Tasman Resource Management Plan- Plan Change 79: Deferred Zoning – Appendix 4 to Section 32 Report

Section 32 Report Appendix 4: Coastal inundation

1 Introduction

This appendix details how coastal inundation and sea-level rise has been considered in relation to low-lying coastal sites included in Plan Change 79. The appendix is structured as follows:

- Sections 2 and 3 sets out the legislative requirements and national guidance for coastal hazards management, including the associated climate change scenarios.
- Section 4 and 5 details Council's 'bathtub' modelling and the assessment completed to determine Plan Change 79 sites that are susceptible to coastal inundation over the longer term.
- Section 6 describes the methodology to determine the Lower Queen Street Light Industrial Zone (Schedule 17.4A) 'trigger' for expiry of limited-duration land use resource consents.
- Section 7 is a list of references used in this appendix.

2 Legislative Requirements

2.1 Resource Management Act 1991 and coastal hazard management

The Resource Management Act 1991 (RMA 1991) Sections 61, 66, and 74 specify a number of matters to be considered by councils when preparing or changing their regional policy statements and regional and district plans. These requirements are relevant to Plan Change 79, specifically in relation to assessing the impacts from relative sea-level rise and coastal storms for coastal areas facing irreversible and ongoing sea-level rise. Policy statements or plans are to be prepared or changed:

(a) In accordance with the provisions of **Part 2 of the RMA 1991**, with relevant sections being:

- Section 5: Purpose – The purpose of this Act is to promote the sustainable management of natural and physical resources, whereby 'sustainable management' means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety…
- Section 6: Matters of National Importance – (h) the management of significant risks from natural hazards.
- Section 7: Other Matters – (i) the effects of climate change.

(b) In accordance with the **New Zealand Coastal Policy Statement 2010 (NZCPS)**. One of the NZCPS's goals is to manage coastal hazards and climate change risks to avoid increasing the risk of adverse effects. The risk from coastal hazards over at least 100 years must be identified. Objective 5 seeks to ensure that coastal hazard risks, taking account of climate change, are managed including by locating new development away from areas prone to such risks. Key NZCPS policies are:

- Policy 3 Precautionary Approach
- Policy 24 Identification of coastal hazards
- Policy 25 Subdivision, use, and development in areas of coastal hazard risk
- Policy 26 Natural defences against coastal hazards
- Policy 27 Strategies for protecting significant existing development from coastal hazard risk

(c) Having regard to the **National Adaptation Plan 2022**. The first national adaptation plan (2022 NAP) contains Government-led strategies, policies and proposals that will help New Zealanders adapt to the changing climate and its effects.

The 2022 NAP states that when making or changing policy statements or plans under the RMA 1991, councils should use recommended climate change scenarios (as a minimum) to identify and assess risk from coastal hazards and the effects of climate change. Councils should screen for hazards and risks in coastal areas using the SSP5-8.5 scenario and use at least two IPCC scenarios[1] (SSP2-4.5 and SSP5-8.5) for detailed hazard and risk assessments, adding the relevant rate of vertical land movement (VLM) locally. Additionally, the 2022 NAP recommends councils should stress-test plans, policies and strategies using a range of scenarios as relevant to the circumstances.

2.2 Coastal Hazards and Climate Change Guidance 2024

NZCPS Policy 24 Identification of Coastal Hazards requires councils to 'take into account national guidance and the best available information on the likely effects of climate change on the region or district'. Of relevance are the Ministry for the Environment's Coastal Hazards and Climate Change Guidance (February 2024), in conjunction with the NZ SeaRise: Te Tai Pari O Aotearoa programme (launched 2022).

Since the early 2000s, the Ministry for the Environment has provided guidance to councils on adapting to coastal hazards and the risks presented from climate change, particularly sea-level rise. The 2017 Coastal Hazards and Climate Change Guidance introduced a 10-step decision making process for councils to work with their communities to develop long-term adaptive planning strategies to respond to coastal hazards and sea-level rise. The 2024 Guidance revises the 2017 publication with a number of updates, including advances in sea-level rise science and global projections[2] and the application of vertical land movement (VLM) – as displayed on the NZ SeaRise online platform.

Through the Council's 'Coastal Management Project' work programme (2019-2022) staff progressed initial work to help inform the development of an adaptive planning strategy following the 2017

[1] The Intergovernmental Panel on Climate Change (IPCC) have developed five climate change scenarios, being SSP1-1.9, SSP2-2.6 M, SSP2-4.5 M, SSP3-7.0, and SSP5-8.5. The scenarios span a wide range of plausible futures, from 1.5 degrees Celsius 'best-case' low-emissions scenario (SSP1-1.9) to over 4 degrees Celsius warming scenario (SSP5-8.5) by 2100 (2024 Guidance).

[2] Based on the 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report sea level data, downscaled to Aotearoa New Zealand.

Guidance. This included release of an online coastal hazards map viewer (2019), coastal hazards risk assessment (2020), and educational engagement on high-level coastal management options (2021). However, the work programme was paused in 2022 for reasons including the uncertainty around the resource management system reform. Funding was allocated in the 2024 Long Term Plan for a 'community adaptation planning' work programme which will replace and expand on the Coastal Management Project by taking an all-hazards approach. The coastal hazards element of the work programme will nonetheless incorporate best practice from the 2024 Guidance.

While some initial work has been completed, the Council is yet to prepare an adaptive planning strategy or local community adaptation plans. In these circumstances, the 2024 Guidance provides recommended relative sea-level rise[3] (RSLR) allowances for councils to use in decision-making processes (e.g., plan making and land-use decisions) in the interim until such time that a council and their community have developed an adaptive planning strategy. These RSLR allowances form a precautionary initial planning and design response and is consistent with the precautionary approach set out in the NZCPS Policy 3[4].

The 2024 Guidance (page 51) states "*For making interim decisions on new coastal development or infrastructure and change in land use, such as intensification and upzoning, the precautionary interim allowance recommended (before an adaptive planning strategy is developed) is to use the SSP5-8.5 H+ based RSLR projection to identify areas 'potentially affected'[5] by coastal hazards and climate change. Timeframes are also informed by the risk of being affected by coastal hazards, with greater or longer-term investments, such as infrastructure or new suburbs, needing assessment over at least a 100-year period out to 2130.*"

Table 1 below shows the recommended precautionary RSLR projections to use as interim allowances, sourced from the 2024 Guidance.

Table 1: Interim precautionary relative sea-level rise allowances recommended to use for coastal planning and policy before undertaking a dynamic adaptive pathways planning approach for a precinct, district or region (Source: Table 8, pages 52-53 of the 2024 Guidance).

Planning category	Recommended interim precautionary RSLR allowances
A. Coastal subdivision, greenfield developments and major new infrastructure	Using a **timeframe** out to **2130** (≥100 years), apply the *medium confidence* **SSP5-8.5 H+** based RSLR projection* that includes the relevant VLM rate for the local and/or regional area. (Note: approximately 1.6 metre rise in MSL, before including VLM.)

