Tonkin+Taylor

7 April 2025
Job No: 1095525

Mangawhai Matters Incorporated
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Attention: Colin Leach

Dear Colin

Mangawhai Matters Coastal Inundation Guidance

1 Introduction

Coastal flooding occurs when coastal water levels rise above the land elevation at the coastal edge, flooding areas of land that are typically not exposed to tidal water levels. To understand the coastal flooding levels presented in the online viewer, it is important to understand the factors that contribute to these coastal water levels.

The coastal inundation viewer for Mangawhai relies on information on coastal inundation hazards that was produced by Tonkin & Taylor Ltd (T+T) for Northland Regional Council (T+T, 2021). For detailed information on coastal inundation hazards refer to this technical report: https://www.nrc.govt.nz/media/nfbhwhgs/t-t-cfhz-report-2021.pdf

Coastal water levels are generally influenced by 4 main components: **tides**, **storm surge**, **waves**, and **relative sea level rise** (RSLR) (see Figure 1.1). This guidance document explains each of these 4 elements in more detail and, using the example of Cyclone Gabrielle and the 1978 storm, shows how these components combine to form a total inundation level. This will allow users to better understand and estimate the impact of different storm events, both at present day and in the future. When comparing sea levels and land elevation it is important to use the same vertical reference. For this guidance document, all levels are presented in New Zealand Vertical Datum 2016 (NZVD16) referred to as reduced level (RL).

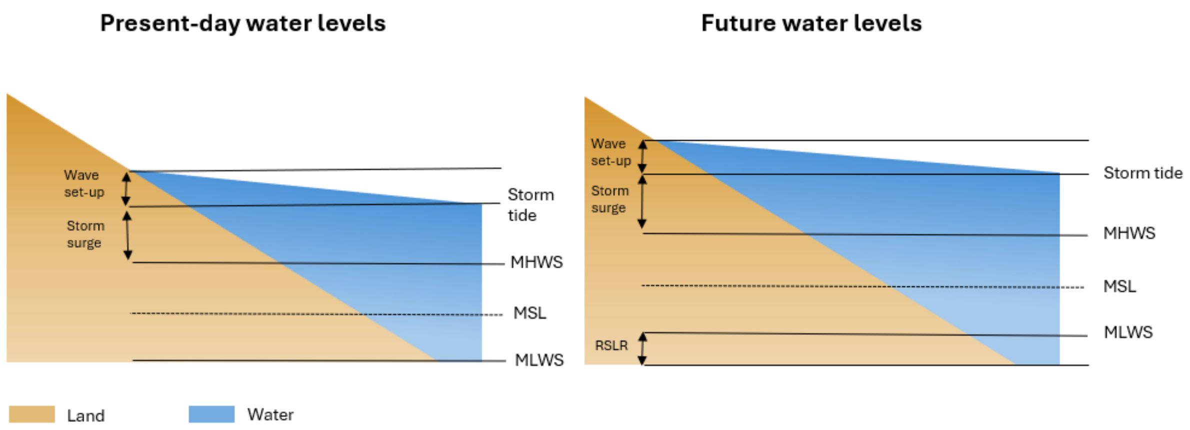

Figure 1.1: Overview of the 4 main components that influence coastal water levels.

2 Navigating the Inundation Viewer

The online Mangawhai coastal inundation map viewer for Mangawhai can be accessed with this link. Once you access the coastal inundation map viewer, the screen in Figure 2.1 should be visible.

