Mean High Water Spring (MHWS) Levels for the Tasman and Golden Bay Coastline

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Climate, Freshwater & Ocean Science

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Version 1.0	Final version sent to client	06/04/2023
Version 2.0	Final - Revised MSL baseline	15/05/2023

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1 Introduction

Tasman District Council (TDC) has requested an update of the Mean High Water Springs (MHWS) levels throughout the district via Envirolink medium advice grant (TSDC183). The update herein supersedes the prior 2013 assessment (NIWA, 2013) providing MHWS at 13 locations referenced to a representative present day Mean Sea Level (MSL) relative to three vertical datums: NZVD 2016, NVD 1955 and where possible Chart Datum (CD).

1.1 Scope of Work

The scope of work includes the following deliverables:

1. Update sea level gauge datum offsets for Little Kaiteriteri, Tarakohe and Nelson Port relative to NVD-1955, NZVD 2016 and Chart Datum.

2. Update the Mean Sea Level (MSL) calculations for Little Kaiteriteri, Tarakohe and Nelson Port relative to NVD-1955, NZVD 2016 and Chart Datum.

3. Monthly mean sea levels for the period January 2013 to December 2021 for Little Kaiteriteri, Tarakohe and Nelson Port.

4. High tide exceedance curves for Little Kaiteriteri, Tarakohe and Nelson Port relative to MSL, NVD-1955 and NZVD 2016.

5. Update Mean High Water Springs - Cadastral (MHWS-C), Mean Low Water Spring (MLWS), Highest Astronomical Tide (HAT), and Lowest Astronomical Tide (LAT) levels for Little Kaiteriteri, Tarakohe and Nelson Port relative to NVD-1955, NZVD 2016 and Chart Datum.

6. Sea level record Quality Assurance and Quality Control (QA/QC) for Little Kaiteriteri, Tarakohe and Nelson Port from January 2013 to December 2021.

7. Tidal harmonic analysis for Little Kaiteriteri, Tarakohe and Nelson Port including reworking of Tidal Statistic Calculations as detailed in the Table1 of NIWA (2013) including climate change scenarios based on 0.5m, 1.0m, 1.5m, and 2m increments of projected Sea Level Rise (SLR).

2 Background

Mean High Water Spring (MHWS) is an important planning demarcation between the coastal marine area (CMA) and land which underpins numerous planning and legislative instruments. There are a variety of methods to calculate MHWS depending on the intended purpose. NIWA (2013) adopted a water level exceedance approach referenced to measurements and predictions at Port Nelson. Since the NIWA (2013) assessment, further water level data has been collected at Port Nelson, Little Kaiteriteri and Tarakohe and the respective datums which were subject to inconsistencies have been further reconciled. The available data enables a revised methodology whereby MHWS is calculated directly which is presented in the following sections.

2.1 Recorded Data

Tidal levels have been recorded at Port Nelson, Little Kaiteriteri and Tarakohe for more than 20 years as summarised in Table 2-1. Data for the 3 gauges was provided by TDC reduced to respective Chart Datums at varying recording intervals ranging from 1 to 15 minutes with the majority less than 2 minutes. The data was subsequently processed to remove spurious data and retimed to a constant 5-minute interval via interpolation. A gap threshold of 15 minutes was adopted whereby time intervals greater than 15 minutes from the previous reading were defined as a gap in the dataset.

Table 2-1: Tide gauge locations

Tide Gauge	Lat (°)	Long (°)	Duration	% Complete (2004-2022)[a]
Port Nelson	-41.2613	173.2728	15/05/1996 - 31/12/2022	99.6%
Little Kaiteriteri	-41.0472	173.0225	16/06/2000 - 06/12/2022	99.6%
Tarakohe	-40.8227	172.8975	21/12/1998 - 14/12/2022	93.5%

a Number of months with greater than 66% data coverage between 2004 and 2022 expressed as a percentage.

Considering the varying start dates for each gauge, data post 1 January 2000 was adopted for comparative assessment. Furthermore, the period of 1 January 2004 to 31 December 2022 was adopted as the baseline period maximising the available datasets. Consistent with NIWA (2022) a monthly 66% complete threshold was adopted to ascertain appropriateness whether data is included in MSL trend analysis. Considering the threshold, monthly completeness exceeded 93% (refer to Table 2-1).

Vertical datum information was sourced from LINZ for Port Nelson, Little Kaiteriteri and Tarakohe tide gauge benchmarks AC4T, EC51 and ABRT respectively. Further information to define Chart Datum referenced to the benchmarks was sourced from LINZ for Port Nelson and from TDC for Little Kaiteriteri and Tarakohe. Tide gauge 0m relative to CD, NZVD 2016 and NVD 1955 is presented in Table 2-2.

Table 2-2: Tide Gauge Zero relative to CD, NZVD 2016 and NVD 1955

Tide Gauge	CD (m)	NZVD 2016 (m)	NVD 1955 (m)	Vertical Accuracy (m)[d]
Port Nelson [a]	-0.0406	-2.5784	-2.2490	0.25/0.01
Little Kaiteriteri[b]	0.0000	-2.2950	-1.9910	0.35/0.02
Tarakohe[c]	0.0000	-2.3510	-2.0280	0.35/0.02

a Chart datum is 5.733m below AC4T (RL 3.1546m NZVD). CD 0m = -2.5378m NZVD.
b Little Kaiteriteri datum information supplied by TDC
c NZVD supplied by TDC; NVD calculated via LINZ online coordinate converter
d XX/YYY - Accuracy to the respective datum (XX); Accuracy compared to surrounding benchmarks (YYY)

Benchmarks are intermittently updated to reflect new level information, the latest version of the deformation model and post-earthquake level changes. Of the three tide gauges only Port Nelson has been updated to reflect level changes, particularly post the 14 November 2016 Kaikoura earthquake. Following analysis, it was discovered the Port Nelson data had intermittent datum corrections post 1 November 2016 which could not be reconciled. The reference benchmark AC4T for the Port Nelson gauge had several level adjustments between 18 November 2016 and 30 November 2018 reducing the benchmark level by 40.6mm.

