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Note / Memo

Haskoning Australia PTY Ltd.
Water & Maritime

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Subject: **Design Crest Levels - Thames**

1 Water Levels

1.1 Datums and Tides

A critical first step is to understand the various Datums. For the concept design NZVD2016 will be adopted. Other common datums, from previous work, include MVD-53, TVD-52, and Mean Sea Level (MSL). Tidal plains against these datum are presented in Table 1.

Table 1 Present day (2023) tide plains and design strom tide to various datum

Datum	m NZVD2016	m TVD-52	m MVD-53	m MSL
LAT (Chart Datum)	**-2.12**	-1.923	-1.805	-1.99
MLWS	**-1.74**	-1.543	-1.425	-1.61
MSL	**-0.13**	0.067	0.185	0.00
NZVD2016	**0.00**	0.197	0.315	0.13
MHWS	**1.48**	1.677	1.795	1.61
HAT (King Tide)	**1.88**	2.077	2.195	2.01
1% AEP Storm Tide	**2.77**	2.967	3.085	2.90

Note : analysis of LAT and HAT are not fully confirmed, and values provided are estimates only.

1.2 Storm Tides

According to previous studies undertaken by RHDHV ("Coastal Protection Feasibility Study for the Coromandel Peninsula – A Summary", September 2022) the 1% AEP storm surge at Tararu (Thames) is 0.97 m, however, the storm tide is a combined level achieved from a storm surge with an associated astronomical tide. The RHDHV study concluded that for the Thames foreshore the 1% AEP storm tide is **2.77 m NZVD2016**, which is 0.89 m above King Tide levels or 1.29 m above MHWS (see Figure 4).

With a relatively small storm surge levels compared to the large tide range (4 m) it is clear that tidal levels are the primary driver of the storm tide level. A storm surge occurring without a spring high tide will not drive a serious flooding event today. It also means that with sea level rise high tides alone will become a serious issue for flooding in Thames if no action is taken to exclude tidal waters.

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1.3 Comparison with Measured Data

An important validation of the above values is how do these storm tide values compare with observed levels during the January 2018 storm NIWA guidance for Storm Tides in this region. NIWA 1% AEP storm tides

2 Design Waves

Storm tides in the Thames area will almost certainly be linked to strong winds with a northerly aspect. These winds will also drive severe wave conditions along the Thames coast. The adopted input wave conditions that were determined to occur in conjunction with the design 1% AEP storm surge are presented in Table 2.

Table 2 Input Wave Parameters

	Thames
Offshore H_s (m)	1.43
Applied H_s (m)	1.43
Offshore T_p (S)	3.98
Offshore L_0 (m)	25

2.1 Acceptable Overtopping

Based on the assumption that mild overtopping rates can be managed by drainage on the lee of the sea defences an acceptable rate of overtopping of 5 l/s/m (0.005 m^3/s/m)was adopted as the tolerable upper limit. This rate was adopted as it represents an overtopping condition that will not damage infrastructure or endanger people and should be manageable in terms of flooding issues.

Overtopping was calculated using the Eurotop 2016 method. The adopted equation for overtopping rate is presented below:

$$q = \frac{0.023\sqrt{g.H_{m0}^3}}{\sqrt{\tan\alpha}}\gamma_b.\xi_{m-1,0}.e^{\left[-\left(\frac{2.7.R_c}{\xi_{m-1,0}.H_{m0}.\gamma_b.\gamma_f.\gamma_\beta.\gamma_v}\right)^{1.3}\right]}$$

Where: H_{m0} is the zero moment wave height (~H_s)
α is the angle of the slope,
$\xi_{m-1,0}$ is the breaker parameter,
R_c is the freeboard (crest level above water level) and
γ is used for reduction factors - berms (b), roughness (f), angle of attack (β), and wave walls (v).

The adopted overtopping rate (q) is based on arrange of factors including safety, damage to infrastructure and flooding. For the wave conditions at this site the tolerable rate of overtopping that is safe for people and will not damage turf slopes is 5 l/s/m. Therefore to assess the crest free board required it is assumed that q = 5 l/s/m. For reference q = 1 l/s/m and q = 0.1 l/s/m will be considered.

The γ value above captures a range of factors linked to the section profile. To assess the free board for a range of sections we have assumed a 1 in 2 slope rock armour wall below 2.5 m NZVD2016 with a berm width of 3 m (path) and then a raised section behind. The adopted reduction factors are:

Bund on foreshore with 3 m wide berm (path at 2.5 m)	γ_b = 0.60
Roughness factor	γ_f = 0.55
Angle of wave attack	γ_β = 1.00
Wave wall factor (no wave wall)	γ_v = 1.00 (bund)
Wave wall factor (wave wall)	γ_v = 0.92 (wave wall)

2.2 Recommended Freeboard to Account for Run-up and Overtopping

2.2.1 Bund or wall close to the foreshore

Assuming no wave dissipation from mangroves then a freeboard in the order of **0.9 m** will provide sufficient protection to keep overtopping rates below 5 l/s/m.

