiri embayment

The Mangawhai-Pakiri embayment extends 25 km between Bream Tail and Cape Rodney. Today it stores Holocene (<10,000 years old) sand in the dunes, beach and offshore including sand contained in the Mangawhai harbour and delta sand bodies at the entrance (Nichol et al. 1996, Healy et al. 1996 and Hume et al. 1998).

Transgressive dunes[3] extend up to 2 km inland and are up to 30 m thick containing c. 92,000 to 552,000 million m^3 of sand (Nichol et al. 1996). There is a lot of uncertainty in this range of estimate of thickness because while the aerial extent of the deposit can be easily measured the transgressive sand sheets overlie an uneven topography of older sediments and there are few outcrops (e.g., in road cuttings) or boreholes from which to measure thickness. In places where the Pleistocene sand deposits were visible in outcrop they were weakly consolidated.

The offshore sand body has been shown by bathymetry and coring to extend seawards some 4 km as a comparatively thin layer (<8 m thick) (Figure 3-1). It contains 82,000 to 142,000 million m^3 of sand in the beach and offshore to 40 m depth where it pinches out (Healy et al. 1996). The Holocene sands overlie a vast store of older Pleistocene sands. The coring and dredging for sand in the offshore area shows the Pleistocene sands to be similar in texture to the Holocene sands, weakly consolidated and orange-coloured from iron staining developed during terrestrial weathering. The estimates of sand storage in the dunes and offshore area include those for the sand bodies of the spit (c. 9 M m^3) and ebb tidal delta (c. 1.93 M m^3 Hicks and Hume 1996) respectively.

[3] Transgressive sand sheets and dunefields are relatively large-scale aeolian sand deposits formed by the downwind and/or alongshore movement of sand over vegetated to semi-vegetated terrain or transgression of sand over land (Hesp & Thom 1990). They may be relatively featureless sandsheets, or comprise a variety of dune types (e.g., barchans, transverse dunes, parabolic dunes).

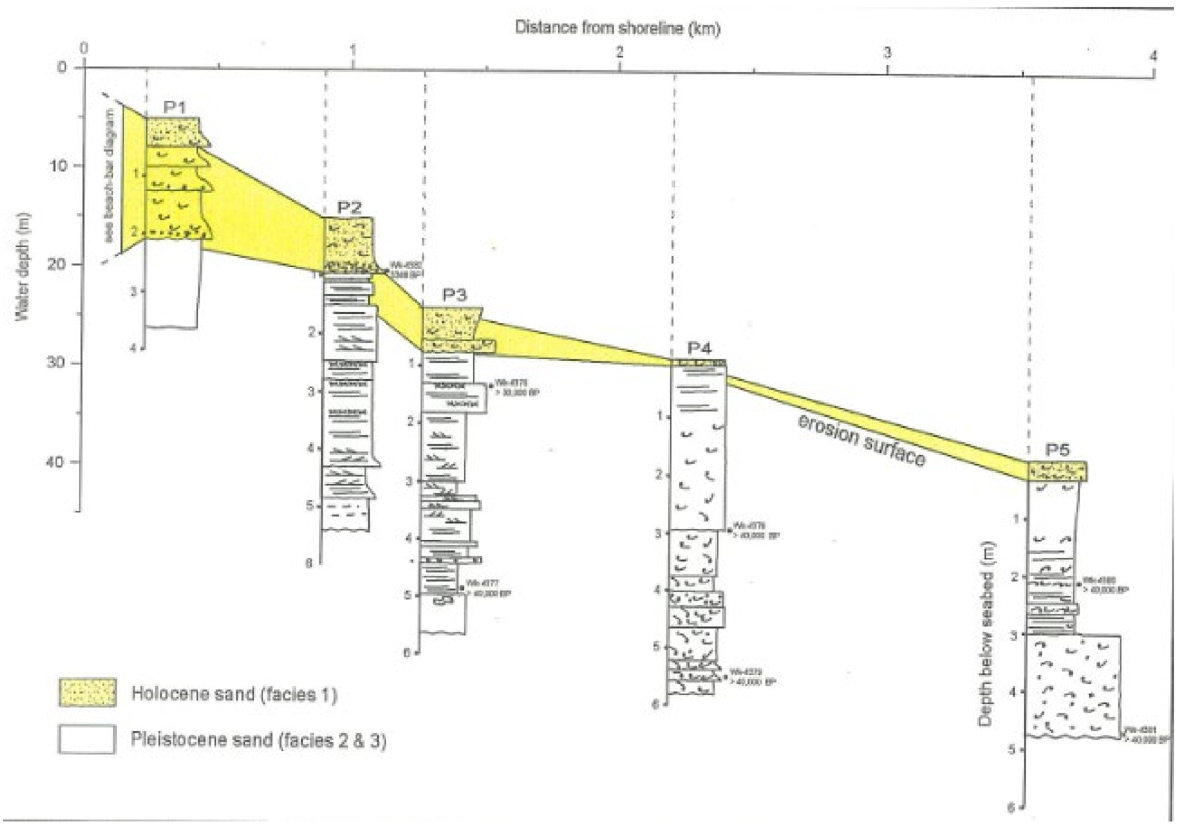

Figure 3-1. Stratigraphy of the upper 6 m of sediment from cores taken off Pakiri Beach. The cores were taken in depths of 5 m, 15 m, 25, 30 and 38 metres. The Holocene sands are shallowest are shown in yellow. Older sediments of Pleistocene age lie below the Holocene. (Source: Hume et al. 1998, Figure 3.5)

<u>Morphological change on the spit in the last 800 years</u>

The spit has undergone considerable morphological change since c. 800 years B.P. Enright and Anderson (1988) used evidence from dating of woody material, shells and volcanic ash to describe changes in the palaeoenvironment for an area at the southern end of the spit. Prior to c. 800 years B.P. this area was vegetated in mixed forest, including totara, kanuka, titoki, lacebark and maire, growing on yellow sandy soils, on a low coastal hill about 20 m in height and 300 m from the sea. Enright and Anderson do not explain what the 'original coastal hill' was but presumably it is comprised of older Pleistocene sediments that they observed exposed in low-lying deflated areas nearby. At least two sets of coastal dunes lay to the east (seaside) of this coastal hill. This implies a coastline extending some 20 m oceanward of its present position.

A phase of instability was initiated by extensive destruction of coastal vegetation by a fire around 800 years B.P. At about 670 years B.P. Kaharoa ash fell on the largely unvegetated dunes an accumulated as thick deposits in dune swales (Depressions). Sites containing Kaharoa ash, indicate that deflation of the land surface and dune field development had already begun at that time. There is little evidence of revegetation after this time. It appears that a major erosional phase of wind erosion and deflation of the dunes during 650-400 years B.P. Maori midden sites established near the end of this period are now found on isolated sandy pedestals near the coast. Enright and Anderson describe this as evidence that between 400 years B.P. and present nearly the whole foredune system has been lost and that erosion has continued from 400 years B.P. to the present. Over time a net east to west movement of sands has resulted in a large deflation surface near the coast. The development of the dune reaching 50 m elevation in the south owes its height to burying the former low coastal hill and associated soils.

The substantial change in the nature of the Mangawahi spit from a vegetated dune field to a barren deflated sandy surface raises the question as to whether this has influenced the present sedimentology and that prior to the fire and in pre-human times the estuary would have been more muddy owing to smaller aeolian contribution. This is probably unlikely because terrestrial mud contribution would also have been lower when catchments were fully forested. Furthermore, similar spit enclosed tidal lagoon estuaries in New Zealand, most of which have vegetated spits, have the distinguishing characteristic of sandy substrates in their lower reaches (Hume et al. 2016). Coring the estuary would reveal whether the seabed substrate inside the spit was once muddier than its sandy composition today.

Why hasn't Mangawhai estuary completely infilled with sediment?

Although estuary infilling by natural processes is slow, the eventual fate of lagoon systems like Mangawhai is to completely infill and become land. We see this today in small remnants of estuaries like the one at Hot Water Beach on the Coromandel east coast. Here a once a larger estuary gradually infilled with sediment, eventually becoming shallow and marshy and finally part of the coastal plain.

However, despite all this sediment input, many estuaries have remained open even after 6,000 years. This suggests that in the long term a balance is achieved between tides, waves, and sediment from the catchment and sea. An important process that prolongs the life span of shallow largely sandy lagoons like Mangawhai is wave action. As estuaries shallow through infilling there comes a point where the orbital currents of small wind generated waves can start to feel the bottom and resuspend the seabed sediments on the tidal flats (Green 2011). So, although the water looks turbid, the small waves actually tend to cleanse intertidal flats of silts and clays, leaving behind the sandy sediments that we associate with a clean estuary. Because the fine sediments resuspended by the waves settle back to the bed quite slowly, they get transported from the area by tidal currents (either to the tidal creeks in the headwaters or out to sea), thus slowing the rate of accumulation over tidal flat areas. This process is most pronounced in larger systems where there is sufficient fetch distance to generate sizable wind waves.

3.2 Mangawhai harbour and spit physical characteristics

The sand spit separating the harbour from the sea is 3 km long. It varies in width from 700 m at the tip, reducing to 400 m at a narrow neck in the middle, and widens to 850 m at the base (Figure 3-2). The surface has highly variable topography dominated by bare and sparsely vegetated dune field to c. 10 m elevation in the north, deflation surfaces, middens, and a large dune reaching 50 m elevation in the south. In the central northern regions depressions at about sea level contain ephemeral 'damp sand plain lakes'[4].

[4] Damp sand plain lake - A palustrine system comprising a small, shallow (1-2 m deep), typically freshwater body (never having a connection to the sea – no tidal inflow). Often elongate in shape and located in the depressions between rows of sand dunes on damp sand plains and often associated with vegetated wetland areas. The basins in which they occur form where the wind has removed sand to form shallow depressions down to about the level of the water table. They are fed by freshwater inputs from rainfall and groundwater and are brackish due to salt spray and evaporation. They are variable in planform, ephemeral in space and time, and can dry out in drought conditions. Their dominant substrate is muddy sand and peat (Hume et al. 2016).

Figure 3-2. Features of the middle and lower harbour showing sandy shoals (SS) built by the incoming tide and the ebb tidal delta sand body (ETD). (Source Google Image 2003).

Mangawhai Harbour is termed a 'permanently open tidal lagoon' (Hume et al. 2016, see Table 3-2). It is shallow (mean depth 2.01 m), elongated in shape, has a surface area at high tide of 4.8 km^2 of which 67% is exposed as intertidal shoals and banks at low tide (Table 3-1). In the headwaters narrow incised tidal channels are flanked by low gradient, soft, muddy tidal flats lined with mangroves.

In the middle reaches the harbour widens to 700 m and subtidal and intertidal banks separate the channels and the substrate is sandy and shelly. Narrow sandy beaches line the shores of the harbour in the middle and lower reaches. The shoreline sediments are characterised by well sorted medium grain sand (D50 = 0.25-0.3 mm) (Tonkin & Taylor 2020). On the western shore the beaches are backed by 40 m tall hard cliff headland with an underlying dacite geology near the entrance, which, going south, transitions into cliffs of historic sand dune formation of Pleistocene age fronted in places by low-lying estuarine coastal terrace. On the eastern (spit) shore the beach sands are unconsolidated and mobile and backed by low dunes. At the harbour entrance the channel throat narrows to c. 200 m and flood and ebb tidal delta sand bodies are the shoals/bars that form in the bay and ocean sides of the throat respectively.

Table 3-1. Metrics for the Mangawhai Harbour and catchment (Source: Hume et al. 2016, the NZ coastal hydrosystems database, and Hicks and Hume 1996).

Parameter	Metric
Surface area of harbour at spring high tide (km^2)	4.8
Surface area of catchment (km^2)	11.7
Shoreline perimeter length (km)	39.3
Width of mouth (m)	1,400
Surface water area at spring low tide (m^2)	1,578,163
Surface water area at spring high tide (m^2)	4,830,618
Intertidal area as a % of high tide area	67
Mean depth at spring high tide (m)	2.01
Neap tidal range (m)	1.47
Spring tidal range (m)	2.05
Spring tidal prism (m^3)	6,562,592
Total volume of water at neap high tide (m^3)	3,156,326
Total volume of water at spring high tide (m^3)	9,718,917
Ratio of tidal prism to total volume at spring tide (%)	68
River inflow over 12.4 hr tidal cycle (m^3)	21,967
Ratio river inflow to tidal prism (%) R12/P	0.33
Ratio of river inflow to total volume (%) R12/V	0.23
Volume of sand in the ebb tidal delta (m^3)	1,930,000

3.3 Harbour hydrodynamics

Mangawhai Harbour is micro tidal estuary with tide ranges of 2.05 m and 1.47 m for spring and neap tides respectively. Tidal processes dominate the hydrodynamics because river input from the catchment is small, and the estuary basin is very shallow and intertidal. Reversing tidal currents in the main channels peak at c. 1 m/sec, while those flowing through the narrow entrance peak at c. 1.5 m/sec for spring tides (Hume and Herdendorf 1992). The spring tidal prism (the amount of water flowing into the harbour on the incoming tide) has been measured by gauging as 6,562,592 m^3 and makes up a large proportion (68%) of the total basin volume at spring high tide. Flushing is good in the harbour, particularly in the middle and lower reaches closer to the entrance, because much of the water leaves the estuary on the outgoing tide. The system is also well mixed because of good flushing, wind mixing, and the shallow depths which prohibit density stratification. Salinity is close to that of the sea.

Mean river flow makes up only 0.33% of the daily (12.4 hr) tidal inflow (Table 3-1). However, river inputs can dominate the hydrodynamics for short periods (days) during floods when seawater can be partially expelled from the system. During floods river inflow gets backed-up by the incoming tide causing low-lying land around the margins to be flooded.

3.4 Harbour sediments and their formation

Sediments in the narrow upper reaches have soft, muddy substrates as they are close to the source of inputs of mud from the catchment. Accumulation of fines is favoured by this low energy environment. Here there are only very weak currents when the area is inundated at higher stages of the tide. Also, the mangrove forest inhibits tidal flow and stirring by wind waves. Furthermore, muds are cohesive and resistant to erosion (compared to sand). Water clarity is reduced by the turbidity in the upper reaches because of the muddy substrate.

Sediments in the mid and lower reaches comprise relatively homogeneous and sandy substrates on account of sand delivery from the catchment and primarily from the sea on the incoming tide. There is also reportedly considerable (although unquantified) sand input via aeolian transport as evidenced by sand blown off the largely unvegetated dunes on the spit and into the harbour. This mechanism is sufficient to build a section of transgressive sand dune wedged against the cliff across the harbour from the spit and also deposit sand on houses on that shore. The tidal flats and the sand banks (e.g., Middle Shoal and the sandy shoals (SS) (Figure 3-2) deposited by the incoming tide) are kept largely free of mud as the result of stirring by wind waves. Waves can be generated over a fetch of about 3 km when winds blow from the northerly and southerly quarters along the length of the harbour. Waves generate orbital currents sufficient to winnow fines from the sediments in the shallow intertidal areas of the bay following which ebb tidal currents flush to the sea.

Sediments at the mouth of the harbour comprise ebb and flood tidal deltas (Figure 3-3). These features are common to tidal lagoons on sandy shores along the coast of New Zealand's North Island (Hicks and Hume 1996). The flood tidal deltas form when sand enters the harbour on the incoming tide after being combed by waves from the seabed and beaches adjacent to the entrance. Sand is deposited where the estuary widens out and current velocity and the sand carrying capacity of the tide drops off. In the Mangawhai entrance this is a very small deposit because it is contained by limited accommodation[5] space in the narrow channel.

The ebb deltas form on the outgoing tide where the tidal entrance widens, and flow decreases and the carrying capacity drops off. In addition, as ocean waves comb sand onto the ebb tidal delta they push the sand body toward the shore building a delta/batwing shape. The planform of the delta at Mangawhai is constrained to the north by Sentinel Rock rocks running to the shore. While ebb deltas tend to retain their overall planform shape,[6] the sand on their surface is very mobile and with time minor channels and banks move about, particularly during storm events. This makes them, at times, dangerous for navigation but provides a challenging variety of wave conditions for surfers.

The ebb delta was classified by Hicks and Hume (1996) as Type 1 ‘free-form’ delta, being longshore-elongated, reasonably symmetrical 'batwing'. These deltas typically occur on inlets on relatively straight, exposed shorelines experiencing littoral drift. The major controls on ebb delta volume are primarily the volume of the tidal prism and secondly the angle of inlet outflow with respect to the shoreline (75 degrees relative to adjacent shore for Mangawhai (Hicks and Hume (1996). The larger the tidal prism the greater the sand volume. Delta sand volume also appears to show a slight increase

[5] Accommodation space is the space that is available for the deposition of sediments. In narrow shallow channels there is little accommodation space compared to deep wide channels.
[6] Planform shape is the shape as viewed from above.

with decreasing wave energy (for a given tidal prism). The volume of sand contained in the Mangawhai delta was estimated as c. 1,930,000m^3 (Hicks and Hume 1996, Table 1).

Figure 3-3. Features at the Mangawhai entrance showing narrow deep throat, ebb tidal delta (ETD) with wave breaking in the shallow water, flood tidal delta (FTD) and flood tidal channel (FTC). The FTC is the primary path that flow takes on the incoming tide inside the ebb tidal delta. (Source: Google Image 2019).

3.5 Catchment and harbour water quality

The catchment of the harbour is 11.7 km^{2}in area (Figure 3-4). It has a mixture of landcover and use being mostly pasture 59 %, scrub 19% and forest 14% with the urban area occupying about 3%[7]. Rainfall is of the order of 1,327 mm/yr. Mean annual runoff is 279 mm/yr and mean annual discharge 0.49 m3/sec. Runoff inflow over 12.4 hr tidal cycle is 21,967 m^3.

<u>Catchment inputs</u>

Lacking any comprehensive ongoing monitoring of water quality in the Mangawhai Harbour (Mangawhai Harbour Water Quality Project Team 2018), the Mangawhai Harbour Water Quality Advisory Panel initiated a project to characterise and compare water quality from the inflows from the major sub-catchments. Testing at 5 sites (Figure 3-5) included the physical attributes of salinity, water temperature, dissolved oxygen, turbidity and visual clarity, biological attributes of total coliforms and E. coli, and chemical attributes of ammoniacal nitrogen, total nitrogen, and total phosphorus. The full year data set included 25 programmed fortnightly samples and 2 samples dictated by high rainfall events.

[7] Source: Hume et al. 2016, and the NZ coastal hydrosystems database.

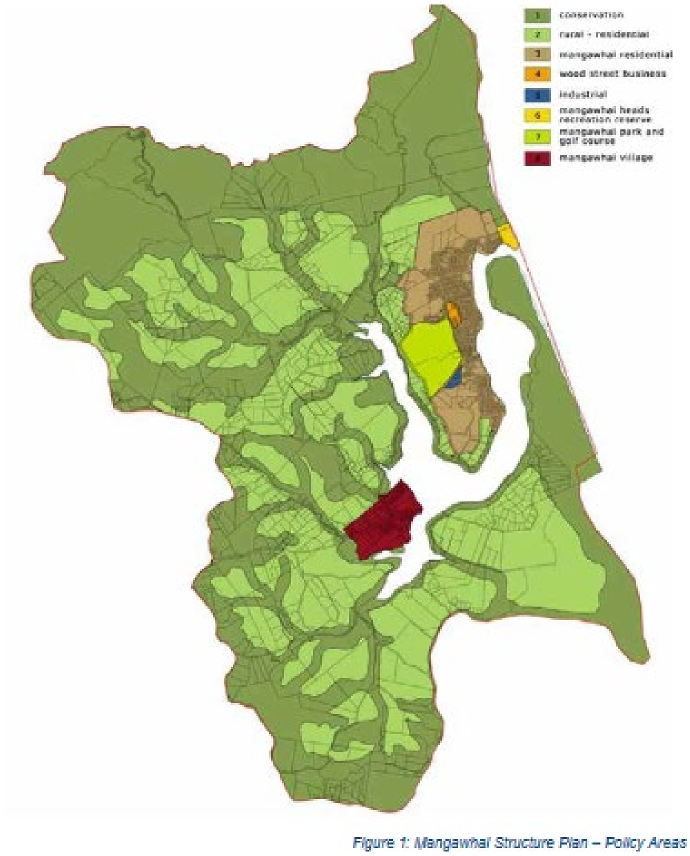

Figure 3-4. Mangawhai catchment and stream network.

Figure 3-5. Location of seven water quality sampling sites.

Some key findings of the study were reported as:

- The two extremes of water quality within the study are the Forest Stream for which the median values of all variables were within the ANZECC (2000)[8] guidelines for lowland streams, compared with Tara Creek at Henry's Bridge (which receives drainage from Forest Stream) which had the highest values for total P, NH4-N, *E. coli*, and turbidity.
- *Total phosphorus (TP), Total Nitrogen (TN), and Ammonium (NH_4-N)*. Forest Stream had by far the lowest levels of these three nutrients with median levels of 0.04, 0.24, and 0.008 mg/L respectively. Median levels at the other 5 sites ranged between 0.6 and 0.8 for phosphorus, 0.46 and 0.57 for nitrogen and 0.03 and 0.06 for ammonium. These nutrients are key indicators of water quality in estuaries and can arise from both natural sources and human activities such as sewerage leakage, dairy shed effluent, and fertiliser runoff. At the sampling sites at Tara Creek and Devich Road Bridge levels of 3 to 6 times the ANZECC guidelines for nitrogen and ammonium were recorded.
- *Turbidity and clarity.* High rainfall events as expected caused high turbidity and low clarity levels at all sampling sites but once again the Forest Stream was much lower and cleared much more quickly than any other site (median turbidity 3.25 NTU, range 1.1 – 55). At Tara Creek comparable values were 9.2 and 3.7 – 180.
- *Salinity and dissolved oxygen.* Salinity was very low except at the Insley Street and Molesworth Drive Causeway sites where tidal influences were greatest, while dissolved oxygen was highest in the Forest Stream.
- *E. coli.* All sites showed high *E. coli* levels after heavy rain, probably from birds, pigs, and other wildlife in the catchment (median 115 MPN/100 mL, range 10 – 6500), although the highest levels in Forest Stream were one-third of the maximum values for any other site. Analysis showed the derivation of all *E coli* to be ruminant with human *E coli* considered absent from the samples. This is to be expected as any sampling following a high rainfall event would be dominated by land runoff completely swamping any human *E coli* component, especially if they were taken outside the high use period for holiday accommodation.

The key finding of very high ruminant derived contamination during high rainfall events clearly suggests stream edge retirement and restoration planting are likely to make the greatest contribution to reducing nutrients and bacterial contamination entering the estuary from overland flows. The study recommended that a joint local authority/community driven strategy is needed to tackle the issue. Consequently, NRC is now undertaking year-round monitoring at four sites on the harbour which will provide on-going data to enable monitoring of harbour health.

Harbour water temperature

At this point in time the Northland Regional Council environmental monitoring data portal[9] only displays water temperature for the harbour (Figure 3-6). Monthly data is listed for the years 2017 – 2023 for five sites listed from headwaters to harbour mouth as: Insley Street causeway, Tern Point channel, Causeway bridge, Boat ramp pontoon and Open coast at Mangawhai Heads. The data show annual fluctuations for Insley Street causeway ranging from 10 to 27 deg C and for the Open coast at Mangawhai Heads site from 14 to 25 deg C. There is no obvious overall trend in water temperatures over the 7 years of record.

[8] https://www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-armcanz-2000

[9] https://www.nrc.govt.nz/environment/environmental-data/environmental-data-hub/

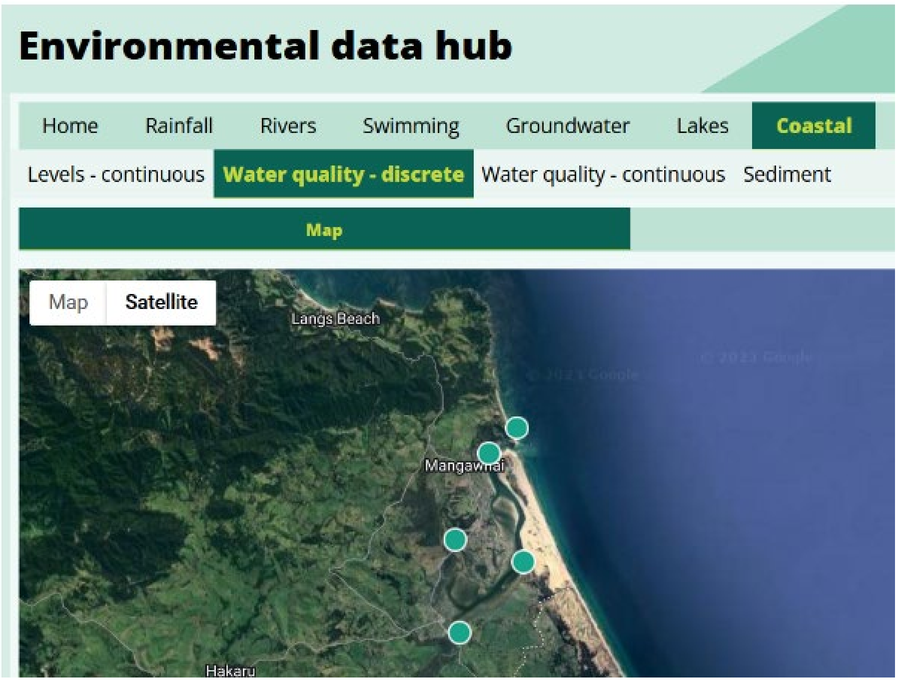

Figure 3-6. Screenshot of Northland Regional Council environmental monitoring data portal showing the water temperature monitoring sites.