To reconcile, the original raw 1-minute data for Port Nelson was sourced from LINZ, quality controlled and retimed to 5 minutes. Two data sets were subsequently created:

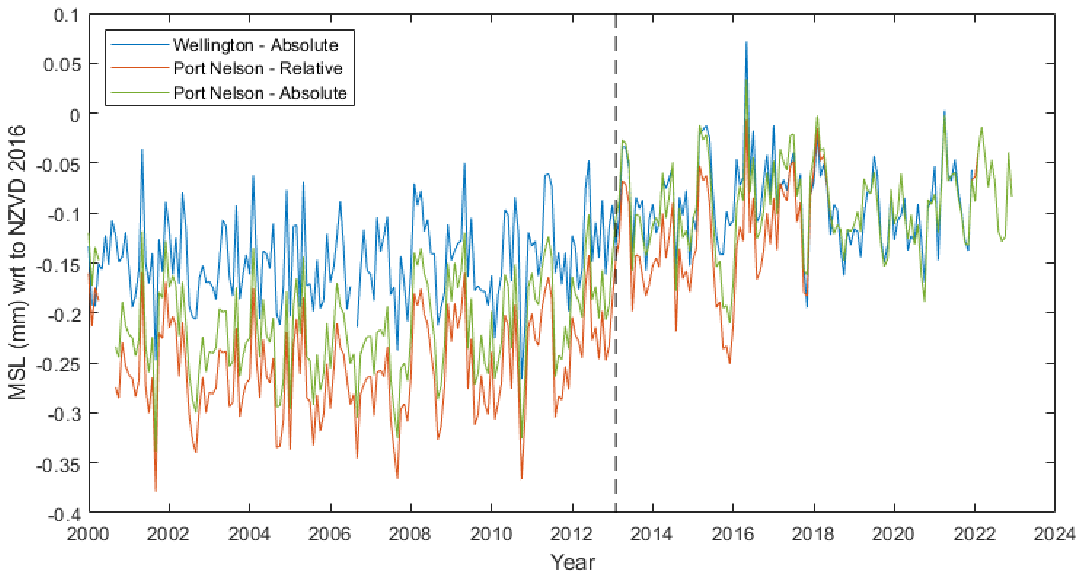
- **Relative sea level**, referenced to the current AC4T level of RL 3.1546m NZVD16. This data set reflects the combined effects of Vertical Land Movement (VLM), sea level variability and ongoing effects of sea level rise.
- **Absolute sea level,** referenced to Chart Datum that was originally established for the tide gauge. This data set removes the effects of VLM and only captures the effects of sea level variability and ongoing effects of sea level rise.

The absolute sea level data set was created by applying the following adjustments to cater for documented subsidence[1]:

- Linear subsidence of 0 to -20.6mm between 14 November 2016 and 1 December 2017.
- Linear subsidence of -20.6 to -40.6mm between 1 December 2017 and 1 July 2018.
- Uniform subsidence of -40.6mm from 1 July 2018 to 31 December 2022.

The Port Nelson relative and absolute monthly MSL compared to the Wellington long term Queens Wharf absolute MSL as documented in NIWA (2022) is presented in Figure 2-1.

Figure 2-1: Wellington and Port Nelson mean sea level



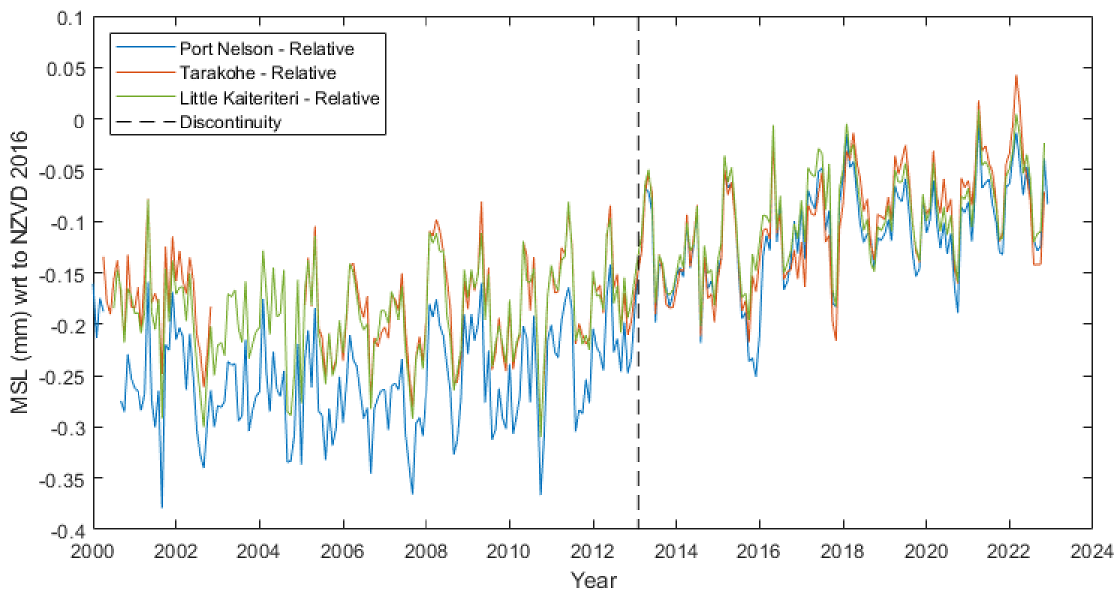
[1] https://www.geodesy.linz.govt.nz/gdb/index.cgi?sessionid=1016055155963168072796 9&code=AC4T&mode=text&nextform=histhgt

Comparing the Port Nelson and Wellington absolute MSL data there is a clear discontinuity in the Port Nelson data on 1 January 2013 where there is an observed offset of approximately 70-80mm for the earlier data. Post 1 January 2013 the absolute MSL for both Wellington and Port Nelson is consistent supporting the adjustments made to the data to compensate for subsidence. Until further investigation and assessment is completed on the Port Nelson dataset, data prior to 1 January 2013 cannot be relied on for MSL analysis.

Relative monthly MSL for Port Nelson, Little Kaiteriteri and Tarakohe is presented in Figure 2-2. The data shows that Little Kaiteriteri and Tarakohe MSL, and Port Nelson MSL post 1 January 2013 exhibit similar trends, noting the clear 1 January 2013 discontinuity in the Port Nelson dataset.

