

# Extreme Weather on the Northland Coast

## The Implications for Mangawhai



### **Sustainable Mangawhai: Protecting our Environment, Sustaining our Community**

Mangawhai Matters is a community group committed to maintaining the qualities of Mangawhai. The Sustainable Mangawhai Project demonstrates the risks to the harbour and distal spit of damaging storms associated with global warming and the consequences for the environment and community. The Project provided the impetus for the establishment of the Mangawhai Harbour Working Group which advocates for the health and functionality of the harbour and comprises representatives of the responsible agencies.

It is hoped that this report helps the Committee to align defensive and mitigation initiatives with the significant risk that the threat of severe storms poses for the harbour and the environment and community that environment depend on it.

## **EXTREME WEATHER ON THE NORTHLAND COAST**

### **THE IMPLICATIONS FOR MANGAWHAI**

Report prepared by Philip McDermott.

AI assistance (Claude, Anthropic) was used in report preparation, including sourcing and data analysis.

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## Preface

The Sustainable Mangawhai Project identified the risks to Mangawhai from coastal inundation under extreme storm conditions. Ex-tropical Cyclone Gabrielle is a recent example of such conditions, with coastal waters elevated close to 2 m. Fortunately, peak inundation did not coincide with high tide in that case.

However, in the future a storm of Gabrielle's intensity on a king tide, or persisting for longer, could easily see inundation 2m above the high tide mark — particularly if heavy rain in the catchment also raises harbour water levels. The resulting flooding would damage private property and public infrastructure around harbour.

Inundation would be even more damaging if there were a breach in the sandspit that shapes and protects the harbour, leading to higher ocean surge and wave damage on its currently sheltered coastline.

The current report complements and builds on the analyses prepared in the course of Mangawhai Matters' *Sustainable Mangawhai Project*, as reported on our website. This indicates that continuing ocean warming will result in greater storm intensity. The long-term risk of "more Gabrielles", or worse, will increase further with sea level rise, which will raise the baseline on which floods build.

To better understand this risk, a comprehensive database of tropical and ex-tropical storms passing within 200 km of Northland since 1960 was assembled from multiple sources with the assistance of AI (Claude). Close analysis of these major storms reinforces and extends our earlier findings. They unpack the conditions that favour storms of different intensity and summarise likely regional impacts.

Most importantly, the analysis provides a clear picture of the probability of damaging storm-driven inundation within the next three decades to inform the adaptive planning required to minimise its impacts.

**The conclusions are compelling.** They reinforce the call for immediate, coordinated action by the agencies responsible for the integrity of the harbour and the well-being of the community. They show that protecting the spit, upgrading stormwater capacity, restricting development in high-risk zones, and assessing vulnerable infrastructure are not precautions against remote possibilities — they are responses to risks that already carry a meaningful probability of occurring within the planning lifetimes of decisions being made today.

**The case is straightforward:** investing in resilience now spreads costs across agencies and time, while waiting concentrates them at the worst possible moment. The cost of mitigation is a fraction of the cost of remediation, assuming it is possible.

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## Executive Summary

Analysis of 20 tropical and ex-tropical storms tracking within 200 km of the Northland coast since 1960 produces the following key findings.

### Storm frequency and intensity

- **Event frequency has accelerated markedly.** Five direct-impact events struck Northland in the five years 2022–2026 — the most compressed run in the 58-year record, with a mean inter-event gap of approximately one year compared with 3.1 years across the full record.
- The three most recent events — *Gabrielle (2023)*, *Tam (2025)* and *Vaianu (2026)* — were classified as subtropical or hybrid systems, retaining more moisture than classical extratropical remnants. This is consistent with climate projections suggesting that warming sea surfaces enable systems to maintain tropical-like organisation to higher latitudes.
- **Season clustering is a significant risk multiplier.** Four seasons in the record produced two named systems within weeks of each other; cumulative impacts across paired events are often more damaging than either storm alone.

### Track, coast, and hazard type

- **The key determinant of storm surge and wave exposure is the storm's track, not its peak tropical intensity.** East coast tracks (55% of events) are flood-dominant, driven by orographic rainfall – the heavy rain experienced on the windward side of the coastal ranges - and wave set-up from unlimited Pacific fetch. West coast tracks are wind-dominant. Despite nearly identical mean severity, east coast tracks have produced three Major events and west coast tracks just one.
- **On the open east coast, wave set-up is the primary hazard.** With significant wave heights of 6–12 m during major events, wave set-up contributions of 0.6–2.4 m are physically plausible — much greater than the combined elevation associated with wind and pressure surge of 0.3–0.7 m. Harbours and estuaries are more surge-dominated as waves are attenuated by refraction.
- **Northland's northeast coast is normally a low-energy lee shore** (ambient waves 0.5–1.5 m). Coastal infrastructure calibrated for this low-energy baseline experiences disproportionate damage when cyclone waves of 6–12 m arrive.
- **Tidal phasing is a critical risk multiplier.** The difference between a surge at low tide and at spring high tide is 1.6–1.8 m. A moderate surge coinciding with a spring high can produce a record coastal water level.

### ENSO and seasonal patterns

- **La Niña is the highest-risk ENSO phase<sup>1</sup>.** Forty-three percent of La Niña events reach Major severity, versus 33% for El Niño and 20% for Neutral. All three of Northland's most damaging events — *Bola (1988)*, *Wilma (2011)* and *Gabrielle (2023)* — occurred under La Niña conditions.
- **April is the most active month** (35% of events), driven by extratropical interactions with mid-latitude troughs. However, all six Major-rated events occurred in the November–March peak tropical season. April brings frequency; the summer season carries the catastrophic potential.

### Infrastructure and recurring vulnerabilities

- **A small number of locations recur in the damage record:** the Brynderwyn Hills/SH1, Kaeo, the Bay of Islands moorings, Pipiwai, and the North Auckland railway. The geography of cyclone damage is predictable even when its timing is not.
- Northland's direct mortality from cyclones is remarkably low: one confirmed death in 58 years, reflecting improved early warning and community preparedness. Rising event frequency increases cumulative exposure.

<sup>1</sup> ENSO (El Niño Southern Oscillation) describes the linked oceanic-atmospheric conditions in the Pacific that fluctuate over a two-to-seven-year cycle. The three phases (La Niña, El Niño, and Neutral) are associated with different prevailing weather conditions.

**Note** – technical phrases and acronyms are explained in the Glossary

## Coastal inundation probabilities

The analysis enables estimation of the probability of the inundation impacts documented by the Sustainable Mangawhai Project. Three water-level thresholds were assessed.

- **The 2.0 m inundation threshold is a near-term risk, not a distant scenario.** Under current climate conditions and without increase in storm intensity, a 2.0 m harbour inundation event has an 18–28% probability of occurring in the first decade (2025–2035) and a 33–49% probability within two decades.
- **The 2.5 m threshold is a credible prospect within 30 years.** Under the Middle of the Road scenario (SSP2-4.5), a 2.5 m event has a 14–26% probability within three decades. Under SSP3-7.0, the three-decade probability rises to 26–46%. By 2060 under higher-emissions pathways, 2.5 m becomes a near-routine extreme event with a probability above 50% per decade.
- **Events above 2.5 m are not a near-term planning scenario under present conditions,** but become credible within 30 years under higher-emissions pathways. The more immediate risk is the non-linear cascade: a 2.0 m event — with an 18–28% probability in the first decade — could trigger spit damage that structurally elevates all subsequent inundation levels.

Storm intensity trends documented since 1988 suggest these statistical probabilities should be treated as conservative lower bounds. The findings reinforce the case for planning to commence immediately under moderate to high emissions pathways.

