Moutere and Waimea estuary extreme sea level assessment

Prepared for Tasman District Council

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Executive summary

Tasman District Council (TDC) utilises the Tasman Coastal Calculator to quantify extreme coastal inundation levels throughout the region (Stephens et al. 2018). However, the calculator is limited to exposed open coast locations and excludes estuaries and harbours.

The hydraulic response of estuaries and harbours are often significantly different to adjacent open coast locations due to geomorphic controls such as number and width of tidal entrances, inner planform shape and depth, tidal volume and varying exposure to wave energy. To explore the influence of estuary dynamics the Waimea and Moutere Estuaries were selected for numerical model investigation.

The numerical study has shown that the western Waimea and Moutere estuaries that have restricted entrances experience lower tidal ranges and levels in the absence of wave impacts compared to the open coast. Maximum spring tide levels within the western Waimea and Moutere estuaries are up to 0.14 m and 0.10 m lower respectively than offshore levels observed at the Fairway Beacon. Conversely during extreme storm tide and wave conditions, the influence of wave setup on sea level amplification within the estuaries is proportionally higher compared to more open coast environs. Relative sea level increases within the estuary during the 1% Annual Exceedance Probability (1%AEP) event are up to 35% and 30% respectively. The resulting 1%AEP sea level for the western Waimea and Moutere estuaries are up to 0.07 and 0.03 m higher than offshore levels observed at the Fairway Beacon.

For the more open eastern portion of Waimea estuary, normal tide ranges and levels in the absence of waves are amplified compared the open coast and the western Waimea estuary. Maximum spring tide levels within the eastern Waimea estuary are up to 0.13 m higher than offshore levels observed at the Fairway Beacon. The influence of wave setup on sea levels within the embayment during extreme events is proportionally less than the more restricted western Waimea and Moutere estuaries. Relative sea level increase within the estuary during the 1%AEP event is up to 24%. The resulting 1%AEP sea level for the eastern Waimea is up to 0.16 m higher than offshore levels observed at the Fairway Beacon.

The results demonstrate that extreme inundation levels within estuaries vary due to the complex interaction of tidal exchange modulated by geomorphic controls and effects of wave processes on both tidal exchange and amplification of sea levels. When compared to extreme inundation levels at the adjacent open coast that include wave setup, as calculated in the Coastal Calculator, inundation levels within the estuaries are notably lower.

1 Introduction

Tasman District Council (TDC) has requested an assessment of inundation levels within the Waimea and Moutere estuaries during extreme conditions via Envirolink medium advice grant (NIW2366).

Coastal areas, particularly estuaries, are vulnerable to extreme sea-level events driven by a combination of wave action and sea levels. Understanding these dynamics is crucial for effective management and future planning. In the Tasman District, the Coastal Calculator developed by NIWA provides valuable predictions of wave heights and sea levels during storm events along the open coast (Stephens et al. 2018). However, its applicability to estuaries, where wave processes are highly localised and influenced by specific factors such as estuary shape, depth, and offshore wave conditions, remains limited.

To provide guidance within estuary environs, the Waimea and Moutere estuaries were selected for numerical model assessment. By developing a coupled SWAN (Simulating WAves Nearshore) and Delft3D FM hydrodynamic model, the study quantifies wave and sea level interactions during 1% and 2% Annual Exceedance Probability (AEP) events.

1.1 Scope of work

The scope of work includes the following:

- Develop a coupled wave (SWAN) and hydrodynamic (Delft3d FM) model of the Waimea and Moutere estuaries.
- Simulate a range of 1% and 2% AEP wave and storm tide levels to identify the combination that results in the highest extreme inundation levels within each estuary.
- Define the 1% and 2% AEP inundation levels around the periphery of each estuary to inform TDC decision making.

Ultimately, the output of the assessment will be integrated into the Coastal Calculator that is used by TDC (at a later date).

1.2 Datum

All levels presented in this report are relative to New Zealand Vertical Land Datum 2016 (NZVD-2016) unless otherwise specified.

Extreme tidal levels are referenced to the 2013 – 2022 Mean Sea Level (MSL) as assessed at the Port of Nelson (Andrews, 2023).

2 Numerical modelling

In order to quantify extreme inundation levels within the Waimea and Moutere estuaries a numerical modelling approach is required to resolve the complex interaction of offshore tidal levels, wave processes and tidal exchange. Accordingly, a coupled wave-hydrodynamic model approach has been adopted. Delft3D has been utilised for this assessment which includes the application of SWAN for wave processes and D-Flow Flexible Mesh (FM) to capture wave impacts on hydrodynamics within the estuaries. Due the close geographic proximity of the estuaries and the flexible mesh approach, both estuaries were simulated within a single model domain.

Informed by the joint probability extreme sea level and wave height assessment contained within the Coastal Calculator at the Fairway Beacon (Stephens et al. 2018) a range of 1% and 2% AEP Significant Wave Height (H_s) and extreme sea level combinations were selected. A range is required as the maximum estuary response could occur for a different H_s – sea level combination compared to the open coast. As the assessment is focused on quantifying the influence of extreme offshore conditions on estuary response, the impacts of wind generated waves within the estuaries has been excluded. It is noted that the influence of wind generated waves on extreme inundation levels within the estuaries is likely to be minimal and be limited to wave runup effects only (not included in the assessment).

The following sections summarise the numerical modelling approach, inputs and results.

2.1 Bathymetry

The model bathymetry was established from the following data sources:

- 2024 TDC single beam channel bathymetry survey.
- 2022 Light Detection And Ranging (LiDAR)[1] data and sub-tidal sounding data sourced from Land Information New Zealand (LINZ).
- 2008–2012 LiDAR data and sub-tidal sounding data sourced from LINZ.
- NIWA High resolution bathymetry data.
- Inferred digitised sub-tidal channel bathymetric contours based on aerial photography.

These baseline bathymetric datasets were combined with high-resolution LIDAR topography of the main intertidal banks of the Moutere and Waimea Estuaries.

Where appropriate the datasets were re-projected to New Zealand Transverse Mercator (NZTM) coordinate system and reduced to NZVD-2016. Due to the large chronological diversity in the bathymetric dataset's preference was given to the most recent and highest resolution data. The consolidated data is presented in Figure 2-1.

2.2 Model domain

The model domain of the Tasman Bay area was developed recognising several geographical regions of interest. These include Waimea and Moutere estuaries and the Nelson Haven. The model grid resolution and shape vary from triangle grids of 500 m offshore to with less than 20 m edge lengths in the main channels within the estuaries. The estuaries and associated channels were defined with a

[1] LiDAR is an aerial laser scanner system capable of resolving elevations to ± 0.06 m.

high resolution to ensure that the complex estuary shape and water depths were resolved including engineering controls such as bridge abutments and causeways. The model domain is presented in Figure 2-2.

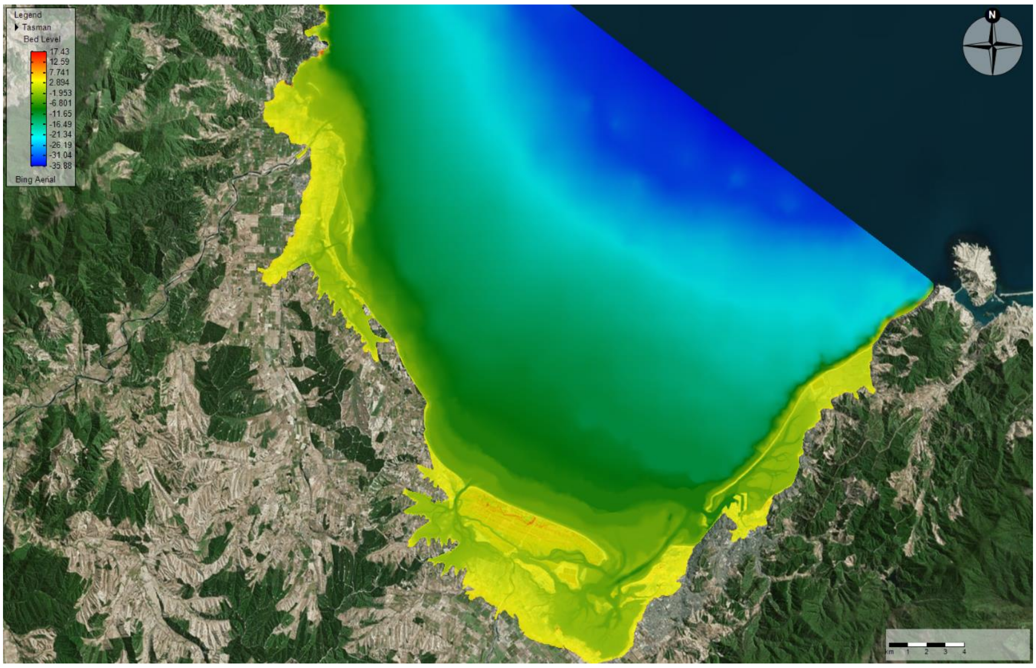

Figure 2-1: Tasman Bay bathymetry extent developed from high resolution LiDAR and single-beam survey, chart data and NIWA bathymetry datasets.

