District-Wide Tidal Flood Mapping - Christchurch and Banks Peninsula

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Christchurch City Council

District-Wide Tidal Flood Mapping
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Executive summary

In April 2025 Jacobs were commissioned by Christchurch City Council (the Council) to undertake 'tidal' mapping of the Christchurch and Banks Peninsula District. The Christchurch City Council Coastal Hazards Portal (https://gis.ccc.govt.nz/hazard-viewer/coastal-flooding) currently presents information for coastal flooding, and shows where flooding would occur in a coastal storm (i.e. for an annual storm, 1 in 10 year storm, and a 1 in 100 year storm).The purpose of this work is to develop an improved understanding of how 'sunny day' or tidal flooding may impact the district under various sea level rise (SLR) increments, representative of future relative SLR scenarios with climate change. This information will help communities to visualise where more frequent flooding (i.e. tidal) could occur in the future with SLR.

This project has mapped two tidal reference elevations:

- **Mean High Water (MHW):** The mean elevation of all predicted high tides (i.e. daily flooding).
- **Mean High Water Spring (MHWS):** The mean elevation of the expected monthly maximum tides (i.e. monthly flooding).

Mapping of higher tidal conditions (e.g. king tides, highest astronomical tides) has not been undertaken as part of this project due to these conditions occurring less frequently, and hence a decision was made to focus on more frequent daily and monthly conditions.

The methodology used in this assessment to identify areas of tidal flooding is the same as that used in the Tonkin and Taylor (2021) Coastal Hazard Assessment (CHA), which assessed the coastal flood hazard during storms across the district. This alignment is to ensure consistency in outputs. A key output of this project includes geo-spatial files that can be accessed by the public through the Christchurch City Council Coastal Hazards Portal. These geospatial files show the extent and depth of flooding for each tidal reference (Mean High Water or Mean High Water Spring), under various future SLR scenarios. The files also identify where flooding has a direct connection to the sea ('connected') or is disconnected (i.e. areas where land elevation is lower than the tidal water level, however there is not a direct pathway (connection) to the sea).

Section 4 of this report presents a high-level summary of the potential exposure of 35 locations around the Christchurch and Banks Peninsula District. The summary includes commentary on the degree (minor or major) of exposure of property and roads (access) to tidal flooding with SLR. This tidal mapping and analysis provides an indication of areas along the district's coastline that may become first impacted by tidal flooding. Generally, the areas that are shown to have the earliest onset of exposure to daily tidal flooding are:

- Brooklands
- Bexley
- Teddington

Fortunately, these areas will have the earliest onset of exposure to daily tidal flooding hazards are sparsely populated. Daily flooding under higher SLR increments will eventually impact more developed urban areas that are much more densely populated. Additionally, areas that will become exposed to relative major monthly flooding (MHWS) with up to 0.6m SLR (including the areas listed above) are:

- New Brighton
- South New Brighton
- Southshore
- McCormacks Bay/Redcliffs
- Purau
- Port Levy
- Okains Bay
- Akaroa
- Takamatua
- Duvauchelle

For each of these areas, the timeframe at which 0.6 m SLR could be realised will vary, depending on which climate change projection occurs in the future, and the magnitude of local VLM.

The areas along the coast that are particularly elevated and are therefore the least impacted by tidal flooding are:

- Waimairi Beach
- Taylors Mistake
- Corsair Bay
- Cass Bay
- Rapaki
- Diamond Harbour
- Birdlings Flat

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to prepare the methodology and results of tidal mapping of the Christchurch and Banks Peninsula District, in accordance with the scope of services set out in the contract between Jacobs and Christchurch City Council ('the Client'). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full, and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, the Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

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1. Project Overview

In April 2025 Jacobs were commissioned by Christchurch City Council (the Council) to undertake 'tidal' mapping of the Christchurch and Banks Peninsula District. This work has been undertaken as part of the the broader Christchurch City Council Coastal Hazards Adaptation Planning Programme. This programme has identified coastal flooding, erosion, and rising groundwater hazards across the city and Banks Peninsula with Sea Level Rise (SLR), and is in the process of developing adaptation plans with communities. The Christchurch City Council Coastal Hazards Portal (https://gis.ccc.govt.nz/hazard-viewer/coastal-flooding) currently presents information for coastal flooding, and shows where flooding would occur in a coastal storm (i.e. for an annual storm, 1 in 10 year storm, and a 1 in 100 year storm).

The purpose of this work is to develop an improved understanding of how 'sunny day' or tidal flooding may impact the district under various sea level rise increments, representative of future relative SLR scenarios with climate change. This information will help communities to visualise where more frequent flooding (i.e. tidal) could be in the future with SLR and consider how this may impact them.

This project has mapped two tidal reference elevations:

- **Mean High Water (MHW):** The mean elevation of all predicted high tides (i.e. daily flooding).
- **Mean High Water Spring (MHWS):** The mean elevation of the expected monthly maximum tides (i.e. monthly flooding).

Mapping of higher tidal conditions (e.g. king tides, highest astronomical tides) has not been undertaken as part of this project due to these conditions occurring less frequently, and hence a decision was made to focus on more frequent daily and monthly conditions. The tidal mapping produced from this project will help provide an understanding of what the 'new normal' might look like with future sea level rise. However, it is important to note that in most instances, meteorological effects (such as storm surges, or waves) will mean that flood levels at the coast will often be higher than what has been mapped.

The methodology used in this assessment to identify areas of tidal flooding is the same as that used in the Tonkin and Taylor (2021) Coastal Hazard Assessment (CHA), which assessed the coastal flood hazard during storms across the district.

A key output of this project includes geo-spatial files that can be accessed by the public through the Christchurch City Council Coastal Hazards Portal. These geospatial files show the extent and depth of flooding in a selected tidal condition (Mean High Water or Mean High Water Spring), under various future SLR scenarios.

This report documents a comprehensive review of MHW and MHWS levels across the district, the methodology used to map the tidal reference elevations, and a high-level summary of the exposure of various communities around the Christchurch and Banks Peninsula coast to tidal flooding.

1.1 Structure of this report

The structure of this report is as follows:

- **Section 2** provides a description of the data sources and methodology used to undertake the mapping of tidal levels;
- **Section 3** details a review and analysis of existing tidal level information, and defines the MHW and MHWS levels for the district used in this assessment;
- **Section 4** presents a high-level interpretation of the results of the mapping;
- **Appendix A** includes a "Plain Language Summary" describing the methods used and outcomes/conclusions of the analysis, to align with incoming LIM regulations (Appendix A).

2. Methodology

2.1 Study area and inundation cells

The study area for this tidal mapping project includes the entire Christchurch District. The study area aligns to the same area considered under the Tonkin and Taylor (2021) Coastal Hazards Assessment (CHA). As per the methodology used in the CHA, the district is split into 13 inundation 'cells' across the district based on data availability and similarity of coastline morphology and environment (e.g. harbours/estuaries, open coast). For each of these cells, a MHW and MHWS water level has been defined in this study using the available data set out in the sections below.

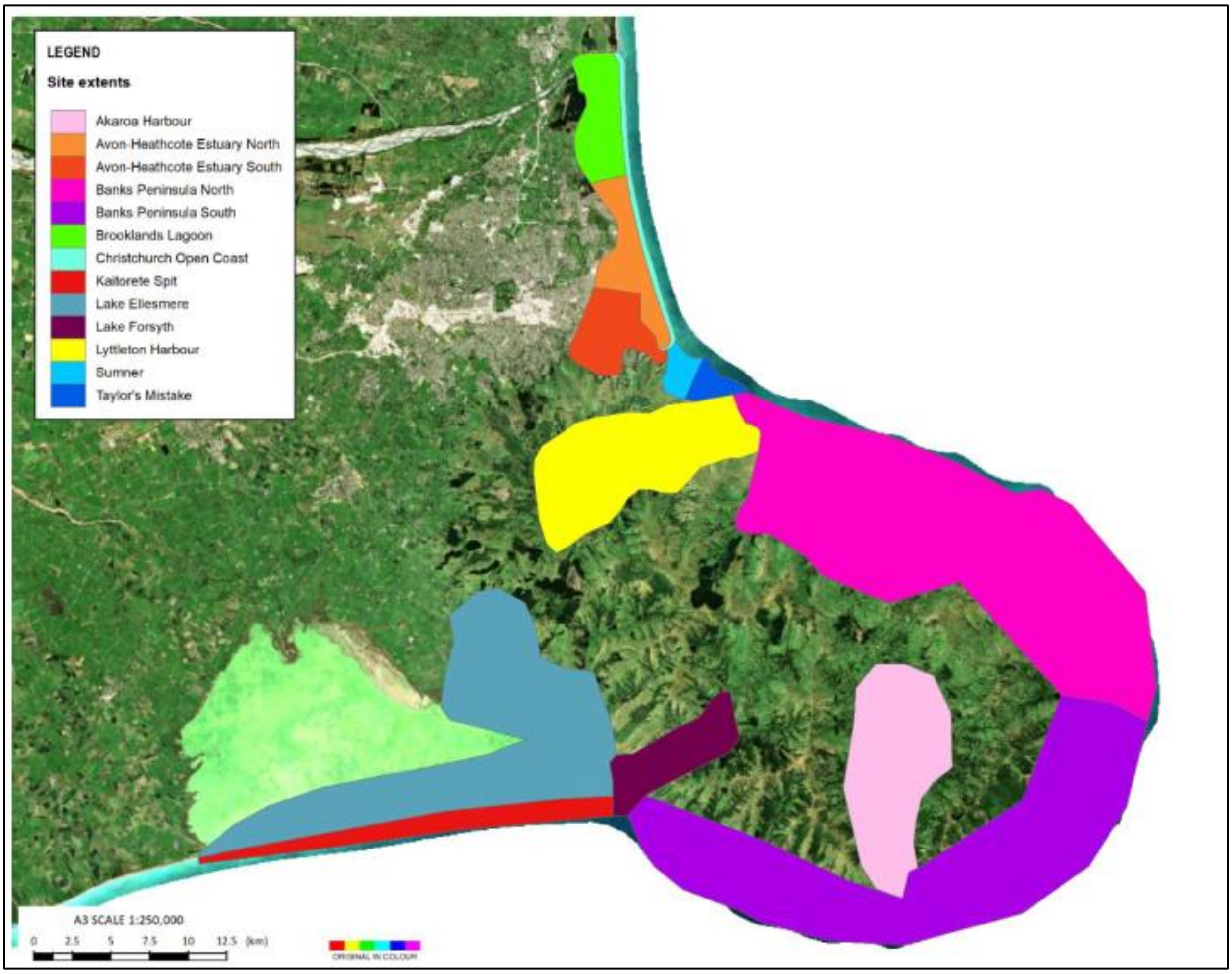


Figure 1: Inundation cell areas (from T&T, 2021).

It is important to note that inland extents of flooding in the Avon, Heathcote and Styx catchments are cut off by the boundary defined in Figure 2. This boundary is based on the hydraulic controls that have been identified within each of the major river systems, where seaward of the boundary, extreme inundation levels are dominated by coastal conditions (tide and sea level rise), and inland of this boundary extreme inundation levels are increasingly dominated by river/stream flow, with lesser reliance on the sea level scenario applied (Tonkin and Taylor, 2021). For consistency with the Christchurch District CHA, this inland extent has been adopted for this mapping.

Further discussion on the definition of the inland extent is available in Tonkin and Taylor (2021).

Figure 2: Inland extent of inundation flooding (from T&T, 2021).

2.2 Defining tidal reference water levels

Tidal water levels are water level variations that are driven by astronomical phenomenon rather than meteorological conditions, and can therefore be predicted with great accuracy into the future from the orbits of the Moon and the Sun. The focus of this study is the high and spring tidal water levels, which can therefore be considered to define areas of semi-permanent (daily high tide) or frequent (monthly spring tide) seawater inundation. The two tidal reference water levels identified for this study are further described below:

Mean High Water level (MHW)

This is defined as being the mean elevation of all predicted high tides, therefore includes diurnal variations, fortnightly spring/ neap cycles, monthly perigean/apogean tide cycles, and the 18-year full astronomical nodal tide cycle. This reference elevation can be referred as the limit of daily permanent inundation that can occur on any day without any meteorological influence, which is also referred to as “sunny day flooding”.

Mean High Water Spring Tide (MHWS)

This reference elevation can be defined in many different ways. The standard definition is the mean elevation of the fortnightly more extreme high tides due to the greater gravitational pull when the Moon and the Sun are aligned. This is referred to as the nautical MHWS ($MHWS_n$), which is calculated as:

$$\mathbf{MHWS_n = M_2 + S_2}$$

Where:

- *M_2 is the principal lunar (moon) semi-diurnal tidal constituent – the direct response of the ocean to the gravitational attraction of the Moon, and*
- *S_2 is the principal solar(sun) semi-diurnal tidal constituent – the direct response of the ocean to the gravitational attraction of the Sun.*

However, for Canterbury (along with other NZ east coast locations), due to the four weekly lunar tides dominating over very small solar tidal harmonics, there is a single dominant monthly spring tide known as a perigean tides when the Moon’s elliptic orbit is closer to earth. Therefore, calculating a fortnightly $MHWS_n$ tide for Canterbury results in a much lower water level that is exceeded more frequently than the spring tide level occurring in other areas. For example, Mulgor (2017) reports $MHWS_n$ at Sumner Head being exceeded for 37.2% of high tides, whereas in other areas the normal exceedance is 10-12%. As a result, Environment Canterbury (ECan) have adopted the following definition as the Regional Coastal Environment Plan MHWS boundary for Canterbury:

$$\mathbf{MHWS_{Ecan} = M_2 + N_2 + MLOS}$$

Where:

- *N_2 is the lunar elliptic semi-diurnal tidal constituent – the effect on the ocean of the elliptic orbit of the Moon, and*
- *MLOS is the Mean Level Of the Sea, or MSL) over a 19-year tidal epoch (i.e. the full range of tidal levels occurs over an 18.6 year cycle).*

For Canterbury, the MHWS tide represents the mean of the expected four weekly maximum tides, which can be interpreted as being the maximum level of permanent seawater inundation.

The height of these tidal reference water levels relative to other tidal water levels are shown in Figure 3.

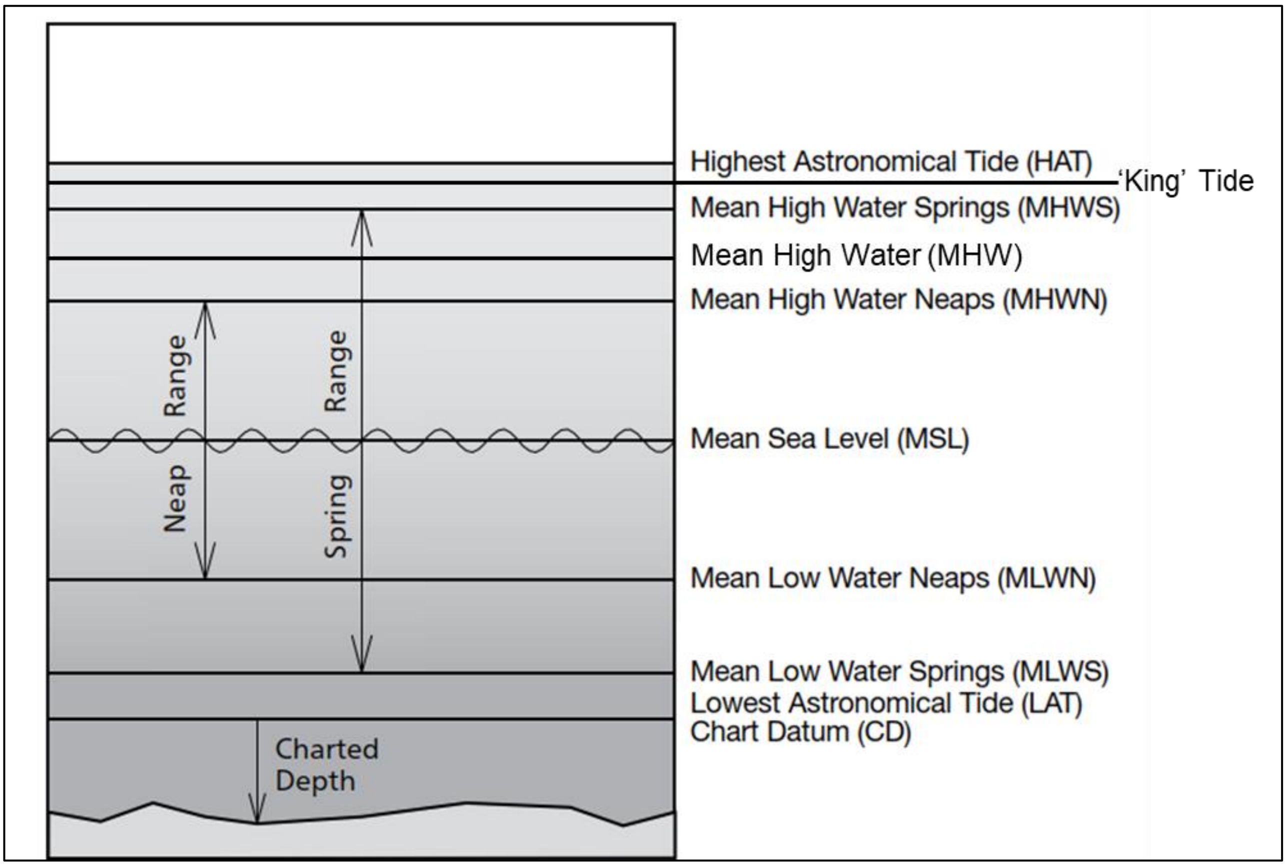


Figure 3: Relative heights of tidal reference levels (Adapted from LINZ 2024; NZ Nautical Almanac 2024/25).

The above tidal levels also vary spatially around the coast due to varying spatial contribution of the tidal harmonics to the high tide sea levels, and the distortion of the tide as it propagates into a shallow estuary or river mouth. For example, Stephens (et al) 2015 presented data showing the contribution of the M_2 harmonic varies by 0.22 m across the Canterbury region, and the contribution of the N_2 harmonic by 0.04m. Therefore, spatial variations in the reference tidal levels around the Christchurch District coast have been investigated as part of this project to give the most accurate definition of the reference water levels possible across the district.

The methodology for the definition of tidal reference water levels involved a review of all existing information of Christchurch District tidal water levels to determine the most appropriate MHW and MHWS levels across the district including the Pegasus Bay open coast of Christchurch City, the Avon-Heathcote Estuary, Brooklands Lagoon, Lyttelton Harbour, Akaroa Harbour, and the Outer Banks Peninsula. The review included the following references, and is presented in Section 3:

- Stephens (et al) 2015; Storm-tides and wave runup in the Canterbury Region. Report prepared for Environment Canterbury.
- Mulgor Consulting Ltd 2017; MHWS in the Avon-Heathcote Estuary/Ihutai. Report prepared for Environment Canterbury.
- Mulgor Consulting Ltd 2018; Extreme sea levels at Christchurch Sites: EV1 Analysis. Report prepared for CCC.
- GHD 2021; LDRP097 Multi-hazard Baseline Modelling – Joint risks of Pluvial and Tidal Flooding. Report prepared for CCC.
- Tonkin & Taylor 2021; Coastal Hazards Assessment for Christchurch District. Report prepared for CCC.

- LINZ Tidal predictions (https://www.linz.govt.nz/products-services/tides-and-tidal-streams/tide-predictions)
- LINZ 2024; NZ Nautical Almanac 2024/25.
- LINZ 2025 NZ Coastline – Mean High Water Springs – Pilot (https://data.linz.govt.nz/layer/121390-nz-coastline-mean-high-water-springs-pilot/)
- NIWA 2025; Sumner Sea Level Station Biennial Report 2023-2024
- Recorded high water levels from tide gauges at Sumner, Lyttelton Port, Styx tidal gates, the Aon-Heathcote Estuary (Bridge St & Ferrymead Bridge) and Akaroa provided by Graham Harrington, CCC,

However, the above information revealed very little information on the MHW elevation. As a result the method for determining the MHW elevation involved calculating the mean of all predicted semi diurnal high tide levels from 2023 to 2027 that can be downloaded from the LINZ online tidal prediction database. Specifically, using data from New Brighton Pier, Sumner Head, Lyttelton and Akaroa. While it is recognised that this dataset does not cover a full a 19-year tidal epoch, and therefore may have a small bias in the data, it is the full limit of the digital data available via the LINZ database.

The Scope of Works for this mapping required that all tidal water levels are presented in NZVD2016. For a number of the above references this involved converting the water level data from local datums including Lyttelton Port Chart Datum (CD), Lyttelton Vertical Datum (LVD1937), and Christchurch Drainage Datum (CDD). An example of the relationship between datums for Akaroa is presented in Figure 4.

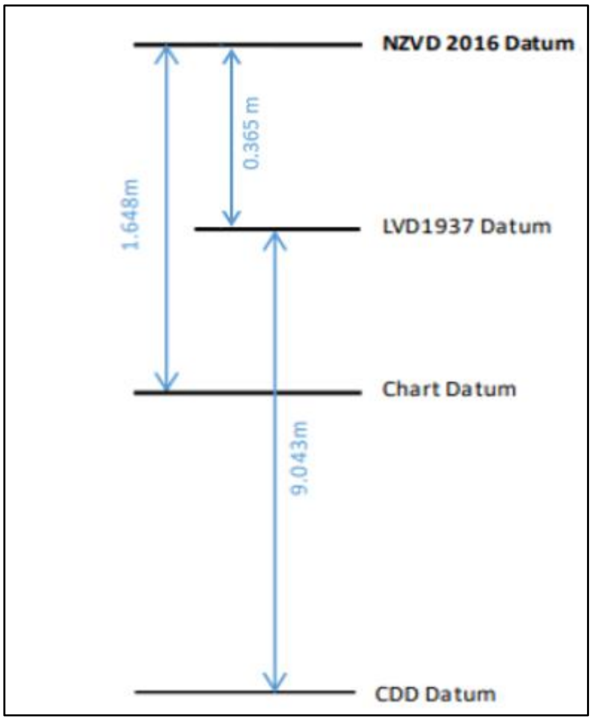


Figure 4: Relationship between commonly used vertical datums for Akaroa. Source: modified from Tonkin & Taylor (2021). Note the conversion to NZVD2016 is site specific to Akaroa, and will vary slightly for other locations.