# 1. Introduction

## 1.1 Purpose and Scope

This report compiles and analyses all named tropical and ex-tropical cyclones recorded as having significant impact on the Northland coast from 1968 to May 2026. The focus is on major storms tracking within 200 km of Northland which is more focused than the assessment of 75 cyclonic storms recorded within 500 km in the earlier Sustainable Mangawhai Project report.<sup>2</sup> The aim is to refine our understanding of the level of risk we might attach to the prospect of similar or more severe storms in the foreseeable future. For this purpose, we adopt a thirty year time horizon.

Northland is the region of New Zealand most frequently reached by tropical cyclone remnants, projecting 350 km further toward the subtropics than the rest of the country. Understanding the frequency, character, and drivers of these events has direct implications for regional emergency management, infrastructure resilience, and long-term climate adaptation.

The catalogue covers 20 direct-impact events beginning with Cyclone Giselle in April 1968 — the start of the reliable satellite-era record for the South Pacific (Table 1). A detailed description of each storm is contained for look-up purposes in the Addendum to this report.

## 1.1 Data Reliability

Data on the twenty storms has been assembled from multiple sources (Appendix One)<sup>3</sup>. Several caveats apply.

- **Sample size.** The 20 events across 58 years are sufficient to identify patterns and tendencies, but too small for robust multi-variable statistical inference. All findings should be read as indicative.
- **Recording improvements.** Northland-specific impacts of events in the 1970s and 1980s are likely to be underreported. More recent events have benefited from more comprehensive media, council, and scientific documentation, which may partly explain the apparent increase in frequency and severity documented in recent years.
- **Intensity data gaps.** Pressure and wind speed data are incomplete for several events, particularly older extratropical-phase observations. Missing data is concentrated in older and less severe events.
- **Fergus gust outlier.** A 400+ km/h Northland gust entry for Fergus 1996 reflects an extreme anemometer reading rather than a representative wind speed and is excluded from analysis.
- **ENSO phase classification.** Season-level classification may not capture the precise ENSO state at the time of storm formation and tracking. The 1997 storms during the transitional phase of the 1997–98 El Niño illustrate this limitation.
- **Northland offshore pressure.** Pressure readings at or near the coast during storm passage are rarely recorded for historical events. Many values are estimates derived from adjacent station or ship reports.

As described in Appendix Two, the severity scale used in this report goes beyond the normal storm categorisation<sup>4</sup> is a subjective composite based on wind intensity, rainfall and flooding, and disruptions experienced in Northland. It is an ordinal measure — used for ranking storms relative to each other — not a cardinal one.<sup>5</sup>

<sup>2</sup> P. McDermott and T. Hume (2025) The Coastal Inundation Risks Facing Mangawhai, Mangawhai Matters Inc.

<sup>3</sup> A more detailed catalogue of storm characteristics is available on request.

<sup>4</sup> Saffir-Simpson Hurricane Scale. See McDermott and Hume Appendix One

<sup>5</sup> The grounds for these scores are set out in Appendix Two.

**Table 1: Northland cyclone catalogue 1968–2026.**

Storm	Dates (NZ)	ENSO Phase	Coast	Peak Cat.	Peak P (hPa)	NL Gust (km/h)	Dur. (days)	NL Days	Severity
<b>Giselle</b>	9–10 Apr '68	Neutral	East	Cat 1 / ExTC	965	130+	8	2	<b>MAJOR</b>
<b>Alison</b>	11 Mar '75	La Niña	West	Cat 4	933	130	9	1	<b>SIGNIFICANT</b>
<b>Hal</b>	18–19 Apr '78	Neutral	West	Cat 1	985	130	17	2	<b>MODERATE</b>
<b>Sina</b>	15–16 Mar '80	Neutral	East	Cat 3	970	120	5	2	<b>MODERATE</b>
<b>Bernie</b>	9 Apr '82	El Niño	East	Cat 4	960	140	13	1	<b>SIGNIFICANT</b>
<b>Bola</b>	6–10 Mar '88	La Niña	N/Bot h	Cat 3–4	~945	—	18	4	<b>MAJOR</b>
<b>Eseta</b>	28–30 Dec '88	La Niña	West	Cat 2	978	90	7	2	<b>MODERATE</b>
<b>Daman</b>	21 Feb 1992	Neutral	East	Cat 3	965	205	8	1	<b>MODERATE</b>
<b>Fergus</b>	30 Dec 1996	Neutral	East	Cat 3	—	—	9	1	<b>MAJOR</b>
<b>Drena</b>	10–11 Jan 97	El Niño (dev.)	West	Cat 3–4	—	160	10	2	<b>MAJOR</b>
<b>Gavin</b>	11–13 Mar 97	El Niño	East	Cat 4+	~920	130	9	2	<b>MODERATE</b>
<b>Ivy</b>	28 Feb Mar '04	Neutral	East	Cat 4	935	100	10	2	<b>MODERATE</b>
<b>Wilma</b>	28–29 Jan '11	La Niña	East	Cat 4 / TC	930	130	11	2	<b>MAJOR</b>
<b>Debbie</b>	3–6 Apr 2017	Neutral	Both	ExTC remnants	—	—	—	3	<b>MODERATE</b>
<b>Cook</b>	12–14 Apr 2017	Neutral	East	Cat 3	~940	—	9	2	<b>MODERATE</b>
<b>Dovi</b>	12–13 Feb '22	La Niña	East	Cat 4	~955	144	9	2	<b>SIGNIFICANT</b>
<b>Hale</b>	10–11 Jan '23	La Niña	East	Cat 1	984	128	5	2	<b>SIGNIFICANT</b>
<b>Gabrielle</b>	12–17 Feb '23	La Niña-Neutral	Both	Cat 3 / Subtropical	~960	—	11	5	<b>MAJOR</b>
<b>Tam</b>	16–20 Apr '25	Neutral	West	Cat 1 / Subtropical	988	151	8	4	<b>SIGNIFICANT</b>
<b>Vaianu</b>	10–13 Apr '26	Neutral	Both	Cat 2–3 / Subtropical	—	~140	9	4	<b>SIGNIFICANT</b>

*Peak Cat.* = maximum intensity category reached during the storm's full tropical life. *Peak P* = lowest central pressure (hPa). *NL Gust* = maximum recorded or estimated wind gust in or near Northland. *Dur.* = total named storm duration. *NL Days* = days of influence on the Northland coast.

**ENSO shading:** blue = La Niña; yellow = El Niño; grey = Neutral.

**Severity:** red = Major; orange = Significant; yellow = Moderate.

## 2. How Cyclones Affect Sea and Harbour Water Levels

This section introduces the dynamics of cyclonic storms with particular reference to their impacts on Northland. It draws on the cyclone database (Table 1), NRC coastal flood hazard assessments (Tonkin & Taylor 2016, 2017, 2021), NIWA storm surge and wave research, MetService event summaries, and coastal oceanographic literature. Where event-specific measurements exist in public sources they are cited; where they do not, estimates are derived from the data available. This assessment supplements, and does not replace, the NRC Coastal Flood Hazard Zone reports as the authoritative quantitative reference for site-specific planning.

### 2.1 Physical Framework: Components of Coastal Water Level

The total coastal water level during a cyclone is the sum of four components. Understanding each separately is essential because their relative importance varies between open coast and harbour settings.

**Astronomical tide.** This is the background tidal oscillation, predictable in advance and independent of the storm. On the Northland east coast, spring tidal range is approximately 1.6–1.8 m at Marsden Point — modest by New Zealand standards, which means storm surge and wave effects represent a proportionally larger fraction of total extreme water level than on the west coast.

