

Assessment of future bed level change in Ihutai/Avon-Heathcote Estuary

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Executive summary

Christchurch City Council (CCC) commissioned NIWA to provide insights into future Ihutai / Avon-Heathcote Estuary bed level changes and the potential extent of seagrass habitat for different sea level rise scenarios. These insights will inform a resource consent application for proposed works along the estuary edge.

CCC is particularly interested in understanding how sedimentation in the estuary, vertical land movement, and sea level rise will impact water levels and intertidal zones by 2045. This will help determine whether activities along the estuary edge could contribute to "coastal squeeze" in the intertidal zone and other areas favoured by seagrass.

We have used existing LiDAR data, vertical land movement assessments for locations close to the estuary, and previous hydrodynamic model runs for current and future sea level rise (SLR) scenarios to support this assessment.

Three scenarios for SLR in 2045 were used in the assessment:

- A 0.070 m increase in SLR, representing the 17th percentile (p17) medium confidence SSP2-4.5¹.
- A 0.155 m increase in SLR, representing the 50th percentile (p50) medium confidence SSP5-8.5.
- A 0.35 m increase in SLR, representing the 83rd percentile (p83) low confidence SSP5-8.5.

In summary, our findings indicate:

- In southern areas of interest, the intertidal zone remains unchanged, even under extreme SLR scenarios (SSP5-8.5 low confidence p83). In areas at the southern part of Southshore, the change in intertidal area is almost negligible.
- The northern part of the area of interest may experience greater impact from SLR. At areas near Ebbtide Street, the intertidal zone could shrink by 60% under the highest SLR scenario (SSP5-8.5 p83), with less than 1% reduction in lower scenarios.
- Similarly, the proportion of seagrass in the intertidal area near Ebbtide Street reduces to 53% under the highest SLR scenario, with no change in other scenarios.
- At areas near Heron and Kingfisher Streets, the intertidal length reduces by 23% under the highest SLR scenario, reducing seagrass coverage to 80%.
- In the southern area of interest, from Penguin Street to the southern part of Southshore, the proportion of seagrass in the intertidal zone remains unchanged under all scenarios.

¹ SSP2 stands for Shared Socioeconomic Pathway 2, and the number 4.5 refers to the approximate amount of radiative forcing (a measure of the change in energy in the atmosphere due to greenhouse gases) in watts per square meter by the year 2100 (i.e., in SSP2-4.5, radiative forcing stabilizes at around 4.5 W/m²).

- The depth of high water spring tides over seagrass increases with SLR. At areas near Ebbtide Street, the average increase of depth above seagrass from the 2020 spring tide level ranges from 20% to 43%.

1 Introduction

The Canterbury Earthquake Sequence affected the extent of intertidal areas at the Ihutai/Avon-Heathcote Estuary² due to tectonic displacement and seabed changes. This resulted in substantial subsidence, leading to relative sea level rise (SLR), which impacted coastal communities and triggered long-term environmental changes in the estuary.

To address “earthquake legacy” issues identified by community, Christchurch City Council (CCC) proposed to undertake physical works including:

- In Southshore: placing structures along the estuary edge in Southshore to reduce the erosion risk and building a new bund to reduce the flood risk.
- In South New Brighton: restoring the estuary edge with cobble beach and constructing a new bund away from the estuary edge within South New Brighton Park.

These infrastructure developments, however, may lead to the loss of natural habitats or deterioration of their quality; a phenomenon known as “coastal squeeze”. CCC requires a qualitative understanding of future estuary bed levels and potential extents of seagrass habitat to inform resource consent applications for works on the estuary edge. To achieve this, CCC engaged NIWA to conduct the following tasks:

- GIS analysis of LiDAR data to identify bed level change by comparing 2015 LiDAR with 2020 data. An uncertainty analysis will be conducted to ensure that changes are only considered significant in areas where bed level change exceeds uncertainty thresholds.
- Review of relevant previous studies and modelling works on riverine and coastal sediment budgets, with a focus on their implications for estuarine sedimentation.
- Provide estimates of bed level response by 2045, based on available data and considering sediment deposition and vertical land movement.
- Evaluate changes in water level under different SLR scenarios and their impact on intertidal area and seagrass habitats. This includes quantifying the proportion of existing intertidal seagrass beds likely to transition to subtidal zones under future SLR, analysing water depth over existing seagrass habitats during high tides, and evaluating changes in the elevation difference between low tide and seagrass habitats.
- Assess the impact of tidal prism volume under various SLR scenarios on the estuary bed channel.
- Create indicative cross-sections showing current bed and water levels, along with projected future bed and water levels under different SLR and vertical land movement scenarios.

After additional meetings with CCC, we also prepared and provided detailed water level estimates for the saltmarsh habitat area. These estimates take into account various tidal conditions as well as different scenarios for SLR.

² To make the report easier to follow, we have simplified the name Ihutai/Avon-Heathcote Estuary to “Te Ihutai” throughout the remainder of the report.

2 Methods

2.1 Changes in bathymetry of Te Ihutai

Trends in bed level changes throughout the estuary over time were investigated by examining differences between two LiDAR-derived digital elevation models (DEMs). To establish mean annual rates, we selected the longest possible interval between LiDAR surveys, focusing on data from 2015, 2018, 2020/21 and 2020-23. Surveys prior to 2015 were excluded, as significant bed adjustments were still occurring due to the 2011 Christchurch earthquake. The two LiDAR DEMs that were chosen for the comparison were Canterbury - Christchurch and Selwyn LiDAR 1 m DEM (2015)³ and Canterbury - Christchurch 1 m DEM (2020-2021)⁴. This selection was based on maximizing temporal separation and capturing the most exposed estuary bed (i.e., lowest water level) during LiDAR collection. Both DEMs are referenced to the New Zealand Transverse Mercator 2000 (NZTM2000) projection and the New Zealand Vertical Datum 2016 (NZVD2016).

2.1.1 Generation of a DEM of Difference

To quantify changes in estuary bed levels, the two DEMs were differenced. However, over the 5-year interval between the surveys, channels and bars shifted positions slightly, particularly near the southern end of the estuary. Additionally, parts of the estuary were covered by water during both surveys, preventing assessment of bed levels in those areas. As an initial step, masks were created for each survey date to identify areas where the bed was inundated. These masks were then combined to exclude all areas covered by water in either one or both LiDAR surveys. Subsequently, the 2015 DEM was subtracted from the 2020 DEM to create a DEM of Difference (DoD) for areas outside the wetted area mask, highlighting areas of deposition and erosion.

2.1.2 Extracting estuary bed for cross sections

Six cross sections of interest, as shown in Figure 2-1, were used to plot current and future SLR scenario water levels along with the projected estuary bed.

For areas outside the channel, estuary bed elevations for the cross sections were extracted from the 2020 DEM.

To incorporate submerged channels into the cross-section analysis, we extended the cross-sections beyond the exposed dry bed captured by the LiDAR surveys. As no recent bathymetric data for the estuary was available, we used channel data from the bathymetric DEM reported by Measures and Bind (2013), based on data collected between 2011 and 2013. This bathymetric DEM was originally referenced to the Lyttelton 1937 vertical datum, so elevations were converted to NZVD2016 to align with the more recent DEM elevations.

Estuary vegetation classification, including current habitat areas for seagrass and salt marsh, was obtained from a NIWA habitat classification study⁵.

