The Coastal Inundation Risks Facing Mangawhai

The Sustainable Mangawhai Project

Mangawhai Matters Inc

August 2025

Protecting our Environment, Sustaining our Community

Mangawhai Matters Incorporated (MMI) is a community group committed to maintaining the qualities of Mangawhai. The Sustainable Mangawhai Project aims to assess the physical risks to the harbour and distal spit and the consequences for the environment and community of any damage to them from a more volatile climate. The objective is to provide authoritative evidence to support community and agency cooperation in the preparation and implementation of harbour management and flood hazard reduction policies and guidelines.

This is a technical report that outlines the flooding risks associated with a more volatile climate. It builds upon an inundation visualisation tool prepared by Tonkin and Taylor Ltd. A shorter version is also available on the MMI website, *Wet Feet: The Coastal Inundation Risks Facing Mangawhai.*

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This report has been prepared by Dr Philip McDermott with assistance from Dr Terry Hume
For further information, visit www.mangawhaimatters.com/sustainablityproject.
Minor editorial changes have been made to the first version distributed in July 2025.

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GLOSSARY

ACKNOWLEDGEMENTS

SUMMARY

CONTENTS

TABLES

FIGURES

GLOSSARY

Acronym	Definition
AEP	Annual Exceedance Probability: the probability of a storm of a given intensity occurring in a year
ARI	Average Return Interval: the expected frequency of a storm of a given intensity occurring in years (E.g., an ARI 50 storm is expected to occur once every 50 years)
hPa	**Hectopascal:** a unit of pressure used to measure atmospheric pressure widely used in weather forecasting and climate studies. The average pressure at sea level is 1013 hPA. Pressures below 1,000 hPA are associated with stormy. Cyclonic storms or ex-cyclonic storms are generally below 970 hPA and extreme storms below 950 hPA. weather.
MfE	**Ministry for the Environment**
MHRS	**Mangawhai Harbour Restoration Society**
MSL	**Mean Sea Level**
MSLP	**Mean Sea Level Pressure**
NOAAA	**National Oceanic and Atmospheric Organization**
NZVD16	**New Zealand Vertical Datum 2016**: the official vertical reference system used to define heights across New Zealand and its offshore islands
RSLR	**Relative Sea Level Rise**: Changes in sea level associated with both ocean warming and vertical land movement.
SLR	**Sea Level Rise:** Changes in sea level due to thermal warming from the thermal warming and expansion and increased ice melt.
SSP	**Shared Socioeconomic Pathways**: Global scenarios prepared by scientists used to show how through different development pathways societies, economies, and policies will influence greenhouse gas emissions.
T+T	**Tonkin and Taylor Ltd**: New Zealand environmental and engineering consultancy.

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We are grateful for their input.

Dr Terry Hume brought his expertise as an oceanographer and his experience of the Mangawhai and other distal spits and barrier harbours throughout New Zealand to the preparation of this report.

Philip McDermott
Mangawhai Matters
July 2025

Summary: The Coastal Inundation Risks Facing Mangawhai

Objective

Mangawhai Harbour and its barrier spit play a critical role in supporting biodiversity, economic activity, and community well-being. However, a changing climate and particularly the increasing frequency of extreme weather events threaten the services it provides. This report, part of Mangawhai Matters' *Sustainable Mangawhai* project, assesses the risks posed by coastal inundation and provides a foundation for adaptive planning to mitigate its threatened impacts. The objective is to inform coastal planning and encourage the implementation of adaptive mitigation and defensive measures by the responsible agencies and the community.

The analysis first outlines the climatological and oceanographic factors that influence coastal flooding. As atmospheric warming accelerates, so too does the energy available for oceanic storms. While the overall frequency of tropical cyclones affecting the Northland region and coastal communities may decline modestly, their intensity is predicted to increase. This means stronger winds, lower central pressures, higher rainfall, and enhanced storm surges. Over time sea-level rise—driven by thermal expansion and ice melt— is expected to elevate the baseline upon which storm tides and wave run-up build, thereby extending the potential reach and depth of the resulting inundation.

The evidence

A review of scientific literature indicates that while the frequency of tropical cyclones may not increase their *intensity*—measured through wind speed, central pressure, spatial coverage, and rainfall—is likely to. There is also evidence of the gradual migration of tropical storm tracks into mid-latitudes in the South Pacific. This raises the probability that regions like Northland will be impacted by more severe cyclonic systems over time, something that will be compounded by sea level rise.

A review of ex-tropical cyclones in Mangawhai in the past establishes that the record is consistent with the expectation of increasing storm intensity. Seventy-five ex-tropical cyclones were identified off Northland between 1955 and 2025. Of 41 storms from 1956 to 1988, three were classified major storms (hurricane levels H3, 4, or 5), two of those in 1988. Of 34 since then, 16 were categorised major.

As storms intensify, wind speeds trend upward, and minimum pressures downward. While such storms weaken as they encounter cooler seas towards Northland, increased initial intensity, continued ocean warming, and a wider geographic impact raise the probability that severe storms in the future will produce more damaging coastal inundation than experienced in the past.

The Prospects

Future flood projections are modelled using three Shared Socioeconomic Pathways. These represent different global development paths which lead to different levels of global warming:

- SSP2-4.5 Middle of the Road sees warming curtailing by around the middle of the century;
- SSP3-7.0 Regional Rivalry sees continuing growth in warming leading to and sustaining severe storms;
- SSP5-8.5 A Divided World sees more fossil fuels being used, leading to sustained emissions and "catastrophic" weather events.

The prospect of more intensive storms suggests that storm tides above 2m will occur within the next fifteen years while 2.5m or more could be reached in the most extreme storms by mid-century. When compounded by local factors such as wave energy and rainfall retention, the extent of inundation could substantially increase, flooding harbour-adjacent properties and infrastructure.

The stability of Mangawhai spit is expected to come under increasing threat. Several low-lying segments are particularly susceptible to over-wash and could precipitate breaching during high-energy events. A simulation of the 1978 storm that breached the spit suggests that without further intervention, future storms of similar magnitude will compromise its integrity. Substantial spit degradation or breaching would have serious implications, reducing the harbour's natural protection and exposing coastal areas in the lower harbour to increased wave setup, wave energy, and inundation.

A Response

The report frames its recommendations within a risk-versus-regret decision model. It argues that the costs of acting early to mitigate future flooding are likely to be far lower than the social, environmental, and financial costs of responding reactively to a major event.

On this basis, it proposes a collaborative, adaptive planning approach by the responsible agencies to the increasing probability of destructive storms and the threat they pose to public and private assets, the community, and the environment.

Regulatory tools, such as zoning restrictions and minimum elevation requirements, are recommended to prevent new development in high-risk zones. Engineering measures include both hard defences (such as seawalls and groynes) and soft interventions (including dune reinforcement, wetland restoration, and beach nourishment). Infrastructure resilience is also a key area for investment, with roads, utilities, and drainage systems needing to be assessed and upgraded based on future flood exposure scenarios.

The most immediate and critical recommendation is to maintain and strengthen the integrity of the sand spit, which remains Mangawhai's primary natural defence against coastal inundation. Supporting actions include ensuring fit-for-purpose stormwater networks, elevating or protecting vulnerable infrastructure, and fostering coordinated governance to implement and monitor long-term adaptation plans.

In conclusion, the increasing probability and severity of coastal inundation events projected for Mangawhai are consistent with both international climate projections and local storm histories. The evidence presented offers a strong foundation for pre-emptive action aimed at preserving Mangawhai's environmental values, infrastructure, and community wellbeing. It proposes that timely, well-informed joint planning by the bodies responsible for the harbour and its community can significantly reduce exposure to storm risk and increase the capacity to recover when major weather events occur.

1. Introduction

Background

Mangawhai Harbour and its barrier spit support biodiversity, economic activity, cultural assets, and community well-being. The Sustainable Mangawhai Project is examining the threats to these services from a changing climate. The aim is to provide evidence to inform actions that may avoid or mitigate the adverse impacts of increasingly volatile weather on the physical environment and community.

Stage One of the Project described the processes affecting the harbour and any threats to it from the prospect of more volatile weather. It also canvassed the value of the recreational, lifestyle, and property services that may be at risk from degradation of the harbour and coast. These reports are available on the Mangawhai Matters website (www.mangawhaimatters.com).

Stage Two is based on expert studies examining more closely the risks identified in Stage One. These studies cover spit morphology and dynamics, catchment land use and run-off, and coastal inundation[1].

This report examines exposure to coastal inundation by severe storms. It describes historical storms and the factors contributing to their impacts and uses this information to assess the potential for increased coastal inundation in Mangawhai. Such events are expected have greater impact in the long-term because of sea level rise.

Tonkin and Taylor Ltd (T+T) assessed extreme water levels for 140 coastal locations for the Northland Regional Council in 2021.[2] Using land elevation data sourced from a 2018 LIDAR survey it estimated the coastal inundation levels that would arise under varying storm conditions over a 130-year horizon. This data has been used here to map in some detail possible coastal inundation in Mangawhai using a web-based tool developed by T+T for Mangawhai Matters[3]. This provides map representations of the potential extent of coastal inundation from any combination of storm tide and sea level rise.

Considering the potential inundation revealed, the report also suggests what measures might be taken in the meantime to mitigate the resulting coastal flooding.

Outline

Section 2 provides an understanding of the factors likely to make intensive storms more common in the future. Section 3 describes past storm events off Northland, including 50 years of cyclonic storms on the Northland coast. It draws on this data and a literature review to consider the prospects for increased storm activity in the future.

Section 4 demonstrates the likely effects of different levels of costal inundation on Mangawhai, indicating that more intensive storms will lead to more extensive flooding than experienced in the past, and confirming the vulnerability of the spit that protects the harbour and the services it provides.

Section 5 addresses the issues around the risks imposed and differences in opinion over the role of global warming. It concludes that the least risk option for responding to the threats identified is to adopt an adaptive planning approach to managing and mitigating coastal flood hazard, and outlines the sorts of policy measures that it might include.

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1 "Coastal inundation" refers to the temporary overflow of seawater onto normally dry land due to extreme weather, high tides, or tsunamis. It is distinct from flooding from overland runoff, although the two may have compounding effects in coastal regions.