**Inverse barometer effect (pressure surge).** Each hectopascal of central pressure below the ambient norm of 1013 hPa raises sea level by approximately 10 mm. This takes the form of a long wave ahead of the storm and is felt before the circulation arrives at the coast. Theoretical contributions range from ~0.29 m (Hale 2023, 984 hPa) to ~0.68 m (Bola 1988, ~945 hPa). However, a simple pressure-to-surge relationship is inadequate for Northland east coast risk assessment: the same pressure deficit produces very different outcomes depending on track proximity, storm speed, shelf geometry, and tidal phasing.

**Wind set-up.** Sustained onshore winds pile water against the coast in the downwind direction. On the Northland east coast, the fetch for northeasterly winds is the open Pacific — effectively unlimited from the Coral Sea and South Pacific. MetService's decomposition of the Wilma (2011) storm tide at Auckland recorded wind set-up of 449 mm — the single largest component of the total storm tide at that location. Inside harbours such as the Bay of Islands and Whangarei Harbour, funnel-shaped geometry further amplifies wind set-up.

**Wave set-up (dominant on the open coast).** When large waves break on a shoaling coast, momentum transfer raises mean water level inside the surf zone — typically 10–20% of the significant offshore wave height. With significant wave heights of 6–12 m reported during major events (Gabrielle 2023, Vaianu 2026), wave set-up contributions of 0.6–2.4 m are physically plausible on exposed open coasts. Critically, wave set-up is not captured by tide gauges, which are located in sheltered harbour positions, and tends to be underestimated in assessments relying only on tide gauge data. The NRC Coastal Flood Hazard Zone assessments (T+T 2021) assess wave set-up separately using a SWAN numerical wave model.

### 2.2 Track Geometry and East Coast Exposure

In the Southern Hemisphere, winds circulate clockwise around a low-pressure centre. For a cyclone or extratropical low tracking southward, the eastern (left-of-track) semicircle carries the most intense winds and the most pronounced onshore component toward the Northland east coast — the "dangerous semicircle".

East coast track events place Northland's east coast inside this dangerous sector: northeasterly to easterly onshore winds with unlimited Pacific fetch generate the largest wind set-up and wave heights. This configuration is responsible for all six Major-rated events in the catalogue. West coast track events place the east coast in the navigable semicircle — winds are offshore or cross-shore rather than onshore — and all five west coast track events are characterised by wind damage rather than coastal flooding. Track geometry, as discussed in Section 5, is the primary determinant of coastal water level risk, not peak tropical intensity.

### 2.3 The Low Baseline Wave Energy Amplification Effect

Under normal conditions, Northland's north and northeast coast is classified as a low-energy lee shore, sheltered from Southern Ocean swell. Prevailing ambient waves are 0.5–1.5 m at 5–7 second period. When a northeast-tracking cyclone brings its dangerous sector over the east coast, wave heights jump from this background to 6–12 m. Coastal and estuarine infrastructure calibrated for a low-energy regime experiences disproportionate damage relative to what the same wave conditions would produce on a high-energy coast.

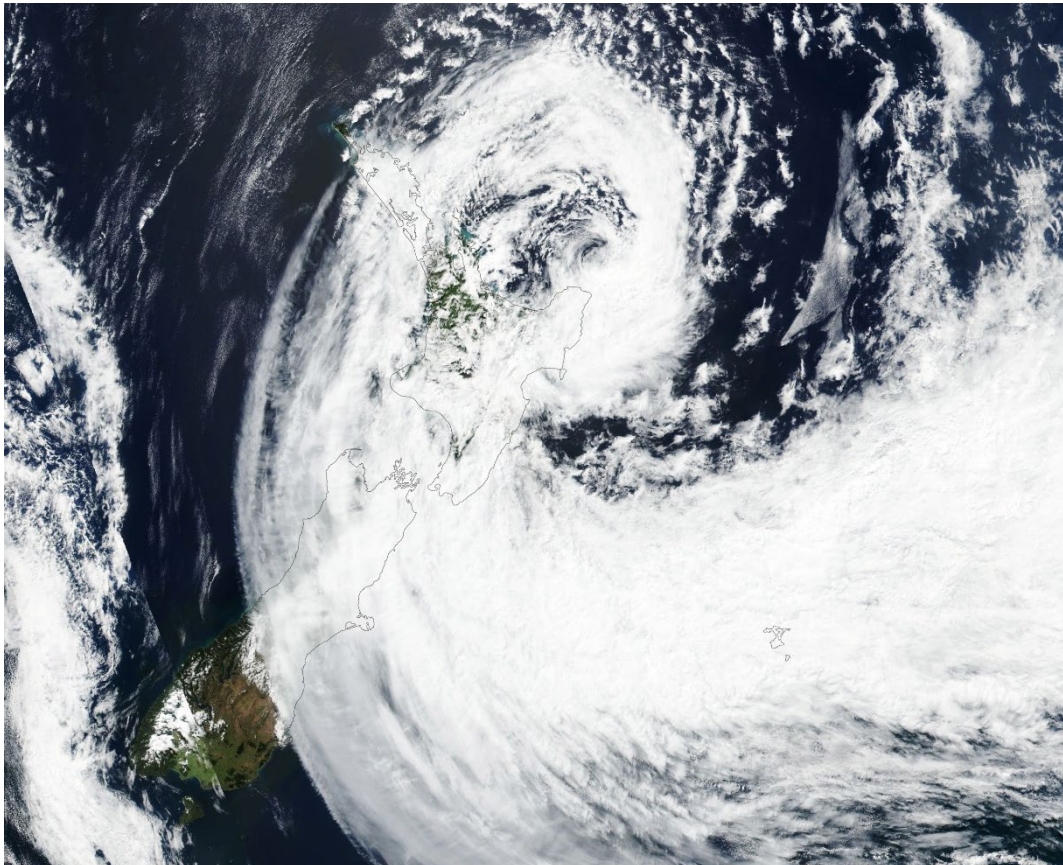
This amplification effect explains why Northland east coast events produce extensive damage despite the region not normally being associated with high wave energy.

## 2.4 Tidal Phasing as a Critical Risk Multiplier

For New Zealand generally, most extreme storm-tide events are driven by moderate surges of 0.3–0.5 m coinciding with high perigean-spring tides, rather than by extreme surges alone. On the Northland east coast, where the spring tidal range is approximately 1.6–1.8 m, the difference between a surge at low tide versus perigean spring high tide can be 1.6–1.8 m — an enormous difference for the many low-lying foreshore communities along the coast (Paihia, Russell, Mangawhai, Kaeo river mouth). Checking the tidal state at the expected time of maximum surge is as important as assessing storm intensity for any individual event. The Vaianu (2026) event was specifically flagged by NIWA and MetService as carrying elevated risk because its surge coincided with an approaching high tide on the Northland and Bay of Plenty coasts.

## 2.5 Slow-Moving Systems and Cumulative Wave Exposure

Bola (1988) subjected the east coast to prolonged northeasterly swell for multiple days as it stalled north of the North Island. The emerging pattern of hybrid subtropical systems (Tam 2025, Vaianu 2026) that approach and slow near New Zealand may repeat this pattern. Storm duration and approach speed affect total wave energy exposure independently of peak intensity, making slow-moving systems a significant hazard even when their measured peak intensity is moderate.



Cyclone Gabrielle centred over the North Island at the height of its impact. Central pressure 966.6 hPa. Image: NASA Earth Observatory / Lauren Dauphin.

### 3. Storm Prevalence and Intensity

#### 3.1 Event Frequency by Decade

The five direct-impact events from 2022 to 2026 exceed the total in any previous decade. The mean inter-event gap across the full 58-year record is 3.1 years; since 2022 it has been approximately one year. By contrast, the 2000s produced only a single event (Ivy, 2004).