3.6 Drivers of shoreline change – water levels

Water levels play an important role in determining coastal processes and hazards by allowing overtopping of coastal barriers, controlling the distance water travels inland over low topography, determining the amount of wave energy reaching the backshore and beach ridge barrier and causing erosion during storms, and by controlling the mean shoreline position on longer time scales.

The key determinants of water level are:

- Astronomical tides.
- Barometric and wind effects, that are generally referred to as storm surge.
- Wave setup and run-up in storm events.
- Medium term fluctuations, including El Niño–Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) effects.
- Long-term changes in sea level due to climate change.

The components of increased water levels during a storm event are illustrated in Figure 3-7.

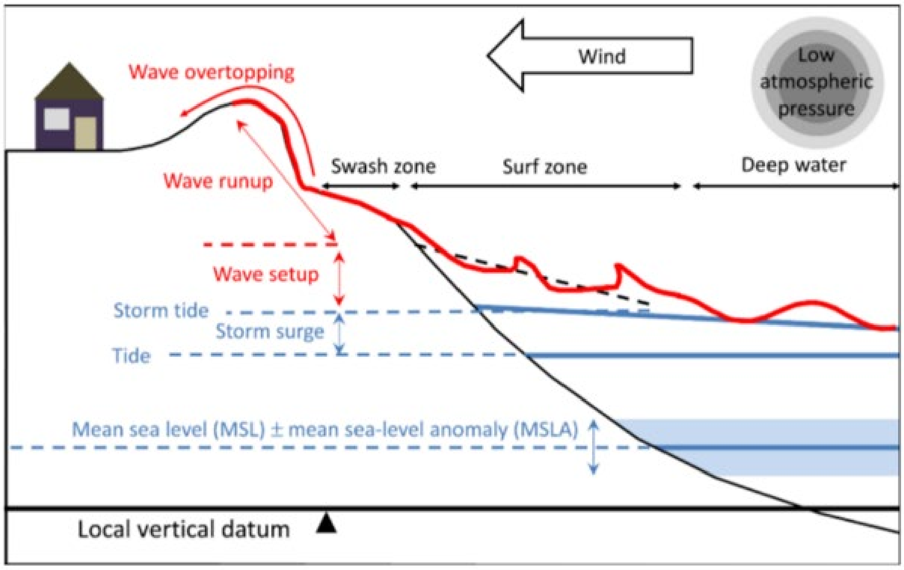

Figure 3-7. Components causing increased water levels along the coast during a storm event. (Source: Stephens 2019).

<u>Astronomical tides</u>

Astronomical tides occur primarily due to gravitational effects of the moon and sun on the Earth's oceans. Spring tides occur when the sun and moon are in alignment, as is the case with a new or full moon, their combined gravitational pull results in exceptionally high and low tides (a large tidal range). King Tide is a commonly used term for the highest tides that occur over the course of the year and that eventuate when a new or full moon occurs at the same time as the moon is at its closest to the earth (in its perigee). Neap tides occur when the sun and the moon are at right angles to each other and pull in opposite directions resulting in lower high tides and higher low tides than usual (a small tidal range).

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ (2020)[10] based on the average predicted values over the 18.6 year tidal cycle. Table 3-2 shows values for Marsden Point in terms of Chart Datum, One Tree Point Vertical Datum (OTP64) and New Zealand Vertical Datum (NZVD2016).

Table 3-2. Tide levels for Marsden Point (LINZ 2020). (Source: T&T 2020, Table 3.2).

Tide state	Chart Datum (m)	OTP64 (m)	NZVD2016 (m)
Highest Astronomical Tide (HAT)	3.01	1.33	1.26
Mean High Water Springs (MHWS)	2.74	1.06	0.99
Mean High Water Neaps (MHWN)	2.31	0.63	0.56
Mean Sea Level (MSL)	1.60	-0.08	-0.15
Mean Low Water Neaps (MLWN)	0.9	-0.78	-0.85
Mean Low Water Springs (MLWS)	0.46	-1.22	-1.29
Lowest Astronomical Tide (LAT)	0.13	-1.55	-1.62

Source: LINZ Nautical Almanac 2019–20

[10] https://www.linz.govt.nz/products-services/tides-and-tidal-streams/tide-predictions

Storm surge

Storm surge is a temporary increase in sea level induced by winds and low barometric pressure associated with weather systems. Its effect is to elevate the water level above the predicted tide across a region. A decrease in atmospheric pressure causes the water to rise (approximately 1 cm water level for every 1 hPa drop in pressure) and is the so-called Inverted Barometer effect. At the same time, onshore winds can push water from deep water and pile it up against the coastline.

Storm surge excludes nearshore effects of storm waves such as wave setup and wave run-up at the shoreline. T&T (2020) report that previous studies of storm surge around New Zealand's coastline have concluded that storm surge appears to have an upper limit of approximately 1.0 m (Hay 1991; Heath 1979; Bell et al. 2000). A standard storm surge of 0.9 m is considered representative of a return period of 80 to 100 years (MfE, 2004).

Medium term fluctuations and cycles (sea level anomaly)

The sea-level 'anomaly' describes the variation of the non-tidal sea level on time scales ranging from month to month, over a year (seasonal changes), several years (El Niño and La Nina Climate Cycles) and over decades (Pacific Decadal Oscillation) due to climatic changes. The non-tidal sea level variations in sea level are due primarily to changes in water temperature and wind patterns. As water gets warmer it expands and sea levels rise. Persistent winds can also 'push' water towards the coast (increasing sea levels) or away from the coast (decreasing sea levels). The combined effect of these fluctuations can see sea level anomaly increases/decreases in any month by up to 0.15 to 0.25m around New Zealand (NIWA 2011). As a consequence, the actual sea level at any given location is likely to differ from the predicted tide.

Storm tides

Storm tides are a combination of the astronomical tides, storm surge and the monthly mean sea level variation (or mean sea level anomaly) (Figure 3-7). The largest storm tides will occur when they coincide with a spring high tide. T&T (2020) undertook an extreme value analysis of hourly sea level data for Marsden Point which provided recurrence intervals for 10- and 100-year Average Recurrence Interval (ARI) peak storm tide levels as 1.6 and 1.83 m (NZVD 2016) respectively (T&T 2020, Table 3.3).

Longer term changes in sea level

Eustatic sea level refers to change in the volume of Earth's oceans. Changes in eustatic sea level are caused by:

- Changes in total ocean water mass, for instance, by ice sheet melt and runoff, particularly the large ice sheets like Greenland.
- Density changes of the water, for instance, by thermal expansion, an important driver of which is a rise in greenhouse gases such as carbon dioxide, methane and ozone.
- Changes in the size of the ocean basin, for instance, by tectonic seafloor spreading or by sedimentation.

The first two are markedly affected by climate change.

Longer-term sea-level rise in New Zealand based on analysis of tide gauge records has averaged 1.7 ± 0.1 mm/year (Hannah and Bell 2012) with Northland exhibiting a slightly higher rate of 2.2 ± 0.6 mm/year. Climate change is predicted to accelerate this rate of sea level rise into the future.

Projections for long-term sea-level rise from climate change in New Zealand (Figure 3-8) suggest that by 2120 absolute mean sea levels will be between 0.55 and 1.36 m above mean 1986 to 2005 levels

(MFE 2017). The actual rise largely depends on the global greenhouse emissions pathway and the non-linear response of the polar ice sheets warming above ipping point. Over the shorter time frame and up to 2060 there is more certainty in projections, with a NZ region absolute mean SLR expected to total between 0.3 and 0.5 m. Locally and regionally relative sea level rise will be offset or compounded to some degree by long term and event based vertical land movements (MFE 2017, pp. 82-86).

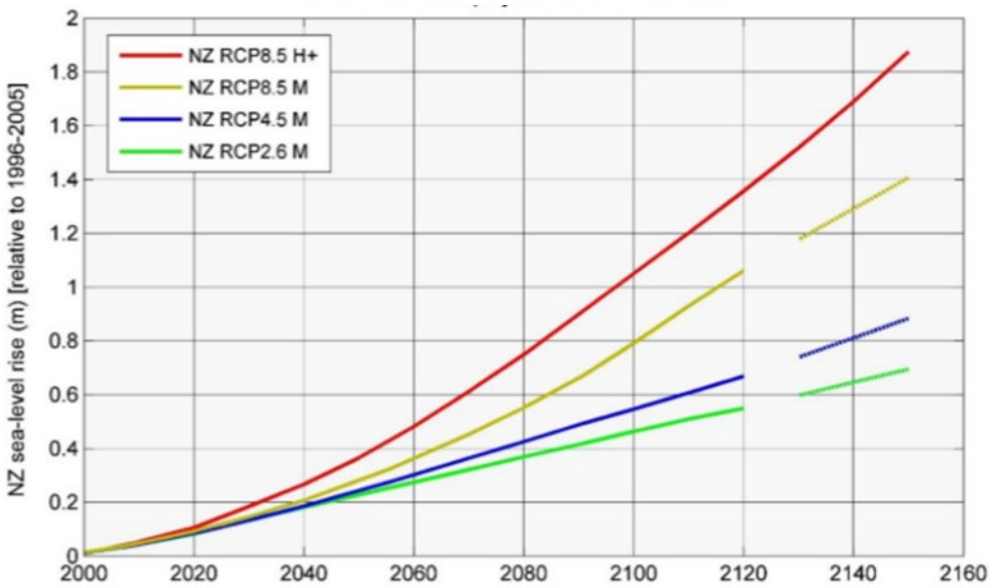

Figure 3-8. Four scenarios of New Zealand-wide regional sea-level rise projections with extensions to 2150 based on Kopp et al. (2014). (Source Figure 27 in MFE 2017).

<u>Wave setup and runup</u>

Waves can produce additional short-term increases in water level during storm events due to the processes of wave setup and runup. This can increase water incursions landward above and beyond the storm tide influence.

Wave setup is the increase in mean still water sea level at the coast resulting from the release of wave energy in the surf zone as waves break. Wave runup is defined as the maximum vertical extent of sporadic wave 'up rush' or flowing water ('green water') on a beach or structure above the still water or storm tide level, and thus constitutes only a short-term upper-bound fluctuation in water level compared with wave setup (MFE 2017).

Wave setup and runup have not been calculated for the Mangawhai coast. These parameters need to be determined as they are important in the context of evaluating coastal hazards and in planning for and designing specific options for mitigating coastal erosion (e.g., dune height, seawalls and revetments).

3.7 Drivers of shoreline change –Wave climate and storm climatology

<u>Storm climatology</u>

T&T (2020) describe the wave climate for the east coast of Northland as being generated primarily by systems of tropical origin that travel down to Northland as tropical or ex-tropical cyclones (Figure 3.9). West coast waves and to a lesser extent those of the east coast are generated by large mid latitude low pressure systems occurring between 50 and 60° S propagating into the Tasman Sea (Figure 3.10) and East coast lows that form off the east coast of Australia.

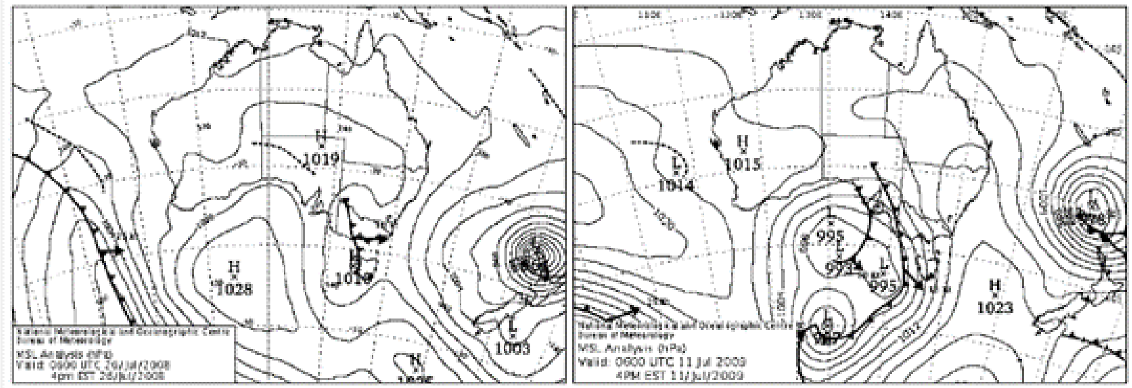

Figure 3-9. Sub-tropical storm systems that caused large waves on the Northland east coast in July 2008 (left) and July 2009 (right) (Source: T&T 2020, Figure 3.8).

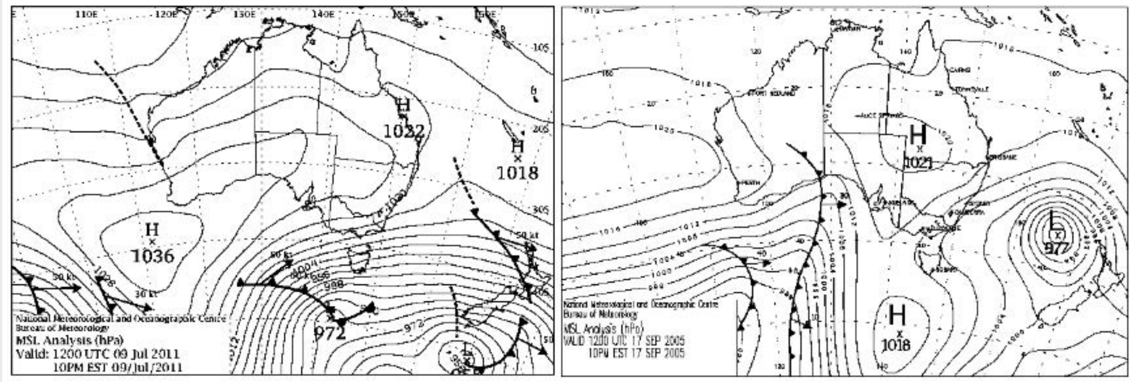

Figure 3.10. Typical storm systems affecting the west coast of Northland with a large mid-latitude cyclone in July 2011 (left) and an East coast low in September 2005 (right) (Source: T&T 2020, Figure 3.7).

On the east coast the largest storms may arrive from a wide range of directions (40 to 100°). T&T (2020) observe that clustering of storm events, which can result in greater beach erosion than would occur for singular events as the beach does not have time to recover between them, is known to occur on the east coast. They cite as an examples Tropical Cyclones Fergus, Drena and Gavin that made landfall between December 1996 and March 1997. The La Niña summer of 2023 saw a cluster of events including ex-tropical cyclone (Gabrielle) and a series of mid-latitude intensive storms moving across or north of the north Island from the Coral Sea in quick succession and bringing erosion to the beaches on the east coast of Northland, Auckland and Bay of Plenty.

Atmospheric anomalies such as the inter-decadal Pacific Oscillation (IPO), Southern Oscillation Index (SOI), and Southern Annular Mode (SAM) modulate the wind wave climate at the global and regional scale.

The phase of the IPO has been shown to cause changes in sea level, prevailing wind direction, storm frequency and wave climate with more events (and increased erosion on the northeast coast of New Zealand) occurring during negative phases (i.e. ,1948 to 1974) than during positive phases (i.e., 1976 to 1998) (de Lange 2000). During La Nina phases warmer water raises water levels through thermal expansion and also provides greater energy to cyclones with damaging winds and waves from the northeasterly quarter. Large positive anomalies (7) of the SOI (Chen 1982) characterise La Niña events, which increase the occurrence of northeasterly winds, and consequently waves along the east coasts of the North Island. The negative/El Niño phase of the SOI has the opposite effect, increasing the southwesterly winds and waves that reach the south and west coasts of New Zealand. The SAM causes an easterly wind anomaly on the austral summer, anomalous northeasterly winds along the North Island during the austral winter (Kidston et al. 2009), and an increased frequency of tropical cyclones undergoing extra-tropical transition near New Zealand during its positive phase (Diamond and Renwick 2015).

Measured and modelled waves

Waves were measured by a directional buoy in 35 m water depth off Mangawhai_for an 18-month period from March 1995 to August 1996 as part of the Mangawhai-Pakiri Sand Study (Bell et al. 1997). This relatively short record was collected to calibrate a wave model and is probably not representative of the long-term wave climate.

A long-term wave climate model for the Mangawhai-Pakiri embayment by MetOcean Solutions (2019) is reported in Jacobs (2020). The wave climate based on wave hindcast modelling for the period 1979-2018 is presented in tables of monthly and annual summaries as three-hourly directional wave data for locations P1 and P2 (Figure 3-11) (see MetOcean Solutions 2019, chapter 4 – p.58-99 and reproduced in Appendix E of Jacobs 2020).

Figure 3-11. Marsden Point wave buoy and sites P1 and P2 (on either side of Te Arai Point) for which for which waves were hindcast for the 40-year period 1979-2018. (Source: Jacobs 2019, Figure 2.4).

The direction and wave height roses for P1 and P2 are shown in Figure 3-12.

The modelled wave climate can be summarised as follows:

- The mean significant wave height (Hs) at both sites was of 0.93 m and the maximum Hs was 6.37 m at P1, 6.31 m at P2

- The Hs was less than 1 m for 67% of the 40-year period, exceeded 2 m 6% of the time, and 3 m 1.3% of the time.
- The modal peak wave period (Tp) was 8-10 seconds (38%), with 75% of waves having Tp in the range 6-12 seconds.
- The majority of waves (66%) arrived from a NE direction (22.5-67.5 0), with a further 20% arriving from the East (67.5. -112.5 0).
- Winter and summer wave distributions were very similar having the same mean Hs (0.97 m), but with winter having slightly more higher waves (1 percentile Hs = 3.65 m compared to 2.85 m in summer)

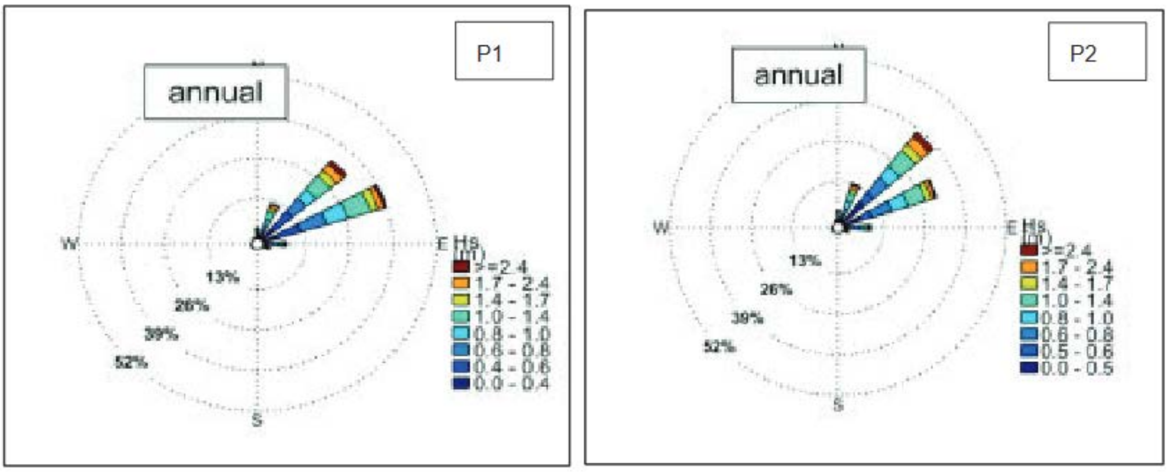

Figure 3-12. Wave direction-height roses for sites P1 and P2 from wave climate modelled for 1979-2018. (Source: Jacobs 2019, Figure 3.5)

The Northport Marsden Point wave buoy located at the northern end of Bream Bay (Figure 3.11) has been recording wave data since 2007 providing hourly time series of wave data. Jacobs (2020) provide a comparison of the wave record from the buoy for the 12 years (2007-2019) with the 40-year modelled record from the Mangawhai-Pakiri embayment. As expected, there are slight differences between the short, measured buoy record and the longer modelled record. Some of this is due to wave buoy location and how its record is affected by the blocking effect of Bream Head on northerly waves arriving at Marsden Point and the reduced blocking effect of Great Barrier Island on easterly waves.

<u>Analysis of storm events</u>

An analysis of storm events recorded at the Marsden Point Buoy (2007-2019) is provided in Jacobs (2019). For the purpose of the analysis, Jacobs defined storm events as periods when Hs exceeded the 1 percentile Hs of 2.59 m (total record) for longer than 3 consecutive hours. Jacobs describe the findings as follows:

- The majority of storm events (44) were from an east direction window (78 to 101 deg.), with the remainder being from ESE or ENE directions (although a number of these storms may in fact have a more northerly approach than indicated by the buoy).
- Storm events were generally of a short duration, with only 11 storms having durations of longer than 24 hours, and the maximum duration being 89 hours (July 2014).
- The event in July 2014 also had the largest wave height on record, with maximum significant wave height (Hs) of 6.37 m and a maximum wave period (Tm) of 10.8 seconds. The only other

storm with maximum Hs greater than 6 m was in July 2009, with a duration of 35 hours and a Tm of 10.3 seconds[11].

- In terms of monthly distribution, the highest frequency of storms occurred in March, June and July (8-9 storms over the 12-year record), with the least being in October and November (nil to one storm).
- In terms of seasonality, more storms (35) occurred in the winter six months from April to September, than in the summer (22) from October to March, with winter storms generally having larger wave heights and longer durations. The greatest number of storms in one winter was five, occurring in four different years (2007, 2011,2012 & 2014), and the greatest number of summer storms (three) occurred in 2008, 2012, and 2014.
- In terms of annual distribution, the greatest number of storm events occurred in 2012 and 2014 (eight events), with 2007 having seven events. The least number of storms occurred in 2015 with one event, and 2010 with two events.

3.8 Shoreline change and coastal erosion

Shoreline change and the associated hazard of coastal erosion affect both the open coast and harbour shorelines. It quite normal for the shorelines of estuaries to be in a state of dynamic equilibrium where they undergo continual change. On the open coast the shorelines advance and retreat in response to weather events and changes in sediment supplies. In the harbour channel meander patterns change in response to changing flow regimes and shoals move about and grow or decrease in size as sediment accumulates or is eroded. When shoals move sideways this in turn forces channels sideways resulting in erosion of soft shorelines. While the changes are generally slow (at annual or decadal time scales), they can be fast and dramatic during storms events when water levels are raised by storm surge and catchment floods.

<u>Spit breach and shoreline change</u>

The storm in 1978 triggered a dramatic change in the shoreline of the spit. The spit was overwashed and breached opening a second entrance to the sea.

The 1978 storm was a very significant and widespread weather event. The NIWA New Zealand Historic Weather Events Catalogue termed the event 'The July 1978 North Island Storm'[12]. It lasted four days (18-21 July) and the effects were felt over the northern and central North Island. It brought high winds, heavy rain, flooding, high seas, coastal erosion and power outages and property damage to Northland, Auckland, Coromandel/Waikato and the Bay of Plenty. Damage also spread down into the Manawatu-Wanganui. Newspapers report winds in the Hauraki Gulf of up to 70 knots (130 km/hr) on the 19th, and Northland experiencing a 'howling gale' on the 18th with winds of 41-55 knots (76-102 km/hr).

McCabe et al. (1985) undertook an analysis of the 1978 storm characteristics for Mangawhai. They reported that the storm peaked over 18-20 July, that the average wind speed at height of the storm was 40 knots (21 m/s) and calculated (using data from weather stations) that significant wave height

---

[11] Of interest here is that during Cyclone Gabrielle (13 February 2023) the Northport Wave Rider Buoy B at Marsden Point recorded Hs of 7.6 m and average period of 18 sec before it was knocked offline. https://www.nzherald.co.nz/nz/cyclone-gabrielle-niwa-reports-12m-high-waves-near-system-centre/INGGXETNHVBN7EB2IMJRRKZOIY/

[12] https://hwe.niwa.co.nz/search/summary/Startdate/01-02-1978/Enddate/01-09-1978/Regions/Northland/Hazards/Maritime+%252F+Coastal/Impacts/all/Keywords/none/numberOfEvents/20/page/1

and period were 5.0 m and 12 secs respectively. Wave refraction simulations showed that sediment ridges (up to 3-4 m tall) on the seafloor in water depths greater than about 32 m refracted the incoming longer period waves from the northeast and east, causing them to focus on the spit shoreline in the vicinity of the spit neck. They surmised that this focussing of wave energy contributed significantly to the overwash and breaching of the spit by increasing breaker heights at the shore and augmenting local wave setup of sea level.

Other factors contributed to the overwash and breach by raising water levels including: spring tides, storm surge, wave runup and river discharge. Frisby and Goldberg (1981) calculated the barometric set-up as 0.24 m, the wind set-up as 0.37 m, wave set-up as 1.15 m and wave run-up as 0.48 m. Together these factors resulted in water level 2.24 m above the predicted tide level. In addition, McCabe et al. (1985) reported that catchment runoff during the storm contributed to the breaching by increasing the total tidal discharge and backing up stream drainage behind the spit. They calculated that runoff could have contributed some 60-75% extra water to the total peak flow through the inlet and caused a raising of water levels in the estuary by 0.2 m during high tide contributing further to inundation of the spit.