2 Tonkin and Taylor Ltd (2021) *Coastal Flood Hazard Assessment for Northland Region 2019-2020*, Report to Northland Regional Council

3 Tonkin and Taylor Ltd (2025) *Mangawhai Matters Coastal Inundation Guidance* Report to Mangawhai Matters Inc

2. Understanding Coastal Inundation

This section sets out the basis for modelling severe coastal storms. First It outlines the development scenarios used internationally for planning for a warming climate. It then describes the processes by which ocean storms are generated, why severe storms will become more frequent, and the conditions influencing the extent of coastal inundation resulting from them.

Shared Socioeconomic Pathways

Shared Socioeconomic Pathways (SSPs) prepared by an international team of climate scientists, economists, and energy modellers[4] provide a framework for exploring the options for avoiding and limiting the adverse outcomes of climate change. The SSPs describe different paths for global development and what each means for emissions and atmospheric warming.

The Ministry for the Environment (MFE) adopted the SSPs to provide a scientifically robust scenarios to assist New Zealand regional councils plan for the impacts of changes of climate change[5].

Each SSP describes a plausible development path based on integrated projections of variables like population growth, GDP, and energy consumption. The climate outcomes are a consequence of the greenhouse gas emissions associated with each development path. This is because differences in the rate and character of growth and the level of greenhouse gas emissions between the paths give rise to differences in Positive Radiative Forcing. PRF measures in watts per square meter the balance between energy coming into the atmosphere and energy radiated out. Differences in PRF from one scenario to the next influence their relative rates of climate warming (Table 1).

Table 1 The Five Shared Socioeconomic Pathways

SSP Scenario	Socioeconomic Setting	Positive Radiative Forcing, 2100	Consequences
SSP1: Sustainability (Green Growth)	Cooperation, renewable energy adoption, and environmental preservation.	~1.9 W/m²	Warming limited to 1.5°C, reduced extreme weather risks.
SSP2: Middle of the Road	Moderate development and transition to renewables.	~4.5 W/m²	Warming stabilizes at 2.5–3.0°C, moderate risks remain.
SSP3: Regional Rivalry (Fragmentation)	Limited collaboration on greenhouse gas reduction, continued fossil fuel reliance.	~7.0 W/m²	Warming > 3.5°C, severe climate impacts like droughts and biodiversity loss.
SSP4: Inequality (A Divided World)	Uneven development between rich and poor regions.	~6.0 W/m²	Warming at 3.0–3.5°C, unequal impacts, vulnerable communities facing worst outcomes.
SSP5: Fossil-Fuelled Development (Conventional Growth)	Maintaining a fossil-fuel based mode of production and distribution Economic growth driven by fossil fuels.	~8.5 W/m²	Warming exceeds 4.0°C, catastrophic impacts extreme heat, sea-level rise, unliveable regions.

Increasing global cooperation over the past twenty years and rapid development of green technology has led to a consensus favouring Middle of the Road (SSP2–4.5) as the most likely development path.[6] However, limited progress in the development of climate targets was seen in 2024 as increasing warming expectations slightly. Given current policy settings, 2.7° warming is expected by the end of the century

[4] Intergovernmental Panel on Climate Change (2023): *Climate Change 2023: Synthesis Report*. Sixth Assessment Report Geneva

[5] Ministry for the Environment (2024) *Coastal hazards and climate change guidelines,* Wellington

[6] E.g., Ministry for the Environment (2023) Aotearoa New Zealand climate change projections: Quick Reference Guide

within a range of between 2.2º and 3.4º of warming[7] Recent threats to international trade relations and policies by some governments for fossil-fuelled industrialisation raise the prospect of Regional Rivalry (SSP3–7.0) with warming reaching or exceeding 3º within the century.

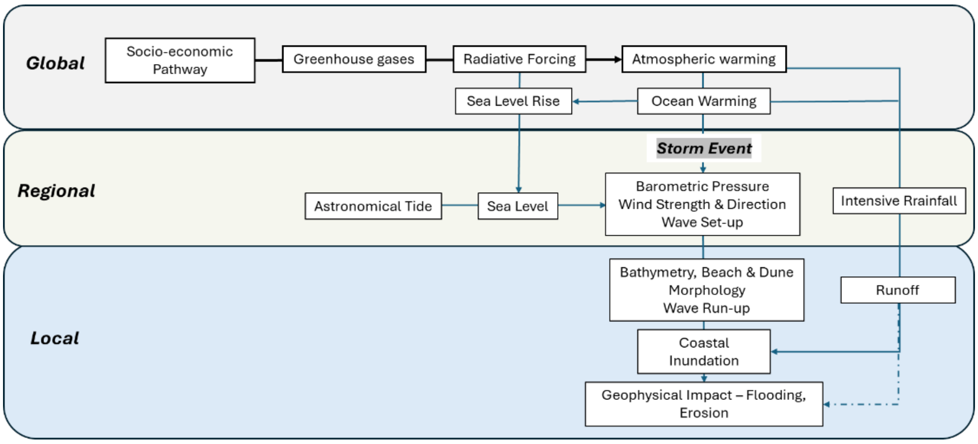
The analysis here is directed primarily towards the Middle of the Road (SSP32 - 4.5) and Regional Rivalries (and SSP3 - 7.0) pathways, with a Fuel Dependent path (SSP5 - 8.5) included as a worst case.

Drivers of Coastal Storms and Coastal Inundation [8]

The SSPs are aligned with different levels of PRF which are, in turn, linked to different rates of greenhouse gas emission and, as a result, differences in atmospheric and ocean warming. These differences will be reflected in the frequency and intensity of storms and the rate of sea level rise. In this way, the probability of severe storms increases over time, although at different rates between the SSPs.

The causal chain underlying these differences is illustrated in in Figure 1, which links the factors which jointly give rise to coastal inundation. The level of storm-induced inundation experienced in a locality is influenced by a combination of global trends, regional st9rm events, and local conditions.

Figure 1 The links between global development and coastal flooding



The key components in this sequence are:

- **Storm Surge:** This is the regional elevation of the sea resulting from the low barometric pressure characteristic of severe storms (allowing the ocean to rise for the duration of the storm) and strong winds piling water up against the coast.
- **Wave Set-up**: As high waves move shoreward some of their energy is transferred into the water below, lifting water levels even higher in the surf zone. Wave set-up mainly affects the open coast but can be influential in the mouth and lower reaches of a harbour.

Together, storm surge, wave set-up, and astronomical tide (see below) combine to form storm tides.

- **Long-term Sea Level Rise (SLR)** Much of the atmosphere's warming is absorbed by the oceans. As they warm, they expand and consequently sea level gradually rises. Ice melt contributes to this expansion. As sea levels rise, the capacity of a storm to penetrate and inundate the coastline is increases. This effect is tempered in areas where there is long term uplift of the land because of tectonic or geological processes and highlighted in areas where there is long-term sinking (the latter being the case for Mangawhai). When vertical earth movement is accounted for SLR is termed Relative Sea Level Rise (RSLR).

7 Climate Analytics & New Climate Institute (November 2024) *Climate Action Tracker: Warming Projections Global Update,* www climateactiontracker.org. 2.7º compares with the 1.5º target, which sees emissions peak in the 2030s.

8 A more detailed description is included in Tonkin and Taylor's *Mangawhai Matters Coastal Inundation Guidance* Report on the Mangawhai Matters website.

- **Wave Run-up** While the bulk of the wave energy on open coasts is released in the surf zone, some is dissipated as it runs up the shoreline above the tide level.

The four factors above drive the inundation potential of a coastal storm. Additional “local” factors that determine just how a storm might impact on a particular locality on a given day include:

- **Astronomical Tide**: While the astronomical (or gravitational) tide sits outside the factors leading to a storm surge, it will influence the impact. A storm surge at the top of the tide results in a **storm tide**.
- **Wind Direction** may influence the fetch (the distance over which the wind can generate waves) and whether or how much a coast is protection by intervening land.
- **Freshwater Retention** An incoming tide and onshore wind may back-up and retain catchment run-off, resulting in a layer of freshwater further elevating water level in the harbour.

Freshwater runoff retained within a harbour elevates its depth, intensifying coastal inundation separately from the flooding of low-lying land by run-off the dashed arrow in Figure 1). In low-lying coastal areas inundation from the sea and from the land can combine to increase the depth and duration of a flood.

- **Storm track.** Storms closer to the coast will generally have higher storm surge and wave setup.
- **Storm duration.** How fast a storm progresses is important: a fast-moving, short duration storm can elevate water levels. A slow-moving storm may provide more time for the land to flood.
- **Physical environment**. Ocean and harbour bathymetry will influence how waves interact with the coast and how currents set up by inundation affect over-wash and drainage during a storm.

Given the dynamic nature of coastlines, both bathymetry and the coastal margin (shorelines, wetlands) may change both between and during storms making the local manifestation of coastal inundation – where it reaches and at what depth – difficult to predict with any precision.

3. Past Storms

This section describes past storms to inform our understanding of their dynamics and to indicate some of the parameters which can be expected to influence their future impacts. It focuses on cyclonic storms that arise in the tropical and subtropical waters north of New Zealand. It concludes that while cyclonic storms are likely to be less frequent in the future, those that do occur will be more extreme.

We can expect a general increase in storm activity based on increasing ocean temperatures. While the timing and intensity of such storms cannot be predicted with any certainty, the conditions favouring their formation can be identified building on evidence from past storms.[9]

The local factors influencing a storm's flooding add to the uncertainty. For example, storms of similar intensity can have different effects depending on their track and duration, tide conditions, rainfall and runoff, and time of year. Regardless of local influences, SLR will compound their effects over time.