[3] The 2024 Guidance (page 42) describes relative sea level rise as the net rise in mean sea level from both: i) the absolute rise in height of sea level; and ii) local vertical land movement. It is therefore the net rise in sea level relative to the local land surface or sea-bed elevation on which assets and people are placed.

[4] NZCPS Policy 3 Precautionary Approach:

(1) Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse.

(2) In particular, adopt a precautionary approach to use and management of coastal resources potentially vulnerable to effects from climate change, so that:
   - (a) Avoidable social and economic loss and harm to communities does not occur;
   - (b) Natural adjustments for coastal processes, natural defences, ecosystems, habitat and species are allowed to occur; and
   - (c) The natural character, public access, amenity and other values of the coastal environment meet the needs of future generations.

[5] As referenced in the New Zealand Coastal Policy Statement Policy 24: Identification of coastal hazards.

B. Changes in land use and redevelopment (intensification and upzoning)	Using a **timeframe** out to **2130** (≥100 years), apply the *medium confidence* **SSP5-8.5 H+** based RSLR projection* that includes the relevant VLM rate for the local and/or regional area. (Note: approximately 1.6 metre rise in MSL, before including VLM.)
C. Land-use planning controls for existing coastal uses and assets (building additions)	Using a **timeframe** out to **2130** (≥100 years), apply the *medium confidence* **SSP5-8.5 M** based RSLR projection that includes the relevant VLM rate for the local and/or regional area. (Note: approximately 1.2 metre rise in MSL, before including VLM.
D. Non-habitable, short-lived assets with a functional need to be at the coast, which are either low consequences or readily adaptable (including services)	Using a **timeframe** out to **2075** (≥50 years), apply the *medium confidence* **SSP5-8.5 M** based RSLR projection that includes the relevant VLM rate for the local and/or regional area. (Note: approximately 0.5 metre rise in MSL, before including VLM.)

Notes for Table 1:

* H+ is the 83rd percentile (or p83 at the top of the likely range on graphs in the NZ SeaRise platform).

i) Relative sea-level rise (SLR) projections that include satellite-derived vertical land movement (VLM) are available from the NZ SeaRise platform. Alternatively, locally monitored VLM can be applied to the SLR projections.

ii) M = median or p50 (50th percentile); MSL = mean sea level; RSLR = relative sea-level rise; SSP = shared socio-economic pathway used by the Intergovernmental Panel on Climate Change; VLM = vertical land movement.

The approximate rise in MSL can be considered broadly representative across Aotearoa New Zealand, because the absolute SLR from north to south only varies by ± 0.025 metres by 2150 (relative to the central location).

3 Climate Change Scenario Applied

IPCC's five shared socio-economic pathways (SSPs) each present a different scenario of how future societal choices, demographics, and economics will influence greenhouse gas emissions. The emissions under each SSP will in turn influence the amount of energy that is trapped in the atmosphere by greenhouse gasses, a process referred to as radiative forcing.

The best way to minimise and reduce long-term coastal hazard risk is to avoid areas that are, or will become, exposed to coastal hazards and sea-level rise. This will avoid costly and avoidable risk which the Council and community would otherwise have to address in the future. To inform Plan Change 79, the Council has screened for hazards and risks in coastal areas using the SSP5-8.5 climate change scenario – both the M (medium, 50^{th} percentile or *p50*) and the upper-bound H+ (83^{rd} percentile or *p83*) (see Table 2).

Table 2: Climate Change Scenarios

Year	Scenario	Confidence Level
2130	• SSP5-8.5 M including VLM • **SSP5-8.5 H+ including VLM**	Medium

SSP5-8.5 is a very high emissions scenario in which the global economy grows rapidly on the back of CO_2 emissions that double by 2050 and triple by 2100. SSP5-8.5 projects a radiative forcing of

8.5 W m^{-2} at the end of the century, with a consequently large temperature increase of over 4°C by 2100. The warming of the Earth system under the scenarios results in sea-level rise due to changes in terrestrial water storage, the melting of land-based ice, and the thermal expansion of ocean water (Figure 4). The 2024 Guidance recommends the use of this high-end emissions scenario in coastal planning. This is to reflect that the world has been on a high emissions trajectory in the past few decades, combined with the very long timeframes for sea-level rise to respond to released emissions and the deep uncertainty about future emissions and tipping points[6].

Sea-level rise projections under each of the climate change scenarios have been produced by the NZ SeaRise programme (e.g., Levy et. al, 2020). Use of these projections is supported by NZCPS Policy 24 which recommends the use of best available information on the likely effects of climate change.

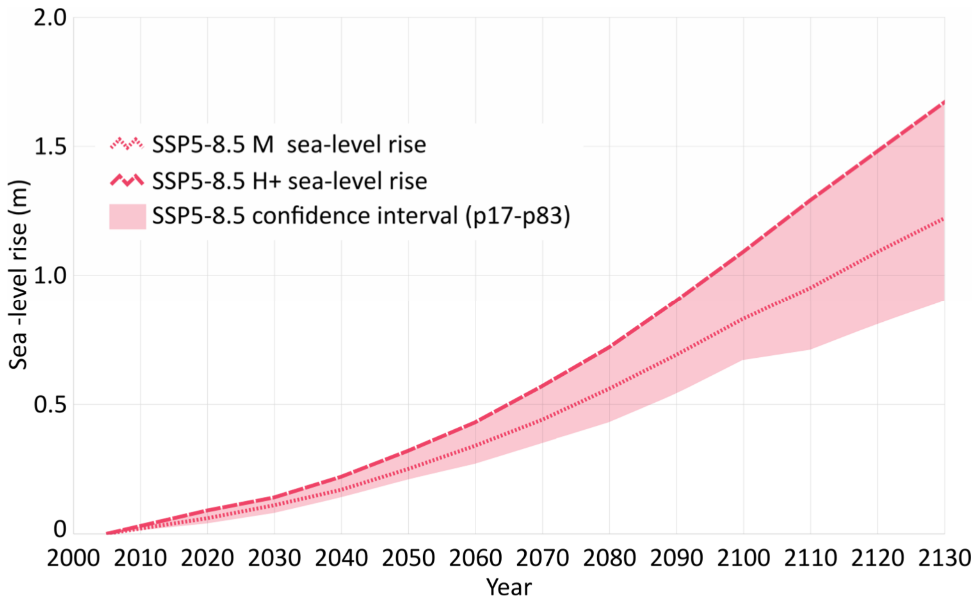

Figure 1: Example for Separation Point (NZ SeaRise site 6361) of SLR under SSP5-8.5. The H+ scenario for SSP5-8.5 corresponds to the upper margin of the red-shaded confidence interval (p17-p83).

Council's screening process has been used to identify localities at high risk of being affected by coastal inundation over the next 100 years (as required by NZCPS Policy 24), considering both long-term and more imminent areas at high risk. To determine the landward boundary for each location for assessing the impacts from relative sea-level rise and coastal storms the SSP5-8.5 H+ scenario has been applied (using the precautionary approach supported by NZCPS Policy 3). In doing so, Council has given regard to the 2022 NAP and taken into account the 2024 Guidance.