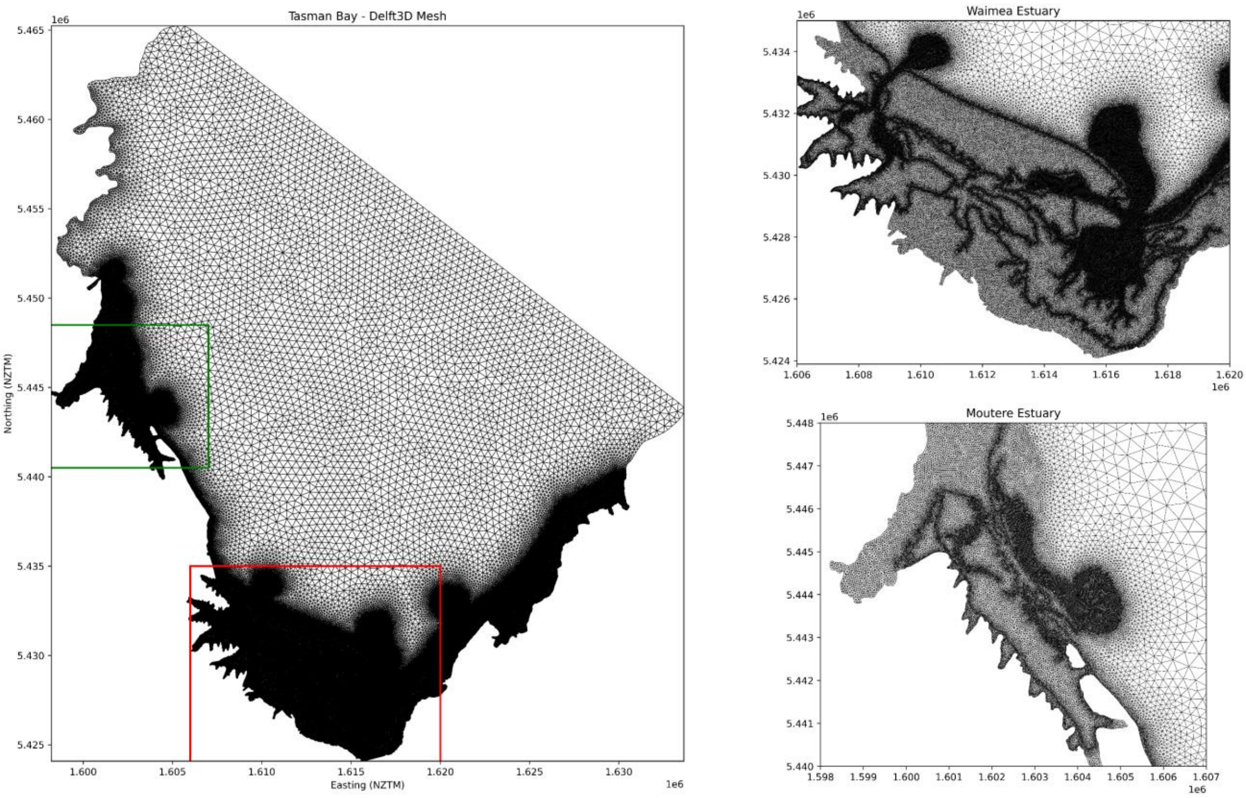

Figure 2-2: Extent and configuration of the Delft3D hydrodynamic model grid. Red box illustrates the zoomed extent of Waimea Estuary, Green box illustrates the zoom extent of Moutere Estuary.

2.3 Boundary conditions

The offshore boundary of the model was extended out to beyond the 30m depth contour allowing for more accurate simulation of tides and waves for several reasons:

1. **Wave Propagation:** By extending the boundary, the model can account for wave generation, propagation, and transformation processes that occur over deeper waters. This is particularly important for understanding how waves interact with the seabed and coast as they approach shallower areas.

2. **Tidal Dynamics:** A wider boundary allows for better representation of tidal dynamics, including the influence of tidal currents and their effects on coastal and estuarine waters. This can improve predictions of tidal heights and flow patterns in the nearshore region.

3. **Boundary Conditions:** Moving the boundary further offshore can reduce the influence of artificial boundary conditions on the model. This means that the model can better reflect the natural tidal and wave conditions that would occur in a real-world scenario.

The Coastal Calculator was used to derive a range of 1% and 2% AEP joint probability wave heights and storm tide levels at the Fairway Beacon which is located at approximately 12m water depth within the model domain. The basis of the selection was identifying the wave-storm tide level combination that resulted in the highest open coast extreme sea level, including wave set-up, as a proxy for estuary response via the Coastal Calculator. Additionally, a lower sea level (and higher H_S) and higher sea level (and lower H_S) for the 1% and 2% AEP events were selected from the Coastal Calculator joint probabilities to ensure that the event that resulted in the highest sea level response in the estuaries was identified. The selected joint probability H_s and storm tide levels are presented in Table 2-1. It is noted that highlighted values in Table 2-1 are the scenarios that result in the highest open coast wave setup. It is noted that the Coastal Calculator does not provide peak wave period (T_p), or wave direction information and the adopted values were derived from analysis of peak events recorded at the Fairway Beacon and TASCAM wave buoy.

Table 2-1: Model scenarios based on storm tide, wave height, wave period and direction at the Fairway Beacon. The bolded rows represent the combination which return the highest open coast water levels.

Scenario	AEP (%)	Storm-Tide (m NZVD 2016)	H_s (m)	T_p (s)	Wave direction (°)
Reference	-	1.90	-	-	-
1	2	1.91	3.74	9	22.5
2	**2**	**2.32**	**3.06**	**9**	**22.5**
3	2	2.36	1.73	9	22.5
4	1	1.91	4.07	9	22.5
5	**1**	**2.32**	**3.58**	**9**	**22.5**
6	1	2.40	2.02	9	22.5

As the model offshore boundary is further offshore than the Fairway Beacon, reverse shoaling is required to recalculate the wave heights at the boundary to account for wave attenuation. The reverse shoaling was completed via a series of simulations where the H_s at the boundary was increased in 1 m increments from 1 to 8 m and the H_s at the Fairway Beacon was recorded (Figure

2-3). A polynomial fit was then applied to the data to enable estimates of the required boundary H_s for each scenario presented in Table 2-1.

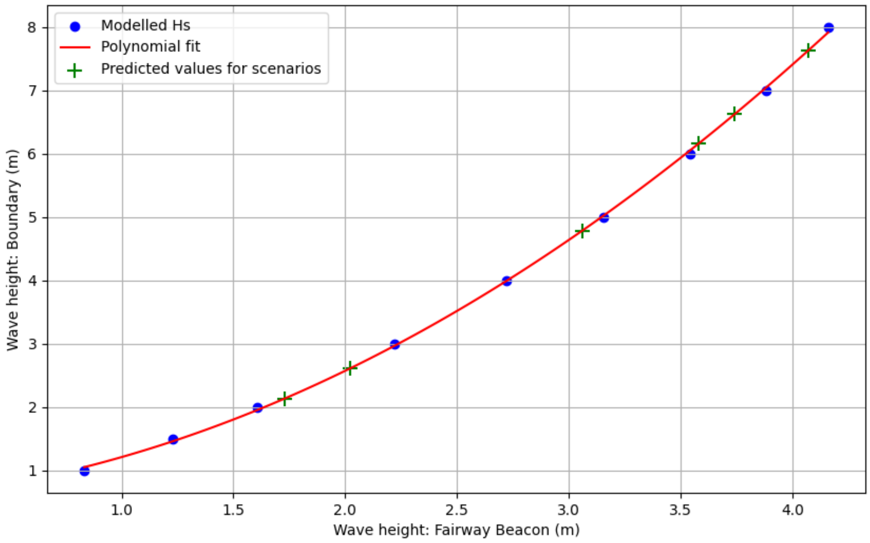

Figure 2-3: Fairway Beacon (x axis) and offshore boundary (y axis) significant wave height (H_s) relationship. Blue dots represent the modelled wave scenarios and the green crosses show the predicted offshore boundary values for the scenarios presented in Table 2-1 at the Fairway Beacon.

The offshore tidal boundary conditions used in the simulations were idealised based on a neap-spring tidal cycle extracted from NIWA's NZ-Tide model (Figure 2-4). For each of the storm tide levels presented in Table 2-1, a 3-day Hanning window was applied to smoothly transition the tidal levels up to the peak extreme sea level for each simulation. Figure 2-4 presents an example of the offshore boundary condition used for Scenario-6. The wave-heights were ramped-up to peak 6-hours before the storm-tide then held constant over the remainer of the simulation period.

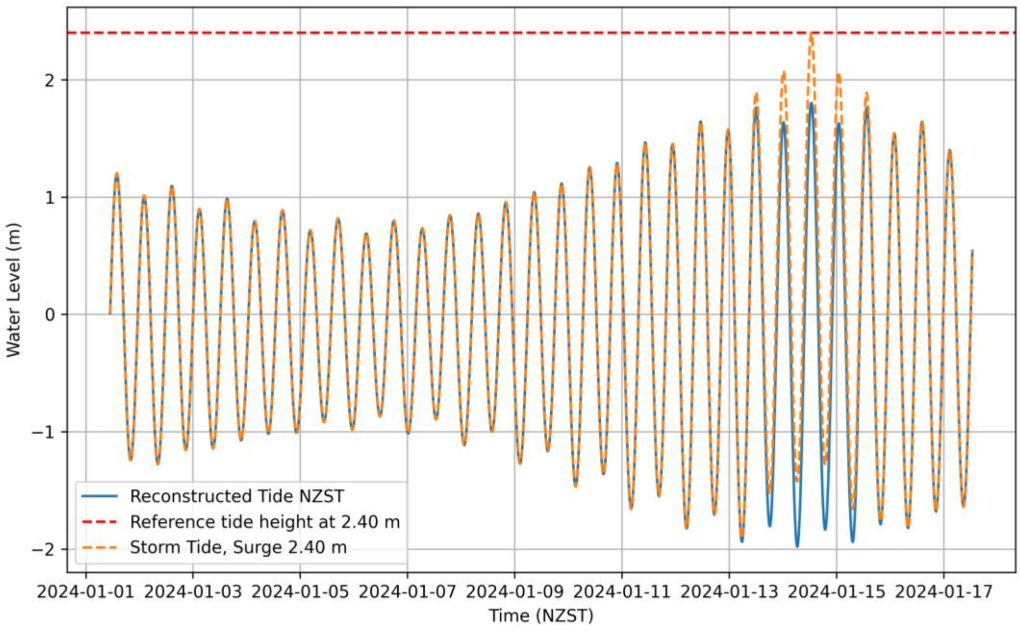

Figure 2-4: Idealised storm tide boundary conditions used for Scenario 6. Blue line is the reference spring-neap tidal cycle, orange line includes a 3-day storm-tide which has a peak height of 2.40 m.