Spit overwash and breach led to dramatic changes in the spit morphology and eventually to the closure of the original northern entrance. Figures 3-13, 3-14 and 3-15 show the changes in spit shoreline, channels and banks configuration from before the breach to after engineering works closed off the breach. Figure 3-13 shows that pre-breach the spit was very narrow at the neck (left image). The dunes were low allowing overtopping by waves and surge and the sea to cut a narrow channel to the sea (right image). Following this the southern inlet widened and there developed a complex and changing configuration of shifting shoals and channels. Figure 3-14 shows the situation 13 years after the breach and a wide shallow southern inlet with a complex configuration of shoals and channels. At this stage the original northern entrance has only a small amount of water flowing through it. By 1992 the northern entrance was closed and the southern entrance well established (Figure 3-15 left image). By August 1999 and after the engineering works to close off the southern inlet the northern entrance was open (Figure 3-15 right image). The 2 km long bund wall that was constructed from sand dredged from the channel can be seen running along the harbour shore of the spit. There is still a small channel connecting the remnant ponds to the sea.

Figure 3-13. Left image shows situation in January 1978 and 6-month before the breach. Right image shows situation in January 1983 and 4 years after the breach. (Source: A. LaBonté presentation).

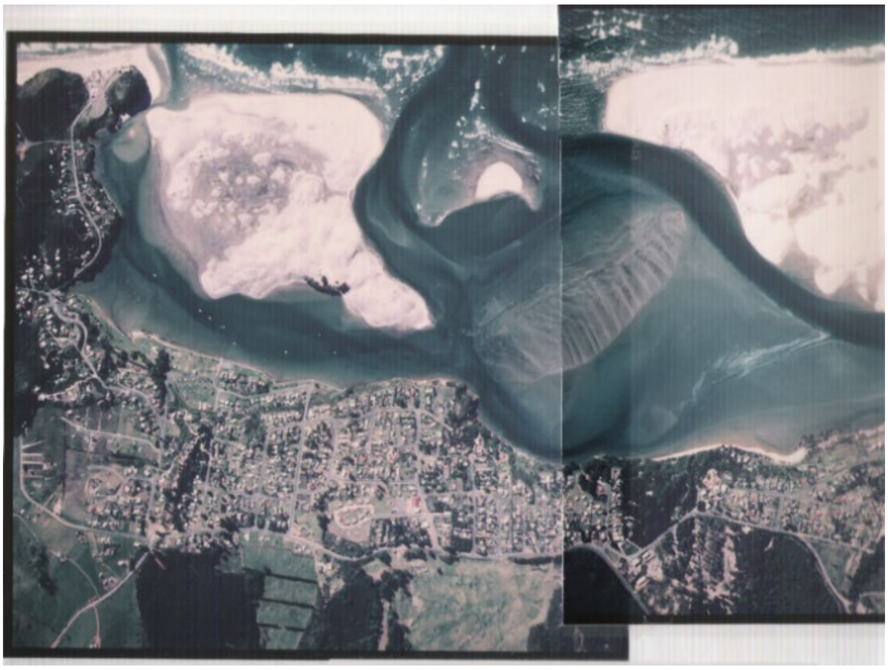

Figure 3-14. Spit breach in 1991. The new southern inlet breach dominates the situation and original northern entrance is effectively closed. (Source: A. LaBonté presentation).

Figure 3-15. Left image shows situation in 1992 with northern entrance closed and southern entrance well established. Right image shows situation in August 1999 after engineering works. Northern entrance is now open. The bund wall can be seen in the vicinity of the neck and remnant ponds have a small channel connecting them to the sea (Source: A. La Bonté presentation).

Reflecting back on the spit breach in the light of the study by Enright and Anderson's (1988) suggests a couple of interesting hypotheses. Firstly, Enright and Anderson reported that dune sands in the southern part of the spit capped older sands, presumably the semi-consolidated iron-stained Pleistocene sediments that are also exposed in outcrops underlying transgressive sand sheets in the Mangawhai-Pakiri embayment described by Nichol et al. (1996). There are no reports of Pleistocene material being exposed during the spit breach when deep channels were cut through the spit. Presumably therefore this harder and more erosion resistant substrate does not underpin the northern and middle parts of the spit which would make the spit more resilient to breach. A Ground Penetrating Radar (GPR) survey extending northwards from the base of the spit might reveal the lateral extent of the underlying 'spine' of Pleistocene sediment.

Secondly, Enright and Anderson reported that in pre-human times there was probably a continuous foredune along the seaward flank of the spit and that the burning of the forest resulted in removal of vegetation, deflation of the dunes and the development of an open sand system with hummocky topography. An implication of this is that the lack of a continuous foredune, or sequence of continuous foredunes, provides pathways for inundation during rare large storm events. Maintaining a continuous foredune of sufficient height to prevent overtopping is therefore essential for spit integrity in the future, particularly in the light of sea level rise and climate change.

<u>Channel meander and eastern shoreline of the harbour</u>

Lawson (1994) examined the way in which the slow process of natural channel meandering affected the inner shoreline of the spit in the vicinity of the neck, eventually making it vulnerable to breach. At the neck the flow at the outside of the channel bend cuts into the shore. Analysis of aerial imagery (1963 – 1994) showed that between1963 and 1978 there was net migration of the shoreline in the region of the neck which is seen as an extension of the meander bend downstream by 250 m, selective bank erosion seawards of 100 m, and a decrease in the curvature of the bend. During the 1978 storm there were fast and dramatic changes in morphology and a cut-off channel developed to form the southern inlet. This channel was in turn cut off and filled in with sand and a major channel and entrance to the ocean developed at the neck. In 1991 – 92 the southern channel took over as the main channel and moved north by 200 m. In 1992-94 the importance of the northern channel continued to decrease but there was little net change in overall channel positions.

A key finding of the analysis by Lawson was that the cut off and development of the southern inlet represented a major change in landform and a new dynamic equilibrium for the inlet system. By 1994 there was no evidence this pattern was changing. Key recommendations of the study were: 1) that particular attention should be given to the design of the bund and its location where the bund attaches to the true right bank (i.e., the western shoreline of the spit) to mitigate enhanced susceptibility of erosion at the point of decreased radius of flow at the bend, and, consequently, 2) that consideration should be given to mitigate the possibility of enhanced erosion by armouring the true right bank with relatively coarse sediment.

<u>Stability of the western shoreline of the harbour</u>

A large portion of the western shoreline of the harbour where it flanks the peninsula is fronted by intertidal sand banks and as such is unaffected by erosion channel meander. Tonkin & Taylor (2020) undertook a survey for Northland Regional Council of the coastal erosion hazard along a 7 km stretch of the western shoreline extending from the harbour mouth to the Molesworth Drive causeway (Figure 3-16). The geology of this coastal stretch varies from hard cliff headland at the harbour entrance extending south into a mix of hard cliff, sandstone cliff and low-lying estuarine coastal terrace. At one point there is a section of transgressive sand dune wedged against the cliff (Cell E in Figure 3-16). A narrow band of sandy beach occurs at the base of cliff and terrace sections from the harbour mouth south to about the southern tip of the Mangawhai Peninsula after which beach sands are typically not present the along the inner shore running northwest to Molesworth Drive causeway (Cells J, K, L in Figure 3-16).

Tonkin & Taylor split the inner shore into 12 cells (Figure 3-16) to assess coastal erosion hazards based on discrete changes in geomorphology and historic shoreline change represented in soft sedimentary cliff, hard cliff, low-lying coastal terraces and coastal terrace with sand dunes. The long-term average rates of shoreline change based on aerial images (1963, 1983, and 2003) and LiDAR (2019) (where negative is erosion and positive accretion) for different shoreline types were:

- The harder cliff in cell A was eroding at -0.01 m/yr.

- The softer sandstone cliff in cells B, C, F, I, and K were eroding at a mean long term rate ranged from -0.02 to -0.12 m/yr[13]
- The low-lying coastal terrace in cells and D, G, H, J, and L typically has long term rates of erosion of 0 to – 0.05 m/yr.
- Cell G in the south end of the peninsula was historically characterised by a local erosion hotspot and is now stabilised by groynes.
- In Cell E transgressive sand dunes have developed between the cliff and high-water mark. Here there is long term accretion at an average rate of +0.2m/yr. However, any material eroded from the dune will likely be washed alongshore by tidal currents thus future accretion will be hydraulically limited by tidal currents.

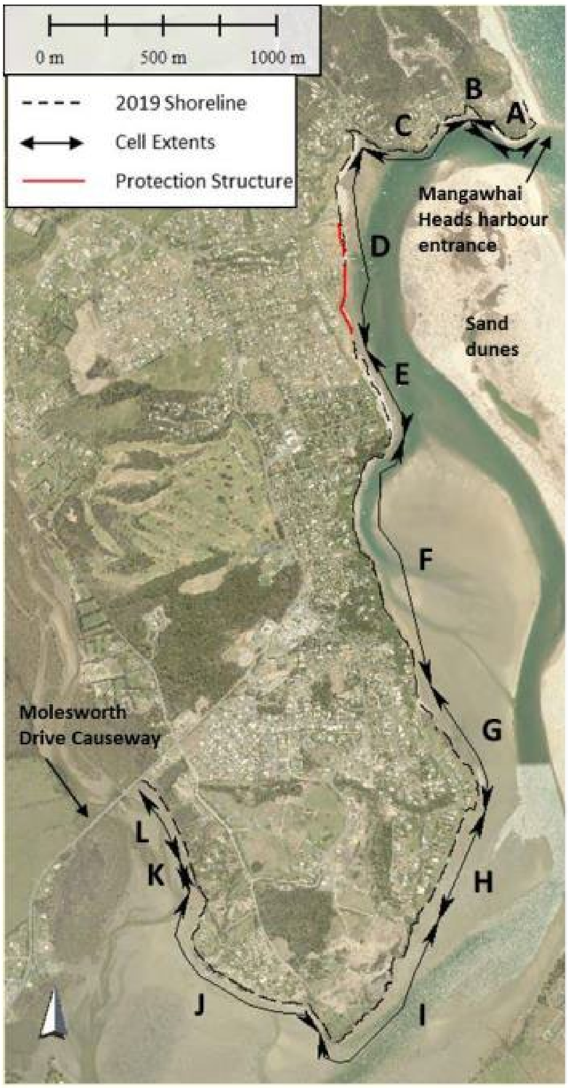

Figure 3-16. Map showing shoreline of the Mangawhai Peninsula and cell extents as mapped by Tonkin & Taylor (2020) (Source: T&T 2020, Figure 32.1)

In summary the rates of erosion and accretion are small but quite variable along the shore depending on the geology and setting. Section 4 of this report describes the potential effects of rising sea levels on this coast and the T&T recommendation for coastal setbacks to accommodate that process.

[13] Note that erosion of consolidated cliff coasts is a one-way process that is not balanced by accretion.

3.9 Coastal inundation

Coastal inundation is a hazard that occurs when the sea floods over low-lying coastal land. It results from:

- Coastal storm surge that causes sea level to rise in response to falling barometric pressure and strong winds which pile water up against the coast and, when combined with high tides (especially higher perigean spring (king) tides), produce higher than normal sea levels and storm tides.
- Wave set-up associated with breaking waves in the surf zone causing the average sea level to rise at the waterline which combined with storm tides allows waves to propagate inland.
- Mean sea level variations due to seasonal, El Niño / La Niña and multi-decade cycles increasing the sea level in any month by up to 0.15 to 0.25 m around New Zealand.
- Long-term average sea level rise due to climate change, resulting in more frequent exceedances of coastal inundation and wave damage.

Coastal inundation can result from any one or some combination of the above factors. It is also associated with tsunami events.

While infrequent, coastal inundation will be the largest and most extensive when storm tides coincide with high tide and king tides and when these conditions are maintained for several days. Inundation from the sea will be further exacerbated during heavy rainfall and stream flooding that is commonly associated with storms. Sea water flooding up rivers and drains prevents the escape of flood waters to the sea and causes water levels to rise to higher levels and travel further inland and, in addition, the land remains inundated with salty water for longer periods of time.

3.10 Potential effects of climate change and sea level rise

Sea level rise is expected to exacerbate coastal erosion as SLR will bring breaking waves closer to the high tide beach more frequently. In addition to SLR, climate change is predicted to result in an increase in the frequency of occurrence and intensification of storms, affecting long term through to inter-annual timescale sea level variations, changes in sediment supply, as well as the levels of incident wave energy at the coast. As a result, coastal systems of many kinds are expected to experience more frequent, widespread, and intense inundation and erosion relative to the present day (Oppenheimer et al. 2019).

New Zealand's wind wave climate is expected to change as a consequence of climate change. Albuquerque et al. (2022) modelled predicted changes in wave climate for several RCP scenarios for both near term and longer term (2081–2100) periods. Their modelling showed a general decrease in significant wave height and period (Hs and Ts) along the north/east coasts and an increase along the south/west coasts of New Zealand, with the intensity of the change increasing towards the end of the century. Projected changes for events of extreme wave height suggests an increase in wave height through the southwest, whilst along most of the other coasts (including the northeast coast) the wave height is expected to show slight decrease (maybe due to the decrease in the intensity of the storms). Seasonal projections show a reduction of extreme wave height during summer, and an increase (decrease) along the west (northeast) during winter and spring. The projected change in annual mean peak wave period Tp shows an overall decrease (down to −4%) along the northeast coast and an increase (up to +4%) throughout the west and southeast coasts. The projected change of annual wave direction is small (several degrees) and generally clockwise along the east coasts anti-clockwise along the west, which has implications for the direction of longshore transport of sand. In summary this points to decreasing wave heights along the north/east coast for annual mean values of significant wave height and period, with the intensity of the change increasing towards the end of the century.

However large energy brought to the northeast coast by tropical cyclones may not be well accounted for because of limits in resolution of the Global Circulation Model predictions. Diamond and Renwick (2015) suggest that the future will see an increased frequency of tropical cyclones. They found that during seasons characterized by positive phases of SAM and both positive and negative Southern Oscillation Index (SOI) values, there is an increased frequency of tropical cyclones undergoing extratropical transition near New Zealand.

General impacts of sea-level rise on different types of coastal morphology

Climate change and sea level rise will bring with it changes to the harbour and spit environments as summarised in Figure 3-17. There is explanation of these changes in the flowing sections of this report.

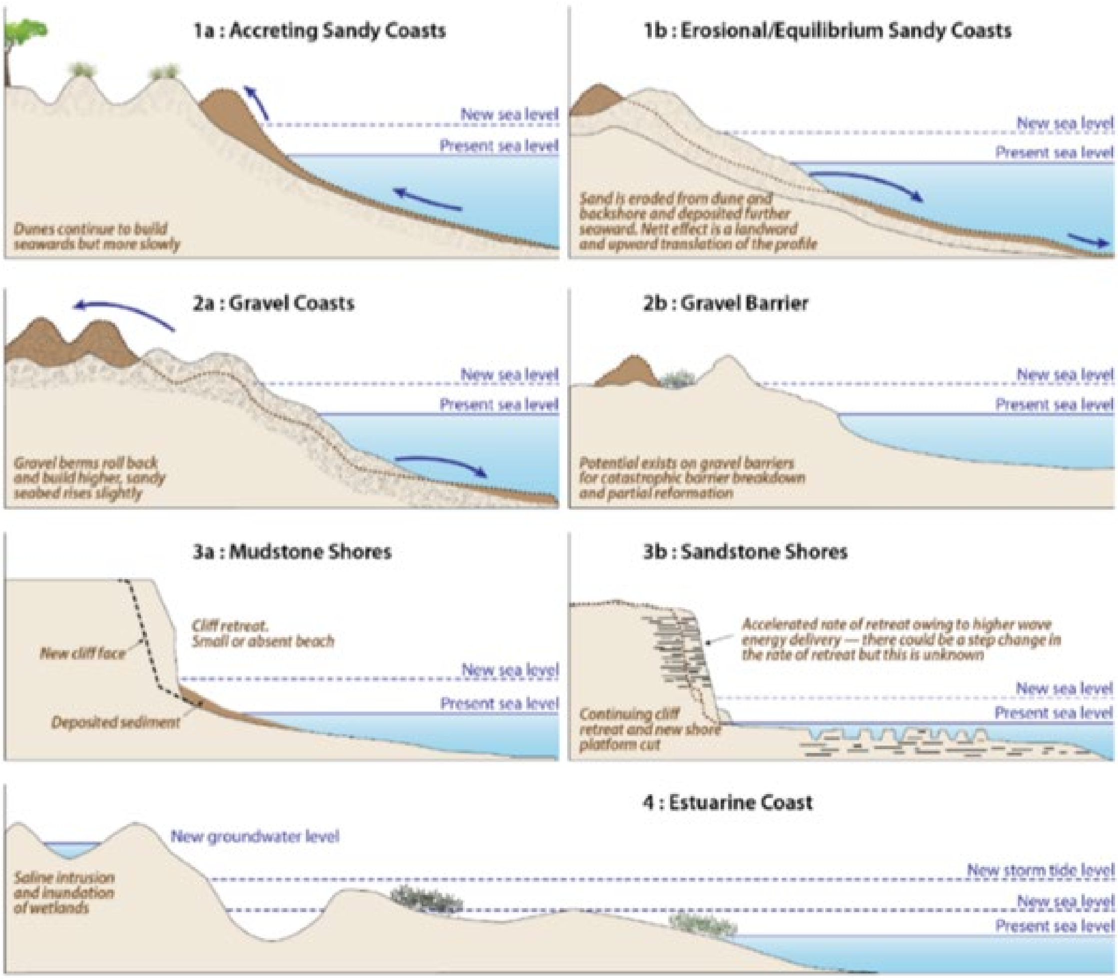

Figure 3-17. Generalised impacts of sea-level rise on different types of coastal morphology. (Source: Figure 32 in MFE 2017).

Harbour and tidal lagoon

For tidal lagoons like Mangawhai Harbour changes will mostly result from sea level rise. When sea level rises and the land is flooded, intertidal flats will migrate inland and the old intertidal flats will become subtidal (permanently submerged). The sediment forming the new intertidal flats will be derived from: 1) terrigenous topsoil reworked by waves, 2) sediments reworked from the lower intertidal and alongshore, 3) river and streams and 4) fine suspended sediment from the subtidal offshore area. There will be a lag (probably decades) between the flooding of the land and the establishment of the new intertidal flat areas, depending on the rate of sediment supply and the rate of sea level rise. Alternatively, and in situations where there is a constraint such as stop banks or shoreline armour, a proportion of the existing intertidal flat will be lost due to permanent submergence in a process termed coastal squeeze (Pontee 2013, Hume and Hart 2022). Coastal squeeze can be offset to some degree if sedimentation occurs at a sufficient rate allowing the intertidal flat to rise vertically despite being constrained to landward.

There is likely to be increased flooding of lagoon margins during storms, as incoming tides and elevated coastal water levels back-up stream outflows. There is likely to be some landward migration of ecological facies[14] (e.g., mangrove and saltmarsh) as sea level rise permanently submerges present-day intertidal areas. An increased frequency of rainfall and runoff events in some regions could lead to more frequent smothering of sandy substrate benthic communities with muddy sediment inputs (see Swales et al. 2020).

Harbour entrance and ebb tidal delta

Sea level rise could see an increase in ebb delta sand volume, but this is likely to be at the expense of the adjacent beaches. Hicks and Hume (1996) have shown that for estuaries with extensive intertidal areas and/or a low-lying hinterland (such as Mangawhai) sea level rise will cause an increase in the discharge through an entrance and increase in tidal prism. At Mangawhai the bed of the inlet throat is sandy and mobile (Hume and Herdendorf 1992) and should readily scour to accommodate sea level rise without any lasting increase in channel velocity.

The increase in tidal prism will result in changes in the ebb delta sand volume as follows. According to the Bruun Rule (Bruun 1962), the level of the seabed offshore from the entrance will need to be lifted to accommodate sea level rise and the ebb delta could be expected to grow in volume until a new equilibrium is established with the larger tidal prism. Given that the major source of sand for the beaches and delta has been crosshore transport from the seabed offshore (and that nett longshore transport, inputs from outside the embayment and river inputs are small), then the sand demand by the delta is likely to be offset by sand being eroded off adjacent beaches while these ebb delta adjustments are occurring.

Ocean beaches and spit shoreline

While many factors can influence erosion and accretion patterns on sandy coasts, if other factors are held constant, an increase in the MSL at a coastline will result in horizontal retreat of the coastline and coastal erosion (Bruun, 1962, MFE 2017). For the Mangawhai-Pakiri embayment parts of the shoreline that have been relatively stable over time are likely to erode under rising sea level, and parts that have been eroding historically are likely to have increased erosion rates. For Mangawhai the increased potential for shoreline erosion with sea-level rise is unlikely to be balanced by sediment supply because stream and cliff inputs are small, supplies from the offshore area are uncertain and the wider embayment is losing sand to mining.

Sea level rise allows waves to reach the backshore and foredunes more readily than at present. This is particularly the case for coasts with relatively small tide ranges because a specific sea level rise will be a higher proportion of a small tide range compared with a higher tide range. The result will be a

[14] General aspect or makeup of an ecological community, especially a local modification of a community characterized by a conspicuous or abundant species, that is absent or less concentrated in other locations.

higher percentage of high tides above the present MHWS mark and, hence, increased likelihood of waves and storm surges combining (Bell 2010).

Sandy beaches go through cycles of cut and fill. Short period storm waves erode (cut) sand and deposit it temporarily in nearshore bars. Between storms, low-amplitude, long-period (swell) waves push the sand ashore, and the beach and dunes accrete (fill). Changes in storminess associated with climate change will alter natural patterns of cut and fill. The potential recovery of foredunes between storms could be more limited than at present, particularly during certain ENSO and IPO phases.

Low elevation parts of sandy spits and barriers_may experience an increased frequency of wave overwash and breach events during storms (i.e., the risk of a repeat of the 1978 breach is increased).

Climate change may also see changes in longshore sediment transport rates which could increase or decrease, depending on local changes in wave climate, particularly wave direction. This may change the patterns and rates of both retreat and advance of the shoreline. Numerical modelling can be used to quantify these effects and patterns.

Dune vegetation is an important tool in mitigating erosion of sandy beaches. Dune grasses and shrubs act to trap sand and stabilise and build up the volume of the beach and dunes.

<u>Sea level rise and increasing frequency of coastal inundation</u>

A poorly understood consequence of sea level rise is that a long-term rise in sea level dramatically increases the frequency[15] of occurrence of higher water levels and coastal inundation events[16]. While calculations have not been undertaken for the Mangawhai situation, modelling for the Kaiaua coast in the Firth of Thames Stephens (2019) clearly demonstrates the potential seriousness of the future situation for low lying areas of the Mangawhai spit and harbour shore.

The Kaiaua coast and southern Firth of Thames experienced extreme storm-tides in 1938 and 2017. Figure 3-18 illustrates how sea level rise will increase the frequency of storm-tides. For instance, MHWS10[17] under present-day sea-level conditions will be exceeded for about 6% of the time, but similar water levels will be exceeded for 60% and 98% of the time when sea level reaches 0.5 m and 1.0 m respectively above present-day levels. Figure 3-19 shows similar information to Figure 3-18, but the percent exceedance has been converted to the number of sea-level events expected within a 10-year monitoring period. The graph shows the likelihood of storm tides reaching the levels they rose to on 5 January 2018 and 4 May 1938 (when storm-tides reached a similar elevation with both having an AEP of around 0.3% at 1998– 2017 MSL). Figure 3-19 shows that if mean sea level stayed as it was from 1998 to 2017, then if we observed for a 10-year period, there is only a very small chance we would see a storm-tide reach the 1938 and 2018 levels. With a 0.3 m relative sea level rise by 2050 we expect the events of 1938 and 2018 size to occur once every 30 years. With a 0.5 m relative sea level rise by 2070 we expect the events of 1938 and 2018 size to occur three times per year. With a 1.0 m relative sea level rise by 2120 we expect the events of 1938 and 2018 size to occur weekly.

The analysis above assumes no morphological response of the coast. In locations where sediment is available (e.g., via longshore transport or river inputs) the storm ridge should increase in size over time

---

[15] Frequency - The number or rate of occurrences of hazard events, usually for a given time period (Ministry of Civil Defence and Emergency Management).

[16] Event - Occurrence or change of a particular set of circumstances. Can be one or more occurrences and can have several causes (AS/NZS ISO 31000:2009 Risk management standard).

[17] MHWS10 is the mean high water spring tide exceeded 10 percent of the time. It is often used as a practical high tide level for infrastructure design works, and also for estimating extreme high (e.g., the 100-year Average Recurrence Interval) storm tides.

providing some protection from inundation. However, the level of the land on which houses sit would not change. As a consequence, when natural storm ridge is breached the low-lying land would be inundated and the flood waters potentially trapped by the raised ridge until the land drains (slowly by gravity drainage).

The bottom line is that sea level rise will dramatically increase the frequency of occurrence of coastal inundation events. Events that are rare today will be increasingly common in the future. The higher water levels will also bring wave breaking closer to the shore and wave uprush higher up the beach and dune face increasing the potential for coastal erosion. Calculations could be undertaken for Mangawhai to quantify this effect.