4 Bathtub modelling

Council has used 'bathtub' modelling to visualise the areas susceptible to coastal inundation from sea-level rise and coastal storms under the SSP5-8.5 climate change scenario (Table 1). Bathtub modelling is so named because it treats the ocean like a bathtub that fills up when water is added.

[6] For more information, refer to 'Box 3: Should the high-end SSP5-8.5 scenario be used in coastal planning?' on page 41 of the 2024 Guidance.

Bathtub modelling maps areas as susceptible to inundation where land elevations are at or below the inundation level that is being mapped. Land elevations are derived from LiDAR surveys of the coast, where land elevations are measured by laser pulses from a plane. Different inundation levels can be mapped for different amounts of relative sea-level rise and/or storm events of different magnitudes. Areas mapped as susceptible to inundation may be either directly connected to the ocean (e.g., via drains or other waterways), or may be disconnected, being at a low elevation but not directly connected to the ocean (Figure 2). Disconnected areas may still be susceptible to inundation as relative sea-level rises despite not being directly connected to the ocean, due to difficulties in evacuating stormwater from these areas. In the same way that water that fills a bathtub is still and does not have waves, bathtub mapping is for a 'static' water level that does not include factors that can dynamically change water levels such as waves and currents.

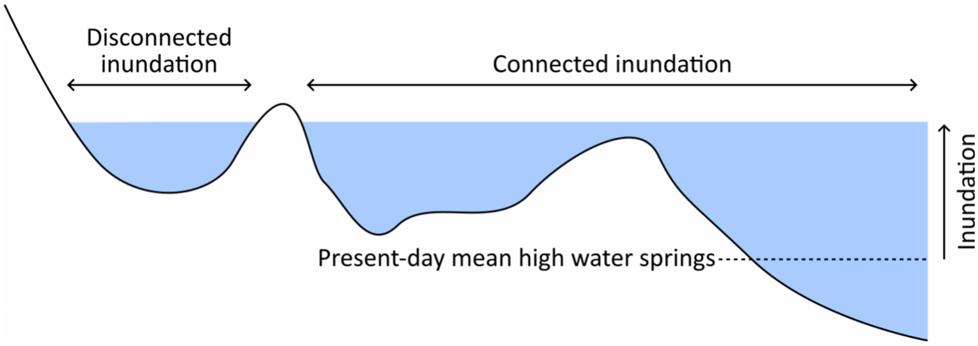

Figure 2: A conceptual illustration of an elevation cross-section of a coastal location where bathtub modelling has been used to identify areas susceptible to inundation due to relative sea-level rise. Areas of connected inundation are directly connected to the present-day coast, while areas of disconnected inundation are not directly connected but are at or below the elevation that may be inundated.

Council's bathtub modelling displays relative sea-leave rise in 0.5m increments up to 2.0m on the online coastal hazards map viewer.

5 Assessment

For each site the assessment of potential impacts of coastal inundation from sea-level rise and coastal storms has involved consideration of the following elements:

(1) relative sea-level rise (due to future climate change using SSP5-8.5 M and H+ scenarios, and vertical land movement).
(2) extreme storm events (1% AEP), including the effects of storm tide and wave setup.

Additionally, to determine the landward boundary of the area susceptible to inundation for planning purposes (e.g. the application of planning objectives, policies and rules), a third consideration was also included:

(3) a 'factor of safety', to account for unknown factors and potential uncertainties.

This is summarised as the following:

Year	Screening Assessment	Landward Boundary of area susceptible to coastal inundation for Planning Purposes

2130	• Relative sea level rise (SSP5-8.5 M including VLM), and 1% AEP coastal storm (storm tide and wave setup) • Relative sea level rise (SSP5-8.5H+ including VLM), and 1% AEP coastal storm (storm tide and wave setup)	Relative sea level rise (SSP5-8.5H+ including VLM), 1% AEP coastal storm (storm tide and wave setup), and 'factor of safety'

Each of the elements used in the screening assessment and to determine the landward boundary for planning purposes are explained in the next sections. Figure 3 provides an illustration of the elements of coastal inundation included within the bathtub modelling and screening assessments.

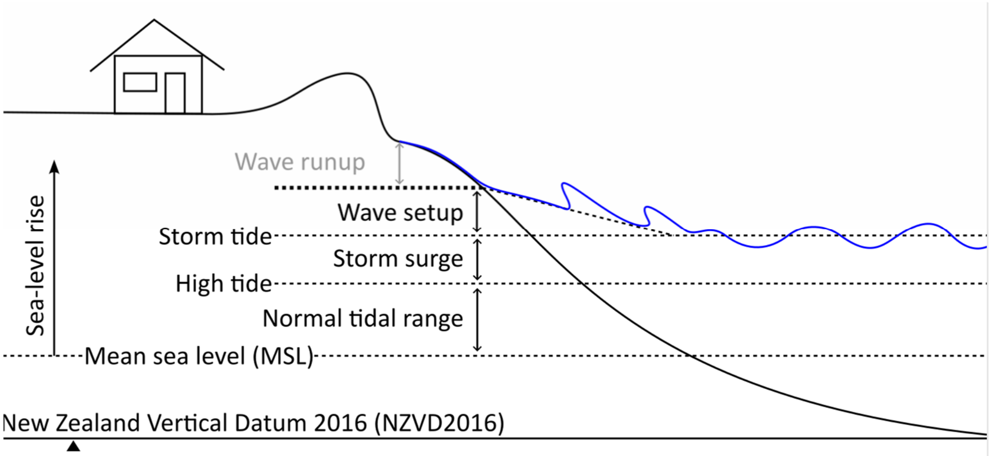

Figure 3: Conceptual illustration of the elements of coastal inundation included within the bathtub modelling and screening assessments. Wave runup is shown in light grey as while this is a component of coastal inundation it is not included within the bathtub modelling and screening assessment.

5.1 Relative sea-level rise

Relative sea-level rise includes both the effects of sea-level rise due to projected future climate change and the effects of vertical land movement.

5.2 Future climate and sea-level rise

The landward boundary of the area susceptible to inundation considers relative sea-level rise under the SSP5-8.5 H+ scenario, while the screening assessment considers sea-level rise under both SSP5-8.5 M and SSP5-8.5 H+. Both have been undertaken for the year 2130.

For Tasman, at 2130 the median sea-level rise projection for SSP5-8.5 is 1.21-1.22 m, while the projected H+ (*p83*) sea-level rise for SSP5-8.5 is 1.66-1.67 m. There is some very minor spatial variability in SSP5-8.5 sea-level rise projections across the district, with values increasing by one-centimetre in the very north of the district compared to the south.