July 1978 – the Breach Storm

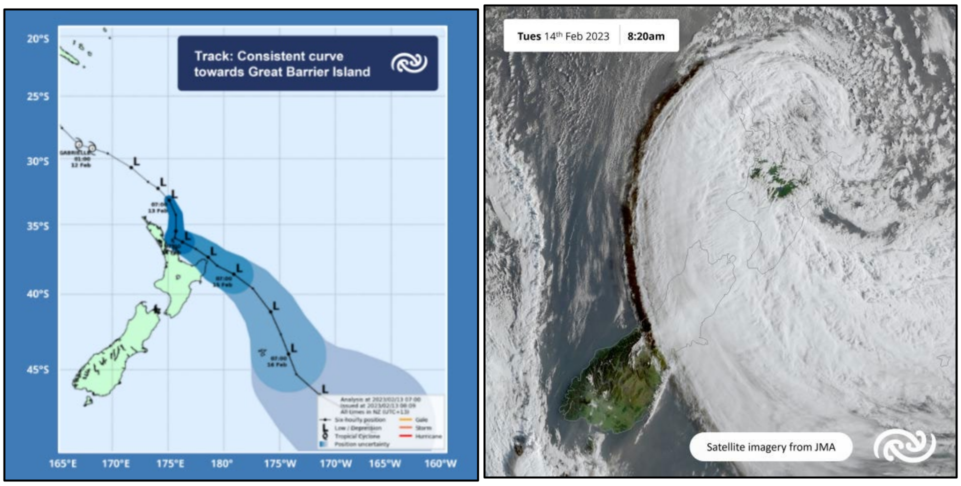
The storm that breached Mangawhai spit ran from 18 to 23 July on the North Island east coast . Easterly winds in Northland reached 150km/h. The highest astronomical tide was 1.14 m NZVD16[10]. Storm surge was an estimated 0.61 m and wave set-up on the open coast was estimated at 1.15 m. Runoff from the surrounding catchment may have raised the harbour water level by another 0.2 m.[11]

Together, these factors resulted in inundation of around 1.95 m inside the harbour. This excludes wave set-up, which is likely to have added to water levels within the vicinity of the harbour mouth. The combined flooding of the western (harbour-side) coast of the spit and overtopping of the dunes on the eastern (open coast) by storm surge, wave set-up, and wave-run-up resulted in the breach of the spit.

Cyclone Gabrielle

Cyclone Gabrielle originated as a tropical summer storm northwest of New Zealand in February 2023. It was marked by intense southeasterlies and sustained winds of over 90km/hr for 48 hours. Gusts reached 140km. Gabrielle had severe impacts across New Zealand's entire east coast. The pressure fell to 964 hPa off Northland, and several stations recorded a 1 in 100-year rainfall over 48 hours.

Figure 2 Cyclone Gabrielle on Northland's East Coast



Source: Tropical Cyclone Gabrielle – Event summary February 2023, MetService Blog

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9 This section draws on a fuller discussion in the Tonkin & Taylor 2025 report.

10 New Zealand Vertical Datum 2016, which is the reference point for measuring vertical elevations across New Zealand. All water level measurements in this report are relative to NZVD16.

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

The predicted high tide was 0.65 m on 13 February. However, the measured level at Marsden Point was 1.56 m NZVD16. This corresponds with an annual storm tide return interval of between 20 and 50 years (Tonkin and Taylor, 2021). Wave set-up was estimated at 0.14 m and inundation level of 1.7m based on photos during the event. Some of this elevation was due to summer warming (about 0.1m above MSL). An estimated 0.81 m of storm surge is likely to be associated with greater than a 100-year return interval, but favourable astronomical tides limited total inundation.

The Differences

Comparing the July 1978 storm and Gabrielle, the lowest barometric pressure was significantly lower for latter. However, the 1978 storm had higher water elevation, 1.95m compared with around 1.7m. The 1978 storm recorded slightly stronger peak wind gusts, but Gabrielle had more sustained winds above 50 knots. The 1978 winds were predominantly easterly, while Gabrielle's were southeasterly.

The greater impact of the 1978 storm by way of breaching the spit is not consistent with its lower intensity and duration compared with Gabrielle.

Four points of difference probably contributed to this. First, there had been a severe storm in May 1978 that eroded a lot of sand from east coast beaches so that lower beach levels are likely to have enabled wave run-up and overtopping on the ocean side. Second, in 1978 the dune on the western side of the spit was too low to prevent the storm tide flooding from the harbour side. Third, the astronomical tide was higher in 1978.

Finally, and importantly, the neck of the spit was very narrow (only 150m) in 1978. This enabled flooding from the west to join wave run-up and over-wash from the east, creating the breach. In 2023 a wider neck (about 430 m) and the bund wall which had been developed along the western side by dredging sand from the channel onto the spit by MHRS provided protection (Figure 3).

Figure 3 Comparing the Spit Neck, 1976 and 2024[12]

12 M. Dickson (2025) *Topographic mapping of Mangawhai sand spit – identifying low points in the foredune* University of Auckland, Report to Mangawhai Harbour Restoration Society

Cyclonic Storms, 1960-2025

Our assessment of the prospect for future storm activity focuses on ex-tropical cyclonic storms which are most likely to impact on Northland. While there is no certainty over their likely timing and frequency, if they migrate further south and mid latitude water temperatures continue to rise it is highly likely that they will bring more severe conditions than in the past. Appendix One explores this proposition. This section summarises the findings and conclusions.

The scientific literature indicates that cyclones may become less frequent but more extreme, with lower central pressures, higher wind speeds, greater rainfall, and a wider area of impact. In both hemispheres, but more so in the south, they are migrating into mid latitudes, and this is expected to continue.

Analysis of cyclone data collected by the National Oceanic and Atmospheric Organisation identified 75 ex-tropical storms that tracked within 500km of Northland's coast since 1955. Nineteen were classified as major or extreme storms (22%) and 26 (35%) as Tropical Storms. The majority had degraded to tropical storm status in the waters off Northland.

While there was no obvious increase in storm frequency over the 70-year period, there has been an increase in the number of major storms since the 1990, accompanied by a tendency to higher wind speeds and lower pressures. While subject to storm-to-storm variation, this trend is pronounced and consistent with the climate modelling reviewed. This shows that poleward migration can be expected to continue with larger areas impacted as storms intensify faster and travel further.

While storms weaken before reaching Northland, the evidence nevertheless suggests that storms affecting Northland, when they occur, can be expected to be more severe than the two documented above. Further, if thermal warming of the sea surface north and east of New Zealand continues, they can be expected to maintain higher energy levels on the Northland coast.

The next section explores the consequences of such an eventuality in terms of coastal inundation.

4. Mapping Coastal Inundation

This section considers potential harbour flood levels in and around Mangawhai in the future. It draws on the Tonkin and Taylor 2025 study and the review of previous storms and expectations for more severe storms in the future to explore the possible extent of coastal inundation in Mangawhai. It maps two levels of inundation, 2m which can be expected to occur within the next 20-years and 2.5m which will be a strong possibility beyond that.

Storm Activity

Section 3 indicates that although storm frequency may decrease, the severity of individual storms will rise. To the extent that severe storms last longer, track further, have stronger winds, and may track further south, a reasonable prognosis is that Mangawhai will be subject to less frequent, but more severe coastal inundation than experienced in the past. The associated flooding can be expected to extend further later in the century because of RSLR.

Storm Surge and Storm Tide

Storm surge is estimated by analysis of past storms, establishing how storms of different intensities align with different inundation levels [13]. The high-water levels that occur when storm surge is piled on top of the regular astronomical tide are known as storm tides.

Storm tide estimates for Mangawhai Harbour have been provided by Tonkin + Taylor for storms of different intensities. Intensity is defined in terms of the Average Return Interval (ARI), or the frequency in years with which they might be expected to occur. This can also be expressed as a probability – the percentage chance of a storm of a given intensity occurring in any given year (known as the annual exceedance probability, or AEP).

Using the T+T analysis, coastal inundation levels have been projected for storms of three different intensities here: a 1 in 5 -year ARI (or 18% AEP) storm, a 20-year ARI (or 4.9% AEP) storm, and a 50-year ARI (or 2.0% AEP) storm.

A potential reduction in the number of cyclonic storms is likely to see fewer moderate storms with high return (a 5-year or 10-year ARI, for example) but more intensive storms with longer return interval (a 50 or 100-year ARI, for example). In effect, the return intervals of more severe storms will fall.

Sea Level Rise

At the same time, the spatial extent of coastal inundation associated with a storm of a given intensity will increase as sea level rises. Projections of different rates of sea level rise are derived from the Shared Socioeconomic Pathways (Figure 4). Three pathways are considered here, Middle of the Road (SSP2-4.5), Regional Rivalries (SSP3-7.0), and Fossil Fuelled Development (SSP5-8.5). Relative Sea Level Rise includes the local downward vertical land movement (VLM or sinking) of the North Island's east coast.[14] For this analysis, the RSLR trajectories start at a common point, based on the 2025 mean sea level referenced back to the NZVD16.

The projections are similar for the three scenarios over the first thirty years, diverging more obviously after that (Figure 4). By 2050, RSLR is projected to rise by around 20cm under SSP3-4.5, by 22cm under SSP3-7.0, and by 23cm under SSP3-8.5. The differences from different development paths only come into play after that. The more rapid rise under SSP3-7.0 and SSP 5-8.5 reflects a higher interim rate of warming associated with their development paths. This contrasts with the expectation that greenhouse gas emissions will peak in about 2040 under SSP2-4.5, with temperatures stabilisation a decade or so later.

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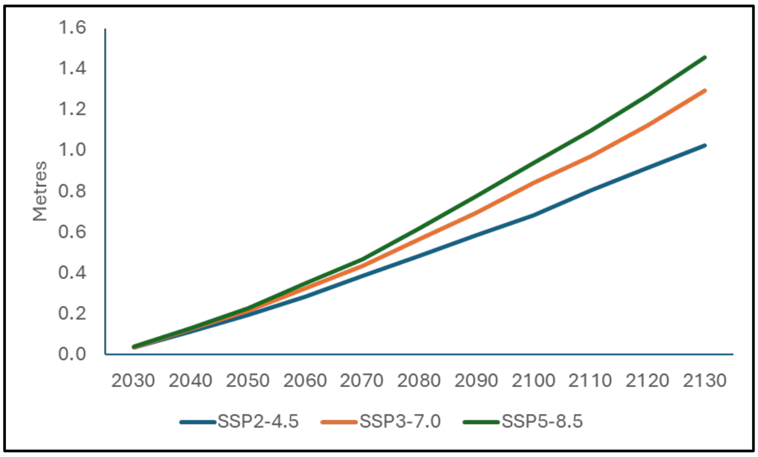
13 See Met Ocean Solutions

14 See New Zealand Sea Level Rise Research Programme, University of Victoria. (Link here)

Figure 4 Shared Socioeconomic Pathways and Sea Level Rise



While the graphs suggest that RSLR will take place steadily on one trajectory or the other, the likelihood is that they will not be that continuous: changes in geopolitical conditions, economic development and trade could all see a shift from a high to a lower emissions trajectory (or vice versa).

For example, resource and political pressures could see the global economy transition from a currently progressive trajectory, SSP2-4.5, to reduced cooperation and fragmentation of supply chains as described by SSP3-7.0. This could see a shift from a moderate rate of warming in the short term (say 10 to 20 years) to a more rapid and prolonged rate in the medium term (20 to 50 years). Conversely, If the current trajectory becomes more obviously unsustainable, we could see a shift to a path even more focused on reducing emissions than SSP2-4.5, with a reduction in expectations for increased storms in the long-term.