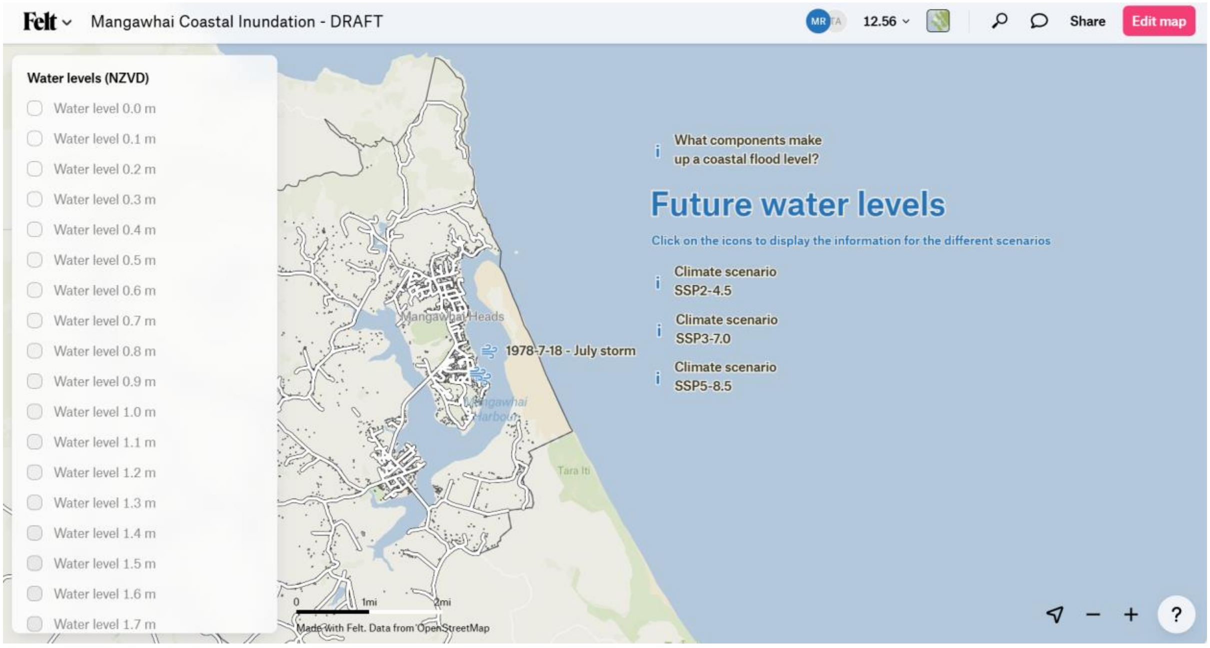

Figure 2.1: Mangawhai coastal inundation map viewer.

2.1 Viewing Water Level Layers

On the left side of the screen, a list of water level layers is displayed, ranging from 0 m NZVD to 3.5 m NZVD in 10 cm increments. To view these layers, select either 'show' or 'show only this' on the right side (see Figure 2.2). These options will appear when you hover over the layer of interest. The 'show' option allows you to display multiple layers simultaneously, while the 'show only this' option highlights a single layer. The water levels illustrate the extent of flooding expected at different water levels.

The flood extent at various water levels is calculated using the 2024 Digital Elevation Model (DEM) for Northland. However, in areas with dense mangrove vegetation, the DEM may not be entirely accurate, as the elevation values in these regions can be slightly overestimated. This could result in an underestimation of the flood extent. In reality, the flooding in mangrove areas may extend further than predicted.

By overlaying the water level layers with the locations of buildings, roads and other assets in the online viewer, it is possible to identify which locations may be affected. However, if a building is indicated as being affected, this doesn't necessarily mean the entire structure is flooded. The flooding could be minimal (i.e. only a few cm). To help assess the depth of flooding at specific locations, we've included a layer of elevation contours in the online viewer. By comparing the water levels to these contours, you can estimate the depth of flooding in any given area.

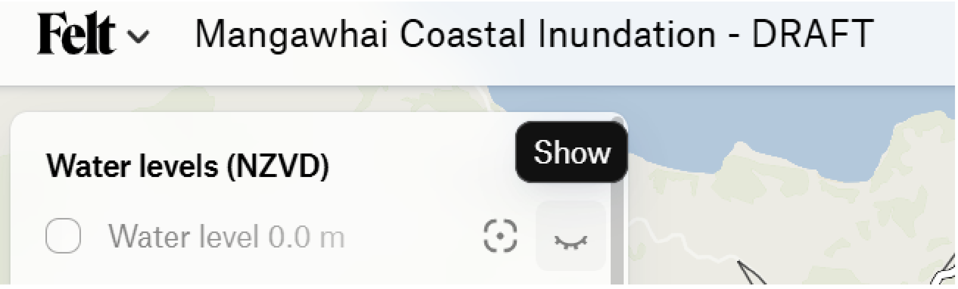

Figure 2.2: Viewing water level layer in the coastal inundation map viewer.

2.2 Information Icons

In the coastal inundation map viewer, various icons are available to provide additional information. Click any of the three icons under 'Future water levels' to explore expected water levels under different tide conditions, storms, timeframes, and climate scenarios. To learn more about inundation levels during past storm events, click on one of the storm icons in the harbour (see Figure 2.3).