5.3 Vertical land movement

Relative sea-level change can be driven by a change in the level of the ocean or vertical movement of the land. Where the land is subsiding, this increases rates of relative sea-level rise (Figure 3). Following the 2022 NAP and 2024 Guidance, VLM is added onto the projected future sea-level rise for both the screening assessment and to determine the landward boundary of the area susceptible to coastal inundation. For the bathtub mapping at the district-scale the rates of VLM produced by the NZ SeaRise programme for sites every 2 km along the coastline have been averaged across sections of the coast. These sections correspond to areas of the coastline that have broadly similar shoreline characteristics and storm inundation levels, as well as similar rates of VLM, and are largely similar to the coastal cells used in the report Coastal Hazards Assessment in Tasman Bay/Te Tai o Aorere and Golden Bay/Mohua (Tasman District Council, 2019). Subsidence is experienced across the district, with the averaged rates of VLM ranging from 4.00 mm yr^{-1} near Richmond to 0.41 mm yr^{-1} at Patons Rock. These rates of subsidence have the effect of increasing the rates sea-level rise experienced along the coast (Figures 4 and 5).

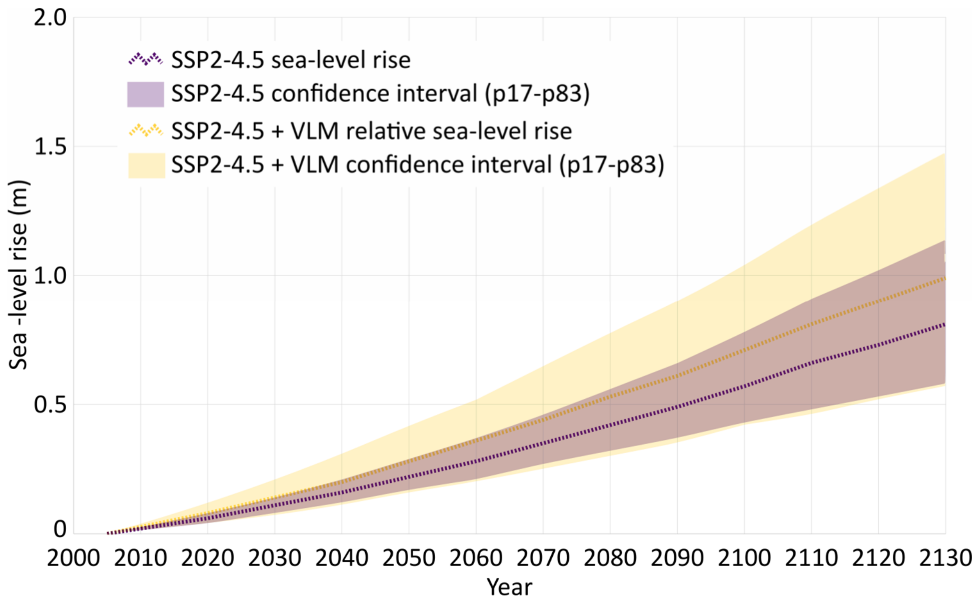

Figure 4: Example for Separation Point (NZ SeaRise site 6361) site showing the effect that subsidence (VLM) has on the rate of relative sea-level rise projected for the site under SSP2-4.5.

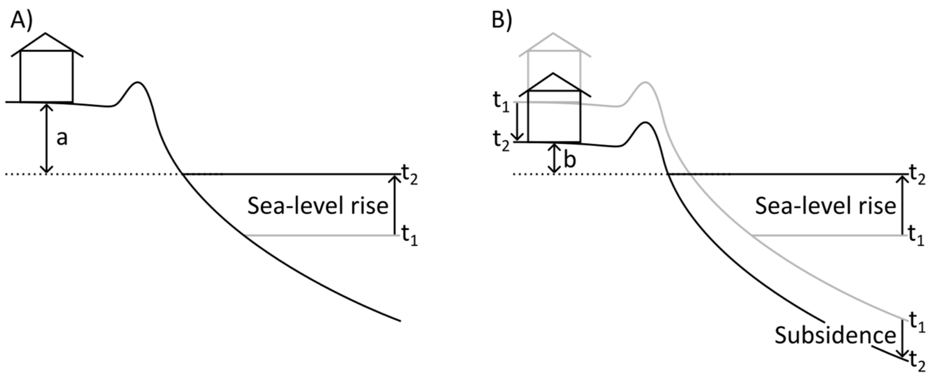

Figure 5: Conceptual illustration showing the effect of subsidence on relative sea-level rise. (A) Sea-level rises between two points in time t_1 and t_2 without any vertical land movement. (B) Sea-level rises the same amount between the same two points in time, while at the same time the land subsides. From the point of view of someone on the land, the sea-level has risen much more in (B) compared to (A)—this can be seen by comparing the difference in the height of the sea at t_2 with respect to the house, distance (a) compared to distance (b).

5.4 Extreme storm events

Extreme storm events inundate low-lying areas of the coast, with sea-level rise progressively increasing the height reached by storm surge and wave setup processes (Figure 3). Storm surge is the elevation in ocean water levels along the coast produced by the low air pressure and strong onshore winds that accompany storms. The height reached by the storm surge above the predicted tide level is referred to as the storm tide (Figure 3). Wave setup is a component of storm inundation that is caused by water being pushed up along the shoreline by the transfer and release of energy from waves breaking at the coast.

For open coast sites storm tide and wave setup values have been taken from the NIWA Coastal Calculator (March 2024 version). For sheltered estuary sites storm tide values have also been taken from the NIWA Coastal Calculator (March 2024 version) and correspond to the storm tide value for the open coast adjacent to the estuary, while wave setup values follow the methodology applied in the report Coastal Hazards Assessment in Tasman Bay/Te Tai o Aorere and Golden Bay/Mohua (Tasman District Council, 2019). The 1% AEP storm tide elevation is approximately 2.43 m NZVD2016[7] in Golden Bay (approximately 0.70 m above mean high water springs, MHWS), and approximately 2.35 m NZVD2016 in Tasman Bay (approximately 0.65 m above MHWS). Wave setup varies from 0.2 m in sheltered estuary locations across Golden and Tasman Bays, to a maximum of 0.71 m at Tata Beach.

Wave runup is not included in the static inundation levels used for the bathtub modelling as runup is a dynamic wave effect that is highly site-specific.

5.5 Factor of safety

A factor of safety of 0.50 m has also been added above the projected 2130 static inundation level to account for unknown factors and potential uncertainties:

- ***Uncertainties and variations in the rates of VLM***. The NZ SeaRise Programme has published rates of VLM for locations every 2 km around the New Zealand coastline. These rates of VLM are averages of all the VLM estimates within 5 km of the averaging location. Error estimates and the maximum and minimum VLM estimate are provided for each average VLM rate. In Tasman and Golden Bays the error estimates range from 0.62 mm a^{-1} near Puponga, to a maximum of 2.86 mm a^{-1} near Tamatea Point. Over 100 years, these rates compound to an uncertainty of between 0.06-0.29 m. VLM rates have been averaged for sections of the coastline with broadly similar shoreline characteristics, storm inundation levels, and rates of VLM. However, in some areas local rates of VLM may be higher than the average rate used for the bathtub modelling.