Either way, for the purposes of defensive or mitigation policies, it makes sense to give most weight to the next 25 to 30 years while recognising the need for any actions taken in the interim to allow for a response for the possibility of increasingly severe events later in the century.

Local Conditions

To identify the potential for flooding associated with sea level rise and storms of varying intensities local conditions at the time of a storm need to be considered.

Wave Set-Up: Wave set-up varies with local coastal bathymetry, wind strength and persistence, and wave energy. Wave setup was estimated at 1.15m on the open coast in the 1978 storm and at 0.14m within the harbour during Gabrielle. While wave setup will penetrate the harbour, its impact will diminish progressively away from the harbour mouth.

Astronomical tide: The impact of storm surge will be amplified by high tides and moderated by low tides. The T+T storm tide estimates include storm surge and the astronomic tide at Mean High Water Springs projected relative to NZVD2016. A storm peaking below MHWS will have a lower flooding effect.

Seasonal Elevation. The most severe storms experienced in Mangawhai are typically ex-tropical cyclones originating north and northwest of New Zealand in mid to late summer (although winter mid-latitude storms can have a destructive impact as demonstrated by the 1978 breach storm). Given the focus on cyclonic storms, the T+T storm tide projections account for seasonal warming.

Fresh water runoff. Runoff in the 1978 breach storm was estimated to add 20 cm to harbour water levels. Given that Northland's severe storms originate mainly in the Coral Sea, heavy rainfall is a commonly associated feature. No estimate is available for Cyclone Gabrielle, but extensive flooding around the upper reaches of Tara arm suggests that there would have been a significant contribution to the elevated harbour water level.

Mangawhai Storm Projections

The components of storms driving sea elevation comprise storm surge, wave set-up, and, in the case of the harbour, rainwater runoff retention. The values used for these components are described below.

Storm Tides

For present purposes, the nominated storm intensities have been projected onto the three scenarios over a 55-year period, 2025 to 2080. These comprise expectations of seeing a storm of a given intensity over 10-year periods under the different development scenarios.

Storm tides, combining storm surge, seasonal oscillation, and astronomical tides, are the key drivers. Figure 5 compares projected storm tides for three SSP scenarios and two levels of storm intensity.

Figure 5 Storm Tides by SSP Scenario, 2030-2080 (m)

The differences for a given intensity of storm become pronounced only after about 2060. When projecting from a common starting point divergence between development paths can only take place well into the future. In effect, the first 20 to 30 years' of RSLR are already less baked into place.

The difference attributable to RSLR between SSP2-4.5 and SSP3-7.0 is just 2cm in 2040, rising to 4cm in 2060 and 8cm in 2080. At that point, the differences in global warming between paths will be having a major influence on the extent of coastal inundation.

Differences among storms of different intensities are more significant early in the period. A 10-year ARI storm in 2030 would generate a storm tide of around 1.5m, a 20-year ARI storm tide would be 30 cm higher, and a 50-year tide 50cm higher (2.1m).

The key effect of sea level rise for at least 25 years will not be to slowly flood coastal areas incrementally but to compound the impact of severe storms, making coastal land increasingly vulnerable to inundation.

Coastal Flood Levels

While storm surge is the principal driver of extreme sea level elevation and, consequently coastal inundation, two other components affect the inundation. The first is wave set-up, which reflects wind speed and fetch, and the speed and track of a given storm. Wave setup is most marked on the open ocean coast but will also have an effect within the harbour, strongest at the mouth and lower and diminishing moving up the harbour.

The second is runoff retention. High sea elevation and incoming tides impede the outflow of freshwater. The longer the storm lasts and the higher the storm surge, the more likely this is. The effect on water levels can be marked, particularly in the upper harbour and tributaries. The intense rainstorm following on the footsteps of Cyclone Gabrielle in February demonstrated this with extensive upstream flooding.

The Tonkin and Taylor projection of inundation levels incorporates storm surge and ocean wave set-up but does not allow for the contribution of runoff freshwater retention. Without recorded measurement of wave set-up in the harbour and freshwater retention in the upper the harbour, they are assumed to be complementary, leading to a reasonably consistent increase in depth across the harbour. For our scenarios, the resulting water elevation is assumed to be 10cm in a 20 year-ARI storm, 20cm in a 50-year ARI storm, and 30cm in a 100-year storm. These are considered reasonable assumptions given expectations for heavy precipitation to accompany storms of increasing intensity.

Table 2 Harbour Inundation Levels

Scenario	Harbour Inundation (metres)			
Storm Intensity	2030	2040	2060	2080
SSP2-4.5				
5-Year ARI	1.7	1.9	2.0	2.2
20-Year ARI	1.9	2.0	2.2	2.4
50-Year ARI	2.1	2.2	2.4	2.6
100-Year ARI	2.3	2.4	2.6	2.8
SSP3-7.0				
5-Year ARI	1.7	1.8	2.0	2.3
20-Year ARI	1.9	2.0	2.2	2.5
50-Year ARI	2.1	2.2	2.4	2.7
100-Year ARI	2.3	2.4	2.6	2.9
SSP5-8.5				
5-Year ARI	1.7	1.8	2.1	2.3
20-Year ARI	1.9	2.0	2.3	2.5
50-Year ARI	2.1	2.2	2.5	2.7
100-Year ARI	2.3	2.4	2.7	2.9

Over the 55 years, sea level rise lifts inundation levels by 0.5m under SSP2-4.5 and by 0.6m under the continued warming scenarios.

Under all three the more immediate risk is the rising intensity of storms which are likely to exceed historic flood levels before 2040. Today, a 5-year ARI storm would go close to matching the worst events of the past; a 50-year storm would surpass them. Under SSP2-3.70 and SSP3-8, a 2m inundation storm is likely within 15 years, 2040.

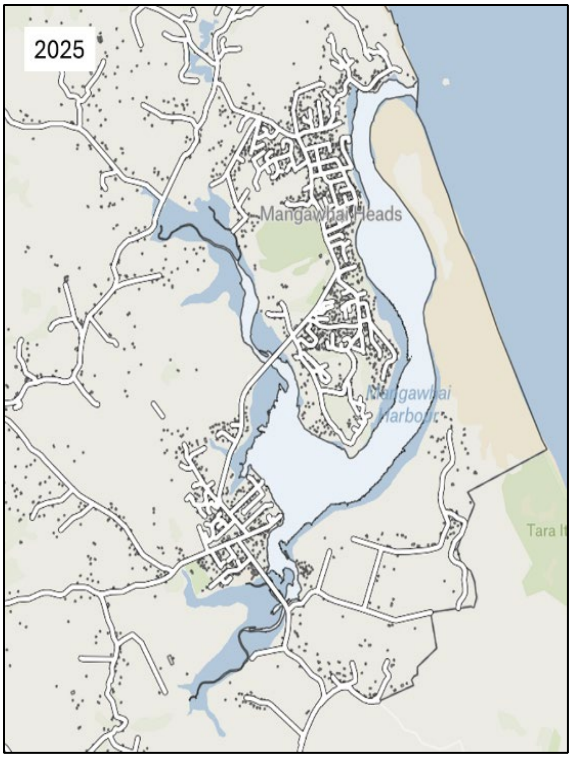
Sea level rise simply raises that threat as time goes by. So, by 2080 a 20-year storm would be approaching 2.5m inundation while a 50-year storm would be 2.6m even under the conservative SSP2-4.5 scenario.

Coastal Inundation Scenarios

The tool prepared by T+T enables us to identify where inundation will occur under different storm and RSLR combinations. Taking 2.0 m and 2.5m harbour inundation as benchmarks enables us to consider the joint significance of RSLR and storm intensity.

Figure 6 Mangawhai Harbour Mean Sea Level 2025

Figure 6 shows the current extent of harbour waters at Mean Sea Level (light blue). This compares with maps of flood levels below[15]:



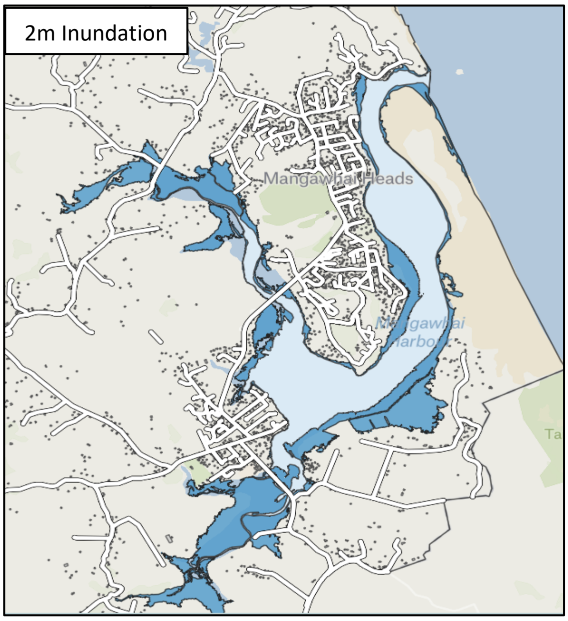
The scenarios suggest that 2.0 m inundation is not likely until after 2040 (15 years out) under the Business as Usual Scenario under 20-year ARI storm conditions. The fact that close to that level was recorded in the 1978 Breach storm and 2023 Cyclone Gabrielle, suggests that it could nevertheless occur much earlier.

2.5m of inundation could occur within 25 years (2060) if warming continues at current or even higher rates. This would be the case with development path SSP3-7.5 (Regional Rivalry) SSP5-8.0 Fossil-fuelled Development).

Even 3m is a prospect between by 2080 if fossil fuel burning does not decline within a reasonable time frame. While such an event falls an outside our immediate timeframe, the prospect that 3m could be exceeded by the end of the century means that that possibility should be built into our long-term thinking about managing the harbour.