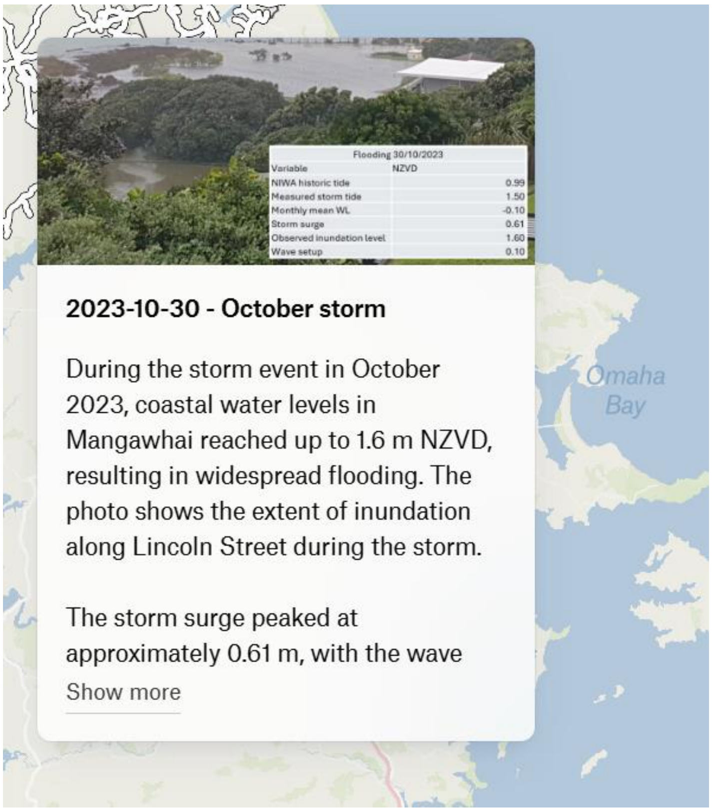

Figure 2.3: Information icons in the coastal inundation map viewer.

3 Why is it Important to Understand Coastal Inundation

Coastal inundation is a natural hazard that impacts land use in low lying areas, including some low areas around Mangawhai Harbour. With sea levels rising due to climate change, these coastal inundation hazards are expected to increase in the future, making it even more important to understand the potential exposure areas. By assessing how high the water might rise – considering factors like climate change and storm intensity – communities can better prepare for what's to come.

Last year, the Ministry for Environment in New Zealand published a guidance document on coastal hazards and climate change. See here for more information.

3.1 What Components make up a Coastal Flood Level?

3.1.1 Tides

Tides are the regular rise and fall of sea levels caused by the gravitational pull of the moon and the sun. It's like the ocean breathing in and out. Mangawhai has a semi-diurnal tide, which means that there are two high tides and two low tides every 24 hours.

High and low tide water levels are not always the same – they change over time. This variation is caused by the position of the earth relative to the sun and moon. When the sun, moon, and Earth line up (during a full moon or a new moon), their gravitational pull causes the highest high tide levels and the lowest low tides. These are called spring tides. On the other hand, when the moon is at a right angle to the Earth and the sun, their gravitational pull works against each other, resulting in lower high tides and higher low tides. These are called neap tides.

So, while tides happen regularly, their heights vary depending on the alignment of the moon and sun. In Table 3.1, you find the different tide levels for Mangawhai based on T+T (2021).[1]

Table 3.1: Tidal water levels for Mangawhai

	Water level [m NZVD-16]
Mean High Water Spring (MHWS)	0.95
Mean High Water Neap (MHWN)	0.45
Mean Sea Level (MSL)	-0.14
Mean Low Water Neap (MLWN)	-0.85
Mean Low Water Spring (MLWS)	-1.25

3.1.2 Storm tide

During a storm, water levels can rise higher than under normal tidal fluctuations. This increase in water levels is known as 'storm surge' and the total water level (which is influenced by both the tides and storm surge) is known as 'storm tide'.

Storm surge occurs for two reasons. First, during a storm, strong winds can 'push' the water toward the shore, causing the sea level to rise locally. Secondly, the centre of a storm has a low air pressure, which causes the water to rise higher because there's less weight pressing down on it.

[1] Tonkin+Taylor (2021). *Coastal Flood Hazard Assessment for Northland Region 2019-2020.*

When discussing storm tide levels, we refer to the water level resulting from the combination of the tide and storm surge. To better understand the likelihood of certain storm tide levels, we often use two key concepts: Average Return Interval (ARI) and Annual Exceedance Probability (AEP).