The 1990s were also highly active. The 1996–97 season produced three events (Fergus, Drena, and Gavin) within ten weeks — a sequence without parallel in the record — despite developing El Niño conditions that typically suppress cyclone delivery to New Zealand. A tendency toward northeasterly flow over the North Island during 1996–97, partly associated with the transitional ENSO state, helped steer multiple systems toward northern New Zealand. The 1980s produced four events including the catastrophic Bola (1988).

#### 3.2 Season Clustering

Four seasons produced two or more named systems in rapid succession: 1988 (Bola in March and Eseta in December); 1996–97 (three systems); 2017 (Debbie remnants and Cook, ten days apart in April); and 2023 (Hale in January and Gabrielle in February, five weeks apart). When atmospheric conditions enable one system to track toward northern New Zealand, the steering pattern that produced that track often persists for weeks. Cumulative impacts — with the second storm strikes ground already saturated and infrastructure already stressed — mean the combined effect is typically more severe than either event in isolation.

#### 3.3 Seasonal Timing

April is the single most active month, accounting for seven of twenty events (35%). This is counterintuitive: the cyclone season peaks in January–March for tropical formation, yet April produces more Northland impacts than any other month. April events are almost all extratropical remnants whose track to New Zealand is enabled by the strengthening mid-latitude frontal systems of early autumn, while sea surface temperatures north of New Zealand remain elevated from summer.

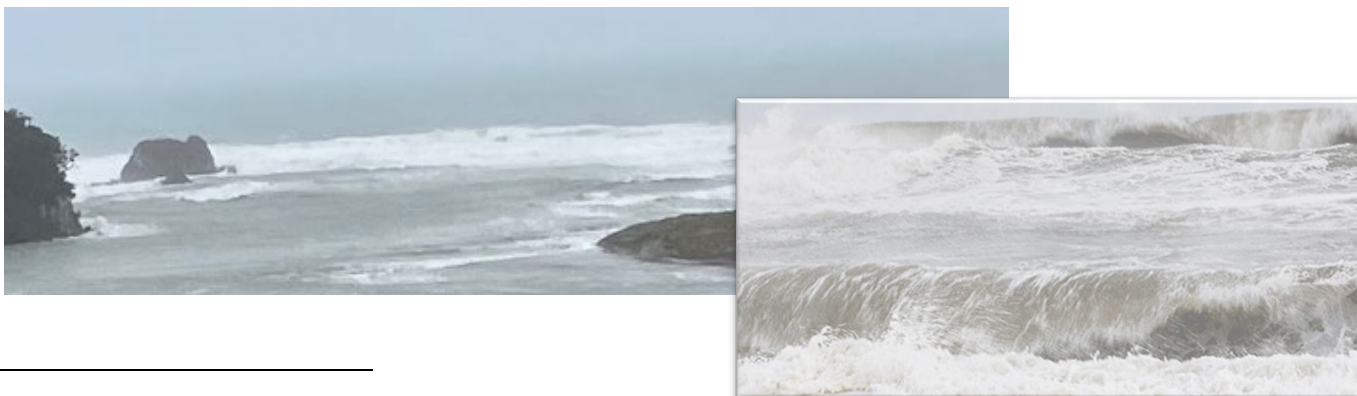
Critically, all six Major-rated events occurred in the November–March peak tropical season. April brings frequency; the summer season carries the greatest potential for catastrophic outcomes.

#### 3.4 Intensity Trends

Mean peak tropical pressure is virtually unchanged between the pre-2000 and post-2000 periods (957.9 hPa vs 956.0 hPa respectively), a difference well within measurement uncertainty:

Decade-mean severity scores<sup>6</sup> (Major=4, Significant=3, Moderate=2) show a broad upward trend: 1960s 4.0 (n=1); 1970s 2.5 (n=2); 1980s 2.75 (n=4); 1990s 3.0 (n=4); 2000s 2.0 (n=1); 2010s 2.7 (n=3); 2020s 3.0 (n=5).

The 2020s are distinctive in that no events are rated below Significant. This could reflect genuinely greater impacts or improved documentation, or both. If the storms' tropical phase there is no statistically meaningful trend toward stronger or weaker peak tropical intensity.



## 4. The Role of ENSO

Of the 20 direct-impact events, seven (35%) occurred under La Niña, ten (50%) under Neutral conditions, and three (15%) under El Niño.<sup>7</sup> Since La Niña and El Niño phases each occur about 30% of the time historically (with 40% Neutral), the observed distribution over-represents La Niña and under-represents El Niño — consistent with established research linking La Niña to greater cyclone penetration into northern New Zealand.

**Table 2: Northland Cyclone Occurrence by ENSO Phase.**

ENSO Phase	Events (n)	Mean Severity	% Major	Mean Peak P (hPa)	Mean Duration (days)
La Niña	7	3.29	43%	955	10.0
El Niño	3	3.00	33%	940	10.7
Neutral	10	2.60	20%	964	9.2

### 4.1 La Niña: Highest-Risk Phase

La Niña strengthens the subtropical ridge and establishes a persistent northeasterly flow across the Tasman and northern New Zealand, creating a steering corridor that guides systems toward Northland rather than deflecting them south or east. This produces the highest proportion of Major-rated events (43%) and the highest mean severity score (3.29). All three of Northland's most consequential events — Bola (1988), Wilma (2011), and Gabrielle (2023) — occurred under La Niña conditions.

### 4.2 El Niño: Fewer but Potentially More Intense Systems

El Niño conditions suppress cyclone activity near New Zealand, producing only three events in 58 years. Those three events had the most intense tropical peaks on average (mean 940 hPa vs 955 hPa for La Niña) and included the Major-rated Drena (1997). During El Niño, only the most energetic systems overcome the unfavourable steering pattern to reach Northland, producing a selection bias toward the more severe end of the intensity distribution.

The 1996–97 season — three Northland-affecting systems during a developing El Niño — is the most important anomaly in the ENSO–cyclone relationship in this dataset. The transitional phase in late 1996 and early 1997, before the El Niño fully suppressed northeasterly steering, temporarily preserved favourable conditions for cyclones. This shows that ENSO phases provide probabilistic, not deterministic, guidance.

### 4.3 ENSO Phase, Track Direction, and Risk

La Niña shows the most diverse track distribution and is the only phase to produce North/Offshore tracks (Bola, 1988). It also generates a higher proportion of west coast tracks (29%) than Neutral conditions (20%), suggesting that the frequency of La Niña events — rather than their individual severity — is what poses the most significant cumulative threat to the east coast.

Neutral conditions are associated with the highest concentration of east coast tracks (60% of Neutral events), consistent with the subtropical ridge reliably steering systems eastward around the Northland peninsula. However, El Niño systems that do reach the east coast — a relatively rare occurrence — arrive at above-average intensity and are potentially the most damaging on a per-event basis.

<sup>7</sup>ENSO (El Niño Southern Oscillation) describes the linked oceanic-atmospheric conditions in the Pacific that fluctuate over a two-to-seven-year cycle, driving medium-term climatic conditions.

## 5. Storm Character

### 5.1 East vs West Coast Tracking Storms

Of the 20 direct-impact events, 11 (55%) tracked along the Pacific/east coast of Northland, five (25%) along the Tasman/west coast, and four (20%) affected both coasts. East coast tracks are more than twice as common, reflecting the dominant synoptic pattern in which extratropical remnants approach from the northeast and are steered southward along the eastern flank of Northland by the mid-latitude westerly belt.