2.4 Calibration

Calibration data for Tasman Bay is limited, which constrained calibration efforts to sea-level gauge data from three key locations: Port of Nelson, Kaiteriteri, and Fairway Beacon. Since the model does not account for atmospheric forces, we have focused on comparing the predicted harmonic sea levels. There is a very good comparison with tidal harmonic predictions over the same month for these 3 sites based on tidal constituents extracted from previous tide-height measurements (Figure 2-5). The model accurately reproduces water levels at each site, indicating a reliable representation of tidal dynamics in the absence of atmospheric influences.

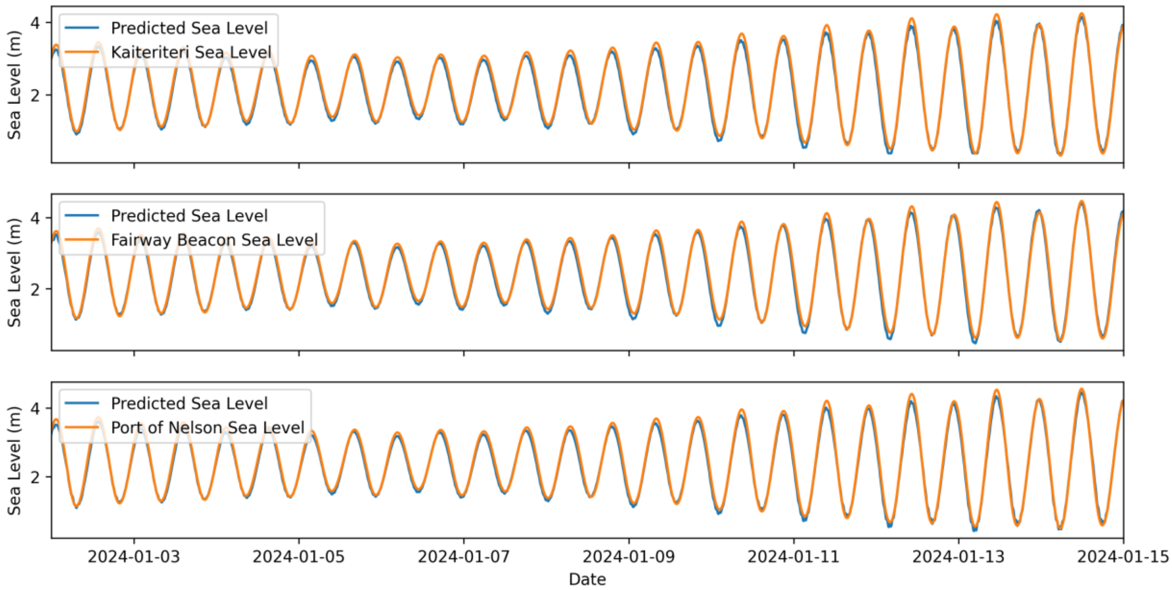

Figure 2-5: Water level calibration for the Delft3D-FM Tasman Bay hydrodynamic model. Comparison of simulated water levels (Blue) and predicted astronomical sea levels (Orange). Top panel: Kaiteriteri, middle panel Fairway Beacon and Bottom panel Port Nelson.

2.5 Results

Model results for each scenario are presented in Appendix A and B in the form of maximum observed inundation level and the percentage difference to the reference tidal simulation that excluded wave impacts.

Consistent with the open coast the extreme sea level and H_s combination that resulted in the highest wave setup also resulted in the highest 1% and 2% AEP inundation levels within the Waimea and Moutere estuaries (Scenarios 2 and 5). It is noted that Scenarios 3 and 6 that had higher storm tide levels and lower H_s resulted in only slightly lower maximum inundation levels. Peak inundation levels for all scenarios (refer to Table 2-1) were extracted at the locations shown in Figure 2-6 and a full list of these levels are presented in Appendix A.

Figure 2-7 presents maximum tidal levels from the tide-only simulation (Reference scenario), excluding the effects of waves, at the extraction locations shown in Figure 2-6. The highest tidal levels occurred in the eastern basin of Waimea Harbour, with a peak of RL 2.07 m at location WE_7 compared to the boundary water level of RL 1.90m. In the western basin, the highest water levels of RL 1.85 m were recorded at WW_5 and WW_6. In Moutere Estuary, the maximum water level of RL 1.90 m was observed at MOT-3 (Table A-1).

Overall, maximum tidal levels within the western and eastern Waimea are up to 0.14 m lower and 0.13m higher respectively compared to the adjacent open coast. Similarly, for the Moutere estuary tidal levels are up to 0.10 m lower than the adjacent open coast.

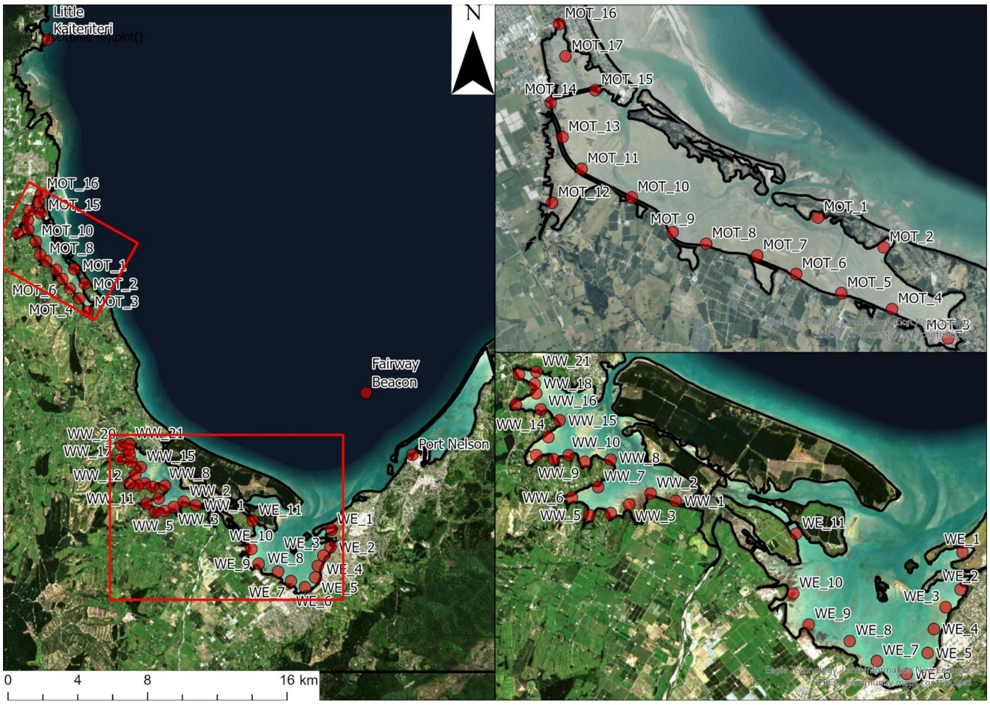

Figure 2-6: Waimea and Moutere estuaries sea level extraction locations. Red boxes show the extent for the two sub-figures of the Waimea and Moutere estuaries. WW-* are locations in the western Waimea, WE-* is the eastern Waimea and MOT-* is Moutere Estuary.

Figure 2-8 presents the maximum 2%AEP inundation levels (Scenario 2) that has a storm tide of RL 2.32 m and H_s at Fairway Beacon of 3.06m. At the extraction locations the highest water levels occurred in the eastern basin of Waimea Harbour, with a peak of RL 2.54 m at locations WE_6 and WE_10. In the western basin, the highest water levels reached RL 2.43 m at WW_3, WW_4, WW_5, WW_6 and WW_7. In Moutere Estuary, the maximum water level of RL 2.40 m was observed at MOT-3, MOT-4, MOT-5 and MOT-6 (Table A-1).

Interestingly, when considering waves and the storm tide, the Moutere Estuary and the western basin of Waimea experienced the largest percentage changes in water levels (Figure 2-9). Comparing the 2%AEP event (Scenario 2) to the reference simulation, water levels at MOT_17 and WW_20 increased by 31.20%, and 31.11% respectively.

Figure 2-10 presents the maximum inundation levels for the 1% AEP event (Scenario 5) that incorporates a storm tide of RL 2.32 m and H_s of 3.58 m at Fairway Beacon. Consistent with the 2%AEP event, the highest water levels were observed in the eastern basin of Waimea Harbour, peaking at RL 2.57 m at several locations. In the western basin, the highest levels reached RL 2.48 m. In the Moutere Estuary, the maximum recorded water level was RL 2.45 m at MOT-3 (Table A-1). Furthermore, when accounting for both waves and storm tide, the Moutere Estuary and the western basin of Waimea exhibited the largest increases in relative sea levels (Figure 2-9). Comparing the 1%AEP event (Scenario 5) to the reference scenario, sea levels rose by 34.99% and 35.31% at WW_17 and MOT_17 respectively.