- ***Vertical uncertainties with the land elevations represented by the LiDAR elevation surface***. This vertical uncertainty is typically ~0.15-0.20 m (e.g., LINZ 2020, 2022).

- ***Uncertainties with projections of storm-tide and wave setup elevation***. Storm-tide and wave setup values have been derived from the NIWA Coastal Calculator for Tasman and Nelson Districts for sections of the coast that have broadly similar shoreline characteristics and wave climate. The Coastal Calculator presents the central (best) estimate of storm-tide plus wave setup. The upper 95% confidence interval of the extreme wave analysis is typically 0.02-0.04 m greater than the central (best) estimate. Wave setup is calculated using an empirical relationship between beach slope and offshore significant wave height—wave setup is therefore highly sensitive to beach slope. For localities where the local beach slope is steeper than the representative beach slope used for that section of the coast local wave setup will be underestimated.

[7] New Zealand Vertical Datum 2016.

- ***Omission of dynamic components of inundation from storms such as wave runup***. The bathtub modelling approach deliberately does not include dynamic components of inundation from storms such as wave runup. Wave runup is principally of concern to locations close to the coastline. However, when considering a 100-year timeframe out to the year 2130, it is not clear where the coastline may be at 2130. For areas close to the coastline at 2130, the static bathtub water level will therefore underestimate susceptibility to inundation during coastal storms.

6 Lower Queen Street Light Industrial Zone (Schedule 17.4A) trigger for expiry of limited-duration land use resource consents

6.1 Introduction

The landward boundary of the area susceptible to inundation by 2130 crosses through two blocks of land located on the southwest side of Lower Queen Street, between McShane Road and Swamp Road. In this area, through Plan Change 79 the Council is seeking to enable appropriate land uses in accordance with the RMA 1991 (particularly s6(h), s7(i)) and the NZCPS). The notified Plan Change 79 framework for Schedule 17.4A enables appropriate land uses including activities and buildings that are temporary, relocatable, or readily removable in the short- to medium-term. The planning framework seeks to enable use of the area in the short- to medium-term while recognising that as sea levels continue rise and coastal and rainfall hazards increase it will become increasingly necessary for land use activities to accommodate and/or retreat from this location. The planning framework provides for limited-duration resource consents that are based around a trigger (decision point), being a nominated amount of relative sea-level rise. When that trigger is reached, existing resource consents will expire after a 12-month period. This timeframe will enable landowners/occupiers enough time to implement response options for their circumstances, for example relocate to another location and remediate their site, or apply for a new resource consent to remain on site for a further limited duration.

A key point is that when the trigger level is reached, it does not necessarily require the land use to cease, rather a specific 'exit plan' may be developed and implemented through the resource consent process for the particular land use. This can take into account the specific circumstances of the locality, the resilience of the particular land use being undertaken, and the ability to manage coastal and stormwater hazards on the site.

The proposed trigger level is specific to the Lower Queen Street Schedule 17.4A location. It is intentionally set at a sea level where the daily tides are yet to directly affect the land, recognising that it is the additional effects of adverse weather events (storms) further elevating sea levels through wave action and storm surge, as well as rainfall generated stormwater flows, that will directly impact activities on these properties. The trigger is a level of the sea that excludes the effects of storms and waves. At the time the trigger is reached, storms and waves coinciding with high tides will result in inundation levels higher than the trigger level. Storm surge and wave setup can add a further 0.6 metres and wave run up can inundated even higher elevations. An implication of this is that the site will be impacted during storms well before the trigger level is reached. The site is currently impacted during extreme sea level events, as demonstrated during ex-tropical cyclone Fehi in February 2018.

The recommended trigger uses relative sea-level measured at either the Port Nelson or Little Kaiteriteri tide gauges. For assessing future sea-level at the tide gauges, mean sea-level should be averaged over a 10-year period. If the Port Nelson tide gauge is used the trigger is 0.26 m of relative sea-level rise above average MSL for the period 2013-2022. If the Little Kaiteriteri tide gauge is used the trigger is 0.30 m of relative sea-level rise above average MSL for the period 2013-2022. Council has determined that when the trigger is met at either of these tide gauges relative sea-level in the Lower Queen Street area will have risen approximately 0.33 m. The following sections details the methodology used to determine this trigger.

6.2 Components for determining a trigger amount of relative sea-level rise

For development within the Schedule 17.4A location, an amount of relative sea-level rise has been nominated that would trigger expiration of existing land use resource consents and for landowners to evaluate their response options (e.g. relocate or reapply for a consent). The trigger is based on:

- Land elevations of the site and of the adjacent road that forms a modest barrier to coastal processes;
- Current mean sea-level and tidal levels;
- Predicted inundation levels from coastal storms and effects of historic storms;

Because in practice the trigger will be evaluated using a tide gauge record some distance from Lower Queen Street (both the Port Nelson and Little Kaiteriteri tide gauges are options), the trigger amount of relative sea-level rise must be modulated or adjusted to allow for differing rates of vertical land movement between the tide gauge and Lower Queen Street.

6.2.1 Assumptions and best available information for developing a trigger

The development of this trigger relies on several assumptions and use of best available information:

- As there is no tide gauge at Lower Queen Street, tide recorders at other locations have to be used. It is assumed that sea-surface height is the same between Lower Queen Street and both the Little Kaiteriteri and Port Nelson tide gauges.
- It is assumed that rates of vertical land movement from the NZ SeaRise Project will continue unchanged into the future.
- It is assumed that rates of relative sea-level rise calculated by Andrews (2023) include the rates of vertical land movement measured by the NZ SeaRise Project.
- There is limited understanding of wave setup in Waimea Inlet, and values of 0.2-0.3 m have been assumed from previous studies (TDC 2019; Haughey and Clarke, 2022). Wave runup has not been quantified in this study, which is a gap.
- The trigger is not informed by stormwater modelling or information on the degree of ponding during rain events.

6.2.2 Land elevations

Land elevations on these sites are highest in the southern corner at around 7.4 m NZVD2016, falling gradually to the north with a low of approximately 2.0 m NZVD2016 on the southern side of the Lower Queen Street road formation (Figure 6). The road formation is slightly higher at around 3.0 m NZVD2016, though the elevation of the crest of the road varies slightly along its length from approximately 2.8-3.1 m NZVD2016. The road forms a modest elevated barrier that provides limited protection to the site from storm surge and waves in Waimea Inlet.