³ Data derived from <https://data.linz.govt.nz/layer/53587-canterbury-christchurch-and-selwyn-lidar-1m-dem-2015/> captured between 5 October and 7 November 2015

⁴ Data derived from <https://data.linz.govt.nz/layer/109641-canterbury-christchurch-1m-dem-2020-2021/>, captured between 18 December 2020 and 17 February 2021

⁵ Derived from: https://www.arcgis.com/apps/mapviewer/index.html?url=https://gisimagery.ecan.govt.nz/arcgis/rest/services/Imagery/NIWA_Classification_Ihutai_2024/ImageServer&source=sd

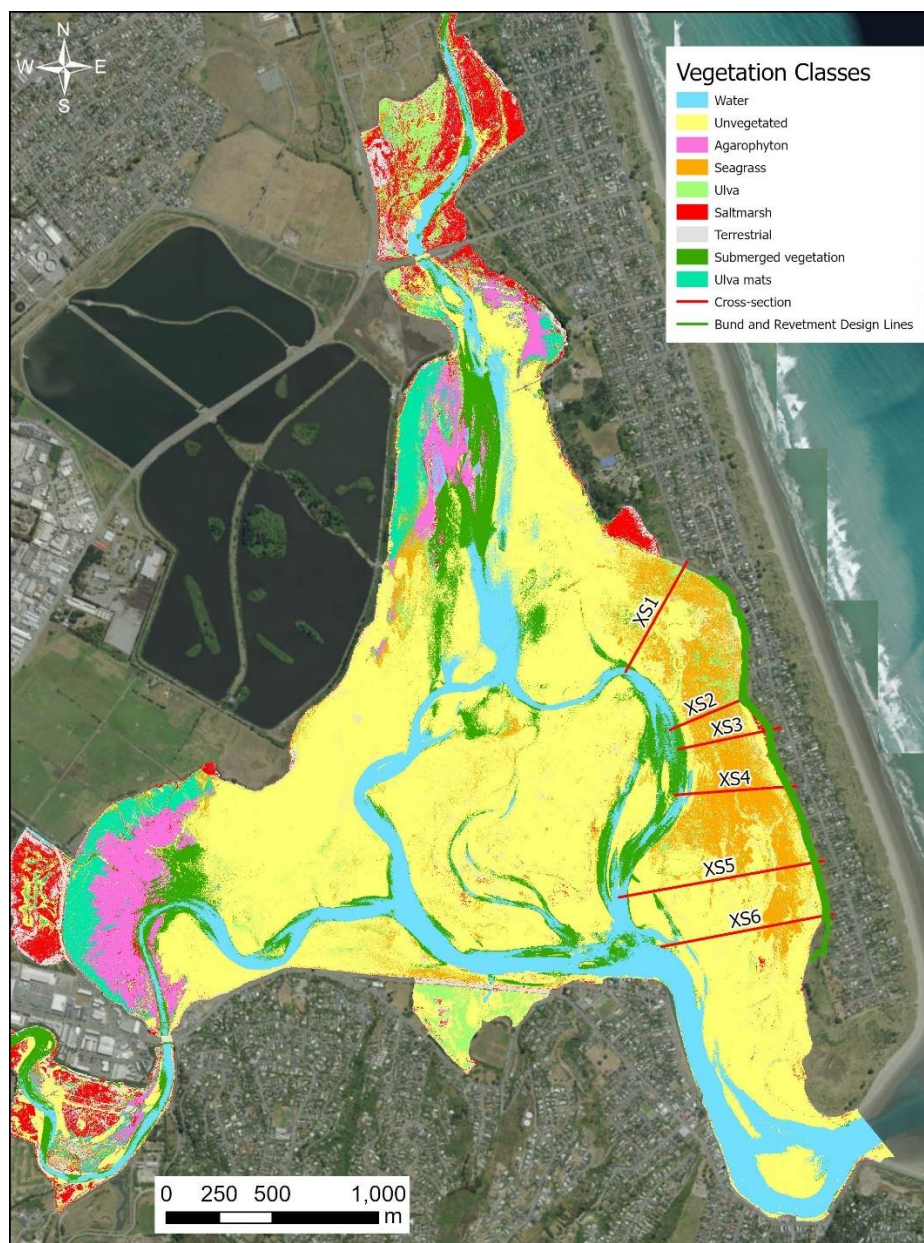


Figure 2-1: Vegetation classification of Te Ihutai, along with the locations of six cross sections.

2.2 Projected changes in the bed of Te Ihutai

Sediment loads for the Avon and Heathcote Rivers were estimated using the New Zealand Sediment Yield Estimator (NZSYE) and adjusted with measured suspended sediment concentrations and flow data (Hicks et al. 2019)⁶. The calibrated sediment loads were then applied to an estuary hydrosystem sediment trap efficiency model to determine the overall deposition rate. The sediment trap efficiency model estimates an estuary-averaged net deposition rates using a simple, uncalibrated, zero-dimensional sediment mass balance approach (Hicks et al. 2019). This model accounts for sediment inputs from tributaries, deposition through settling, resuspension by waves, and re-entrainment by currents. Wave-induced resuspension occurs in intertidal areas, while re-

⁶ The NZSYE estimator generally assumes zero sediment yield for urban catchments if no calibration data are available for those catchments. For Te Ihutai, calibration data were available, and therefore sediment yields from urban catchments are included.

entrainment is concentrated in tidal channels. Deposition, however, can potentially occur across both channels and intertidal areas.

Following the Canterbury and Kaikoura earthquakes, Te Ihutai experienced an increase in land subsidence. Vertical land movement (VLM) data from GNS reports for the nearest location, Brighton Spit, were used to project future changes to Te Ihutai's bed (Hamling and Kears 2023; Hamling 2024).

2.3 Water level scenarios in the estuary

Tidal variations in water level for a 2020 scenario were derived from Orchard et al. (2020)⁷. Since the water level records dated back to 2015, they were adjusted to account for the measured mean sea level rise of 2.24 mm per year at the Lyttelton site. Table 2-1 summarises the estimates of water levels at Te Ihutai for 2020.

Table 2-1: Modelled 2020 water levels for high and low spring and neap tides at cross sections of interest in Te Ihutai. MHWS represents Mean High Water Springs, MLWS is Mean Low Water Springs, MHWN is Mean High Water Neaps, and MLWN is Mean Low Water Neaps.

	XS1	XS2	XS3	XS4	XS5	XS6
Average water level (m)	0.021	-0.083	-0.089	-0.096	-0.128	-0.157
MHWS (m)	1.01	1.01	1.01	1.01	1.00	1.00
MLWS (m)	-0.78	-0.80	-0.85	-0.90	-1.12	-1.23
MHWN (m)	0.53	0.52	0.52	0.52	0.51	0.51
MLWN (m)	-0.76	-0.78	-0.79	-0.79	-0.80	-0.80

Three scenarios for SLR in 2045 were used in the assessment:

- A 0.070 m increase in SLR, representing the p17 medium confidence SSP2-4.5.
- A 0.155 m increase in SLR, representing the p50 medium confidence SSP5-8.5.
- A 0.35 m increase in SLR, representing the p83 low confidence SSP5-8.5.

2.4 Tidal prism impact on cross sectional area of estuary channel

As a first step to assess the impact of changes in tidal prism due to SLR on cross sectional area of estuary channel, tidal prism volumes were derived from two model scenarios by Measures and Bind (2013): one with no SLR and another with a 0.5 m SLR.

Changes in the spring tidal prism (calculated as the average of the volume entering and leaving through the estuary mouth on flood and ebb tides) were used to estimate the proportional increase in cross-sectional area under different SLR scenarios.

⁷ These tidal data were originally referenced to the Lyttelton 1937 local vertical datum (LVD37) and were converted to the New Zealand Vertical Datum 2016 (NZVD2016) for consistency with other data, including estuary bathymetry.

The empirical relationship between the cross sectional area of a tidal inlet, Ω , and the spring tidal prism, P is (O'Brien 1969):

$$\Omega = kP^\alpha \quad (1)$$

Where the scaling coefficient of α typically lies in the range of 0.85 – 1.10 (D'Alpaos et al. 2010).

The following assumptions were made when calculating changes in cross sectional area resulting from changes in spring tidal prism volume.

- Changes in tidal prism volume due to SLR were calculated using a model with no bed movement.
- The cross-sectional area of the estuary channel is assumed to have a linear relationship with the spring tidal prism. This means that the scaling coefficient is equal to unity.
- Changes in tidal prism volume for SLR scenarios were linearly interpolated between model scenarios of no SLR increase and a 0.5 m increase.
- Increases in depth and width, resulting from increases in cross-sectional area, are assumed to be proportional.
- The mean sea level used to calculate cross-sectional area is assumed to increase with SLR.

3 Results

3.1 Changes in bathymetry of Te Ihutai

Figure 3-1 shows the DEM of Differences (DoD) between the 2015 and 2020 LiDAR data. Grey areas indicate inundated regions where bathymetric data were unavailable in one or both LiDAR datasets.

Most areas of Southshore, where seagrass vegetation is of interest, show negligible changes in bed elevation when comparing the 2015 and 2020 LiDAR data. This indicates that the bed remained largely stable in these areas during this period.

Most uplift and deposition occurred near the estuary mouth and in the southern area of seagrass coverage (i.e., near cross sections XS5 and XS6).