**Table 3: Summary comparison of east and west coast track events.**

Track Type	Events (n)	Mean Severity	Major Events	Mean NL Gust (km/h) <sup>1</sup>	Mean NL Days
East (Pacific)	11	2.82	3	136	1.7
West (Tasman)	5	2.80	1	132	2.2
Both / Mixed	4	2.50	1	140	3.8

1. Cyclone Fergus gust outlier omitted.

### 5.2 The Fundamental Difference: Rainfall vs Wind

**East coast tracks are flood-dominant.** When a system tracks along the east coast, warm moist easterly and northeasterly flow is forced to ascend the ranges, amplifying rainfall on east-facing slopes. Wilma (2011) produced 250+ mm in 18 hours from Mangonui Forest to Mangawhai, triggering record levels in eight river catchments. Fergus (1996) exceeded 400 mm in parts of Northland. Gabrielle (2023) triggered a 60,000 m<sup>3</sup> railway slip and destroyed critical infrastructure.

**West coast tracks are wind-dominant.** When a system tracks along the Tasman side, the most destructive conditions are gale-force winds wrapping around the system's southern and eastern quadrants. Drena (1997), Alison (1975), Hal (1978), and Tam (2025) all emphasised wind damage over flooding. Tam produced structural damage and gusts to 151 km/h with more diffuse rainfall.

This distinction has direct implications for emergency responses. West coast track events require wind and marine preparedness (structural damage, moorings, power lines), while east coast track events require flood response, slope stability management, and planning for prolonged road access disruption.

### 5.3 Duration and Seasonal Timing

West coast events linger near Northland slightly longer on average (2.2 days vs 1.7 days for east coast tracks). Systems approaching from the northwest often slow as they encounter the peninsula and the strengthening mid-latitude westerlies, while east coast systems on a northeasterly-driven track tend to sweep through more rapidly. A longer dwell time amplifies cumulative wind and rain exposure for west coast events. West coast tracks also tend to occur slightly later in the season, consistent with mid-latitude troughs in the Tasman becoming more active as autumn progresses.

As noted in Section 3.3, all six Major-rated events occurred in from November to March window. While April is the most active month reflects the role of mid-latitude frontal interactions at the end of the season, but frequency does not translate to catastrophic outcomes.

### 5.4 Peak Tropical Intensity Does Not Predict Northland Impact

There is no simple relationship between a storm's peak intensity in the originating tropical waters and its subsequent impacts on Northland. Category 3 storms produced the highest number of Major events (4 of 7 events, 57%), while more intensive Category 4 systems produced only one Major event (Bola) and three Moderate events from seven. The least severe Category 1 storms included one Major event (Giselle, which was boosted as pressures drop as it moved outside the tropics).

Category 3 systems appear most effective at producing Major impacts in Northland because they retain enough convective moisture to generate sustained rainfall through the subtropical transition zone, while Category 4 systems frequently move at tracks or speeds that limit concentrated rainfall or wind delivery.

It can be concluded that track geometry and how the extratropical transition manifests – in terms of speed and changing pressure - , matter more than peak tropical intensity.

## 5.5 Northland's Infrastructure Weak Points

East coast track flooding events have caused the most persistent infrastructure damage arising from cyclonic storms. West coast wind events cause more immediate power outages and marine damage but generally shorter road closure durations and faster recovery.

The small number of locations that appear repeatedly in the cyclone impact record are east coast facing:

- **Brynderwyn Hills / SH1.** Closed by slips in at least Fergus (1996), Wilma (2011), and Gabrielle (2023). This single-point failure disconnects Northland from Auckland on the main northern arterial.
- **Kaero.** River flooding noted in Bernie (1982), Wilma (2011), Cook (2017), and Dovi (2022). The catchment's steep terrain makes it particularly responsive to easterly rainfall.
- **Bay of Islands (Russell, Opuā).** Marine damage and boat losses noted in Fergus, Drena, Dovi, and Vaianu. The bay's semi-enclosed geometry concentrates swell energy from certain approach directions.
- **Piawai / Hikurangi River.** Isolated by floodwater in Wilma (2011) and Vaianu (2026). The catchment responds rapidly to sustained rainfall.
- **North Auckland railway.** The line's route through narrow hill-country corridors makes it acutely vulnerable to slip events; damaged in Wilma and destroyed in Gabrielle.

## 5.6 Key Findings

While limited to only twenty storms, they encompass the events that have generated most significant coastal storm impacts over a thirty year period. The preceding comparisons reveal a number of features likely to influence when, where, and how severely future coastal storms might impact in Northland.

**Track geometry, not storm intensity, determines east coast surge and wave exposure.** The most intense tropical system at its peak (Ivy 2004, 935 hPa) produced a Moderate Northland impact. The less intense Fergus produced a Major event. All five west coast track events are rated Moderate despite several involving intense tropical origins.

**Pressure is a useful but imprecise proxy for surge potential.** The inverse barometer provides a theoretical upper bound on pressure surge (10 mm per hPa below 1013). However, the same pressure deficit produces very different outcomes depending on track proximity, storm speed, shelf geometry, and tidal phasing.

**Wave set-up is the dominant coastal hazard on the open Northland east coast.** For open coast sites, wave set-up contributions of 0.6–2.4 m are physically plausible for major events — substantially exceeding the pure pressure/wind surge of 0.3–0.7 m. Wave set-up is not captured by harbour tide gauges.

**Harbours and estuaries are surge-dominated; open coasts are wave-dominated.** Inside the Bay of Islands and Whangarei Harbour, wave heights are attenuated by refraction and the primary driver shifts to surge. The T+T finding that the Opuā Wharf observed record exceeds the statistically derived 1% AEP level confirms that direct cyclone passages are the controlling design events for harbour communities.

**Tidal phasing is a critical risk multiplier.** With spring tidal range of ~1.6–1.8 m, the difference between a surge at high perigean-spring tide versus low tide is 1.6–1.8 m in total water level.

**The low baseline wave energy of the northeast coast amplifies cyclone impacts.** Infrastructure calibrated for ambient waves of 0.5–1.5 m experiences disproportionate damage when cyclone waves of 6–12 m arrive.

**Slow-moving systems pose elevated wave hazard through duration.** Bola (1988) and the emerging pattern of hybrid subtropical systems (Tam 2025, Vaianu 2026) demonstrate that storm duration and approach speed affect wave energy exposure independently of peak intensity.

## 6. Coastal Inundation Thresholds in Mangawhai

### 6.1 Analytical Framework

Coastal water level at Mangawhai Harbour is the sum of four components: astronomical tide (MHWS = 0.95 m NZVD16); storm surge (pressure and wind set-up); wave set-up (10–20% of offshore significant wave height on open coasts, estimated at 0.14 m inside the harbour during Gabrielle 2023 and 1.15 m on the open coast during the 1978 breach storm); and relative sea level rise.

The T+T (2021) storm tide levels represent tide + surge + seasonal oscillation only, and exclude wave set-up and freshwater retention. The McDermott and Hume (2025) harbour inundation levels add estimated wave set-up and freshwater retention (10–30 cm depending on storm intensity), producing the total harbour water levels used here.

Three probability frameworks are applied (described in Appendix Three). The T+T storm tide ARI/AEP values define current statistical return periods. The compound probability formula  $P = 1 - (1 - AEP)^N$  gives the probability of at least one exceedance in N years. Sea level rise progressively lowers the effective ARI of each fixed threshold over time.

### 6.2 Observed Benchmarks

Two historical events establish the empirical range for this analysis.

**Table 4: Observed Mangawhai harbour inundation levels for the two best-documented events.**

Event	Tide (m)	Surge (m)	Wave set-up (m)	Freshwater (m)	Total (m)	Inundation ARI
Cyclone Gabrielle (13 Feb 2023)	0.65	0.81	0.14 (harbour)	—	1.70	20–50 yr
1978 Breach Storm (Jul 1978)	1.14	0.61	1.15 (open coast)	0.20	~1.95	~100–200 yr est.