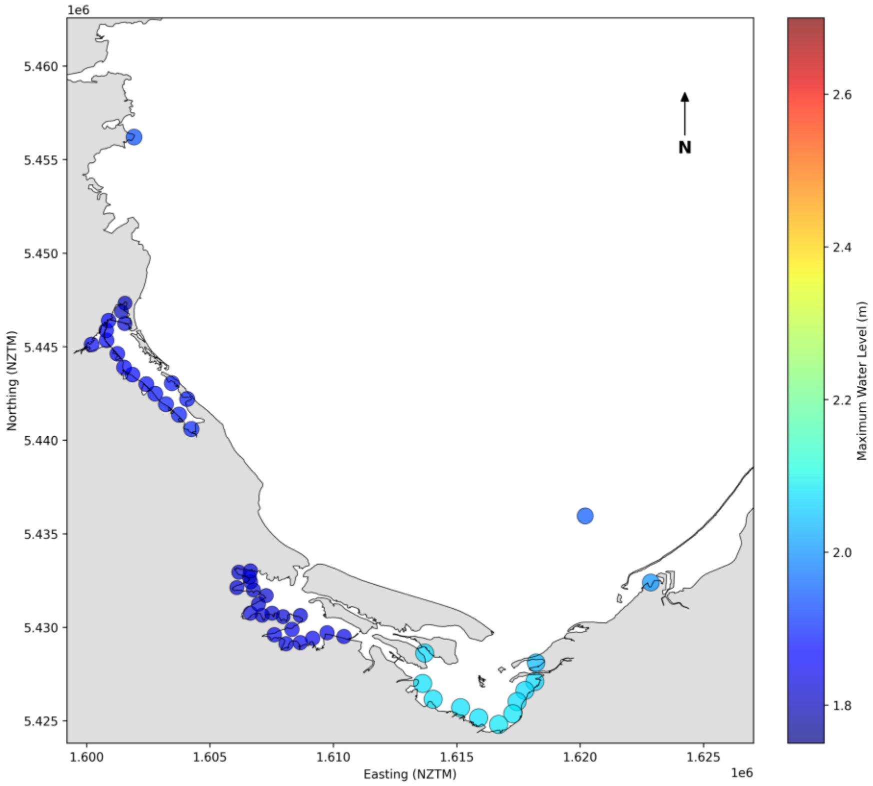

Figure 2-7: Maximum water levels predicted for the reference (tide only) scenario in the absence of waves and storm tides. Colour bar represents water height at extraction locations in meters.

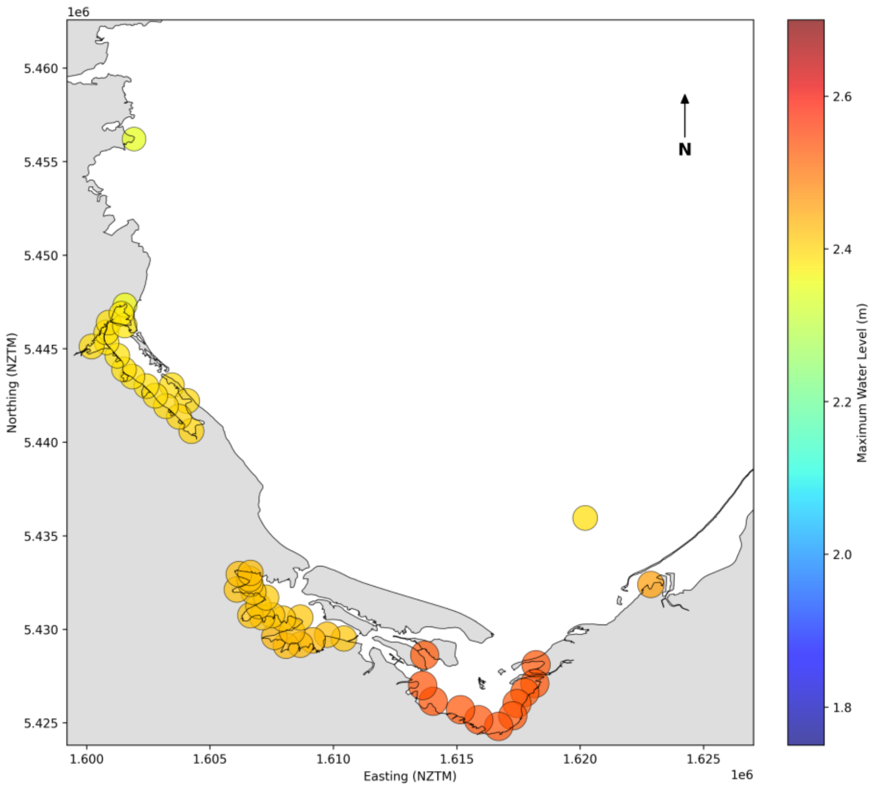

Figure 2-8: Maximum water levels predicted for 2%AEP event (Scenario 2). Scenario storm tide = RL 2.32 m and wave Height = 3.06 m. Colour bar represents water height at extraction locations in meters.

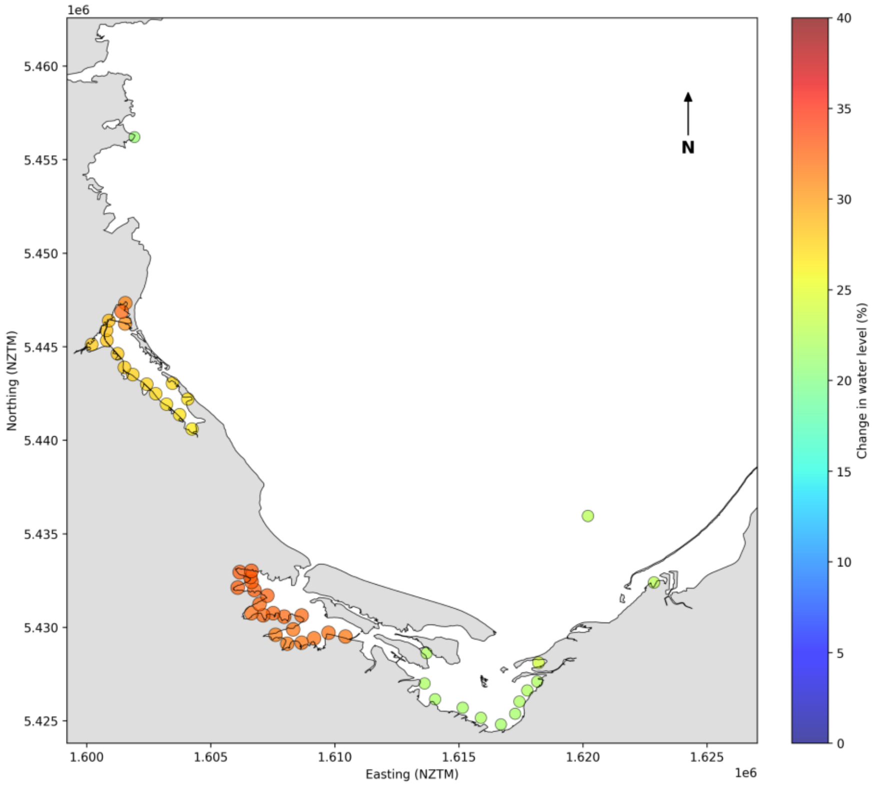

Figure 2-9: Percentage difference in water level between the reference simulation and 2%AEP event (Scenario 2). Colour bar represents percentage difference.

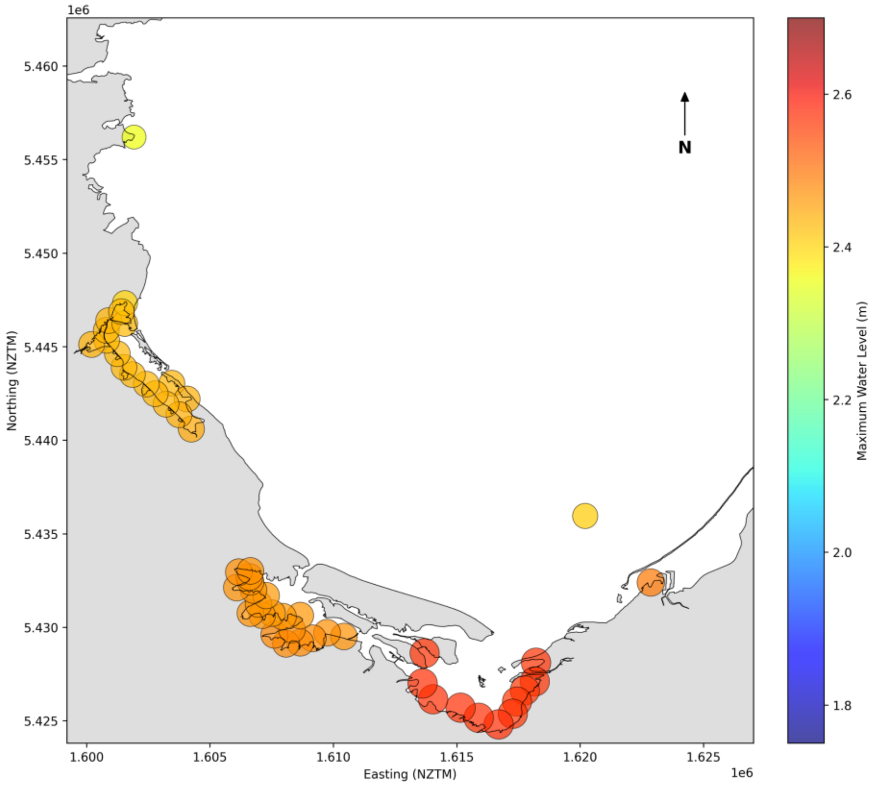

Figure 2-10: Maximum water levels predicted for 1%AEP event (Scenario 5). Scenario storm tide = RL 2.32 m and wave Height = 3.58 m. Colour bar represents water height at extraction locations in meters.