Relative SLR trends post 2013 are 9 mm/year for Little Kaiteriteri and Tarakohe and 8 mm/year for Port Nelson. The rate of relative SLR compared to the absolute SLR observed at Port Nelson and Wellington indicates a likely uniform regional subsidence is occurring which is not being reflected in the benchmarks and datums at both Little Kaiteriteri and Tarakohe.

Figure 2-2: Monthly Mean Sea Level since 2000 (mm NZVD 2016)



Accordingly, for the purposes of establishing MSL emphasis is placed on absolute MSL post 2013 for Port Nelson. For calculating tidal constituents and consequently MHWS, the analysis methodology (Section 2.4) enables the use of the full datasets.

2.2 Tidal Levels

A number of meteorological and astronomical phenomena control sea level:

- Astronomical tides.
- Monthly variability in sea level from climate cycles (seasonal, El Niño, La Niña, etc.).
- Storm surge during low-pressure systems and set-down during anticyclones.
- Wave setup during storms.
- Climate-change effects including sea-level rise.

Both storm surge/set-down and monthly variability in sea level tend to be normally distributed above and below MSL with no net effect on MHWS. Consequently, MSL and astronomical tides are the dominant components used to define MHWS levels. LINZ define MSL, MHWS and MLWS as follows:

Mean sea level (MSL)[2]: The average level of the sea surface over a long period or the average level which would exist in the absence of tides.

Mean high water springs (MHWS) and mean low water springs (MLWS)[2]: The average of the levels of each pair of successive high waters, and of each pair of successive low waters, during that period of about 24 hours in each semi-lunation (approximately every 14 days), when the range of the tide is greatest (spring range).

LINZ further provides a "Cadastral MHWS" for cadastral and engineering purposes based on an 18.6-year period as opposed to the typical published nautical levels that are based on predictions for the next 12 months. The 18.6-year period captures the full range of oscillation of the orbital surface of the moon around the earth which causes long-term modulation of oceanic tides. The current LINZ 18.6-year duration is 1 January 2000 to 31 December 2018[3]. The 18.6-year duration is also used in MSL trend analysis and for establishing baselines for future sea level rise.

Three baseline periods are used in this assessment as follows:

- 1995 – 2014, which is the baseline period used for the IPCC (2021) AR6 sea level rise projections;
- 2004 – 2022, period to provide average MSL over the 18.6-year lunar cycle; and
- 2013 – 2022 period to provide a representative present day MSL.

2.3 Mean sea level

Monthly MSL describes the variation of the non-tidal sea level over time periods ranging from months up to decades and is the result of climate variability, including the effects on sea level, winds, and sea temperatures from:

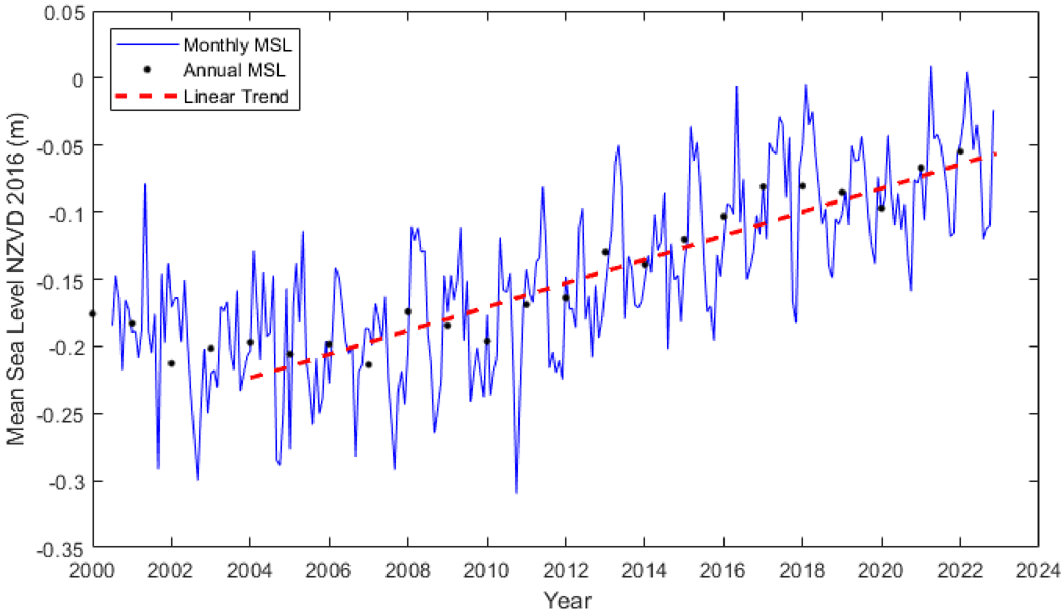
- persistent patterns of storminess or fair-weather conditions,
- seasonal warming/cooling effects,
- 2–8 year El Niño–Southern Oscillation (ENSO) cycles, and
- 20–30 year Inter-decadal Pacific Oscillation (IPO) cycles.

MSL can vary along a coastline due to the interactions between the bathymetry and the processes that control sea level, particularly tides, oceanographic currents, and prevailing winds.

Monthly and annual relative MSL for Little Kaiteriteri is shown in Figure 2-3 which shows a rapid change in MSL between 2010 and 2012 and post 2020 which is consistent with periods of strong La Niña. Conversely, negative MSL trends are observed during periods of El Niño such as the period 2018 to 2019. Underlying these variations is the ongoing trend of accelerating SLR and VLM.

[2] https://www.linz.govt.nz/guidance/marine-information/tide-prediction-guidance/tides-glossary accessed 1 February 2023.
[3] https://www.linz.govt.nz/guidance/geodetic-system/coordinate-systems-used-new-zealand/vertical-datums/tidal-level-information-surveyors accessed 1 February 2023.

Figure 2-3: Little Kaiteriteri monthly and annual relative MSL (m NZVD)



Mean sea levels for the 2004 - 2022 and 2013 - 2022 reference periods are presented in Table 2-3 and Table 2-4 respectively. Of the 3 datums it is recommended NZVD 2016 is used for comparative assessment. Furthermore, it is noted that these levels are based on relative MSL with respect to the respective benchmarks.