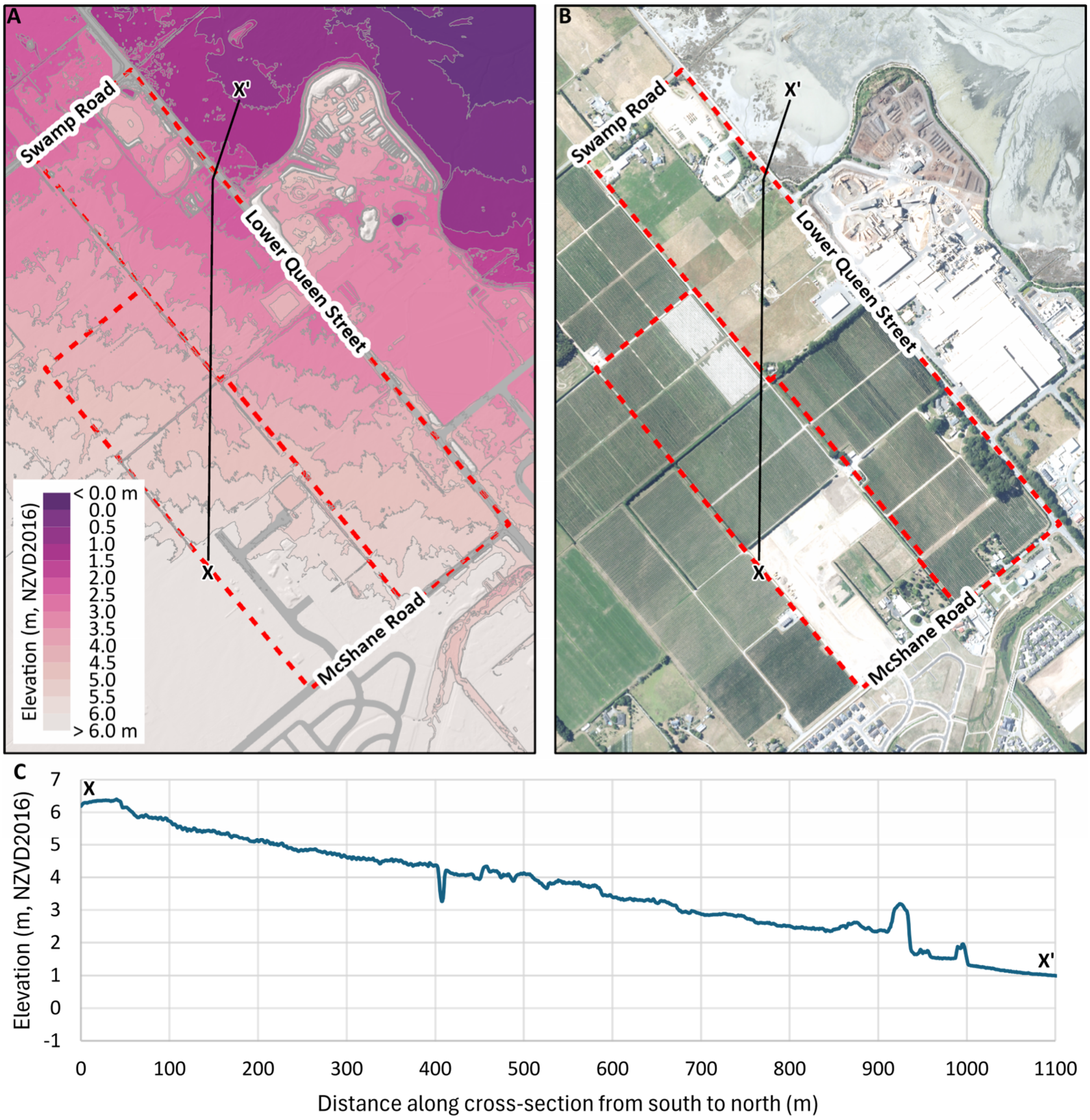

Figure 6: Map of the Lower Queen Street area. (A) Elevations across the sites, with a gradual fall in land elevations northward towards the margin of Waimea Inlet. An elevation cross-section runs along the line from X-X'. (B) Aerial photo of the area. (C) Elevation cross-section from X-X'.

6.2.3 Rates of vertical land movement (VLM)

The coastline of Tasman District is subsiding, which has the effect of increasing the rate of relative sea-level rise experienced along the coast. For the area of Lower Queen Street east of Swamp Road, the average rate of subsidence measured by the NZ SeaRise Project is 4.00 mm a^{-1} (the average of the three NZ SeaRise Project sites 6471-6473). Based on NZ SeaRise Project VLM measurements the tide gauges at Little Kaiteriteri and Port Nelson are also subsiding, though at lower rates. The average rate of subsidence for the Little Kaiteriteri tide gauge is 2.82 mm a^{-1} (the average of NZ SeaRise Project sites 6409 and 6410), while the average rate of subsidence for the Port Nelson tide gauge is 2.25 mm a^{-1} (the average of the three NZ SeaRise Project sites 6484-6846). These differences in the rates of vertical land movement mean that the Lower Queen Street area is subsiding at approximately 1.8 mm a^{-1} faster than the Port Nelson tide gauge, and at approximately 1.2 mm a^{-1} faster than the Little Kaiteriteri tide gauge. The rate of relative sea-level rise is therefore higher at Lower Queen Street compared to either of the tide gauges.

6.2.4 Current mean sea-level and mean high water springs

Sea-levels in Tasman Bay are monitored by tide gauges at Port Nelson and Little Kaiteriteri. Recent analysis by NIWA (Andrews, 2023) has provided measurements of key tidal levels, including:

- Mean sea-level (MSL)—the average level of the sea surface over a long period, or the average level that would exist in the absence of tides. For the period 2013-2022 Andrews (2023) adopted a regionally uniform MSL of −0.093 m NZVD2016 (rounded to −0.09 m).
- Mean high water springs (MHWS)—the long-term average of each pair of successive high tides that occurs after every new and full moon, when the range of the tide is greatest (the spring range). Relative to the 2013-2022 MSL of −0.09 m NZVD2016, Andrews (2023) calculated that cadastral MHWS at the eastern end of Moturoa Rabbit Island was 1.72 m NZVD2016. Andrews (2023) estimated that high tides greater than cadastral MHWS occur approximately 12 per cent of the time.
- Highest astronomical tide (HAT)—the highest tidal level that can be predicted to occur under average meteorological conditions during an 18-year period (the length of time that captures the full range of variation in the angle of the moon's orbital plane which causes long-term modulation of the oceanic tides). Andrews (2023) calculated that cadastral HAT was 0.41-0.42 m above cadastral MHWS.

6.2.5 Levels of projected storm events and effects of historic storms

The margins of Waimea Inlet may be affected by coastal inundation during storm events. Values for storm tide and wave setup follow the same approach as that used for the screening assessment and bathtub modelling. Based on the NIWA Coastal Calculator, the 1% AEP storm tide elevation for Rabbit Island (the open coast location adjacent to the estuary) is 2.37 m NZVD2016[8], which is 0.65 m above cadastral MHWS. Wave setup during a 1% AEP storm event is estimated to be 0.20-0.30 m (e.g., TDC 2019; Haughey and Clarke, 2022). This is lower than the wave setup given by the NIWA Coastal Calculator for Rabbit Island, but reflects that local wave setup within Waimea Inlet will be lower than wave setup within Tasman Bay. There is currently no information available on wave runup within Waimea Inlet.