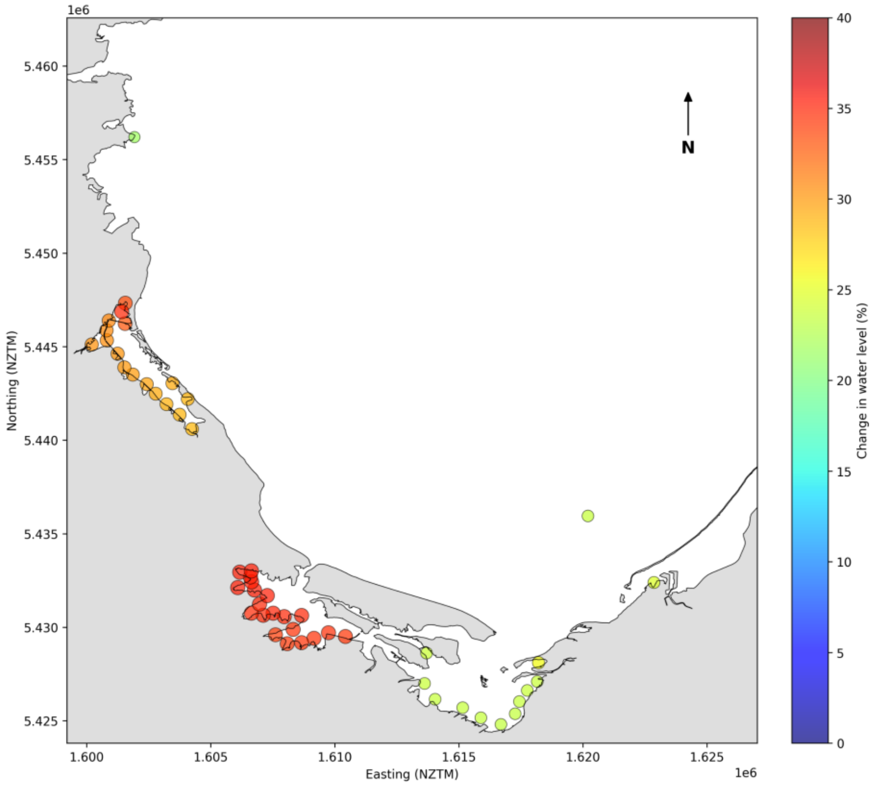

Figure 2-11: Percentage difference in water level between the reference simulation and 1%AEP event (Scenario 5). Colour bar represents percentage difference.

2.6 Discussion

2.6.1 Estuary configuration

Waimea Estuary is a barrier-enclosed system with two entrances: a smaller, more constrained entrance to the west, and a larger, open inlet to the east, featuring multiple channels. The eastern and western basins are nearly separated by Motuora/Rabbit Island, an outer barrier island, and Rough Island, which lies further inland, both connected to the mainland by bridges, causeways and culverts. This physical separation contributes to the distinct hydrodynamic responses observed in the two basins. As a result, the estuary is best understood as having two distinct basins—the western and eastern. The Moutere Estuary is a barrier-enclosed estuary with two entrances. It has a near-central entrance and a western entrance, both of which are relatively constrained.

The hydraulic response of estuaries and harbours are often significantly different to adjacent open coast locations due to geomorphic controls such as number and width of tidal entrances, inner planform shape and depth, tidal volume and varying exposure to wave energy.

2.6.2 Astronomical tide response

Astronomical tidal levels, excluding the impact of waves and atmospherics, vary along the Tasman Bay coastline with notable amplification in the eastern Waimea estuary and lower tidal levels in western Waimea and Moutere estuaries relative to the open coast (refer to Figure 2-7 and Appendix B).

Tidal variability is a function of coastline shape and configuration of embayment's that amplify or suppress tidal variation and levels. Estuary response is dependent on the tidal volume of the estuary and the dimensions of the estuary entrance. In environs such as the western Waimea and Moutere estuaries the entrance modulates tidal exchange resulting in suppressed tidal levels within the estuary and prolonged ebb tidal flows (refer to Figure 2-12). Accordingly, maximum spring tidal levels within the western Waimea and Moutere estuaries are 0.13 and 0.10 m lower than adjacent open coast levels.

Conversely, in environs with more open entrances such as eastern Waimea estuary or the Nelson Haven tidal levels can be and, in these cases, amplified. Maximum spring tidal levels within the eastern Waimea estuary and at Port Nelson within the Nelson Haven are up to 0.14 and 0.05 m higher than adjacent open coast levels.

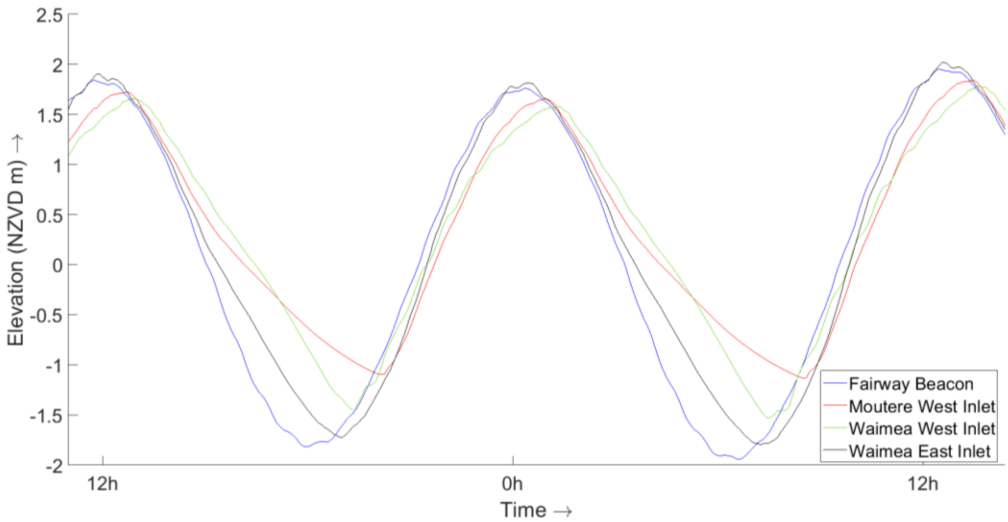

Figure 2-12: Typical tidal variation at Waimea and Moutere Estuary Inlets and Fairway Beacon.

Accordingly, astronomical tidal levels such as Mean High Water Springs (MHWS) within western Waimea and Moutere estuaries are expected to be lower (slightly) when compared to offshore levels at the Fairway Beacon or reported for Port of Nelson.

2.6.3 Response to Tides and Waves

The results from Scenario 5 (1%AEP), highlight the difference in hydrodynamic response of the Waimea and Moutere estuaries to tidal and wave forces (Figure 2-11). Compared to normal tidal variation, the additional impact from elevated storm tide and waves during extreme events result in amplification of sea levels compared to sea levels observed at the Fairway Beacon. Extreme sea levels within the western Waimea and Moutere estuaries are approximately 35% and 30% higher respectively relative to normal springs tidal levels within each estuary. For the more open eastern Waimea estuary extreme sea levels are approximately 24% higher.

The constricted entrances at the western basin of Waimea and Moutere estuaries is a key factor in amplification and sustained elevated water levels during extreme events. Wave setup at the entrance results in amplification of water levels within the estuaries, albeit modulated compared to the open coast, and sustains sea levels as wave setup slows ebb tidal flow, trapping water inside the estuary (Rautenbach 2023). In contrast, the eastern Waimea basin, with its open connection to the sea, experiences lower percentage change increases in sea level due to the reducing influence of wave setup on estuarine hydrodynamics. This highlights the role of estuary geometry in modulating water levels, particularly during extreme events.

The numerical modelling shows that the hydraulic behaviour of the Waimea estuary is complex due to substantially different entrance widths and geomorphic controls that limit hydraulic exchange between the western and eastern sides of the estuary. During normal spring tide conditions there is potential for up to a 0.27 m variation in sea level across the estuary. During extreme conditions this reduces 0.13 m and 0.11 m during 2%AEP and 1%AEP events respectively.

When considering the combined effects of astronomical tide, storm tide and wave impacts during extreme events the net effect is a super elevation of sea levels within the estuaries relative to offshore. For the western Waimea and Moutere estuaries that have lower tidal ranges and levels compared to offshore, combined with the relatively high impact from waves on estuarine hydrodynamics, the net 1%AEP inundation level increase is up to 0.07 m and 0.03 m respectively. Inundation levels within the more exposed eastern Waimea estuary are up to 0.16 m higher than offshore. When compared to extreme inundation levels at the adjacent open coast that include wave setup, as calculated in the Coastal Calculator, inundation levels within the estuaries are notably lower.

Inundation levels around the periphery of the estuaries have the potential to be affected by localised runup from locally wind generated waves. Due to the limited wave penetration into the estuaries from offshore, coupled with the restricted fetch to generate waves locally, the inundation impacts from runup are likely to be minor.

The numerical study has shown that the dynamic interaction between tidal energy, wave action, and estuarine morphology is critical in understanding the potential inundation impact during extreme events and that each estuary has a bespoke hydraulic response.

3 Conclusions

The numerical model investigation has demonstrated that the physical characteristics of Waimea Estuary, particularly the contrast between the open eastern basin and the constrained western basin and Moutere Estuary, lead to significant differences in how each estuary responds to tides, storm tides, and wave energy.

The eastern Waimea basin consistently experiences higher water levels under normal tidal conditions, while the western basin and Moutere Estuary are more susceptible to large increases in water levels during storm tide and wave events. The constricted entrance of the western Waimea basin and Moutere Estuary result in prolonging ebb tide sea levels, which could exacerbate flooding impacts on the surrounding environment.