2.2.2 Bund or wall sheltered from wave action

For structure set back more than approximately 20 m from the crest of the seawall we can assume that the wave climate is significantly moderated. If we assume 50% attenuation in wave heights (H_s = 0.72 m) then a freeboard of **0.5 m** would suffice.

Similarly if a mangrove forest shelters a foreshore, then significant wave attenuation is expected. Again a freeboard of 0.5 m would suffice. It is not recommended that mangrove protection be adopted for design as mangroves can be lost for many reasons, however, it is important to be aware of this when examining performance of structures in the lee of mangroves.

2.3 More Conservative Freeboards for Consideration

These are considered as sensitivity checks for the relationship between freeboard and overtopping rates.

2.3.1 1 l/s/m overtopping rate

Freeboard for 1 l/s/m overtopping are:

- Fully exposed to waves – freeboard = 1.2 m
- Sheltered – freeboard = 0.7 m

2.3.2 0.1 l/s/m overtopping rate (effectively no overtopping)

Freeboard for 0.1 l/s/m (effectively nil) overtopping are:

- Fully exposed to waves – freeboard = 1.5 m
- Sheltered – freeboard = 1.0 m

2.4 NIWA Guidance (for comparison)

As described below the NIWA guidance is in line with the values we are adopting for present day conditions and validates the approach.

2.4.1 Storm Tide

For reference NIWA have provided guidance that Bund levels in the Thames area should be raised to a level that can resist a storm tide of 2.98 m TVD-52 (2.845 m NZVD2016), refer Table 6. This value is slightly higher than the adopted value from the RHDHV study of 2.91 m TVD (2.77 m NZVD2016).

Further this level is close to the observed level of 2.9 m TVD-52 (2.77 m NZVD2016) measured in the January 2018 storm.

Table 3 NIWA 2019 Storm Tide Guidance (relative to TVD-52)

	AEP (%)	63	39	18	10	5	2	1	0.5	0.2	0.1
	ARI (years)	1	2	5	10	20	50	100	200	500	1000
Analysis i: MCJP (Stephens et al. 2015)	Median		2.58	2.66	2.73	2.81	2.92	3.00	3.09		
	Lower 95th% CI		2.57	2.65	2.72	2.80	2.90	2.97	3.04		
	Upper 95th% CI		2.58	2.66	2.74	2.83	2.94	3.04	3.14		
Analysis ii: SSJPM 1990–2014	Median	2.61	2.65	2.71	2.76	2.81	2.89	2.95	3.02	3.11	3.19
	Lower 95th% CI	2.60	2.64	2.69	2.72	2.76	2.81	2.84	2.88	2.92	2.95
	Upper 95th% CI	2.62	2.67	2.75	2.83	2.93	3.12	3.31	3.54	3.93	–
Analyses iii and iv: (inclusion of 1938 event did not change the analysis) SSJPM 1990–2018	Median	**2.61**	**2.66**	**2.72**	**2.77**	**2.82**	**2.91**	**2.98**	**3.06**	**3.16**	**3.25**
	Lower 95th% CI	2.61	2.65	2.70	2.73	2.77	2.82	2.86	2.90	2.94	2.97
	Upper 95th% CI	2.63	2.68	2.76	2.84	2.95	3.17	3.40	3.68	–	–
	Lower 50th% CI	2.61	2.66	2.71	2.76	2.81	2.88	2.94	3.00	3.09	3.15
	Upper 50th% CI	2.62	2.66	2.73	2.78	2.84	2.94	3.03	3.12	3.27	3.39
Analysis v:	Not undertaken because it does not materially change relative to analysis i.										

Note : these levels include 0.1 m for infragravity waves and 0.4 m for near shore effects, but no wave runup allowance.

2.4.2 Freeboard for runup and overtopping

NIWA suggest a freeboard of 0.7 m for waves, giving a total bund level today of 3.68 m TVD-52 (3.55 m NZVD2016). This includes no allowance for sea level rise.

Our analysis is that a freeboard of 0.9 m is required to address wave runup and overtopping, which combined with our storm tide level gives a crest level without SLR of 3.81 m TVD-52 (3.67 m NZVD2016).

3 Climate Change

3.1 Scenarios

A significant issue in developing designs for future conditions is how warm the climate will get and how much will sea levels rise. The Inter-Government Panel of Climate Change (IPCC) puts out periodic guidance on the trajectories (Scenarios) that we have been taking and may take in the future. A graphical representation of the different scenarios is presented in Figure 1.