These benchmarks establish that the 1978 breach storm came within approximately 0.05 m of the 2.0 m threshold assessed here. This threshold represents the largest historically recorded Mangawhai harbour inundation event, narrowly exceeded. The probability of these thresholds being breached over the next thirty years is discussed below. An alternative illustration relating combinations of storm intensity (ARI) to tide levels at current sea level and with projected SLR to 2055 is presented in Appendix Four.

### 6.3 The 2.0 m Threshold

The 2.0 m threshold calls for a near-term planning horizon. A storm would reach this level today with a combination of a 30–50 year ARI (2.0–3.3% AEP) storm tide, an east coast track system, peak NZ pressure of approximately 960–970 hPa (equivalent to Gabrielle or Fergus), arriving on a spring or perigean (“king”) spring high tide, with sustained onshore northeast winds. Had the surge peaked at MHWS rather than at 0.65 m when Gabrielle peaked on 13 February 2023, it would have produced 2.00 m harbour inundation. Similarly, a Gabrielle-equivalent system with slightly greater harbour wave set-up (0.31 m instead of 0.14 m) would have reached 2m level.

Six of the seven Major east coast track events occurred during La Niña or Neutral ENSO phases. La Niña should be treated as the high-risk phase for threshold monitoring.

**Table 5: Evolving exceedance probability for 2.0 m harbour inundation at Mangawhai.**

Period / Condition	Effective ARI for 2.0 m	Annual AEP	P (10 yr)	P (20 yr)	P (30 yr)
Present day (2025)	~30–50 yr	2.0–3.3%	18–28%	33–49%	46–64%
By 2030 (all SSPs)	~20–30 yr	3.3–4.9%	28–40%	49–63%	63–78%
By 2040 (all SSPs)	~10–20 yr	4.9–9.5%	40–63%	63–86%	78–95%
By 2055 (all SSPs)	~5 yr	~18%	~86%	~98%	>99%

Colour key: ■ P < 20% ■ P 20–49% ■ P ≥ 50%

Compound probabilities:  $P = 1 - (1 - AEP)^N$ . AEP ranges reflect variation across SSP2-4.5 to SSP5-8.5 scenarios.

A 2.0 m harbour inundation event has an 18–28% probability of occurring in the first decade (2025–2035) and a 33–49% probability within two decades under current climate conditions alone, without any increase in storm intensity.

With intensification trends identified since 1988 — 47% of post-1988 storms classified as major compared with 7% pre-1988 — these probabilities should be treated as conservative lower bounds.

## 6.4 The 2.5 m Threshold

The 2.5 m threshold requires a significantly more severe event. Under current conditions, even a 500-year ARI (0.2% AEP) storm tide (1.8 m) requires a further 0.7 m from wave set-up and freshwater retention to reach 2.5 m. Today, this would represent the ultimate worst case scenario. This It requires a Cat 3–4 cyclone (with NZ passage pressure 945–960 hPa), a close east coast approach on a perigeon spring high tide, sustained northeast winds generating offshore wave heights of 8–12 m, and heavy antecedent rainfall saturating the catchment.

**Table 6: Evolving exceedance probability for 2.5 m harbour inundation at Mangawhai.**

Period / Condition	Effective ARI for 2.5 m	Annual AEP	P (10 yr)	P (20 yr)	P (30 yr)
Present day (2025)	~100–200 yr	0.5–1.0%	5–10%	10–18%	14–26%
By 2040 (SSP3-7.0 / SSP5-8.5)	~50–100 yr	1.0–2.0%	10–18%	18–33%	26–46%
By 2060 (SSP3-7.0 / SSP5-8.5)	~20–50 yr	2.0–4.9%	18–40%	33–63%	46–78%
By 2080 (SSP3-7.0)	~5–10 yr	9.5–18%	63–86%	86–98%	95–>99%

Colour key: ■ P < 20% ■ P 20–49% ■ P ≥ 50%

If global temperatures continue to rise, however, 2.5m becomes a more credible prospect. Under the Middle of the Road (SSP2-4.5) scenario, a 2.5 m event has a 14–26% probability within three decades. Under SSP3-7.0, the three-decade probability rises to 26–46%. By 2060 under higher-emissions pathways, 2.5 m becomes a near-routine extreme event.<sup>8</sup>

## 6.5 Above 2.5 m: Spit Integrity and Cascading Risk

Events above 2.5 m represent qualitatively different impacts. At this level, the entire harbour floor floods, seawater penetrates Tara Creek, Lincoln Street, Alamar Crescent, the holiday park and southern shoreline, and the spit comes under severe threat of over-wash or breach.

A spit failure following an event at or above 2.0 provides an alternative pathway to levels exceeding 2.5 m. If a 1978-type event breaches the spit, subsequent moderate storms could produce effective harbour levels of 2.5m or more due to the loss of protection from waves.

A breach of the spit would change things dramatically. The harbour's natural wave-barrier would be compromised, exposing the western shores to open-coast wave set-up and dramatically raising effective inundation levels for even moderate storms.

The 2.5 m threshold is not a near-term planning event under present conditions, but becomes credible within 30 years under higher-emissions pathways. The more immediate possibility is the spit-breach cascade pathway: a 2.0 m event — at the threshold of probability within a decade — which would permanently elevate risk for the entire harbour community and environment.

## 6.6 Planning Implications

Three planning triggers follow directly from the probability analysis:

<sup>8</sup> A look-up table identifying threshold associated with different storm frequencies and Shared Socio-Economic Pathways (as they influence SLR) is presented in Appendix Four.

- **Trigger 1 — Immediate (now to 2035).** A 2.0 m event has an 18–28% probability within a decade. Spit integrity maintenance, stormwater system review, regulatory restrictions on low-lying development, and Red Alert tide monitoring protocols should be activated now.
- **Trigger 2 — Medium term (2035–2045).** A 2.0 m event becomes highly probable (~60–80%) by the mid-2040s. Hard and soft coastal defences, road and bridge resilience upgrades, and lifeline service reviews should be designed and programmed by 2030 to allow lead time for implementation.
- **Trigger 3 — Long range (2045–2055).** A 2.5 m event has a 26–78% probability within 30 years (SSP-dependent). Land use restrictions, development setbacks, and the feasibility of strategic retreat from the most exposed harbour-margin properties should be assessed within this decade to prevent further capital commitment in high-risk zones.

## 6.7 Caveats and Data Limitations

Several caveats apply to the probability estimates in this section:

- **Gauge data limitations.** The T+T storm tide ARI values are derived from tide gauge records in sheltered harbour positions. Wave set-up is not captured in those gauges, and the MMI harbour inundation levels incorporate wave set-up and freshwater estimates that carry their own uncertainty, particularly for extreme events outside the observational record.
- **Stationarity assumption.** The compound probability calculations assume stationarity of the storm climate. Evidence of increasing major storm frequency since 1988 suggests this assumption is conservative; non-stationarity would increase exceedance probabilities beyond those shown.
- **RSLR uncertainty.** The Vertical Land Movement estimate of  $-2.6$  mm/yr at Mangawhai has an uncertainty of  $\pm 2.8$  mm/yr. Higher subsidence rates would accelerate the arrival of lower effective ARIs for each threshold.
- **Non-linear spit dynamics.** The spit-breach cascade pathway is not amenable to standard statistical analysis because it involves a structural state change. The probability tables do not incorporate post-breach elevated baseline risk.