Upstream of the estuary mouth, erosion was predominantly near the submerged channel, possibly indicating a lateral shift in the deeper sections of the estuary towards the eastern part of Southshore, resulting in a loss of suitable habitat for seagrass. Further erosion and subsidence of the estuary bed were also observed at the mouths of the Avon and Heathcote Rivers.

3.2 Projected Te Ihutai bed elevation in 2045

Changes in the elevation of the estuary bed were estimated by accounting for VLM and deposition of sediment supplied from the Avon and Heathcote Rivers' upstream catchments. The VLM rate of -7.5 mm per year has been measured at Brighton Spit (the closest available measurement point to Te Ihutai). The annual sediment load entering the estuary from the Avon and Heathcote Rivers totals 3685 t/yr. From both rivers, 99% of the sediment load is carried in suspension and consists of clay and silt particles (Hicks 1993). With an estimated trap efficiency of 0.969, the resulting deposition rate of fine sediment is 0.32 mm/yr (Hicks et al. 2019).

We note that the estimated sediment deposition rate is an average across the estuary, and the actual deposition rate will vary spatially depending on estuary hydrodynamic and sediment transport processes. As we are unable to resolve sediment deposition patterns within the scope of this project, we assume a uniform deposition across the estuary.

By projecting these factors to 2045, the net change in bed elevation is predicted to be a subsidence of -180 mm. This subsidence is applied uniformly to the entire cross-section of the estuary, except for submerged estuary channels. For these channels, fine sediment deposition (8 mm) has not been included, as sediment is unlikely to deposit in these areas due to permanent submergence and strong currents. These projections are labelled as '2045 Bed' and are represented by a black line in Figure 3-2.

3.3 Estuary bed and water level scenarios at cross sections

Figure 3-2 presents the uppermost (XS1) and lowermost (XS6) cross-sections within the area of interest on the Southshore of Te Ihutai, where seagrass is the dominant vegetation. The plots show the estuary bed profile in 2020 (grey lines) and the projected bed in 2045 (black line), accounting for VLM and sediment deposition from the Avon and Heathcote catchments. Areas covered by saltmarsh and seagrass are indicated with square symbols, along with high and low spring tide water levels for 2020 and three SLR scenarios, each represented with different line styles.

Cross sectional plots, including neap tide and spring tide water levels for all sections, are presented in Appendix A. Similar plots to Figure 3-2 showing only spring tide water levels for the remaining four cross sections (XS2 to XS5), are provided in Appendix B.

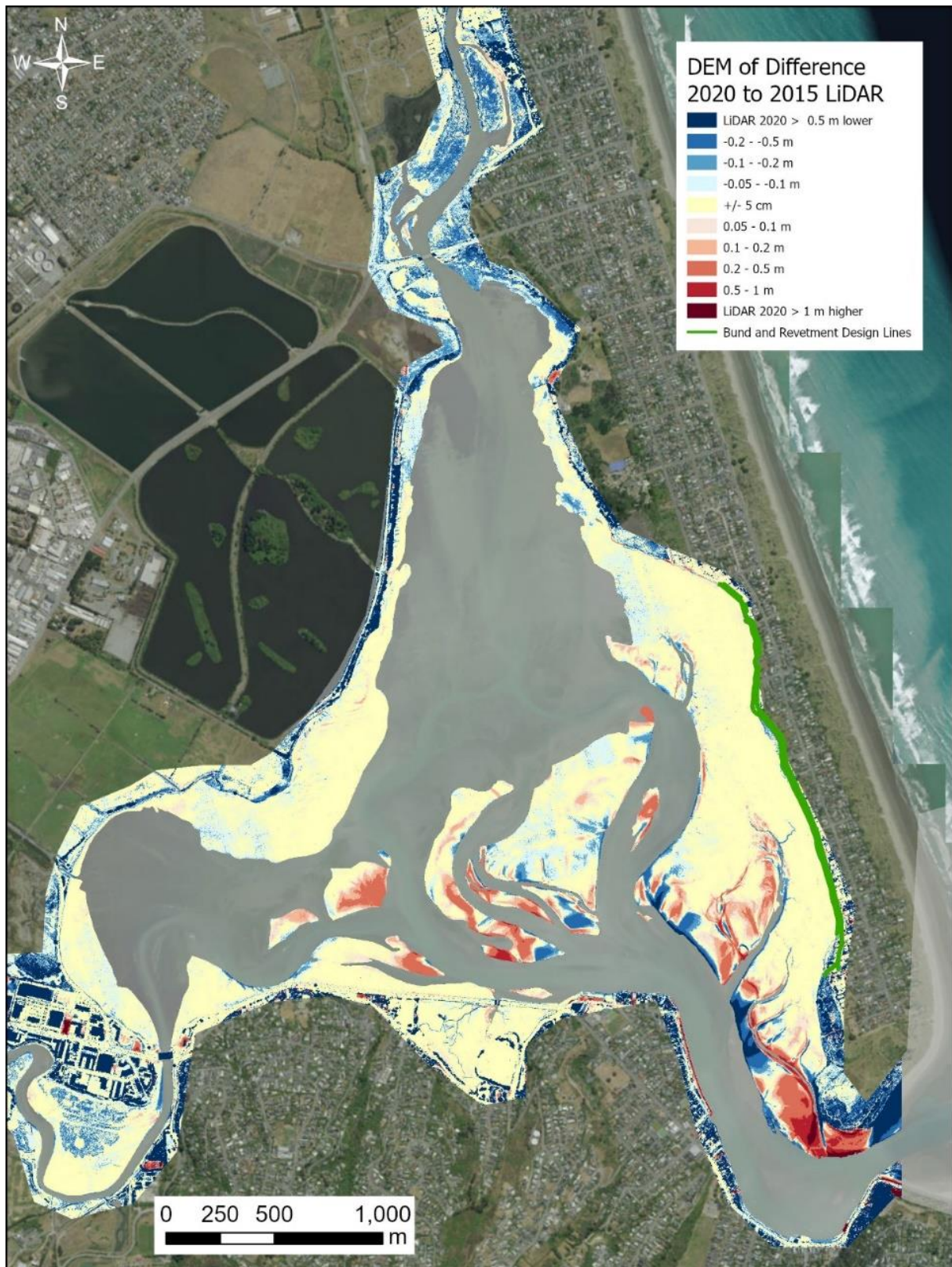


Figure 3-1: DEM of difference between 2015 and 2020 LiDAR. Proposed bund and revetment design lines are also shown in the map.