An Average Return Interval (ARI) describes the expected frequency of a storm tide level. For example, if a storm tide level has a 50 yr ARI, it means that, on average, such a storm tide level is expected to occur once every 50 years. Larger storm tides with higher storm tide levels typically have longer ARIs because they are less likely to occur.

In addition to an ARI, we use the concept of Annual Exceedance Probability (AEP). The AEP of a storm tide level is the likelihood of that storm tide level being exceeded in any given year. AEP is the inverse of ARI: the higher the ARI, the lower the AEP. For example, a storm tide level with a 50 yr ARI would have a 2% AEP, meaning there is a 2% chance that that storm tide level will be exceeded in any given year. Different storm tide ARIs and corresponding AEPs are listed in Table 3.2.

Table 3.2: Conversion between event ARI and AEP

ARI (years)	1	2	5	10	20	50	100	500	1000
AEP (%)	63.2	39.4	18.1	9.5	4.9	2.0	1.0	0.2	0.1

Table 3.3 shows different storm tide levels for Mangawhai, each linked to different ARIs and AEPs.[2]

Table 3.3: Storm tide levels for different return periods for Mangawhai

ARI (years)	AEP (%)	Water level [m NZVD-16]
5 yr	20.0	1.4
20 yr	4.9	1.5
50 yr	2.0	1.6
100 yr	1.0	1.6

3.1.3 Waves

When waves move into shallow water, they push the water level onto the coast, including the mean water level at the shoreline. This happens because the energy from the waves piles up against the shore, creating a “higher than normal” water level. You can think of it as the surf-zone stacking up water against the coast. We call this phenomenon wave set-up.

Wave set-up is dependent on the height of the incoming waves: the higher the incoming waves, the higher the wave energy and the more the water level is pushed up. It is important to note that wave set-up is not the same as wave run-up, which is the distance that the waves themselves travel up the beach or shore. Unlike wave set-up, wave run-up is a dynamic process that varies with each wave. It is not a consistent component in the calculation of flood levels and is therefore not further considered in this document.

Wave set-up occurs close to shore, and because of this, it can be difficult to measure accurately. Tide gauges, which are commonly used to measure water levels, are usually positioned in wave sheltered locations, meaning they often don’t capture the changes caused by wave set-up near the shore. As a result, it can be challenging to get precise measurements of this phenomenon.

[2] Tonkin+Taylor (2021). *Coastal Flood Hazard Assessment for Northland Region 2019-2020.*

As a general rule-of-thumb, wave set-up is 10 - 20% of the offshore breaking wave height on an open coast. However, since Mangawhai is located inside an estuary, the wave set-up is lower. Estuaries typically experience less wave set-up compared to open coastlines, because the shallow depths and constricted entrances limit the amount of incoming wave energy. A nominal value of 0.3 – 0.4 m was adopted by T+T (2021) for Mangawhai Estuary for extreme events.[3] Inundation level is the sum of wave setup and storm tide level.

3.1.4 Sea Level Rise (SLR) and vertical land movement (VLM)

Our climate is changing, and the world is warming up. The water in our oceans takes up a large part of the additional heat, and as the water warms up, it expands. In combination with melt water from the melting of land-based ice, this leads to increasing sea levels. We call this sea level rise or SLR.

At the same time, our land does not remain in the same position either. Depending on the location, land masses either move slowly up or down. We call this vertical land movement or VLM.

When we talk about sea level rise, it is important to consider both the rise in sea level itself and the movement of the land beneath it. The combination of both sea level rise (SLR) and vertical land movement (VLM) is known as relative sea level rise (RSLR). In some areas, the land may be rising, which can partly offset the effects of sea level rise. However, in other areas, land subsidence (sinking) may worsen the impact of sea level rise. Therefore, relative sea level rise provides a more accurate measure of how sea levels are changing in a specific location, taking both SLR and VLM into account.

It is hard to predict the rate of future sea level rise, because it depends on the amount of future global greenhouse gas emissions. Over the past years, the International Panel on Climate Change (IPCC) has developed a range of scenarios and linked these to different rates of sea level rise. More information on these scenarios can be found here.

In Table 3.4, we have listed both the expected sea level rise (SLR) and relative sea level rise (RSLR) for different climate scenarios and different time horizons specifically for Mangawhai.[4] This is based on local VLM observations by NZ Sea Rise of -2.6 mm/yr (subsidence) with uncertainty of ± 2.8 mm.