By and large, eliminating these caveats could be expected to lift the probabilities, rather than reduce them. In this sense, our estimates are conservative, reinforcing the urgency of proceeding, with the measures proposed under Trigger 1.

## 6.8 Data Gaps and Recommended Next Steps

This assessment is limited by the absence of systematic tide gauge and wave buoy records across the full 58-year catalogue. The following steps would substantially strengthen the quantitative evidence base:

- Obtain NRC tide gauge records (Bay of Islands/Opua Wharf, Marsden Point, Whangarei Harbour) for events from approximately 1990 onwards.
- Request NIWA's 40-year wave and storm surge hindcast (~1980–present) to provide modelled estimates at consistent offshore locations for each catalogue event.
- Integrate NRC Bay of Islands wave buoy records and MetService coastal monitoring data for Gabrielle (2023) and Vaianu (2026) into any quantitative assessment.
- For Mangawhai, seek measurements to establish the potential for rainwater retention in the harbour during periods of intense rainfall coinciding with peak east coast storm tracking.



## 7. Conclusion

The evidence assembled in this report points to a clear and escalating risk of storm-driven coastal inundation across Northland. The implications most directly documented for Mangawhai in this and antecedent MMI reports should be seen as applicable to a greater or lesser degree to all barrier sit opr lagoon harbours on the east coast of Northland , if not the entire norther North Island.

The data shows that the frequency and intensity of direct-impact events has been rising. Five storms struck the coast in the five years 2022–2026. The three most recent — Gabrielle, Tam, and Vaianu — were all subtropical hybrid systems, retaining tropical-like intensity to higher latitudes. Such storms can be expected to become more common as sea surfaces warm. Against this backdrop, the physical mechanisms driving surge and wave set-up as set out in Section 2, require that the statistical probabilities derived in Section 6 should be treated as conservative lower bounds. Any uncertainty calls for early cation rather than delay.

A breach of the spit is the most consequential non-linear outcome. It removes the harbour's primary natural protection, exposing the western and southern harbour shores to open-coast wave energy and structurally raising the inundation risk from every subsequent storm, however modest. This prospect cannot be captured in standard AEP analysis. It underscores why the 2.0 m threshold — at the threshold of probability within a decade — is the most urgent planning horizon.

These findings reinforce the conclusions of the Sustainable Mangawhai Project regarding the need for immediate, coordinated action. The most pressing priorities are maintaining and strengthening the spit, ensuring the stormwater system can handle the volumes implied by these events, applying regulatory restrictions to development in low-lying high-risk zones, and initiating engineering assessment of the most vulnerable infrastructure. These are not speculative precautions: they are responses to risks that, under current conditions and without any acceleration of storm intensity, already support a non-trivial probability of occurring within the planning lifetimes of decisions being made today.

The case for acting now rather than waiting is straightforward. Early investment in resilience spreads costs across agencies and time. In an area experience significant growth, delay simply compounds the costs. And reactive recovery from a major breach or inundation event will lift and concentrate costs at a moment when the harbour, the spit, the community, and the environment are least able to absorb them.

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## Appendix One: Data Sources

Source	Type	URL / Reference	Role in this report
Hauraki Gulf Weather (HGW)	Specialist upper North Island cyclone history tracker	haurakigulfweather.com/cyclonehistory	Primary source for individual storm intensity tables; most comprehensive NZ-specific cyclone database publicly available.
NIWA Historic Weather Events (NIWA-HWE)	NZ national weather events archive	hwe.niwa.co.nz	Rainfall, river level, and damage data for individual events. Best primary source for Cyclone Wilma 2011 Northland hydrology.
Northland Regional Council (NRC)	Local government flood reports	nrc.govt.nz	Post-event hydrological reports. The 2011 Wilma flood report is the most detailed Northland-specific cyclone impact document in the public record.
MetService New Zealand / TCWC Wellington	NZ operational met authority	metservice.com	WMO-designated Tropical Cyclone Warning Centre for the NZ area. Source for warnings, track and intensity data for NZ-area storms.
IBTrACS / NOAA NCEI	International Best Track Archive	ncei.noaa.gov/products/ibtracs	Primary global best-track archive. Reliable from ~1969 (satellite era).
JTWC (Joint Typhoon Warning Center)	US Navy/Air Force advisory centre	metoc.navy.mil	Issues advisory data for South Pacific; feeds into IBTrACS. Key source for intensity classification of major events.
RSMC Nadi / Fiji Met Service	WMO Regional Specialised Met Centre	met.gov.fj	Official naming authority for South Pacific tropical cyclones.
Te Ara: Encyclopedia of New Zealand	Scholarly reference (Brenstrum)	teara.govt.nz	Historical overview of cyclone impacts; primary reference for events predating systematic digital records.
Wikipedia — individual cyclone articles	Synthesis / cross-referenced	Multiple articles per storm	Used for synthesis across international sources. All entries cross-checked against primary meteorological and governmental sources.
NZ Herald / Northern Advocate	Newspaper of record	nzherald.co.nz	Contemporary reporting and insurance claim data.
RNZ (Radio New Zealand)	National broadcaster	rnz.co.nz	Contemporary reporting, particularly for Vaianu 2026 and Gabrielle 2023.
ClimSystems (Urich et al.)	Consultancy analysis (2022, reissued 2026)	climsystems.com	ERA5 wind gust analysis for Cyclone Dovi 2022.
NZ Geographic	Magazine / historical record	nzgeo.com	Key historical source for the 1996–97 cyclone season.
NIWA (Sinclair, 2002)	Peer-reviewed research	niwa.co.nz/water-atmosphere/vol10	Foundational frequency analysis (~1 storm per year within 555 km of Northland). Key reference for ENSO–track relationships.
NOAA CPC Oceanic Niño Index	ENSO classification	cpc.ncep.noaa.gov	Monthly ONI values used for ENSO phase classification across all events.
Waikato Civil Defence (2026)	Local civil defence updates	waikatocivildefence.govt.nz	Key source for Vaianu 2026 state of emergency declarations and impact reporting.

*The National Hurricane Center (NHC) does not operationally forecast South Pacific tropical cyclones. NOAA's primary contribution is through the IBTrACS best-track archive. Operational warning responsibility sits with TCWC Wellington (MetService) for storms entering New Zealand waters and RSMC Nadi (Fiji Meteorological Service) for naming and initial tracking in the South Pacific basin.*

## Appendix Two: Rating Storm Severity

The severity scale used in the analysis is a subjective composite assessment, not a formally defined or algorithmically derived measure.

The scale applies a four-tier ordinal rating — Major (4), Significant (3), Moderate (2), with Minor theoretically possible but unused in the 20-event catalogue — assigned to each storm based on its documented Northland-specific impact. The implicit criteria are: wind intensity at Northland (gust records where available, qualitative descriptions where not); rainfall and flooding (mm totals, river levels above threshold, catchments affected); infrastructure disruption (road closures, power outages, duration); emergency response triggered (Civil Defence declarations, evacuations, rescues); economic damage (insurance claims where available); and casualties.

The rating is not derived from any single measured variable. Peak tropical pressure correlates poorly with severity — Ivy has the deepest tropical pressure in the record at 935 hPa yet rates only Moderate; Fergus has no reliable pressure figure yet rates Major. The rating is closer to an expert consensus assessment than a calculated index.

The numeric encoding (Major=4, Significant=3, Moderate=2) is applied for charting purposes — computing decade means and displaying trends — and should not be treated as a cardinal scale. Severity is ordinal: it ranks storms relative to each other but does not imply equal gaps between tiers.

If the scale needs to be formalised for subsequent work, the most defensible approach would be to define explicit threshold criteria for each tier against measurable variables (e.g. peak NL gust, rainfall total, number of road closures, Civil Defence activation), then re-rate each storm systematically.