The relationship between the CDD, CD, and LVD1937 datum are the same across the whole district. However, due to NZVD2016 being a Geoid based datum, the conversion to be applied to the local datums to obtain NZVD2016 elevations varies spatially by a small magnitude. Presented for Table 1 is the conversion from LVD1937 to NZVD2016 provided by LINZ Lyttelton 1937 to NZVD2016 Conversion | LINZ Data Service for nodes closest to key coastal locations across the Christchurch District. As can be seen in this table, these conversions vary by 42 mm across the coastline of the district, with no particular spatial pattern to the variations.

Table 1: Conversions from LVD1937 to NZVD2016. Source: LINZ Lyttelton 1937 to NZVD2016 Conversion | LINZ Data Service.

Site	Conversion LVD1937 to NZVD2016	Notes
Brooklands Lagoon	0.363 m	Same for all nodes around lagoon
New Brighton	0.368 m	Node on beach. Landward node conversion = 0.357 m
South shore	0.346 m	Node on estuary edge of Brighton Spit. Nearshore node conversion = 0.368 m
Sumner	0.388 m	Node in nearshore. Landward node conversion = 0.35 m
Lyttelton Port	0.378 m	Node at Port.
Teddington	0.38 m	Node on land.
Diamond Harbour	0.385	Node on land
Pigeon Bay	0.37 m	Node over water at Middle of Bay
Okains & Le Bons Bays	0.366 m	Note on land at head of bays
Akaroa	0.365 m	Node on land in Children's Bay
Birdlings Flat	0.359 m	Node in nearshore. Node on Lake Waihora edge = 0.358

It is important to note that on occasions higher levels of 'sunny day flooding' can occur around the district than what has been mapped, for the following reasons:

- The tidal reference levels mapped are 'means' of either all high tides (MHW) or spring tides (MHWS), and so water levels above these 'means' should be expected.
- 'King Tide' events, which are the highest monthly perigean tides that occur once or twice a year when the earth is closest to the Sun, so the S_2 component of tides is greater. Based on the LINZ tidal predictions, these extreme annual tidal predictions are generally 0.1 m higher than the $MHWS_{ECan}$ level, and a maximum of 0.2 m higher at HAT (Highest Astronomical Tide) over the 18.6 year tidal cycle.
- Longer-term sea level variability can affect the Mean Level Of the Sea (MLOS), such as seasonal climatic fluctuations such as El Nino-Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO).
- Meteorological impacts (e.g. storm surge), and wave set-up which increase observed sea levels at the shore. These impacts out of scope for this assessment, as they are included in the Tonkin & Taylor (2021) CHA used to map coastal flooding in the Christchurch City Council Coastal Hazards Portal.

2.3 Sea level rise increments

The Tonkin and Taylor (2021) CHA followed the MfE (2017) guidance, which recommends either use of sea level rise scenarios, or adoption of increments of sea level rise to inform adaptation planning. The CHA used increments of sea level rise which aligned approximately with the range of sea level rise scenarios up to 2150 from IPCC (2014).

The sea level rise increments adopted in the CHA, and used for this assessment, are:

- 0 m ('Current day' 2020 conditions)
- +0.2 m
- +0.4 m
- +0.6 m
- +0.8 m
- +1.0 m
- +1.2 m
- +1.5 m
- +2.0 m

Since the time of the Tonkin and Taylor (2021) assessment, new information on SLR projections has become available from the most recent IPCC (2021) report, and the development of the NZSeaRise platform (https://www.searise.nz), which combines the IPCC (2021) sea-level data (downscaled to Aotearoa) with localised rates of averaged VLM at 2 km spacings along the coastline.

The comparison of these increments to the five SLR scenarios presented on the NZSeaRise platform (excluding VLM) are shown in Figure 5. Generally, without VLM, the increments still show good alignment to the range of medium confidence SSP-RCP scenarios to 2150 now being used. These sea level rise increments are added to present day MHW and MHWS water levels to represent future daily and monthly tidal flooding under the range of climate change scenarios and timeframes to understand how the hazard may change over the next 100+ years.

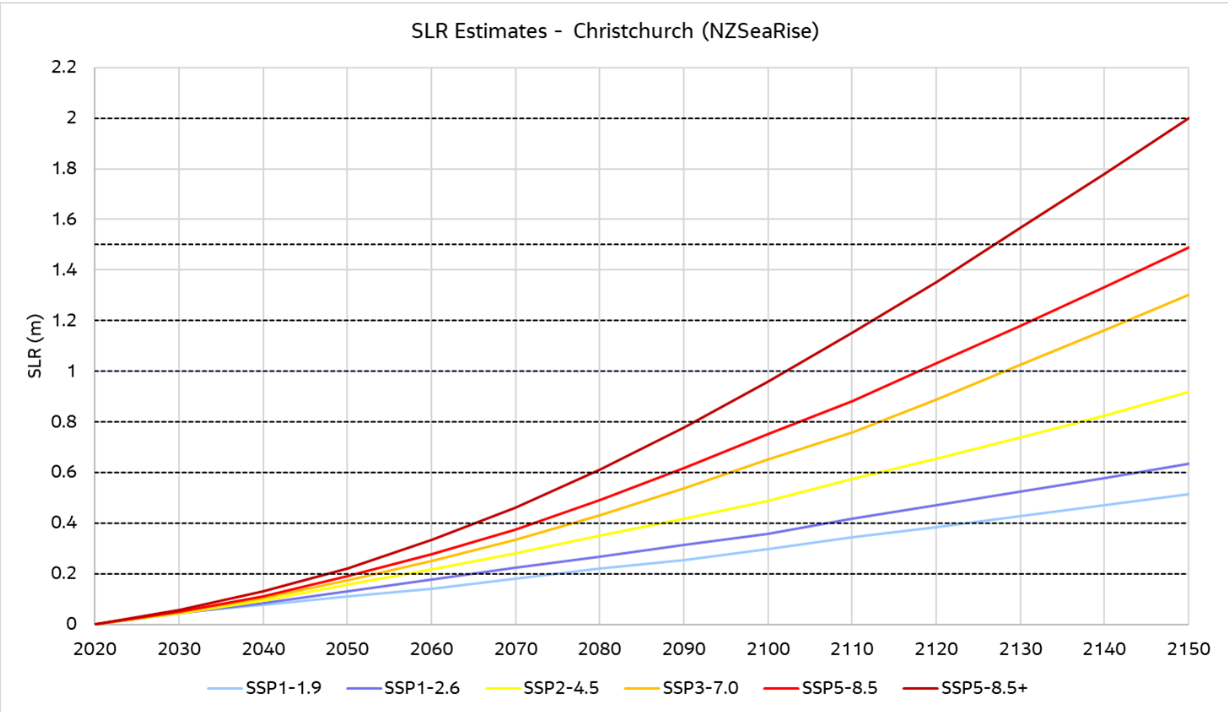


Figure 5: SSP-RCP Scenarios from NZSeaRise relative to Christchurch District. Increments of SLR used in this assessment show as dotted black lines.

2.3.1 Vertical land movement

Relative sea level rise estimates account for the amount of sea level rise that is likely to occur relative to the surrounding land, which may be subsiding, uplifting, or stable. The estimates of absolute sea level rise given in Section 2.3 assume that the land now and in the future is stable. For land that is subsiding, estimates of relative sea level rise will be higher (or realised sooner) than absolute sea level rise. Conversely, for uplifting land, relative sea level rise estimates will be less (or realised later) than absolute sea level rise.

NZSeaRise data suggests that local vertical land movement across Christchurch City consists of generally low rates of subsidence to low rates of uplift. However, the underlying data for the platform is based on satellite data that pre-dates the Canterbury Earthquake Sequence (CES) in 2010-2011, and therefore is not inclusive of the changes in post-seismic rates which are known to have occurred following the CES (Otago University, 2022)[1]. Ministry for the Environment (2024)[2] recognises that one of the biggest uncertainties in calculating Relative Sea Level Rise (RSLR) projections is local VLM, and acknowledges that *Independently determining locally measured VLM rates may also be relevant for Christchurch, North Canterbury and Kaikōura, once monitoring establishes a consistent post-earthquake trend in VLM.*

To further understand post-CES VLM rates across the district, CCC commissioned additional analysis by GNS to understand what more recent rates of VLM are at a district-wide scale, and to understand what the variability in these rates may be in the future. This analysis further highlighted the variability in VLM rates both spatially across the district, and also through time, in both pre- and post-CES.

Further work is being undertaken by CCC and GNS to understand in higher resolution the VLM rates across the Christchurch and Banks Peninsula District, and to determine whether and how this data can be incorporated into future assessments. For this assessment, no further analysis or application of the VLM data from previous studies has been applied. When using the geospatial data for site specific assessments, further consideration should be had for the timeframes at which the SLR increment would be realised when taking into consideration VLM.

2.4 LiDAR data

The Canterbury LiDAR 1m DEM (2020-2025) dataset available from LINZ Data Service was used for this assessment. This dataset contains the DEM for the Canterbury Region from LiDAR captured between 1 May 2020 and 22 April 2024. This dataset utilises the surveys captured for Christchurch City and Lyttelton Harbour (2020-2021), and Banks Peninsula (2023).

The datum of the DEM and outputs of this project are in NZVD2016.

2.5 Mapping of tidal water levels

In line with the Tonkin and Taylor (2021) CHA, a bathtub approach has been applied to identify the extent of tidal flooding in the district with sea level rise. The bathtub approach assumes that all land below the tidal reference level will be flooded.

As noted in Section 2.1, a water level for each tidal reference (MHW and MHWS) is assigned to each of the 13 inundation cells, which is then used to undertake the bathtub mapping. The tidal references used for the mapping are presented in Table 2 (MHW) and Table 3 (MHWS) below. A detailed review and analysis for how these water levels were defined is presented in Section 3.

Table 2: Mean High Water (MHW) level defined for each inundation cell used in this study for present day (0m SLR) and with SLR.

Inundation Cell	MHW levels with Sea Level Rise (m)								
	0 m SLR	0.2 m SLR	0.4 m SLR	0.6 m SLR	0.8 m SLR	1 m SLR	1.2 m SLR	1.5 m SLR	2 m SLR
Brooklands Lagoon	0.66	0.86	1.06	1.26	1.46	1.66	1.86	2.16	2.66
Christchurch Open Coast	0.50	0.70	0.90	1.10	1.30	1.50	1.70	2.00	2.50

[1] School of Surveying, Otago University (2022). Christchurch City Ground Height Monitoring. Vertical land motion in Eastern Christchurch. Report to Environment Canterbury.

[2] Ministry for the Environment (2024). Coastal hazards and climate change guidance.

Avon-Heathcote Estuary North	0.54	0.74	0.94	1.14	1.34	1.54	1.74	2.04	2.54
Avon-Heathcote Estuary South	0.54	0.74	0.94	1.14	1.34	1.54	1.74	2.04	2.54
Sumner	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Taylors Mistake	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Lyttleton Harbour	0.63	0.83	1.03	1.23	1.43	1.63	1.83	2.13	2.63
Banks Peninsula North	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Banks Peninsula South	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Akaroa Harbour	0.74	0.94	1.14	1.34	1.54	1.74	1.94	2.24	2.74
Lake Forsyth	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Kaitorete Spit	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52
Lake Ellesmere	0.52	0.72	0.92	1.12	1.32	1.52	1.72	2.02	2.52

Table 3: Mean High Water Spring (MHWS) level defined for each inundation cell used in this study for present day (0m SLR) and with SLR.

Inundation Cell	MHWS levels with Sea Level Rise (m)								
	0 m SLR	0.2 m SLR	0.4 m SLR	0.6 m SLR	0.8 m SLR	1 m SLR	1.2 m SLR	1.5 m SLR	2 m SLR
Brooklands Lagoon	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.50	3.00
Christchurch Open Coast	0.88	1.08	1.28	1.48	1.68	1.88	2.08	2.38	2.88
Avon-Heathcote Estuary North	0.87	1.07	1.27	1.47	1.67	1.87	2.07	2.37	2.87
Avon-Heathcote Estuary South	0.87	1.07	1.27	1.47	1.67	1.87	2.07	2.37	2.87
Sumner	0.86	1.06	1.26	1.46	1.66	1.86	2.06	2.36	2.86
Taylors Mistake	0.86	1.06	1.26	1.46	1.66	1.86	2.06	2.36	2.86
Lyttleton Harbour	0.92	1.12	1.32	1.52	1.72	1.92	2.12	2.42	2.92
Banks Peninsula North	0.86	1.06	1.26	1.46	1.66	1.86	2.06	2.36	2.86
Banks Peninsula South	0.86	1.06	1.26	1.46	1.66	1.86	2.06	2.36	2.86
Akaroa Harbour	1.05	1.25	1.45	1.65	1.85	2.05	2.25	2.55	3.05
Lake Forsyth	0.83	1.03	1.23	1.43	1.63	1.83	2.03	2.33	2.83
Kaitorete Spit	0.83	1.03	1.23	1.43	1.63	1.83	2.03	2.33	2.83
Lake Ellesmere	0.83	1.03	1.23	1.43	1.63	1.83	2.03	2.33	2.83

The mapping outputs identify two different ‘types’ of flooding:

- Areas of ‘connected’ flooding in varying shade of blue. These are areas where flooding has a direct pathway (connection) to the sea; and
- Areas of ‘disconnected’ flooding in varying shades of green. There are areas where land elevation is lower than the tidal water level, however there is not a direct pathway (connection) to the sea. It is noted that these areas could be connected via underground stormwater networks . Similarly, due to being such low elevation, could be impacted by groundwater. Areas of disconnected flooding could become connected over time as sea levels rise, and these higher water levels are able to overtop or breach the land and create new pathways for direct flooding.

Mapping of flooded areas has been undertaken at a 5 m resolution for consistency with the CHA. The seaward limit of the mapped flood area is confined to the position of present day MSL (taken as -0.15 m NZVD2016). It is noted that this position may differ from the Tonkin and Taylor (2021) CHA, for which it is assumed that the seaward limit was taken as the present day MHWS. However, for this assessment we are interested in tidal reference positions including and lower than MHWS, and therefore it was necessary to adopt MSL as the seaward limit.

Flooding is shown for areas above MSL, and geomorphic features within waterbodies that were above MSL (e.g. channels and associated bars in the Avon-Heathcote Estuary) were removed. The waterbodies of Lake Wairewa (Lake Forsyth) and Te Waihora (Lake Ellesmere) were manually removed using 1:50,000 Topomap Lakes, Ponds and Rivers Polygon available via ECan's Public MapServer. These were manually removed due to the LiDAR information reporting what appears to be water levels rather than bathymetry levels of the lake, and therefore for consistency with the rest of the district the water bodies were removed.

For consistency with the outputs of the CHA, flooding around Te Waihora and Lake Wairewa has been included in this assessment. However, it is important to note that there is generally no tidal influence in these areas due to Te Waihora being closed (and occasionally artificially opened).

The GIS outputs of this mapping have been provided to CCC as a series of rasters of classified depth data which can be used on the Coastal Hazards Portal, and similar spatial platforms. Classification of the depth data relating to the raster data is shown in Table 4, as well as symbology for the different depth categories presented in the Maps in Appendix C.

Table 4: Symbology and classification for connected and disconnected flooding.

Connected Flooding			Disconnected Flooding		
Symbol	ID	Flooding Depth	Symbol	ID	Flooding Depth
	2	0.0 – 0.2 m		1	0.0 – 0.2 m
	4	0.2 – 0.5 m		3	0.2 – 0.5 m
	6	0.5 – 1.0 m		5	0.5 – 1.0 m
	8	More than 1.0 m		7	More than 1.0 m

2.6 Mapping limitations

The mapping outputs produced for this project were developed using a 'bathtub' approach, which can be considered a conservative estimate of where flooding may be in the future, as it does not take into account the variation of water levels and volumes over a tidal cycle.

Additionally, the mapping assumes flooding with SLR against present day geomorphology and structures. This may under-estimate the flood risk to areas that are currently protected by dunes or structures. In the future, dunes may erode and no longer provide protection, creating pathways from the sea into low lying areas. Similarly, protection structures that currently are in place may not be re-consented (or maintained) at the end of their design life; or conversely, protection structures that have not been built yet or were not captured in the underlying LiDAR data used to inform the mapping (e.g. Avon River Stopbanks) may provide a greater level of protection than what is mapped, which could result in flooding being disconnected rather than connected.

3. Review of Tidal Reference Water Levels

3.1 Review of Existing Information

The purpose of this information review is to define appropriate current day water levels for MHW and MHWS tidal levels and the spatial variations in these levels across the Christchurch District. The following reviews are presented from the more generic and general information (e.g. district-wide) to the more site-specific (e.g. tide gauges) information to define the tidal reference water levels for sites within the Christchurch district. Section 3.2 provides a summary of the key takeaways described in Section 3.1.

3.1.1 Stephens et al (2015) Storm tides and Wave run-up

This report and the accompanying Coastal Calculator worksheets present information on MSL (used interchangeably with MLOS in this report) in relation to LVD1937, and MHWS values for 19 open coast locations in Canterbury including 7 in the Christchurch City District.

The report defines MSL for a number of epochs since the 1937 base date for the LVD (e.g. MSL = 0 m LVD1937) based on levels from the Lyttelton tide gauge. Within this current study, these MSL values can be used as estimates of the MLOS value in the $MHWS_{ECan}$ calculation. The two most relevant epochs and MSL values for this study are:

- The 1993-2012 epoch, being the most recent 18.6 year tidal epoch at the time, with a MSL of +0.165 m LVD1937, and
- The 2003-2012 epoch, being the most recent decade, with a MSL of +0.189 m LVD1937.

The report notes that the analysis did not calculate MSL post 2012 due to uncertain effects of the Canterbury earthquake sequence on the Lyttelton gauge.

The report also gives the values of the M_2, S_2 and N_2 tidal constituents, and the elevation of the $MHWS_n$ ($M_2 + S_2$), MHWPS (Perigean; $M_2 + S_2 + N_2$), and $MHWS_{10}$ (elevation exceeded by 10% of the high tides) in terms of the LVD1937 datum for seven sites within the Christchurch City District. This information is reproduced in Table 5.

Table 5: Tidal Constituents and MHWS Elevations for Christchurch City District sites from Stephens (et al) 2015. Elevations are relative to MSL, so require a MLOS value to be relative to other vertical datums (e.g. LVD1937, NZVD2016).

Site	M_2	S_2	N_2	$MHWS_n$	MHWPS	MHWS10
Waimairi Beach	0.83	0.05	0.19	0.88	1.07	1.07
New Brighton	0.83	0.05	0.19	0.88	1.07	1.07
South New Brighton	0.84	0.05	0.19	0.89	1.07	1.07
Sumner	0.84	0.05	0.19	0.89	1.07	1.07
Taylors Mistake	0.84	0.05	0.19	0.89	1.07	1.07
Lyttelton gauge	0.87	0.06	0.19	0.92	1.12	1.11
Birdlings Flat	0.81	0.08	0.18	0.89	1.08	1.05

The difference between the $MHWS_n$ and MHWPS elevations at each site in the Christchurch City District is 0.18 – 0.20 m, being the influence of the N_2 tidal constituent. The MHWPS and the MHWS10 elevations are very similar, which the report infers is a similar frequency as $MHWS_n$ for other New Zealand sites, and is therefore a good estimate for MHWS in Canterbury.

The elevations in the table do not include any offset for MLOS, or a calculated level of $M_2 + N_2$, therefore none of the MHWS levels are the same as $MHWS_{ECan}$. However, putting aside the MLOS offset, the MHWPS elevations will be similar, but slightly higher than $MHWS_{ECan}$ due to the inclusion of the very low S_2 values (0.05 – 0.08 m).

The results also show negligible spatial variation in the MHWS values for the open coast sites due to very similar M_2 and N_2 values across the district, with only the Lyttelton Harbour gauge site having a slightly higher level (0.05 m) due to a greater M_2 tidal constituent contribution.

3.1.2 Mulgor (2017) MHWS in the Avon-Heathcote Estuary/Ihutai

This report explains calculation of MHWS in Canterbury as defined by the Regional Coastal Environment Plan (RCEP), however notes that the MLOS component is calculated only over the last 12 month period, and may vary from year to year by up to ± 40 mm depending on whether El Nino or La Nina conditions are dominant. More importantly, the report points out that while these predictions are relevant for the open coast, there is difficulty when the tide propagates into a shallow estuary or river mouths due to the shape of the tide wave being distorted as a result of friction with the bed, such that the assumption of the tide being a linear combination of individual sinusoidal waves becomes invalid. This distortion of the estuary tide levels is shown in Figure 6, with a higher high tide and a lower low tide due to backwater effects from the narrow estuary entrance (where the rising tide pushes against the natural flow of the river and estuary, causing flow to slow and water levels upstream to rise).

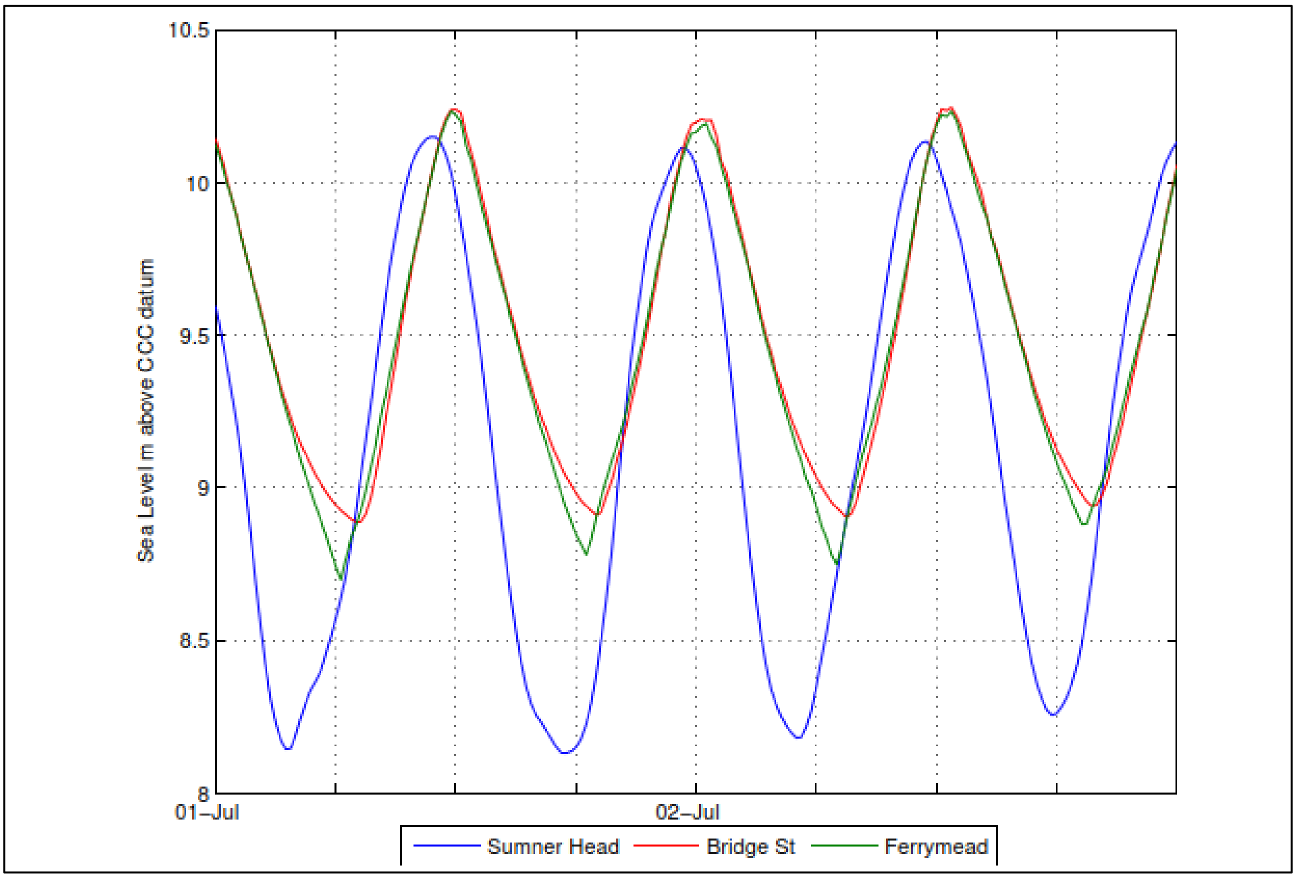


Figure 6: Comparison of Sumner Head tides to Bridge St and Ferrymead tides in the Avon-Heathcote Estuary Tides. Source: Mulgor (2017).