15 Levels are relative to NZVD16 datum which approximates mean sea level in 2025.

Figure 7 Potential Flood Levels, 2m Inundation

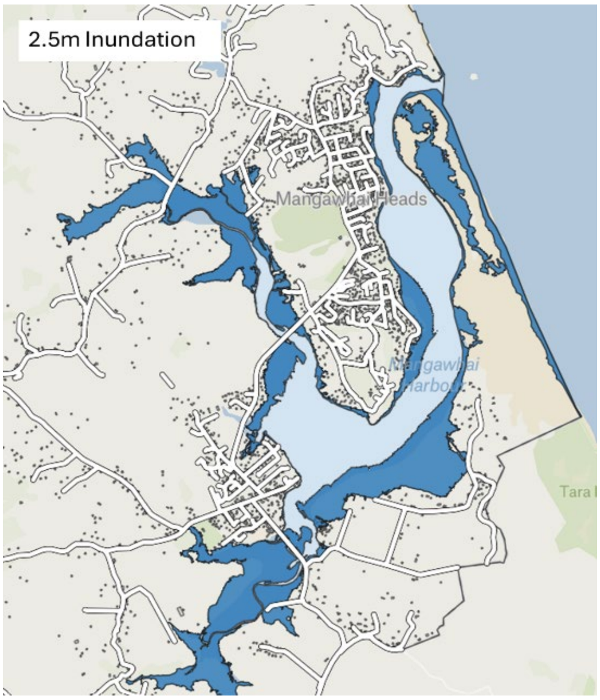


The bulk of Mangawhai lies above 4m (above MSL or NZVD2016) and so avoids the direct impacts of coastal inundation (Figure 7). There are, though, significant areas of coastal reserve and some settlement at lower levels likely to be exposed to increased hazards from coastal inundation over the next 10 to 20 years.

In addition, overtopping of upper harbour tributaries will generate significant flooding in the lower catchment, posing threats to urban edge subdivision, lifestyle residences, and roads and bridges to the west.

The northern tip of the spit could suffer erosion from the high-water levels, and even some incursion of sea water depending on the state of internal flow paths, weakening its capacity to resist internal flooding in peak storms rest repeat storms.

Figure 8 Potential Flood Levels, 2.5m Inundation



Comparing maps (Figures 7 and 8) suggests that flooding expands significantly when inundation reaches 2.5m. At that level, the entire harbour floor is flooded, shoreline flooding occurs around Lincoln St, Alamar Crescent, and Mangawhai Heads Holiday Park. Seawater penetrates and floods around Tara Creek in the vicinity of the King Rd and lower Jack Boyd Drive, Back Bay, the Insley St causeway, and the southern shore in the vicinity of Raymond Bull Drive (north), and Tern Point.

Coastal inundation reaching 2.5m will have impacts beyond those properties and amenities directly affected because of their impact on key components of infrastructure. Low-lying roads like Lincoln St, Cove Rd and Black Swamp Rd would be impassable, and potentially suffer significant damage. Stormwater and wastewater networks would be disrupted if not damaged. Causeways and bridges may be at risk.

Inundation over 2.5m poses a major risk to the spit. It is likely to be accompanied by runup on the ocean coast and overtopping ocean-side dunes. Much of the northern part of the spit could be lost altogether, along with seabird roosting and breeding grounds. Severe erosion of the spit, whether by flooding of the northern end or breach in the vicinity of the neck would expose the properties and amenities in the lower and middle reaches to the more extensive flooding The degradation of the spit, then, is likely to compound the threats arising from a more volatile climate.

The Prospects for the Spit

Coastal inundation modelling undertaken by Auckland University confirms the risks facing the spit. [16]

Figure 9 1978 Breach Storm Features Applied to 2025 Spit Form

To understand the significance of increased storms on the spit, bathtub modelling was undertaken. This effectively overlays a detailed map of current spit shape and morphology with the level of inundation that would occur if the 1978 breach storm were to occur today (Figure 6). [17]

The model provided for a water level of 1.9 m (in relation to NZVD16), with no allowance for wave set-up within the harbour, but including 20cm as the freshwater component. This aligns broadly with the 2m inundation in Figure 6.

In this case, the open-coast water level was modelled at 3.4 m (blue hatching) allowing for the joint impacts of storm surge, wave setup, and wave runup.

Near the northern end of the spit, a water level of 2.4m results, demonstrating some of the effects on the open coast of wave setup and runup.

The conclusions that can be drawn from this are that:

- At 2m inundation the northern low points (gaps 1 and 2, as marked) will connect with the dune lake, resulting in its extension and an increase in salination.
- Runup overtopping the spit occurs at gap 3.
- There will be substantial inundation at gap 4, the narrowest part of the spit.
- Substantial inundation occurs at gap 5, a threat to current Tara Iti nest sites.
- Substantial inundation occurs at gap 6 raising the prospect of sea water accessing the inner dune (bund wall) and flooding tara iti nesting sites.

Assuming no morphological adjustment of the spit in response to sea level rises, a 1978-style storm would lead to significant inundation. While the bund wall and increased spit width have so far prevented a repeat of the 1978 breaching, even in severe storms, more storms of greater magnitude mean current measures alone are unlikely to prevent it under the sorts of storm event likely by 2040 and beyond.

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16 Professor Mark Dickson, Assoc. Prof. Murray Ford, Dr Emma Ryan, Auckland University (2024) *Topographic mapping of Mangawhai sand spit and development of a draft framework for monitoring future changes* Report prepared for Mangawhai Matters Inc.

17 Dickson, M (2025) *Topographic mapping of Mangawhai sand spit – identifying low points in the foredune*, Report to Mangawhai Harbour Restoration Society.

5. Coastal Flood Hazard Planning

While severe storms capable of elevating coastal waters as described are a growing threat, measures can be taken to limit the resulting flood impacts. This section considers the grounds and possible components of an adaptive management plan to limit these flood impacts and to mitigate their effects.

The Policy Question

The preceding analysis provides grounds for expecting Mangawhai to experience increased coastal inundation sufficient to impose high costs on the community and the environment. Elsewhere, we have explored some of the costs that will be imposed on the community, covering loss of benefits to recreational visitors, a reduction in local business turnover as a result, and a reduction in the value of property at risk.[18] These and other, more subjective costs to the community need to be considered when responding to the threats posed by a more volatile climate. The social, economic, and environmental consequences of increasing levels of coastal inundation support the view that the community should invest in mitigation measures sooner rather than later.

An alternative view is that the science behind climate change is flawed: either we are in a natural cycle of volatile weather or the more extreme global weather events are random, with no guarantee that they will be repeated or amplified in the foreseeable future. Consequently, further investment in mitigation is not justified. (In the case of Mangawhai, however, modest investment in mitigation has been underway for some time through the defensive work of the Mangawhai Harbour Restoration Trust on the spit).

Somewhere between these opposing views is the argument that while there may be a significant risk, it is easier to deal with this when and if an extreme event occurs. This stance defers expenditure on prevention even though it accepts the possibility of high costs by way of damage, loss, and recovery if expectations of more severe coastal inundation events prove correct.

Deferring spending may have merit if the risk is not perceived as high. However, the effect is to transfer the risk to future asset owners, the public sector, or insurers (which spreads but does not reduce costs). While delaying action may have legitimacy as a policy position, the consequences of being wrong should be transparent and open to change if the risk is seen to increase.

The question this raises is:

Should the community, through its agencies, invest in measures to deflect, defer, or mitigate the sorts of impacts indicated in this report?

Risk and Regret

To determine a course of action in the face of contrasting views, it is important to consider the risk of a wrong decision.

The option of responding proactively to the risk of increased inundation will call for early investment and almost certainly lead to changing public and private spending priorities.

The option of doing nothing minimises immediate outlays. Should significant flooding occur without mitigation, however, costs will be incurred, most likely over a very short period, albeit at a later but indeterminate date. The losses from damage to and destruction of properties, infrastructure, amenity, and the environment will be substantial. Major ecosystem damage or may be incurred within the marine and coastal environments. Significant cultural sites may disappear or be degraded. There is also the possibility that lives – as well as livelihoods – will be lost.

The policy question can be refined, then, to:

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18 Mangawhai Matters (2023) Mangawhai Harbour, Coast, And Community: The Sustainable Mangawhai Project Stage One Report, Section 4. Link here.

S***hould we incur moderate early costs to reduce the potentially very high costs from an event over which there is no certainty?***

Placing this in a risk-regret framework clarifies the trade-offs. Doing nothing exposes the community to possibility of "*maximum regret*" should damaging flooding occur with no or inadequate measures to mitigate it (Cell 3, Table 4). If, however, major floods do not occur, doing nothing incurs no costs (Cell 1).

The option of planning and investing in mitigation incurs early costs. If no major flood occurs within the planning horizon this expenditure could be deemed – by hindsight – unnecessary (Cell 2). Any regret from what might turn out to be unnecessary expenditure would be offset in part, at least, by the comfort of living with a heightened level of resilience in the meantime and the knowledge that it is still likely to be called for if sea level continues to rise in the long-term. Any signs of a global shift towards a high emissions scenario (as in SSP5-8.5) strengthen the argument for commitment to mitigation.

Table 3 The Risks and Regrets Behind the Policy Choice

	Policy Decision	
Coastal Inundation:	Do Nothing/ Minimum	Invest in Mitigation
Current Flood Levels	1 Minimum Regret	2 Moderate Regret
Flood Levels Increase	3 Maximum Regret	4 Minimum Regret

Assessing The Probability of More Severe Storms

There is a supplementary question. Does our current knowledge support a high enough probability of coastal inundation to justify moving ahead with a flood hazard management plan? There are several reasons to suggest that this is the case, including:

1. All scenarios see significant lifts in flood levels over the next 25 years, primarily in response to increased storm activity arising from current levels of atmospheric and oceanic warming.
2. The prospect is for increasing RSLR raising inundation levels in the middle of the century if global warming does is not moderate in the short term. [19]
3. Extreme cyclonic storms with low barometric pressures have been relatively uncommon off the Northland coast but are likely to be more frequent in the future.
4. Recent experience on the coast, especially since the 1990s, is consistent with this prognosis.
5. Any shift from a Middle of the Road to a Regional Rivalries development path brings the prospect of more damaging inundation forward. Accelerated warming would raise the likelihood of 2.5m storm tides well within 50 years (and 3m by the turn of the century).
6. The assumptions regarding seasonal elevation, freshwater retention, and wave setup used in the modelling are reasonable. They are grounded in historical storms, but potentially conservative under the more extreme wind and rain conditions anticipated in the future.
7. The bathtub model used to assess inundation prospects makes no provision for the cumulative erosive effect of a succession of storms, which, as 1978 demonstrated, is likely to increase vulnerability of the spit to over-wash or breach.[20]
8. The scenarios do not provide for the contribution to freshwater flooding from major storms other than through elevating harbour water levels. Direct flooding of low-lying the land through runoff will compound inundation from the sea in low lying areas.