For lower magnitude storms there is little difference in the storm tide predicted by the NIWA Coastal Calculator. For example, for a 10% AEP storm event (a 1-in-10-year storm) the predicted storm tide elevation is 2.34 m NZVD2016, while a ~39% AEP storm (a 1-in-2-year storm) the predicted storm tide elevation is 2.24 m NZVD2016. There is currently no information available on what wave setup or wave runup might be expected for lower magnitude storms within Waimea Inlet.

The effects of tropical cyclone Fehi in February 2018 provide a useful model to understand the potential effects of future storms following a period of relative sea-level rise. During Fehi the storm surge and wave setup coincided with a king tide (the largest predicted tide of the year, higher than MHWS). As a result of the storm surge and wave setup from Fehi and the king tide, static water levels (so excluding wave runup) in Waimea Inlet reached approximately 2.6-2.7 m NZVD2016, around 1 metre higher than present day cadastral MHWS. During the peak of the tide this elevated water level and the accompanying wave runup resulted in seawater surging over the Lower Queen Street road formation and ponding in the lower-lying area behind. Notably, very little rainfall (< 30 mm) fell during Fehi which lessened the impact of flooding. Stephens et al. (2018) estimated that at the shoreline Fehi had an annual recurrence interval of ~110–170 years (~0.9–0.6% AEP). Rising sea-

[8] Based on the 2013–2022 MSL of −0.09 m NZVD2016 (Andrews, 2023).

levels will cause effects similar to Fehi to occur more frequently as smaller storms and/or smaller tides will be needed for waves to overtop the Lower Queen Street road formation.

6.3 Determination of the trigger amount of relative sea-level rise

As discussed above, the aim of the 'trigger' is to enable some period of use of the low-lying land along Lower Queen Street before future relative sea-level rise makes overtopping of the Lower Queen Street road formation a frequent occurrence. The amount of relative sea-level rise that would trigger the expiry of land use resource consents issued for the Schedule 17.4A Lower Queen Street location therefore represents the difference between present day storm water levels and the future water levels that will result in overtopping of the lower Queen Street Road formation and impair the evacuation of stormwater from behind the road formation (Figure 7). This future level is represented by the elevation of the crest of the road formation. Consequently, this technical advice outlines a range of trigger values for storms of differing magnitudes (Table 3).

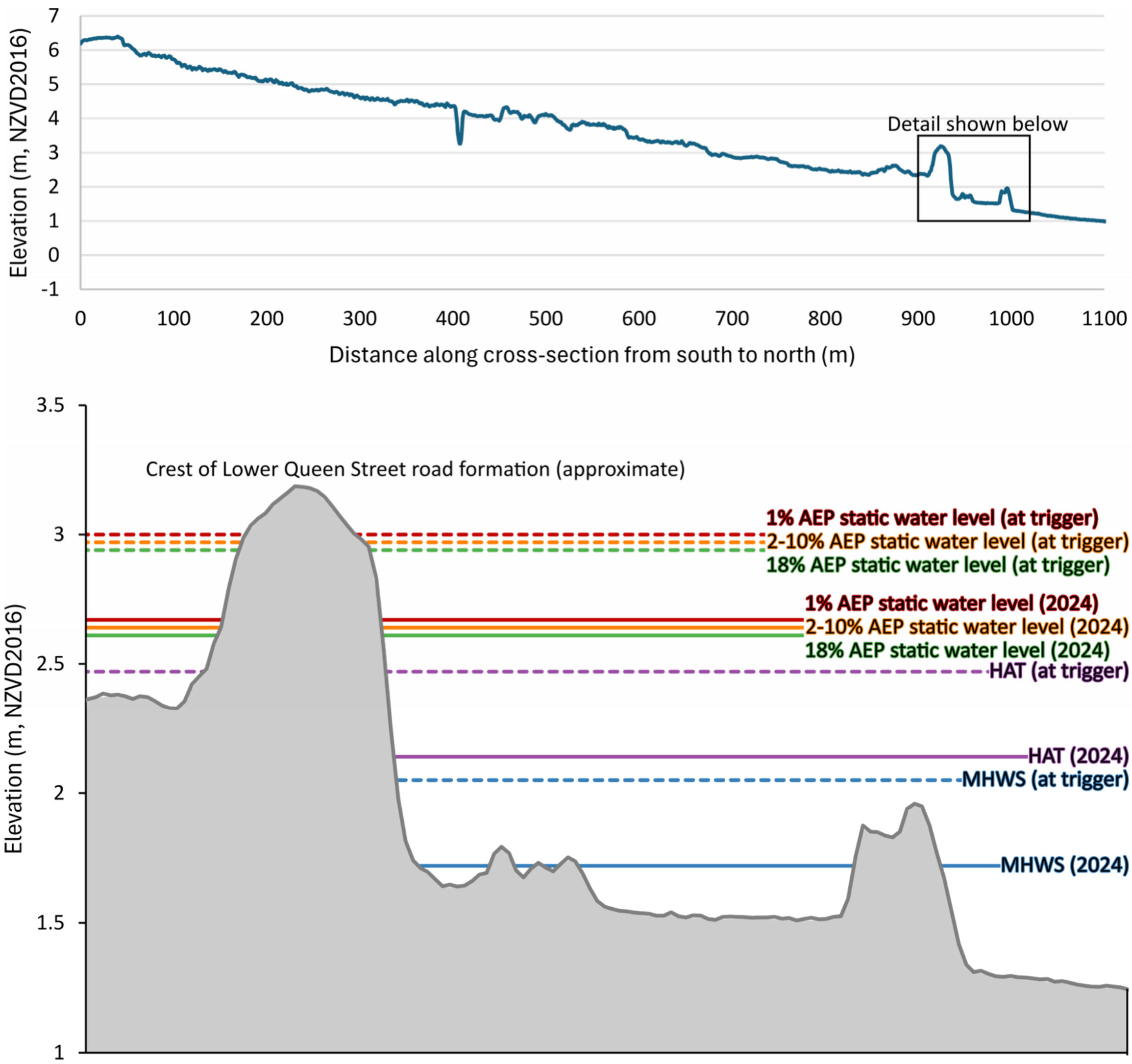

Figure 7: (top) Elevation cross-section along the line X-X' as shown in Figure 6. The region in the black square is enlarged in the lower figure. (bottom) Detail of the area around the Lower Queen Street road formation showing the elevation of the crest of the road and present day and future tidal and storm water levels. HAT is highest astronomical tide; MHWS is cadastral mean high water springs (Andrews, 2023).

Table 3: Non-modulated trigger amounts of relative sea-level rise (RSLR) for storms of different likelihoods from 18% AEP up to 1% AEP.

Storm likelihood (AEP, %)	Storm likelihood (ARI, years)	Storm static water level (storm tide[1] + wave setup[2]) (m NZVD2016)	Non-modulated trigger amount of RSLR[3] (m)
1	100	2.67	0.33
2	50	2.64	0.36
5	20	2.64	0.36
10	10	2.64	0.36
18	5	2.61	0.39

[1] From NIWA Coastal Calculator 2024, for Rabbit Island.