The spatial variability of extreme inundation levels along embayed coastlines and estuaries is a function of the combined net effects of tidal attenuation or amplification from geomorphic controls and the impact of wave setup on local hydrodynamics.

These findings highlight the importance of considering local estuarine dynamics when assessing the potential impacts of extreme water levels, particularly in light of future sea-level rise and climate change.

4 Glossary of abbreviations and terms

AEP	Annual Exceedance Probability
H_s	Significant Wave Height
T_p	Wave Period

5 References

Andrews, C. (2023) Mean High Water Spring (MHWS) Levels for the Tasman and Golden Bay Coastline. *NIWA Client Report* 2023062HN. Prepard for Tasman District Council.

Rautenbach, C. (2023) Wave set-up in constricted estuaries. *Coastal Engineering*, 186: 104393. 10.1016/j.coastaleng.2023.104393

Stephens, S.A., Robinson, B., Allis, M. (2018) Storm-tide and wave hazards in Tasman and Golden Bays. *NIWA Client Report* to Tasman District Council and Nelson City Council, June 2018, 2018208HN, 61 p.

Appendix A Maximum water level at extraction locations

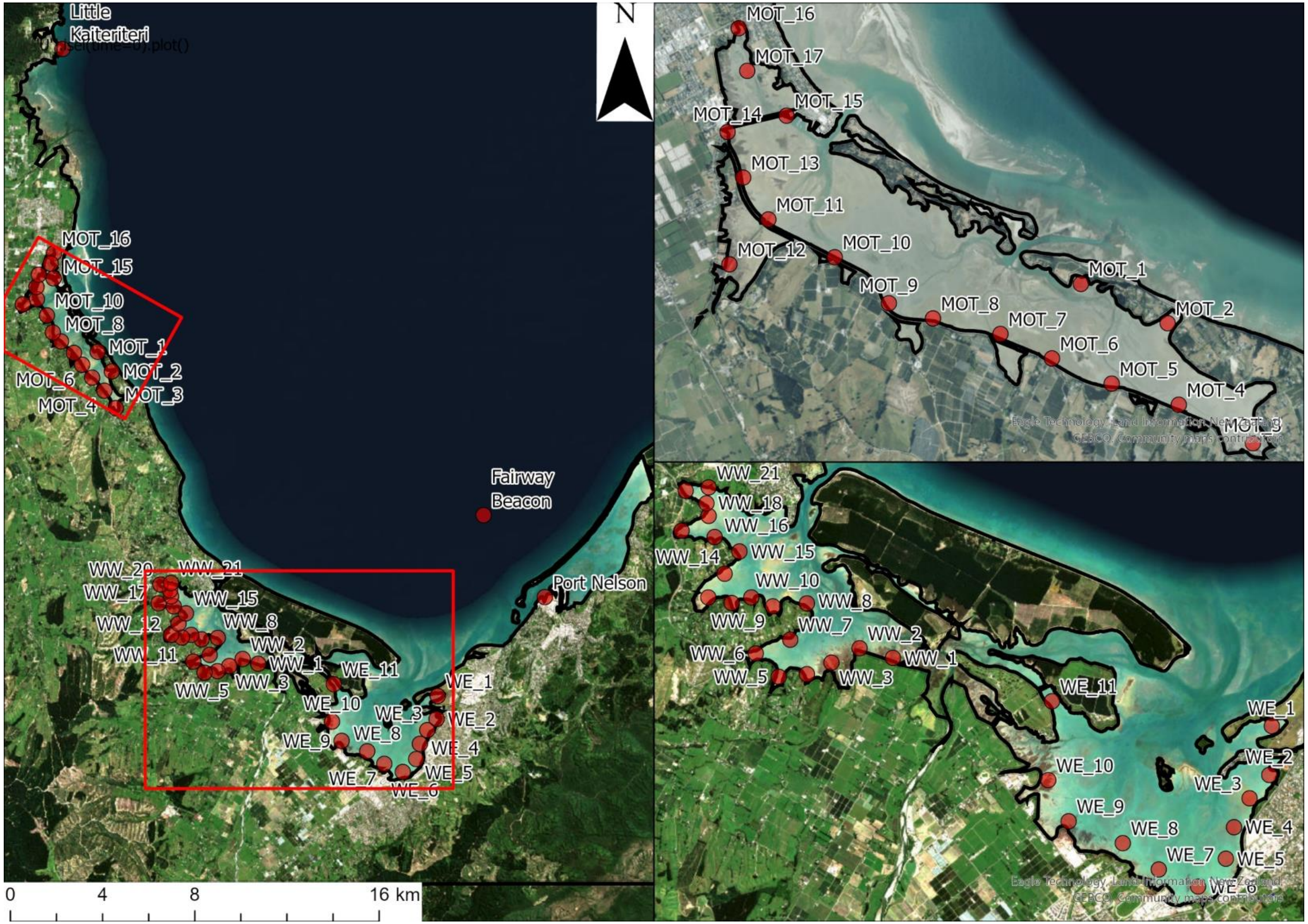

Figure A-1: Water level extraction locations from Waimea and Moutere estuaries. Red boxes show the extent for the two sub-figures of the Waimea and Moutere estuaries. WW-* are location in the West of Waimea, WE-* is the East of Waimea and MOT-* is Moutere Estuary.

Table A-1: Highest water level extracted from each scenario. Station name is illustrated in Figure A-1, the "Reference" simulation represents a scenario with no storm-tide or waves.

Extraction Location	Northing (NZTM)	Easting (NZTM)	Reference (tide only) (m)	2%AEP Scenario 1 (m RL)	2%AEP Scenario 2 (m RL)	2%AEP Scenario 3 (m RL)	1%AEP Scenario 4 (m RL)	1%AEP Scenario 5 (m RL)	1%AEP Scenario 6 (m RL)
Fairway Beacon	5435948	1620207	1.95	2.01	2.39	2.41	2.03	2.41	2.45
Port of Nelson	5432392	1622867	2.00	2.12	2.46	2.45	2.15	2.50	2.49
Little Kaiteriteri	5456197	1601925	1.94	1.96	2.34	2.38	1.98	2.36	2.42
WE_1	5428106	1618216	2.04	2.20	2.53	2.51	2.23	2.57	2.56
WE_2	5427100	1618165	2.07	2.22	2.53	2.51	2.24	2.56	2.55
WE_3	5426623	1617762	2.07	2.21	2.53	2.51	2.24	2.56	2.55
WE_4	5426030	1617444	2.07	2.21	2.53	2.51	2.24	2.56	2.55
WE_5	5425376	1617272	2.08	2.22	2.53	2.51	2.24	2.57	2.56
WE_6	5424808	1616699	2.09	2.22	2.54	2.52	2.25	2.57	2.56
WE_7	5425161	1615891	2.08	2.22	2.53	2.51	2.25	2.57	2.56
WE_8	5425701	1615157	2.08	2.22	2.53	2.51	2.25	2.57	2.55
WE_9	5426152	1614045	2.08	2.22	2.53	2.51	2.25	2.57	2.56
WE_10	5426995	1613621	2.08	2.22	2.54	2.51	2.25	2.57	2.56
WE_11	5428618	1613702	2.07	2.21	2.53	2.51	2.24	2.56	2.55
WW_1	5429506	1610431	1.84	2.02	2.42	2.38	2.06	2.47	2.44
WW_2	5429706	1609748	1.84	2.03	2.42	2.39	2.07	2.47	2.45
WW_3	5429408	1609163	1.84	2.03	2.43	2.40	2.07	2.48	2.45
WW_4	5429176	1608662	1.84	2.03	2.43	2.40	2.07	2.48	2.46
WW_5	5429121	1608084	1.85	2.03	2.43	2.40	2.07	2.48	2.45
WW_6	5429598	1607612	1.85	2.04	2.43	2.40	2.08	2.48	2.45
WW_7	5429885	1608324	1.84	2.03	2.43	2.40	2.07	2.47	2.45
WW_8	5430627	1608664	1.83	2.02	2.42	2.38	2.06	2.46	2.44
WW_9	5430567	1607963	1.83	2.01	2.41	2.38	2.05	2.46	2.44
WW_10	5430750	1607519	1.82	2.01	2.41	2.38	2.05	2.46	2.44
WW_11	5430640	1607118	1.83	2.02	2.42	2.38	2.06	2.46	2.44
WW_12	5430751	1606640	1.83	2.02	2.42	2.39	2.06	2.47	2.45
WW_14	5431239	1606969	1.83	2.01	2.42	2.38	2.06	2.46	2.44
WW_15	5431693	1607280	1.82	2.01	2.41	2.38	2.05	2.46	2.44
WW_16	5431992	1606763	1.82	2.01	2.42	2.39	2.05	2.46	2.44
WW_17	5432120	1606090	1.82	2.01	2.42	2.39	2.05	2.47	2.45
WW_18	5432426	1606648	1.82	2.01	2.42	2.39	2.05	2.47	2.45
WW_19	5432688	1606602	1.83	2.02	2.42	2.39	2.06	2.47	2.45
WW_20	5432944	1606172	1.83	2.02	2.42	2.39	2.06	2.47	2.45
WW_21	5433011	1606642	1.83	2.02	2.42	2.39	2.06	2.47	2.45
MOT_1	5443043	1603458	1.88	2.05	2.39	2.38	2.08	2.43	2.42