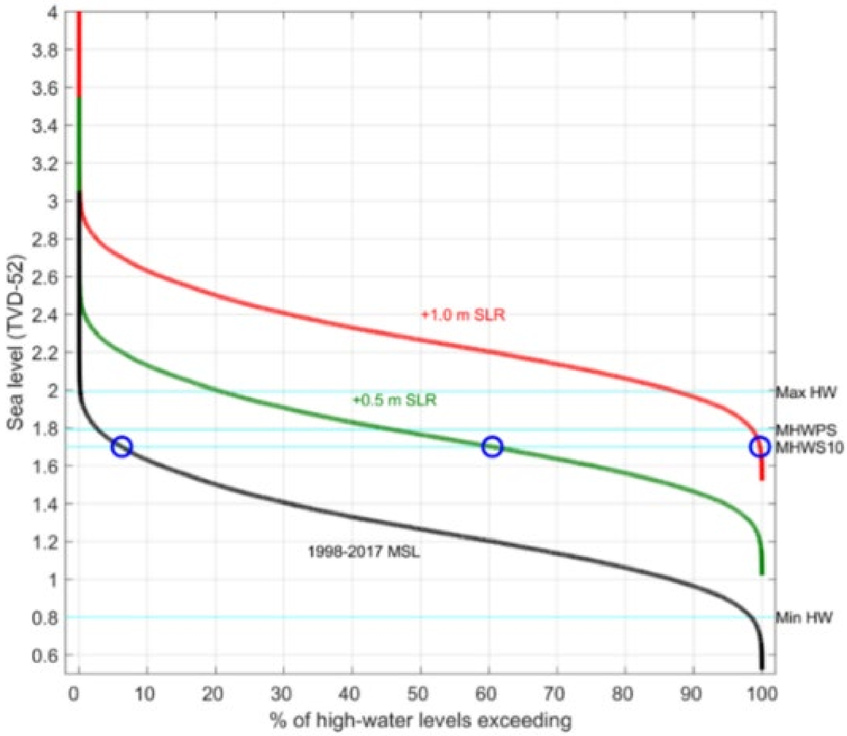

Figure **3-18**. Storm-tide exceedance curve at Tararu, demonstrating the effects of sea-level rise. The plotted sea-level elevations are the 15-minute-averaged storm-tide elevations at the time of high tide. The sea level elevations include the 1998–2017 MSL, which was 0.05 m relative to TVD–5218. Tidal high-water marks are shown on the rightmost vertical axis (e.g., MHWPS is Mean High Water Perigean-Spring mark and MHWS10 is the Mean High Water Spring tide exceeded 10 percent of the time. (Source: Stephens 2019).

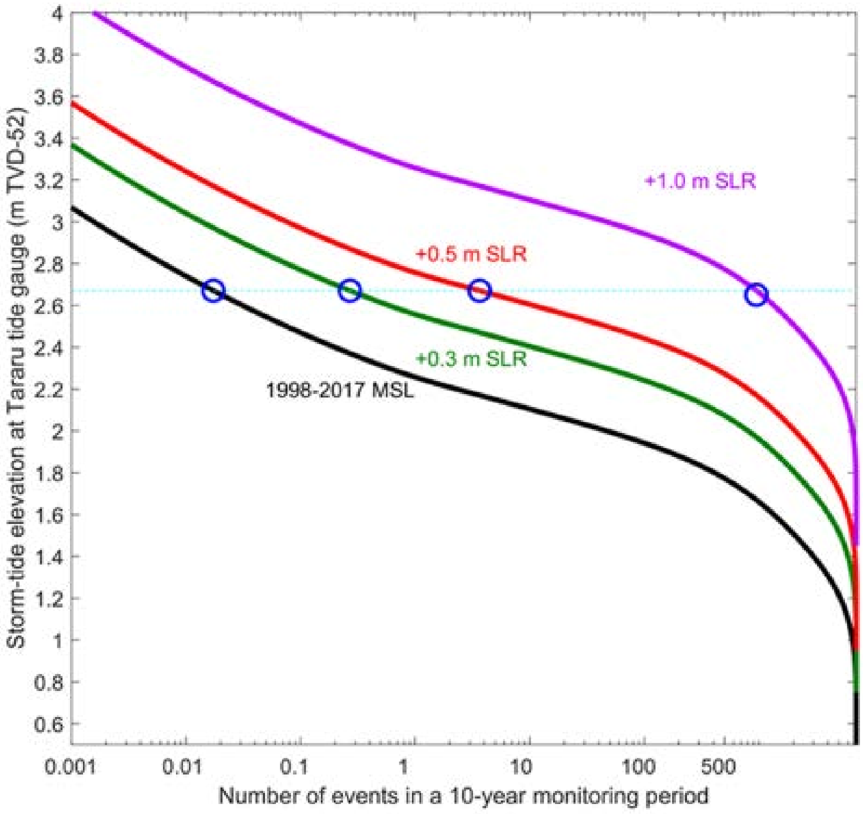

Figure 3-19. Expected number of storm-tide events within a 10-year monitoring period at Tararu tide gauge, including change with sea-level rise. The plotted sea-level elevations are the 15-minuteaveraged storm-tide elevations at the time of high tide and do not include infragravity wave effects. The sea-level elevations include the 1998–2017 MSL, which was 0.05 m relative to TVD–52. The blue circles mark the maximum storm tide still-water level at Tararu on 5 January 2018 of 2.62 m TVD–52. (Source: Stephens 2019).

<u>Effect of vertical land movement</u>

A salutary message for Mangawhai lies in the consideration of the effects of vertical land movement (VLM) because the potential effects of sea level rise can be affected by vertical land movement. Subsidence of the land increases (and uplift offsets) the threat of sea level rise and associated potential for coastal inundation (flooding from the sea) and coastal erosion and in the long term the height of storm surge and extreme water levels.

The NZ SeaRise project recently reported results of analysis of InSar satellite data for the period 2003 – 2011. It showed that around the shores of the Mangawhai Harbour there is minor subsidence (-2 mm/yr) in the harbour's headwaters area, and greater subsidence (about -3-4 mm/yr) around the main body of the harbour (Figure 3-20).

So, for Mangawhai the subsidence of the land effectively doubles the current rate of effective sea level rise (currently 2.2 ± 0.6 mm/yr for Northland) and if subsidence continues will increase the threat of coastal inundation and erosion and in the long term the height of storm surge and extreme water levels.

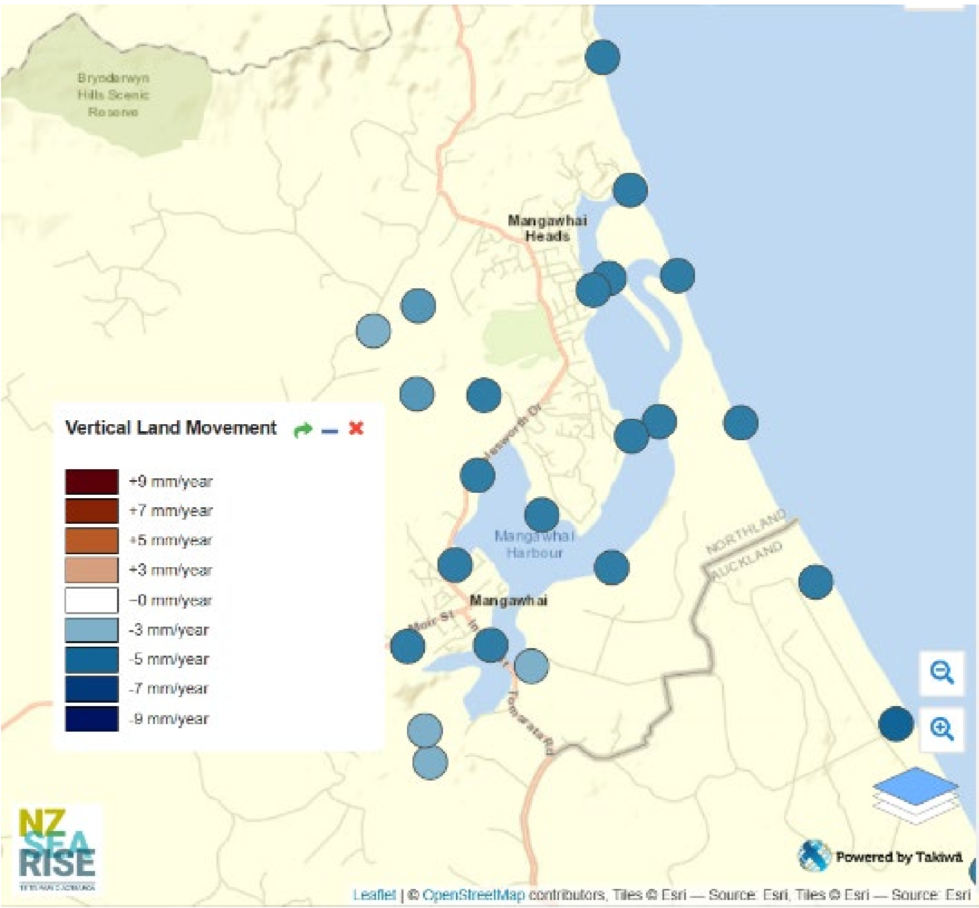

Figure 3-20. Vertical land movements (units are mm/year) derived from InSar data. The data points are 2 km apart. (Source: NZ SeaRise project website[18])

3.11 Human influences on coastal processes

This section provides a brief introduction to human influences on coastal processes in the harbour and on the spit. Issues and mitigation options are discussed in 4 and 5 associated with these influences are discussed further in Sections 4 and 5 of this report.

Catchment development

Catchment development by way of changing land use from forest to pasture and urban uses has had a gradual but unquantified effect on the harbour ever since the Mangawhai area was first settled. Land clearance of vegetation initially by logging and then for farming, and the hardening of surfaces and channelising flows with urban development all make runoff events 'flashier'. They deliver higher sediment loads to the streams and harbour waters resulting in more turbid waters and siltation. The upper reaches of the harbour being close to source and less well flushed will be most affected by these processes. Continuing and intensifying catchment development along with climate change are expected to accentuate these processes.

Mangroves

Mangroves have expanded in the middle and upper reaches of Mangawhai Harbour since about 1980. They have been the subject of hot debate in the Mangawhai community. Arguments for their protection cite their ecological value. Arguments for their removal cite improvements to harbour

[18] https://searise.takiwa.co/map/6233f47872b8190018373db9/embed)

flushing and making the substrate sandier. Removal also favours wading birds and channel feeders over and above whatever other fauna might utilise the shelter mangroves provide. In effect, and based on current knowledge, the decision on removal comes down to form of biodiversity/habitat that is favoured.

A clearance of mangroves was carried out in the upper reaches of Mangawhai Harbour below the causeways commencing in 2015. This followed years of debate, court action and appeals costing around $400,000 and involving Forest and Bird, DoC, Northland Regional Council, and several environmental experts - agreement finally reached allowing the MHRS to remove up to 16 hectares[19]. The area targeted runs from near the Lincoln St reserve, around to Molesworth Causeway and the Insley St inlet.

While formal monitoring has not taken place there is evidence that clearance leads to a healthier benthic floor and increased capacity to support the fish population (Alfaro 2010). Monitoring the benthic floor, avian and fish species in and around the areas subject to clearance may still yield useful insights into the effects of mangrove removal given the relatively slow rate at which cleared sites recover.

Causeways

Causeways cut across the upper arms of the Mangawhai Harbour in four places. They comprise narrow raised engineered embankments constructed of compacted earth and rock that have a bridge section (and/or culverts) to permit tidal flow through the structure. Detrimental effects of causeways on estuaries have been variously described as: restriction of tidal flow to areas upstream of the structure, reduction of the tidal prism and flushing capacity, causing increasing muddiness of substate due to the lower energy environment and contributing to the expansion of the mangroves within the enclosed area behind them.

Spit breach closure

As described above, major human intervention in coastal physical processes followed the spit breach storm in 1978. The ‘big dig’, as it was termed, comprised major engineering works over nearly 20 years at considerable cost (c. $750,000) and effort (c.125,000 hours) by volunteers (Ross 2007). Works included using heavy machinery and a dredge to build a 2 km long sand bund across the breach to block the tidal flow, wind break fencing, and planting the harbour and ocean shorelines with thousands of native sand binding plants (supplemented with rabbit control) to build up sand storage and ensure the integrity of the spit from further breach. Maintenance work has been necessary through to today.

Water recreation and associated infrastructure

The harbour provides valuable opportunities that serve the recreational and commercial needs of the community and its visitors. Recreation in the area has seen an increase in the use of vessels of various types including yachts and kayaks and powered vessels such as trailered boats, jet skis and Sealegs. To service these activities there are boat ramps, swing moorings, and piles in the channel for navigational purposes. These activities bring with them potential impacts such as increased usage of roads and boat ramps by trailered vessels, conflicts between boats jets skis and kayaks in limited space (and particularly in the area of the ski lane) and the potential for erosion of the shoreline from vessel wakes.

[19] Mangawhai Focus April 14, 2014

Dredging sand to nourish the spit

Dredging is currently undertaken from sand traps in the channel. The sand is primarily used to build up the shorelines of the spit. Small amounts of sand have been used to nourish the beaches on the western shoreline of the harbour. The dredging is said to offset channel infilling caused by sand blowing off the spit. There are no records of channel infilling, although repeat surveys of bathymetry have been undertaken on parts of the channel and would quantify areas of deposition and erosion, but not necessarily the aeolian contribution.

No accurate tally of dredging quantities is available, Dredging is estimated to be about 10,000 m^3 per 'season'[20] (P. McDermott pers comm). Going forward it would be valuable to record dredging quantities and locations.

Land protection works

Land protection works occur in cell D (Figure 3-16) in the vicinity of the main holiday park and reserve where a seawall stabilises the shoreline and in cells G and H where there are local coastal protection structures including groynes and seawalls.

Sand mining

Sand was mined from the mouth of the Mangawhai Harbour from 1953 for use as construction aggregate. Hilton (1989) reported 200,000 m^3 as being extracted from the ebb tide of the Mangawhai Inlet from the time extraction began up to 1979 when extraction was suspended following breaching of the barrier spit during a major storm in 1978. Extraction resumed in 1989. Resource consents were approved in 1993 for a term of 10 years for Norsand Ltd and Sea Tow Ltd for maximum annual extraction 25,000 m^3/yr (Ramsay 2004). Application for a renewal of consent for 20 years for maximum annual extraction 27,000 cubic m^3/yr was declined on the basis that there were uncertainties relating to the potential effects on beaches and nearshore seabed adjacent to the Mangawhai entrance.

Auckland Council historical records indicate that sand extraction from the Mangawhai-Pakiri embayment has been occurring since the 1920's. Although exact records are not available, it is estimated that the extraction volumes prior to 1966 could have been in the order of 2 million m^3. Council records show that a total of around 5.4 million m^3 of sand has been extracted from the Mangawhai-Pakiri embayment since 1966 (Jacobs 2020). The total extraction from the embayment is therefore about 7.4 million m^3 of sand. The sand is used to supply the Northland-Auckland region with a high-quality sand requiring minimum processing for use in the concrete industry.

Permits for extraction are now up for renewal and going through the hearing and appeal process. Between three applications McCallum Bros is looking to take up to c. 7 million cubic metres of sand over the next 35 years. The applications are for extraction in the 'inshore' (5-10 m depth), 'mid shore' (15-25 m depth) and 'far shore' (25-40 m depth). The inshore and mid-shore applications are each for 70,000 m^3/yr of sand over the next 35 years. The 'far shore' application is for 2 million cubic metres of sand over the next 35 years. There is considerable debate as to whether this practice is contributing to erosion of the beaches in the Mangawhai-Pakiri embayment and just how sustainable it is.

[20] The dredging season is currently March to August in a year.

4 A coastal physical process lens on issues and threats

This section discusses issues and threats facing Mangawhai Harbour and spit from a coastal physical perspective along with potential mitigation actions (some of which are already being progressed) and what can be done going forward to strengthen the response. A key element underpinning any remedial action is consideration of the effects of climate change and sea level rise and the necessary data collection and monitoring to inform good decision making and options.

4.1 Catchment development and runoff

Development in the catchment by way of land clearance, hardening of surfaces and channelising flows makes runoff events 'flashier', delivers higher sediment loads to the streams and harbour waters resulting in more turbid waters and siltation. The upper reaches of the harbour being close to source and less well flushed will be most affected by these processes. Continuing and intensifying catchment development along with climate change are expected to accentuate these processes.

Water quality monitoring

There are no technical reports describing the downstream consequences of runoff from Mangawhai catchment runoff on plant and fish life[21] or accelerated sediment accumulation/accretion on the harbour.

Comprehensive monitoring of water quality from the catchment inflows was lacking until picked up by the Mangawhai Harbour Water Quality Project Team (2018). They monitored catchment inflows at 5 sites over 12 months for salinity, water temperature, dissolved oxygen, turbidity and visual clarity, total coliforms and E. coli, ammoniacal nitrogen, total nitrogen, and total phosphorus. The monitoring found higher levels of contamination associated with runoff from catchment floods (as expected) although the median values of all variables were within the ANZECC (2000) guidelines for lowland streams.

The project team suggested that stream edge retirement and restoration planting are likely to make the greatest contribution to reducing sediments, nutrients and bacterial contamination entering streams from overland flows. However, the level to which this is being put into practice is unclear. A commitment to year-round monitoring at four sites on the harbour by Northland Regional Council will provide on-going data to enable monitoring of harbour health and the success of that strategy. However, there do not appear to be any triggers or thresholds set to initiate action should levels exceed guidelines. Nor were means identified for assessing the success of stream edge retirement and restoration planting. It is important that the monitoring continue, and action strategies be drafted given that catchment development is intensifying and issues associated with runoff are like to be accentuated with climate change.

Controlling runoff

While there are no specific studies on the matter, continuing and intensifying catchment development are expected to accentuate runoff and sediment inputs to Mangawhai Harbour. Runoff is best controlled at source because dredging and disposal of muddy sediments is difficult and costly. In general terms best practice during construction to avoid or minimise the potential for scour and sediment to enter the CMA, requires all construction related water must be subject to erosion and sediment control measures prior to discharge. This includes following a risk management process and construction water management principles. Specific erosion and sediment controls are usually

[21] Ecological issues are outside the scope of this report.

detailed within Site Specific Erosion and Sediment Control Plans (SSESCP's) developed by the contractor and include check dams, decanting earth bunds, super silt fences and progressive stabilisation. Mitigation of effects can be further achieved by confining construction works to fine weather windows when there is little surface runoff.

In the lower reaches of the harbour there have been undocumented observations of thin layers of mud being deposited on the upper intertidal areas and beaches in the mid and lower parts of the harbour following floods. Generally good flushing (high tidal exchange) in the lower harbour means that the resuspended sediment derived from the catchment is primarily flushed downstream by the outgoing tide and eventually out to the sea, while some is likely pushed back up the harbour by the incoming tide. Thin layers of mud are generally a short-lived effect and will not make beaches muddy permanently. The thin layers are usually winnowed from the substrate by orbital currents associated with wind waves and advected from the area by tidal currents. Wave action is a reason sandy beaches remain sandy.

The situation is different for tidal flats where thick layers of mud can be deposited following extreme rainfall events. How long muddy sediment remains on the upper tidal flats is difficult to predict being dependent on the thickness of the mud, the state of the tide (neap versus spring) at the time of the event, whether wave events are large enough to resuspend it, and whether the mud has had time to dry out between the tides. Mud can also accumulate immediately adjacent to locations where streams/drains emerge on the tidal flats of the western shoreline of the lower harbour.

Climate changes will cause changes to freshwater inputs as rainfall and runoff patterns change, altering balances between river and tide forcing. MFE (2018) provides climate change projections for rainfall and wind for New Zealand based on simulations from the IPCC Fifth Assessment. Projections are highly variable by region and time and between models. The overall pattern in annual precipitation trend is for a reduction in the north and east of the North Island, with spring decreases in Auckland, Northland and Bay of Plenty. Extreme events are likely to increase and include an increase in the frequency of heavy precipitation events and the potential for associated flooding. Extreme wind speeds are expected to increase, with up to 10% or more in parts of the country. The biggest increases are expected to occur in the southern half of North Island, and throughout the South Island. More frequent droughts or floods or droughts could deliver lesser or greater amounts of catchment sediment to coasts, although basin shallowing from sedimentation may be offset by sea level rise.

4.2 Mangroves

Mangroves are influenced by changes in the physical processes of hydrodynamics and sedimentation. They colonise the intertidal flats from the high tide level down to about the mid tide level. Their spread has been attributed to increased sediment runoff from the catchment and activities such as causeway construction altering hydrodynamic conditions. In turn, they are seen to modify the physical environment they colonise most notably by increasing the muddiness of former sandy substrate. Mangroves have been cleared from parts of the Mangawhai Harbour (Figures 4-1 and 4-2). Mangrove clearance is covered by rules set out in section C.1.4 - Mangrove Removal, of the Proposed Regional Plan for Northland (Northland Regional Council 2022).

<u>The debate about removal</u>

Mangroves have expanded in the middle and upper reaches of Mangawhai Harbour since about 1980. They have been the subject of hot debate in the Mangawhai community with argument for their protection citing their ecological value and argument for their removal citing improvements to harbour flushing and making the substrate sandier. Their ecological value is based around provision of a nursery ground for fish, sanctuary and feeding area for certain birds (e.g., banded rail), and provide energy and organic matter in the form of leaf, seed, and woody debris to the environment, which is incorporated into the food web, thus supporting a diversity of animal life including both estuarine and terrestrial fauna and flora. They also sequester carbon, and are, therefore, contributing to mitigating against climate change. The argument for removal is that mangroves accelerate deposition and the build-up of fine sediment changing substrate from sand to mud, within the forest and reduce the tidal prism and therefore harbour flushing. The 'for and against' mangrove clearance is still being debated in the Mangawhai community.

Figure 4-1. Mangrove forest before clearance in 2014 (left image) and tidal flats after clearance in 2019 (right image) from the shoal downstream of Molesworth Drive. (Source: Google images).

Figure 4-2. Mangrove forest before clearance in 2014 (left image) and tidal flats after clearance in 2019 (right image) in the area downstream of the Tomarata Road causeway. (Source: Google images).

At the community level the argument is not so much about a trade-off between ecological benefits and water/substrate quality, but really about the type of environment that different sections of the community favour. For instance, large parts of the upper harbour were originally free of mangroves favouring benthic communities associated with sand flats and wading birds. Those areas probably had greater water clarity and provided greater public space for water recreation such as fishing and boating. Today the mangrove areas favour benthic communities associated with mud flats and provide refuge for some birds along with other ecological benefits described earlier. These areas today are more turbid and there is less public space for water recreation. Both situations have their values.

Do mangroves affect flushing of the harbour?

Following its appeal to the Environment Court in April 2012, the Mangawhai Harbour Restoration Society won the right to remove mangroves from specific areas within Mangawhai Harbour and also remove juvenile propagules that re-emerge until 2038. A clearance of some 16 ha of mangroves was undertaken in the upper reaches of Mangawhai Harbour below the causeways. While there are no measurements, observations suggest that in places the substrate is reverting to its former sandy nature as the orbital currents from small wind waves resuspend mud which then is then flushed from the area.

The question remains whether clearance of mangroves has increased the tidal prism and therefore the flushing capacity of the harbour. A back-of-the-envelope calculation suggests that removing 16 ha of mangroves will make only a very minor difference to the flushing. Removing a 20 cm layer of mud over 16 ha equates to an increase in the tidal prism (6.562×10^6 m^3) of 32,000 m^3 or only c. 0.5%. Given uncertainties in field measurement of tidal prism and also the fact that the tidal prism changes daily due to the fluctuating tide range from sun/moon and weather (e.g., wind and air pressure), this small percentage of change cannot be measured/proven with any degree of certainty.

A numerical model of the harbour would provide a useful tool for testing how tidal prism and patterns of current flows and sedimentation might change with mangrove removal, and provide a means to advise removal strategy and outcomes.

Role of mangroves in hazard mitigation

Another factor to take into consideration with removal is that mangroves can provide a potential means of hazard mitigation. Their protection against natural hazards such as storms, tsunamis and coastal erosion has been widely reported (e.g., McIvor et al. 2012, Spalding et al. 2014). Farmers in the southern Firth of Thames reported significant wave attenuation by the 800 m wide swath of mangroves during Cyclone Drena. It was suggested that mangroves probably increased the level of protection provided by the stop banks (Dahm and Munro 2002 p89).

Policy 26(2) of the New Zealand Coastal Policy Statement recognises the potential for mangroves to provide a natural defence against coastal hazards. Wide stands of mangrove forest have been reported to slow down and limit the extent of inundation from the sea during surge events and tsunami and by lining the upper shore. They provide some protection for banks against coastal erosion by wind generated waves at high tide. T+T (2020) recognised that mangrove removal in Mangawhai Harbour likely influenced local shoreline morphology and stability (i.e., allowed localised erosion) in

Guidance on best techniques to manage mangrove expansion

Lundquist et al. (2017) provides excellent guidance on the best techniques to manage mangrove expansion, while maintaining the ecological integrity of estuaries and harbours. The report describes mangroves, their physical environment, the ecological services they provide, how they might be affected by climate change, best removal practices and their effectiveness and cost, monitoring effects and alternative management approaches. They report that mangroves have expanded in extent in New Zealand, mainly seaward across tidal flats, over the past half century. Accompanying expansion there has been increasing muddiness, reduction in current flows and exposure to waves, and a build-up in the height of tidal flats[22]. Interestingly, research from the Firth of Thames found that muddy sediments are typically deposited before mangroves expand into new areas, rather than mangroves causing an increase in deposition of muddy sediments (Swales et al. 2015).