The report points out that this makes tidal analysis of the Bridge St and Ferrymead records within the Avon-Heathcote Estuary problematic, as it is not possible to just extrapolate the M_2 and N_2 tides from Sumner, hence an alternative method for calculating MHWS is required. Therefore, the report recommended that for the estuary a "pragmatic MHWS (PMHWS)" be applied, which involved the following steps in the calculation:

1. Remove the effects of storm surge from the Sumner sea level records (June 1994 to June 2017),
2. Calculate the MLOS over the 23 years of record. Calculated to be 0.133 m LVD1937.
3. Calculate the percentage of residual high tides at Sumner than exceeded $MWHS_{ECAN}$ (M_2 +N_2 + MLOS = 1.159 m LVD1937), which was calculated to be 13.4% of high tides.

Apply this percentage to the distribution of high tides for Bridge St and Ferrymead to obtain the PMHWS for these estuary sites. There was consideration of the effect of river flood flows on the estuary high tide levels, but these flows were found to only slightly affect the high tide levels during large flood events, and only for one high tide. The resulting $MWHS_{ECAN}$ levels for Sumner, Bridge St and Ferrymead are given in

4. Table 6.

It is noted that Sumner M_2 + N_2 value in the Table would be 1.026 m, which is the same (to 2 decimal places) as given by Stephens et al. (2015).

Table 6: $MHWS_{ECan}$ at Sumner Head open coast recorder compared to Bridge St and Ferrymead recorders in the Estuary. Source: Mulgor (2017).

Site	MHWS in CDD (m)	MHWS in LVD1937 (m)	Basis
Sumner Head	10.202	1.159	MLOS + M_2 + N_2
Bridge St	10.257	1.214	13.4% exceedance
Ferrymead	10.247	1.204	13.4% exceedance

Of relevance to this current study are the following report conclusions:

- Year to year variations in MLOS are in the order of ± 10 cm.
- $MHWS_{ECan}$ calculated by MLOS + M_2 + N_2 is not appropriate for the Avon-Heathcote Estuary because of the hydraulic effects on the tide as it propagates into the estuary (alternative approach presented in Section 3.2.2.2 using recorded water levels and subtracting potential meteorological effects).
- MHWS levels in the estuary are in the order of 5 cm higher than at Sumner Head.
- MHWS levels at Bridge St and Ferrymead are only 1 cm different, which is the limit of accuracy of the calculations, and therefore either could be used for the entire estuary.

The report also presents an elevation above MLOS for MHW at Sumner Head from the 23 years of reporting, being 0.834 m (above MLOS), which is exceeded by 48.4% of all high tides. However, it is unclear whether this level has been filtered for storm surge effects or not.

3.1.3 Mulgor (2018) Extreme Sea Levels at Christchurch Sites: EV1 Analysis

This report is concerned with the calculation of extreme sea levels at Sumner Head and Avon-Heathcote Estuary sites, which includes the contribution of meteorological storm surge to extreme levels. The report does not include any references or data on either MHWS or MHW levels, so is not relevant to this review.

3.1.4 GHD (2021) Joint Risks of Pluvial and Tidal Flooding

As with the above report, this report is primarily concerned with extreme water levels at Sumner Head, Lyttelton, and within the Avon-Heathcote estuary. The report updates and supersedes the analysis presented in Mulgor (2018) but does not include any direct references or data on either MHWS or MHW levels. However, the report does present the following information of relevance to defining MHWS elevation.

- The rate of relative SLR at Lyttelton has increased from about 2 mm/yr in the 1920-1990 period to in the range of 4-7 mm/yr from 1990 to 2020. This has consequences for the level of MLOS in the $MHWS_{ECan}$ calculation. The report also notes that the more recent rate of high tide sea level rise has been higher than the rate of MSL rise, implying that the tidal range is increasing, but further analysis would be required to validate and understand the cause of these differences.
- Within the Avon-Heathcote Estuary, tidal patterns between Ferrymead and Bridge St differ, particularly at low water due to shallow water effects, but are more consistent at high water.
- 46% of the differences in water levels between Bridge St and Ferrymead is due to wind effects, with 81 mm difference occurring in a 10m/s wind from the SSW direction.
- The amplitude of fitted tidal constituents (M_2, N_2) used in the calculation of $MHWS_{ECan}$ are given for Lyttelton and Sumner (from both NIWA & LINZ data) and compared to the values adapted from Mulgor (2018) for Sumner. The results are shown in Table 7, which indicate the following:

- The value of the fitted constituents (or Harmonics) at Sumner given by GHD (2021) and adapted from Mulgor (2018) are the essentially the same, and
- Assuming that MLOS is the same across both sites, $MHWS_{ECan}$ at Lyttelton should be in the order of 0.03 m higher than at Sumner, which is the same difference presented by Stephens et al (2015) as shown in Table 5 but less that the 0.1 m difference (to 1 dp) given in the LINZ tidal predictions as shown in Table 10.

Table 7: Amplitude of M_2 and N_2 Tidal Constituents for the calculation of $MHWS_{ECan}$ given in GHD 2021. Amplitudes given in metres.

	GHD (2021) Fitted Lyttelton[1] (m)	GHD (2021) Fitted Sumner[1] (m)	Mulgor (2018) Sumner (m)
M_2 constituent	0.856	0.831 – 0.834	0.834
N_2 Constituent	0.197	0.191 – 0.192	0.192
$M_2 + N_2$	1.053	1.022 – 1.026	1.026
[1]Includes both NIWA and LINZ data presented in GHD (2021).			

3.1.5 Tonkin & Taylor (2021) Coastal Hazards Assessment

This assessment gives the MHWS elevation at Lyttelton Port, Sumner, and Akaroa in NZVD 2016 as presented in Table 8, with the source of this information being given as LINZ (2021) online tidal information for cadastral and engineering purposes (which are analysed up to 2025 in Section 3.1.10). Based on the vertical datum conversion of the elevation given compared to the LINZ information presented below in Sections 3.1.8, 3.1.9, and 3.1.10, it is assumed that it is the latter (e.g. online tidal information for cadastral and engineering purposes). As with the LINZ data presented in the following sections, the calculation method for the MHWS elevation is not given but is assumed to be the standard $MHWS_n = M_2 + S_2$ formula rather than the more appropriate $M_2 + N_2$ for Canterbury.

Table 8: MHWS elevations given in Tonkin & Taylor (2021). Elevations are given in NZVD (2016).

Site	MHWS in NZVD2016 (m)
Sumner	0.76
Lyttelton Port	0.84
Akaroa	1.08

As noted in the report, and Table 8, there are spatial differences in the MHWS elevation, with Sumner being 0.08 m lower than at Lyttelton, and Akaroa 0.24 m higher, which the report suggests is likely to be as a result of tidal amplification in the harbour. Although these spatial variations are similar to those given in the LINZ secondary ports table presented as Table 10 (although to 2 decimal place rather than 1 decimal place), the difference between Lyttelton and Sumner is larger than the 0.03 m calculated by the respective tidal constituents (M_2, N_2) given in Stephens et al. (2015) and GHD (2021).

The report presents static and dynamic sea water inundation levels for the whole Christchurch City district, breaking the district into 13 output cells as previously presented in Figure 1. The report notes that for each area the inundation levels are dependent on the water level time series, the wave time series, and the surfzone/beachface slope, all of which vary from area to area. The water level time series is the storm tide series which includes water level variations from astronomical tides and storm surge, with information on the extreme water levels for Brooklands Lagoon, the Avon-Heathcote Estuary and Lyttelton Harbour being sourced from GHD (2021). The resulting extreme water levels are presented for ARI events from 1 year to 200 years.

Within this analysis of extreme water levels, the only references to MHWS were:

- To apply the MHWS offset between Lyttelton and Akaroa from Table 8 above (i.e. Akaroa being 0.24 m higher) to estimate extreme water levels in Akaroa, as these are not presented in GHD (2021).
- For the outer Banks Peninsula and Birdlings Flat, apply the same extreme water levels as Sumner on the basis that there is no MHWS offset across these areas based on the information presented in Stephens et al. (2015) (i.e. $MHWS_n$ level of 0.89 m above MSL across all of these areas as shown in Table 5 above).

3.1.6 NIWA (2025) Sumner Sea Level Station Biennial Report for 2023-2024

This report is part of a biennial series of reports that presents an analysis of the NIWA Sumner Head sea level recorder dataset, but also includes a table of the Annual Mean Sea Level (AMSL) for each year since the recorder site was established in 1996. A plot of this data is presented in Figure . MLOS is the parameter used in $MHWS_{ECan}$. Although this data includes meteorological impacts and climate cycles on the recorded water levels, the meteorological impacts are both positive and negative.

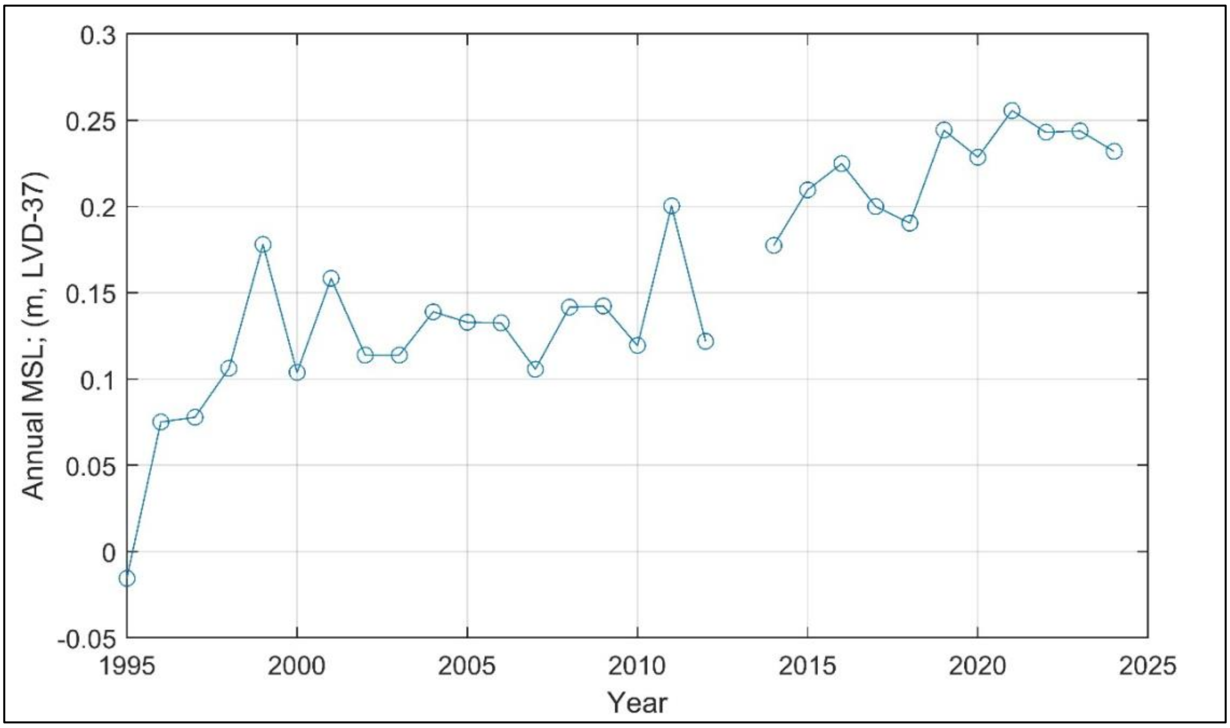


Figure 7: Annual MSL from the NIWA Sumner Head sea level gauge 1996-2024. Source: NIWA 2025.

The report notes a rapid rise in AMSL between 1996 and 1999, arising from the switch in the Interdecadal Pacific Oscillation (IPO) to the negative phase, and a rise in sea level in the past decade. The resulting average MSL relative to LVD1937 given in the report are:

- 2002 – 2024: 0.18 m
- Last 10 years (2015-2024): 0.23 m (LVD1937)
- 2023 and 2024: 0.24 m and 0.23 m respectively (LVD1937)

Although an increase in AMSL is identified in the record, the report notes that the record is too short to ascertain long-term SLR. However, the report considers that the long-term trends of SLR from Lyttelton would also apply to Sumner, which is given as being 1.33 ± 0.25 mm/yr from 1901 to 1960, doubling to 2.77 ± 0.20 mm/yr from 1960 to 2020 (60 years). We note that these rates of rise are around half of those reported in GHD (2021) for the 1990-2020 period, which is due to GHD (2021) using a more recent and shorter period (30 years) to derive the rate of SLR from.

The report also presents values of the peak amplitude of the peak mean sea level anomaly (MSLA) and the peak storm surge elevation for each year since the water level records started (1995). The resulting mean peak anomaly over the 30-year period (1995-2024) was 0.041 m, and the mean annual peak surge over the same period was 0.36 m. However, since these levels are peak values from storm events, it is not possible to extrapolate average meteorological impacts on tide levels from this data set.

3.1.7 CCC Survey Team (2025) Determination of MHWS and CMA boundary – Avon Estuary

This report sets out a practical methodology for the determination of the MHWS position in the estuary based on site evidence of the location of estuary banks, vegetation and debris lines. The methodology includes reference to a theoretical elevation of MHWS provided by Graham Harrington (CCC) based on 5 years (2018-2023) of recorded estuary spring tide levels at Bridge St. This level is given as:

- 10.53 m CDD, or
- 1.13 m NZVD2016.

Further review of these recorded levels is provided in Section 3.1.12.

3.1.8 LINZ Tidal Predictions

This online resource ((https://www.linz.govt.nz/products-services/tides-and-tidal-streams/tide-predictions) provides links to the daily time and height tidal predictions from 2023 to 2027 for standard and secondary ports throughout New Zealand. Within the Christchurch City District this includes daily predictions for Lyttelton (Standard Port), New Brighton Pier, Sumner Head, and Akaroa. These height predictions are in terms of Lyttleton Port Chart Datum. Although these online data sets do not cover a full a 19-year tidal epoch, calculating the mean of all predicted semi diurnal high tide levels over the 5-year period available provides an appropriate approximation of the MHW elevation that is not biased by any meteorological effects.

The results of this analysis are presented in Table 9 which shows very small annual variations in the order of 1 cm in the MHW elevation at all sites, but larger variations between sites in the $MHW_{2023-27}$ elevation, with Akaroa being 10 cm higher than Lyttelton, which in turn is 10-14 cm higher than the Sumner and New Brighton open coast sites. These differences in tidal elevations are due to the effect of the harbour geometry and bathymetry on tidal propagation (e.g. tidal set-up in the harbour basins). These effects are likely to be greater for the Avon-Heathcote Estuary than the harbour environments due to greater friction and backwater effects from shallower water depths and a narrower inlet entrance, leading to greater tidal amplification.

Table 9: MHW levels from LINZ tidal predictions 2023 - 2027 at Christchurch City District sites 2023. All elevations are in terms of Lyttelton Chart Datum.

Site	2023	2024	2025	2026	2027	Average
New Brighton Pier	2.148	2.151	2.150	2.158	2.158	**2.153**
Sumner Head	2.188	2.186	2.188	2.197	2.196	**2.191**

Lyttelton	2.289	2.288	2.289	2.297	2.297	**2.292**
Akaroa	2.382	2.388	2.392	2.401	2.398	**2.392**
Average by Year	**2.251**	**2.253**	**2.255**	**2.263**	**2.262**	**2.257**

The LINZ 'New Zealand secondary ports table' provides information on the spring and neap MHW and MLW levels and MSL for the above sites plus, Purau, Le Bons Bay, Tikao Bay and Te Oka Bay within the Banks Peninsula. This information is summarised in Table 10.

Table 10: LINZ Secondary Port Table for Christchurch City District sites. All elevations are in terms of Lyttelton Chart Datum.

Site	MHWS	MHWN	MLWN	MLWS	MSL
Lyttelton	2.5	2.0	0.8	0.3	1.45
New Brighton Pier	2.4	1.9	0.8	0.3	1.3
Sumner Head	2.4	2.0	0.7	0.3	1.3
Purau	2.6	2.1	0.8	0.3	1.5
Le Bons Bay	2.5	2.1	0.9	0.4	1.5
Akaroa	2.7	2.1	0.9	0.4	1.5
Tikao Bay	2.6	2.2	0.9	0.6	1.5
Te Oka Bay	2.3	1.9	0.7	0.4	1.4

LINZ MHWS elevations are calculated from the standard $MHWS_n = M_2 + S_2$ formula, and therefore may not be relevant for this mapping project (where $MHWS_{ECan} = M_2 + N_2 + MLOS$). However, the results do show the spatial variability in the elevation of this reference level, having a range of 0.4 m across the Christchurch City District, with the highest MHWS elevations being in Lyttelton and Akaroa Harbours, and the least being at Te Oka Bay on the southern side of Banks Peninsula near to Birdlings Flat.

3.1.9 LINZ (2024) NZ Nautical Almanac 2024/25

This source provides the same daily tidal predictions for all 'NZ standard ports', including Lyttelton, from July 2024 to June 2025, and the secondary ports table as available from the LINZ online tidal predictions portal. The publication also provides useful information of the definitions and calculation of tidal levels and provides the following information in Table 11 on Lyttelton tidal levels at a greater accuracy than the online prediction (i.e. to 2 decimal places as opposed to 1 decimal place).

Table 11: LINZ tidal data for Lyttelton Primary Port from the NZ Nautical Almanac 2024/25. All elevations are in terms of Lyttelton Chart Datum.

Standard Port Site	MHWS	MHWN	MLWN	MLWS	MSL	HAT	LAT
Lyttelton	2.58	2.04	0.81	0.34	1.45	2.75	0.14

The notes about the information include the following relevant points:

1. The values for MHWS, MHWN, MLWN, and MLWS are the average of the all spring and neap tides predicted in the period 1 July 2024 - 30 June 2025 using the harmonic constituents derived from the analysis of observations at the port over an 18.6 year period from 2004 to 2023.
2. The average annual value of MWHS etc varies from year to year in a cycle of approximately 18.6 years. This variation is in the order of 0.1 – 0.15 m.
3. The value of MSL has been derived from the analysis of tidal observations over an 18.6 year period from 2004 to 2023.
4. The values of HAT and LAT are the highest and lowest tidal levels predicted to occur in the period from 1 January 2000 to 31 December 2018.
5. The values in the table are not intended to be used for the determination of cadastral or administrative boundaries. A table of standard port values for cadastral purpose is available from the LINZ web site.

As with the LINZ tidal prediction information, it is assumed that the MHWS elevation is calculated from the standard $MHWS_n = M_2 + S_2$ formula, so may not be relevant for this mapping project ($MHWS_{ECan} = M_2 + N_2 + MLOS$).

3.1.10 LINZ Tidal Levels for Cadastral and Engineering Purposes

Following on from note 5 in Section 3.1.9 above, the LINZ website (Tidal level information for surveyors | Geodetic Guidance) gives the following tidal values for Lyttelton to be used for cadastral and engineering purposes. The values are calculated from tidal data from between 1 January 2000 to 31 December 2018.

Table 12: LINZ tidal data for Lyttelton to be used for cadastral and engineering purposes. All elevations are in terms of Lyttelton Chart Datum.

Standard Port Site	MHWS	MHWN	MLWN	MLWS	MSL	HAT	LAT
Lyttelton	2.49	2.05	0.65	0.27			

As with the above LINZ tidal prediction information, it is assumed that the MHWS elevation is calculated from the standard $MHWS_n = M_2 + S_2$ formula, so may not be relevant for this mapping project ($MHWS_{ECan} = M_2 + N_2 + MLOS$). However, what is noticeable from the data is that the value of MHWS calculated over the 18.6 year period (i.e. 2000 to 2018) is the same as given in the secondary ports table, but 0.09 m lower than the 2024-2025 MHWS value given in the latest nautical almanac, hence demonstrating the annual variability in tidal levels.

3.1.11 LINZ (2025) NZ Coastline – Mean High water springs – Pilot

This dataset defines the MHWS coastline of New Zealand and offshore islands (https://data.linz.govt.nz/layer/121390-nz-coastline-mean-high-water-springs-pilot/). It is a pilot dataset released while further refinements are being made to the dataset, and will supersede the MHW 2020 coastline. The primary elevation data used in the dataset for Canterbury is a 1-meter resolution DEM derived from LiDAR flown between 2020 -2023. The tidal information used in the dataset was computed in 2024 and uses primarily standard and secondary ports data, with MHWS being defined as the mean of high water at spring tides over a 12-month period.