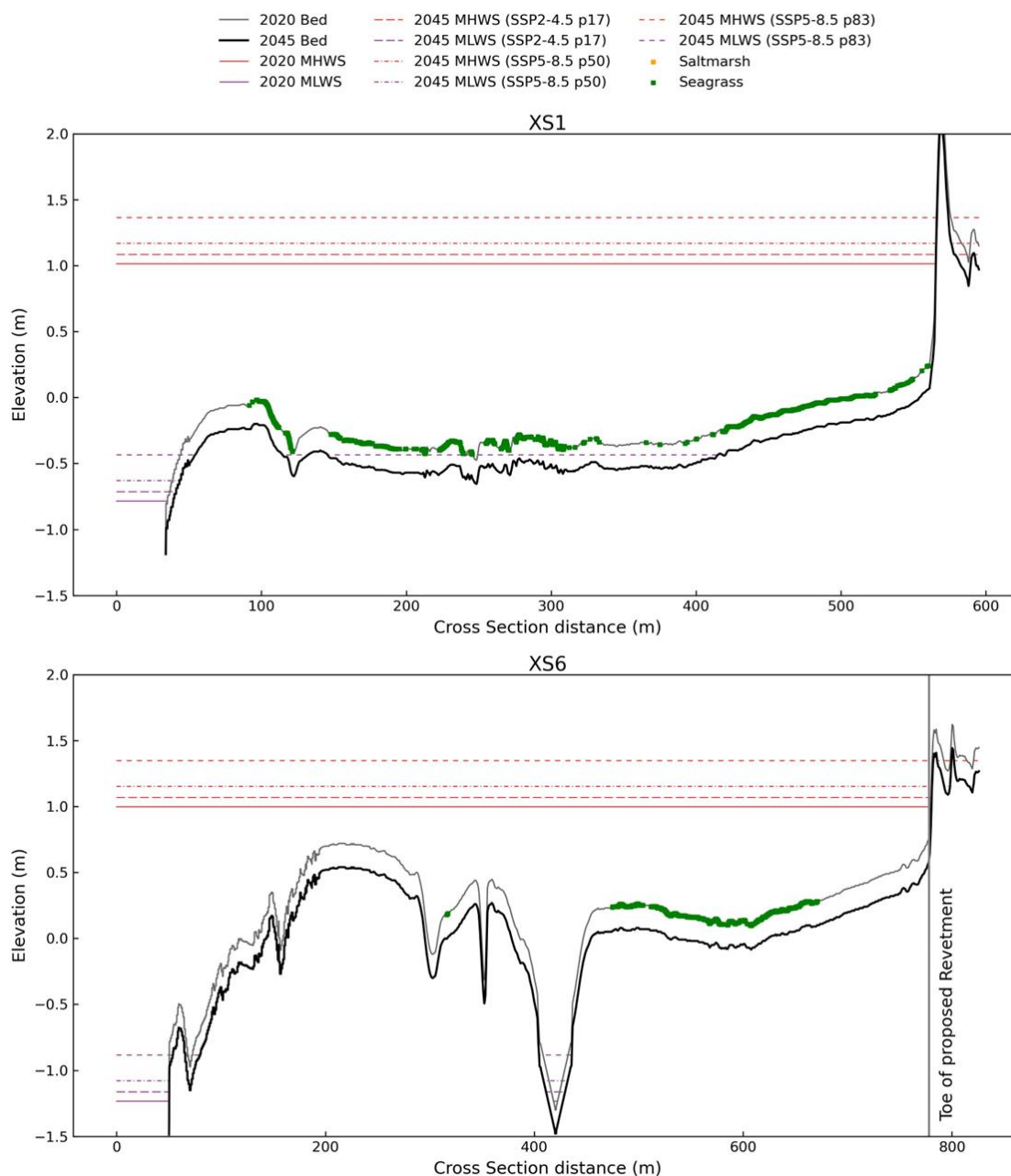


Figure 3-2: Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) for 2020, along with projected water levels for SLR scenarios. Figure shows cross-section 1 (upper) and cross-section 6 (lower). The green and yellow symbols indicate areas of the estuary bed currently covered by seagrass and saltmarsh.

The intertidal distance for each cross section was measured by calculating the length of the cross-section located between the high spring tide (MHWS) and the low spring tide (MLWS), excluding estuary channels. With SLR, the intertidal zone showed the most significant reduction at cross section XS1, decreasing from 526 m in 2020 to 223 m under the SSP5-8.5 p83 SLR scenario (Table 3-1). Under this highest SLR scenario, a large reduction was also notable at cross section XS2, with a 65 m decrease in intertidal length. However, changes were less pronounced at cross section XS3 and the other cross-sections further south.

Table 3-1: Intertidal distance (m) for each cross section under 2020 and future SLR scenarios for 2045.

	XS1	XS2	XS3	XS4	XS5	XS6
2020	526.2	284.4	382.3	505.1	695.4	713.5
SSP2-4.5 p17 medium confidence	524.4	280.9	380.2	503.3	692.8	709.5
SSP5-8.5 p50 medium confidence	519.6	268.2	377.2	501.5	690.6	701.4
SSP5-8.5 p83 low confidence	222.7	220	354.7	494.4	687.4	678.2

To assess the proportion of seagrass coverage within the intertidal zone under future SLR scenarios, the length of the intertidal zone with seagrass cover was compared to the intertidal length under future SLR scenarios. Table 3-2 summarizes these proportions for three future SLR scenarios. Intertidal changes primarily impacted cross sections XS1 and XS2, especially under the highest SLR scenario (SSP5-8.5 p83).

Table 3-2: Proportion of existing seagrass within the intertidal zone (%) for each cross section that is projected to remain intertidal under various SLR scenarios for 2045. The results in this table do not account for the effects on low tide levels caused by changes in channel morphology due to an increased tidal prism.

	XS1	XS2	XS3	XS4	XS5	XS6
SSP2-4.5 p17 medium confidence	100	100	100	100	100	100
SSP5-8.5 p50 medium confidence	100	99	100	100	100	100
SSP5-8.5 p83 low confidence	53	80	96	100	100	100

Water depth above seagrass cover at high tide was determined for each cross section (XS1 to XS6) under different SLR scenarios (Table 3-3). At cross section XS1, the minimum depth increases from 0.77 m in 2020 to 1.3 m under the SSP5-8.5 p83 scenario, while the average depth increases from 1.22 m in 2020 to 1.75 m under SSP5-8.5 p83. Depth above seagrass is less at the downstream cross sections. For example, at cross section XS5, the average depth is 0.85 m in 2020 and 1.38 m under SSP5-8.5 p83. Water depth above seagrass cover during low spring tides under different SLR scenarios indicates the potential transition from intertidal to subtidal zones. This transition was observed only under the highest SLR scenario (SSP5-8.5 p83) and was limited to three cross-sections: XS1, XS2, and XS3.

As SLR increases, the distance between low water spring tide and seagrass decreases across all cross sections (Table 3-4).

Similar analyses were conducted for saltmarsh at cross section XS3 where it is present. With rising SLR, the depth of high water spring tide above the saltmarsh increases, and the elevation difference between low water spring tide and saltmarsh decreases (Appendix C).

Table 3-3: Maximum, minimum and average depth above seagrass relative to MHWS and MLWS under 2020 and three future scenarios of 2045.

	2020		SSP2-4.5 p17 medium confidence		SSP5-8.5 p50 medium confidence		SSP5-8.5 p83 low confidence	
	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
XS1								
Min (m)	0.77	0.00	1.02	0.00	1.11	0.00	1.30	0.00
Max (m)	1.45	0.00	1.70	0.00	1.78	0.00	1.98	0.18
Average (m)	1.22	0.00	1.47	0.00	1.55	0.00	1.75	0.04
XS2								
Min (m)	0.79	0.00	1.04	0.00	1.12	0.00	1.32	0.00
Max (m)	1.51	0.00	1.76	0.00	1.84	0.00	2.04	0.22
Average (m)	1.15	0.00	1.40	0.00	1.49	0.00	1.68	0.01
XS3								
Min (m)	0.73	0.00	0.98	0.00	1.06	0.00	1.26	0.00
Max (m)	1.40	0.00	1.65	0.00	1.74	0.00	1.93	0.08
Average (m)	1.07	0.00	1.32	0.00	1.41	0.00	1.60	0.00
XS4								
Min (m)	0.65	0.00	0.90	0.00	0.99	0.00	1.18	0.00
Max (m)	1.11	0.00	1.36	0.00	1.44	0.00	1.64	0.00
Average (m)	0.97	0.00	1.22	0.00	1.31	0.00	1.50	0.00
XS5								
Min (m)	0.56	0.00	0.81	0.00	0.90	0.00	1.09	0.00
Max (m)	1.34	0.00	1.59	0.00	1.68	0.00	1.87	0.00
Average (m)	0.85	0.00	1.10	0.00	1.19	0.00	1.38	0.00
XS6								
Min (m)	0.72	0.00	0.97	0.00	1.05	0.00	1.25	0.00
Max (m)	0.90	0.00	1.15	0.00	1.24	0.00	1.43	0.00
Average (m)	0.80	0.00	1.05	0.00	1.14	0.00	1.33	0.00

Table 3-4: Maximum, minimum and average elevation of seagrass relative to MLWS under 2020 and three future SLR scenarios. A '-' indicates that the seagrass remains submerged at MLWS under the given scenario.