Surveys of 40 mangrove removal sites throughout New Zealand by Lundquist et al. (2017) showed that removal of mangroves rarely results in a return of sand flats, and often has detrimental effects on the local ecosystem and amenity (sight and smell). However, sandy sites in more exposed locations with wave and current action had a higher chance of erosion of muddier sediments after mangroves were removed, while sheltered and muddy sites showed only minimal, if any, erosion of muddy sediments. The timing of return of muddy substrate to sandier sediment after mangrove removal is site specific, depends on choosing the right removal method for the area and is generally slow (years/decades).

Lundquist et al. (2017) make the point that the removal of mangroves is a temporary fix unless further catchment management decisions are taken to minimise the input of land-based sediments and nutrients entering waterways such as happened with increased conversion of land for agriculture, forestry or urban use.

Response to climate change and sea level rise

Changes in the extent of mangrove habitats in Auckland east coast estuaries in response to climate change have been modelled in work by Swales et al. (2009) and McBride et al. (2016). They found that sediment supply and sea level rise both drive changes in suitable mangrove habitat. A fundamental premise of the modelling is that mangroves maintain their lower limit of expansion at about the level of mid tide.

In most scenarios of sea level rise modelled, with even today's or increasing sediment supply, suitable mangrove habitat is maintained or expanded, often predicted to increase in extent by over 50%. A reason for this is that sediment supply when sufficient builds up the bed level due to deposition. In contrast, reduced sediment supply predicts large decreases in mangrove coverage in upper intertidal zones as sediment supply is not sufficient to build up the bed to above mid tide level to maintain mangrove distributions in the face of sea level rise.

Looking ahead

For Mangawhai, a fundamental decision that has to be made is how far down harbour mangrove should be allowed to spread. Success of mangrove clearance in terms of returning to a sandy substrate will depend on how sandy the sediments were before colonisation. Also, sites more exposed to wave and current action have a higher chance of dispersal by erosion of muddier sediments following removal. Whatever the situation the return to sandy sediments is likely to be slow, of the order of years or decades. To prevent further spread of mangroves in the cleared areas there needs to be continual maintenance in the form of removal of mangrove propagules.

In future, and while the mangrove debate continues, it is important that projects involving clearance of mangroves are underpinned by data driven initiatives. For instance, making measurements of shoreline position, substrate type and ecology (e.g., bird and fish life, benthic ecology) before and after mangrove clearance to enable the perceived outcomes of the project to be assessed in an objective and quantitative manner. Even sometime after the Mangawhai clearance, there is probably value in monitoring the benthic (bugs) and faunal (birds, fish) ecology of the cleared areas and adjacent mangrove forest to document the values of each. Also, taking short shallow cores in the

[22] The mechanism for this is described in a study by Haughey (2017) in the southern Firth of Thames which showed that the presence of mangrove forest influences the tidal wave dynamics by reducing wave orbital current velocity and tidal amplitude across the intertidal flats, which is conducive to sedimentation of fines.

substrate of the cleared areas would identify underlying sand layers (or not) and provide information to help manage the time frame of expectation of change in substrate from mud to sand.

Importantly, mangrove removal is a temporary fix unless further catchment management decisions are taken to minimise the input of land-based sediments and nutrients entering waterways.

4.3 Causeways

There have been no specific studies and measurements of the physical effects of causeways on the Managwhai Harbour. The potential effects of causeways on estuaries are commonly cited as reducing flushing and causing an accumulation of muds and mangrove proliferation upstream of the structure.

Sjardin (2011) investigating the link between causeways and the associated habitat change, identified a total of 186 causeways in 160 estuaries in New Zealand. Some key findings were:

- Causeways generally affect only small percentages of the total area of estuaries as most enclose limited areas around the estuary's upper shorelines (this is the situation in Mangawhai Harbour).
- Effects on sediment characteristics and benthic fauna were highly variable, with only one site found to have statistically different percentages of fine sediments above the causeway, although there is some evidence for a general pattern of greater fine sediment percentages near to causeways.
- Mangrove propagule retention occurred in greatest proportions in close proximity to the causeway in areas above the mid-tide, Nevertheless, retention below the causeway was greater than expected in the mid-tide areas.

A study by Hume (1991) compared the morphological stability of natural and causeway modified estuarine waterways (tidal channels and creeks) in the upper reaches of Auckland estuaries. The 11 tidal waterways are like those at Mangawhai, being of fine-grained substrate and having little littoral drift and stream inflow. The key findings were that:

- There was a strong coherence between waterway shape (throat cross-sectional area) and tidal flow parameters at spring tides.
- Empirical relationships (equations 3 and 4 in Hume 1991 p.1110) were developed relating tidal prism to throat cross-sectional area for both the natural and causeway modified situations.
- Adjustments to waterway throat dimensions following constriction by causeways are slow (c. 10 to 15 years) compared to inlets on sandy shores (several months to a year).
- The equations can be used to size the dimensions of the channel throat through a causeway structure to minimise the impact on the tidal flow regime and sediment transport patterns.

Historical images provide some insight into the effects of causeways on Mangawhai Harbour. Images of the Molesworth Drive causeway reveal changes in the channel and shoal morphology that took place following causeway construction. Comparing the 1963 (pre-causeway) and the 2015 (post-causeway) images shows that the bridge spans the deepest part of the original channel (Figure 4-3). The overall alignment of the channel is similar. A major change is the development of shoals in the central channel areas for about 200 m immediately up- and down-stream of the bridge. This results from a reduction in the tidal discharge after passing through the constriction at the bridge on the incoming and outgoing tide. Mangroves have colonised the tidal flats up- and down-stream of the causeway. The degree to which mangrove growth upstream of the causeway is due to increased sediment accumulation upstream of the structure is unclear from the images.

Today the system may have reached a more stable state. Comparing the 2015 and the 2023 images shows little change in shoal and channel configurations, indicating that the system had probably reached a state of dynamic equilibrium by 2015 with respect to flows and sediment transport (Figure 4-4). There are similar types of changes in channel and shoal morphology at the Tomarata Road causeway, although of smaller scale as the flows there are less. The channel and shoal morphology can't be seen at the other small causeway because mangroves have completely infilled the channel.

Figure 4-3. Comparison of channel morphology between pre-causeway situation in 1963 (left image) and post causeway situation in 2019 (right image) in area of the Molesworth Drive causeway. The black line on the left image shows the approximate line of the causeway. (Source: Images from Retrolens 1963 and Google 2019).

Figure 4-4 Changes in channel morphology in the vicinity of the Molesworth Drive northern causeways. (Source: Images from Google 2015 and 2023).

At Mangawhai the causeways clearly alter the channel morphology locally in the vicinity of the causeways. Here they trap muddy sediment and raise the level of the channel bed to above mid-tide, they alter the environment to one that favours mangrove colonisation. The causeways will continue to shelter tidal flats upstream of the structure from substrate reworking by tidal flow and wave action, promoting sediment accumulation by preventing a process that would aid transition to a sandier substrate. The degree to which the Mangawhai causeways contribute to mangrove growth upstream of the structure given the substantial growth of mangroves downstream of the causeways is uncertain, although mangroves undoubtedly contribute to the colonisation downstream of the structure via the release of propagules.

Mangawhai causeways have been in place for at least two decades so the channel throat would have had time to scour down to accommodate the flow constricted by the structure (unless the bed is lagged or rock). Whether or not the Mangawhai causeways are today reducing tidal flow to the upper reaches is more uncertain. The impact could be tested could be tested against equation 4 in Hume (1991) for channel design or preferably with a numerical model. If the throat proves to be too small, then culverts could be added to assist with tidal exchange.

Under sea level rise and associated increases in tidal prism the Mangawhai causeway openings may be too small to accommodate the increased discharge unless they can scour the bed to increase the cross-sectional area of the throat. Adding culverts to improve the throat capacity would help address this issue. Also, the level of the causeway embankments may need to be checked to ensure that they are tall enough to avoid overtopping during storm surge and floods.

4.4 Stability of the spit and its shorelines

Past events have shown that when the Mangawhai sand spit breaches there are serious and widespread consequences for the functioning of the harbour and its economic value. After the 1978 breach there was loss of a safe navigable entrance for vessels, erosion of the inner shore, loss of moorings and eutrophication of the lagoon.

Restoring spit stability

Analysis of channel migration and other changes following the 1978 spit breach (Lawson 1994, McCabe 1985, LaBonté 1994) made it clear that the system had found a new state of dynamic equilibrium and was unlikely to revert to its pre-1978 state (at least within decades) without human intervention. Restoring the spit to its previous state was only achieved following major intervention by coastal engineering experts, detailed study and planning (LaBonté 1994) was costly, involved thousands of hours of community effort over some 5 years and ongoing effort after that. While the project brought the community together it was not without considerable of friction between the community and authorities (Councils and DOC) over methodology and consents (e.g., Flood et al. 1993, Blackett and Hume 2006).

Today remedial work continues to stabilise the shorelines by way of ongoing nourishing of the spit with sand from channel dredgings, stabilisation and build-up of wind-blown sands by planting and sand fencing. While this work continues a spit breach is unlikely, but if it does happen history has shown that the consequences are major. Hence the element of risk is very high and must dictate effective interventions and any management regime. Importantly, while these interventions may be sufficient to maintain the spit shoreline under current conditions (even acknowledging recent storm activity), the question arises as to how effective they will be under climate change and sea level rise and the associated increased occurrence of storm events, larger and more intense storms, river floods, higher water levels, increasing coastal inundation, and more frequently occurring and stronger easterly winds which will blow increasing amounts of sand off the spit and into the estuary.

The integrity of the spit is dependent on maintaining the position of its shorelines while recognising that they are in a state of dynamic stability. That is to say, the shorelines will fluctuate back and forth to some degree due to erosion/accretion events and channel meander but maintain their position over longer (years) time scales. For both the coast and harbour shorelines the important factors for shoreline stability are the height and sand volumes of the shoreline dunes. The height (elevation above the sea level) needs to be sufficient that the ridge line is never overtopped by extreme water levels and waves. There can be no gaps or blow outs in the dunes where the sea or tidal flow can push through. On the ocean coast in particular sand volumes in the frontal dunes also need to be sufficient in height and width that they can buffer short term cut during storm events.

Open coast shoreline

The ocean coast shoreline is a weak point for spit integrity during storm events. Complete breakthrough happened in 1978, In January 2005 there was extensive flooding from the sea through low area of the dunes in (Figure 4-5). Inspection of the shore in March 2023 following cyclone Gabrielle showed severely eroded dunes along much of the shoreline (Figure 4-6) and areas where the dunes are very low and non-existent and gaps where the sea can potentially flood through (Figure 4-7).

The coincidence of spring tides, storm surge and large wave uprush are the prime events for overtopping and inundation and coastal erosion by the sea. Under climate change with more frequent/intense tropical cyclones and surge events and high water levels inundation will occur more frequently. Storm events most likely to cause erosion are those that bring storm surge and high waves and are sustained for days. Furthermore, the clustering of storm events, can result in greater beach erosion than would occur for singular large events as the beach does not have time to recover between events. The early storms lower the beach allowing high water levels (storm surge) and waves to attack the shore higher up the beach and eroding the dunes in subsequent events. Hume (1979) reported this effect at Bream Bay where beach profile analysis showed how a storm in May 1978 cut out sand from the lower and mid beach allowing the following July storm to cut back to the dunes. T&T (2020) report this effect for the east coast during tropical Cyclones Fergus, Drena and Gavin that made landfall between December 1996 and March 1997. This effect presumably contributed to breach of the Mangawhai spit in 1978.

Figure 4-5. Seaward flat of the spit inundated by the sea on 30 Jan 2005. (Image source: A LaBonté presentation).

Figure 4-6. Open coast beach front about 1km south of the tip of the spit where the dunes are very eroded. Images taken 28 March 2023 following Cyclone Gabrielle.

Figure 4-7. Open coast beach front about 2 km south of the tip of the spit where the dunes are very low or non-existent and where the sea can flood inland during storms. Images taken 28 March 2023 following Cyclone Gabrielle.

It is important that shoreline stability continues to be monitored and coastal erosion and inundation hazard hot spots be identified where the height of the dunes and volume of sand needs to be built up. Dune build-up on the open coast could be carried out by pumping sand from the dredge (for which there are precedents). Although there are practical difficulties to overcome in pumping sand the distance to the open coast, earth moving machinery could be used in conjunction with pumping. Earth moving machinery could also be used to build-up the dunes by beach scraping or sand push ups[23], These are temporary options that can be used to speed up natural recovery and repair or restore natural dune protection following storms. Beach scraping is a restricted activity in the proposed regional plan (Northland Regional Council 2022, Rule C.1.5.10 Beach scraping). While earth moving machinery is an option it is likely to be more acceptable to undertake dune repair with using sand trap fencing and planting unless or until such time as more extreme conditions call for a more definitive response.

[23] Beach scraping (taking sand from one part of the beach and moving it laterally along the beach to place at another part) and sand push-ups (pushing sand up from the lower part of the beach to the upper beach) are temporary options that can be used to speed up natural recovery following storms. Both options involve moving sand by mechanical means from areas where there is a surplus to areas where there may be a deficit. Accompanied with dune restoration planting, these methods can more quickly rebuild the beach and dune after an erosion event.

I would recommend that calculations be undertaken to determine the optimum dune height and volume of dunes to guard against the hazards of overtopping during storm surge and short term cut from coastal erosion. The calculations should take into account projections for sea level rise in the next 100 years. Today there is good information and methodologies for doing this using LiDAR topography, wave hindcast data, predictions of future water levels and combined with numerical models of cross-shore sediment transport and profile change models such as SBEACH[24] (Larson and Kraus, 1989) to define storm cut volumes and horizontal movement of the dune toe. These calculations will help scope and budget the size of the task of building up the shoreline and dunes in a quantitative methodology allowing for sea level rise as opposed to a qualitative 'eyeballing' manner.

Harbour shoreline and neck

The harbour shoreline at the neck of the spit is a weak point for spit integrity. It is the narrowest (400 m wide) section of the spit. is the location of the 1978 spit breach and here the bund wall was constructed along the western shore to close the southern inlet. It is vulnerable to erosion because it is on the outside a meander bend where ebb tidal currents are focussed against the shore. The very soft sand along the upper intertidal beach and sand waves in the channel testify to active sand transport in this area. At present the shoreline is maintained by placement of dredged sand and planting of sand trapping vegetation.

In the future alternatives to the current soft engineering options (nourishment with dredged, planting and wind break fencing) may need to be considered given that climate change and sea level rise will increase the threat of erosion due to increasing tidal prism/currents and higher water levels during tidal and surge events bringing water levels and waves higher up on the shore. One alternative is to armour the western shore in the vicinity of the neck to fix the channel meander position and stabilise the shore. This was recommended by Lawson (1994) following an analysis of channel stability that mitigation of enhanced erosion could be achieved by armouring the true right bank (i.e., the western shoreline) with coarse sediment (presumably rock).

Another alternative may be to construct a series of groynes extending into the channel from the shore which trap sand rather than simply armour the shore. Once built that section of shoreline may require less dredging and sand nourishment to hold its position. Either option would require design by a coastal engineer. For groynes decisions need to be made on location, number, spacing, optimum length and height, construction materials and back filling along with filter mat requirements and the aesthetics of any such structures. This solution is common in river channels where the flow is unidirectional (i.e., downstream), although it is used to stabilise the channels southern shore at the mouth of Otago Harbour. It is best applied in coastal situations where hydraulic or numerical modelling guide the design. The choice between soft engineering (planting and renourishment) versus hard engineering options (armour and groynes) is an important decision for the community to decide. Both done properly have the potential to stabilise the spit shoreline, although hard engineering options may provide a more permanent solution involving less maintenance. Soft engineering options are often less expensive than hard engineering options (at least in the sense of up-front capital costs) and considered a more sustainable and natural approach to managing the coast and therefore have less impact on the environment.

Any engineering options need to be balanced against both the cost of dredging and establishing and maintaining vegetation cover and the impact structures have on the and naturalness and aesthetic value of the shoreline. Of relevance here is that the Proposed Regional Plan states that priority will be

[24] SBEACH is a numerical simulation model for predicting beach, berm, and dune erosion due to storm waves and water levels.

given to the use of non-structural measures over the use and construction of hard protection structures when managing hazard risk (Northland Regional Council 2022, Rule D.6.1 Appropriateness of hard protection structures). The plan lists situations under which new hard protection structures may be considered appropriate.

In the meantime, it is important that the stability of the inner shoreline of the spit continues to be monitored. The line of the bund wall should be maintained. The height and volume of sand should be built up as necessary with sand from dredging and sand trap fencing as an adequate volume of sand will guard against scour cutting into the shoreline.

<u>Sand spit dunes and lakes</u>

Under existing conditions, the sand dunes on the spit are likely to undergo modification of their topography by deflation in areas that are unvegetated. With climate change the predictions are for increasing frequency/intensity of tropical cyclones which bring winds s from the north-easterly quarter. As a consequence, there will be increasing deflation and modification of the spit surface and delivery of wind-blown sand to the harbour.

For the damp sand plain lakes on the sand spit, the overall responses to climate changes and sea level rise are likely to result in a range of outcomes between complete losses of some systems to minor water balance effects in others (Hume and Hart 2022). Rising sea level and storm tides will inundate these features in situations where the sand plains are low lying unless inundation is offset by plain accretion through aeolian processes. As a result, damp sand plain habitat will be lost as inundation advances inland while a warming climate may see the lakes drying out more frequently, with consequent shifts in their biota. In some places, rising groundwater levels could lead to lake formation in previously dry depressions or to the deepening of lakes.

4.5 Vegetating the spit

Vegetating the dunes on the spit provides a means of stabilising spit and its shorelines and particularly the shorelines of the open coast. Vegetation of the dunes prevents damaging blowouts developing through which the sea can move inland and cause erosion.

Storm events most likely to cause deflation of the dunes are those with strong winds that are sustained for days and with little rain (wet sand is less erodible). Vegetation of the spit will also cut down the amount of sand blowing into the estuary to some degree, although this needs to be balanced against both the cost of establishing and maintaining vegetation cover and the impact and naturalness and aesthetic value of the largely unvegetated sand dune system. It should also be noted that the partially vegetated nature of the dune today has provided a habitat suited to the summer breeding of the fairy tern. At the same time, it should be acknowledged that the natural state of the spit in c. 1400, and before it was ravaged by fire, was vegetated in forest (Enright & Anderson 1988).

Past efforts by the community volunteers with support from Councils have demonstrated that building up the shoreline and dunes by sand trap fencing, planting of dune vegetation and rabbit control is an effective and durable solution[25]. Dahm and Bergen (2016) in a report to Northland Regional Council provide a comprehensive strategy for stabilising the central-northern and southern areas of the spit and preventing future breaches. It promotes planting of native sand binding vegetation (primarily spinifex with some pingao), pest control (of rabbits) and invasive weed eradication, while taking account of the need, and providing for, critical shorebird habitat. The strategy also stresses the

[25] It has been bought to my attention that there are issues around consenting related to the use of HDPE (high-density polyethylene) fencing.

importance of restoring a naturally vegetated frontal dune, some 30-50 m in width, along the seaward margin of the spit to reduce the risk posed by storm overtopping. They also make the point that this will reduce the risk of invasion of shorebird habitat by sand blown in from the open coast. They strongly recommend that dune restoration along the seaward shoreline be given a priority over other areas until such time as a well-vegetated frontal dune is restored.

I strongly recommend that these management practices be continued. In a future of climate change this action will become more important to mitigate the effects of more frequently occurring easterly winds blowing deflating the spit and increasing amounts of sand blown off the spit and into the estuary.

4.6 Dredging to build up the spit and its shorelines

Dredging is currently undertaken from sand traps in the channel primarily to supply sand to build up the shorelines of the spit (Figure 4-8). Small amounts have been used to nourish the beaches on the western shoreline of the harbour. The dredging is also said to offset channel infilling caused by sand blowing off the spit although there are no studies of the aeolian contribution. A study to assess the amount of sand blowing off the spit would quantify this process and inform decisions as to whether vegetating the spit would help mitigate channel infilling.

Consents for the dredging are restricted to March to August to take account of bird nesting on the spit. The dredging consent requires annual monitoring and inspection of turbidity levels at the dredge site/operation. For the past two decades and following closure of the inlet breach dredging of sand from the channel and sand traps has not taken place during the summer period (December to February inclusive). In agreement with the department of Conservation, there is no dredging during the September to February period in areas where disposal is on the spit. In the past two annual dredging seasons DOC placed further restrictions on sand transfer activity from 1 March to 31 July. In progressing the latest Consent Application, the MHRS has agreed to accept a condition that dredging be restricted to the 5-month period between 1 March to 31 July (inclusive)[26].

[26] Note that a condition that MHPS requested for emergency dredging outside of these dates if required has been removed in order to get some progress on the consent.

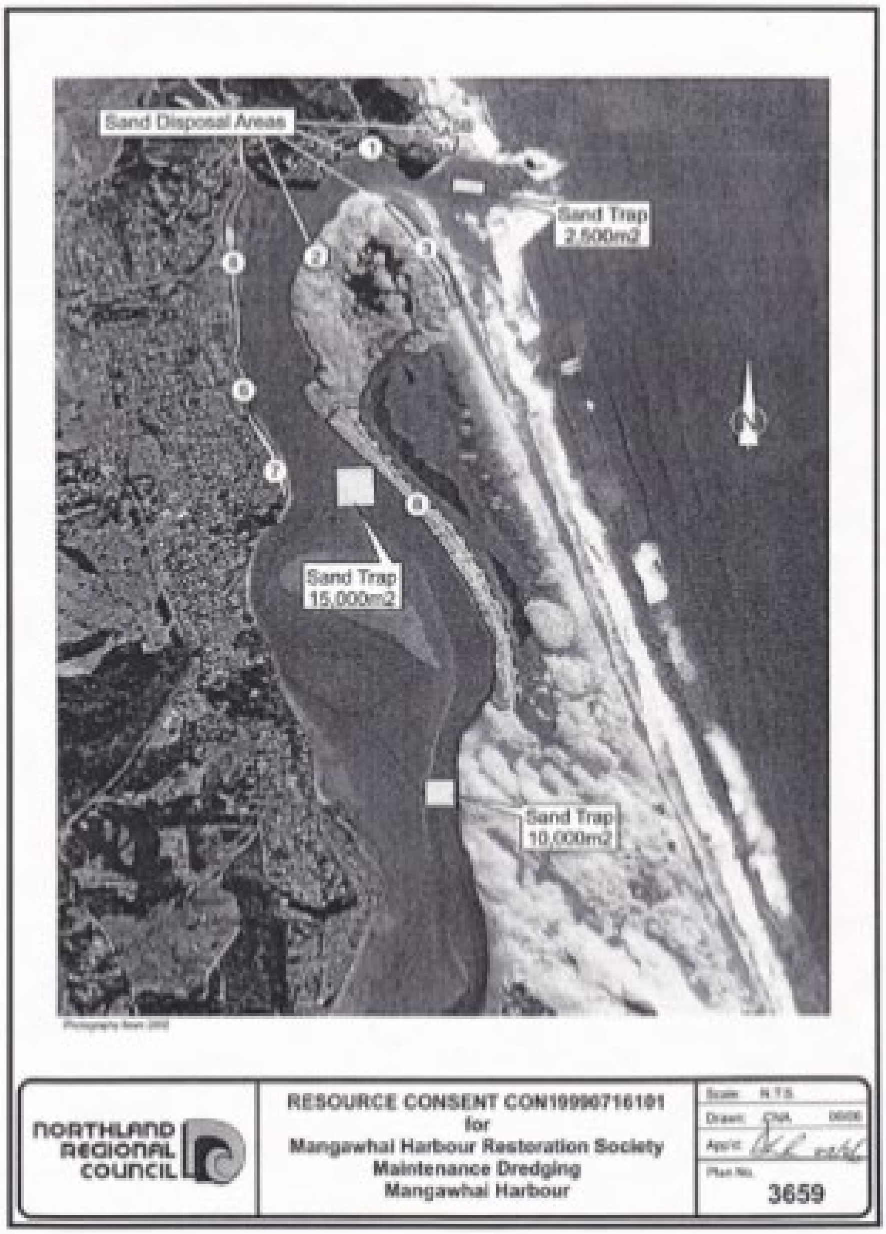

Figure 4-8. Maintenance dredging sites and sand traps.

Whether dredging is a good option or not depends on the objective. If the objective is to supply sand to build up the spit, then the method is fit-for-purpose. Dredging from sand traps provides less need to move the dredge about, an unconsolidated and therefore easily dredged substrate, clean sand with few fines and minimal turbidity during dredging, a minimum impact on ecology (compared to dredging over a wide area) and also simplifies the consenting process. Any variation to the current practice, which is contained and conservative, needs to be based on sound data and subject to maintaining records of volume and locations of placement. Dredging needs to be complemented with stabilisation of the placed sand by vegetation.