Segments of the coastline are represented by the MHWS level from 19 Primary ports, with the southern part of the Christchurch City District, to the south of Le Bons Bay being represented by the MHWS level at Timaru, and the northern part (north of Le Bons Bay) being represented by the MHWS level at Lyttelton. The MHWS levels for these ports are given in the meta data as being:

- Timaru: 0.889 m (NZVD2016)
- Lyttelton: 0.932 m (NZVD2016)

From applying the vertical datum conversion given in Section 2.2, this Lyttelton MHWS elevation is the same as given in the Primary Port Table in the LINZ 2024/25 Nautical Almanac, but is 0.092 higher than the Lyttelton MHWS elevation given in Tonkin & Taylor (2021) (see Table 8).

As with the other LINZ MHWS values, the calculation method for defining this water level contour is not given, but is assumed to be calculated from the standard $MHWS_n = M_2 + S_2$ formula, rather than the $MHWS_{ECan}$ formula ($M_2 + N_2$ + MLOS), which is more relevant for Canterbury.

The accompanying data dictionary for the dataset includes an investigation of the differences between the MHWS and the MHWS-10 (e.g. MHWS exceeded by 10% of all high tides) evaluations over a year long period from the start of July 2022 to the end of June 2023 at 186 tide stations. The results of the investigation were that the differences were generally small, being an average of +0.015 m (e.g. MHWS above MHWS-10) with the greatest positive and negatives differences being +0.105m and -0.060m (e.g. MHWS below MHWS-10). It is unknown whether any of the sites used in this investigation were in Canterbury, but these results are contrary to the larger differences between MHWS and MHWS-10 for Canterbury reported in Stephens et al. (2015) and Mulgor (2017). The pilot dataset is of limited value to the current study due to the larger-scale approach adopted, and for the current study more localised sources of data have been relied upon to derive the MHW and MHWS levels across the district.

3.1.12 Harrington (Pers com) Recorded High Tide Water levels

As stated in Section 3.1.7, Graham Harrington (CCC) has previously calculated MHWS from recorded water levels at Bridge St in the Avon-Heathcote estuary between 2018 and 2023. This analysis also included additional water level recorder sites around the estuary (Ferrymead, Kerrs Reach), Brooklands Lagoon (Styx Tidegates), and Sumner Head, plus the calculation of the MHW level over the same 5-year period. For this current study, Graham Harrington extended the dataset for all sites to include data through until the beginning of May 2025, pushed the start of the Sumner, Styx and Kerrs Reach data back to the beginning of 2017, provided MHWS and MHW at Lyttelton Port from 2008 to May 2025, and for Akaroa for the November 2023 – March 2025 period (water level recorder not installed until 2023).

For the analysis, high tide levels were determined by a height filter on the full water record, and then further filtered for the high tide peaks, with only the absolute single peak tide within a cluster being assigned as the Monthly Spring Tide elevation. There was no attempt to align these peak tides to the phases of the moon, so individual peaks could be due to the influence of larger storm surge rather than true Spring Tides driven by the orbit of the moon. However, as shown by Figure 7, the majority of the identified peak tides line up well with the predicted spring tide dates from phases of the moon.

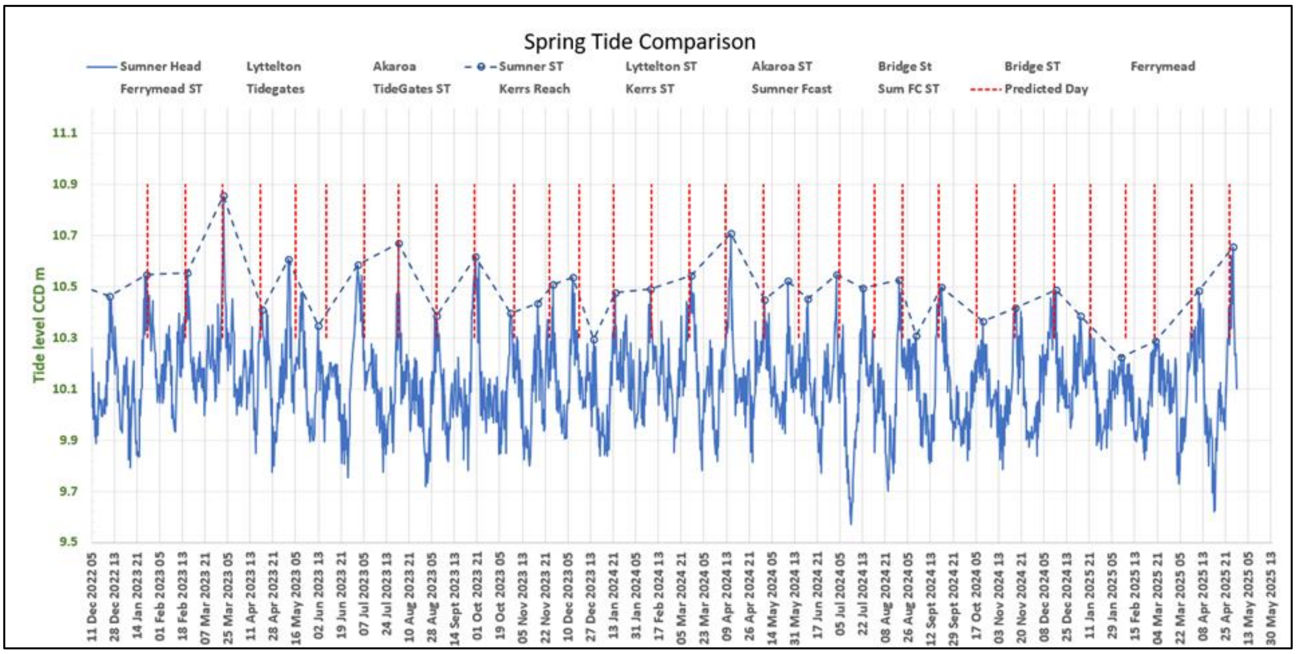


Figure 7: Comparison of Sumner Spring Tide dates for predicted tides v. filtered recorded peak tide heights from Harrington (pers com) 2025.

The results of this analysis are presented in Table 13. Although these recorded levels include meteorological influences on the high tide level and do not cover a full 18.6 year tidal range, they do provide an indication of the spatial variably in the reference levels due to estuary and inlet effects, which can be compared to the astronomical tidal predictions from LINZ (Section 3.1.8).

Table 13: Calculated MWHS and MHW levels from water level recorders. All elevations in terms of CDD. Source: Graham Harrington (CCC).

Site	Record Length	MHWS (CDD)	MHWS (NZVD2016)	MHW (CDD)	MHWS (NZVD2016)
Styx Tidegates	1/01/2017 – 7/05/2025	10.66	1.26	10.27	0.87
Ferrymead Bridge	1/12/2018 – 4/5/2018	10.52	1.13	10.14	0.76
Bridge St Bridge	1/12/2018 – 3/5/2025	10.50	1.11	10.13	0.74
Kerrs Reach PS205	1/01/2017 – 6/05/2025	10.47	1.08	10.11	0.72
Sumner Head	1/1/2017 – 4/5/2025	10.57	1.13	10.17	0.73
Lyttelton Port	10/12/2018 – 16/05/2025	10.60	1.17	10.21	0.79
Akaroa	31/10/2023 – 8/5/2025	10.42	1.01	10.08	0.67
Note: (1) levels are in terms of CDD.					

The results indicate that the elevation of MHWS is in the range of 0.34 m (Akaroa) to 0.39 m (Styx) higher than the MHW level, except for Kerr's Reach (0.64 m), which may be influenced by river level.

Notable spatial variations include:

- Lyttelton levels being higher than Sumner levels. This is similar to other analysis, but the difference is less than from LINZ tidal predictions and from T&T (2021).
- Sumner levels are slightly higher than Avon-Heathcote levels. While tidal amplification in the estuary leads to higher MHW and MHWS levels (as noted in other analysis), the recorded water levels indicate the meteorological effects on the open coast water levels are have more of an affect than the impacts of tidal amplification.
- Lyttelton Port levels are higher than Akaroa levels, which is contrary to the relationship between the site in the LINZ tidal predictions (Section 3.1.8). However, this may be due to the record being over different periods (the Akaroa dataset being particularly short).
- The tidal reference levels at the Styx tide gates are higher than any other site.

3.2 Conclusion of Tidal Reference Water Levels

The above review of reports and recorded water level data presents a range of estimates of levels of MHW and MHWS tidal reference levels across multiple elevation datums. In many cases, the analyses include meteorological effects that require understanding and unpicking if they are to be direct value to this study. The purpose of this section is to draw this information together into an appropriate estimate of each reference elevation in terms of NZVD (2016) for each inundation cell across the Christchurch City and Banks Peninsula district.

3.2.1 Mean High Water (MHW) Levels

3.2.1.1 Discussion

There are two types of data sources for MHW level, being the LINZ tidal predictions and the calculated means from the recorded water levels (Mulgor 2017, Harrington pers com (2025)). The comparative results from these sources normalised to NZVD2016 are presented in Table 14.

Table 14: Comparative levels of MHW in terms of NZVD2016 from multiple sources.

Site	LINZ Tidal Predictions (2023-2027)	Recorded Water Levels	
		Mulgor (2017) (1996-2017)	Harrington (pers com) (2017/18 - 2025)
Styx Tide gates			0.865
Ferrymead Bridge			0.755
Bridge St Bridge			0.739
New Brighton Pier	0.502		
Sumner Head	0.520	0.579	0.727
Lyttelton Port	0.631		0.790
Akaroa	0.744		0.671(2)

Note: (1) levels are in NZVD2016 and are based on the relationships between CDD, CD, and LVD1937 shown in Figure 2.2 and the conversions from LVD1937 to NZVD2016 given in Table 2.1.

(2) Akaroa recorded water levels are from 2023 to March 2025 due to recorder not established till 2023.

The key takeaways of MHW levels presented in Table 14 are as follows:

- For sites with both LINZ tidal predictions and recorded water levels, as expected the tidal predictions are less (except for Akaroa). Although the data sets do not totally overlap so are not directly comparable, the difference in levels is considered to be due to the influence of meteorological factors on the recorded high tide water levels. The difference in the MHW levels between recorded and predicted is 0.207 m at Sumner and 0.159 m at Lyttleton. For sensitivity testing purposes, a comparison of the predicted and recorded water levels for the 2 years period covered by both data sets was also undertaken. The resulting differences between the MHW from these datasets were only 10 mm lower, being 0.197 m for Sumner and 0.148 m for Lyttleton, indicating that there is general consistency in difference between the two data sources even over different records.
- The reverse pattern at Akaroa of higher tidal predictions than recorded levels was unexpected and the cause is not clear. Possibilities include the shorter record (less than 2 years), a lower meteorological impact at this site due to different orientation of the harbour opening (i.e. to the south rather than to the east), or other local measurement nuances relevant to its location at the Akaroa Yacht Club wharf. The difference in the MHW levels between recorded and predicted levels is also much smaller at Akaroa (-0.073 m).
- Based on the above interpretation, it is considered that the 2023-2027 LINZ tidal predictions are a better estimate of the MHW level for the sites where these predictions are available than the recorded water levels. This is due to the need to extract the meteorological component from the 'recorded water level', and the fact that this meteorological component varies across the district (between inundation cells). It is recognised that this data (2023-2027 LINZ tidal predictions) does not cover a full 19-year tidal epoch, which may alter these MHW estimates, however the differences are likely to be small, possibility in the order of 0.04 m based on the 30-year mean MSL anomaly presented in NIWA (2025).
- The spatial pattern of the tidal predictions shows a north to south increase in level. The southern two sites (Lyttelton and Akaroa) are harbour sites, where a higher MHW level is expected due to tidal set-up within the harbour. The predicted MHW level at Lyttelton is 0.111 m higher than at Sumner, and Akaroa is a further 0.113 m higher than Lyttelton.
- For recorded water levels, the MHW level at Lyttleton is also higher than Sumner, so the relativity is conserved, although with a smaller difference (0.063 m). However, as above, the relativity of the MHW level at Akaroa to the other two sites is reversed, with Akaroa having the lowest recorded MHW level.
- As expected, recorded MHW levels were higher in Brooklands Lagoon and the Estuary than the Christchurch open coast site at Sumner.
- The Mulgor (2017) MHW level for Sumner is based on the MLOS in 2017 (-0.255 m NZVD2016), so does not include the influence of SLR on MLOS over the last 7-8 years, and reportedly has the meteorological impacts removed. It is 0.057 m higher than the MHW from the tidal predictions 2023-2027. To take account of SLR since 2017, we recalculated using the NIWA (2025) MLOS value from 2002-2024, (-0.2 m NZVD2016), giving a MHW level of 0.634 m (NZVD2016), which is 0.114 m higher that MHW from the LINZ tidal predictions. Although not as high as the Harrington (2025) MHW from recorded water levels (2017-2025), it is not considered further as there is no way to verify the how the meteorological impacts have been removed, and whether it is consistent with the methods applied through this study.

3.2.1.2 MHW levels used in this assessment

The resulting MHW levels used in the mapping for this assessment are presented in Table 15 for the 13 coastal inundation cells. For cells without LINZ tidal predictions the following assumptions have been made to obtain MHW levels:

- For Brooklands Lagoon and the Avon-Heathcote Estuary, MHW level was estimated from the relationship between the tidal predictions and recorded water levels at Sumner (i.e difference of 0.207m). Sumner was chosen as the base site as considered to be more representative to meteorological impacts in the estuary and Brooklands Lagoon than Lyttelton. The resulting predicted tidal MHW levels (e.g. without meteorological impacts) for Brooklands Lagoon and the Estuary are:
  - Brooklands Lagoon: 0.658 m NZVD2016
  - Avon-Heathcote Estuary: 0.540 m NZVD2016 (taken as the mean of Bridge St and Ferrymead sites).

  These levels retain the relativity of the Brooklands Lagoon and Estuary tidal levels as being higher than the open coast sites (i.e. Sumner and Brighton) due to the tide set up effects in these narrow inlets.
- For the open coast Banks Peninsula sites, the MHW level is assumed to be the same as Sumner.
- For Kaitorete Spit, the MHW level was estimated from the relativity between the $MHWS_{ECan}$ and MHW levels at Sumner and Lyttelton (average 0.314 m) applied to the $MHWS_{ECan}$ level at Birdlings Flat calculated from the tidal constituents.
- At Lake Forsyth/ Wairewa and Lake Ellesmere/Waihora, MHW is assumed to be the same as along Kaitorete Spit. However, it is noted that these lakes are not normally open to the sea due to the gravel barrier, so these water bodies are (generally) disconnected from the open coast.

Table 15: Mean High Water Levels for each inundation cell used in this assessment in NZVD2016.

Name	Mean High Water Level (m)
Brooklands Lagoon	0.66
Christchurch Open Coast	0.50
Avon-Heathcote Estuary North	0.54
Avon-Heathcote Estuary South	0.54
Sumner	0.52
Taylors Mistake	0.52
Lyttleton Harbour	0.63
Banks Peninsula North	0.52
Banks Peninsula South	0.52
Akaroa Harbour	0.74
Lake Forsyth/ Wairewa	0.52
Kaitorete Spit	0.52
Lake Ellesmere/ Waihora	0.52

3.2.2 Mean High Water Spring ($MHWS_{ECAN}$) Levels

3.2.2.1 Discussion

As stated in Section 2.2, the $MHWS_{ECan}$ formula is given as $MHWS_{ECan} = M_2 + N_2 + MLOS$. As also pointed out in Section 2.2, this is a different calculation for MHWS than most of New Zealand given (or assumed) in the LINZ databases to be $MHWS_n$ ($M_2 + S_2$) due to the dominance of the monthly lunar tides (M_2) in Canterbury. The following discussion examines the water level values from the MHWS predictions given in the literature and the calculation of $MHWS_{ECan}$ elevation from the reported values of the astronomical constituents and the MLOS.

3.2.2.1.1 MHWS Predictions in the Literature

The various LINZ MHWS predictions are given in Tables 9, 10, 11, and 12. These are summarised below in Table 16, all standardised to NZVD2016, along with the MHWS values given in Tonkin & Taylor (2021).

Table 16: Summary of MHWS predictions in the literature standardised to NZVD2016.

Site	Source	Given MHWS (multiple sources)	MHWS in NZVD2016
New Brighton Pier	LINZ Secondary Ports Table	2.4 m CD	0.749 m
Sumner Head	LINZ Secondary Ports Table	2.4 m CD	0.729 m
	Tonkin & Taylor (2021)	0.76 NZVD2016	0.76 m
Lyttelton Port	LINZ Secondary Ports Table	2.5 CD	0.839 m
	LINZ Cadastral & Engineering	2.49 CD	0.829 m
	LINZ 2024 Nautical Almanac	2.58 CD	0.919 m
	LINZ 2025 MHWS pilot mapping	0.93 NZVD2016	0.93 m
	Tonkin & Taylor (2021)	0.84 NZVD2016	0.84 m
Purau (Lyttelton Harbour)	LINZ Secondary Ports Table	2.6 CD	0.939 m
Le Bons Bay	LINZ Secondary Ports Table	2.5 CD	0.839 m
Akaroa	LINZ Secondary Ports Table	2.7 CD	1.052 m
	Tonkin & Taylor (2021)	1.08 NZVD2016	1.08 m
Te Tikao Bay (Akaroa Harbour)	LINZ Secondary Ports Table	2.6 CD	0.952 m
Te Oka Bay (southern Banks Peninsula)	LINZ Secondary Ports Table	2.3 CD	0.632 m

The method of calculation of these MHWS elevations are not given, but as stated in the literature review (Section 3), are assumed to be by the standard $MHWS_n$ formula ($M_2 + S_2$), so are in general lower than $MHWS_{ECan}$ calculation ($M_2 + N_2 + MLOS$) given below (up to 0.13 m lower at Sumner Head), except for the LINZ 2024 Nautical Almanac and 2025 pilot mapping levels at Lyttelton Port, which are similar to $MHWS_{ECan}$. Level.

Note all of the sites of above predictions are open coast or harbour sites, with none being for Brooklands Lagoon or the Avon-Heathcote Estuary. The only reported MHWS levels for these sites are from Mulgor (2017) which give the calculated $MHWS_{ECan}$ level in the estuary as 0.868 m and 0.858 m (NZVD2016) at Bridge Street and Ferrymead Bridge respectively based on 13.4% exceedance of recorded high tides from 1994 to 2017.

3.2.2.1.2 Calculated $MHWS_{ECan}$

Astronomical Constituents (M_2, N_2)

The value of the M_2 and N_2 tidal constituents is given by Stephens et al (2015), Mulgor (2017 & 2018), and GHD (2021). These values are independent of vertical datum and are presented in Table 17.

Table 17: Values of M2 and N2 Tidal Constituents for Christchurch City District sites from the literature.

Site	Stephens et al (2015)			Mulgor (2017, 2018)			GHD (2021)		
	M_2	N_2	$M_2 + N_2$	M_2	N_2	$M_2 + N_2$	M_2	N_2	$M_2 + N_2$
Waimairi Beach	0.83	0.19	1.02						
New Brighton Pier	0.83	0.19	1.02						
South New Brighton	0.84	0.19	1.03						
Sumner Head	0.84	0.19	1.03	0.834	0.192	1.026	0.834(1) 0.831(2)	0.192(1) 0.191(2)	1.026(1) 1.022(2)
Taylors Mistake	0.84	0.19	1.03						
Lyttelton Port	0.87	0.19	1.06				0.856	0.197	1.056
Birdlings Flat	0.81	0.18	0.99						
Note (1) is from NIWA data, (2) is from LINZ data.									

As expected, the values for both M_2 and N_2 at Sumner Head are very similar across all three sources, so there is a high degree of confidence in these values for this site for input into the $MHWS_{ECAN}$ calculation. Also as expected, the tidal constituent values for the other open coast sites from Stephens et al. (2015) are also similar to the Sumner values, with small differences in the M_2 value for Lyttelton (0.03 m higher due to tide set up in the harbour) and Birdlings Flat (0.03 lower). The Lyttelton values are also very similar to these presented by GHD (2021) for this site, again giving a high degree of confidence in these values for input into the $MHWS_{ECAN}$ calculation at this site.

None of the references present the values of the M_2 and N_2 tidal constituents with Brooklands Lagoon, the Avon-Heathcote Estuary or at Akaroa. As pointed out by Mulgor (2017), due to the distortion of tides in the estuary as a result of the narrow entrance, extracting the amplitudes of the M_2 and N_2 tides for calculating MHWS in the Estuary is not possible. It is assumed that a similar situation would occur for Brooklands Lagoon as demonstrated by the higher MHW levels than experienced on the open coast. For Akaroa, it is assumed that the M_2 and N_2 would fall within the range of Lyttelton and Birdlings Flat, with more likely to be similar to the higher M_2 value for Lyttelton due to tidal set-up in the harbour.

MLOS

MLOS is given over a specified time epoch so that it takes account of the 18.6 year cycle of tidal variations due to astronomical conditions, variations due to long and medium-term meteorological cycles such as the IPO & El Nino-La Nina cycles, and the effects of local vertical land movement. A plot of the variations in the AMSL at the Sumner Head from 1995 to 2024 from NIWA (2025) is presented in Figure 7.

The data on MLOS for the Christchurch City District is restricted to the Sumner Head and Lyttelton Port water level gauges and is presented in Table 18.

Table 18: MLOS at Sumner Head and Lyttelton Port water level recorders.

Site	Source	Dates	MLOS (LVD1937)	MLOS (NZVD2016)(1)
Sumner	Mulgor 2017	1994-2017	0.133	-0.255
	NIWA 2025	2002-2024	0.188	-0.200
	NIWA 2025	2015-2024	0.23	-0.158
Lyttelton	Stephens 2015	1993-2012	0.165	-0.213
	Stephens 2015	2003-2012	0.189	-0.189
	Stephens 2015 + 4-7mm/yr SLR since 2012 (from GHD,2021)	2003-2024	0.202 to 0.211	-0.176 to -0.167
	(2) SLR since 2012 at 4-7 mm/yr (from GHD, 2021)	2012-2024	0.211 to 0.228	-0.167 to -0.150

Note:

(1) MLOS (NZVD2016) are negative values as the datum at this location is at a higher elevation than the MLOS elevation.

(2) SLR since 2012 was added to assumed 2012 MLOS of 0.189 from Stephens et al (2015)

In assigning MLOS values for use in the calculation of MHWS elevations, the following considerations were made:

1. As reported in NIWA (2025) there was a rapid rise in AMSL from 1996 to 1999 arising from a switch in the IPO to a negative phase, so data from prior to this is less relevant to the contemporary MLOS value.