	2020	SSP2-4.5 p17 medium confidence	SSP5-8.5 p50 medium confidence	SSP5-8.5 p83 low confidence
XS1				
Min (m)	0.35	0.10	0.02	-
Max (m)	1.03	0.78	0.69	0.50
Average (m)	0.58	0.33	0.24	-
XS2				
Min (m)	0.31	0.06	0.01	-
Max (m)	1.03	0.78	0.69	0.50
Average (m)	0.66	0.41	0.33	0.18
XS3				
Min (m)	0.45	0.20	0.12	-
Max (m)	1.13	0.88	0.79	0.60
Average (m)	0.78	0.53	0.45	0.27
XS4				
Min (m)	0.81	0.56	0.47	0.28
Max (m)	1.26	1.01	0.92	0.73
Average (m)	0.94	0.69	0.60	0.41
XS5				
Min (m)	0.77	0.52	0.44	0.24
Max (m)	1.55	1.30	1.22	1.02
Average (m)	1.27	1.02	0.93	0.74
XS6				
Min (m)	1.33	1.08	0.99	0.80
Max (m)	1.51	1.26	1.18	0.98
Average (m)	1.43	1.18	1.10	0.90

4 Limitations and uncertainties

4.1 Impact of tidal prism volume change due to SLR at low tide water levels

As described in section 2.4, changes in tidal prism may result in changes in channel geometry to accommodate the increased tidal flow. Increased tidal prism under SLR may result in channels deepening, with impacts on water levels at low tide. This increase in water depth includes both the increase in water level from SLR as well as scouring of the channel bed to obtain the required larger channel cross-section. Changes in channel geometry cannot be calculated with high accuracy within the scope of this project, but we estimate its likely magnitude and compare to the changes in water level at low tide resulting from SLR.

For SLR of 0.5 m, the spring tidal prism volume increases by 42%. Based on the assumptions in Section 2.4, the cross-sectional area increases linearly with the spring tidal prism volume. Assuming equal proportional increases in depth and width, the depth of the estuary channel increases by 19%.

Changes in channel bed elevation, and consequently low tide water levels, are estimated based on the increased channel depth required beyond what is accounted for by SLR. Linear interpolation between the 0.5 m SLR and three SLR scenarios results in proportional increases in low tide depth of the estuary channel as follows:

- SSP2-4.5 p17 (medium confidence): 2.9%.
- SSP5-8.5 p50 (medium confidence): 6.3%.
- SSP5-8.5 p83 (low confidence): 13.8%.

Table 4-1: Tidal prism volume of Te Ihutai for the current sea level and a 0.5 m SLR, based on model runs by Measures and Bind (2013).

Model runs	Neap tidal prism (m ³)	Average tidal prism (m ³)	Spring tidal prism (m ³)
Current	6,327,765	8,678,386	9,985,000
0.5 m SLR	8,807,465	12,542,308	14,190,340
Difference	39%	45%	42%

The impact of increased depth is represented as the lower band values for low spring and neap tides across all three scenarios. Since cross section XS1 is located in an area where the intertidal zone is likely to be most affected by various SLR scenarios, only the lower band values of low tide are shown for this cross section illustrates the impact of tidal prism volume changes under different SLR scenarios for cross section XS1.

Changes in the cross-sectional area of the submerged channel primarily affect low tides. Our analysis, based on the approach and assumptions outlined in Section 2.4, suggests that low tide levels may increase slightly from the 2020 baseline due to SLR. If accurate, this would indicate minimal change in the intertidal area at this section. This represents the lower range of potential changes in low tide water levels. For example, at cross-section XS1 under the highest SLR scenario (SSP5-8.5 p83), the spring low tide level decreases by 0.26 m when accounting for the tidal prism volume, compared to conditions with no tidal impact. We anticipate that actual changes in low tide levels may fall between

the range shown in Figure 3-2 and the low tide level adjusted for tidal prism impact (shown in Figure 4-1).

Further southern cross sections are not shown, as the increase in low tide levels due to SLR was minimal, remaining close to current levels. This is attributed to the increase at depth of the estuary channel resulting from the impact of tidal prism changes.

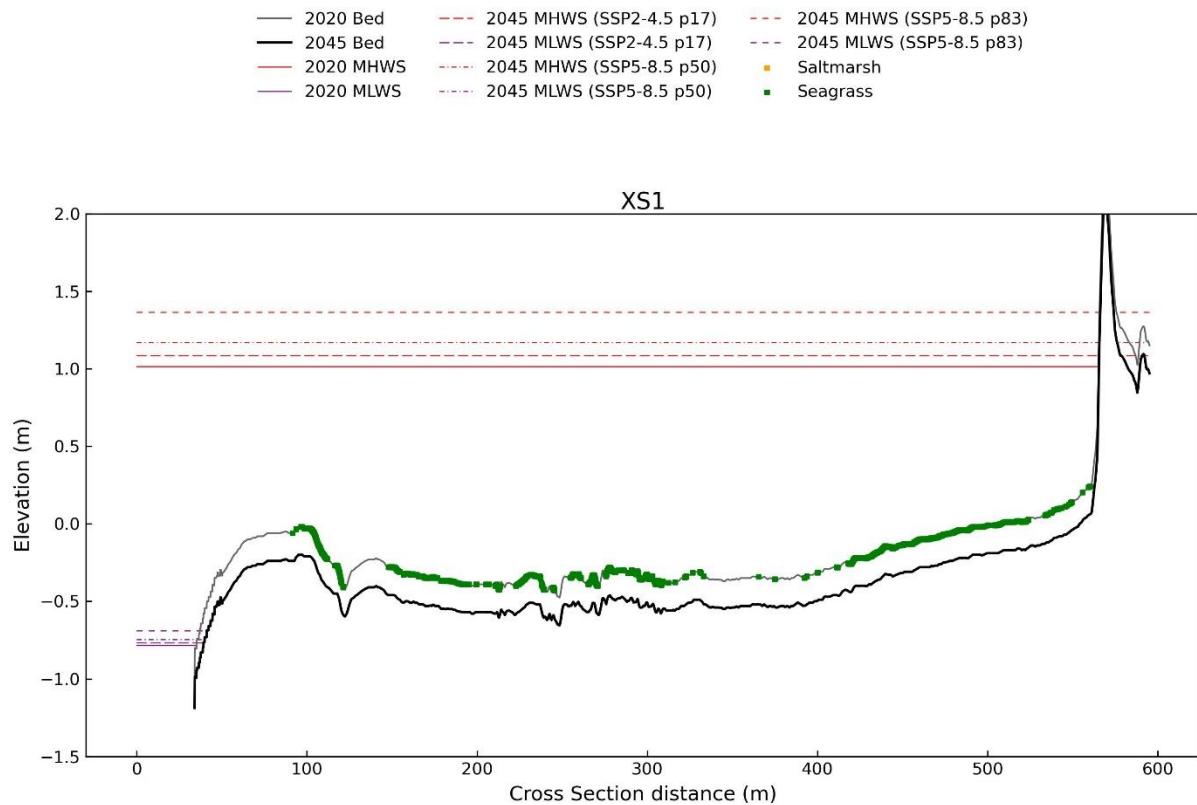


Figure 4-1: Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) for 2020, along with projected water levels for SLR scenarios at cross section XS1, considering the impact of tidal prism volume on cross-sectional changes. High water spring levels remain the same with those in Figure 3-2.

4.2 Other limitations

Additional limitations and assumptions related to water level and intertidal zone estimates under future SLR scenarios include:

- The estimated sediment deposition rate represents an average across the estuary, but actual rates vary spatially due to hydrodynamic conditions and sediment transport processes such as currents, wave action, and localized sediment supply. Since this project does not include detailed modelling of spatial variations, a uniform deposition rate has been assumed for simplicity, recognizing that this approach may not fully capture localized sedimentation dynamics.
- The estimated sediment deposition rate represents an estuary-wide average and is based on a single settling velocity of 0.25 mm/s, corresponding to a grain size of 0.023 mm. Deposition is assumed to occur over an area calculated as the average between high and low tide extents, with no net erosion assumed, meaning entrainment and resuspension do not exceed deposition.

- The rate of land subsidence (i.e., vertical land movement or VLM rate) within Te Ihutai is assumed to remain constant over time.
- Although sea level rise (SLR) may alter seagrass bed extents by changing the intertidal area, our projections for the proportion of seagrass within the intertidal zone and the depth above seagrass relative to tide levels assume no change in seagrass extent.

5 Summary

Without running a hydrodynamic model similar to those used by Measures and Bind (2013) and Orchard et al. (2020), we cannot estimate the proportion of time the estuary's intertidal area was inundated over a tidal cycle for the 2020 sea level and future SLR scenarios. However, by extracting tidal water level data from previous model runs and adjusting it to our current estuary bed profile, we can provide an indicative assessment of changes in the intertidal zone.

Using spring tides, with their larger tidal range and extreme high and low water levels, along with neap tides, which have less variation in water level (i.e., lower highs and higher lows), provides insight into immersion zones and potential shifts from intertidal to subtidal at areas of interest for future SLR scenarios.