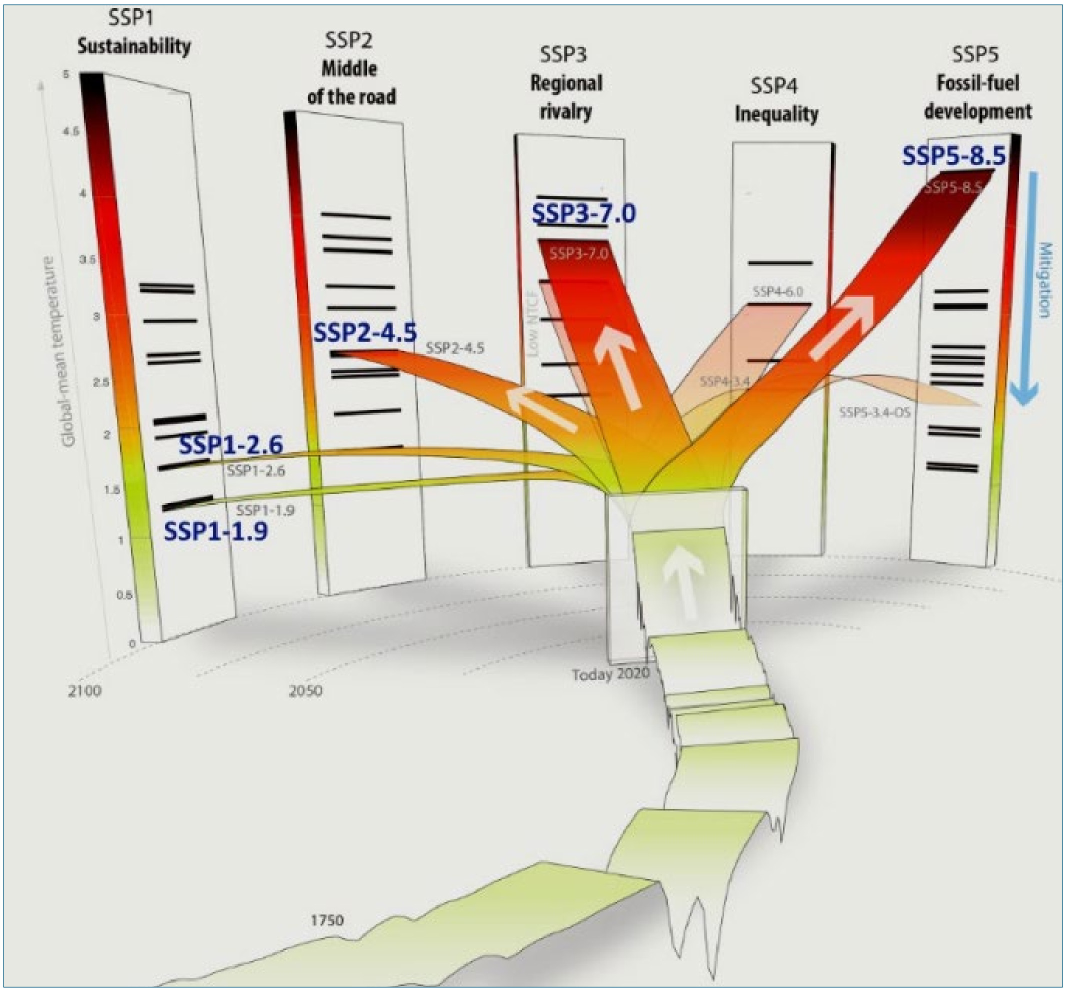

Figure 1 Schematic of Scenarios (Source Ministry For the Environment "Interim guidance on the use of new sea-level rise projections")

Current global targets as defined by the Kyoto Protocols are to restrict global warming to 1.5°C above pre-industrial levels. It is important to note that the current global temperature increase is 1.25°C. It would be prudent to assume that given the realities of global action, the agreed target will be exceeded. The climate change scenario to be adopted needs to be agreed, but reviewing the above guidance initially it is recommended that:

a. Optimistic low emissions scenarios such as SSP1 should not be adopted for design.
b. Design must address likely (medium) scenarios including forecasts for SSP2, SSP3 and SSP4.
c. Consider how to adapt to the low confidence high emission forecasts for SSP5.

3.2 Sea Level Rise

New Zealand specific forecasts have been prepared by Ministry for the Environment (2024), based on IPCC guidance. The values proposed are very similar to the latest IPCC guidance (IPCC 2023) and as such have been adopted. The forecast sea level rises for various emissions scenarios and time horizons is presented in Table 4 and Table 4 and Figure 2 and Figure 3.

Table 4 New Zealand Guidance for Sea Level for Various Scenarios (based on 1995 – 2014 baseline)

Year	SSP1–2.6 M (median) [m]	SSP2–4.5 M (median) [m]	SSP3–7.0 M (median) [m]	SSP5–8.5 M (median) [m]	SSP5–8.5 H+ (83rd percentile) [m]
2005	0	0	0	0	0
2020	0.06	0.06	0.06	0.06	0.09
2030	0.11	0.11	0.11	0.11	0.15
2040	0.15	0.16	0.16	0.18	0.23
2050	0.20	0.22	0.24	0.26	0.32
2060	0.24	0.28	0.31	0.34	0.43
2070	0.29	0.35	0.40	0.44	0.57
2080	0.34	0.42	0.50	0.56	0.72
2090	0.38	0.49	0.61	0.69	0.90
2100	0.44	0.57	0.73	0.83	1.09
2110	0.50	0.66	0.83	0.95	1.28
2120	0.55	0.74	0.95	1.08	1.47
2130	0.60	0.81	1.07	1.21	1.66
2140	0.64	0.89	1.19	1.34	1.84
2150	0.68	0.96	1.30	1.46	2.01