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19 Recent evidence points to higher levels of sea level rise than previously projected. See, for example, James E. Hansen, et al. (2025) "Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed? *Environment: Science and Policy for Sustainable Development*, 67:1, 6-44,

20 Dickson (2025) suggests that such changes to spit morphology during a storm could also alleviate flooding, by accelerating drainage for example.

9. Degradation of the spit would lift the risk levels for assets surrounding the harbour. The Mangawhai Harbour Restoration Society has, since 1998, restored and maintained the spit in the face of strong storms. However, areas of vulnerability have been identified recently, particularly on the northern and eastern coasts of the spit, so that more intensive storms will challenge the current programme. Any loss of harbour protection by the spit is likely to expose the western and southern shores to increased erosion from wave setup and runup, increasing extent of inundation they might expect from even more modest 5 or 20-year ARI storms.

In summary, the studies described in this report point to an increase in the likelihood of storms of greater intensity than those that have in past impacted on Mangawhai, The threat they pose to existing property, services, and amenities are sufficient to justify investing in risk reduction and mitigation measures in a timely manner, thereby lowering the impact when floods do occur (Cell 4, Figure 10).

An Adaptive Planning Response

Adaptive planning is promoted as the way regional and local councils can work together to respond in a timely manner to the growing risk and severity of coastal inundation events. [21] It enables costs to be shared between responsible agencies and spread over a reasonable timeframe.

Adaptive planning requires an understanding of available policy actions, how they work, their costs, when they might be implemented, and by whom. To apply them effectively means first identifying a plausible adaptation pathway from the toolkit of management options available and then establishing a monitoring framework that provides thresholds to identify when to implement different measures.

Monitoring should be directed towards signs of increased risk. Indicators may include, globally, trends in oceanic warming and the amplitude and return time of El Nino-ENSO conditions; regionally, a continuing increase in the frequency and intensity of severe storms in the Southwest Pacific; and, locally, changes in the morphology of the spit and ocean and harbourside dunes and beaches. It also means identifying the consequences of storm events when they do occur, by way of tide and inundation levels, changes to beach and dune profiles, and impacts on and the capacity of local stormwater systems.

Assessing the Options: A Policy Toolbox

This section describes some of the policy tools that may be relevant to the threats that Mangawhai faces from coastal inundation. They are required to reduce the threats posed and enhance the capacity to recover from flood events. Measures to mitigate coastal inundation should complement measures to manage flooding from the land.

The tools available can be grouped into regulatory, soft and hard engineering, and infrastructure measures. Regulatory measures are perhaps the most readily implemented. They focus on avoidance and resilience and apply mainly to new development and construction. Engineering and infrastructure measures focus on protecting existing assets and activity from the impacts of inundation.

Regulatory Measures

Regulatory measures are intended to reduce exposure to the impacts of inundation. They apply to development and land management practices and rely heavily on zoning for implementation. They cover land use in and around vulnerable areas to limit exposure and in the wider catchment to reduce risk by managing runoff.

Regulation requires the development of rules to lower the impacts of coastal inundation by:

- Restricting development in high-risk areas;
- Requiring land use and stormwater management practices, especially on development sites, that limit or mitigate the impact of rapid runoff during and following high intensity rain events.
- Encouraging or requiring the raising or relocation of buildings from the most vulnerable areas.

[21] A detailed framework for adaptive planning for coastal hazards is set out in the MfE 2024 guidelines.

While rules applied to zones or structures are generally coercive, there may be a case for financial support for any that require existing property owners to take expensive measures to reduce exposure.

Soft Engineering Measures

Soft engineering measures work with natural systems, primarily to create barriers to flooding or buffers to reduce its impact, particularly around existing development.

It is already accepted that the most immediate need for Mangawhai is to protect the spit**.** This has been undertaken to good effect by the MHRS, mainly through dredging wind-blown sand from the harbour channel to the western side of the spit, building and maintaining the harbourside dune (the bund wall), and restoring or sustaining dunes by shelter fencing and planting.

With the evidence provided by the Dickson study of increased risk to the spit, a case has been made for moving sand from high to low points to raise vulnerable points on the coastline, to impede flow paths within the spit, and to reduce the potential for over-wash from the ocean side.

A programme of beach nourishment to the western side of the harbour may also be justified, to build defences against increased flooding in the vicinity of the reserves, roads, and adjoining structures.

As new initiatives, the extension and maintenance of wetlands and basins on the harbour edge could be undertaken to detain floodwaters from storm tides and catchment runoff. Sufficient area of wetlands can be expected to moderate their flow.

At the same time, maintenance of existing stormwater networks should ensure they retain sufficient capacity to handle peak flows arising from increased inundation extended over larger areas.

Soft engineering options offer the advantages of relatively low costs, ecological and aesthetic benefits, and extended public reserves. They do require ongoing maintenance, though, and may be subject to erosion in extended or frequent storms. In the most severe storms may provide a limited buffer only.

Hard Engineering Measures

Hard engineering solutions have the advantage of quick and targeted implementation, particularly in developed areas. Well-placed groynes can provide beach remediation by trapping and retaining sediment locally. Seawalls are used generally to protect properties from inundation from the harbour. They may need arrangements to prevent waters that do spill over them from undermining the land side, as well as flood gates to ensure they do not provide of flood entry points when sea levels do rise.

Hard solutions are expensive to build and may be locally disruptive to ecosystems. Seawalls require ongoing maintenance and if not integrated into adjoining landforms or designed to defend entire compartments at risk can damage adjoining areas. Consequently, the long-term and wider effects of hard solutions depend on their scope, the quality of design, taking into account local currents and wave action.

Infrastructure Measures

There are two sorts of infrastructure measure. The first overlaps with hard engineering and comprise mainly those that reduce the prospect of coastal flooding. The most obvious is an effective stormwater system that can detain and moderate high flows and does not risk intensifying run-off in vulnerable areas.

The second ensures that infrastructure is fit for purpose under flood conditions. Standards that reflect the heighted risk should be applied to new infrastructure and the resilience of existing networks reviewed with a view to progressive improvement through modified maintenance programmes if need be. The design of road or rail corridors close to the coast falls into this category and should ensure effective use of swales and drains, elevated carriageways, and culvert capacity in low lying areas.

Lifeline services - water and wastewater systems, communications, and power supply – also need to be reviewed to ensure they can withstand anticipated coastal flooding and so limit service failures, to provide access for emergency services, and promote rapid post-flood recovery.

The cost of achieving resilience across all elements of infrastructure will be high. This suggests the need for a medium term (10-20 year) programme of upgrading existing facilities and ensuring that design standards and associated regulatory measures promote the necessary resilience in new infrastructure.

Towards A Policy Framework

The relationships between vulnerabilities and policy measures are broadly indicated in Table 4. This sort of framework can be used to coordinate actions among the responsible agencies relative to areas most at risk, and to prioritise actions. Some measures may be more effective than others while differences in vulnerability may justify earlier attention in some areas than others. Such a framework should be developed cooperatively and in consultation with the community to clarify responsibilities, the timing of initiatives, and the links among the agencies required to achieve an integrated plan.

Table 4 Indicative Plan Framework

Category+C37:M4C37:M44	Regulatory - Avoidance			Engineering - Mitigation				Infrastructure - Defence		
Objective	Avoidance			Mitigation		Defence				
Implementation	Immediate		Medium-Term	Immediate		Medium Term			Medium-Long Term	
Measures Protection to::	Restrict Development - District Plan	Design Rules - Building Standards	Relocation & Lifting of Structures - Building Act	Preserve Natural Buffers - Spit	Preserve Natural Buffers - Wetlands	Raise Coastline	Seawalls & Groynes	Stormwater System	Raise Roads & Bridges	Upgrade Lifeline Services
Harbourside Reserves & Structures				X		X	X	X		X
Waterside Properties	X	X	X	X	X	X	X	X		X
Roads, Bridges, Causeways		X				X			X	X
Lieline Services		X							X	X
Back Bay-Molesworth (Part)	X				X			X		
Molesworth Drive (Causeway)						X			X	
Thelma Rd South	X	X	X		X					
Jack Boyd Drive, King/Cove Roads	X	X	X		X			X		X
Insley St Causeway & Black Swamp Rd							X		X	
Southern Shoreline (Holiday Park, Tern Pt)		X		X	X		X	X	X	
Southern Arm	X	X			X				X	

By way of illustration, and based on our analysis, the following priorities can be suggested.

1. **Advance measures to protect the spit**.

   Rationale: Loss of the integrity of the spit in part or whole will lead to a substantial downgrading of the recreational capacity of the harbour and loss of important wildlife habitat. If it is breached the western shore of the upper and mid harbour (including the southern coast) would be exposed to more extensive coastal inundation and damage from higher wave setup and runup.

2. **Address the regulatory requirements**

   Rationale: Areas in which development should be restricted or banned and the development and building standards on land less than , say, 4m above MSL, should be identified and subject to development, stormwater, and building conditions that avoid or lower the inundation risk. The regional and district plans and building regulations are the obvious channels for these initiatives.

3. Ensure that the existing **stormwater system is fit for purpose**.

   Rationale: Any failures will exacerbate and prolong local flooding, contribute to and accelerate freshwater flows into the harbour, and delay recovery. Two structural issues could be addressed: the capacity to cope with run-off from elevated areas to avoid overloading harbourside drainage and the capacity of the harbour edge network to detain and discharge under high sea level conditions.

4. More generally, identify and programme **hard engineering responses** for property and infrastructure at risk. This means assessing the consequences of coastal inundation for local public and private assets and setting those against the cost of engineering options for reducing the threats they face.
5. Identify opportunities and areas to **increase floodwater detention** capacity.
6. Prepare an **expanded road maintenance and development programme** to create a more resilient network, raising the causeways and carriageways in critical locations and ensuring that alternative routes are available in the event of a major storm.
7. Review the **resilience of lifeline services** and prepare a programme for improvement if required.

Conclusion

The increased probability of more serious coastal inundation than experienced in the most severe of past and the scale of damage that could result justifies a commitment to proactive planning. The mapping done for this study points to major impacts on property and infrastructure, and the undermining of the services to the community and the environment which the harbour and spit currently provide.

Whatever form it takes, planning is not just about recognising the long-term effects of rising sea levels. It is about preparing for a near future in which storms will become more severe and increasingly damaging. Consequently, it should, among other things, address the likely need for soft and hard engineering initiatives, ensure that the stormwater system is fit for purpose in the event of widespread flooding, and ensure that infrastructure is sufficiently resilient to enable a quick recovery from any such event.