The results indicate that:

- For southern areas of interest, the intertidal zone remains unchanged, even under the most extreme SLR scenario (SSP5-8.5 p83). In cross section XS3 and areas at the southern part of the Southshore, the change in intertidal area is almost negligible.
- The northern part of the area of interest may experience greater impact from SLR. At cross section XS1 (near Ebbside Street), the intertidal zone could shrink by about 60% at the highest water level increase for SLR scenario (SSP5-8.5 p83). For lower SLR scenarios, the reduction is much smaller, with less than 1% of the estuary transitioning to subtidal area (Table 3-1).
- Similarly, the proportion of seagrass within the intertidal area at cross section XS1 reduces to 53% under the highest SLR scenario, while other scenarios show no change in the proportional intertidal area of seagrass.
- At cross section XS2 (area near Heron Street and Kingfisher land), the intertidal length reduces by about 23% (from 284 m to 220 m) for the highest SLR scenario (Table 3-1). This change reduces the intertidal proportion of seagrass in this area to 80% (Table 3-2).
- In the southern area of interest, from Penguin Street to the southern part of Southshore, the proportion of seagrass in the intertidal zone remains unchanged.
- The depth of high water spring tides above seagrass increases with rising SLR. At XS1, the average increase from the 2020 spring tide level ranges from 20% (from 1.22 m in 2020 to 1.47 m for SSP2-4.5 p17) to 43% (to 1.75 m for SSP5-8.5 p83). At XS6, the average increase is between 31% (from 0.8 m in 2020 to 1.05 m for SSP2-4.5 p17) and 60% (to 1.33 m for SSP5-8.5 p83) (Table 3-3).