Table 5 Timelines to achieve different SLR outcomes for the various scenarios

SLR (m)	Year achieved for SSP5-8.5 H+ (83rd percentile)	Year achieved for SSP5-8.5 (median)	Year achieved for SSP3-7.0 (median)	Year achieved for SSP2-4.5 (median)	Year achieved for SSP1-2.6 (median)
0.3	2050	2055	2060	2060	2070
0.4	2060	2065	2070	2080	2090
0.5	2065	2075	2080	2090	2110
0.6	2070	2080	2090	2100	2130
0.7	2080	2090	2100	2115	2150
0.8	2085	2100	2110	2130	2180
0.9	2090	2105	2115	2140	2200
1.0	2095	2115	2125	2155	>2200
1.2	2105	2130	2140	2185	>2200
1.4	2115	2145	2160	>2200	>2200
1.6	2130	2160	2175	>2200	>2200
1.8	2140	2180	2200	>2200	>2200
2.0	2150	2195	>2200	>2200	>2200

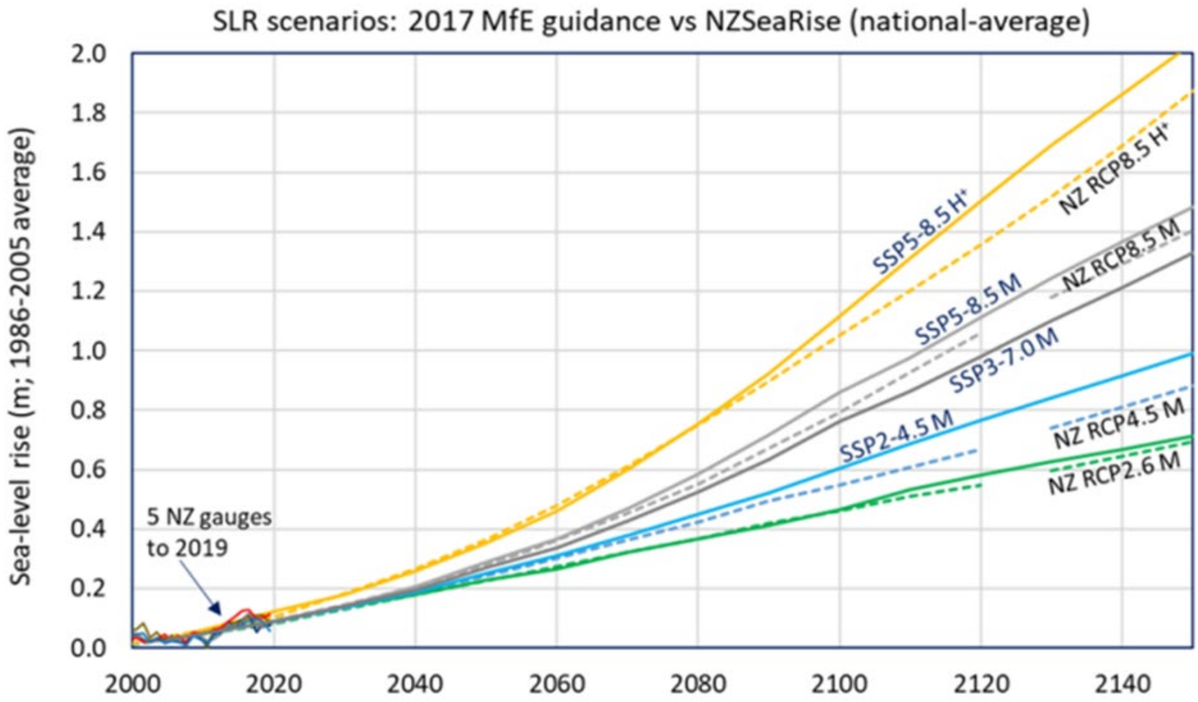

Figure 2 New Zealand specific Forecasts (refer Ministry for Energy "Interim guidance on the use of new sea-level rise projections")