As expected, the measured MSL is relatively uniform across the 3 sites for each reference period with a measured variation of approximately 1 cm, noting that benchmarks for Little Kaiteriteri and Tarakohe have a lower order of vertical accuracy compared to Port Nelson (refer to Table 2-2) and subject to VLM. Comparing the reference periods, the 2013-2022 period (midpoint 2017.5) is approximately 4 cm higher than 2004 - 2022 (midpoint 2013) reflecting accelerating SLR. Since 2004, relative MSL at Little Kaiteriteri and Tarakohe gauges has increased 0.14-0.15m.

Table 2-3: 2004 to 2022 average relative mean sea level

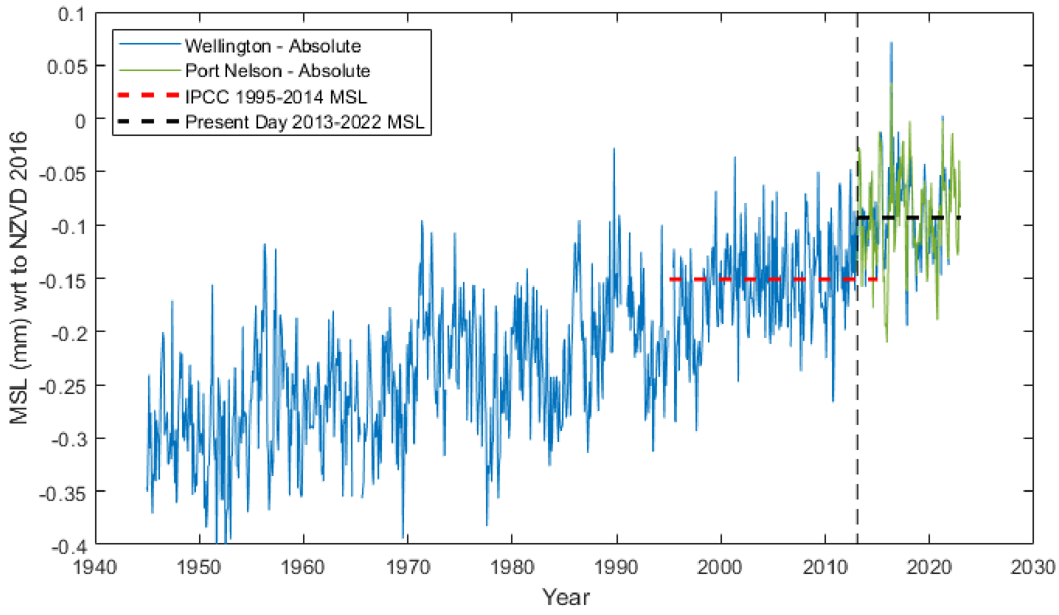
Tide Gauge	CD (m)	NZVD 2016 (m)	NVD 1955 (m)
Port Nelson	-	-	-
Little Kaiteriteri	2.155	-0.140	0.164
Tarakohe	2.212	-0.139	0.184

Table 2-4: 2013 to 2022 average relative mean sea level.

Tide Gauge	CD (m)	NZVD 2016 (m)	NVD 1955 (m)
Port Nelson	2.466	-0.112	0.217
Little Kaiteriteri	2.199	-0.096	0.208
Tarakohe	2.249	-0.102	0.221

Absolute SLR measured at Wellington and Lyttelton have a long-term 1961 - 2020 average of 2.84 and 2.77 mm/year respectively (NIWA, 2022). As shown in Figure 2-4 absolute MSL at Port Nelson and Wellington is consistent for the overlapping periods and hence in lieu of longer-term local data, the trends observed at Wellington are likely to be applicable to the Tasman and Golden Bay region.

Figure 2-4: Wellington and Port Nelson absolute MSL and reference MSL levels.



MSL for the 2013-2022 period for Port Nelson and Wellington is presented in Table 2-5 and Figure 2-4, noting MSL is similar with a level of RL 0.09m NZVD (2 d.p.). Accordingly, for the purposes of establishing a regionally consistent MHWS throughout the Tasman and Golden Bay region a uniform MSL of -0.093m NZVD has been adopted.

Table 2-5: 2013 to 2022 absolute mean sea level

Tide Gauge	CD (m)	NZVD 2016 (m)
Port Nelson	2.445	-0.093
Wellington	1.169	-0.089

Due to the limitations of the Port Nelson, Little Kaiteriteri and Tarakohe datasets neither can be used to define the 1995 – 2014 IPCC reference MSL. Rather, the observed MSL of -0.151m NZVD as observed at Wellington (refer to Figure 2-4) has been adopted.

2.4 Astronomical tidal levels

Astronomical forces acting on deep oceans cause long waves (tides) that propagate into the shelf areas and amplify. The Collingwood area has the distinction of having the highest tide range in New Zealand, exceeding 4 m due to a standing long wave generated to the west of Cook Strait. There are a variety of quantitative and qualitative definitions of what constitutes the astronomical tide depending on its intended usage (refer to Section 2.2). Furthermore, there are various methods for calculating respective levels. For this assessment the recorded tide data was analysed with the tidal harmonics analysis package T_Tide (Pawlowicz et al, 2002).

For each tide gauge dataset tidal constituents were compiled by assessing each year independently and then averaging to providing a representative tidal constituent dataset. For the 3 gauges 59 constituents were predominant throughout the analysis, however for some years up to 67 constituents were resolved where shallow water harmonic signals were detected. For consistency, the analysis was limited to the dominant 59 constituents noting the additional constituents have negligible impact on predicted tidal levels.

Following analysis, tides at 5-minute intervals were predicted for the LINZ cadastral reference period of 1 January 2000 to 31 December 2018. The predicted data was analysed to provide spring and neap high tide cadastral levels as per the LINZ definitions (Section 2.2). Astronomical tide levels for Port Nelson, Little Kaiteriteri and Tarakohe with reference to the present day MSL of -0.093m NZVD (i.e. the 2004–2022 baseline period) are presented in Table 2-6, Table 2-7 and Table 2-8.