2. The more appropriate MLOS values are those that include the most recent data in the time epoch so that recent trends in SLR are included. As also recorded in NIWA (2025) there has been a rise in AMSL over the past decade, so these values will be the most appropriate.
3. Since the drivers of MLOS operate at a large spatial scale, the values should be relativity similar across the Sumner and Lyttelton sites. However, it is noted that 0.01 m of the difference in NZVD2016 values between the sites are due to differences in the geoid conversion from LVD1937.

Based on these considerations the following MLOS values were adopted for use in the calculation of $MHWS_{ECan}$.

- Sumner: -0.158 m (NZVD2016) from NIWA (2025) 2015-2024 MLOS
- Lyttelton: -0.167 m (NZVD2016) from SLR of 4 mm/yr since 2012 on top of Stephens et al (2015) MLOS of 0.189 m (LVD1937) in 2012.

Resulting $MHWS_{ECan}$

Using the above MLOS with the M_2 and N_2 tidal constituents given in Table 16, the calculated $MHWS_{ECan}$ levels for Sumner and Lyttelton are as follows:

- Sumner: 0.86 m (NZVD2016)
- Lyttelton: 0.91 (NZVD2016)

Assuming that MLOS at Sumner is the same for other open coast sites, the following $MHWS_{ECan}$ levels are calculated for the following sites with M_2 and N_2 tidal constituents given in Table 17:

- Waimairi & New Brighton beaches: 0.88 m (NZVD2016)
- Taylors Mistake: 0.87 m (NZVD2016)
- Birdlings Flat: 0.86 m (NZVD2016)

3.2.2.1.3 Recorded MHWS levels

The recorded MHWS levels from Harrington (pers com), which include meteorological effects, are presented in Table 13. The comparison of these levels to the calculated $MHWS_{ECAN}$ level is only possible at Sumner Head and Lyttelton Port, with the differences due to meteorological effects being very similar at both sites; 0.254 m at Sumner and 0.26 m at Lyttelton. This suggests that this correction is consistent across the two locations and could be applied to the other sites with recorded levels to estimate $MHWS_{ECAN}$ where information about tidal constituents is not available. However, it is noted there is likely to be limitations of this due to geographic spread of sites and local conditions.

The resulting levels are as follows:

- Brooklands Lagoon (Styx Tide gates): 1.002 m (NZVD2016)
- Avon - Heathcote Estuary: 0.868 (NZVD2016)
- Akaroa: 0.75 m (NZVD2016)

The results for Brooklands Lagoon and the Estuary appear to be reasonable estimates, fitting the spatial relativity to the Sumner and Lyttleton sites as established for the adopted HMW values. Therefore, the above $MHWS_{ECAN}$ estimates have been adopted for Brooklands Lagoon and the Estuary.

However, the above estimate for Akaroa does not fit the established relativities, being too low, and up to 0.3 m less than the reported tidal predictions. As with MHW record for this site, this may be due to the shorter record (less than 2 years), and a lower meteorological impact at this site due to different orientation of the harbour opening. Consequently, the above estimate for $MHWS_{ECAN}$ at Akaroa is not accepted, and LINZ Secondary Port data has been used (Table 19).

3.2.2.2 MHWS levels used in this assessment

The resulting $MHWS_{ECan}$ levels used in the mapping for this assessment are presented in Table 19, along with the method used to calculate or estimate the level.

Table 19: $MHWS_{ECan}$ levels for each inundation cell used in this assessment in NZVD2016 (to 2 dp).

Name	$MHWS_{ECan}$ (m)	Calculation/Estimation Method
Brooklands Lagoon	1.00	Mean recorded 2017-2025 (Harrington pers com 2025) – Sumner MHWS met effect (0.25 m)
Christchurch Open Coast	0.88	From Tidal constituents at New Brighton & Waimairi
Avon-Heathcote Estuary North	0.87	Mean recorded 2018-2025 (Harrington pers com 2025) – Sumner MHWS met effect (0.25 m)
Avon-Heathcote Estuary South	0.87	
Sumner	0.86	From Tidal constituents
Taylors Mistake	0.87	From Tidal constituents
Lyttleton Harbour	0.91	From Tidal constituents
Banks Peninsula North	0.88	Transferred from Sumner (0.02 m difference due to Geoid conversion).
Banks Peninsula South	0.88	
Akaroa Harbour	1.05	LINZ secondary Ports
Lake Forsyth	0.86	Transferred from Kaitorete Spit (Birdlings Flat)
Kaitorete Spit	0.86	From Tidal constituents at Birdlings Flat
Lake Ellesmere	0.86	Transferred from Kaitorete Spit (Birdlings Flat)

3.2.2.2.1 Sensitivity testing

For sensitivity testing, the above $MHWS_{ECan}$ levels were compared to the adopted MHW levels (Section 3.2.1) and to the storm tide levels from Tonkin and Taylor (2021) to ensure that the relativity of the monthly peak levels to daily mean high tide levels and high frequency storm levels are within acceptable ranges. Appendix C presents the comparable values that are used in the ARI coastal storm inundation maps available on the Christchurch City Council Coastal Hazards Portal.

The results of this sensitivity testing show that the $MHWS_{ECan}$ levels are in the order of 0.3 – 0.4 m above MHW levels, and in the order of 0.4 – 0.5 m below the 1-year storm tide levels (excluding wave set-up).

4. Results

This section provides a high-level summary of the exposure of coastal suburbs and communities to daily tidal flooding (e.g. Mean High Water 'MHW') and monthly tidal flooding (e.g. Mean High Water Spring 'MHWS') with SLR.

The coastline has been broken down into 35 areas based on where communities and suburbs are located across the district. The location of these is shown in Figure 8. Maps of tidal flooding for MHW and MHWS with 0m SLR, 0.6m SLR, and 1.2m SLR are presented for each of these areas in Appendix B.

Table 20 provides a high-level qualitative assessment of under what SLR increment a local suburb or community could become exposed to MHW (e.g. daily) or MHWS (e.g. monthly) tidal flooding. This qualitative assessment considers the exposure under each SLR increment, and at a high level identifies where there is:

- No significant connected or disconnected flooding to the local community area (light grey);
- Minor exposure of property and roads within the local community to connected flooding, and/or exposure of property and roads to disconnected flooding (light blue),
- Major exposure of property and roads within the local community to connected flooding (dark blue).

Commentary is provided for each area on the connected/disconnected nature of the flooding, the extent of the flooding, and exposure of property and roads. For property or infrastructure specific information, a more detailed investigation of the spatial data (available on the Coastal Hazards Portal) is required.

It is important to note that at open coast sites, the extent to which tidal flooding impacts this area is likely to be heavily influenced by the future position of the dunes (erosion), which this assessment does not consider. In areas where this is relevant, the future tidal flood hazard may be underestimated, particularly along the Christchurch Open Coast from Spencer Park to Southshore. Conversely, the mapping does not account for any future planned flood protection scheme upgrades (such as stopbanks on the Lower Avon River, or the flood protection bund at Southshore). Hence, if these planned works are implemented, the mapping may be considered to be conservative.

It is also important to note also that the mapping outputs are derived from the input LiDAR data, which in some areas identifies structures around the water (i.e. jetties, bridges), and in others it does not. In some cases, the mapping produces areas of flooding over a bridge area, however this is because the structure is not captures in the LiDAR. This is particularly relevant around the small communities around the bays of Banks Peninsula. Where this has occurred, a pragmatic approach to interpreting the flood hazard has been undertaken to identify whether the bridge has actually flooded. This is reflected in the results table below. Similarly, as a function of the LiDAR and mapping approach, there are some areas mapped as 'disconnected' flooding, which in reality would be connected via culverts beneath roads which are not identified in the LiDAR. Where this could have a potential impact of roads or property, it is noted in the results table below.

This tidal mapping and analysis provides an indication of where along the district's coastline may become first impacted by tidal flooding. Generally, the areas that are shown to have the earliest onset of exposure to daily tidal flooding are:

- Brooklands
- Bexley
- Teddington

Fortunately, these areas will have the earliest onset of exposure to daily tidal flooding hazards are sparsely populated. Daily flooding under higher SLR increments will eventually impact more developed urban areas that are much more densely populated. See the table below for details of these areas.

Additionally, areas that will become exposed to relative major monthly flooding (MHWS) with up to 0.6m SLR (including the areas listed above) are:

- New Brighton
- South New Brighton
- Southshore
- McCormacks Bay/Redcliffs
- Purau
- Port Levy
- Okains Bay
- Akaroa
- Takamatua
- Duvauchelle

For each of these areas, the timeframe at which 0.6 m SLR could be realised will vary, depending on which climate change projection occurs in the future, and the magnitude of local VLM.

The areas along the coast that are particularly elevated and are therefore the least impacted by tidal flooding are:

- Waimairi Beach
- Taylors Mistake
- Corsair Bay
- Cass Bay
- Rapaki
- Diamond Harbour
- Birdlings Flat

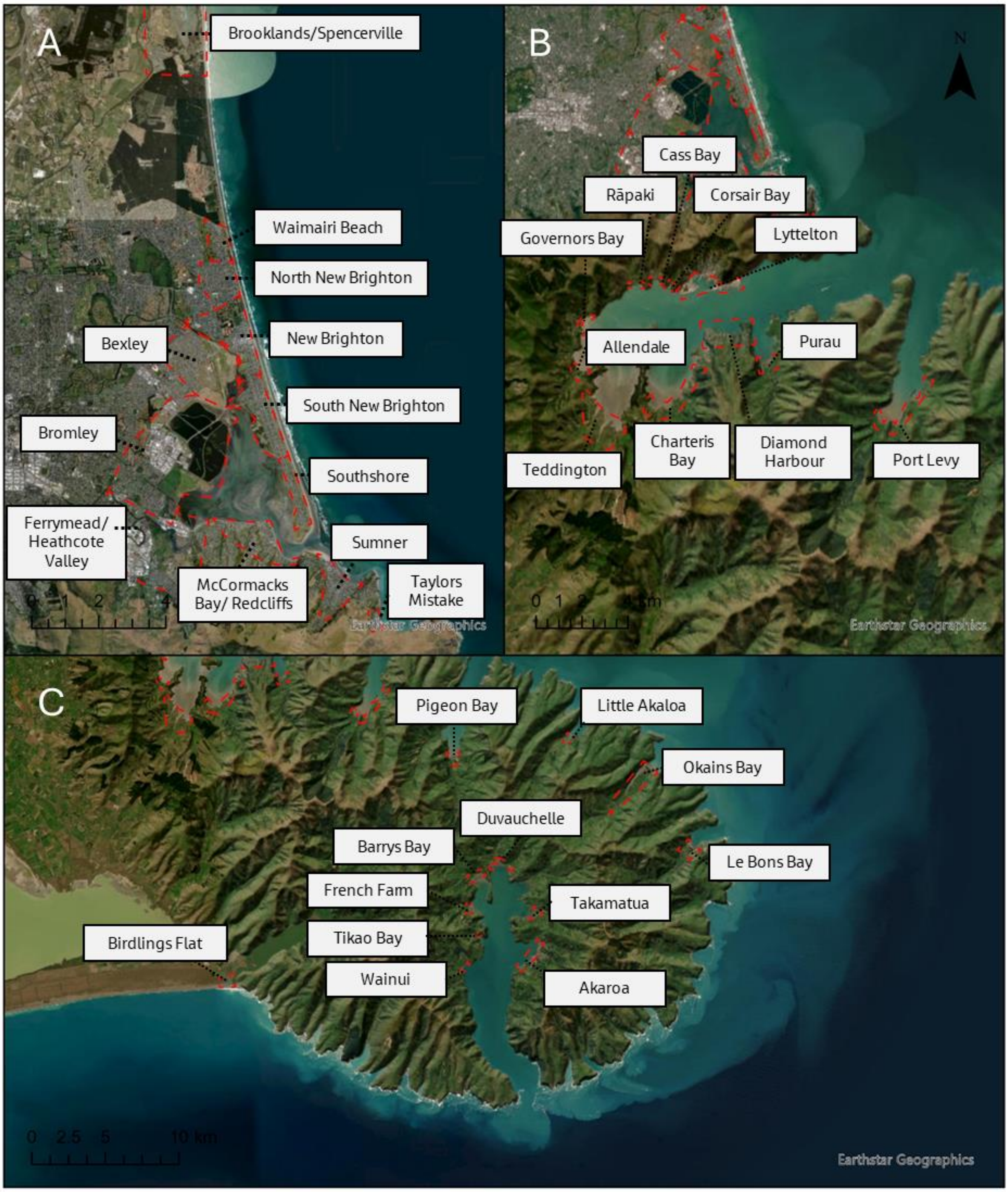


Figure 8: Location of communities/suburbs discussed in Table 21. Map A (top left) shows areas within Christchurch City, Map B (top right) shows the areas discussed within Lyttelton Harbour; and Map C (bottom) shows the areas discussed at Banks Peninsula.

Table 20: Summary of exposure to MHW (Daily) and MHWS (Monthly) flooding across the district.

Key

Grey	No significant connected or disconnected flooding to the local community area
Light blue	Minor exposure of property and roads within the local community to connected flooding, and/or exposure of property and roads to disconnected flooding
Blue	Major exposure of property and roads within the local community to connected flooding.

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
Christchurch City											
Brooklands/ Spencer Park	MHW (Daily)	Light blue	Light blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	**Daily tidal flooding -** Under current sea level, mapping indicates that parts of Lower Styx Road could be exposed to daily tidal flooding, however it is recognised that currently flood control mechanisms on the Lower Styx River generally prevent this from occurring. With 0.4m to 0.6m SLR, a number of properties along Lower Styx Road become exposed to connected tidal flooding. Disconnected flooding exposes several properties and access with 0.8 m SLR, which becomes connected and more extensive with 1 m SLR. With 1.2 to 1.5 m SLR Spencerville becomes almost completely flooded with MHW levels.
	MHWS (Monthly)	Light blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	**Monthly tidal flooding -** Under current sea level, mapping indicates that parts of Lower Styx Road could be exposed to monthly tidal flooding, however it is recognised that currently flood control mechanisms on the Lower Styx River generally prevent this from occurring. With 0.2 m SLR, properties along Lower Styx Road also are exposed to connected tidal flooding, with most properties and roads along lower Styx Road impacted with 0.4 m SLR. With 0.4 m SLR there is also disconnected flooding on roads and property at Spencerville, which becomes extensive and connected across properties with 0.8 m SLR. With 1 m SLR, most properties and roads are exposed to MHWS flooding.
Waimairi Beach	MHW (Daily)	Grey	Grey	Grey	Grey	Grey	Grey	Light blue	Light blue	Light blue	**Daily tidal flooding –** Exposure is largely limited to the long-term (beyond 2100). Small amounts of disconnected daily flooding impact access on Aston Drive with 1.2 m SLR. Flooding increases in extent mostly along roads up to 2.0 m SLR, and remains disconnected to the sea.
	MHWS (Monthly)	Grey	Grey	Grey	Grey	Light blue	Light blue	Light blue	Light blue	Light blue	**Monthly tidal flooding -** Small amount of disconnected flooding along Aston Drive with 0.8 m SLR. The extent of disconnected flooding increases mainly along roads as sea level rises, and exposes a large number of properties with 2.0 m SLR. However, flooding remains disconnected to the sea across all SLR increments.
North New Brighton	MHW (Daily)	Grey	Grey	Grey	Grey	Grey	Grey	Grey	Light blue	Light blue	**Daily tidal flooding –** Very minor disconnected flooding exposes a small number of properties with 1.5 m SLR. Flooding remains disconnected with 2.0 m SLR and increases in extent across properties and along Marine Parade.
	MHWS (Monthly)	Grey	Grey	Grey	Grey	Grey	Grey	Light blue	Light blue	Blue	**Monthly tidal flooding -** Very minor amount of disconnected flooding exposes a small number of properties with 1.2 m SLR, becoming wider spread with 1.5 m SLR along Marine Parade but remaining disconnected, potentially disrupting access. Connected flooding with 2.0 m SLR through Rawhiti Domain from the Avon River causes flooding along Bowhill Road and adjacent streets, and disconnected flooding along Marine Parade becomes more widespread.
New Brighton	MHW (Daily)	Grey	Grey	Light blue	Light blue	Blue	Blue	Blue	Blue	Blue	**Daily tidal flooding -** Disconnected flooding begins to encroach on properties along the banks of the Avon River with 0.4 m SLR and into Owles Terrace and Beresford Street. Disconnected flooding begins to encroach into private property with 0.6 m SLR, becoming connected and increasing in extent with 0.8 m SLR. Large areas of the community are exposed with 1 to 1.2 m SLR.

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
	MHWS (Monthly)										**Monthly tidal flooding –** Disconnected flooding begins to encroach on properties with only 0.2 m SLR, as well as intersecting with roads along Beresford Street and Owles Terrace. Disconnected flooding becomes connected with 0.6 m SLR by flooding from the Avon River, and exposes a significant number of properties within the suburb. All flooding is via the Avon River up to 2 m SLR, at which level it becomes directly connected to the sea at the New Brighton Library and Pier area. .
South New Brighton	MHW (Daily)										**Daily tidal flooding -** Disconnected flooding exposes the road (and access) along Estuary Road-Ebbtide Street, and Kibblewhite Street-Union Street with 0.6 m SLR. Disconnected flooding becomes more extensive impacting a number of properties with 0.8 m SLR, and becomes connected via the estuary with 1 m SLR, exposing a high number of properties and roads in the community, and potentially blocking access to Southshore along Rockinghorse Road.
	MHWS (Monthly)										**Monthly tidal flooding -** Minor disruption to access at the southern end of Estuary Road and Kibblewhite Street-Union Street from disconnected flooding with 0.2 m SLR. Flooding becomes wider spread with 0.4 m (but still disconnected), exposing properties and roads. Flooding becomes more extensive and connected to the estuary with 0.6 m SLR. Source of flooding up to >2.0 m SLR is from the estuary, as there is not a direct connection of flooding via the dunes.
Southshore	MHW (Daily)										**Daily tidal flooding –** Disconnected flooding along Rockinghorse Road with 0.6 m SLR, which becomes widespread with 0.8 m SLR and encroaches into a number of properties. Flooding becomes connected to the estuary with 1m SLR and most properties within Southshore are exposed.
	MHWS (Monthly)										**Monthly tidal flooding -** Minor disconnected flooding along Rockinghorse Road with 0.2 m SLR. Flooding becomes more widespread into properties (but still disconnected) with 0.4 m SLR. Flooding becomes connected to the estuary with 0.6 m SLR, with most properties and roads exposed to monthly flooding.
Bexley	MHW (Daily)										**Daily tidal flooding -** Disconnected flooding at present day across red zoned land and across Pages Road. This area becomes connected via the Avon River with 0.2 m SLR, and continues to increase in extent and depth with SLR, increasingly impacting access along Pages Road and ANZAC Drive into New Brighton.
	MHWS (Monthly)										**Monthly tidal flooding –** Connected flooding at present day across red zone area and along Pages Road via the Avon River. Stopbanks not identified in the LiDAR likely prevent this connection currently. The extent and depth of flooding increases with SLR along Pages Road and ANZAC Drive.
Bromley	MHW (Daily)										**Daily tidal flooding -** Small amounts of disconnected flooding across coastal paddocks with 0.2 m SLR, becoming connected and wider spread with 0.4m SLR. Properties west of Dyers Road are exposed to disconnected flooding with 1.2 m SLR, and becomes connected and wider spread with 2 m SLR across properties and roads.
	MHWS (Monthly)										**Monthly tidal flooding –** Disconnected flooding across coastal paddocks at present day, becoming connected and increasingly widespread with 0.2 m SLR. Disconnnected flooding begins to encroach on properties west of Dyers Road with 0.8 to 1 m SLR, and becomes widespread and connected with 1.2 to 1.5 m SLR.
Ferrymead/Heathcote	MHW (Daily)										**Daily tidal flooding –** Paddocks throughout the Heathcote Valley become exposed to disconnected flooding with 0.4 m SLR, which becomes increasingly connected and exposed with 0.6m SLR. Disconnected flooding begins to encroach on roads around the industrial area with 1.0 m SLR, which becomes connected by 1.2 m SLR, where property becomes exposed. Widespread exposure of properties and roads within Ferrymead with 1.5 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –**Paddocks exposed to disconnected flooding with 0.2 m SLR, which become increasingly exposed to connected flooding from 0.4 m SLR. Minor disconnected flooding along roads in industrial area with 0.6 m SLR, which becomes connected and wider spread with 1 m SLR across property and roads. Most of the industrial area becomes exposed to monthly flooding with 1.2 m SLR.
McCormacks Bay - Redcliffs	MHW (Daily)										**Daily tidal flooding –** Very minor areas of disconnected flooding around Celia Street, Beachville Road and Redcliffs School with 0.6 m SLR, which becomes widespread and connected with 1 m SLR. Access around McCormacks Bay Road becomes compromised with 0.8m SLR. Properties along the Main Road at Redcliffs become exposed to disconnected

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
	MHWS (Monthly)										flooding with 0.8 m SLR. Flooding along the Main Road at Redcliffs becomes connected with 1 m SLR, exposing a number of properties, and impacting access to Sumner and Taylors Mistake. **Monthly tidal flooding -** Minor disconnected flooding around Celia Street and Redcliffs School with 0.2 m SLR, which becomes more extensive and connected to the estuary with 0.6 m SLR. Access around McCormacks Bay Road begins to be compromised with 0.4 m SLR. Properties along the Main Road at Redcliffs begin to be exposed through disconnected flooding with 0.4 m SLR, which becomes connected with 0.8 m SLR and will impact access along the Main Road to Sumner and Taylors Mistake.
Sumner	MHW (Daily)										**Daily tidal flooding –** Very minor disconnected areas of flooding begin to encroach on properties along eastern Sumner with 1.0 m SLR. Flooded areas become widespread (still disconnected) with 1.2 m to 1.5 m SLR. The tidal flooding becomes connected with 2.0 m SLR. Access to Sumner via the Main Road becomes impacted with 1.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** Minor disconnected flooding encroaches on properties with 0.6 m SLR, and remains disconnected but increases in extent up to 1.2 m SLR. Flooding becomes connected to the sea with 1.5 m SLR, where a significant number or properties and roads are exposed. Access to Sumner via the Main Road becomes impacted with 0.8 m SLR.
Taylors Mistake	MHW (Daily)										**Daily tidal flooding -** Access to Taylors Mistake via the Main Road in Sumner/Redcliffs becomes impacted with 1.0 m SLR. However, roads or property around Taylors Mistake and Beach are not exposed up to 2.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding -** Access to Taylors Mistake via the Main Road in Sumner/Redcliffs becomes impacted with 0.8 m SLR. However, only minor connected flooding at surf club carpark with 2 m SLR.
Lyttelton Harbour											
Lyttelton	MHW (Daily)										**Daily tidal flooding –** Minor flooding around the fringes of the port and marina with1.5 m SLR. Area of connected flooding across the port becomes widespread with 2.0 m SLR, and there is a significant area of disconnected flooding across the fuel storage site (NZ Oil Services). However, flooding does not impact access or private properties within the township.
	MHWS (Monthly)										**Monthly tidal flooding –** Minor flooding around the fringes of the port and marina up to 1.2 m SLR. With 1.5 m to 2.0 m SLR, there is increasing areas of connected flooding across the port, and significant disconnected flooding across the fuel storage site (NZ Oil Services). Access to the Lyttelton township and properties remains unaffected by monthly flooding even with 2.0 m SLR.
Corsair Bay	MHW (Daily)										**Daily tidal flooding -** No areas of road or property in Corsair Bay are exposed to daily tidal flooding with SLR. Walking tracks around the side of the bays could be exposed with 2.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** No road or property in Corsair Bay are exposed to monthly flooding with SLR up to 2.0 m. Walking tracks around the side of the bays could be exposed with 1.5-2.0 m SLR.
Cass Bay	MHW (Daily)										**Daily tidal flooding -** No areas of road or property are exposed to daily tidal flooding with up to 2.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding -** No areas of road or property are exposed to daily tidal flooding with up to 1.5 m SLR. Access along Bayview Place could be impacted with 2.0 m SLR.
Rapaki	MHW (Daily)										**Daily tidal flooding -** No areas of road or property are exposed to daily tidal flooding with up to 2.0 m SLR. Access around the jetty and boat ramp at Kina Road becomes increasing exposed from 0.4 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** No areas of road or property are exposed to monthly tidal flooding with up to 2.0 m SLR. Access around the jetty and boat ramp becomes increasingly exposed with 0.2 m SLR.
Governors Bay	MHW (Daily)										**Daily tidal flooding -** Daily Tidal Flooding begins to encroach on Jetty Road with 0.8 m SLR, and is completely exposed with 2.0m SLR, With 2.0 m SLR, access to the wharf may be impacted by daily flooding. No property is exposed to daily tidal flooding with SLR up to 2.0 m SLR
	MHWS (Monthly)										**Monthly tidal flooding –** Monthly tidal flooding begins to encroach on Jetty Road with 0.6 m SLR. With 1.5 m SLR, Jetty Road is completely exposed, impacting access. No property is exposed to monthly tidal flooding with SLR up to 2.0 m SLR.