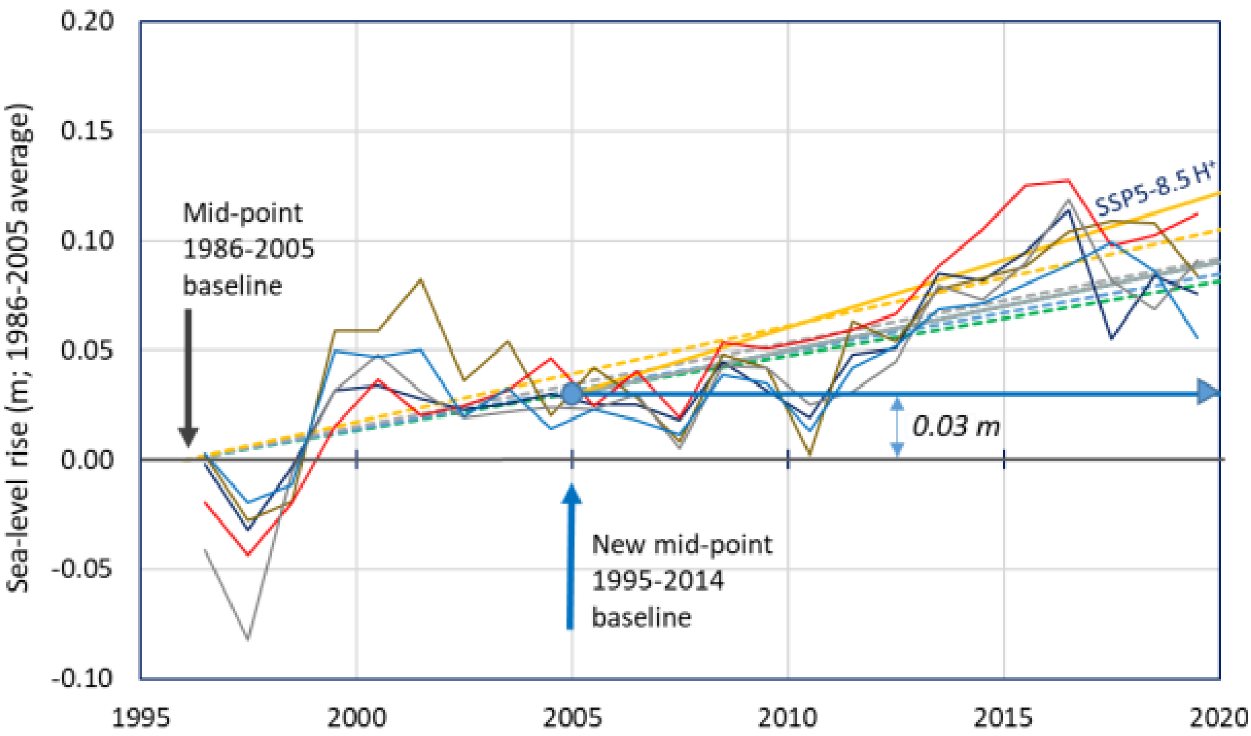

Figure 3 Historic changes (refer lower left of Figure 2)

According to the Ministry for the Environment in their "Coastal Hazards and climate change guidance")" all 5 SSP emission scenarios should be considered, however, as discussed above, SSP1 is optimistic and from the perspective of defences design should not be considered. For the middle road emissions scenario (SSP2-4.5) this is considered a likely outcome and is a minimum level that should be considered for an adaptive solution. The scenario where regional self-interest impacts emissions reduction (SSP3-7.0) is a more pessimistic likely outcome and represents a high end likely scenario. The SSP5 scenario is pessimistic, and the upper envelope 83rd percentile value even more so. Despite this guidance from Ministry if Energy is that these high values should be used to stress-test plans.

Looking further into the future the forecasts become increasing unreliable, though even the most optimistic scenarios have sea levels continuing to rise for at least 300 years. Long range forecasts from IPCC 2023 are presented in Figure 4.

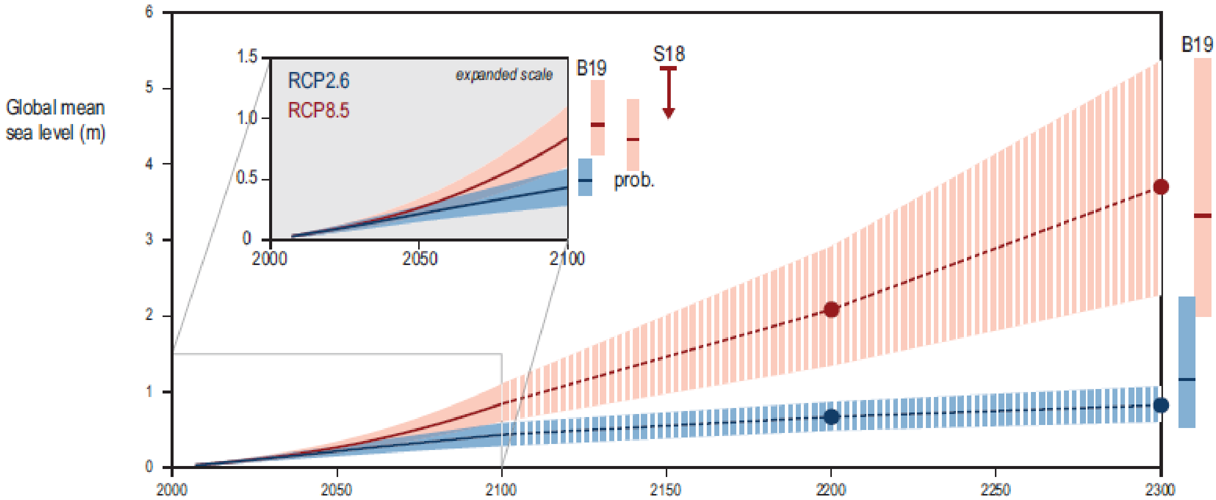

Figure 4 IPCC 2023 long range forecasts for sea level rise for the low (RCP2.6) and high (RCP8.5) emission scenarios

3.3 Near Future (2030)

For the near future (almost immediately after initial construction works) a sea level rise of **0.03 m** above present day levels (0.1 m above baseline) is anticipated.