[3] Tonkin+Taylor (2021). *Coastal Flood Hazard Assessment for Northland Region 2019-2020.*

[4] The values in this table are based on the predictions as reported on the NZ SeaRise website, see: Takiwa - Map Page. The values were taken from point 910. The values were adjusted such that the values are referenced to 2025, instead of 2005.

Table 3.4: Projected sea level rise (SLR) and relative sea level rise (RSLR) for different climate scenarios and different time horizons for Mangawhai

	SSP1-1.9M	SSP1-2.6M	SSP2-4.5M	SSP3-7.0M	SSP5-8.5M
	SLR **(RSLR) [m]**	SLR **(RSLR) [m]**	SLR **(RSLR) [m]**	SLR **(RSLR) [m]**	SLR **(RSLR) [m]**
2030	0.03 **(0.04)**	0.03 **(0.04)**	0.03 **(0.04)**	0.03 **(0.04)**	0.03 **(0.04)**
2040	0.06 **(0.10)**	0.07 **(0.11)**	0.08 **(0.12)**	0.09 **(0.13)**	0.10 **(0.13)**
2050	0.10 **(0.16)**	0.11 **(0.18)**	0.14 **(0.20)**	0.16 **(0.22)**	0.18 **(0.23)**
2060	0.13 **(0.23)**	0.16 **(0.26)**	0.20 **(0.29)**	0.23 **(0.33)**	0.26 **(0.35)**
2070	0.17 **(0.29)**	0.21 **(0.34)**	0.27 **(0.39)**	0.32 **(0.44)**	0.36 **(0.47)**
2080	0.21 **(0.36)**	0.26 **(0.41)**	0.34 **(0.49)**	0.41 **(0.57)**	0.48 **(0.62)**
2090	0.26 **(0.44)**	0.31 **(0.49)**	0.41 **(0.59)**	0.51 **(0.70)**	0.61 **(0.78)**
2100	0.29 **(0.50)**	0.36 **(0.57)**	0.48 **(0.69)**	0.61 **(0.85)**	0.74 **(0.94)**
2110	0.34 **(0.58)**	0.42 **(0.67)**	0.57 **(0.81)**	0.72 **(0.98)**	0.87 **(1.10)**
2120	0.38 **(0.65)**	0.48 **(0.75)**	0.65 **(0.92)**	0.84 **(1.13)**	1.02 **(1.27)**
2130	0.43 **(0.72)**	0.54 **(0.84)**	0.74 **(1.03)**	0.96 **(1.30)**	1.17 **(1.46)**

Source: The values in this table are based on the predictions as reported on the NZ SeaRise website, see: Takiwa - Map Page. The values were taken from point 910. The values were adjusted such that the values are referenced to 2025, instead of 2005.

4 Examples

4.1 Example 1 – Cyclone Gabrielle

After this explanation of the different components that make up a coastal water level, let's focus on a practical example for Mangawhai. In February 2023, cyclone Gabrielle caused high coastal water levels near Mangawhai, leading to observed flooding on Lincoln St.

Figure 4.1 shows a photo, taken at 1 pm on 13 Feb 2023, that indicates the extent of the flooding. Next to it is a screenshot from Google Maps showing the normal conditions at the same location. By comparing these photos with an elevation map of the area, we can determine that at the time the photo was taken, the water level had reached approximately 1.7 m NZVD-16.

Figure 4.1: Left – Photo taken during cyclone Gabrielle. Right –Google Maps screenshot at the same location.

The predicted high tide level was 0.65 m (NZVD) on 13 February 2023.[5] However, the measured water level at a nearby tide gauge (Marsden Point) was 1.56 m NZVD. Mean sea level is slightly higher in summer months and during February 2023, this was 10 cm above the long-term average. The remaining difference between the predicted tide and the measured water level is attributed to storm surge of 0.81 m above the predicted tide, which is the storm surge component. As shown in Table 3.3, which details the storm tide levels for different return periods, this measured storm tide level of 1.56 m (NZVD) corresponds to a return period between 20 and 100 years. The wave set-up was calculated to be 0.14 m by subtracting the storm tide level from the observed inundation level. When added to the tide and storm surge, this brought the total water level near Mangawhai to approximately 1.7 m, matching the flooding as observed in the photos.