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
Allandale	MHW (Daily)										**Daily tidal flooding -** Disconnected flooding begins to encroach on Governors Bay-Teddington Road with 0. 6m SLR, which becomes connected to the sea with 1.5 m SLR, impacting access. Connected flooding begins encroaching into low lying property with 0.8 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding -** Disconnected flooding covers Governors Bay-Teddington Road with 0.4 m SLR, and becomes connected with 1.2 m SLR, impacting access along this road. Connected tidal flooding begins to encroach on low lying property with 0.6 m SLR. With 2.0m SLR there is widespread connected flooding across low lying land and the road.
Teddington	MHW (Daily)										**Daily tidal flooding -** Connected tidal flooding covers low lying paddocks with 0.4 m SLR. Flooding becomes widespread across paddocks and encroaches on Governors Bay-Teddington Road with 0.6 m SLR. Access along Governors Bay-Teddington Road impacted with connected daily tidal flooding with 1.2 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** Connected flooding across low-lying paddocks with 0.2 m SLR, becoming wide-spread and encroaching on Governors Bay-Teddington Road with 0.4 m SLR. With 1m SLR, access along Governors Bay-Teddington Road is completed flooded by monthly flooding, impacting access to bays on the southern side of the harbour.
Charteris Bay	MHW (Daily)										**Daily tidal flooding –** Daily tidal flooding begins to encroach on a small number of low-lying properties with 0.6 m SLR. With 1.0 m SLR, daily tidal flooding across Charteris Bay Road/Marine Drive could occur, disrupting access to other bays on the southern side of Lyttelton Harbour.
	MHWS (Monthly)										**Monthly tidal flooding –** Connected flooding begins to encroach on lower-lying properties with 0.4 m SLR. Access along Charteris Bay Road/Marine Drive begins to be exposed with 0.8 m SLR, impacting access to other bays along the southern edge of Lyttelton Harbour.
Diamond Harbour	MHW (Daily)										**Daily tidal flooding -** Due to high land elevations, roads or property are not exposed to tidal inundation with up to 2.0 m SLR. The carpark access to the wharf is shown to be exposed to flooding with 2.0 m SLR. Access to Diamond Harbour via Charteris Bay Road could become exposed with 1.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** Similar to daily flooding, high land elevations at Diamond Harbour mean there is generally no exposure of property or roads to MHWS up to 2.0 m SLR. Flooding encroaches on the carpark at the wharf with 1.5 to 2.0 m SLR. Access to Diamond Harbour via Charteris Bay Road could become exposed with 0.8 m SLR.
Purau	MHW (Daily)										**Daily tidal flooding -** Minor disconnected flooding on the southern side of Camp Bay Road at properties with 0.6 m SLR, which becomes connected and widespread across properties and Camp Bay Road with 1 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding -** Disconnected flooding occurs at some properties with 0.4 m SLR onwards, increasing in extent and depth with SLR. Flooding becomes connected to the sea across Camp Bay Road with 0. 6m SLR, impacting properties and access.
Port Levy	MHW (Daily)										**Daily tidal flooding –** Connected flooding covers Wharf Road and Fernlea Point Road with 1.0 m SLR, impacting access. There is disconnected tidal flooding across Pa Road with 1.0 m SLR, which becomes connected and more extensive with 1.2 m SLR, impacting access and properties.
	MHWS (Monthly)										**Monthly tidal flooding –** Connected flooding covers Wharf Road and Fernlea Point Road with 0.6 m SLR, impacting access. Very minor disconnected flooding on Pa Road with 0.6 m SLR, which becomes connected with 0.8 m SLR, and begins to encroach on properties.
Banks Peninsula (east and south of Port Levy)											
Pigeon Bay	MHW (Daily)										**Daily tidal flooding -** The campground is exposed to connected tidal flooding with 1.0 m SLR. Daily flooding encroaches on Wharf Road with 1.2 m SLR, and covers the road with 1.5 m SLR, impacting access. Holmes Bay Road does not get exposed to flooding, even with up to 2.0m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** The campground is exposed to connected flooding with 0.8m SLR, which exposes road access along Wharf Road. Connected flooding across Wharf Road occurs with 1.2 m SLR. Access to the settlement along Pigeon Bay Road, as well as access along Holmes Road, becomes exposed to connected flooding with 2.0 m SLR.
Little Akaloa	MHW (Daily)										

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
	MHWS (Monthly)										**Daily tidal flooding –** Flooding across Decanter Road occurs with 1.2 m SLR, disrupting access to a small number of properties. Flooding encroaches on Little Akaloa Road with 1.5 m SLR, disrupting access to a larger number of properties. **Monthly tidal flooding –**Disconnected flooding across Decanter Road with 0.8m SLR begins to encroach on low lying property. Flooding becomes connected and widespread with 1.0 m SLR and begins to encroach on Little Akaloa Road. Little Akaloa Road exposed to monthly flooding with 1.2 m SLR, disrupting access to a number of properties. .
Okains Bay	MHW (Daily)										**Daily tidal flooding - The** campground becomes exposed to disconnected flooding with 0.6m SLR, which becomes connected with 1.0 m SLR, and widespread with 1.2 m SLR. Disconnected and connected tidal flooding begins to encroach on properties with 0.6 – 0.8 m SLR, and becomes connected and widespread with 1.0 m SLR. Access along Okains Bay Road becomes impacted with 1.2 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** Disconnected flooding occurs across the campground with 0.2-0.4 m SLR, and becomes connected and wide-spread with 0.6 m SLR. Monthly flooding begins to encroach on properties via the river with 0.2-0.4 m SLR, increasing in extent and depth with SLR. Access along Okains Bay Road impacted with 0.8 to 1 m SLR.
Le Bons Bay	MHW (Daily)										**Daily tidal flooding -** Small amount of disconnected flooding begins encroaching on properties with 1.0 m SLR, and becomes widespread with 1.2-1.5 m SLR (but remains disconnected). Flooding becomes connected with 2.0 m SLR. Access maintained up to 1.5 m – 2.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –** Small amount of disconnected flooding encroaching on properties with 0.6m SLR. Disconnected flooding increases in extent and depth up to 1.5m SLR, potentially disrupting access with 1.2m SLR. Flooding becomes connected and widespread across the community with 2.0m SLR.
Akaroa Township	MHW (Daily)										**Daily tidal flooding -** Access along Beach Road becomes impacted with 0.6 m SLR, which becomes more extensive with 1 m SLR, encroaching on property along the main street. Access along Rue Lavaud and Rue Brittan become impacted by disconnected flooding with 0.6 m SLR, which becomes connected to the sea and widespread with 0.8 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding** Access along Beach Road near the Wharf becomes exposed with 0.4m SLR. Flood extent increases and encroaches on property with 0.6 m SLR. Disconnected flooding occurs along Rue Brittan with 0.2 m SLR. Flooding around this area becomes extensive and connected with 0.6 m SLR, impacted the main access route.
Takamatua	MHW (Daily)										**Daily tidal flooding -** Access along Takamatua Bay Road becomes increasingly exposed to tidal flooding with SLR from 0.6m SLR. Daily flooding encroaches on properties and access along Takamatua Beach Road with 0.6 m SLR, exposing serval properties and the road with 0.8 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding –**Very minor disconnected flooding encroaches on properties along Takamatua Bay Road with 0.2 m SLR, which becomes connected and wider spread with 0.4 m SLR – impacting most bay-front properties along Takamatua Beach Road. Access along Takamatua Bay Road completely flooded with 1 m SLR.
Duvauchelle	MHW (Daily)										**Daily tidal flooding –** Properties along Onawe Flat Road begin to be impacted with 0.8 m SLR, and the road itself is shown to be impacted with 0.2 m SLR. Daily flooding occurs along Seafield Road with 0.8m SLR, encroaching into the Holiday Park and impacting access. With 1m SLR, disconnected flooding begins to encroach on to properties adjacent to the campground, becoming connected flooding with 1.2m SLR. Exposure of key access along Seafield Road with 0.8m SLR, and along SH75 begins to occur with 1 m SLR, which will impact access to Takamatua and Akaroa.
	MHWS (Monthly)										**Monthly tidal flooding –** Properties along Onawe Flat Road could be exposed to monthly flooding with 0.4 m SLR, and areas along Onawe Flat Road are already exposed to MHWS with 0.2 m SLR. Monthly flooding occurs along Seafield Road with 0.6m SLR, and begins to encroach into the holiday park. Adjacent properties to the holiday park start to become impacted by MHWS with 0.8m SLR. Access along SH75 is impacted with 0.8m SLR, with flooding becoming more extensive across the road and properties as SLR increases, which will also impact access to Takamatua and Akaroa.
Barrys Bay	MHW (Daily)										**Daily tidal flooding –** Minor disconnected flooding on the landward side of SH75 with 0.8 m SLR, which becomes connected flooding with 1 m SLR across SH75 and encroaches on property. Flooding will impact access to Duvauchelle,

Area	Tidal Reference	SLR Increment									Commentary
		0 m	0.2 m	0.4 m	0.6 m	0.8 m	1.0 m	1.2 m	1.5 m	2.0 m	
	MHWS (Monthly)										Takamatua, and Akaroa. Onawe Flat Road becomes exposed to disconnected flooding with 0.6m SLR, which becomes connected and widespread with 0.8 m SLR, impacting access along this road. **Monthly tidal flooding –** Areas along SH75 become exposed to disconnected flooding with 0.6m SLR, which becomes connected and widespread with 0.8m SLR, potentially disrupting access to Duvauchelle, Takamatua, and Akaroa. Onawe Flat Road exposed to connected flooding with 0.4m SLR, impacting access along this road.
French Farm	MHW (Daily)										**Daily tidal flooding –** Flooding begins to encroach on Wainui Main Road at French Farm with 0.8 m SLR, and becomes widespread with 1.2m SLR, which will impact access to Wainui.
	MHWS (Monthly)										**Monthly tidal flooding –** Flooding begins to encroach on Wainui Main Road with 0.6 m SLR, with the road becoming increasingly exposed with SLR. Access along Wainui Main Road is completely flooded with 1 m SLR, where access to French Farm and Wainui is disrupted.
Tikao Bay	MHW (Daily)										**Daily tidal flooding –** Disconnected flooding begins to encroach on small number of properties with 1.5 m SLR, which becomes connected with 2.0 m SLR, and impacting access to other properties (along Tikao Bay Road).
	MHWS (Monthly)										**Monthly tidal flooding –** Disconnected flooding begins to encroach on property with 1.2 m SLR. Flooding becomes connected and could disrupt access along Tikao Bay Road with 1.5 m SLR.
Wainui	MHW (Daily)										**Daily tidal flooding -** Disconnected tidal flooding encroaches on properties with 0.8 m SLR, which becomes more extensive with SLR across properties, before it connects to the sea with 2.0 m SLR.
	MHWS (Monthly)										**Monthly tidal flooding -** Disconnected flooding encroaches on properties with 0.6 m SLR. Disconnected flooding becomes extensive across properties, then becomes connected to the sea with 1.5m SLR.
Birdlings Flat	MHW (Daily)										**Daily tidal flooding -** No properties are exposed to flooding with up to 2.0 m SLR, however access along SH75 is exposed to disconnected flooding from 1.2 m SLR onwards.
	MHWS (Monthly)										**Monthly tidal flooding -** No properties are exposed to flooding with up to 2.0 m SLR, however access along SH75 is exposed to disconnected flooding from 0.8 m SLR onwards.

Appendix A. 'Plain Language' Summary

Mapping of tidal water levels has been undertaken as a part of the broader Christchurch City Council Coastal Hazards Adaptation Planning Programme. This programme has identified the coastal flooding, erosion, and groundwater-rise hazards across the city and Banks Peninsula with sea level rise into the future, and is in the process of developing adaptation plans for council assets that service communities. The council hazard web viewer currently presents information for coastal flooding, and shows where flooding would occur in a coastal storm event (i.e. for an annual storm, a 1 in 10 year storm, and a 1 in 100 year storm).

The mapping of tidal water levels in this study show where 'sunny day' flooding that occurs under normal weather conditions with and without sea level rise will reach throughout Christchurch and Banks Peninsula. The methodology used in this assessment to determine the tidally mapped areas is the same as that used in the Tonkin and Taylor (2021) Coastal Hazard Assessment for the district, which assessed the coastal flood hazard during storms. This study has mapped two tidal positions:

- **Mean High Water (MHW):** This where water will reach on an average high tide, representing daily flooding; and
- **Mean High Water Spring (MHWS):** This is the average of the higher 'spring' tide level, and represents where water could reach approximately once a month (i.e. monthly flooding).

More significant coastal flooding conditions will occur less regularly during king tides (not modelled in this study). The mapping of tide levels presented in this report show where these two tidal levels occur today (with no sea level rise). Sea level rise is then added to show how flooding could change in the future (with up to 2.0 m of sea level rise). The maps show areas shaded in blue and green, where darker shades are representative of deeper flooding. Areas shaded in blue show flooding above mean sea level that is directly connected to the sea, and there is currently a pathway through which water can travel to reach that location. Areas shaded in green are not directly connected to the sea, but are shown as potentially flooded due to land elevations being lower than the tide level mapped. These areas could be connected via infrastructure (e.g. stormwater pipes), or may connect in the future with sea level rise.

The results of the tidal mapping show that generally across the district, areas where property or roads (impacting access) will become exposed to daily tidal flooding first are:

- Brooklands
- Bexley
- Teddington

Fortunately these areas are sparsely populated. Daily flooding under higher SLR increments will eventually impact more developed urban areas that are much more densely populated. In addition to these, areas along the coast where access or properties could become effected by monthly flooding first are:

- New Brighton
- South New Brighton
- Southshore
- McCormacks Bay/Redcliffs
- Purau
- Port Levy
- Okains Bay
- Akaroa
- Duvauchelle
- Takamatua

Other areas along the coast also become exposed to regular tidal flooding with higher projections of sea level rise. However, there were several locations around the coastline where only minor or disconnected tidal flooding is anticipated with up to 2.0 m SLR:

- Waimairi Beach
- Taylors Mistake
- Corsair Bay
- Cass Bay
- Rapaki
- Diamond Harbour
- Birdlings flat

Appendix B. Mean High Water and Mean High Water Spring Maps

The following present maps at various locations through the Christchurch District discussed in Section 4 of this report. Maps are presented for community area that show flooding under Mean High Water (MHW) and Mean High Water Spring (MHWS) water levels for present day (0m SLR), 0.6 m SLR, and 1.2 m SLR. Spatial data for the additional SLR scenarios not mapped in the follow sections is available on the Christchurch City Council Coastal Hazards Portal.

The maps show:

- Areas of 'connected' flooding in varying shade of blue. These are areas where flooding has a direct pathway (connection) to the sea; and
- Areas of 'disconnected' flooding in varying shades of green. There are areas where land elevation is lower than the tidal water level, however there is not a direct pathway (connection) to the sea. It is noted that these areas could be connected via underground stormwater network, or due to being such low elevation could be impacted by groundwater.

The varying shades of blue and grey are representative of water depths across the area, using the following key:

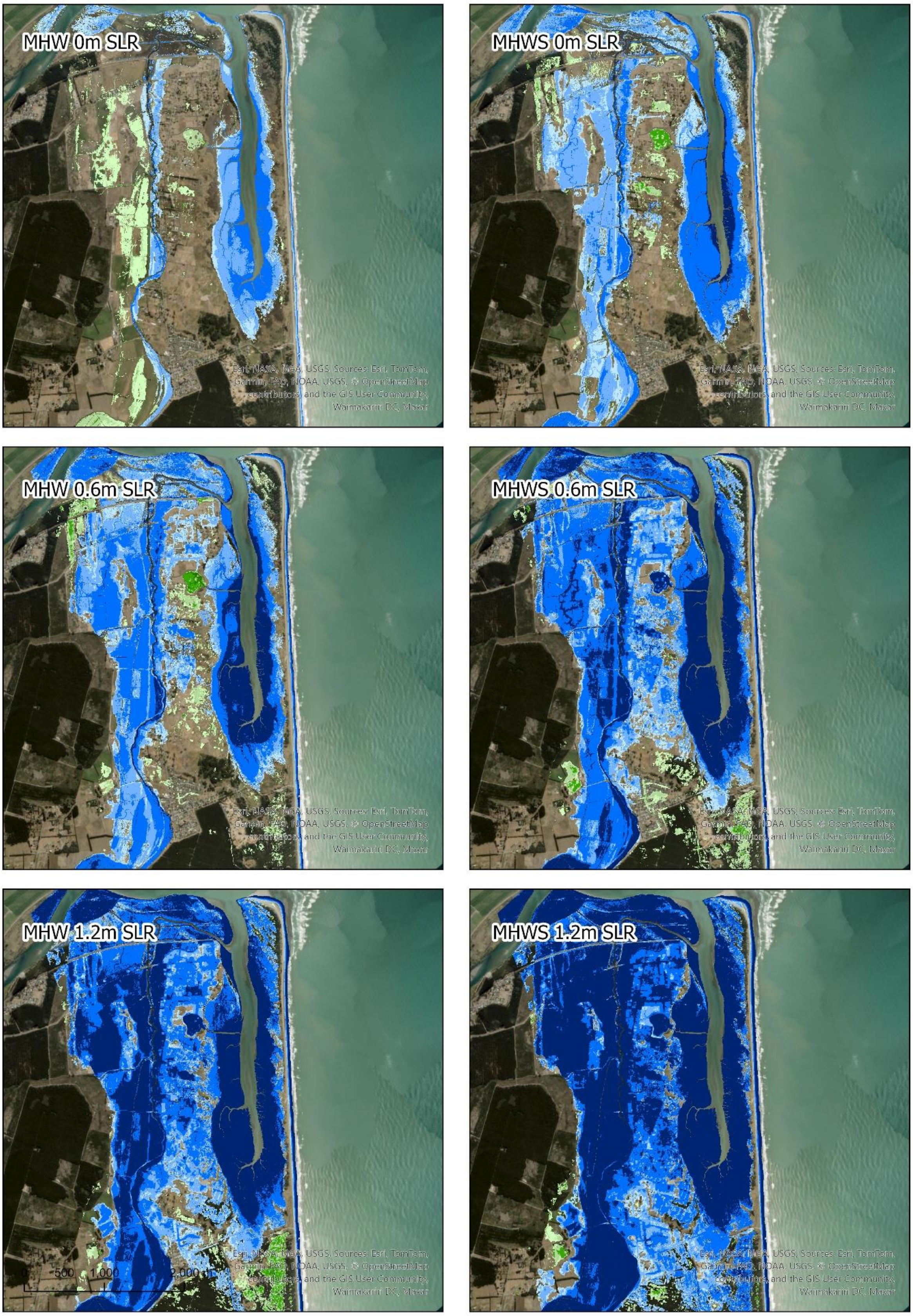
Connected Flooding		Disconnected Flooding	
Symbol	Flooding Depth	Symbol	Flooding Depth
	0.0 – 0.2 m		0.0 – 0.2 m
	0.2 – 0.5 m		0.2 – 0.5 m
	0.5 – 1.0 m		0.5 – 1.0 m
	More than 1.0 m		More than 1.0 m

Maps are provided for areas along the coast where there are communities of interest:

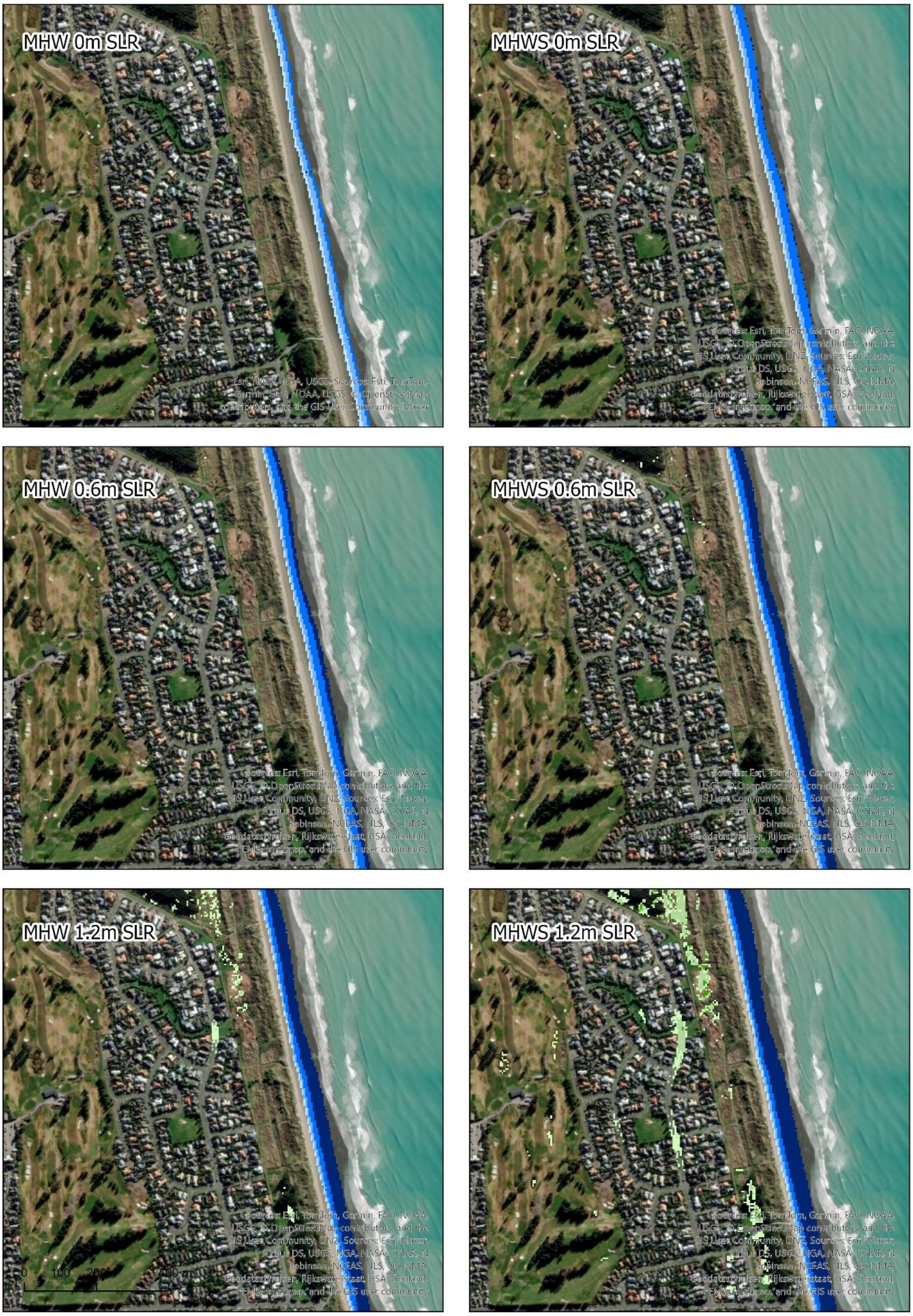
- Maps B1-B12 cover Christchurch Open Coast and Avon-Heathcote Estuary;
- Maps B13-B23 cover Lyttelton Harbour and Port Levy;
- Maps B24 – B27 cover bays with communities on Northern-Eastern Banks Peninsula;
- Maps B28-B34 cover bays and townships within Akaroa Harbour; and
- Map B35 covers Birdlings Flat.