3.4 Short Term (25 years)

Mid-range Emission 2055 Scenarios a near horizon of 2055 is considered a minimum standard for initial works. In 2055 a sea level rise in the order **0.15 m** above today (0.22 m above baseline) would be appropriate.

As can be seen in the forecasts the adopted scenario does not have significant impacts on sea level rise going forward 25 years, and 0.15 m remains a suitable forecast level.

3.5 Medium Term (50 years)

Note that the value for sea level rise adopted for 50 years plus is rounded to 1 decimal place to reflect the uncertainty in the estimate. Mid-range emission scenarios in 2080 would be associated a likely sea level rise in order of 6.4 mm/a will result in a sea level rise in the order of **0.3 m**.

High emission scenario in 2080, with the low confidence SSP5-8.5 sea level rise of 7.9 mm/a, leads to a sea level rise in the order of ***0.5 m***.

3.6 Longer Term (75 years)

Mid-range emission scenarios in 2105 would be associated with a sea level rise in the order of **0.6 m** above present day.

Low confidence high emission scenario in 2105 results in a sea level rise a sea level in the order of ***1.0 m***.

3.7 Long Term (100 years)

The mid-range scenario for a long term horizon of 2130 would be associated with a sea level rise in the order of **0.9 m** above present day.

Low confidence high emissions scenario in 2130 will lead to a forecast sea level rise a sea level of ***1.5 m***.

3.8 Over the Horizon (200 years)

A very long term horizon of 2230 with a mid-range emission scenario would result in a 7 mm/a sea level rise for 100 years beyond 2130 leading to a sea level rise in the order of **1.6 m** above present day.

The high emissions scenario for 2230 has a forecast sea level rise in the order of ***3.4 m***.

Sea level rise forecasts this far into the future carry a significant degree of uncertainty.

4 Vertical Land Movement

According to the most up to date data, NZ Sea Rise (https://www.searise.nz/) shows that the land at Thames is rising at approximately **2.35 mm/a**. This figure is based on a two square kilometre grid, which averages the range of measured VLM. It is noted VLM varies considerably over short distances and so the averaged figure may not be accurate for areas less than two square kilometre grid. Additionally, as seen in Figure 5, there is variability between the gridded locations, with the far bank of Waihou River sinking at a rate of 1.70 mm/a.