Table 4.1: Storm water level components Cyclone Gabrielle

Cyclone Gabrielle 13 Feb 2023	
Variable	**Value**
NIWA historic tide	0.65 m NZVD
Monthly mean increment	0.10 m
Storm surge	0.81 m
Storm tide	1.56 m NZVD
Wave set-up (inner harbour)	0.14 m
Observed inundation`	1.7 m NZVE

4.1.1 What if Cyclone Gabrielle would happen in 2050?

If cyclone Gabrielle were to occur in 2050, the effects of sea level rise and vertical land movement up to 2050 would need to be considered. From Table 3.4, we can see that depending on the climate scenario, the relative sea level rise by 2050 is projected to be between 0.16 and 0.23 meters. This means that, in addition to the water levels observed during Cyclone Gabrielle in 2023, we would need to add this rise in sea level to the current water level. As a result, the total water level in 2050 could range between 1.86 and 1.93 m.

4.2 Example 2 – 1978 storm

The storm in 1978, which lasted from 18 to 23 July, was a widespread weather event that affected many coastal areas across New Zealand.[6] In Mangawhai, the storm led to a dramatic change in the morphology of Mangawhai Spit. The spit was overtopped and breached, creating a second entrance to the sea.

From historical tide data the highest tide level during the storm was estimated to be 1.14 m NZVD-16.[7] Additionally, an analysis of the 1978 storm[8] revealed that the storm surge was 0.61 m. Offshore wave heights were more than 5 m and the wave set-up along the open coastal was estimated to be 1.15 m.[9] Wave setup is expected to be lower inside Mangawhai harbour.

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[5] NIWA, (2025, January). *Tide Forecaster*. Retrieved from NIWA: NIWA Tides

[6] Hume, T.M. 2023. *Mangawhai Harbour and spit. Coastal physical processes and management.* Hume Consulting Report prepared for Mangawhai Matters Inc. 22 July 2023.

[7] NIWA, (2025, January). *Tide Forecaster*. Retrieved from NIWA: NIWA Tides.

[8] Frisby and Goldberg, 1981*. Storm wave run-up levels at Onepoto Bay, East Coast, North Island, New Zealand.* Water and Soil Technical Publication. Volume 21, pages 59-63.

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

Furthermore, it was reported that the runoff from the surrounding catchment likely contributed to a significant increase of the volume of water in the estuary, raising the water level by 0.2 m.[10]

Taken together, these factors would have resulted in an inundation level of at approximately 1.95 m NZVD inside the harbour (excluding wave set-up). Although there is some error in adding up these values due to limited measured data during the event.

Table 4.2: Storm water level components for 1978 storm

Storm 18-23 July 1978	
Variable	**Value**
NIWA historic tide	1.1 m NZVD
Storm surge	0.6 m
Additional water level due to catchment runoff	0.2 m
Estimated total inundation level	1.9 m NZVD
Wave set-up (Ocean Coast)	1.2 m

The relative sea level rise between 1978 and the present is uncertain, making it difficult to predict the coastal water level if the 1978 storm were to occur in 2050. However, by referring to the look-up tables in the next section, we can determine that a coastal water level of 1.9 NZVD will be less extreme in the future. Under the SSP3-7.0 climate scenario, such a coastal water level corresponds to a 5-yr ARI coastal water level in 2050 (see Table 5.2).

5 Inundation scenarios

The Mangawhai coastal inundation viewer is setup to be agnostic of specific timeframes and climate change pathways. The user can load any level between 0 – 3.5 mRL, allowing selection of a suitable layer for most scenarios of interest. To guide the selection of an inundation for commonly adopted scenarios, a range of look up tables are provided so users can track how tide and inundation levels are adjusted under different climate change pathways. The inundation levels include storm tide level and wave setup, based on T+T (2021).

Using these tables, you will be able to look up the coastal water level that can be expected among a range of climate scenarios, time frames and storms. In Table 5.1, Table 5.2 and Table 5.3, we have included the tidal water levels (i.e. MHWS, MSL, and MLWS) and the inundation levels for different return periods (i.e. 5, 10, 20, 50, 100, and 200 years) for different years in the future, under different climate scenarios.

You can also have a look at these tables in the inundation viewer itself. Click under one of the icons under ‘Future water levels’ to display the same tables.