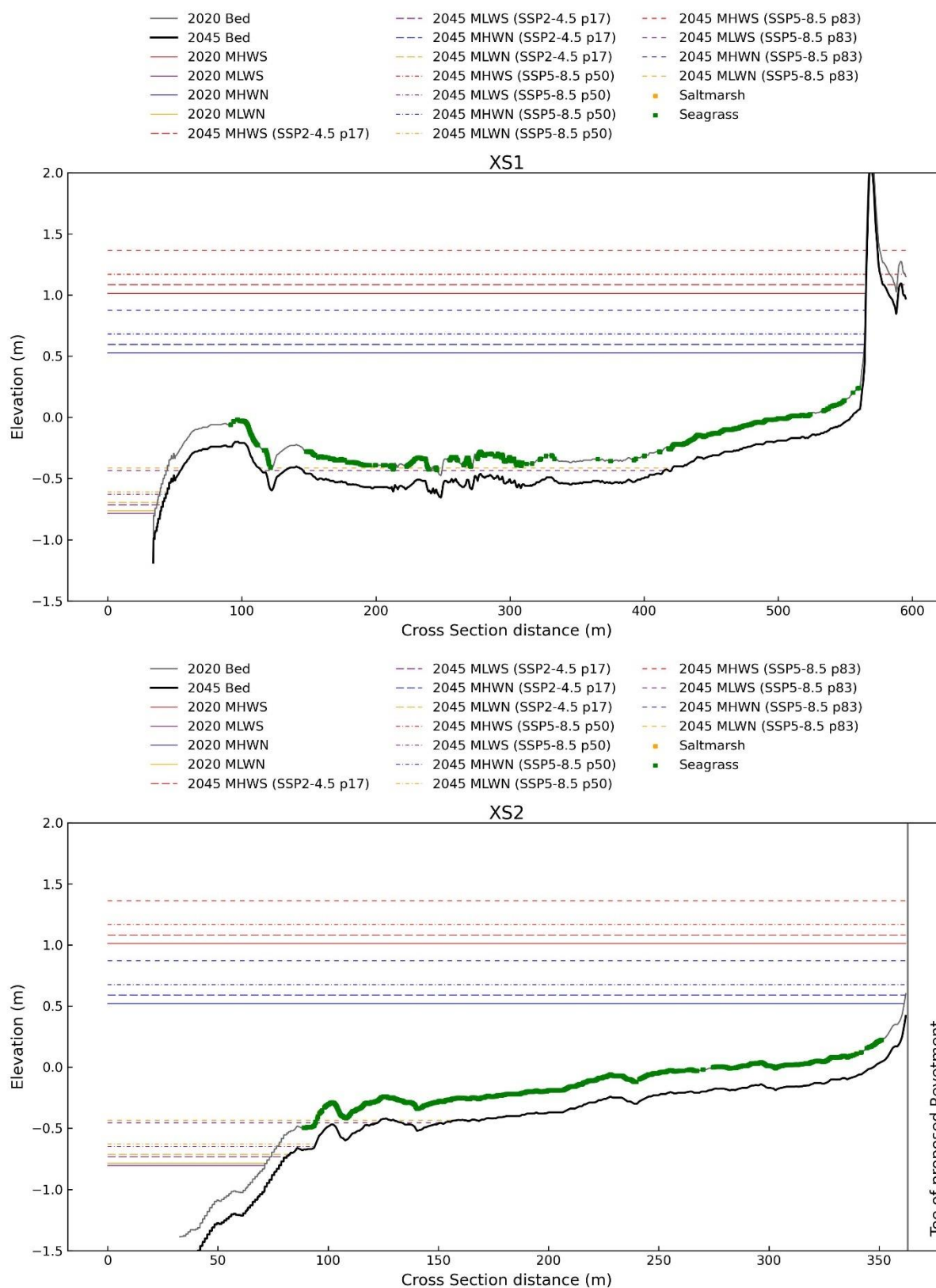
6 Acknowledgements

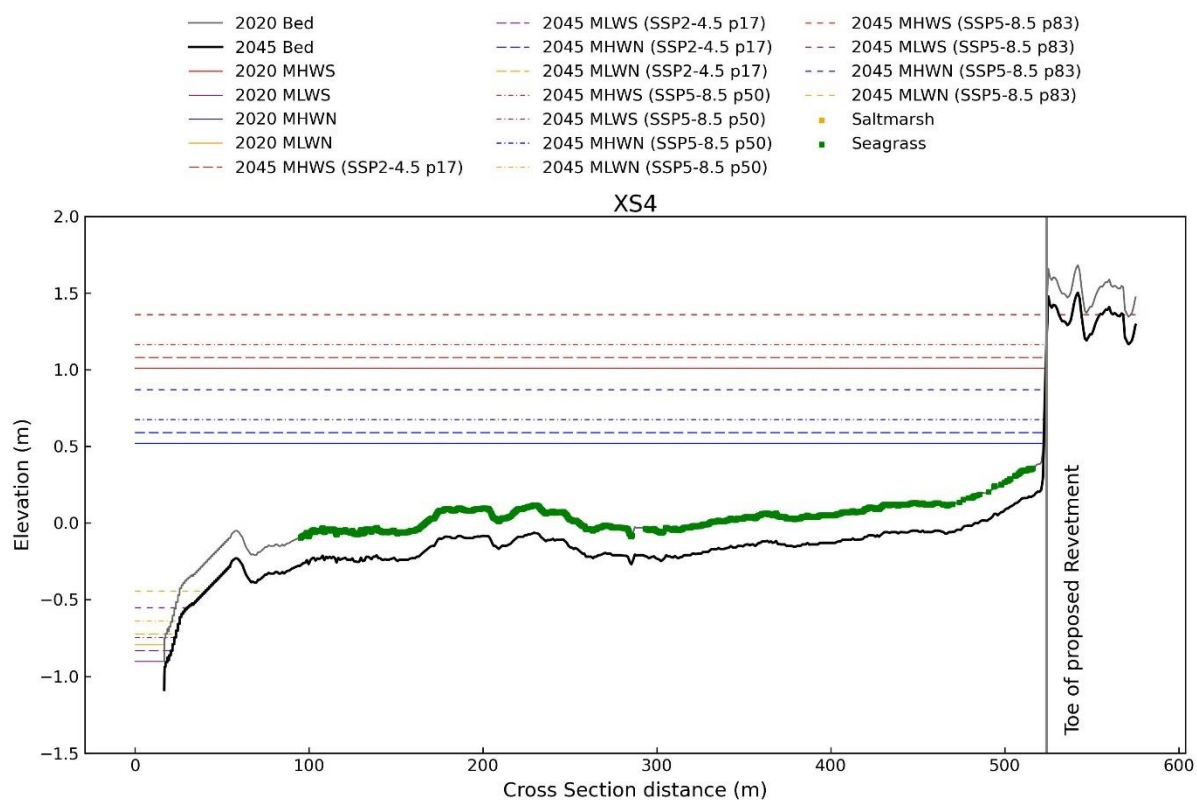
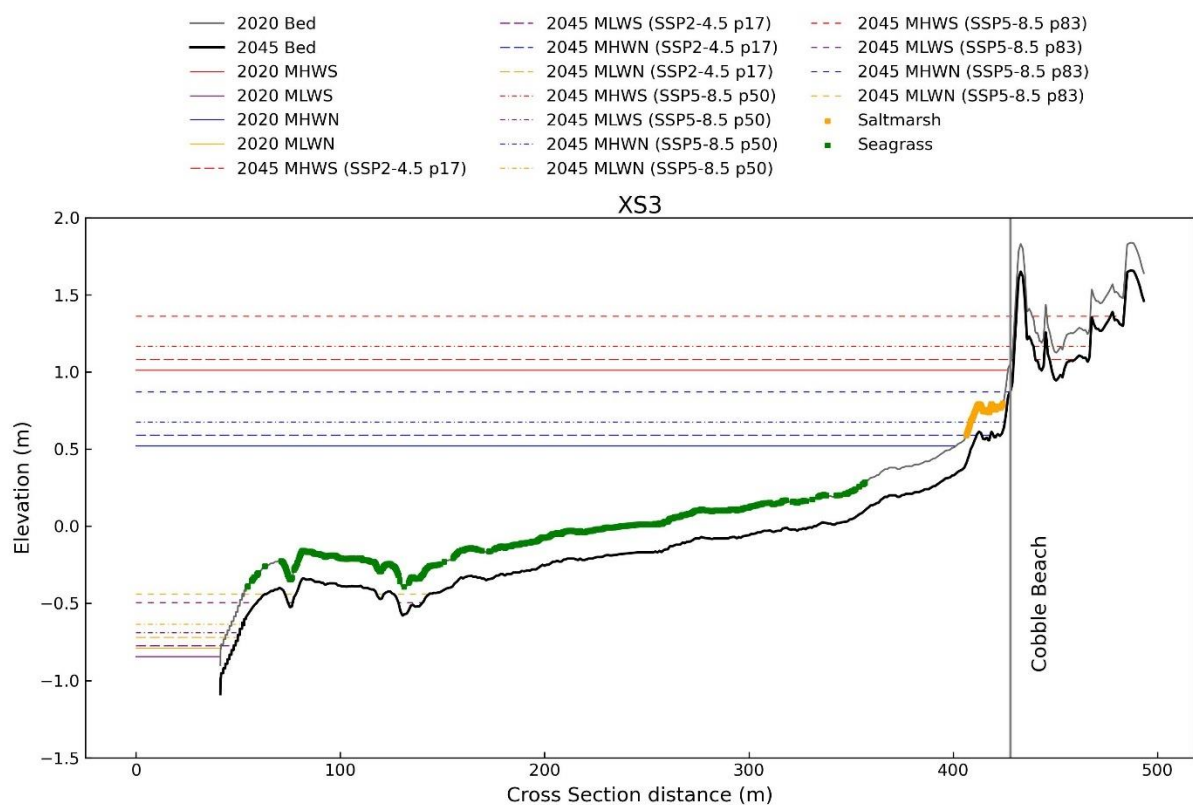
We would like to thank Tomasso Alestra and Tanya Blakely from Boffa Miskell Ltd. for their valuable input.

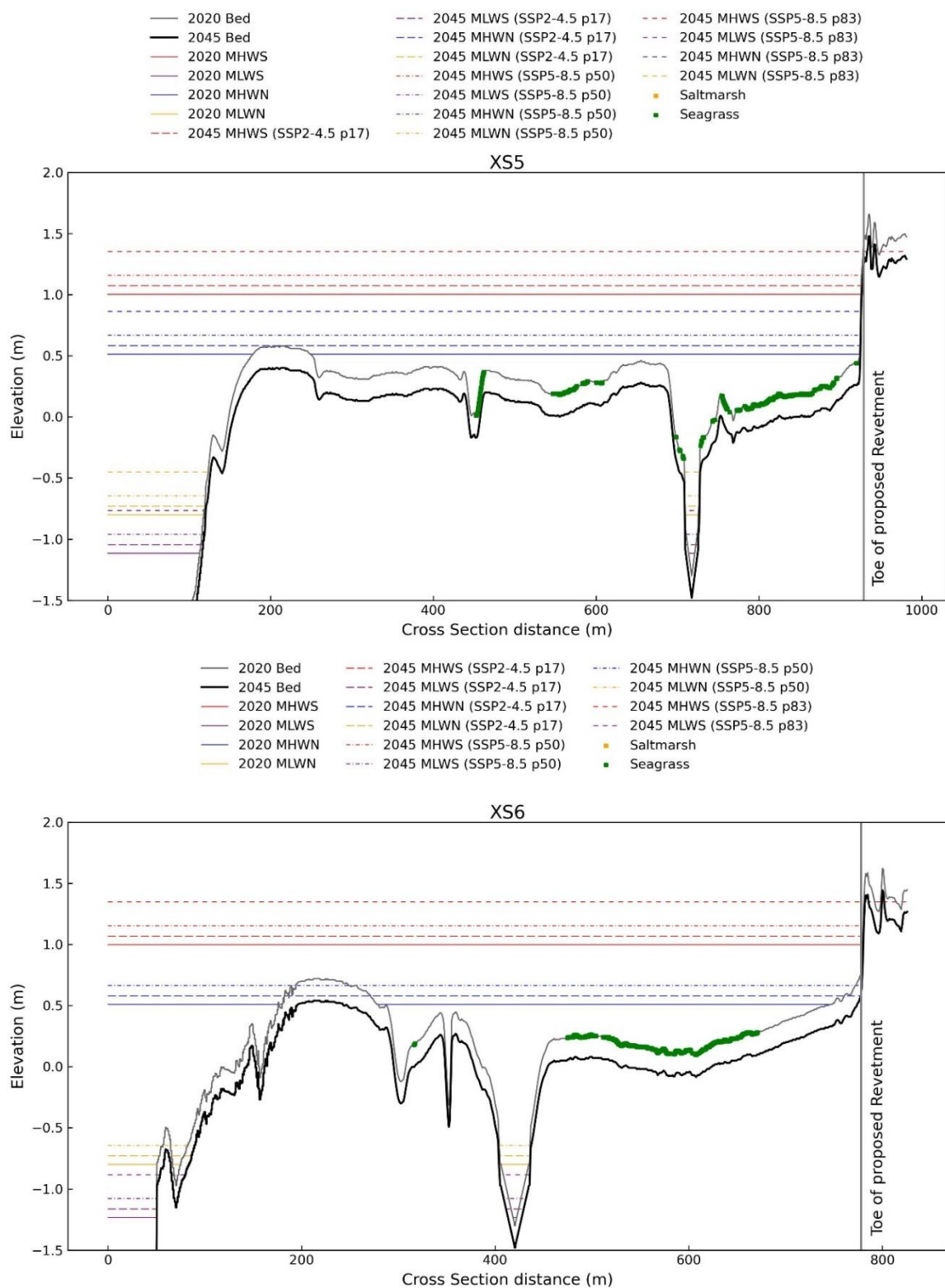
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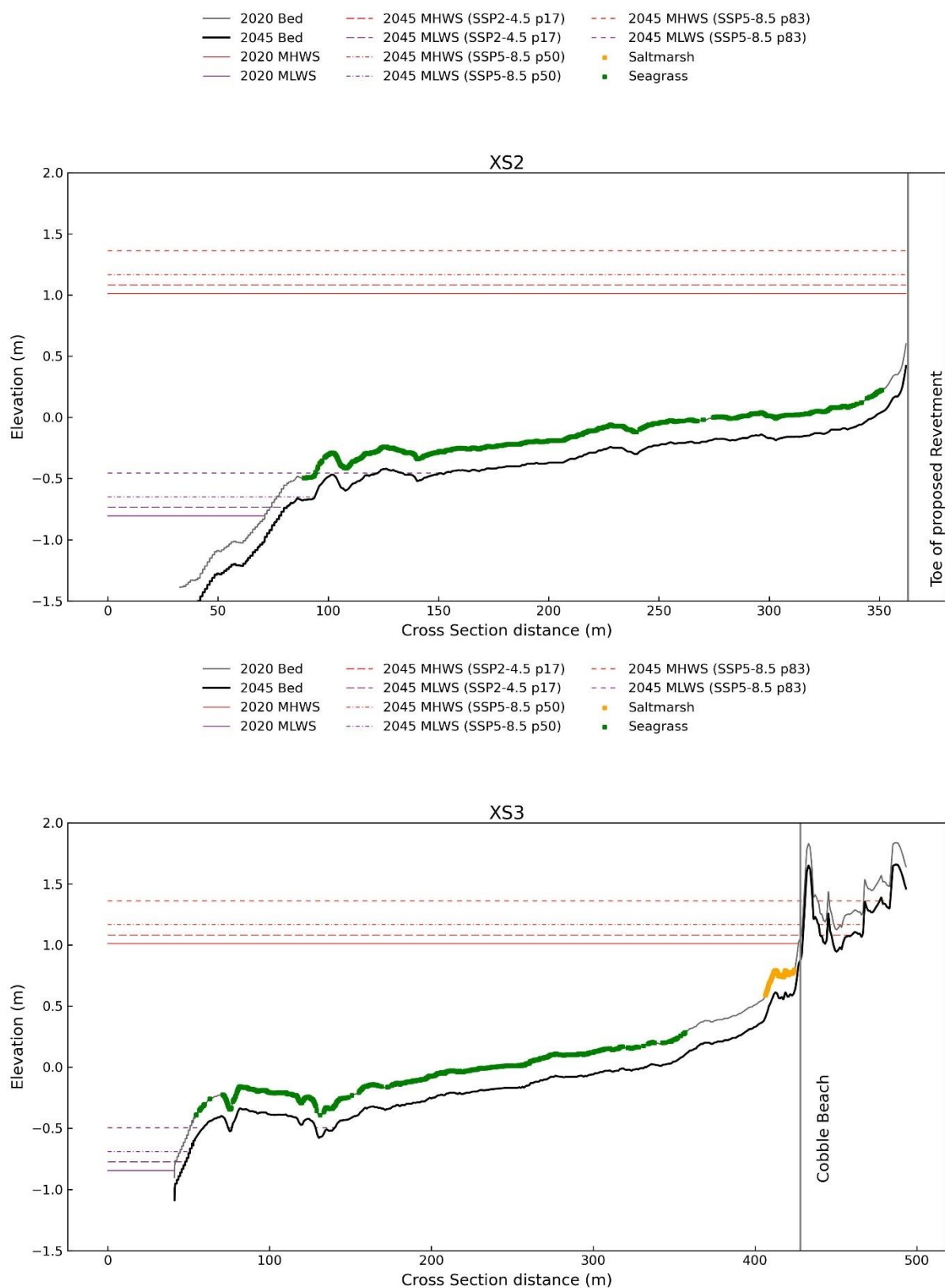
Appendix A Estuary bed and water level scenarios with neap and spring tides and seagrass and saltmarsh for all cross sections