Commentary on each area includes analysis of when properties or infrastructure may become an issue for the community across all SLR increments (0m, 0.2m, 0.4, 0.6m, 0.8m, 1.0m, 1.2m 1.5m, 2.0m SLR) is included in Section 4 of this report.

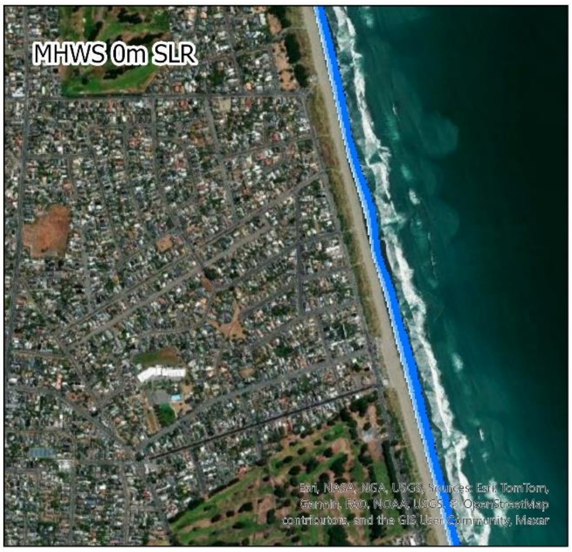
B.1 Brooklands-Spencer Park

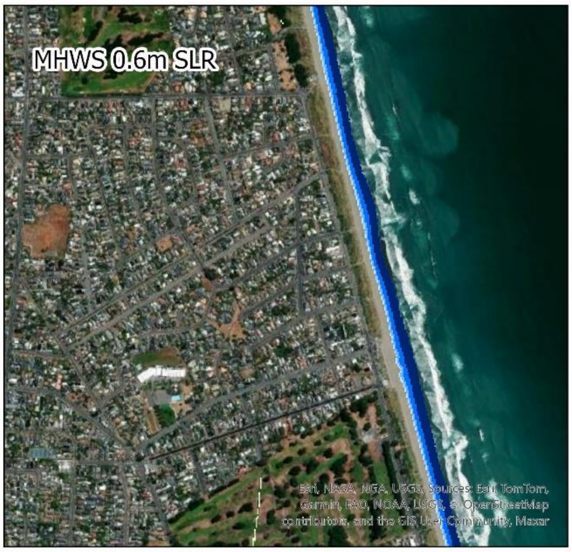


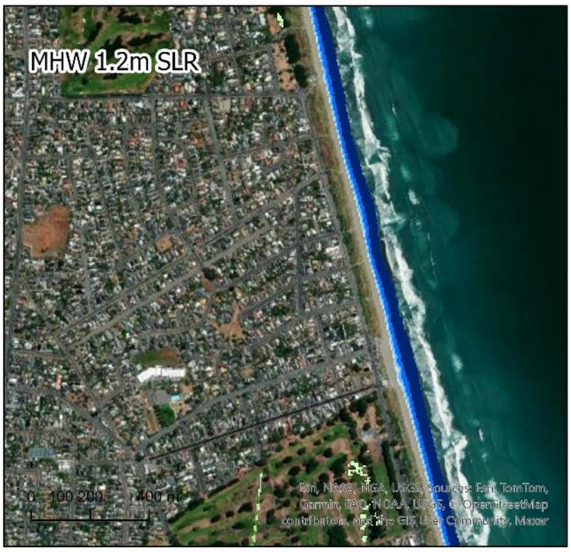
B.2 Waimairi Beach



B.3 North New Brighton



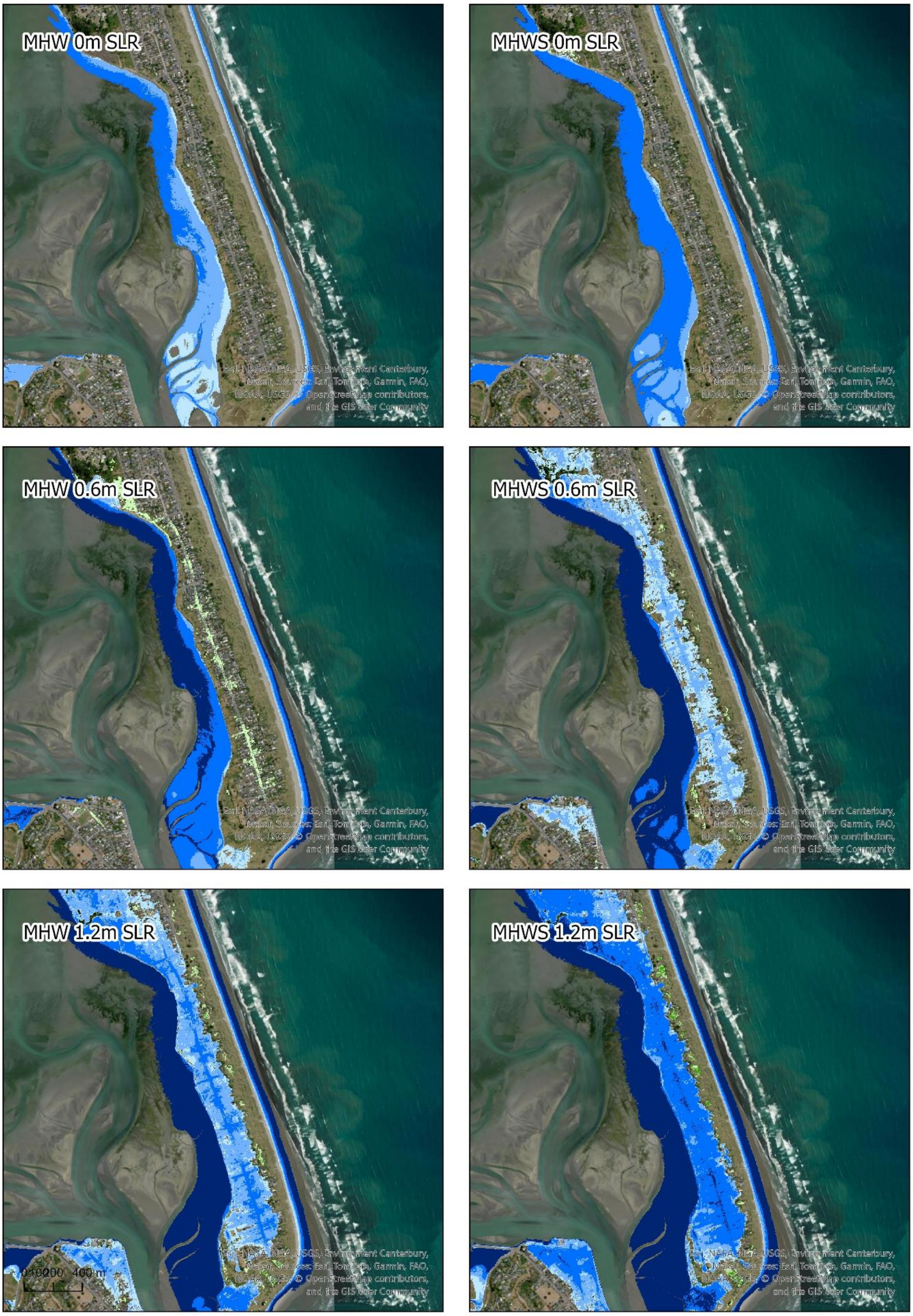




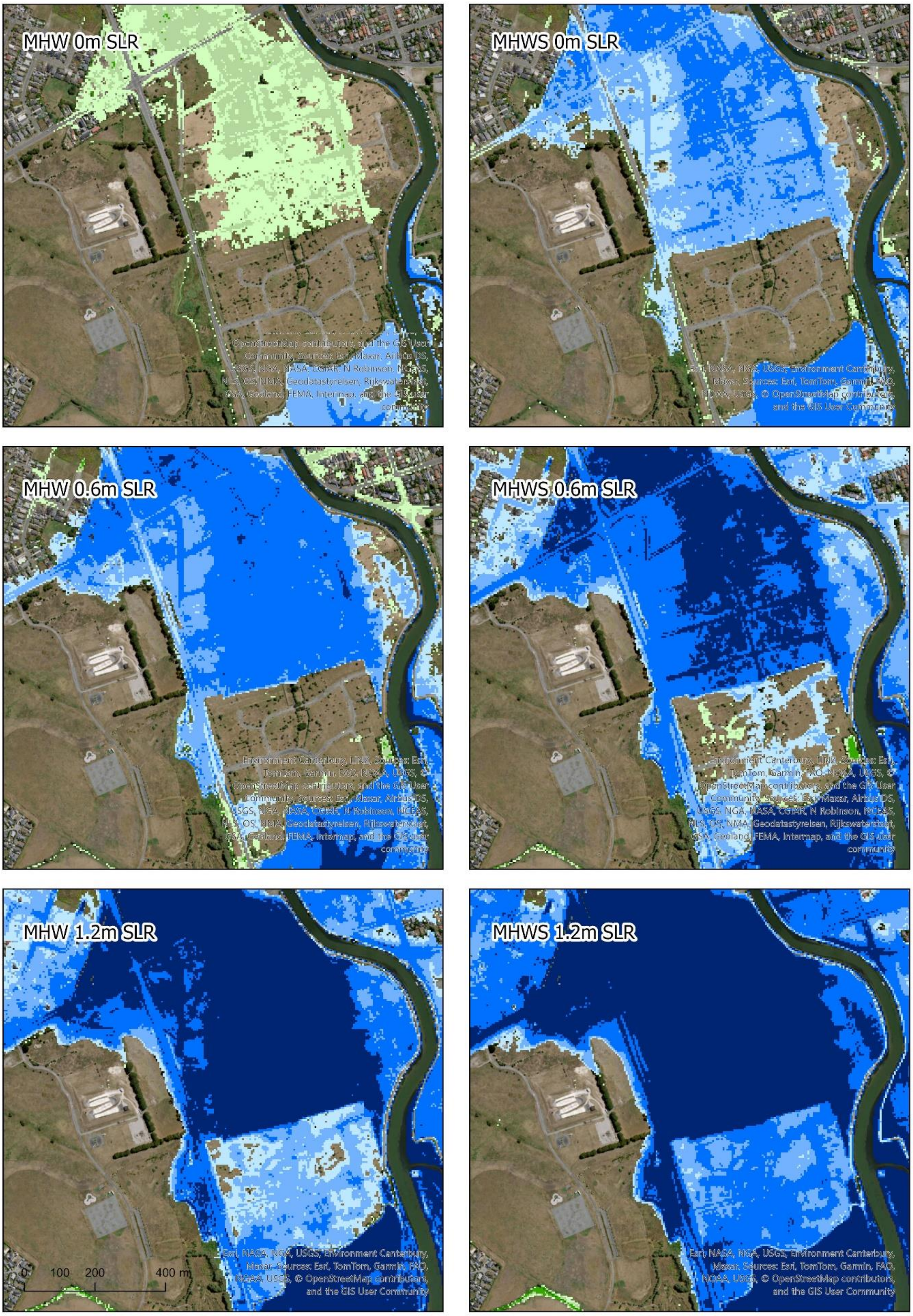
B.4 New Brighton

B.5 South New Brighton

B.6 Southshore



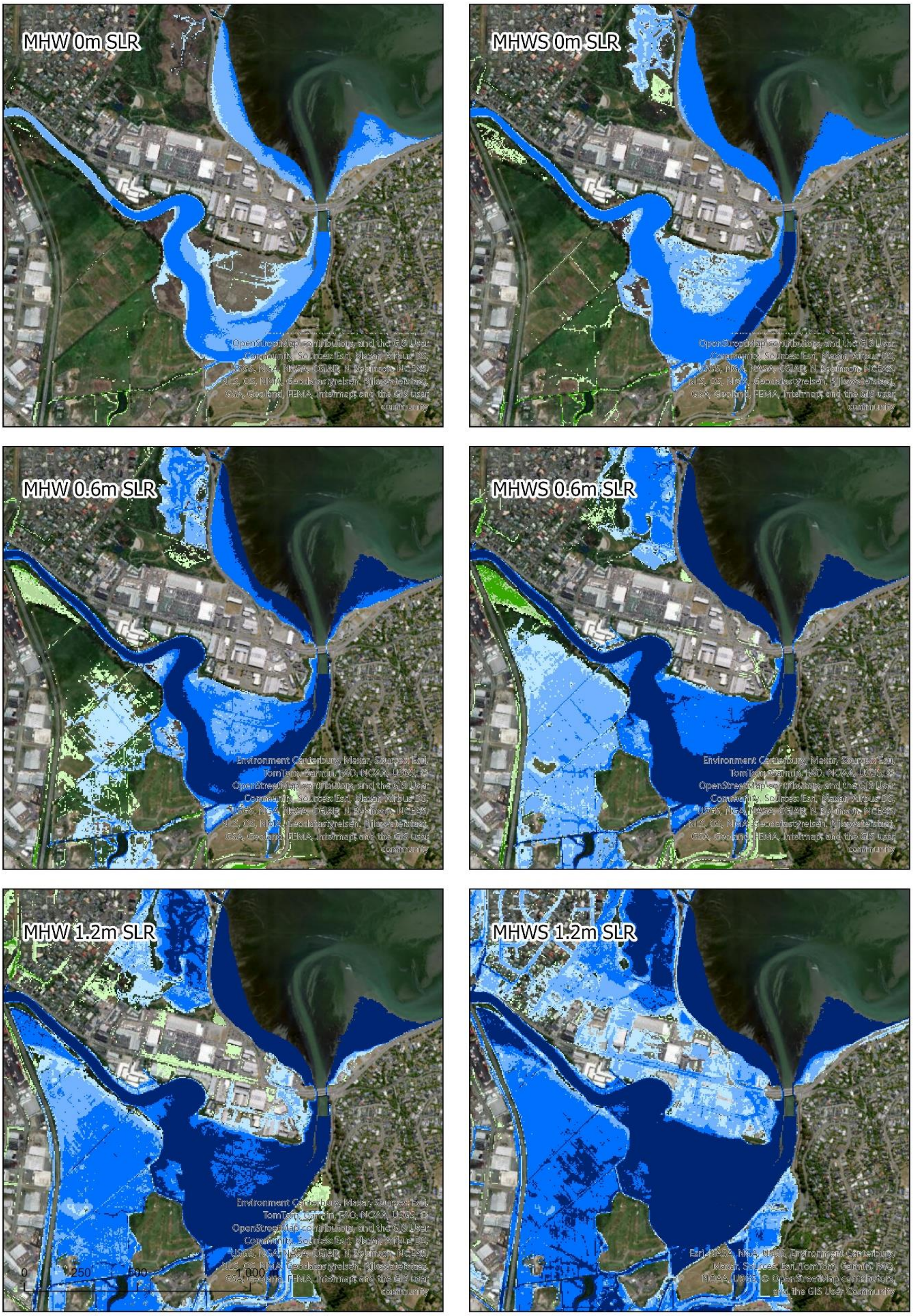
B.7 Bexley


MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR
0 100 200 400 m
Esri, NASA, NGA, USGS, Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

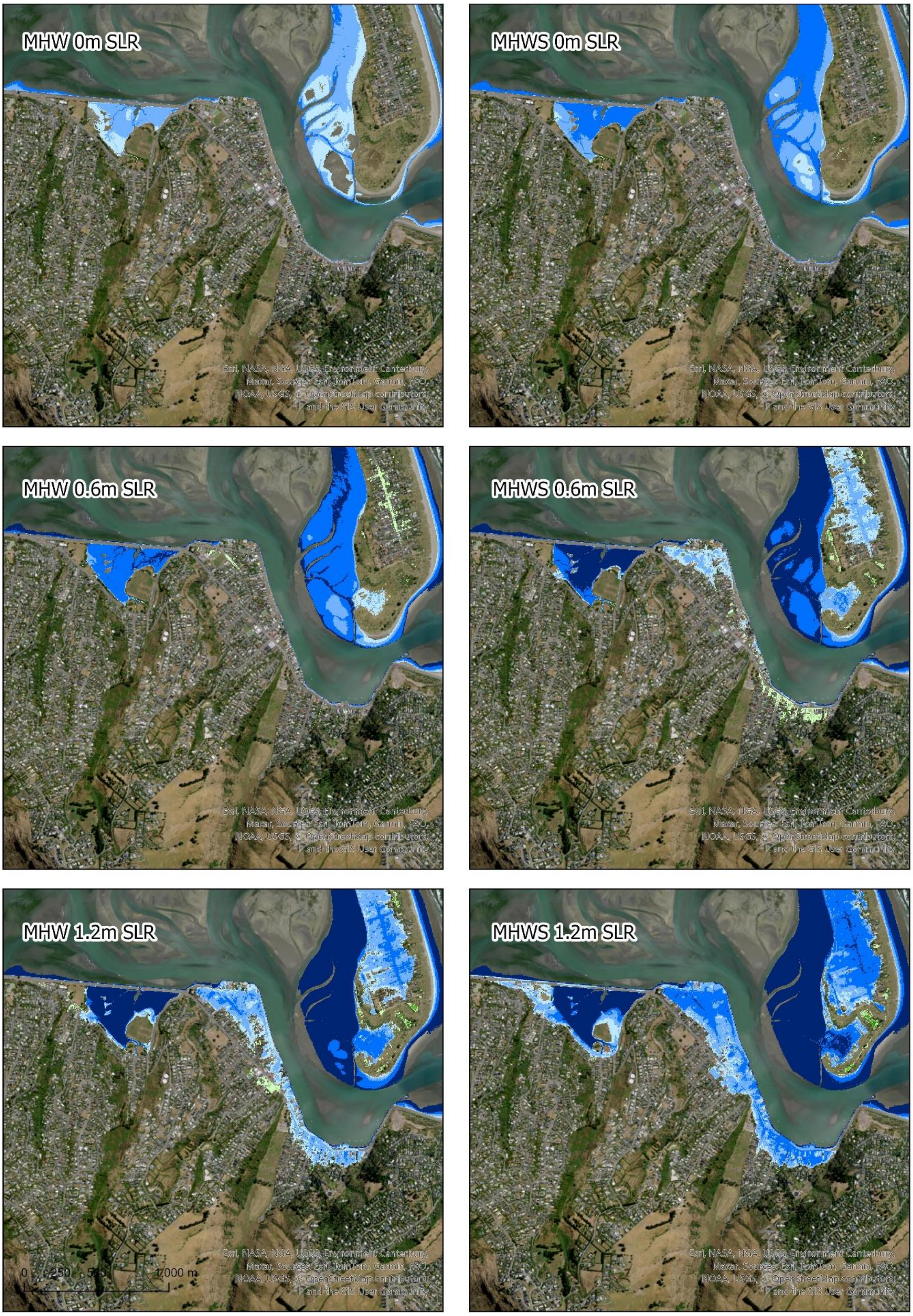
B.8 Bromley


MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR
Esri, NASA, NGA, USGS, Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