## Appendix Three: Estimating Exceedance Probabilities

Three formulae underlie all the probability numbers in Section 6.

**Formula 1 —  $AEP = 1/ARI$ .** This converts the statistical return period to the annual probability. A 50-year ARI storm has a 2% chance of occurring in any given year. The ARI is a long-run average, not a scheduled recurrence — a 100-year event can happen twice in a decade or not at all for centuries.

**Formula 2 —  $P(N) = 1 - (1 - AEP)^N$ .** This gives the probability of at least one exceedance of the threshold over a planning horizon of N years. If exceedances in successive years are statistically independent, the probability of no exceedance in N years is  $(1 - AEP)^N$ , and the complement gives at least one exceedance. Example: 50-year ARI ( $AEP = 2\%$ ) over 30 years:  $P(30) = 1 - (0.98)^{30} = 46\%$ .

**Formula 3 — Effective ARI after sea level rise.** In rigorous form this requires fitting a Generalised Extreme Value distribution to the gauge record and shifting the quantile function by  $RSLR(t)$ . In practice this report uses the simplified version: subtract the projected RSLR from the fixed threshold and read off which T+T ARI level matches — which is why the Section 6 tables show the effective ARI narrowing decade by decade.

Four caveats apply to all probability estimates:

- **Independence assumption.** Formula 2 understates risk during La Niña clustering, when multiple events can occur within a single season.
- **Stationarity assumption.** The post-1988 intensification trend means non-stationarity would increase exceedance probabilities beyond those shown. The reported probabilities are conservative lower bounds throughout.
- **Rising AEP over time.** The static-AEP version of Formula 2 understates true exceedance probability over multi-decade horizons because AEP itself rises as sea level rises.
- **Spit-breach cascade.** This pathway involves a structural state change that is not amenable to standard statistical analysis. The probability tables do not incorporate post-breach elevated baseline risk.

## Appendix Four: Storm Intensity and Harbour Inundation Thresholds

*Scope. This table covers 5- to 50-year ARI storm events only. Values for 200-year ARI and above involve extrapolation beyond the directly calibrated range of the T+T (2021) storm tide framework and are excluded. All water levels in metres NZVD16. Non-tidal residual (NTR) is calibrated to Cyclone Gabrielle (February 2023): observed NTR ~1.00 m at ~20-year ARI. The conditions column uses catalogue storm character descriptions from Section 5.*

**Table A4:** Storm intensity (ARI) and estimated harbour inundation at current sea level and with projected SLR to 2055.

Storm ARI	Annual AEP	NTR	Low water ~0.0 m	Mod. spring ~-0.65 m	MHWS ~0.95 m	Conditions and notes
<b>Current sea level (2025 baseline)</b>						
5-year	18.1%	0.70 m	0.70	1.35	1.65	Below 2.0 m at all tide states. Moderate ExTC system; no coastal emergency threshold reached.
10-year	9.5%	0.85 m	0.85	1.50	1.80	Approaches 2.0 m only at perigean spring tide. Cat 2 or strong ExTC near coast.
20-year	4.9%	1.00 m	1.00	1.65	1.95	Gabrielle-equivalent surge. Reaches 1.95 m at MHWS — 5 cm below 2.0 m. East coast track + spring tide required.
50-year	2.0%	1.20 m	1.20	1.85	2.15	Exceeds 2.0 m at MHWS only. Cat 2–3 east coast track with onshore fetch required.
100-year	1.0%	1.40 m	1.40	2.05	2.35	Exceeds 2.0 m at moderate spring; approaches 2.5 m at MHWS. Cat 3 close-approach; perigean spring needed for 2.5 m.
<b>2055 — SSP2-4.5 (low emissions, RSLR +0.245 m)</b>						
5-year	18.1%	0.94 m	0.94	1.59	1.89	Still below 2.0 m at all tide states. SLR of +0.245 m lifts all levels ~25 cm above current baseline.
10-year	9.5%	1.09 m	1.09	1.74	2.04	Crosses 2.0 m at MHWS. Annual probability 9.5%; P(exceedance in 10 yr) = 63%.
20-year	4.9%	1.25 m	1.25	1.90	2.20	Exceeds 2.0 m at MHWS. Gabrielle-equivalent surge crosses 2.0 m at any spring tide state.
50-year	2.0%	1.44 m	1.44	2.09	2.39	Exceeds 2.0 m at moderate spring; approaches 2.5 m at MHWS. Cat 2–3 east coast track.
100-year	1.0%	1.65 m	1.65	2.29	2.59	Exceeds 2.5 m at MHWS. Analogous to Bola- or Giselle-type system at perigean spring tide.
<b>2055 — SSP3-7.0 (middle road emissions, RSLR +0.275 m)</b>						
5-year	18.1%	0.97 m	0.97	1.62	1.92	Approaches 2.0 m at MHWS (1.92 m). Even modest storms require coastal monitoring at spring tides.
10-year	9.5%	1.13 m	1.13	1.77	2.08	Crosses 2.0 m at MHWS. Annual probability 9.5% — higher than the current 50-year ARI threshold.
20-year	4.9%	1.27 m	1.27	1.92	2.22	Exceeds 2.0 m at MHWS. Gabrielle-equivalent exceeds 2.0 m at any spring tide.
50-year	2.0%	1.48 m	1.48	2.12	2.42	Exceeds 2.0 m at moderate spring; approaches 2.5 m at

Storm ARI	Annual AEP	NTR	Low water ~0.0 m	Mod. spring ~0.65 m	MHWS ~0.95 m	Conditions and notes
						MHWS. Spit integrity at risk from recurrence.
100-year	1.0%	1.67 m	1.67	2.32	2.62	Exceeds 2.5 m at moderate spring tide. Amplified 1978 breach storm analogue with additional SLR.
<b>2055 — SSP5-8.5 (high emissions, RSLR +0.290 m)</b>						
5-year	18.1%	0.99 m	0.99	1.64	1.94	Marginally higher than SSP3-7.0; scenario divergence accelerates post-2060.
10-year	9.5%	1.14 m	1.14	1.79	2.09	Crosses 2.0 m at MHWS. Effectively identical to SSP3-7.0 outcome at this horizon.
20-year	4.9%	1.29 m	1.29	1.94	2.24	Exceeds 2.0 m at MHWS. East coast track + spring tide required.
50-year	2.0%	1.49 m	1.49	2.14	2.44	Exceeds 2.0 m at moderate spring; approaches 2.5 m at MHWS.
100-year	1.0%	1.69 m	1.69	2.34	2.64	Exceeds 2.5 m at moderate spring and at MHWS. Most extreme credible scenario within 30-year horizon.

Colour coding: amber = approaching 2.0 m ( $\geq 1.8$  m); orange = exceeds 2.0 m; red = exceeds 2.5 m. NTR = non-tidal residual (storm surge + harbour wave set-up + seasonal MSL anomaly). Tidal levels: low water ~0.0 m; moderate spring ~0.65 m (tide at time of Gabrielle); MHWS / perigean spring ~0.95 m NZVD16 (T+T 2021 Table 4.1). RSLR at 2055 interpolated from T+T Table 4.4, including VLM  $-2.6$  mm/yr. SSP scenarios are closely clustered at 2055 (range 4.5 cm); divergence accelerates post-2060.

Sources: Tonkin & Taylor / Rottink (2025) Mangawhai Coastal Inundation Guidance; McDermott & Hume / MMI (2025) Flood Risks Facing Mangawhai; NIWA coastal inundation programme; NZ SeaRise (VLM). This table is a planning reference only and does not replace site-specific coastal hazard assessment.