Table 2-6: Nelson Cadastral Tidal Levels relative to 2013-2022 MSL

Tide Gauge	MSL (m)	CD (m)	NZVD 2016 (m)	NVD 1955 (m)
Highest Astronomical Tide (HAT)	2.23	4.67	2.14	2.47
Mean High Water Springs (MHWS)	1.81	4.26	1.72	2.05
Mean High Water Neaps (MHWN)	0.88	3.32	0.78	1.11
Mean Sea Level (MSL)	0.00	2.45	-0.09	0.24
Mean Low Water Neap (MLWN)	-0.89	1.56	-0.98	-0.65
Mean Low Water Springs (MLWS)	-1.77	0.68	-1.86	-1.53
Lowest Astronomical Tide (LAT)	-2.11	0.34	-2.20	-1.87

Table 2-7: Little Kaiteriteri Cadastral Tidal Levels relative to 2013-2022 MSL

Tide Gauge	MSL (m)	CD (m)	NZVD 2016 (m)	NVD 1955 (m)
Highest Astronomical Tide (HAT)	2.19	4.39	2.09	2.40
Mean High Water Springs (MHWS)	1.77	3.98	1.68	1.99
Mean High Water Neaps (MHWN)	0.87	3.07	0.77	1.08
Mean Sea Level (MSL)	0.00	2.20	-0.09	0.21
Mean Low Water Neap (MLWN)	-0.87	1.33	-0.96	-0.66
Mean Low Water Springs (MLWS)	-1.78	0.42	-1.87	-1.57
Lowest Astronomical Tide (LAT)	-2.15	0.06	-2.24	-1.93

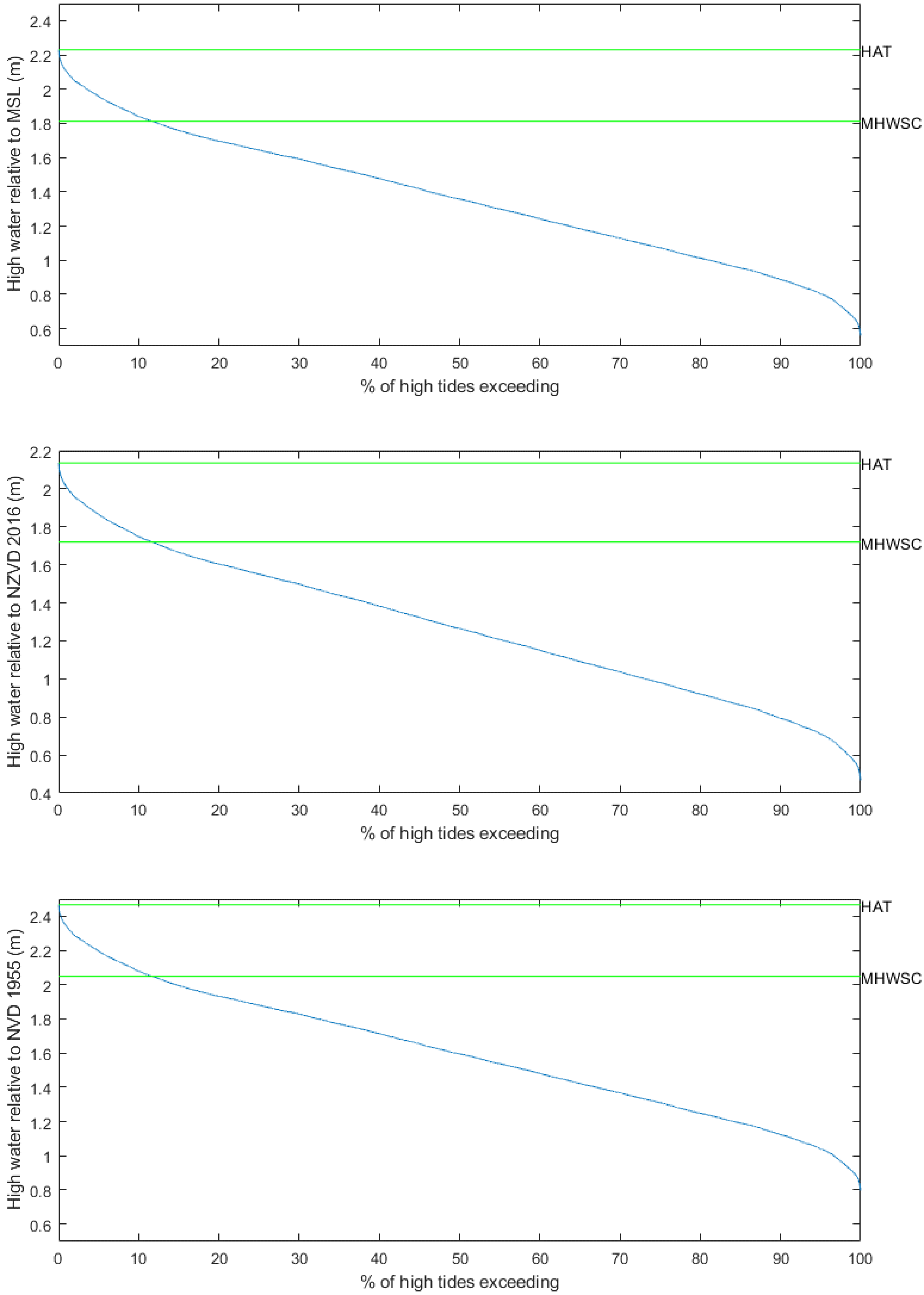
Table 2-8: Tarakohe Cadastral Tidal Levels relative to 2013-2022 MSL

Tide Gauge	MSL (m)	CD (m)	NZVD 2016 (m)	NVD 1955 (m)
Highest Astronomical Tide (HAT)	2.20	4.46	2.11	2.43
Mean High Water Springs (MHWS)	1.80	4.06	1.71	2.03
Mean High Water Neaps (MHWN)	0.89	3.14	0.79	1.12
Mean Sea Level (MSL)	0.00	2.26	-0.09	0.23
Mean Low Water Neap (MLWN)	-0.89	1.37	-0.98	-0.66
Mean Low Water Springs (MLWS)	-1.80	0.45	-1.90	-1.57
Lowest Astronomical Tide (LAT)	-2.18	0.08	-2.27	-1.95

The proportion of high tides over a particular level, expressed as a tidal exceedance is presented in Figure 2-5 for Port Nelson. Exceedance curves for Little Kaiteriteri and Tarakohe are presented in Appendix A.

For Port Nelson, Little Kaiteriteri and Tarakohe high tides in excess of the cadastral MHWS occurs approximately 12% of the time which is consistent with MHWS exceedances observed around New Zealand.