Appendix B Estuary bed and water level scenarios with only spring tides showing seagrass and saltmarsh for cross sections 2 to 5



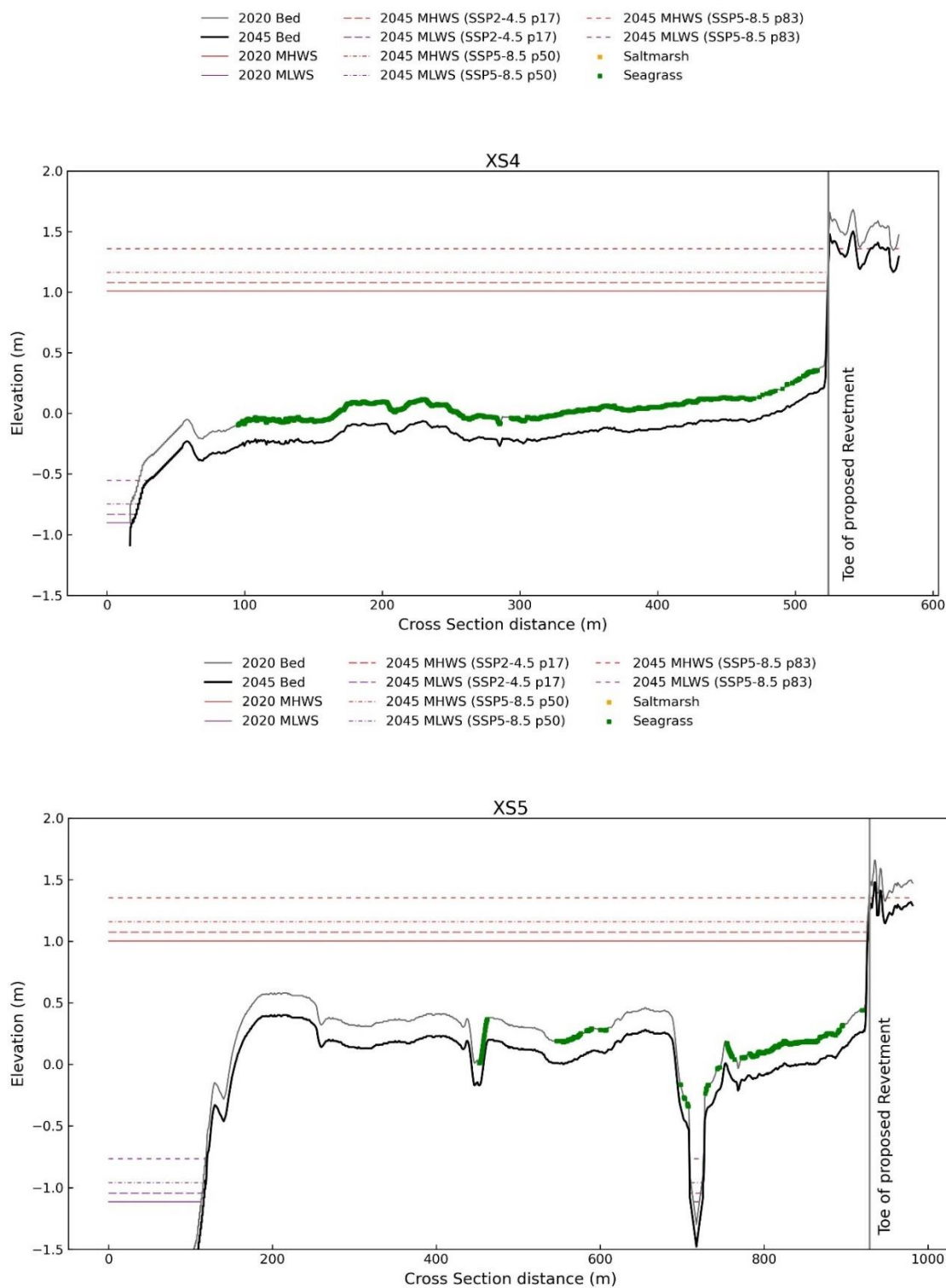


Figure B-1: Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) for 2020, along with projected water levels for SLR scenarios for cross sections XS2 to XS5. Cross sections shown are from 2 (top) to 6 (lower). The green and yellow symbols indicate areas of the estuary bed currently covered by seagrass and saltmarsh.

Appendix C High water spring tide depth above salt marsh for cross sections where saltmarsh exists, and elevation distance between low water spring tide and saltmarsh

Table C-1: Maximum, minimum and average depth above saltmarsh relative to MHWS and MLWS for current and three future SLR scenarios.

	2020		SSP2-4.5 p17 medium confidence		SSP5-8.5 p50 medium confidence		SSP5-8.5 p83 low confidence	
	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
XS3								
Min (m)	0.21	0.00	0.46	0.00	0.55	0.00	0.74	0.00
Max (m)	0.42	0.00	0.67	0.00	0.76	0.00	0.95	0.00
Average (m)	0.27	0.00	0.52	0.00	0.60	0.00	0.80	0.00

Table C-2: Maximum, minimum and average elevation distance between MLWS and saltmarsh for current and three future scenarios.

	2020	SSP2-4.5 p17 medium confidence	SSP5-8.5 p50 medium confidence	SSP5-8.5 p83 low confidence
XS3				
Min (m)	1.43	1.18	1.10	0.90
Max (m)	1.64	1.39	1.31	1.11
Average (m)	1.59	1.34	1.25	1.06