If the primary objective of the dredging is to deepen the channel, then I suspect the effect is very local, confined to the vicinity of the trap site and of fringe benefit. Surveys of channel bathymetry to check for areas of deposition and accretion and a numerical model of sand transport could be used to check the scale of these perceived benefits. Consideration could perhaps be given to dredging the middle shoal which as it grows east pushes the channel meander to the east and causes erosion at the neck of the spit. Analysis of historical imagery and bathymetry should be used to monitor channel meander, and where it shows that there is shoreline cut back at the neck then the eastern flank of the middle shoal could be dredged to mitigate the meander and erosion. A numerical model of sand transport could be used to the effectiveness of this intervention. Issues to address would be moving the dredge about, pumping the sand across the channel and obtaining a consent. The latter would require a study of the effects on the ecology, similar to what was undertaken to consent dredging in the sand traps.

Looking ahead, a question that arises is how much dredging is enough given the ongoing cost? There is a continuing need to identify and build up weak spots in the bund wall as they emerge. The consequences of not doing so are risk associated with erosion of the shoreline dunes, tidal inundation and maybe spit breach in a worst-case scenario. I am usure as to whether there is an overall specification for the dimensions/location of the shoreline dunes against which to match the effort and make the call as to when 'enough is enough'. Regular monitoring of the spit shoreline is necessary to provide the information on which to make these decisions. Given the potential effects of climate change and the threats to the spit integrity described earlier I consider the idea of obtaining a consent for emergency dredging to be a sound proposal. Such a proposal should identify triggers/thresholds on which to initiate action and plan to operationalise an emergency response.

There is also a need to consider obtaining consent for emergency dredging to address situations where the physical integrity of the Mangawhai sandspit and inner harbour is endangered or damaged due to tsunami, storm, cyclone or another event. This will enable the Consent Holder to undertake emergency dredging and deposition (and/or sand scraping or push ups) to prevent or remediate the Mangawhai sandspit and inner harbour from breach or damage.

4.7 Coastal erosion hazard on the harbour's western shoreline

Tonkin & Taylor undertook a survey for Northland Regional Council of the coastal erosion hazard along a 7 km stretch of the eastern shoreline of the harbour extending from the harbour mouth to the Molesworth Drive causeway (T+T 2020) (Figure 3-16). To consider the effect of sea level rise coastal erosion hazard zones (CEHZ) were calculated and mapped for all cells based on projections to the years 2080 and 2130 and future sea level rise scenarios (Table 4-1).

Table 4-1. Adopted sea level rise values (m) based on four RCP[27] scenarios included in MFE (2017) adjusted to 2019 baseline. (Source: Figure 32.2 in T+T 2020)

Year	RCP2.6M	RCP4.5M	RCP8.5M	RCP8.5+
2080	0.16	0.21	0.33	0.51
2130	0.28	0.42	0.85	1.17

T+T adopted three planning time frames to provide information on current hazards and information at sufficient time scales for planning and accommodating future development (Table 4-2). Three scenarios represent different likelihoods, sea level rise magnitudes and time horizons that are suitable for updating planning maps. CEHZ1 with a 66% probability of being exceeded (P66%) at 2080 and CEHZ2 with a 5% probability of being exceeded (P5%) at 2130, have been adopted as prudent likely and potential CEHZ values. CEHZ3 is similar to CEHZ2 (i.e., 5% probability of being exceeded at 2130)

[27] The RCP (Representative Concentration Pathway) scenarios are descriptions of how our climate may change in future, in the light of how mankind will behave. For example, whether we continue to burn fossil fuels at an ever-increasing rate, or shift towards renewable energy. The RCP's try to capture these future trends.

but instead using the RCP8.5H+ scenario. Minimum set-back values have been adopted for each coastal type to account for potential uncertainties and limitations in data and methods. CEHZ lines have been mapped with respect to 2019 baseline.

Table 4-2. The three CEHZ scenarios that represent different likelihoods, sea level rise magnitudes and time horizons that are suitable for updating planning maps. (Source: T+T 2020 p5.)

	Timeframe	Probability of exceedance	RCP scenario	Sea level rise[1]
CEHZ1	2080	66% *(likely)*	8.5M	0.33
CEHZ2	2130	5% *(potential)*	8.5M	0.85
CEHZ3	2130	5% *(potential)*	8.5H+	1.17

[1]Based on reference date of zero in 2019

The results are tabulated and also mapped in for the Mangawhai estuary shoreline as shown in Figure 4-9.

T+T (2020) recommend regular monitoring of the shoreline position to improve the length and quality of background data on which the CEHZ are based. They recommend that the adopted baselines and CEHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

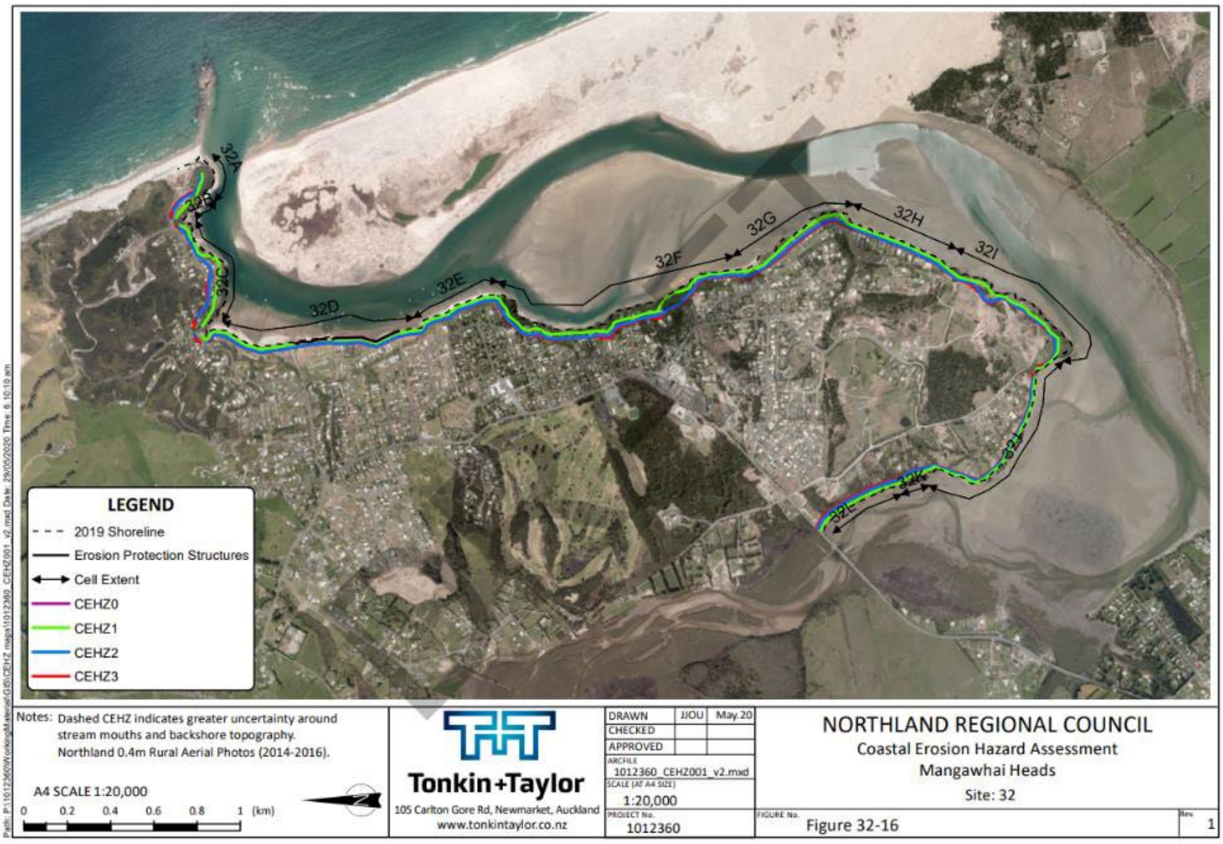

Figure 4-9. Mapping the Coastal Erosion Hazard Zone widths and future shoreline distances (Source: Figure 32.16 in T&T 2020).

T+T recommend regular monitoring of the shoreline position to improve the length and quality of background data and that the adopted baselines and CEHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

4.8 Coastal inundation hazard

Coastal inundation is flooding from the sea. As discussed here mainly as it relates to threat to the low-lying land bordering the shoreline of Mangawhai Harbour. Here, coastal inundation is a greater hazard than coastal erosion. There is significant potential for lasting damage to properties on low-lying land. While small inundation (and erosion) events are common, extreme and damaging coastal inundation and erosion events coincide infrequently. These events require the meteorological and oceanographic 'ducks to line up' namely: high tide, king tide, low atmospheric pressure, strong northerly winds, large waves, sand stores on the beaches in a depleted state and stream flooding. Climate change and sea level rise will increase the potential by bringing more frequently occurring high water levels.

While a little can be done at the time of the coastal inundation event to mitigate the effects, a lot can be done beforehand. Strategies to mitigate coastal inundation (and also coastal erosion) and inform adaptive planning include:

- Today warnings of extreme weather events are becoming increasingly available from various sources. The public has access to wind, rainfall, wave, tide forecasts via numerous online sources including social networks and use them to plan recreational pursuits (e.g., boating, fishing and surfing). Councils, MetService and NIWA provide warnings based on a more sophisticated analysis of combinations of physical forcings (i.e., predicted tide state and level, wind strength and direction and waves height period and direction) and consideration of the risk to lifelines, property and public safety. Together these help in immediate response, planning responses and to mitigate risk and damage.
- Warnings of coastal inundation events can be gained from sources such as the 'NIWA storm-tide red alerts' [28]. These alerts announce the highest high tide (also known as king tides) dates and times when emergency managers and the public should keep an eye on adverse weather. While dates can be given for when these events may happen, the exact scale and timing of inundation events is difficult to forecast, particularly when multiple drivers coincide. The potential for coastal erosion events is also signalled by storm-tide red alerts.
- The potential for coastal inundation can be mapped following modelling using topographic surveys of land elevation from LiDAR combined with probabilistic modelling of predictions of return frequencies and magnitude of water levels and extent of inundation.

The mapping of inundation is imperative for future long-term planning to assess risk and undertake cost benefit analysis of possible mitigation options. It will for example: 1) identify what parts/how often the shoreline margins will be overtopped/flooded, 2) provide engineers with information of where/whether to raise the levels of roads and strengthen bridge abutments, 3) serve to identify pathways of inundation events under various scenarios and identify escape route options and 4) determine whether some houses be moved back or relocated or raised above storm levels or left to suffer the risk of inundation.

Coastal Inundation Tool

Waikato Reginal Council developed the WRC Coastal Inundation Tool to map the potential extent of inundation under various states of the tide (e.g., spring tide, storm tide) and also accounting for projected sea level rise of 0.5 m and 1.0 m.

This interactive online tool uses a static or 'bathtub' hydrodynamic modelling of coastal inundation that essentially transfers the coastal water level inland until that land elevation is reached. It does not

[28] https://niwa.co.nz/natural-hazards/physical-hazards-affecting-coastal-margins-and-the-continental-shelf/Storm-tide-red-alert-days-2020

include the dynamic or transient effects of waves wave set up and runup or storm tide flooding of land which increases the water levels and can change the flow paths. ‘Bathtub’ models will in general overestimate flooding effects. The model floods a topography determined from LiDAR imagery. In recognition of approximations in the model the tool operates in increments of 20 cm (vertically) which therefore defines the maximum resolution of the mapping[29]. While the results from flooding mapping using this methodology are approximate and need to be confirmed with ground surveys and more detailed analysis of the LiDAR topographic data, they nevertheless illustrate the vulnerability of various features and assets to coastal inundation.

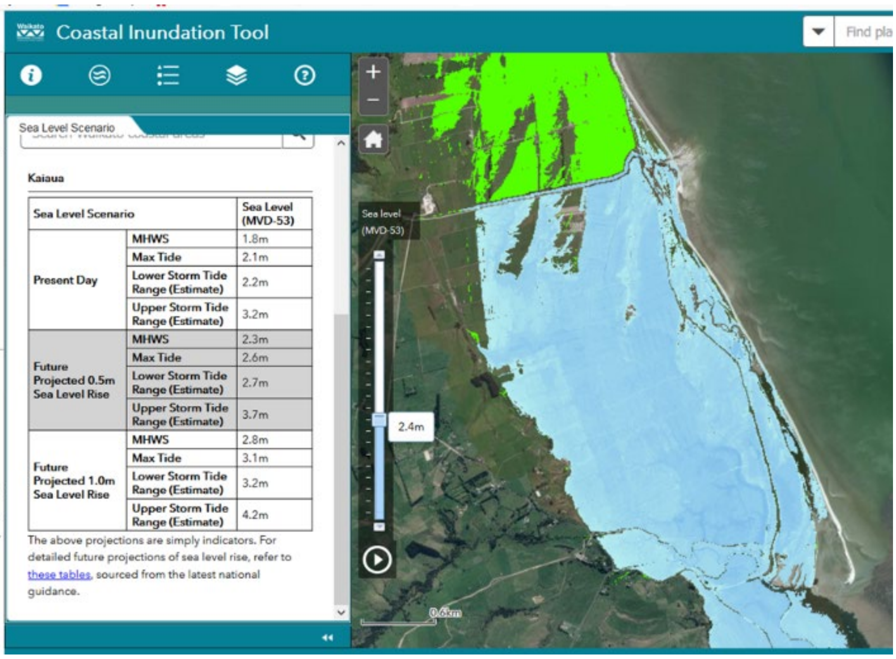

Figure 4-10. Screenshot image from the Coastal Inundation Tool showing the extent of flooding of farmland (blue colour) when the water level reaches 2.4 m (MVD-53) which is 0.6 m above MHWS. It shows how the road in the vicinity of Miranda (in lower part of image) is flooded while East Coast Road (thin grey line close to the coast) is mostly above the water level. The tool shows: 1) Connected inundation (blue shaded areas), which represent areas where water could directly (or via waterways) flow to the sea for a chosen water level and 2) Disconnected inundation (green areas), which represent areas that are at or below a chosen water level, but may have no direct flow path to the sea. Disconnected areas may still be affected by coastal inundation in some way, e.g., via groundwater. The sidebar shows water levels under present day conditions for spring, maximum and storm tides, and for future predicted sea level rise of 0.5 m and 1.0 m (relative to MVD-53).

Dynamic Adaptive Policy Pathways (DAPP) approach

In responding to hazards such as coastal inundation and erosion communities must be careful not to lock themselves into defend or retreat positions that preclude better options in the future. For instance, expensive infrastructure like a seawall to counter rising sea levels may only protect the needs of a few properties, require maintenance during its lifetime, extension to service other properties and even more expense when it finally needs to be removed. While it’s difficult to be certain about the

[29] There is a full description of the Coastal Inundation Tool in the online user guide at: http://waikatoregion.govt.nz/services/regional-services/regional-hazards-and-emergency-management/coastal-hazards/coastal-flooding/coastal-inundation-tool

range and extent of changes we will face from sea level rise and climate change, we need to keep our options open for as long as possible while preparing for any outcome.

DAPP is a decision-making tool that considers changing risk profiles. The DAPP approach plans out a series of possible actions over time (pathways). It involves making decisions on those pathways (using knowledge available at the time) as conditions change, before severe damage occurs, and as existing policies and decisions prove no longer fit for purpose. Triggers are set to determine which pathway to follow. For example, as the sea-level rises, the frequency or magnitude of inundation events will exceed an agreed trigger. At this point additional or different actions may need to be taken and an alternative pathway to avoid reaching the threshold at which damage occurs.

Pathways are chosen depending on community risk threshold and time frame. Time frames are best set for specific situations and where short-, medium- and long-term have planning horizons defined in years (e.g., long-term may be 70-100 years to fully take account of climate change). Several pathways may be chosen for a location. For instance, a pathway could comprise actions such as:

- Short term - Status quo (no action needs to be taken as risk threshold has not been reached)
- Medium term - Install flood gates and improve drainage
- Long term - Inundation accommodation (raise buildings), re-engineer flood gate design/and drainage

An alternative could be:

- Short term - Install flood gates and improve drainage
- Medium term - Inundation accommodation (raise buildings)
- Long term – Managed retreat (relocate buildings on low lying land)

The value of the DAPP approach is that it explores different pathways early allowing the design of an adaptive plan that includes a mix of short-term actions and long-term options, and eventually reassessing the objectives of the plan itself.

One of the options in DAPP might be managed retreat of buildings and associated infrastructure. This is an option for consideration in the medium and long term before they are severely impacted by coastal hazards, including sea-level rise. The idea is for coastal communities to relocate slowly, in a carefully thought-out and planned process, before it is too late and retreat becomes inevitable, haphazard and 'unmanaged' (see https://resiliencechallenge.nz/edge-programme/3296/).

The Deep South Challenge research programme is designed to "enable New Zealanders to adapt, manage risk and thrive in a changing climate". It describes tools needed to enable decision makers to respond appropriately to climate related impacts, to limit damage and costs to the nation and its communities (see https://deepsouthchallenge.co.nz/research-project/tools-for-decision-makers/).

4.9 Sand mining in the Mangawhai-Pakiri embayment

The Mangawhai-Pakiri embayment was described by Hume et al. (1998) as being 'essentially closed'. That is to say there is little exchange of sand, either in or out of the embayment, around the bounding headlands of Bream Tail and Cape Rodney. As a consequence, the continuing mining of large quantities of sand from the Mangawhai-Pakiri embayment (open coast) has the potential to cause increased erosion of the beaches and shoreline, particularly if the net losses due to extraction are not balanced by inputs of sand from natural processes (the sand budget), or if the stores of sand are not substantially larger than the extraction quantities.

Stores of sand in the embayment comprise those in transgressive dunes onshore (c. 92,000 to 552,000 million m^3 of sand) and in the beach and offshore to about 40 m depth (82,000 to 142,000 million m^3 of sand). However, there is a lot of uncertainty in this range of estimate of thickness for the transgressive sands because while the aerial extent of the deposit can be easily measured the transgressive sand sheets overlie an uneven topography of older sediments and there are few outcrops (e.g., in road cuttings) or boreholes from which to measure thickness (Nichol et al. 1996). While the annual take of sand today is small (90,000 m^3/yr, Jacobs 2020) compared to the large sand stores, there is the cumulative effect from extraction since the 1920's to consider (7.4 million m^3).

The annual budget of sands estimated by Hume et al. (1998) is shown in table 4-2. There was considerable uncertainty in the cross-shelf transport calculation for which the estimate ranged from 200 to 64,000 m^3/yr. No contribution was allocated to shell production to the sand size was allocated because of the high level of uncertainty in the production estimates provided by Hilton (1990).

Table 4-2. Sediment budget for the embayment from Hume et al. (1998).

Inputs		Losses	
Source	**Volume (m^3/yr)**	**Source of losses**	**Volume (m^3/yr)**
Cliffs	6,000	Onshore winds	2,000
Rivers	2,000	Mangawhai Inlet	3,000
Biogenic (shell)	Insufficient data to calculate	Around Cape Rodney	2,000
Around Bream Tail	0	Extraction	102,000
Diabathic supply (cross shore from 40 m depth)	12,000		
Total losses	**20,000**	**Total losses**	**109,000**

Jacobs (2020) provided an updated budget as shown in Table 4-3.

Table 4-3. Sediment budget for the embayment as revised by Jacobs (Source: Table 3.7 in Jacobs 2020).

Inputs		Losses	
Source	**Volume (m^3/yr)**	**Source of Losses**	**Volume (m^3/yr)**
Cliffs	6,000	Onshore winds	2,000
Rivers	17,000	Mangawhai Inlet	3,000
Biogenic from <25 m depth	7,000	Around Cape Rodney	1,000
Around Bream Tail	25,000	Extraction from < 25 m depth	90,000
Diabathic supply (cross-shore from >25 m depth)	76,500	**Total Losses** **Storage/Surplus**	**96,000**
		Storage in dune/beach as accretion	35,500
Total	**131,500**		**131,500**

The main differences between the Hume et al. and Jacobs budgets are the inputs. Jacobs (2020) increased the river and cliff inputs from 8,000 to 23,000 m^3/yr based on accepting an Environment Court decision in 2006. Jacobs add a 7,000 m^3/yr contribution from biogenic production (shell). This is a more thorough estimate for shell production than that provided by Hilton (1990) which Hume et al. considered to be unreliable and unusable. Shell makes up only a small proportion (2-5 %) of the beach sediment. It is also uncertain how permanent that contribution is to the overall budget for the embayment given that shell presumably breaks down more rapidly via physical and chemical processes than feldspar and quartz (on the Mohs hardness scale calcite is 3 while feldspar and quartz are 6 and 7 respectively). Furthermore, the feldspar and quartz that make up the bulk of the sand have survived since they were derived from the Waikato River some 16-18,000 years ago. The input from around Bream tail is quoted as 25,000 m^3/yr but no new modelling was undertaken to check this number which is based on accepting an Environment Court decision in 2006. The diabathic (cross-shelf transport) supply of 76,500 m^3/yr is a reinterpretation of the modelled estimate presented in Hume et al. (1998), although no new modelling was undertaken to check this number. In short there is uncertainty in some of the input numbers.

These budget terms are important in determining a sustainable extraction level and time frame for mining activity. Because effects are spread over a wide area of shore and seabed, cause (mining) and effect (shoreline erosion) are difficult to prove. However, coastal erosion and shoreline retreat can be expected to accelerate in the face of climate change and sea level rise, suggesting that continued mining at former levels would become more problematic over time. There remains uncertainty over the precise figures of the sand budget and consequences.

The modelling presented by Hume et al. (1998) providing input numbers is over 25 years old and the river and cliff input estimate nearly 20 years old. The budget terms should be updated using improved tools available today (i.e., numerical modelling of cross shore and longshore sand transfers and inputs from stream and cliffs).

Permits for sand extraction are now up for renewal and going through the hearing and appeal process. That process is showing that debate is continuing, about whether mining is contributing to erosion of the beaches in the Mangawhai-Pakiri embayment and just how sustainable the practice is. In the light of this it’s probably best to wait until the hearings are complete, evidence presented becomes available, and a decision made on the consent, to decide on the best course of action on this issue.

4.10 Water recreation and associated infrastructure

Boat ramps and moorings in the harbour are few in number and will only have a very local impact on their immediate environment. Boat ramps for instance form a partial barrier to sand transport along the shore and either backup of sediment or result in downcutting adjacent to the structure depending on the direction of longshore transport. On the western shore of the harbour longshore transport is small and so the effects are small. A related effect on coastal processes is that provision of these facilities and increasing usage by larger vessel results in calls for maintenance of navigable waterways and dredging to deepen channels. The occupation of the common marine and coastal area with a mooring and a vessel using the mooring is a permitted activity, provided certain conditions are met (Northland Regional Council 2022, Rule C.1.2.4 in the Proposed Regional Plan).

Disturbance of the shoreline seabed by vessel wakes and prop wash and vehicles and/or Sealegs amphibious boats traversing the intertidal areas is seen as an issue by some. The wakes of larger vessels can cause erosion of the shoreline, but this effect is confined to a couple of hours either side of high water when the waves reach the shore. This effect should be controlled by Maritime NZ Rules on the Water[30] that specify that vessels: *Operate at a speed that allows for the time and distance necessary to avoid a collision. You must not exceed a speed of 5 knots (a fast-walking speed) if you are: within 200m of the shore*. Prop wash does disturb the seabed, but the effect is localised to a narrow track, and only occurs in very shallow water when the turbulence from props can penetrate to the bed.

Vehicles and/or Sealegs traversing the sand flats have the potential to crush shellfish, but this does depend on the weight of the vehicle, tyre type and the speed its driven. The footprint of the effect will be wiped out once sand is mobilised by wave action and currents and is temporary. The use of a vehicle on the foreshore or seabed and any associated disturbance of the foreshore and seabed is not the subject of a rule in the proposed plan and are permitted activities provided certain conditions are adhered to (e.g., vehicles must ensure minimal disturbance of the foreshore and seabed; apart from emergency services vehicles providing an emergency response, vehicles do not drive over pipi or cockle beds (Northland Regional Council 2022, Rule C.1.5.1 in the Proposed Regional Plan).

[30] https://www.maritimenz.govt.nz/content/recreational/rules/default.asp

5 Looking ahead

5.1 Issues, threats, risk and mitigation

This section summarises potential threats, effects and risk to elements and activities in the Mangawhai Harbour and spit environments. Mitigation options and monitoring strategies are suggested and gaps in information identified. Tables 5-1 and 5-2 summarise and order this information so it can be used to develop research, monitoring, and management policies.

Threats can originate from inside the harbour catchment (e.g., catchment runoff) or from outside the catchment (e.g., sand extraction in the Mangawhai-Pakiri embayment). They can be local (e.g., causeways) or global (e.g., climate change). Threats can have different time frames, the impacts can be permanent or temporary, and while some impacts can be mitigated, some cannot.

In the context of this study risk refers to uncertainty about the adverse effects of an event (or series of events) significantly modifying the physical environment. The value of a risk assessment is that it allows authorities and communities to develop a "watch list". The watch list facilitates decision making by:

- Highlighting the greatest risks, supporting allocation decisions for limited resources.
- Allowing management agencies to ask "what if" questions regarding the consequences of various potential management actions.
- Facilitating explicit identification of environmental values of concern.
- Identifying the need for monitoring.
- Identifying critical knowledge gaps, thereby helping to prioritise future research and investigation.