Extraction Location	Northing (NZTM)	Easting (NZTM)	Reference (tide only) (m)	2%AEP Scenario 1 (m RL)	2%AEP Scenario 2 (m RL)	2%AEP Scenario 3 (m RL)	1%AEP Scenario 4 (m RL)	1%AEP Scenario 5 (m RL)	1%AEP Scenario 6 (m RL)
MOT_2	5442199	1604076	1.89	2.05	2.40	2.38	2.09	2.44	2.43
MOT_3	5440595	1604248	1.90	2.06	2.40	2.39	2.10	2.45	2.44
MOT_4	5441361	1603747	1.89	2.06	2.40	2.38	2.09	2.44	2.43
MOT_5	5441922	1603218	1.89	2.05	2.40	2.38	2.09	2.44	2.43
MOT_6	5442482	1602784	1.88	2.05	2.40	2.38	2.08	2.43	2.43
MOT_7	5442993	1602422	1.87	2.04	2.39	2.37	2.07	2.43	2.42
MOT_8	5443504	1601859	1.87	2.04	2.39	2.37	2.07	2.43	2.42
MOT_9	5443887	1601520	1.87	2.04	2.39	2.37	2.07	2.43	2.42
MOT_10	5444618	1601248	1.86	2.03	2.39	2.37	2.07	2.43	2.42
MOT_11	5445333	1600815	1.86	2.03	2.39	2.37	2.06	2.43	2.42
MOT_12	5445111	1600205	1.87	2.03	2.40	2.37	2.06	2.44	2.43
MOT_13	5445868	1600800	1.86	2.03	2.39	2.37	2.06	2.43	2.42
MOT_14	5446390	1600896	1.86	2.03	2.39	2.37	2.06	2.43	2.42
MOT_15	5446229	1601549	1.83	1.99	2.38	2.36	2.02	2.43	2.42
MOT_16	5447323	1601558	1.80	1.97	2.36	2.34	2.01	2.40	2.39
MOT_17	5446870	1601412	1.80	1.97	2.38	2.36	2.01	2.43	2.42

Table A-2: Percentage difference in the maximum water level between the reference scenario and the scenarios with storm-tides and waves.

Extraction Location	Northing (NZTM)	Easting (NZTM)	2%AEP Scenario 1 (%)	2%AEP Scenario 2 (%)	2%AEP Scenario 3 (%)	1%AEP Scenario 4 (%)	1%AEP Scenario 5 (%)	1%AEP Scenario 6 (%)
Fairway Beacon	5435948	1620207	2.87	22.57	23.69	3.91	23.49	25.82
Port of Nelson	5432392	1622867	5.78	22.76	22.24	7.41	24.58	24.44
Little Kaiteriteri	5456197	1601925	1.12	21.03	22.94	2.19	21.63	24.94
WE_1	5428106	1618216	7.84	23.96	22.92	9.33	25.68	25.19
WE_2	5427100	1618165	6.89	22.06	21.12	8.30	23.68	23.21
WE_3	5426623	1617762	6.84	22.06	21.11	8.24	23.67	23.21
WE_4	5426030	1617444	6.61	21.90	20.93	8.03	23.56	23.06
WE_5	5425376	1617272	6.47	21.67	20.66	7.83	23.35	22.83
WE_6	5424808	1616699	6.40	21.62	20.65	7.76	23.29	22.80
WE_7	5425161	1615891	6.61	21.93	20.95	8.05	23.59	23.08
WE_8	5425701	1615157	6.66	21.85	20.86	8.11	23.57	23.01
WE_9	5426152	1614045	6.67	21.83	20.84	8.13	23.52	23.00
WE_10	5426995	1613621	6.79	22.02	21.03	8.28	23.67	23.19
WE_11	5428618	1613702	6.86	22.08	21.12	8.34	23.84	23.27
WW_1	5429506	1610431	10.26	31.67	29.86	12.44	34.34	33.12
WW_2	5429706	1609748	10.32	31.99	30.21	12.51	34.62	33.43
WW_3	5429408	1609163	10.23	31.97	30.16	12.40	34.48	33.34
WW_4	5429176	1608662	10.22	31.84	30.15	12.40	34.39	33.28
WW_5	5429121	1608084	10.19	31.54	29.91	12.32	34.18	32.95
WW_6	5429598	1607612	10.18	31.49	29.81	12.30	34.05	32.83
WW_7	5429885	1608324	10.23	31.77	30.08	12.36	34.38	33.23
WW_8	5430627	1608664	10.45	32.32	30.60	12.61	35.00	33.79
WW_9	5430567	1607963	10.38	32.30	30.59	12.48	34.91	33.74
WW_10	5430750	1607519	10.40	32.39	30.68	12.63	35.04	33.89
WW_11	5430640	1607118	10.43	32.35	30.61	12.64	34.96	33.82
WW_12	5430751	1606640	10.24	32.18	30.48	12.46	34.70	33.60
WW_14	5431239	1606969	10.36	32.33	30.62	12.60	34.90	33.78
WW_15	5431693	1607280	10.47	32.54	30.83	12.72	35.18	34.05
WW_16	5431992	1606763	10.42	32.58	30.89	12.66	35.24	34.11
WW_17	5432120	1606090	10.38	32.58	30.92	12.61	35.31	34.12
WW_18	5432426	1606648	10.43	32.60	30.92	12.64	35.21	34.08
WW_19	5432688	1606602	10.46	32.66	31.01	12.68	35.21	34.09
WW_20	5432944	1606172	10.45	32.74	31.11	12.68	35.28	34.16
WW_21	5433011	1606642	10.48	32.68	31.04	12.69	35.23	34.12
MOT_1	5443043	1603458	8.71	27.31	26.35	10.45	29.36	28.89
MOT_2	5442199	1604076	8.66	26.86	25.98	10.38	28.90	28.43

Extraction Location	Northing (NZTM)	Easting (NZTM)	2%AEP Scenario 1 (%)	2%AEP Scenario 2 (%)	2%AEP Scenario 3 (%)	1%AEP Scenario 4 (%)	1%AEP Scenario 5 (%)	1%AEP Scenario 6 (%)
MOT_3	5440595	1604248	8.56	26.51	25.51	10.22	28.66	28.16
MOT_4	5441361	1603747	8.64	26.72	25.83	10.36	28.87	28.35
MOT_5	5441922	1603218	8.66	26.90	26.01	10.37	28.93	28.48
MOT_6	5442482	1602784	8.67	27.19	26.26	10.41	29.25	28.79
MOT_7	5442993	1602422	8.90	27.60	26.61	10.66	29.68	29.17
MOT_8	5443504	1601859	8.95	27.80	26.82	10.75	29.92	29.40
MOT_9	5443887	1601520	8.93	27.85	26.82	10.74	30.01	29.51
MOT_10	5444618	1601248	9.00	28.06	26.93	10.80	30.30	29.76
MOT_11	5445333	1600815	9.01	28.18	27.07	10.76	30.55	30.00
MOT_12	5445111	1600205	8.69	28.12	26.86	10.36	30.38	29.87
MOT_13	5445868	1600800	9.03	28.30	27.19	10.80	30.68	30.14
MOT_14	5446390	1600896	9.16	28.52	27.41	10.94	30.93	30.40
MOT_15	5446229	1601549	8.92	30.65	29.40	10.89	33.03	32.49
MOT_16	5447323	1601558	9.45	31.02	29.88	11.33	33.43	32.90
MOT_17	5446870	1601412	9.54	32.36	31.20	11.48	34.99	34.42