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

Table 5.1: Tide and inundation levels for different return periods and timeframes, as expected under climate scenario SSP2-4.5

SSP2-4.5	Tide levels (NZVD-16)			Inundation levels (NZVD-16)			
	MLWS	MSL	MHWS	5 yr ARI (18 % AEP)	20 yr ARI (5 % AEP)	50 yr ARI (2 % AEP)	100 yr ARI (1 % AEP)
Present-day	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2030	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2040	-1.1	0	1.1	1.9	1.9	2.0	2.1
2050	-1.1	0.1	1.1	1.9	2.0	2.1	2.2
2060	-1.0	0.1	1.2	2.0	2.1	2.2	2.3
2070	-0.9	0.2	1.3	2.1	2.2	2.3	2.4
2080	-0.8	0.3	1.4	2.2	2.3	2.4	2.5
2090	-0.7	0.4	1.5	2.3	2.4	2.5	2.6
2100	-0.6	0.5	1.6	2.4	2.5	2.6	2.7
2110	-0.4	0.7	1.8	2.5	2.6	2.7	2.8
2120	-0.3	0.8	1.9	2.6	2.7	2.8	2.9
2130	-0.2	0.9	2.0	2.7	2.8	2.9	3.0

Note: The water levels in this table are calculated by adding the RSLR as listed in Table 3.4. Inundation is storm tide level plus wave setup consistent with T+T (2021).

Table 5.2: Tide and inundation levels for different return periods and timeframes, as expected under climate scenario SSP3-7.0

SSP3-7.0	Tide levels (NZVD-16)			Inundation levels (NZVD-16)			
	MLWS	MSL	MHWS	5 yr ARI (18 % AEP)	20 yr ARI (5 % AEP)	50 yr ARI (2 % AEP)	100 yr ARI (1 % AEP)
Present-day	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2030	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2040	-1.1	0	1.1	1.8	1.9	2.0	2.1
2050	-1.0	0.1	1.2	1.9	2.0	2.1	2.2
2060	-0.9	0.2	1.3	2.0	2.1	2.2	2.3
2070	-0.8	0.3	1.4	2.1	2.2	2.3	2.4
2080	-0.7	0.4	1.5	2.3	2.4	2.5	2.6
2090	-0.6	0.6	1.6	2.4	2.5	2.6	2.7
2100	-0.4	0.7	1.8	2.5	2.6	2.7	2.8
2110	-0.3	0.8	1.9	2.7	2.8	2.9	3.0
2120	-0.1	1.0	2.1	2.8	2.9	3.0	3.1
2130	0.0	1.2	2.2	3.0	3.1	3.2	3.3

Note: The water levels in this table are calculated by adding the RSLR as listed in Table 3.4. Inundation is storm tide level plus wave setup consistent with T+T (2021).

Table 5.3: Tide and inundation levels for different return periods and timeframes, as expected under climate scenario SSP5-8.5

SSP5-8.5	Tide levels (NZVD-16)			Inundation levels (NZVD-16)			
	MLWS	MSL	MHWS	5 yr ARI (18 % AEP)	20 yr ARI (5 % AEP)	50 yr ARI (2 % AEP)	100 yr ARI (1 % AEP)
Present-day	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2030	-1.2	-0.1	1.0	1.7	1.8	1.9	2.0
2040	-1.1	0	1.1	1.8	1.9	2.0	2.1
2050	-1.0	0.1	1.2	1.9	2.0	2.1	2.2
2060	-0.9	0.2	1.3	2.1	2.2	2.3	2.4
2070	-0.8	0.3	1.4	2.2	2.3	2.4	2.5
2080	-0.6	0.5	1.6	2.3	2.4	2.5	2.6
2090	-0.5	0.6	1.7	2.5	2.6	2.7	2.8
2100	-0.3	0.8	1.9	2.6	2.7	2.8	2.9
2110	-0.1	1.0	2.1	2.8	2.9	3.0	3.1
2120	0.0	1.1	2.2	3.0	3.1	3.2	3.3
2130	0.2	1.3	2.4	3.2	3.3	3.4	3.5

Note: The water levels in this table are calculated by adding the RSLR as listed in Table 3.4. Inundation is storm tide level plus wave setup consistent with T+T (2021).

6 Applicability

This report has been prepared for the exclusive use of our client Mangawhai Matters Incorporated, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
	
....	....
Martine Rottink Coastal Engineer	Richard Reinen-Hamill Project Director

Technical Review by Dr Eddie Beetham

7-Apr-25
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