Risk assessment requires judgements about appropriate objectives and actions mediated by the probability of occurrence (which requires some analysis and regular review). Implementation of policies responding to the possibility or prospect of undesirable events also requires the cost of avoidance measures to be weighed against the magnitude of impact of the event and the cost of post-event mitigation.

In short, a risk assessment involves estimation of the likelihood or probability that an event will occur (level of risk) and the magnitude of potential consequences (level of impact) should it occur. Sea level rise and climate change does mean that there is a shifting of baseline here and that a DAPP approach is best implemented when planning a way forward.

The risk assessment described in this report is qualitative because there is insufficient numerical data and modelling of future coastal processes to carry out a quantitative risk assessment. Furthermore, there is uncertainty associated with the potential response of the coastal sedimentary system to climate change and sea level rise.

Risk categories are defined here as:

- Major – Serious, extensive and large-scale changes to the environment and/or coastal processes and/or natural character, that cannot be reversed or mitigated without considerable human intervention (effort and resources). Permanent impacts on access to and/or enjoyment of the resource; and/or results in health and safety issues (e.g., water quality, navigability); and/or potential for physical changes to a large part of the feature; and/or a permanent change to the natural character or aesthetics.

- Significant – Smaller scale effects that will have a serious adverse impact on the environment, that can last for sustained periods, but can potentially be avoided, mitigated or remedied.
- Minor - Effects that are noticeable and local in scale but will not cause any significant adverse impacts. Activity temporally effects, access to and/or enjoyment of the environment.
- Less than minor - Adverse effects that occur infrequently, discernible day-to-day, local, but will not cause any significant adverse or lasting impacts.

Based on the information and analysis contained in this report, Table 5-1 provides a summary of the major threat events facing the harbour and its management for the foreseeable future. Spit breach and coastal inundation relate largely to natural processes which are likely to be intensified and accelerated under more volatile climatic conditions and with sea level rise. Human agency in this analysis is confined to the ongoing impact of the established barriers to tidal flow (causeways) and ongoing development in the wider catchment. The role and expansion of mangrove forest and is seen as an outcome associated with both natural processes and the effects of development.

Table 5-1. Assessment of threats, risk, effects and mitigation and monitoring - Mangawhai Harbour and spit environments.

Threats/Events	Risk	Effects	Mitigation and monitoring
Spit breach The spit has been breached in the past. This was caused by wave overtopping of the seaward shoreline and channel migration cutting into the inner shore combining to cut through at the neck.	**Medium:** Climate change and sea level rise will increase the potential for breach by bringing more intensive and frequently occurring storms, storm surge, wave over topping and inundation and erosion of the shoreline. Following breach the new southern inlet appeared to reach a state of dynamic equilibrium with the spit and was unlikely to return to its former state. There is a high likelihood of breach without human intervention to maintain the stability of the spit shorelines.	**Major**. The consequences of a breach would be substantial, degrading water quality in the lagoon, loss of a navigable entrance, reducing the shelter provided to property, threatening local infrastructure, and transforming the coastal and marine habitat in the vicinity.	• Undertake calculations to determine optimum dune height and volume to guard against overtopping during storm surge and short term cut from coastal erosion, using projections for sea level rise in the next 100 years. • Eliminate gaps and build up shoreline dune height to prevent overtopping and inundation of low areas. • Stabilise channel meander at the inner shore of the spit (the neck). • While build up of the spit can be carried out with earth moving machinery (e.g., beach sand scraping or push ups) or by pumping sand from the dredge, it is likely to be more acceptable to continue to do so with sand trap fencing and planting (and rabbit control) unless until such time as extreme conditions call for a more definitive response. • Develop an emergency response plan along with triggers/criteria to activate a response in case of a severe threat of spit over topping and breach. **Monitoring** • Monitor and identify coastal erosion and inundation hazard hot spots where the height and volume of sand needs to be built up.
Shoreline erosion Small wind generated waves and currents slowly erode the western shoreline of the lower harbour.	**Medium:** In the absence of a spit breach, loss of shoreline will primarily be related to and increase with sea level rise and a long-term issue.	**Moderate**: Localised to lower estuary but significant risk to private property (housing, accommodation), roads and reserves in a limited, albeit high value, area. Access to the harbour may be compromised for the wider population.	• Build protective hard engineering structures (e.g., seawalls or groynes) or nourish shorelines with sand (soft engineering) at erosion hot spots. **Monitoring** • Regular monitoring of the shoreline position to improve the length and quality of background data and record erosion. Reassess adopted baselines and CEHZ values at least every 10 years as recommended by T+T (2020).
Causeways Restrict tidal flow and decrease the tidal prism.	**Medium:** Long-term sea warming and intensive La Nina and El Nino oscillation mean more frequent and intensive rainstorms, and total water level extremes will be worse with sea level rise and with more freq and extreme cyclones. Sea Level rise may increase the action of such events on the causeways.	**Minor:** Build-up of fine sediment and raising bed level upstream, provides mangrove habitat, and reduces flushing capacity. Jury is out on effect of tidal prism and harbour flushing on mangrove expansion upstream. Effects probably stabilised currently at existing level. Under climate change and sea level rise the waterway openings may be too small to accommodate increased discharge resulting in in local effect on channel morphology and sediment accumulation.	• Undertake numerical modelling to check if adding culverts will improve tide flow flushing to upper reaches. Undertake similar modelling to check if an increase in tidal prism accompanying sea level rise will/or not scour the channel to accommodate increased discharge necessitating increased flow capacity via culverts. • Check by survey and calculation that the causeway embankments are tall enough to avoid inundation and road closures during storm surge and floods. • Establish thresholds at which further action may be required. **Monitoring** • Review tidal prism and culvert capacity periodically (five yearly).

Threats/Events	Risk	Effects	Mitigation and monitoring
Lower water quality and sedimentation Increasing sediments, nutrients and bacterial contamination from Streams entering harbour as a result of increased rain events (intensity, duration, frequency), inappropriate land use, and catchment over-development.	**Medium:** long-term sea warming and intensive La Nina and El Nino oscillation mean more frequent and intensive rainstorms and runoff; significant development pressure, extensive pastoral farming on hill country.	**Moderate:** Reduction in water quality and loss of sandy substrate to mud from catchment run off. Potential effects widespread but impacts greatest in headwaters as close to source and less well flushed. Significant effects in upper reaches (mud accumulation and turbidity). Minor risk in lower reaches where flushing is good, but significant (turbidity and mud deposits) for short periods (days) during/following floods. Effects difficult to remedy once in the harbour.	• Activities best controlled at source rather than subsequent dredging through initiatives to reduce sediments, nutrients and bacterial contamination entering streams such as: o Use related aligned with capacity of land. o Stream edge retirement and riparian planting. o Restoration planting. • Sediment load reduction through construction water management via site specific erosion and sediment control plans and working in fine weather. **Monitoring** • Monitor water quality in streams and harbour to assess effectiveness of mitigation initiatives.
Mangrove expansion Widespread expansion continuing down harbour. Permanent change unless human intervention. ,	**Medium**: Under today's conditions mangrove expansion is likely to continue. Under climate change mangrove cover most likely to be maintained or expanded unless increase in water depth with sea level rise is offset by sediment accumulation resulting from increased catchment runoff.	**Moderate:** Loss of sandy substrate and habitat it provides, reduction in space for some water recreation activities and loss of natural character. Localised effects through expansion in upper reaches on tidal flats above mid tide level. Associated siltation and build-up of level of tidal flats if extensive may reduce tidal prism and flushing. Reduction in area of open water body, potentially permanently changing the natural character of the wider harbour.	• Make a decision on the desired environment and place a limit on future spread of mangroves. Follow best practice guidelines for managing mangrove expansion and clearance (Lundquist et al. 2017). • Pursue policies to reduce land-based input of sediments and nutrients into waterways (as above) • Continue maintenance in the form of removal of mangrove propagules. **Monitoring** • Monitor the benthic (bugs) and faunal (birds, fish) ecology of the mangrove versus cleared areas to document values of each and changes in the latter. • Take cores in the substrate of the cleared areas to identify underlying sand layers (or not) and provide data to help manage the time frame of expectation of change in substrate from mud to sand. • For any future clearance - Monitor before- and after-effects (on substrate, ecology, shoreline stability) of removal to test if desired outcomes achieved.
Coastal inundation Flooding of low-lying coastal margins of harbour during storm surge events when they combine with high tide.	**Significant:** Potential for lasting damage to properties and infrastructure. Infrequent events under today's conditions. Climate change and sea level rise will increase the potential by bringing more frequently occurring high water levels.	Effects confined to coastal margin. Potential for lasting damage to properties (houses) and infrastructure (damage and short-term closure to roads), temporary loss of access to properties.	• Map coastal inundation using topographic surveys of land elevation from LiDAR combined with probabilistic modelling of predictions of return frequencies and magnitude and water levels and extent of inundation under different scenarios. • Consider engineering (raise buildings) and planning responses (documenting flood risk on LIM reports). • Develop an emergency response plan along with triggers/criteria to activate a response in case of a severe threat of inundation.

Threats/Events	Risk	Effects	Mitigation and monitoring
			• Undertake longer term planning and a DAPP approach with triggers to initiate progress along different pathways. **Monitoring** • Monitor warnings of wind, rainfall, wave, tide events via numerous online sources and from Councils, MetService and NIWA and check NIWA storm red tide alerts. • Monitor and identify coastal erosion and inundation hazard hot spots where the height and volume of sand needs to be built up.

5.2 Identifying the risk and adverse impacts

The basic drivers of change to the Mangawhai harbour and coastal environment are climate change and development. Climate change will bring in more frequent and intensive storms, sea level rise, and extreme stormwater discharges, and development. Catchment development will bring intensification of land uses in the catchment, the impact of structures (e.g., causeways, bridges), and activities such as sand mining, and harbour and spit access and use.

How these drivers act on and transform the spit and the harbour, its shoreline and estuaries, will influence the risk of the damaging events discussed in this report. The drivers can also interact, compounding effects. For example, more intensive storms with inadequate stormwater provisions will increase the risk of sedimentation. Some drivers, such as the sand mining offshore over the past 100 years, might have delayed and cumulative impacts. Others, such as several storms over a relatively short period can see a series of small events resulting in much greater beach erosion than a single large event.

Table 5-1 enables us to compare the potential impact of these drivers on Mangawhai Harbour and environment. For example, increasing storm activity raises the risk of a spit breach, shoreline erosion, coastal inundation and sediment accumulation (of muds) through the combined impacts on wave-based erosion, catchment floods and runoff and aeolian sand transport. Such impacts are exacerbated if the storms coincide with higher water levels associated with heavy rain or sea level rise. Development may also increase the risk of such adverse events through, for example, reducing the permeability of the land, decreasing vegetation cover, accelerating erosion, or channelling run off.

Table 5-2 compares the relative risks of the events described in Table 5-1 occurring. While no formal probability assessment has been undertaken, an approximately thirty-year time frame for planning for long-term mitigation, subject to regular review and updating of the risk profile, could be appropriate.

Table 5-2. Identifying the risk of adverse impacts.

Driver	Risk factors	Events					
		Spit breach	**Shoreline erosion**	**Coastal inundation**	**Lower water quality**	**Sediment accumulation**	**Mangrove expansion**
Catchment change	Increased storm action	**X**	**X**	**X**	**X**	**X**	
	Sea level rise	**X**	**X**	**X**			
	Stormwater		**X**	**X**	**X**	**X**	
Catchment development	Land use			**X**	**X**	**X**	**X**
	Sand mining	**X**	**X**				
	Causeways					**X**	
	Water recreation						
Relative risks		Medium	Medium	High	Medium	Low	Low

The current analysis indicates that coastal inundation and sediment accumulation are the most likely events. The far-reaching effects of a spit breach call for a focus on relevant mitigation options. Shoreline erosion is more localised but nevertheless would have significant impact (by eroding the dunes and providing pathways for the sea to cross the spit and initiate a breach), sufficient to justify investigation of and potential investment in mitigation. Water quality and sedimentation face a significant risk in the face of climate change but with potentially lower effects than a spit breach or coastal inundation. Nevertheless, with mitigation relatively straight forward (focussing on catchment management) initiatives to reduce the risk can presumably still be justified.

5.3 Aligning risk and impacts

The assessment of issues in Table 5-1 also enables an ordering of the threats identified according to the magnitude of their possible effects and, consequently, a possible prioritising of management initiatives.

From the information provided in this study and as indicated in Table 5-1 assessment, the most disruptive impact would follow a breach of the sandspit (Table 5-3). Such an event would also interact with the other threats. For example, and as observed following the 1978 breach, it would heighten the risk and likely scale of erosion to the western shoreline and by blocking off the northern entrance cause eutrophication of the cut-off arm. Increased water movement and flushing could limit the spread of mangroves, while the conditions that might lead to a breach, such as sea level rise, could also see mangrove retreat. Mangroves are identified in Table 5-3 as low impact and low risk because under the existing consent for clearance their downstream limit of spread is constrained. Coastal inundation of low-lying properties is seen as having a higher risk of occurrence but a lower impact, insofar as the effects are more localised along narrow low-lying strips of the shoreline. A decline in water quality is seen as a high modest risk and limited impacts, with sediment accumulation of muds seen as a slightly higher risk and impacts.

Table 5.3.: Issues facing the harbour: aligning risks and impacts.

		Risk (Probability of Occurrence)		
		High	Medium	Low
Impacts (Scope and scale)	High	Coastal Inundation	Spit breach	
	Medium		Erosion of western shoreline Sedimentation	
	Low		Decline in water quality	Expansion of mangrove forest

On these grounds, the risk-impact matrix points to a strong focus on maintaining the integrity of the distal spit, complemented by management and monitoring policy aimed at maintaining good standards of catchment and stormwater management.

<u>Protecting the spit</u>

The dune and shoreline erosion process is slow but episodic. Cyclones can cause rapid erosion and retreat of the shoreline, although it does depend on 'the ducks lining up'. The July 1978 North Island Storm saw extensive erosion and flooding due to the coincidence of spring tide, storm surge, stream floods and large waves. While Gabrielle had large waves it came at neapish tides (at Auckland, water levels would have been about 50 cm higher if it had arrived at springs) and also that the angle of wave approach was not ideal for eroding E/NE facing beaches.

The consequences of a potential breach are far-reaching. The three main measures for spit management are maintaining its volume and form by moving and/or replenishing sand, the placement of structures to modify water flow and sand deposition on the shoreline, and ongoing measures to maintain and extend vegetation cover.

Conducting repeat volumetric surveys of the spit using a drone would provide a pretty quick and cost-effective method of obtaining high resolution data from which digital terrain models can be developed to map how sand is moving around and through the spit. This information could be used to determine dredging requirements and target sand placement and planting.

Vegetating the spit provides a natural means of stabilising the dune areas, preventing blow outs in the dunes which enable the sea to cut though, particularly on the ocean shore. Vegetation prevents deflation of the spit and aeolian transport of sand into the harbour. This can be achieved using sand trap fencing along and planting to accelerate or restore sand accumulation in vulnerable areas.

Climate change will bring more frequent and stronger easterly winds which will blow increasing amounts of sand off the spit and into the estuary. This raises the threat to the stability of the spit, moving the issue to the left in the risk-impact matrix, into the high risk-high impact zone. This threat may be mitigated if it intensifies by using earth moving machinery to build up more exposed eastern parts of the spit or by ongoing sand replenishment by dredging from the harbour bed.

Dredging is currently undertaken from sand traps in the channel to stabilise spit shorelines and height. To this end, sand has been used to nourish the beaches on the western shoreline of the harbour. Dredging also deepens the channel improving navigability. Dredging is, however, subject to seasonal constraints associated with avoiding activity on the spit in the Fairy Tern breeding season (September to February).

There would be a significant risk to spit shoreline stability if dredging and sand nourishment do not continue. The existing dredging practice operation should be monitored, recording dredging quantities and location of placement on the spit. In the event of an increase in the risk of a breach, it would be appropriate to have the capacity to undertake emergency dredging and placement (or some other option such as beach scraping or push ups for the open coast) at any time in the year. The 'big dig' and closure of the spit breach dig (Ross 2017) was initially enacted under an emergency consent. If, in the long term, more intensive weather conditions reduce the effectiveness of dredging and sand placement, alternative methods such as groyne development or rock armour may be called for to protect the western shoreline.

More generally, long-term sea-level rise will dramatically increase the frequency of occurrence of coastal inundation events. Events rare today will be increasingly common in the future. Their impact will be compounded by higher water levels bringing wave breaking closer to the shore, increasing the potential coastal erosion. While a breach of spit remains a long-term risk, the severity of potential impacts calls for the avoidance of actions that will increase or bring forward the risk and calls for a better understanding of the forces behind it. To this end, there is some urgency in modelling how the increasing frequency of higher water levels will impact Mangawhai to ensure the reasonableness of decisions to mitigate their effects.

<u>Managing water quality</u>

Catchment over-development and conversion to inappropriate land use invariably result in a reduction in water quality and loss of sandy substrate to mud from sediments, nutrients, and bacterial contamination from streams entering harbour in rain events. In the longer-term climate change will be accompanied by long-term warming and more intensive La Nina and El Nino oscillation. This will bring mean more frequent and intensive and longer duration rainstorms and floods. Increased catchment erosion and runoff to the harbour will result.

While the potential effects in the harbour will be widespread the impacts will be greatest in headwaters and the tidal creeks as they are close to the source of inputs and here flushing is relatively poor. Significant effects in upper reaches include mud accumulation and turbidity and a change in ecology where sandy substrate becomes muddy and waters more turbid.

The effects can cascade down harbour. However, in the middle and lower reaches the risks are less because the flushing is better and locally generated wind waves can resuspend mud that settles on sandy substrate. Effects will only last for short periods (days) during and following floods.

A major consideration in terms of mitigation is that it is very difficult to remediate water quality once the nutrients and sediments have entered the harbour. The only practical solution is to control activities at source through initiatives such as riparian planting of stream margins to reduce sediments, nutrients and bacterial contamination entering streams.

Sand mining on the open coast

Just as discontinuing dredging and placement of sand to build up the spit shorelines would move the stability of the spit into the high risk category, the continuing removal of sand from the Mangawhai-Pakiri embayment (open coast) may also increase the risk.

While the annual take of sand from the embayment is small compared to the total volume of sand in the bay, there is a cumulative effect from extraction taking place from the embayment since the 1920's that needs to be considered.

Also, there is uncertainty as to whether the take of sand from extraction is replenished and balanced by that from streams, cliff erosion, shell production and sources offshore. Although the exact numbers consigned to these sediment budget figures is debated, loss of sand from the coastal sand budget is permanent and erosion of the spit shoreline likely. However, because effects are spread over a wide area of shore and seabed, cause and effect are difficult to prove and will take some time to become evident. The potential effects on the Mangawhai spit will be greatest when extraction is close to the spit and when extraction is in the nearshore and mid shore (i.e., inside closure depth estimated at about 25 m).

The modelling presented by Hume et al. (1998) providing input numbers is over 25 years old and the river and cliff input estimate nearly 20 years old. It is time that the sand budget terms were updated using improved tools available today (i.e., numerical modelling of cross-shore and longshore sand transfers and inputs from stream and cliffs).

Net erosion of the Mangawhai-Pakiri embayment shoreline, including the spit, is gradual, small, and obscured by the 'noise' of storm events. However, it can be expected to accelerate in the face of climate change and sea level rise. Under these circumstances, ocean mining can be seen to increase the risk. Renewal of permits for sand extraction are currently going through the hearing and appeal processes. Evidence presented and decisions from the hearings will help decide on the best course of action on this issue. In the meantime, consents for sand extraction in the nearshore and mid shore should be opposed on precautionary grounds.

5.3 Conclusion

This report assembles and interprets information on the coastal physical environment. It identifies the risk factors facing the harbour and spit and the nature of potentially damaging effects and the likelihood of their occurrence.

Consideration of risk and an assessment of their probable effects on the environment of the different events has enabled some ordering of priorities of potential policies for avoidance and mitigation. While the priorities and actions proposed are not definitive, the report provides both an information base and a platform for building both a framework for identifying, prioritising and targeting any further investigations required a plan of action. Jointly, the information and assessment here provide an opportunity for a shared understanding of coastal processes to inform any debate about appropriate harbour management actions among the community and the agencies responsible for ensuring the health of the harbour and spit.

6 Acknowledgements

I thank Phil McDermott and Colin Leach for their guidance in shaping this report. Heather Quinn, archivist at Mangawhai Museum, took a deep dive into the archives to search out information that help build the knowledge base for the report. André and Robin La Bonté shared their considerable knowledge of the spit breach and closure and subsequent stabilisation of the spit, along with their understanding of the other issues and coastal processes and provided useful documents. I benefited from an off-road tour of the spit and its harbour shorelines with Richard Bull, Kevin Eddington and Phil McDermott.

Professor Mark Dickson, School of the Environment, University of Auckland, provided a very valuable and insightful review that improved the depth of content and understanding of coastal processes in a number of areas.

Lastly, I wish to thank Phil McDermott for valuable feedback at all stages of this study and his input on aspects relating to threat and risk analysis.

7 References and information sources

Albuquerque, J., Antolínez, J. A., Méndez, F. J., and Coco, G. 2022. On the projected changes in New Zealand's wave climate and its main drivers. New Zealand Journal of Marine and Freshwater DOI: 10.1080/00288330.2022.2135116

Alfaro, A.C. 2010. Effects of mangrove removal on benthic communities and sediment characteristics at Mangawhai Harbour, northern New Zealand. ICES Journal of Marine Science 67: 1087-1104.

ANZECC 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment & Conservation Council, and Agriculture and Resource Management Councils of Australia & New Zealand. Canberra, Australia. 316 pp.

Bell, R.G., Hume, T.M., Hill A.F., Black, K.P., de Lange, W., You, Z., Greilach, P., Turnbull, J., Hatton, D. 1997. Oceanography and sediment processes. Mangawhai-Pakiri Sand Study Module 4 Technical Report. NIWA Consultancy Report ARC60201/4. 169 pp.

Bell, R.G.; Goring, D.G.; de Lange, W.P. 2000. Sea-level change and storm surge in the context of climate change. Institute of Professional Engineers of New Zealand (IPENZ). IPENZ Transactions, General 27 (1): 1-10.

Black, K.P., Oldman, J.W., Bell, R.G., Gorman, R.G., Hume T.M. 1998. Numerical modelling. Mangawhai-Pakiri Sand Study Module 5 Technical Report. NIWA Client Report ARC60201/8. 206 pp.

Blackett, P. and Hume, T.M. 2006. Community involvement in coastal hazard mitigation: An initial scoping of process and pitfalls. NIWA Client Report HAM2006-083. 82 p.

Blackett, P., Hume, T., Dahm, J. 2010. Exploring the social context of coastal erosion management in New Zealand: what factors drive particular environmental outcomes? Special issue of Australasian Journal of Disaster and Trauma Studies: Natural Hazards Planning in Australasia. 2010-01. Online journal http://trauma.massey.ac.nz/issues/2010-1/blackett.htm

Borrero, J.C. and O'Neill, S. 2019. Development of Products and Procedures for the Mitigation of Tsunami Hazards at Maritime Facilities in Northland. eCoast Ltd Report. 55 pp.

Bruun, P. 1962. Sea level rise as a cause of shore erosion. Journal of Waterway, Port, Coastal and Ocean Engineering 88: 117-130.

Chen, W.Y. 1982. Assessment of southern oscillation sea-level pressure indices. Monthly Weather Review. 110: 800–807.

Clement, A.J. H; Whitehouse, P.L., Sloss, C.R. 2016. An examination of spatial variability in the timing and magnitude of Holocene relative sea-level changes in the New Zealand archipelago. Quaternary Science Reviews 131, Part A: 73-101.

Dahm, J. and Bergen, D.O. 2016. Mangawhai government purpose wildlife refuge reserve: Dune restoration management strategy (Draft for stakeholder input and comment). Report prepared for Northland Regional Council. 18 pp.

Dahm, J. and Munro, A. 2002. Coromandel Beaches: Coastal Hazards and Development Setback Recommendations. Environment Waikato Technical Report, 02/06. 194 pp.

de Lange, W. P. 2000. Interdecadal Pacific Oscillation (IPO): a mechanism for forcing decadal scale coastal change on the northeast coast of New Zealand? Journal of Coastal Research, Special Issue 34, ICS 2000: 657-664.

Diamond, H. and Renwick, J. 2015. The climatological relationship between tropical cyclones in the southwest Pacific and the southern annular mode. International Journal of Climatology. 35: 613–623.Research 1-38.

Dougherty, A.J. 2014. Extracting a record of Holocene storm erosion and deposition preserved in the morphostratigraphy of a prograded coastal barrier. Continental Shelf Research 86; 116-131.

Dougherty, A. J. and Dickson, M. E. 2012. Sea level and storm control on the evolution of a chenier plain, Firth of Thames, New Zealand. Marine Geology 307-310: 58-72.

Enright, N.J. and Anderson, M.J. 1988. Recent evolution of the Mangawhai Spit dunefield. Journal of the Royal Society of New Zealand 18 (4): 359-367. DOI: 10.1080/03036758.1988.10426462

Flood, S., Cocklin, C., Parnell, K. 1993. Coastal resource management conflicts and community action at Mangawhai, New Zealand. Coastal Management 21 (2): 91-111. DOI: 10.1080/08920759309362195.