Figure 2-5: High tide exceedance for Port Nelson relative to 2013-2022 MSL (m)



3 District wide MHWS

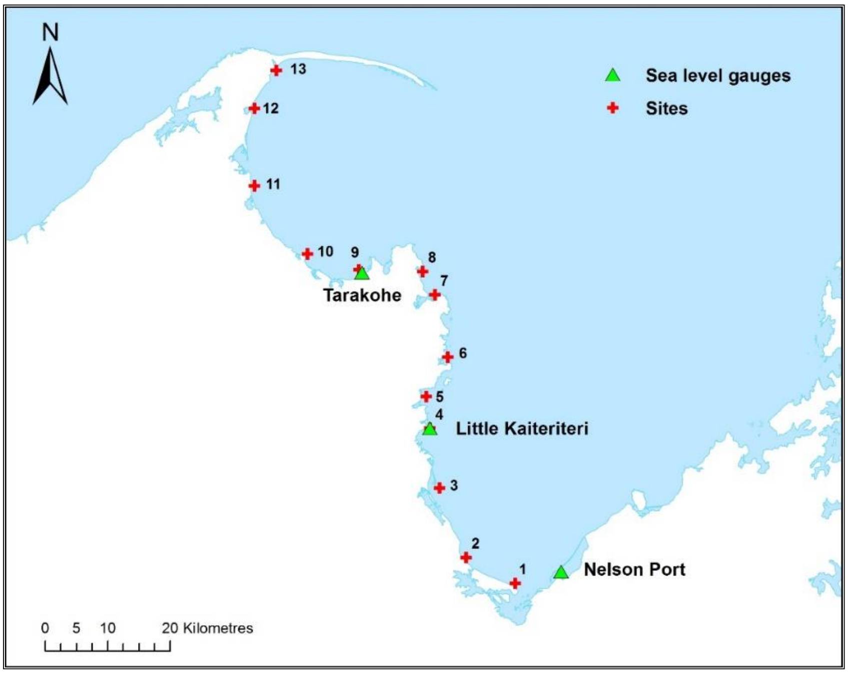
3.1 Background

The NIWA (2013) assessment adopted an approach that involved the combination of:

- an algorithm, using high-tide predictions covering a 100-year period to include all possible tidal combination, and
- a degree of judgement in selecting an appropriate percentile of all the high tides that would exceed a MHWS level.

NIWA (2013) used a MHWS exceedance of 6% which was closely aligned with the LINZ cadastral MHWS at Port Nelson at the time of the assessment. MHWS levels at 13 locations (refer to Figure 3-1) throughout the district were assessed based on the NIWA EEZ tide model (Walters et al, 2001). The reference locations were selected to cover settlements or towns at a reasonably consistent spacing around the coastline, which enables MHWS levels to be easily interpolated for sites in between (NIWA, 2013).

Figure 3-1: Tasman Bay coastline illustrating the 3 tide gauge and the 13 MHWS assessment locations.



3.2 Methodology

Rather than use a MHWS exceedance of 6% to approximate cadastral MHWS, cadastral MHWS was calculated directly. This decision was made because cadastral MHWS can be calculated directly from the timeseries and enables direct comparison with MHWS calculated and reported by LINZ. The cadastral MHWS method includes:

1. Utilising the NIWA EEZ tide model to source the 13 tidal constituents which make up most of the tide observed around New Zealand for each location. Following comparison to the constituents derived from the tide gauge analysis the number of constituents were reduced to 12 to remove a constituent that was not regularly observed at the tide gauges.

2. To correct for any bias (offset) in the tide model within the Tasman Bay Region, a comparison was made between the phase (timing) and amplitude (=half tidal range) of the tidal constituents from the model with those derived from the tide gauges. A correction matrix was developed to modify the amplitude and phase of each constituent based on spatial linear interpolation (refer to Tables B1 and B2 in Appendix B).

3. Utilising the biased corrected constituents, sea levels at 5-minute intervals were predicted for the LINZ cadastral reference period of 1 January 2000 to 31 December 2018.

4. The MHWS level as per the LINZ cadastral definition (Section 2.2) was calculated directly from the predicted time series.

5. The assessed MHWS was further biased corrected to cater for the small difference between the predictions utilising 59 constituents versus 12 (refer to Table B3 in Appendix B).

3.3 Results

MHWS for each of the 13 reference locations relative to 2013-2022 MSL and referenced to NZVD and NVD is presented in Table 3-1. MHWS NVD 1955 was calculated based on transformation of the MHWS NZVD 2016 values via the LINZ online coordinate converter.

Table 3-1: MHWS (m) relative to 2013-2022

Site	Longitude (°) WGS84	Latitude (°) WGS84	MHWS (m) w.r.t MSL	MHWS (m) NZVD 2016	MHWS (m) NVD 1955
1	173.190	-41.272	1.81	1.72	2.05
2	173.096	-41.234	1.81	1.71	2.05
3	173.046	-41.134	1.79	1.70	2.01
4	173.027	-41.048	1.77	1.68	1.99
5	173.020	-41.002	1.77	1.68	1.99
6	173.061	-40.946	1.75	1.66	1.98
7	173.037	-40.855	1.74	1.65	1.97
8	173.014	-40.822	1.75	1.66	1.98
9	172.892	-40.819	1.80	1.71	2.03
10	172.795	-40.796	1.82	1.73	2.05
11	172.694	-40.697	1.84	1.75	2.08
12	172.695	-40.586	1.86	1.77	2.09
13	172.736	-40.531	1.87	1.77	2.10

3.4 Sea Level Rise

In order to utilise the current IPCC (2021) sea level rise projections[4], which are referenced to the 1995–2014 baseline period and/or projections for Vertical Land Motion (VLM) as assessed via NZSeaRise[5] Equation 3-1 should be applied. Equation 3-1 is a simple adjustment to the MSL baseline to allow direct application of the published SLR projections, which may or may not include VLM. It is

[4] https://environment.govt.nz/publications/interim-guidance-on-the-use-of-new-sea-level-rise-projections-quick-reference-guide/
[5] https://www.searise.nz/maps-2

noted that the correction is only required for the MHWS referenced to vertical datums NZVD 2016 and NVD 1955 and not for MHWS referenced to MSL.