[2] Assumes 0.3 m wave setup.

[3] Difference between the crest of the road formation (3.0 m NZVD2016) and the static water level.

One limitation is that wave runup and overtopping processes on the margins of Waimea Inlet are not well understood compared to the same processes on the open coast which are modelled in the NIWA Coastal Calculator. Therefore, if the trigger amount of relative sea-level rise is set based on a storm of a given likelihood, once the trigger is reached then during storms of that magnitude or greater waves will be freely overtopping the Lower Queen Street road formation. For this reason it is recommended that the trigger be based on the more conservative option of a storm with an annual exceedance probability of 1%.

The trigger values presented in Table 3 must be modulated or adjusted for differing rates of VLM between Lower Queen Street and the tide gauges that will be used to assess the trigger amount of relative sea-level rise. This is because Lower Queen Street is subsiding at a faster rate compared to both the Port Nelson and Kaiteriteri tide gauges. Therefore, over a given period of time Lower Queen Street will experience a faster rate of relative sea-level rise than both of the tide gauges (assuming that the change in sea-surface height is the same between both locations, which over the short distances involved is a reasonable assumption).

Based on NZ SeaRise analysis of VLM the land along Lower Queen Street is subsiding at approximately 1.8 mm a^{-1} faster than the Port Nelson tide gauge, and at approximately 1.2 mm a^{-1} faster than the Little Kaiteriteri tide gauge. Recent analysis by Andrews (2023) showed that the trend in relative sea-level rise was 8 mm a^{-1} at the Port Nelson tide gauge and 9 mm a^{-1} at the Little Kaiteriteri tide gauge. It is assumed that both tide gauges are recording the same change in sea surface height which is produced by the melting of land-based ice and the thermal expansion of ocean water. The slight difference in the rates of relative sea-level rise measured by the two tide gauges would therefore represent variability in the rates of subsidence being experienced by each tide gauge. By assuming that the rate of VLM measured by the NZ SeaRise Project coincides with the rate of relative sea-level rise calculated by Andrews (2023), the change in sea-surface height in Tasman Bay can be estimated at approximately 6 mm a^{-1} (Table 4).

Table 4: Comparison of rates of vertical land movement and relative sea-level rise, and determination of approximate rates of change in sea-surface height for the tide gauges at Little Kaiteriteri and Port Nelson.

Tide gauge	Annual rate of VLM (mm a^{-1})	Relative sea-level rise (RSLR) trend[1] (mm a^{-1})	VLM relative to Lower Queen Street (mm a^{-1})	Change in sea surface height (RSLR−VLM) (mm a^{-1})
Little Kaiteriteri	−2.82	9	1.2	6.18
Port Nelson	−2.25	8	1.8	5.75

[1] From Andrews (2023).

Relative sea-level rise (the combined effects of changes in sea-surface height and the change in vertical land movement) at Lower Queen Street is therefore approximately 10 mm a^{-1}. This is 10 per cent faster than the rate measured at the Little Kaiteriteri tide gauge and 20 per cent faster than the rate measured at the Port Nelson tide gauge. The non-modulated trigger amounts of relative sea-level rise given in Table 3 should therefore be reduced by these percentages depending on which tide gauge is used to measure the rate of relative sea-level rise (Table 5).

Table 5: Non-modulated and modulated trigger amounts of relative sea-level rise (RSLR) for storms of different likelihoods from 18% AEP to 1% AEP.

Storm likelihood (AEP, %)	Storm likelihood (ARI, years)	Non-modulated trigger amount of RSLR (m)	Modulated trigger amount of RSLR for Little Kaiteriteri tide gauge (m)	Modulated trigger amount of RSLR for Port Nelson tide gauge (m)
1	100	0.33	0.30	0.26
2	50	0.36	0.32	0.29
5	20	0.36	0.32	0.29
10	10	0.36	0.32	0.29
18	5	0.39	0.35	0.31

6.4 Recommended trigger amount of relative sea-level rise.

Following the results from Table 5 and the recommendation to use a trigger based on a 1% AEP storm event, the recommended trigger amount of relative sea-level rise is 0.26 m if assessed using the Port Nelson tide gauge, or 0.30 m if assessed using the Little Kaiteriteri tide gauge. For the future assessment of the trigger it is recommended that average MSL for the period 2013–2022 be used as the baseline for comparison (cf. Andrews, 2023), with future sea-levels averaged over 10-year period.

6.5 What will the Lower Queen Street area look like when the trigger is tripped?

When the trigger is met relative sea-level in the Lower Queen Street area will have risen approximately 0.33 m. This is due to a combination of subsidence of the land and an increase in sea-surface height due to the melting of land-based ice and the expansion of ocean water. Land that is currently at or below 2.05 m NZVD2016 will be at or below MHWS when the tigger is met. However, MHWS may not be at exactly this level as measured by the tide gauges at Port Nelson and Little Kaiteriteri—this is due to the differing rates of subsidence between the tide gauges and the Lower Queen Street area. Because of this increase in the level of MHWS, some land on the southern side of the Lower Queen Street Road formation will therefore be at or below the level of MHWS. This will increase the difficulty of evacuating stormwater from the southern side of the road formation during rainfall events, particularly during king tides which will reach approximately 2.47 m NZVD2016 following 0.33 m of relative sea-level rise. This is only 0.5 m lower than the crest of the road formation which is approximately 3.0 m NZVD2016.

If a 1% AEP storm event occurs when the tigger is reached, then the extreme static water level (the combination of storm surge and wave setup) will be approximately equal to the current elevation of the crest of the Lower Queen Street road formation. This means that waves will freely overtop the road formation, inundating the low-lying area on the southern side of Lower Queen Street. Wave overtopping during such an event will likely be greater than was experienced during tropical cyclone Fehi (in 2018), as the extreme static water level during Fehi was ~0.3-0.4 m below the crest of the road formation. In addition, if the storm event includes periods of sustained rainfall then the degree of inundation will likely exceed that of Fehi, which was accompanied very little rainfall (less than 30 mm). Storms of a magnitude less than a 1% AEP event will still likely have effects more severe than Fehi. The extreme static water level of storms with a recurrence interval of between 10–50 years will reach 2.97 m NZVD2016, while the static water level of a storm with a recurrence interval of 1-in-5 years will reach 2.94 m NZVD2016 (cf. Table 3), only 0.06 m below the crest of the Lower Queen Street road formation. Like the 1% AEP storm described above, waves from all such storms will freely overtop the road formation leading to significant inundation of the area on the southern side of Lower Queen Street.

6.6 How long before the trigger is reached?

Based on the current trends in relative sea-level rise calculated by Andrews (2023) for the Port Nelson and Little Kaiteriteri tide gauges, the trigger amount of relative sea-level rise based on the 1% AEP storm event will be reached in approximately 33 years. This time will decrease if the rate of relative sea-level rise experienced by the tide gauges increases.

7 References

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