Appendix One: Are Cyclonic Storms Intensifying?

In Short

This appendix considers the prospect of more severe storms impacting on Mangawhai. It considers, first, the scientific literature and, second, the record of tropical storms off the Northland coast.

Evidence from the literature suggests:

- Cyclones generally will be less frequent;
- Extreme cyclones, however, will be more common so that the intensity of storms that do occur will be greater, with higher wind speed, storm surge, and precipitation, and wider geographic coverage;
- Cyclonic storms are migrating south from the subtropics towards mid-latitudes;

The evidence from 75 storms tracking within 500km of Northland since 1955, reported below, is consistent with those findings. Frequency has not been noticeably increasing, but a greater share of storms since 1988 can be classified as major with evidence of increasing wind speeds. The more intense effects of extreme storms are reduced off Northland, dissipating over cooler waters. However, continued warming of the oceans north and east of Northland and their poleward migration is expected to lead to future storms having a greater impact than those experienced in the past.

The Issue

Tropical cyclones are intense circular storms that form over warm tropical waters. They are marked by low atmospheric pressure, winds exceeding 64knots (118 kph), and heavy rain. They are classified by hurricane categories according to wind speed and destructive potential (Table A1). Those recording speeds between 64 and 82 knots (119-153 km/hour), for example, are classified H1 (Table A1). Storms at the upper end of the scale (H3, H4, and H5) are the most destructive ("major storms").

Table A1: Saffir-Simpson Hurricane Wind Scale

Category	Wind*	
H1	64-82 kt 119-153 km/h	Very dangerous winds produce some damage: Large branches of trees will snap and shallowly rooted trees may be toppled. Roof damage to homes
H2	83-95 kt 154-177 km/h	Extremely dangerous winds cause extensive damage: Well-constructed could sustain major roof and wall damage. Shallowly rooted trees will be snapped or uprooted.
H3	96-112 kt 178-208 km/h	Devastating damage: Well-built framed homes may incur major damage, loss of roofs. Trees will be snapped or uprooted. Electricity and water lost for several days to weeks after the storm passes.
H4	113-136kt 209-251 km/h	Catastrophic damage will occur: Well-built homes sustain severe damage with lost roof structure and/or some exterior walls. Most trees snapped or uprooted, power poles downed.
H5	137+kt 252+ km/h	Catastrophic damage: A high percentage of homes destroyed, Fallen trees and power poles isolate residential areas.

At the other end of the scale, sitting outside the hurricane category, are Tropical Storms and Tropical Depressions. The former is a weaker form of a tropical cyclone, with sustained winds between 34 and 64knots (63–118 km/h). Tropical depressions are weaker again, although with winds around 34 knots (approaching gale force). Both can still bring significant rainfall although lack the intensity of a full-fledged cyclone. Northland, between latitudes 34^{o} and 36^{o} south, experiences cyclones mainly as tropical storms as they dissipate over the cooler waters.

The question considered in this appendix is whether cyclonic or ex-cyclonic storms are likely to become more common and more intense off Northland's East Coast.

What Does the Literature Tell Us?

While the prospect for SLR on low-lying settlements has been reported widely, there appears to be less focus on the character of the storms as affected by changing sea temperatures. The studies consulted for this review, however, highlight the increasing intensity of tropical storms and their migration towards mid-latitudes. Modelling by Chang, for example, show increased frequency of extreme cyclones in the southern Indian and Pacific oceans. [22] These are what pose the most serious challenge to Mangawhai over the next fifty to sixty years.

Priestley and Cato (2022) used updated models to project storm tracks and wind speeds in mid-latitude regions across four scenarios[23]. Their modelling shows the number of cyclones falling slightly (by around 5%), although extreme storms are becoming more common. More storms are expected to exceed past intensity thresholds. Their models also show storm tracks shifting polewards, strengthening mid-latitude wind speeds.

In addition, they found that the areas covered by high storm winds could increase by up to 40% by the end of the century, widening their spatial impact. Extreme cyclones will experience larger increases in wind speed than average cyclones and propagate more rapidly. The authors suggest that such outcomes can be mitigated if warming follows SSP2-4.5. The area of extreme winds would still be expected to increase but by less than half of what can be expected under SSP3-7.0 or SSP5-8.5.

These findings are supported by a range of other studies[24], reinforcing the finding that tropical storms are migrating towards higher latitudes, a tendency expected to increase in the Southern Hemisphere. It has been most apparent over the past five decades in the southern Indian Ocean and, significantly for New Zealand, the Solomon Sea and northern Coral and Tasman seas[25].

The prospect of more severe and far-reaching tropical storms forming in those seas lifts the probability of more intensive storms passing close to Northland despite rates of oceanic warming off the east coast lower than elsewhere.

The inference is that while cyclones generally may be less frequent, there will be more in the extreme categories tracking south and southeast across Northland or off the east coast. These can be expected to bring stronger winds and waves, with increased sea surge as a result, and heavy rain.

What Does the Record Show?

To cast some light on this prospect, tropical storms recorded since the 1950s by the National Hurricane Centre and Central Pacific Hurricane Centre of the NOAA[26] have been analysed. The NOAA website provides storms by category and name, lowest central pressure, and highest wind speed. Tracks are

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22 Chang E.K.M. (2017) "Projected Significant Increase in the Number of Extreme Extratropical Cyclones in the Southern Hemisphere" *Journal of Climate*, 30, 4915 – 4935

23 Priestley, M.D.K. and. Catto, J.L. (2022) "Future changes in the extratropical storm tracks and cyclone intensity, wind speed, and structure" *Weather and Climate Dynamics*, European Geosciences Union, 3, 1,337-360

24 For example:
NASA Science editorial Team (2020) *How Climate Change May Be Impacting Storms Over Earth's Tropical Oceans* **(**Link here)
IPCC (2022) Special Report on the Ocean and Cryosphere in a Changing Climate (Link here)
Gilford D.M., Giguere J. and Pershing A.J., (2024) "Human-caused ocean warming has intensified recent hurricanes", *Environment Research: Climate* 3 (Link here)
Kossin, J. P., Emanuel, K. A., & Vecchi, G. A. (2014). "The poleward migration of the location of tropical cyclone maximum intensity" *Nature*, 509(7500), 349–352 (Link here)

25 Statistics New Zealand (2025) Sea Surface temperature: Data to 2023 (Link here)
Bureau of Meteorology (2025) Oceans: Sea Temperatures, State of the Climate 2024 (Link here)
Trenberth K.E., Lijing Cheng, Yuying Pan, Fasullo J, Mayer M.(2025) "Distinctive Pattern of Global Warming in Ocean Heat Content" American Meteorological Society Online Article (Link here)
Radio NZ News (2025) "Ocean near New Zealand warming faster than anywhere else, study finds (Link here)

26 Click here: National Oceanic and Atmospheric Administration

plotted at six hourly intervals over the life of the storm, enabling estimates of their duration and reach. They do not provide storm surge or rain data.

The present analysis focuses on tropical and ex-tropical storms likely to give rise to strong onshore winds, storm surge, high surf, and heavy rainfall on Northland's east coast. [27] Data was extracted initially for 75 such storms tracking within around 500km of Northland.[28] The majority were, or had downgraded into, Tropical Storms by the time that reached the seas off Northland (35%, Table A2[29]). Thirteen fell into categories, H4 and H5, with extreme low pressures and very high winds. Another nine fell into H3, a "major" storm category. (Table A2).

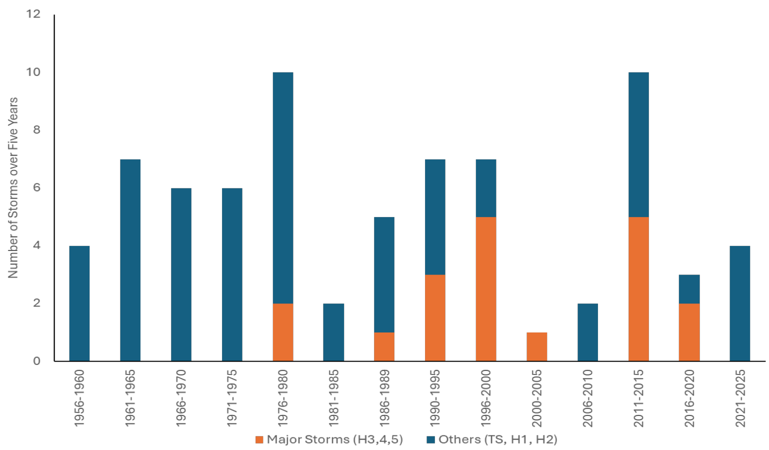
Table A2: Topical Storms Tracking Within 500km of Northland, 1956 to 2025

	Storms			Averages	
	Number	Share	Wind, Knots	Lowest Pressure	Duration Days
H5	3	4%	140	939	11
H4	7	9%	117	958	8
H3	9	12%	91	971	14
H2	13	17%	88	968	5
H1	17	23%	71	975	10
TS	26	35%	48	990	7
	75	100%	93	967	9

Source: National Hurricane Centre, National Oceanic and Atmospheric Administration

When placed in sequence, from the 1950s to the 2020s, there is no obvious evidence of an increase in storm frequency (Figure A1). However, there was an increase in the number in the major categories since the 1990s. Of 41 storms from 1956 to 1988 (1.3/year), three were classified major storms. Of 34 storms since then (1.0/year), 16 (47%) were H3, 4, or 5. This is consistent with the findings of Diamond and others, which found a "statistically significant greater frequency of major TCs was found [in the South Pacific] during the latter half of the study period [1991–2010] compared to 1970–90 period".[30]

Figure A1: Incidence of Tropical Storms within 500km of Northland, Five-Year Periods, 1955-1925



27 Low and mid latitude winter storms tend to travel from southwest to northeast, impacting more on New Zealand's southern and western coasts than the northern and eastern coasts. Cyclone Giselle in April 1968 wreaked havoc in the when it "collided" with a fast-moving frontal storm in the southern North Island (the "Wahine storm").