Equation 3-1: Future MHWS with SLR

$$Future\ MHWS = MHWS_{(2013-2022)} - 0.061 + RSLR_{(1995-2014)}$$

where:

MHWS $_{(2013\text{-}2022)}$ = the MHWS level from Table 3-1 in metres (datum independent)

R*SLR* $_{(1995-2014)}$ = magnitude of desired relative SLR in metres to be assessed

Example output from applying Equation 3-1 to the MHWS NZVD 2016 levels for SLR increments of 0.5m is presented in Table 3-2.

Table 3-2: Future MHWS for 0.5m increments of SLR (m NZVD 2016)

Site	MHWS (m) NZVD 2016	MHWS (m) + 0.5m SLR NZVD 2016	MHWS (m) + 1.0m SLR NZVD 2016	MHWS (m) + 1.5m SLR NZVD 2016	MHWS (m) + 2.0m SLR NZVD 2016
1	1.72	2.16	2.66	3.16	3.66
2	1.71	2.15	2.65	3.15	3.65
3	1.70	2.14	2.64	3.14	3.64
4	1.68	2.12	2.62	3.12	3.62
5	1.68	2.12	2.62	3.12	3.62
6	1.66	2.10	2.60	3.10	3.60
7	1.65	2.09	2.59	3.09	3.59
8	1.66	2.10	2.60	3.10	3.60
9	1.71	2.15	2.65	3.15	3.65
10	1.73	2.17	2.67	3.17	3.67
11	1.75	2.19	2.69	3.19	3.69
12	1.77	2.21	2.71	3.21	3.71
13	1.77	2.21	2.71	3.21	3.71

4 Recommendations

The following actions are recommended to refine MHWS and monitor SLR across the region:

1. Due to the accelerating rates of SLR and change in MSL it is recommended to update the MHWS levels at a minimum of every 5 years.

2. Benchmark datum surveys at the respective gauges should be completed to ensure subsidence is adequately quantified. Benchmark AC4T at Port Nelson should be prioritised.

3. MSL and SLR trends for Little Kaiteriteri and Tarakohe should be reassessed following refinement of the respective gauge benchmark levels.

4. Further assessment is required to reconcile the Port Nelson dataset prior to 2013 which will further inform quantification of longer term sea level rise trends within the region.

5 References

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (eds.) (2021) *IPCC, 2021: Climate Change, 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. In press, doi:10.1017/9781009157896.

Ministry for the Environment, (2022) *Interim guidance on the use of new sea-level rise projections.* Wellington: Ministry for the Environment. https://environment.govt.nz/assets/publications/Files/Interim-guidance-on-the-use-of-new-sea-level-rise-projections-August-2022.pdf

NIWA (2013) *Mean High Water Spring (MHWS) levels including sea-level rise scenarios* Envirolink Small Advice Grant (1289-TSDC95).

NIWA (2022) *Update to 2020 of the annual mean sea level series and trends around New Zealand* Prepared for Ministry of Environment, September 2022. https://environment.govt.nz/assets/publications/update-to-mean-sea-level-series-and-trends.pdf

Pawlowicz, R., Beardsley B., S. Lentz (2002) Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. *Computers and Geosciences* 28 (2002), 929-937.

Walters, R.A., Goring, D.G., Bell, R.G. (2001) Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research* 35: 567–579

Appendix A High Tide Exceedance Curves

Figure A-1: High tide exceedance for Little Kaiteriteri relative to 2013-2022 MSL (m)