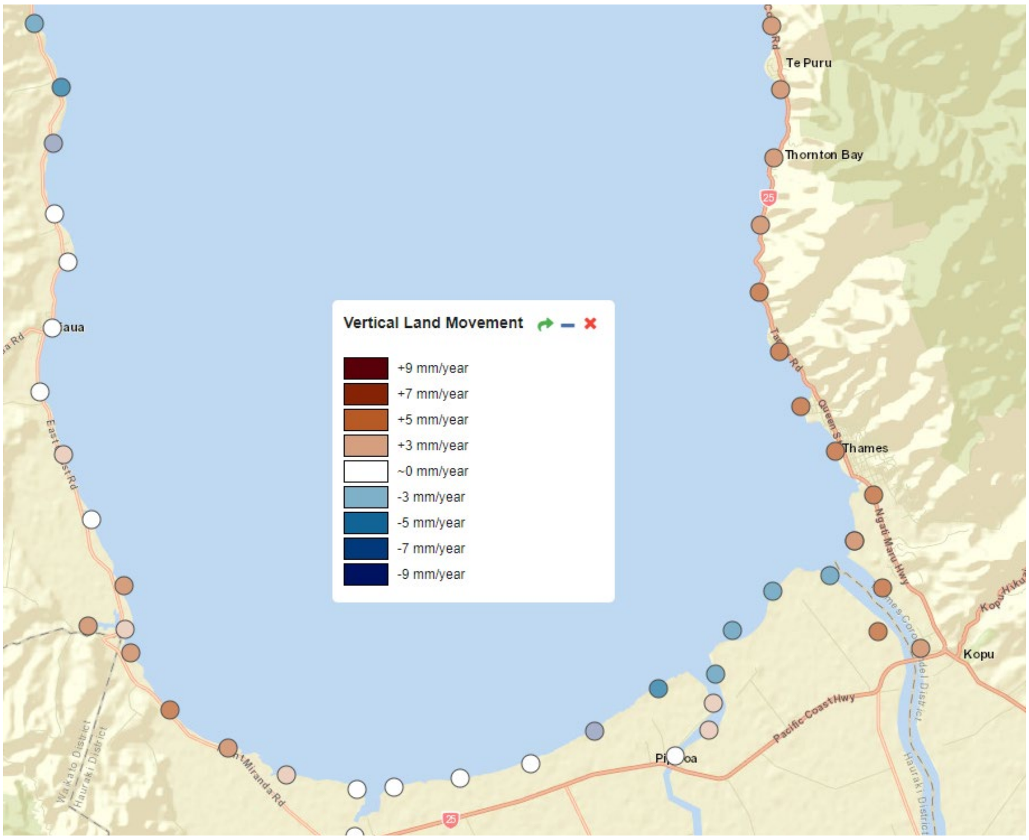

Figure 5 Vertical Land Movement published by NZ Sea Rise (https://searise.takiwa.co/map/6245144372b819001837b900/embed)

On the Thames foreshore the ongoing settlement of the recent deposits (many anthropogenic) is resulting subsidence, despite the adjacent land rising. The rate subsidence varies with land located over deeper and/or younger mud profiles more likely to experience subsidence.

Based on satellite data, settlement/subsidence of 3 mm/a has been adopted, in lieu of accurate information. The adopted vertical land movement equates to additional SLR of:

- **0.075 m in 25 years**
- **0.150 m in 50 years**
- **0.225 m in 75 years**
- **0.300 m in 100 years.**

It is recognised that the actual rates of land movement will vary in location and over time. The adaptive approach adopted for design is able to incorporate any uncertainty in vertical land movement.

5 Crest Levels

5.1 Summary of Crest Level Inputs

5.1.1 Storm Tide

The present day Thames foreshore 1% AEP storm tide still water level is **2.77** m NZVD2016. It is worth noting that 1% AEP is 0.9 m above King Tide level.

5.1.2 Sea Level Rise

Based engineering principals and consistent the Ministry for Energy guidance:

- A mid-range forecast sea level rise (SSP2-4.5 and SSP3-7.0) should be the minimum level adopted for developing a response to future conditions.
- A pessimistic future emissions scenario (SSP5-8.5 and SSP5-8.5 $^{85th\ percentile}$) as a minimum should be considered to stress test the planning.

Recommended values are presented in Table 5.

Table 6 Summary of recommended sea level rises for various time horizons (assuming works undertaken in 2030)

Horizon	Mid-range forecasts (anticipated)	*High Range forecasts (possible)*
2055 (25 years)	0.15 m	*0.15 m*
2080 (50 years)	0.30 m	*0.50 m*
2105 (75 years)	0.60 m	*1.00 m*
2130 (100 years)	0.90 m	*1.50 m*
2230 (200 years)	1.60 m	*3.40 m*

5.1.3 Vertical Land Movement

Adopted additional sea level rise allowance for vertical land movement, due to subsidence, is presented in Table 7.

Table 7 Adopted vertical movement for various time horizons (assuming works undertaken in 2030)

Horizon	Vertical land movement
2055 (25 years)	0.08 m
2080 (50 years)	0.15 m
2105 (75 years)	0.23 m
2130 (100 years)	0.30 m
2230 (200 years)	0.60 m

Note that freeboards would need to be increased by approximately 0.5 m to prevent overtopping.

5.1.4 Combined Levels

Combining VLM and SLR,the design water levels presented in Table 8 would be adopted for different design horizons.

Table 8 Effective Design 1% AEP water levels for various time horizons (assuming works undertaken in 2030)

Horizon	Adopted Water Levels	*Extreme SLR Water Level Scenario*
2055 (25 years)	3.00 m NZVD2016	*3.00 m NZVD2016*
2080 (50 years)	3.22 m NZVD2016	*3.42 m NZVD2016*
2105 (75 years)	3.60 m NZVD2016	*4.00 m NZVD2016*
2130 (100 years)	3.97 m NZVD2016	*4.57 m NZVD2016*
2230 (200 years)	4.97 m NZVD2016	*6.77 m NZVD2016*

5.1.5 Freeboard

The freeboard required to restrict overtopping to an acceptable 5 l/s/m are:

- 0.9 m for locations exposed to waves.
- 0.5 m for locations sheltered from waves, including barriers set more than 20 m back from the foreshore.

5.2 Adopted Solutions

5.2.1 Stage 1 (Initial Works)

For Stage 1 works it is assumed that the primary aims are:

1 Develop a consistent level of protection from marine and fluvial flooding for a medium horizon (2080).

2 Provide a platform that will facilitate future increased protection.

3 Endeavour to minimise costs and community impacts.

4 Where coastal erosion threats are identified include seawall protection. Note that erosion threats that require a rock armour seawalls include all concrete wall structures located on the foreshore and any bunded structure located on exposed foreshores (assessed based on historic erosion). Delaying construction of seawalls is a potential cost savings for the initial works but areas not protected will need to be monitored to ensure that erosion was not impacting the bund integriy.