Appendix B Extreme water levels

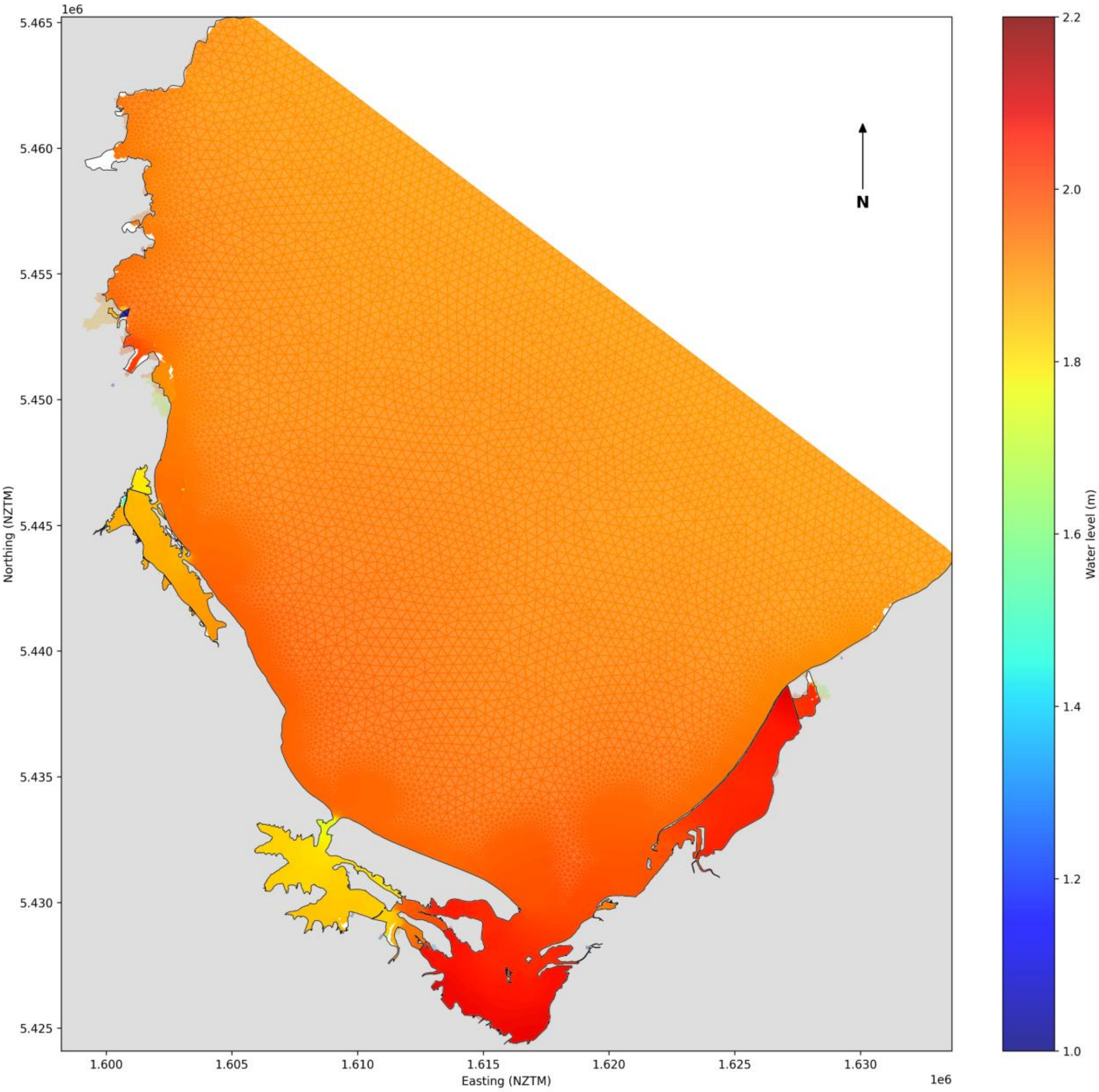

Figure B-1: Maximum water levels predicted for the reference (tide only) scenario in the absence of waves and storm tides.

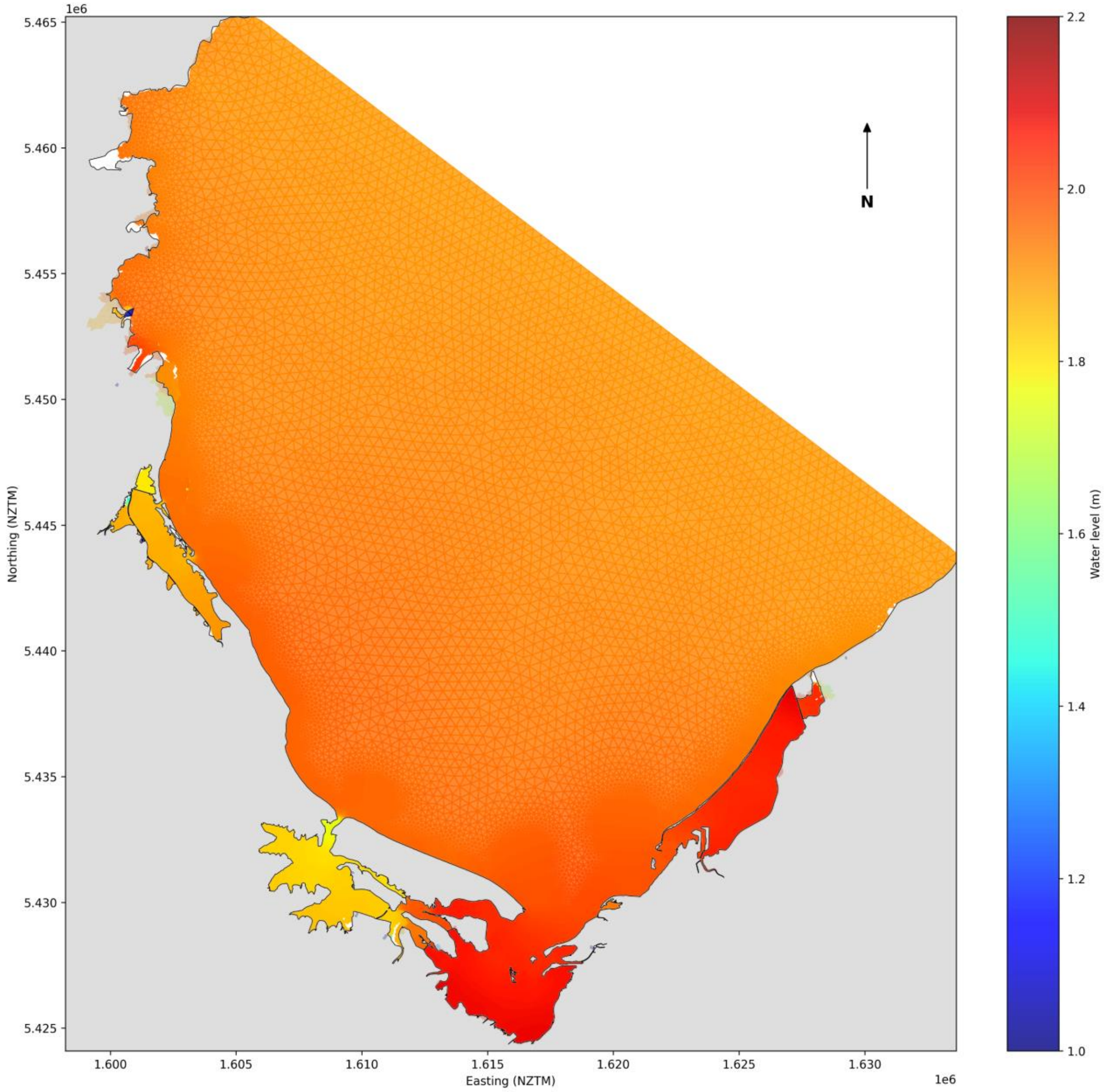

Figure B-2: Maximum water levels predicted for 2%AEP event (Scenario 2). Scenario storm tide = RL 2.32 m and wave Height = 3.06 m.

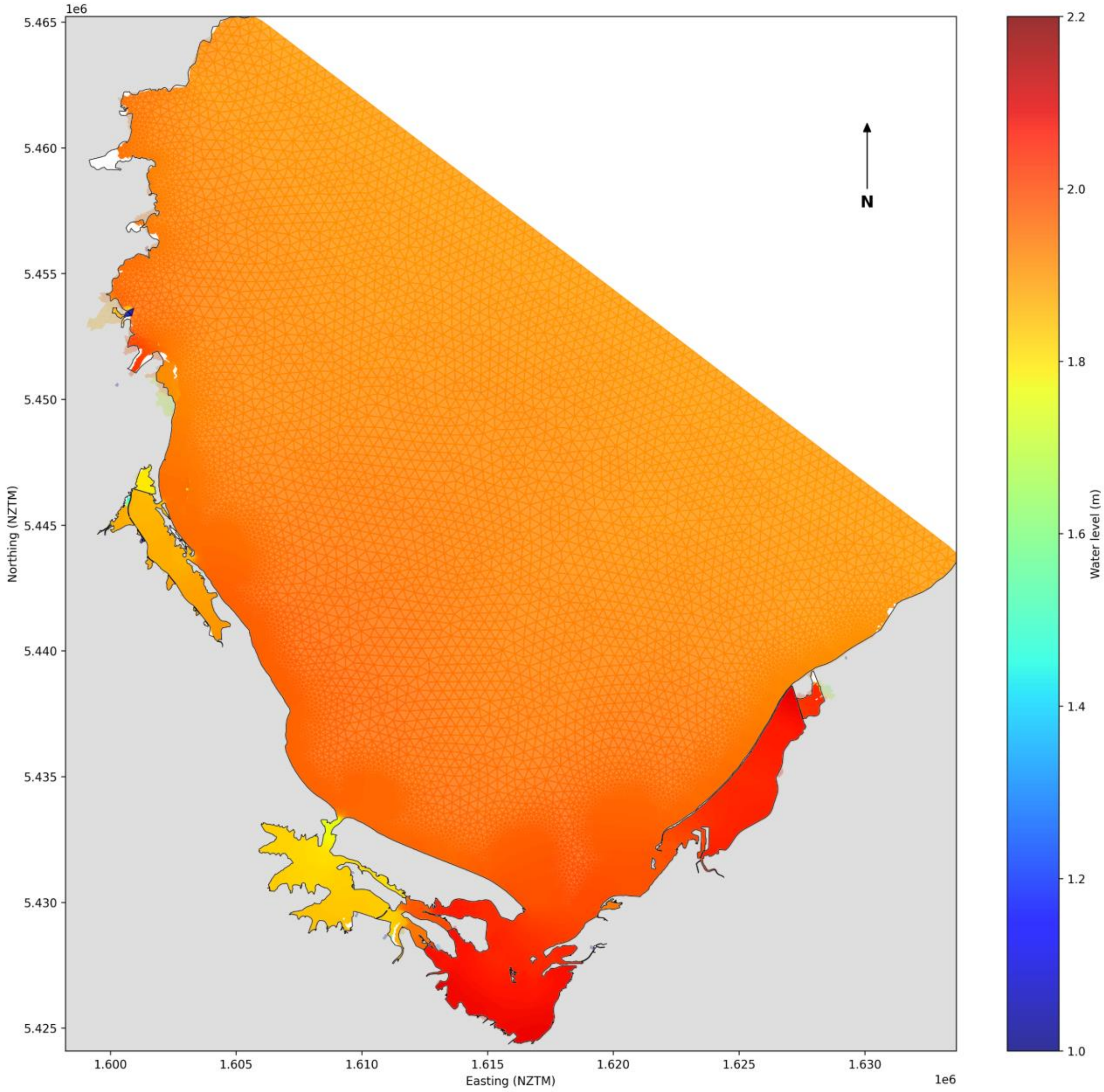

Figure B-3: Maximum water levels predicted for 1%AEP event (Scenario 5). Scenario storm tide = RL 2.32 m and wave Height = 3.58 m.