Frisby, R.B. and Golberg, E. 1981. Storm wave run-up levels at Onepoto Bay, East Coast, North Island, New Zealand. N.Z. Ministry of Works and Development Water and Soil Technical Publication 21: 59-63.

Gibb, J.G. 1986. A New Zealand regional Holocene eustatic sea-level curve and its application to determination of vertical tectonic movements. Royal Society of New Zealand Bulletin 24: 377–95.

Green, M.O. 2011. Dynamics of very small waves and associated sediment resuspension on an estuarine intertidal flat. Estuarine, Coastal and Shelf Science, 93 (4): 449–459.

Griffiths, G. and Glasby, G. 1985. Input of river-derived sediment to the New Zealand continental shelf. Estuarine Coastal and Shelf Science 21: 773–787.

Hannah, J. and Bell, R.G. 2012. Regional sea level trends in New Zealand. Journal of Geophysical Research 117, C01004. 7 pp. DOI:10.1029/2011JC007591.

Hay, D.N. 1991. Storm and oceanographic databases for the Western Bay of Plenty. Unpublished MSc Thesis, Department of Earth Sciences, University of Waikato. 209 pp.

Haughey, R. R. 2017. Modelling the hydrodynamics within the mangrove tidal flats in the Firth of Thames. MSc thesis, University of Waikato. 91 pp + app

Healy, T., Immenga, D., Mathews, J., Nicol, S., Hume, T. 1996. Marine Sands. Mangawhai-Pakiri Sand Study Module 2 Technical Report. NIWA Consultancy Report ARC60201/2. 101 pp.

Heath, R.A. 1979. Significance of storm surges on the New Zealand coast. New Zealand Journal of Geology and Geophysics 22: 259-266.

Hesp, P.A. and Thom, B.G., 1990. Geomorphology and evolution of active transgressive dunefields. In: Nordstrom, K.F., Psuty, N.P., Carter, R.W.G. (Eds.), Coastal Dunes: Form and Process. John Wiley and Sons, Chichester. Pp. 253 –288.

Hesp, P. and Hilton, M.J., 1996. Nearshore -surfzone system limits and the impacts of sand extraction. Journal of Coastal Research 12 (3): 726-747.

Hicks, D.M., Hume, T.M. 1996. Morphology and size of ebb tidal deltas at natural inlets on open-sea and pocket bay coasts, North Island, New Zealand. Journal of Coastal Research 12: 47–63.

Hicks, D. M., Green, M. O., Smith, R. K., Swales, A., Ovenden, R., Walsh, J. 2002. Sand volume change and cross-shore sand transfer, Mangawhai Beach, New Zealand. Journal of Coastal Research 18 (4): 760-775.

Hilton, M.J. 1989. Management of the New Zealand coastal sand mining industry: Some implications of a geomorphic study of the Pakiri sand body. New Zealand Geographer 45 (1): 14-25.

Hilton, M.J. 1990. Processes of sedimentation on the shoreface and continental Shelf and the development of facies, Pakiri, New Zealand. Ph.D. Thesis, University of Auckland. 352 pp.

Hilton, M. J. 1995. Sediment facies of an embayed coastal sand body, Pakiri. New Zealand Journal of Coastal Research 11 (2): 529-547.

Hilton, M. J., and Hesp, P. 1996. Determining the limits of beach-nearshore sand systems and the impact of offshore coastal sand mining. Journal of Coastal Research 12 (2): 496-519.

Hilton, M. and Nichol, S. 2003. Offshore sand systems: geomorphology and management. In: Goff, J.R., Nichol, S.L., Rouse, H.L. (Eds.), The New Zealand Coast. Dunmor Press Palmerston North. 312p.

Hume, T.M. 1979. Factors contributing to coastal erosion on the east coast of Northland during July 1978. Water and Soil Division Report, MWD, Auckland. January 1979: 25p.

Hume, T.M. 1991. Empirical stability relationships for estuarine waterways and equations for stable channel design. Journal of Coastal Research 7 (4): 1097–1112.

Hume, T.M., Sherwood, A.M., Nelson, C.S. 1975. Alluvial sedimentology of the Upper Pleistocene Hinuera formation, Hamilton Basin, New Zealand. Journal of the Royal Society of New Zealand 5 (4): 421-462. DOI: 10.1080/03036758.1975.10419362.

Hume, T. M. and Herdendorf, C.E. 1992. Factors controlling tidal inlet characteristics on low drift coasts. Journal of Coastal Research 8 (2): 355–375.

Hume, T.M., Beamsley, B., Green, M.O., de Lange, W., Hicks, D.M. (1995) Influence of sea bed topography and roughness on longshore wave processes. Abstract and Paper, Coastal Dynamics ’95 - International Conference on Coastal Research in Terms of Large Scale Coastal Experiments. Gdansk, Poland.

Hume, T., Bell, R., Black, R., Healy, T., Nichol, S. 1998. Sand movement and storage and sand extraction in the Mangawhai-Pakiri embayment. Mangawhai-Pakiri Sand Study Final report. NIWA Client Report ARC60201/10 (revised July 1999). 76 pp.

Hume, T.M., Smith, R.K., Oldman, J.O., Ovenden, R. 1998. Morphodynamics. Mangawhai-Pakiri Sand Study Module 3 Technical Report. NIWA Client Report ARC60201/7. 150 pp.

Hume, T.M., Oldman, J.W., Black, K.P. 2000. Sediment facies and pathways of sand transport about a large deep water headland, Cape Rodney, New Zealand. New Zealand Journal of Marine and Freshwater Research 34 (4): 695- 717.

Hume, T., Gerbeaux, P., Hart, D., Kettles, H., Neale, D. 2016. A classification of New Zealand’s coastal hydrosystems. NIWA Client report HAM2016-062. 120 pp.

https://www.mfe.govt.nz/publications/marine/classification-of-new-zealands-coastal-hydrosystems

Hume, T.M. and Hart, D.E. 2020. Coastal hydrosystem responses to sea level rise. Pp. 45-53 in: Hendlass, C.; Morgan, S.; Neale, D. (Eds) 2020. In: Coastal systems & sea level rise: What to look for in future. New Zealand Coastal Society Special Publication #4. December 2020. 68 pp.

Jacobs 2020. Pakiri sand extraction consents - Assessment of effects on coastal processes. Report for McCallum Bros Ltd. 60 pp + app.

Kidston, J., Renwick, J.A., McGregor, J. 2009. Hemispheric-scale seasonality of the southern annular mode and impacts on the climate of New Zealand. Journal of Climate. 22: 4759–4770.

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., Tebaldi, C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future 2 (8): 383–406. Retrieved from http://dx.doi.org/10.1002/2014EF000239.

Larson, M. and Kraus, N. C. 1989. "SBEACH": Numerical Model for Simulating Storm-Induced Beach Change, Report 1: Theory and Model Foundation". Technical Report CERC-89-9, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg USA.

Lawson, W. 1994. Intertidal meandering at Mangawhai Harbour past, present and future. Report prepared for Mangawhai Harbour Restoration Committee. 8 pp + app.

LaBonté, A. 1994. Mangawhai Harbour restoration and maintenance plan. Report prepared for the Mangawhai Harbour Restoration Committee. Mangawhai, New Zealand in support of Restricted Coastal Activity Application. May 1994.

LINZ 2020. Tidal Level Information for Surveyors. http://www.linz.govt.nz/geodetic/datums-projections-heights/vertical-datums/tidal-level-information-for-surveyors.

Lundquist, C., Carter, K., Hailes, S., Bulmer, R. 2017. Guidelines for Managing Mangroves (Mānawa) Expansion in New Zealand. NIWA Information Series No. 85. National Institute of Water & Atmospheric Research Ltd. http://www.niwa.co.nz/managingmangroveguide

Mangawhai Harbour Restoration Society 2003. Mangawhai Harbour draft sustainable management plan. 17 pp.

Mangawhai Harbour Water Quality Project Team 2018. Mangawhai Harbour Water Quality Project – Position Paper. 7 pp.

McCabe, P. 1985. Mangawhai Harbour and the development of its dual inlet system. MSc. Thesis, University of Waikato, Department of Earth Sciences. 219 pp.

McCabe, P., Healy, T.R., Nelson, C.S. 1985. Mangawhai Harbour and the development of its dual inlet system. Pp 537-546 in Proceedings of the 7th Australasian Conference on Coastal and Ocean Engineering, Christchurch.

McBride, G., Reeve, G., Pritchard, M., Lundquist, C., Daigneault, A., Bell, R., Blackett, P., Swales, A., Wadhwa, S., Tait, A., Zammit, C. 2016. The Firth of Thames and Lower Waihou River, Synthesis Report RA2, Coastal Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100. MBIE contract CO1X1225: 50. http://ccii.org.nz/outputs/

McIvor, A.L., Spencer, T., Möller, I., Spalding, M. 2012. Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. The Nature Conservancy and Wetlands International.

MetOcean Solutions 2019. Pakiri hindcast metocean study: Wind, wave and current ambient and extreme statistics. 136 pp.

MFE 2017. Coastal hazards and climate change: Guidance for local government. 279 pp. http://www.mfe.govt.nz/climate-change/technical-guidance/guidance-local-governmentpreparing-climate-change

MFE 2018. Climate change projections for New Zealand: Atmosphere projections based on simulations from the IPCC Fifth Assessment, 2nd Edition. Wellington: Ministry for the Environment. 131 pp.

Nichol, S., Smith, R.K., Ovenden, R.O., Hume, T.M. 1996. Long term to short term shoreline change along the Mangawhai Pakiri coast. Mangawhai-Pakiri Sand Study Module 1 Technical Report, Onshore Sands.

NIWA 2011. Scenarios of storminess and regional wind extremes under climate change. Report prepared for Ministry of Agriculture and Forestry. NIWA Client Report: WLG2010-31 March 2011. 80 pp.

Northland Regional Council 2022. Proposed Regional Plan for Northland. Appeals Version - 8 December 2022. 345 pp.

Oliver, T.S.N., Dougherty, A.J., Gliganic, L.A., Woodroffe, C.D. 2015. Towards more robust chronologies of coastal progradation: Optically stimulated luminescence ages for the coastal plain at Moruya, south-eastern Australia. The Holocene 25 (3): 536-546.

Oppenheimer, M., Little, C.M., Cooke, R.M. 2016. Expert judgement and uncertainty quantification for climate change. Nature Climate Change 6 (5): 445–451. Retrieved from http://dx.doi.org/10.1038/nclimate2959.

Parnell, K.E. 1992. The Mangawhai northern tidal inlet: Physical processes and human intervention. Report to the Department of Conservation. Auckland Uniservices Ltd, Project 4103. 46 pp.

Pontee, N. 2013. Defining coastal squeeze: A discussion. Ocean and Coastal Management 84: 204-207.

Ramsay, D. 2004. Review of the assessment of environmental effects submitted in support of an application for resource consents to (continue to) extract sand at the entrance to Mangawhai Harbour. Report for Northland Regional Council. NIWA Client report HAM2004-032. 15 pp.

Ross, B.C. 2007. They dared the impossible. Self-Published. 102 pp.

Roy, P.S., Cowell, P.J., Ferland, M.A. (1994) Wave dominated coasts. In: Carter, R.W.G. and Woodroffe, C.D. (eds) Coastal Evolution: Late Quaternary Shoreline Morphodynamics. Cambridge: Cambridge University Press, pp. 121–186.

Schofield, J.C. 1965. The Hinuera Formation and associated Quaternary events. N.Z. Journal of Geology and Geophysics 8: 772-791.

Schofield, J.C. 1970. Coastal sands of Northland and Auckland. N.Z. Journal of Geology and Geophysics 13 (3): 767- 824.

Schofield, J.C. 1973. Post-glacial sea levels of Northland and Auckland. N.Z. Journal of Geology and Geophysics 16: 359–366.

Schofield, J.C. 1985. Coastal change at Omaha and Great Barrier Island. N.Z. Journal of Geology and Geophysics 28: 313–322.

Sjardin, C.J.N. 2011. The effects of causeways on estuaries. MSc Thesis, University of Auckland.

Stephens, S. 2019. Storm-tide analysis of Tararu sea-level record. Report prepared by NIWAfor for Waikato Regional Council. NIWA Client Report No. HAM2018289HN. August 2018 (Minor updates November 2019). 31 pp + app.

Swales, A., Bell, R., Lohrer, D. 2020. Estuaries and lowland brackish habitats. Pp 55-64 in: Hendlass, C., Morgan, S., Neale, D. (Eds) 2020. In: Coastal systems & sea level rise: What to look for in future. New Zealand Coastal Society Special Publication #4. December 2020. 68 pp.

Hume, T. M. and Hart, D.E. 2020. Coastal hydrosystem responses to sea level rise. Pp. 45-53 in: Hendlass, C., Morgan, S., Neale, D. (Eds) 2020. In: Coastal systems & sea level rise: What to look for in future. New Zealand Coastal Society Special Publication #4. December 2020. 68 pp.

Spalding, M., McIvor, A., Tonneijck, F.H., Tol, S., van Eijk, P. 2014. Mangroves for coastal defence. Guidelines for coastal managers & policy makers. Published by Wetlands International and The Nature Conservancy. 42 pp.

Swales, A., Bell, R.G., Gorman, R., Oldman, J.W., Altenberger, A., Hart, C., Claydon, L., Wadhwa, S., Ovenden, R. 2009. Potential future changes in mangrove-habitat in Auckland's east-coast estuaries. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Publication TR 2009/079.

Swales, A., Bentley, S., Lovelock, C.E. 2015. Mangrove-forest evolution in a sediment-rich estuarine system: opportunists or agents of geomorphic change? Earth surface processes and landforms. 40 (12): 1672-1687. DOI 10.1002/esp.3759

Thom, B.G., Bowman, G.M., Gillespie, R. 1981: Progradation histories of sand barriers in New South Wales. Search 12: 323–325.

Tonkin & Taylor 2020. Coastal Erosion Hazard Assessment for Selected Sites 2019-2020. Report for Northland Regional Council. 73 pp + app.

Wratt, D., Mullan, B., Salinger, J., Allen, S., Morgan, T., Kenny, G. 2004. Climate change effects and impacts assessment: A guidance manual for local government in New Zealand. Ministry for the Environment, Wellington. 153 pp.

Appendix A: Monitoring and information gaps

Monitoring the stability of the spit

There is a need for regular (at least annual) surveys of the outer coast and harbour shorelines of the spit harbour shore to monitor their stability and to determine erosion hot spots. Together with LiDAR and drone imagery the surveys will identify areas are shoreline and dunes that need building up and inform a plan for placing nourishment and planting.

Surveys to provide this information could include:

- Shoreline surveys by RTKGPS (walking or mounted on a quad bike) providing a 2-D image of the shore. I suggest this be underpinned by an updated analysis of historical shorelines (using air photos, Google imagery and LiDAR) to provide longer term (decadal) information on variations in shoreline position. This will assist with designing triggers.
- Surveys of topography and sand volumes in the shoreline dunes to estimate buffer for storm cut and gap filling requirements on the basis of LiDAR and beach profiles. This could be supported by drone imagery/topography and supply information on vegetation coverage along the shoreline.
- Surveys of the topography of the entire spit comparing the existing LiDAR imagery with LiDAR imagery flown in future to develop digital terrain models of the spit so that broad scale shifts in sand storage (dune erosion and deflation) and vegetation can be determined and monitored.
- A study to quantify the quantity the amount of sand blowing off the spit.

I recommend that priority be given to the first two surveys.

Emergency response

The surveys described above can be used to inform a dynamic (ongoing) emergency response plan. The plan should flag the criteria to activate a response in case of a severe threat of spit over topping and potential breach and support applications for consents. The plan needs to set out criteria and triggers to activate the response, and other information required for consents for emergency dredging and placement of sand to build up the spit.

Extreme water levels

Calculations for the open coast of extreme water levels due to storm surge. wave set up and run up under present day conditions and considering sea level rise in the next 100 years should be undertaken and to identify areas where the dunes need to be built taller to prevent overtopping. This would be task and not need to be repeated unless the projections for sea level rise change significantly.

Coastal inundation mapping

The potential for coastal inundation due to high tides and storm surge should be mapped following modelling using topographic surveys of land elevation from LiDAR combined with probabilistic modelling of predictions of return frequencies and magnitude of water levels and inundation.

A matter related to this is the potential for coastal inundation from tsunami. The study and modelling of the tsunami hazard for Northland by Borrero and O'Neill (2019) provides a good platform and tools for a site-specific analysis and mapping of the potential effects of tsunami for Mangawhai. The analysis could provide information on the extent of flooding low-lying land around the harbour, the potential for runup and over topping of the coastal dunes and define likely maximum credible events for the purposes of planning evacuation routes and increasing public awareness. Tsunami occurrence will not be affected by climate change, however higher long-term sea levels associated with climate change will allow the tsunami to propagate further landward.

Sand budget for the open coast

I recommend that the sand budget for the Mangawhai-Pakiri embayment be revised an updated using up to date information and numerical models.

Sedimentary budgets are a coastal management tool used to analyse and describe the different sediment inputs and outputs on the coasts, which is used to predict change in any particular coastline over time. Within a coastal environment, the rate of change of sediment depends on the amount of sediment brought into the system compared to the amount of sediment that leaves the system. In this respect the coastal sediment budget is like a bank account - when more material is added than is removed, there is a surplus of sediment, and the shore builds seaward (progrades) and vice versa. Although human activity contributes to the budget, by modifying catchment inputs or sand extraction, it is predominantly natural processes that contribute to the coastal sedimentary budget.

A budget for the Mangawhai Pakiri embayment was developed nearly 20 years ago as part of the Mangawhai Pakiri Sand Study (Hume et al. 1998). Inputs were calculated/modelled for rivers, cliff erosion, shell material, cross-and long-shore transport), and outputs for cross-and long-shore transport and sand mining. The progradation of the shoreline was determined. Jacobs (2020) revised some aspects of that budget (e.g., improved calculations of inputs from biogenic material) and reviewed shoreline progradation. Despite this there are some aspects of the budget that need to be improved, in particular those for cross-and long-shore transport. There are today much improved (compared to 1998) numerical models available to undertake these calculations.

This work could potentially be organised as a MSc or more probably a PhD project through a university.

Numerical model of the harbour

A numerical model of hydrodynamics and sediment transport developed for the harbour would greatly assist with the understanding and quantifying processes and making predictions on various matters. For instance, as the dispersion and flushing of catchment inputs, patterns of sedimentation and channel meander, the need for culverts in causeways, effects of mangrove removal on tidal prism and flushing, sites for dredging, design of structures such as groynes and how some of these may be affected by rises in sea level accompanying climate change. While the modelling is a one-off exercise, model can be updated as physical processes change (e.g., the bathymetry of the harbour).

This work could potentially be organised as a MSc or more probably a PhD project through a university.

Te ao Māori and mātauranga Māori

While not addressed in this report it would be valuable to undertake a study in respect to the way in which te ao Māori and mātauranga Māori can the inform the understanding of coastal physical processes and the future management of the Mangawhai coastal environment.

Documenting hazard events

Documenting hazard events along with post-event debriefing and analysis of the spatial extent, location and cost of damage provides invaluable information to inform public consultation and future planning. This reporting serves to refresh the memories of those who experienced the event first-hand and serve as a warning to new residents (and managers). Reports should document personal stories and observations by communities, secure images from the event, record post event aerial and ground surveys and of event parameters and frequency of occurrence. An important aspect of this is the community involvement. Feedback to community members is important to sustain their engagement in the processes.

Information management and record keeping

Consideration setting up a repository for data storage or at least a metadata archive for technical information relating to the harbour and spit. This is maybe a role for the Mangawhai Museum and overseen by Mangawhai Matters Inc.

Appendix B: Peer review of report

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

SCIENCE
SCHOOL OF ENVIRONMENT

Science Centre, Building 302
23 Symonds Street
Auckland, New Zealand
T +64 9 9238329
E m.dickson@auckland.ac.nz
The University of Auckland
Private Bag 92019
Auckland 1142
New Zealand

Dr Mark E. Dickson
Professor

20/06/2023

Re. Review of 'Mangawhai Harbour and Spit' Report by Hume Consulting Ltd

To Phil McDermott, Mangawhai Matters Inc,

I have reviewed the report prepared by Terry Hume on Mangawhai Harbour and Spit. Terry was asked to prepare a comprehensive report, based largely on existing information, 'to identify the factors most likely to affect the integrity of Mangawhai Harbour in the future and to highlight issues justifying more intensive study to better inform future management options studying the processes affecting the harbour and its environs'.

I can confirm that the report addresses the scope, is comprehensive in its coverage of the most important issues, and is up to date in terms of best available scientific knowledge. I also consider the report to be well balanced in its consideration of potential management options. Mangawhai Matters Inc are to be commended for commissioning the report and getting in front of future issues that will be exacerbated by climate change. The report provides a very useful synthesis document on which to ground these considerations.

In the attached pdf I have made quite extensive (~100) comments. The comments include a number of corrections, suggested wording changes, and some general observations. Below I summarise key points for further consideration.

1. The evolution of the spit barrier should briefly consider the work of Dougherty (2014) from Omaha and Oliver et al (2015) from Moruya, Australia. These and other studies challenge the classic southeast Australia barrier progradation model; evidence is accumulating that barrier progradation in northeast NZ was mainly driven by relative sea level fall over the last 4,000 years, as opposed to earlier views relating to high sediment supply at the end of the postglacial transgression and a subsequent period of relatively stable sea level. This context is important, because it speaks to the issue of sediment supply, and implies that the current sea level rise should drive shoreline erosion, although as Hume's report notes, we cannot yet clearly see the signal. In this context, we have just mapped the historic coastal changes in Mangawhai as a part of our national coastal change mapping programme through the Resilience Science Challenge and will be happy to make these data available to the Sustainable Mangawhai Project in due course.

2. Can you provide a brief clarification of the pre-Holocene topography beneath the dune sands? It appears that this surface is up to 20m high in places, with a cap of 30m dune sand. It wasn't clear to me from Enright and Anderson whether it is safe to assume that it is Pleistocene sand that has no additional resistance to erosion and can therefore be neglected in relation to considering potential future breach locations? The stratigraphy off Pakiri (Fig 3.1) seems to imply that.

3. The vegetation changes from pre-human to present and implications for dune and harbour morphology and sedimentology are really striking. It leaves one wondering about how to think about 'natural'. I have included some comments within the report to help leave the reader clear about the nature of the pre-human environment, which presumably constituted a strand-plain of dune ridges that would likely have been significantly lower than present are probably more or less continuous, with dune grasses on the foredune and forested areas of the back dune. Can you clarify what you think the surficial sedimentology of the harbour would have been like at this time? Burning dramatically transformed the environment leading to cannibalization of the foredunes and the current open sand system and perforated foredune, which allows breaching during extreme storms.

4. The 1978 breach is recognized as a key past event and is symbolic of an important future risk. Is it possible for the report to include a little more detail on the dynamics of storm and the morphology of

the dunes leading up to the breach, including an account of the storm wave heights, duration, period, surge, rainfall, etc? You note that early storms (prior to 78) lowered the beach allowing high water levels (storm surge) and waves to attack the shore higher up the beach and eroding the dunes in subsequent events, and that 'This situation presumably contributed to breach of the spit in 1978'. Can you clarify the evidence for this? I am not sure if more detail on the 1978 storm is already available in another report, but the context is important in respect to guidance on the possible location of a future breach, or conditions leading up to a breach, and how to mitigate.

5. I find Fig 3-17 hard to interpret alongside the preceding bullet points. Can this be revisited for consistency please.

6. I have made several comments in respect to the future wave climate – see in particular Albuquerque et al 2022. (Diamond and Renwick 2015 is perhaps also useful in respect to the relationship between cyclones and SOI – full references in the pdf comments doc). The general point is that, according to Albuquerque et al 2022, over the next Century mean Hs may actually decrease a little, and so may extremes, but their work doesn't account for cyclones, as the resolution of GCM predictions is too coarse, and I agree with your report that presumably cyclones will increase in intensity and frequency. Albuquerque et al 2022 also predict a mostly clockwise rotation in wave direction and this could be important for the longshore transport and spit development. A model is needed here to get a sense for the magnitude. The report has relatively little to say about longshore sediment transport, but I guess this is because not a lot is known?

7. Are there any numbers associated with the dredging and renourishment work that has been done? It would be useful to provide a table if there are any data available? I agree that it would be useful to update the sediment budget work and having a sense for the volumes associated with dredging would be very useful.

8. Northland and Auckland have flown LiDAR surveys and it would be very useful to build a digital elevation model of the spit. I think it would be valuable to conduct repeat volumetric surveys of the spit. For example, drone photogrammetry using structure-from-motion principles could be pretty quick and enable high resolution elevation models showing how sand is moving around and through the spit; this would be particularly useful associated with any dredging/renourishment/planting etc.

9. The document is silent in respect to te ao Māori and mātauranga Māori. One recommendation is to include these perspectives in regard to future management considerations.

10. In regard to adaptation, I think the report could add a short section about dynamic planning and signals and triggers (see links in my comments in the pdf) to help lay some foundation for communities to plan out and avoid lock-in traps and binary defend or retreat positions.

11. Some of the tables and text recommendations toward the end of the report are not explicit with respect to timeframes (see my comments within the pdf). Some clarification would be useful in this regard.

Sincerely,

M.E.Dickson

Prof. Mark E. Dickson
School of Environment
The University of Auckland