5 Note - where concrete barriers are used aim to achieve Stage 2 level of protection.

Adopting a high end forecast sea level rise over 50 years (2080) would result in crest levels:

Still Water level

Storm Tide	2.77 m NZVD2016
SLR	+0.30 m
VLM	+0.15 m
Water Level	3.22 m NZVD2016

Foreshores exposed to waves (0.9 m freeboard)

Crest Level 4.2 m NZVD2016

Or sheltered locations (0.5 m freeboard)

Crest Level 3.8 m NZVD2016

5.2.2 Stage 2 (100 year Horizon)

For Stage 2 works it is assumed that the primary aims are:

1 Undertaken in the future, when defined triggers reached (e.g. acceptable flooding risk).

2 Will provide consistent protection for next 50 years (2130).

3 Will endeavour to remain within the Stage 1 footprint.

4 Any exposed foreshores not already protected by a seawall should be upgraded at this time.

If we just want to achieve 1% AEP immunity until 2130 then suggested adopted conditions are:

Water level

Storm Tide	2.77 m NZVD2016
SLR	+0.90 m
VLM	+0.30 m
Water Level	3.97 m NZVD2016

Foreshores exposed to waves

Crest Level **4.9 m NZVD2016**

Or sheltered locations

Crest Level **4.5 m NZVD2016**

5.2.3 Potential Extreme Sea Level Rise Scenario

If sea level rise occurs at the upper envelop extreme rates (refer Table 6) the design horizons to exceed design water levels will be shortened.

- **Stage 1 : SWL ≤ 3.3 m NZVD2016 – exceeded in 2070 (40 years)**
- **Stage 2 : SWL ≤ 4.0 m NZVD2016 – exceeded in 2105 (75 years)**

5.2.4 Distant Future (not part on concept design)

In the development of a plan consider how protection for more extreme sea level rises might be incorporated. As a guide this might include levels:

Water level

Storm Tide	2.77 m NZVD2016
SLR	+1.60 m
VLM	+0.60 m
Water Level	4.97 m NZVD2016

Recognising that the exposed Stage 2 crest level is 4.9 m NZVD2016, the works would offer reasonable levels of protection up to a water of 4.4 m NZVD2016, with increased overtopping issues during extreme events.

6 Rock Armour

Considering both the Van Der Meer and Hudson equations armour size has been assessed for stability. Adopting a rock density of 2,600 kg/m^3, a revetment slope of 1 in 2 and a tolerable level of damage for the 1% AEP event then based on a deign wave climate as presented in Table 2 the adopted design armour solution is armour that is notionally a 1T rock armour:

Primary Armour
D_{50} = 0.86 m (1,000 kg)
D_{NLL} = 0.65 m (430 kg) to D_{NUL} = 0.95 m (1,300 kg)
Double Layer Thickness = 1.45 m

Secondary Armour
D_{NLL} = 0.2 m to D_{NUL} = 0.5 m
Double Layer Thickness = 0.64 m

Total armour thickness = 2 m

Armour would be laid over a heavy duty geotextile (e.g. Texcel 1200R)

7 Design Profile

7.1 Bunds (Stage 1)

7.1.1 On Exposed Foreshores

Key design features are:

- The front slope of the bund is 1 in 2 with rock armour placed on the face, if erosion issues are an immediate concern.
- Crest level for Stage 1 is 4.2 m NZVD2016.
- The crest will incorporate a path. It is assumed that the bund crest width will be 4 m wide.
- The rear slope will be mild to permit landscaping and mowing (1 in 5 assumed)
  - If space constraints prevent mild slopes vertical walls or steeper slopes can be adopted, though careful consideration of the amenity and use is required.

7.1.2 Sheltered Bunds

If we are not concerned about wave action then:

- Both front and rear faces should have mild slopes (1 in 5) to facilitate public use and landscaping, though steeper slopes can be considered if space is limiting.
- Crest level for Stage 1 is 3.8 m NZVD2016.
- The crest will incorporate a path. It is assumed that the bund crest width will be 4 m wide.

7.2 Concrete Walls (Stage 2)

Concrete walls would be raised to Stage 2 levels initially as raising the concrete walls later is not practical. Concrete walls are initially only proposed for locations where space constraints prevent bunds being used.

The basic assumed design:

- A large L shaped section
- 3 m wide base slab (path)
- Crest of wall to 4.9 m NZVD2016 (exposed to waves) or 4.5 m NZVD2016 if sheltered.
- Wall situated on landward side.
- May need piles key wall if loading indicates stability issues.
- Thickness 0.3 m (TBC).

7.3 Stage 2 Raising for Bunds

At this stage it is assumed that bunds raised to Stage 1 level can be lifted to Stage 2 levels in the future with the installation of a low concrete wall (0.7 m high). The wall would be incorporated into the path and would be suitable for seating.

Further any foreshore not already armoured would need to be armoured during this stage.

Regards

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