28 Storms were assigned to distance bands based on low-resolution, large-scale plots on the NOAA website.

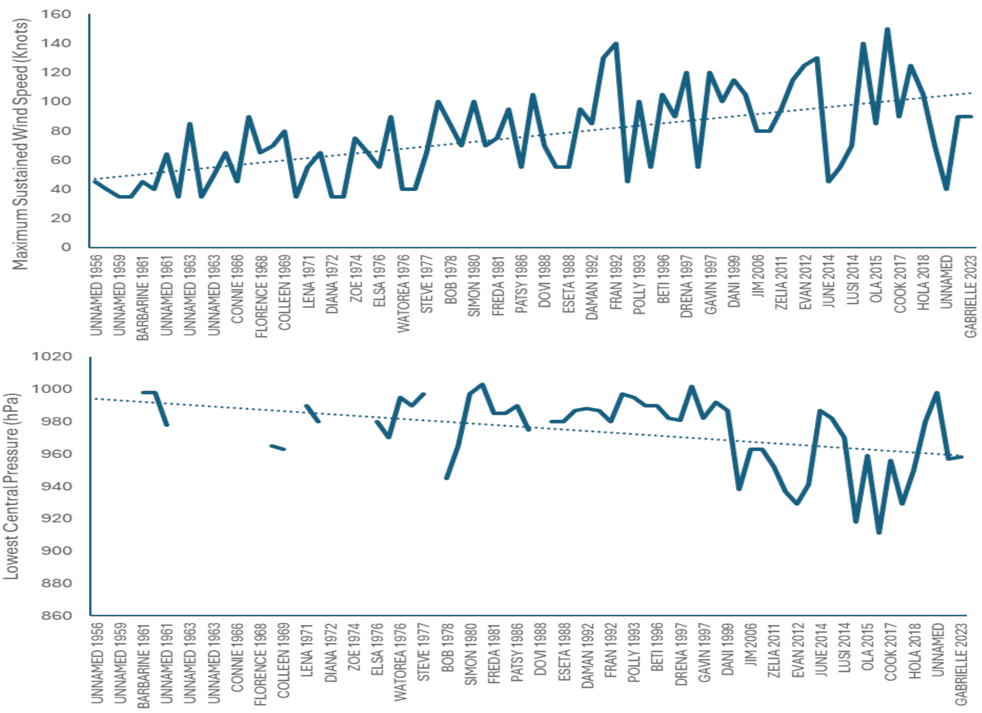
29 Tropical depressions have not been included

30 Diamond H.J., Lorrey A.M., Renwick J.A. (2013) "A Southwest Pacific Tropical Cyclone Climatology and Linkages to the El Nino–Southern Oscillation", *Journal of Climate*, 26, 1, 3-25

Source: National Hurricane Centre, National Oceanic and Atmospheric Administration

There has been an upward trend in maximum recorded wind speeds and a downward trend in central pressure (Figure A2), although both are subject to significant inter-storm variability. Evidence suggesting a downward trend in pressure is further qualified by gaps in observations. While the conclusions in both cases are tentative, the broad trends are consistent with the observations elsewhere and the predictions of the climate models.[31] On these grounds, it can be concluded that it is reasonable to assume that a long-term increase in maximum wind velocities is likely, especially given the expectation of more extreme storms.

Figure A2: Trends in Wind Speed and Central Pressure



Against this expectation, storms paths were reviewed but as far as could be determined, showed no evidence of a systematic increase in their southern reach that would reveal progressive migration towards higher latitudes to date.

Of the 75 identified approaching within 500km of Northland since 1955, 40 storms (53%) tracked across or east of the east coast; seven approached from the north but dissipated before or at around 35°S, while the balance (28 or 37%) tracked down the west coast (Table A3).

31 The series are not strictly linear. Improved, if still modest, explanation is achieved with 4th order polynomials, suggesting a degree of cyclicity which would further obscure trends. Given the weak relationships the "best" projection may be a continuation of modest linear trends.

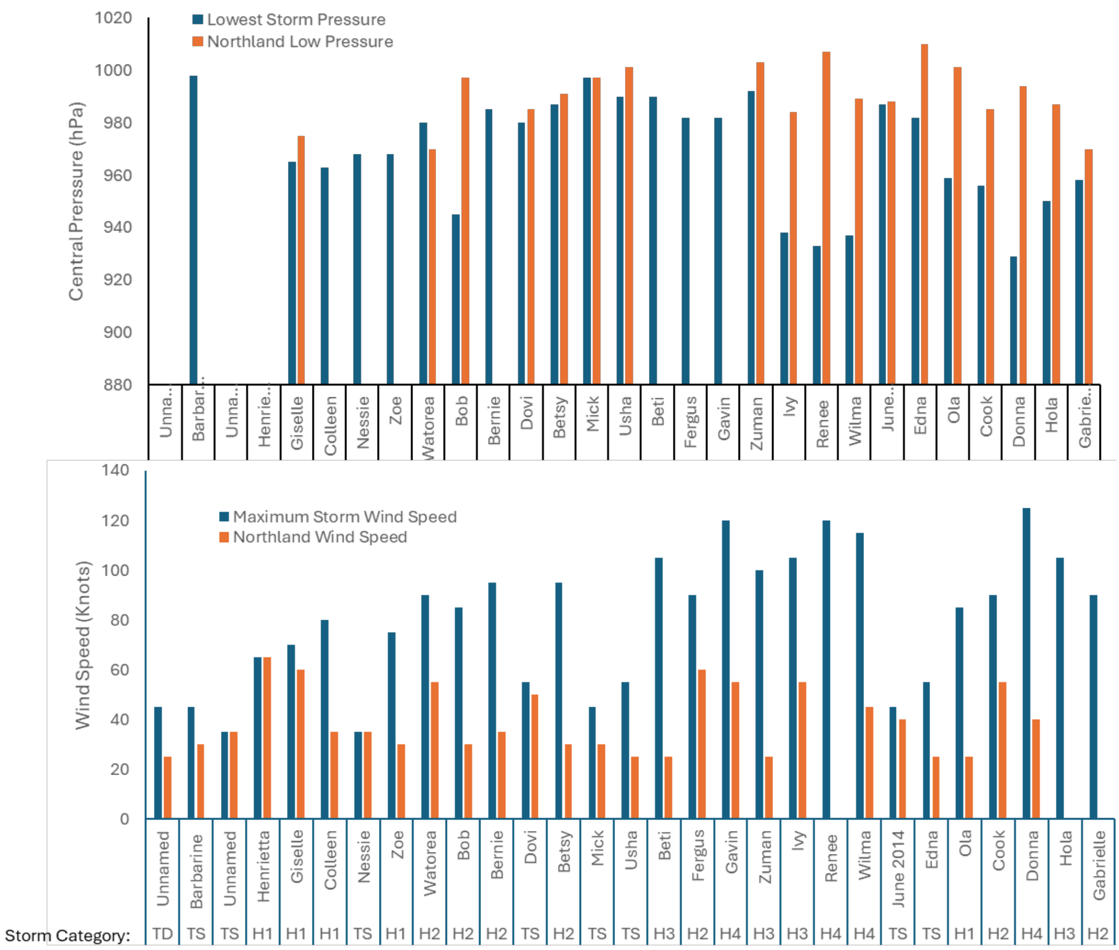
Table A3: Tropical Storms, 1955 t0 2025

Tracking relative to Northland:	Storms		Averages	
	Number	Shares	Knots	hPa
East	40	53%	75	977
West	28	37%	76	973
North	7	9%	76	970
Total	75	100%	77	974

Source: National Hurricane Centre, National Oceanic and Atmospheric Administration

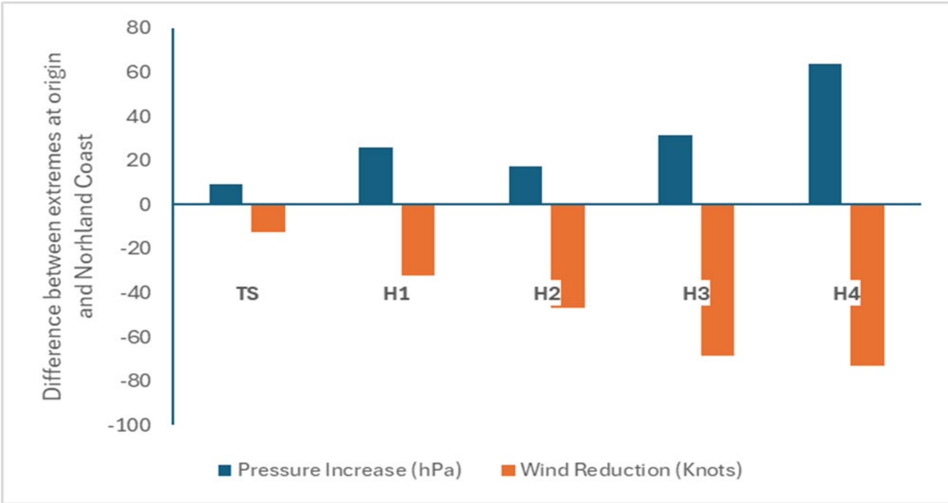
Twenty-nine of the eastern storms were within 400km of the coast and have been further analysed. Their maximum recorded wind speeds and minimum central pressures have been compared with the levels – where recorded - off the nearest point on the east coast. Even with limited data, the dissipation of storms by the time they reach Northland is clear (Figure A3). On average, the central pressure was 26hPa higher off Northland and wind speed 38 knots (43%) lower than maximum recorded.

Figure A3: Central Pressure and Storm Wind off the Northland Coast, 1955-2023



Grouping storms by shows the increased pressure and reduced wind speeds as they approach Northland (Figure A5), with loss of wind velocity and gains in pressure greater for more intensive storms (Figure A4).

Figure A4:Deviations in Storm Pressure and Wind Speed by Storm Type



It can be concluded that that the temperature gradient from the warm waters of the Coral and Solomon seas through to cooler north and east of New Zealand has a significant effect on storm intensity. An inference is that Northland is not yet experiencing the impacts of the tendency for storms to migrate polewards. If, the propensity of extreme storms to migrate further south is realised, or if the seas northeast of New Zealand show an increase in thermal heating (in much the same way as the Tasman Sea has done to the west),[32] past storms are unlikely to be a sufficient guide to the possible intensity of future storms.

Conclusion

This exploratory analysis indicates that the frequency of cyclonic storms may be falling in the areas in which they originate northwest of New Zealand, but that more of them are major or severe storms and a greater share is likely to traverse Northland waters over time. The literature, the prospect of continued thermal ocean warming, and the record of cyclonic storms off the Northland coast points to more intensive storms than experienced in the past will impact on Mangawhai within the next twenty to thirty years – or sooner - and that their impacts will be amplified over time by sea levels projected to continue rising for at least the next fifty years.

32 World Meteorological Organization (2024) *State of the Climate in the South-West Pacific 2024,* WMO 1364, Geneva