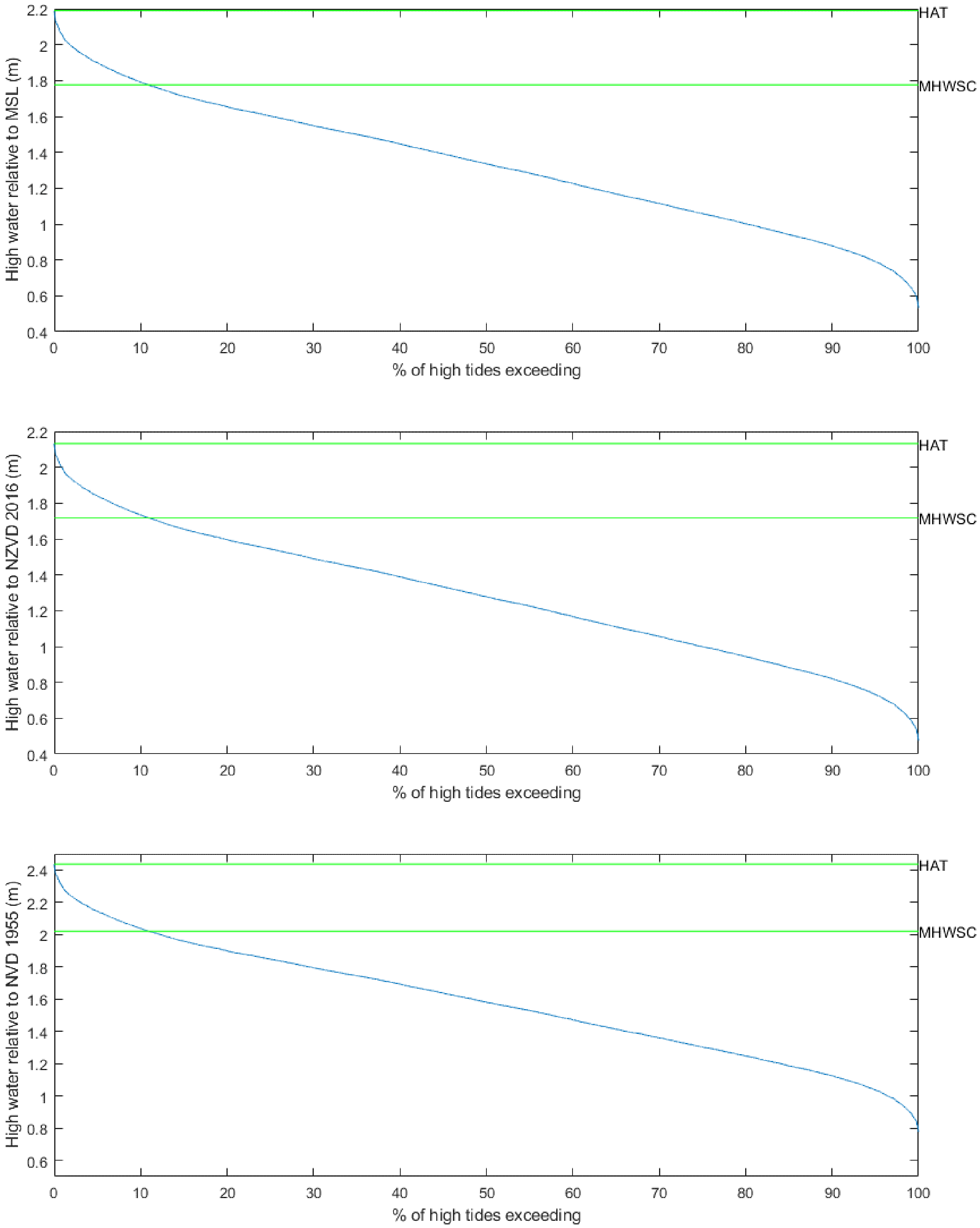
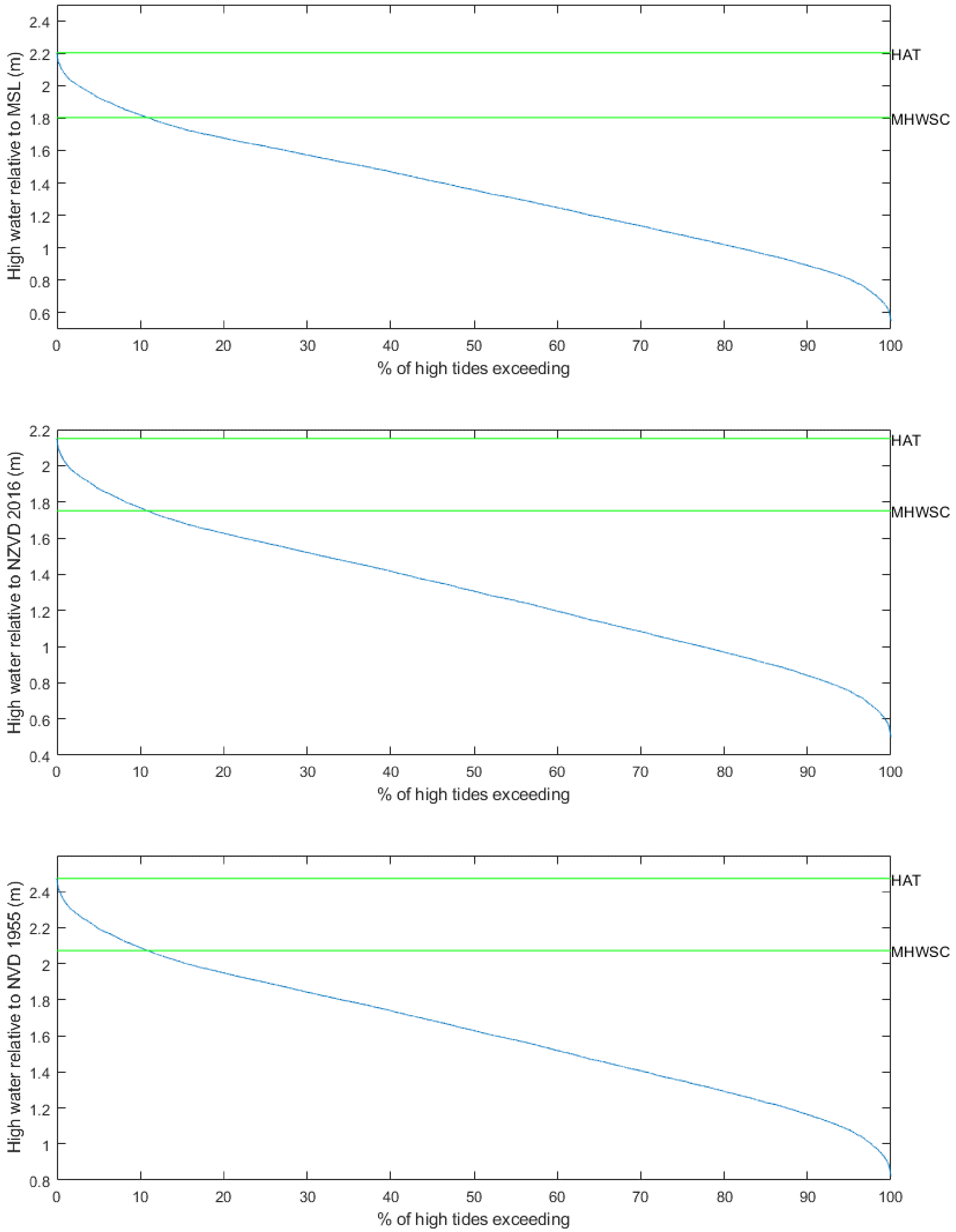


Figure A-2: High tide exceedance for Tarakohe relative to 2013-2022 MSL (m)



Appendix B Tidal Constituent Corrections

Table B-1: Phase corrections for NIWA EEZ Model at tide gauge locations (degrees)

Constituent	Port Nelson	Little Kaiteriteri	Tarakohe
M2	3.06	-2.92	-3.70
S2	3.54	-3.16	-4.13
N2	2.13	-4.04	-4.54
K2	-3.30	-10.38	-11.00
K1	-9.31	-14.70	-16.07
O1	40.87	36.33	41.70
P1	0.00	0.00	0.00
Q1	50.70	48.84	54.62
2N2	9.40	4.18	3.49
MU2	23.89	14.47	12.85
NU2	-2.87	-8.44	-8.50
L2	-7.51	-8.80	-10.33

Table B-2: Amplitude corrections for NIWA EEZ Model at tide gauge locations (mm)

Constituent	Port Nelson	Little Kaiteriteri	Tarakohe
M2	-17.9	-12.0	-4.2
S2	-10.2	-5.7	1.9
N2	-3.9	-2.7	-0.4
K2	4.1	5.2	7.6
K1	2.4	0.8	-0.7
O1	11.7	12.2	12.9
P1	2.3	1.1	-0.3
Q1	2.1	2.1	2.1
2N2	8.0	6.4	6.9
MU2	-0.3	-0.5	-0.5
NU2	-6.5	-3.8	-3.4
L2	10.5	8.0	8.1

Table B-3: Bias correction at tide gauge sites for 12 vs 59 constituents

Tidal Level	Port Nelson	Little Kaiteriteri	Tarakohe
MHWS	1.0129	1.0002	0.9988
MLWS	0.9873	1.0064	1.0008