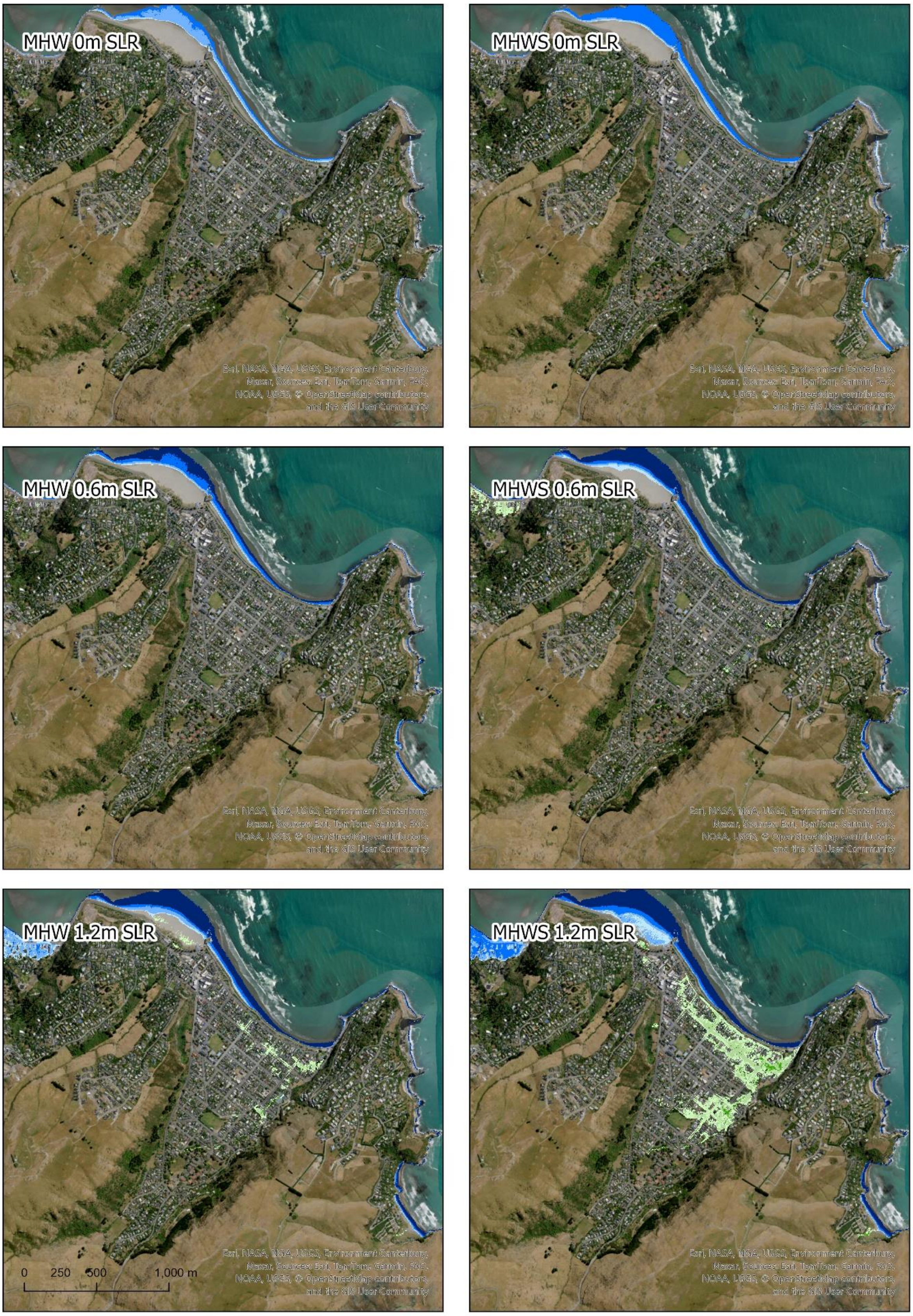
B.9 Ferrymead



B.10 McCormacks Bay – Redcliffs



B.11 Sumner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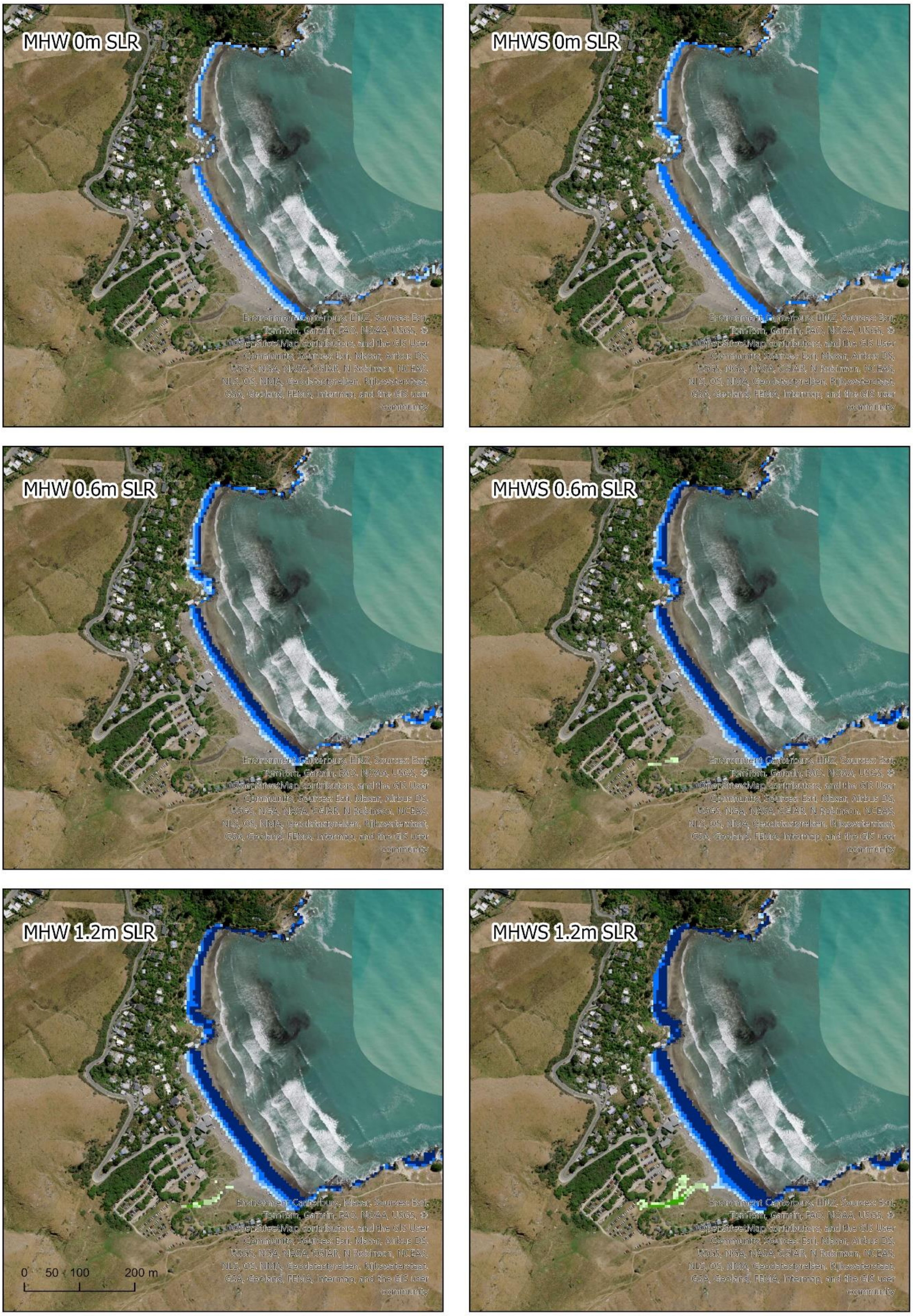
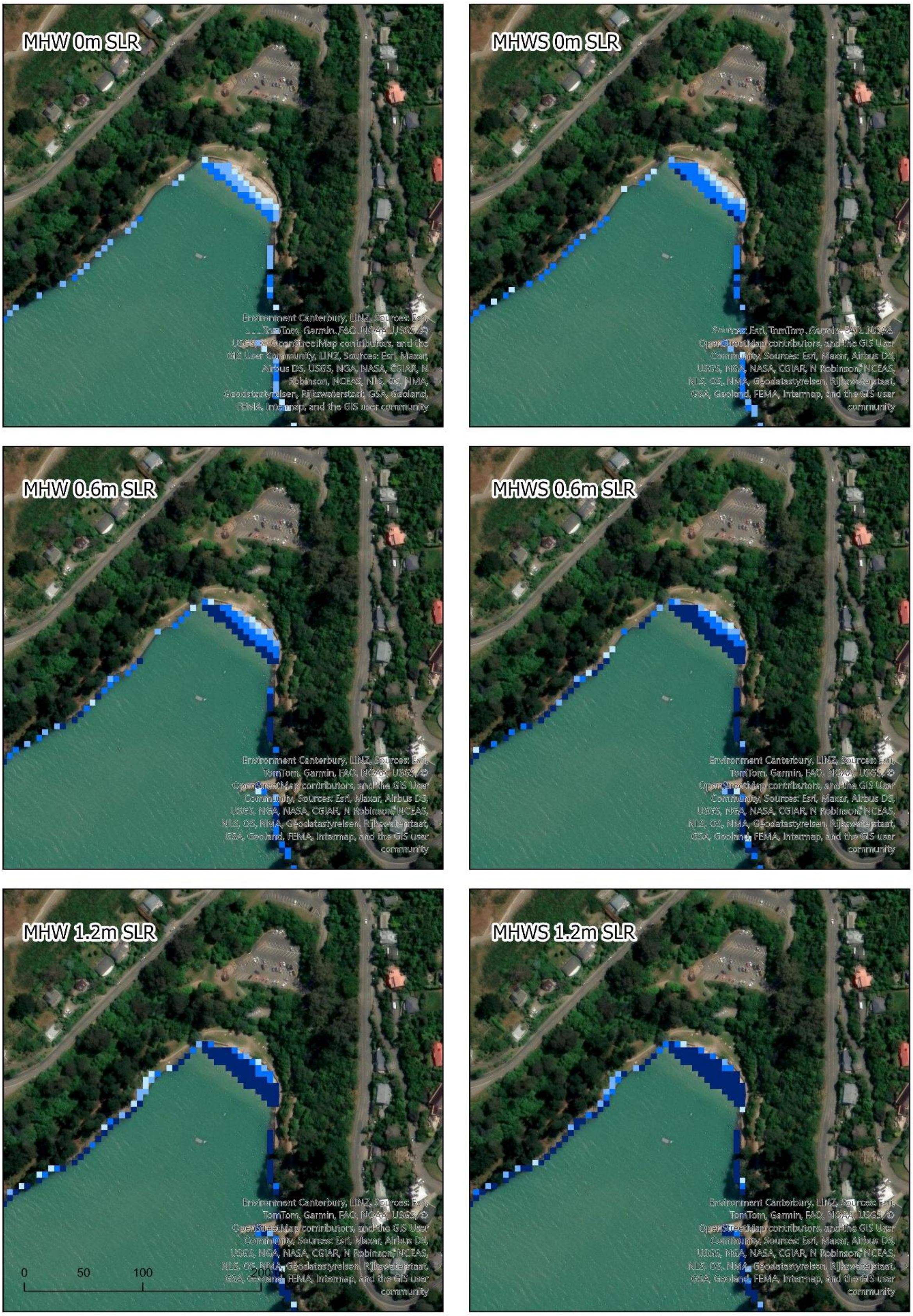
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR
0 250 500 1,000 m
Esri, NASA, NGA, USGS, Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

B.12 Taylors Mistake

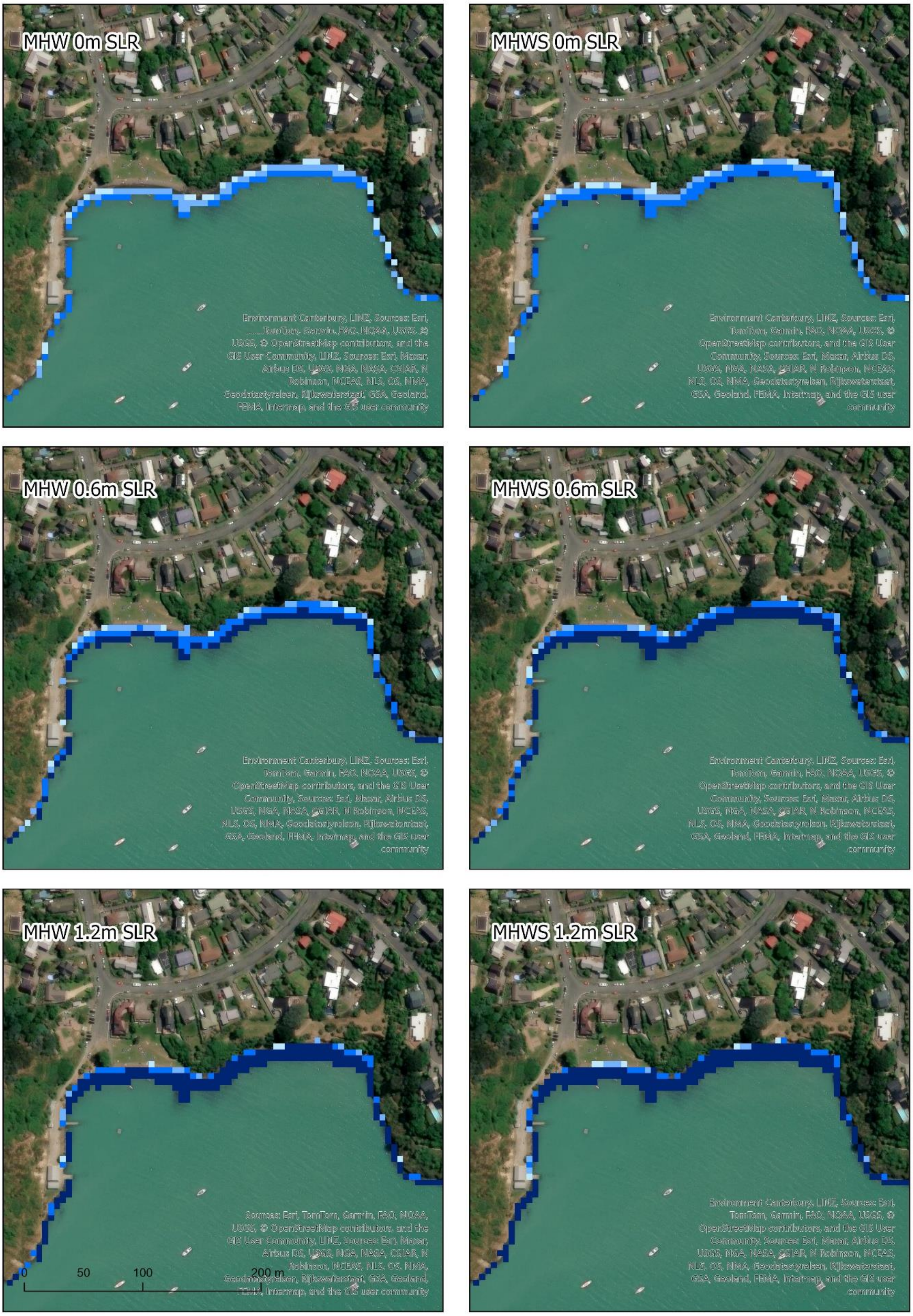


B.13 Lyttelton

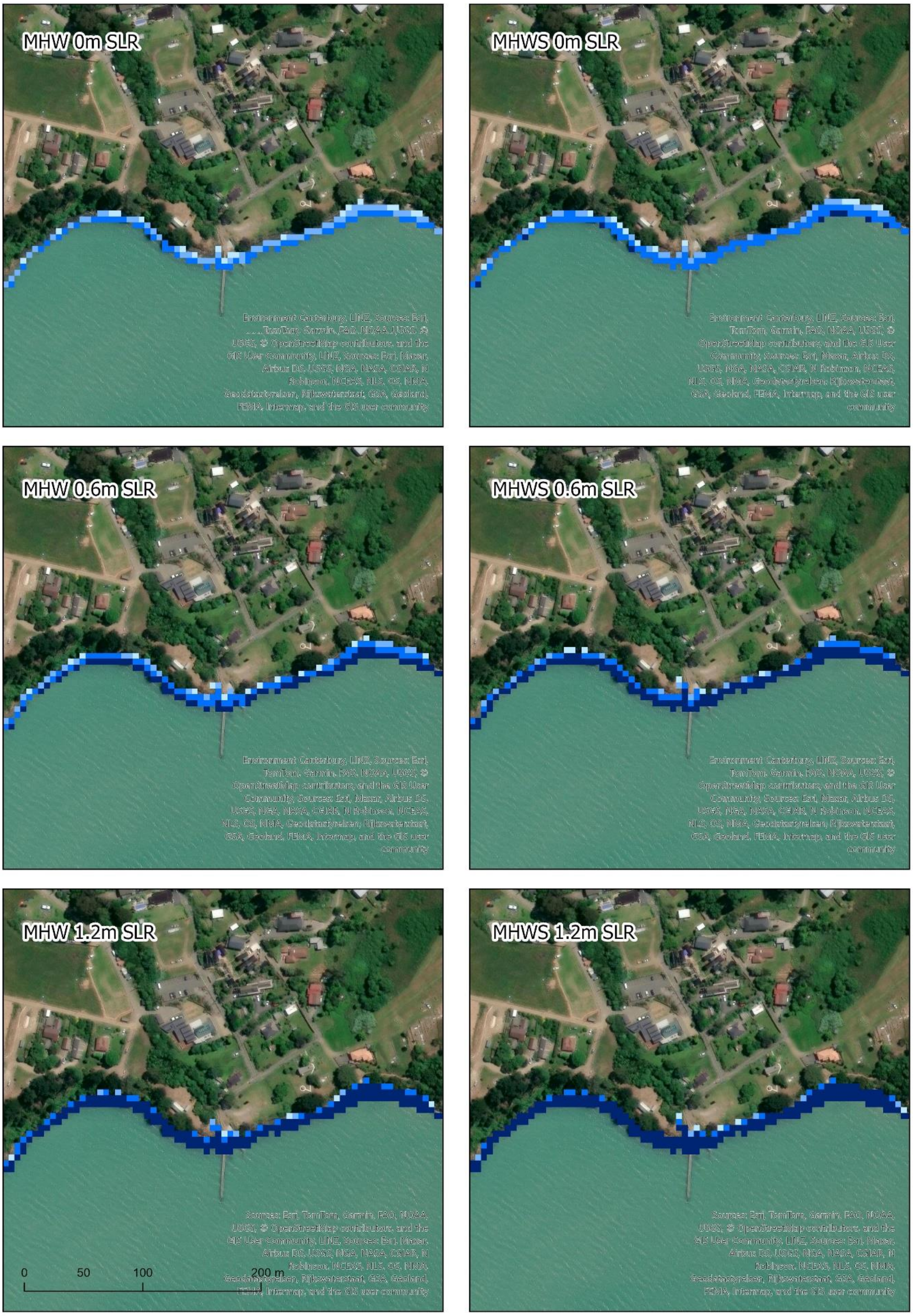
B.14 Corsair Bay



B.15 Cass Bay

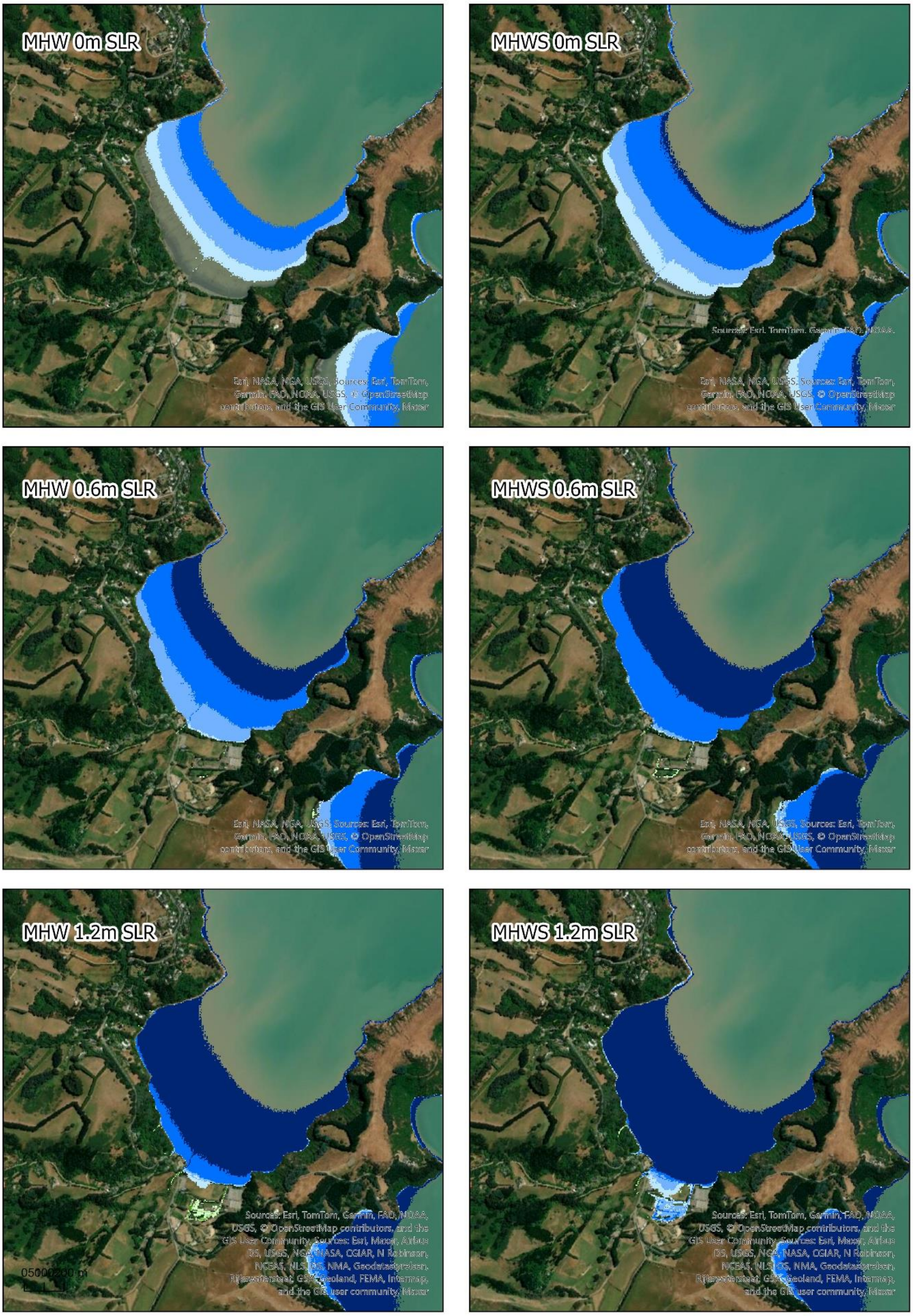

MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR
0
50
100
200 m

B.16 Rāpaki

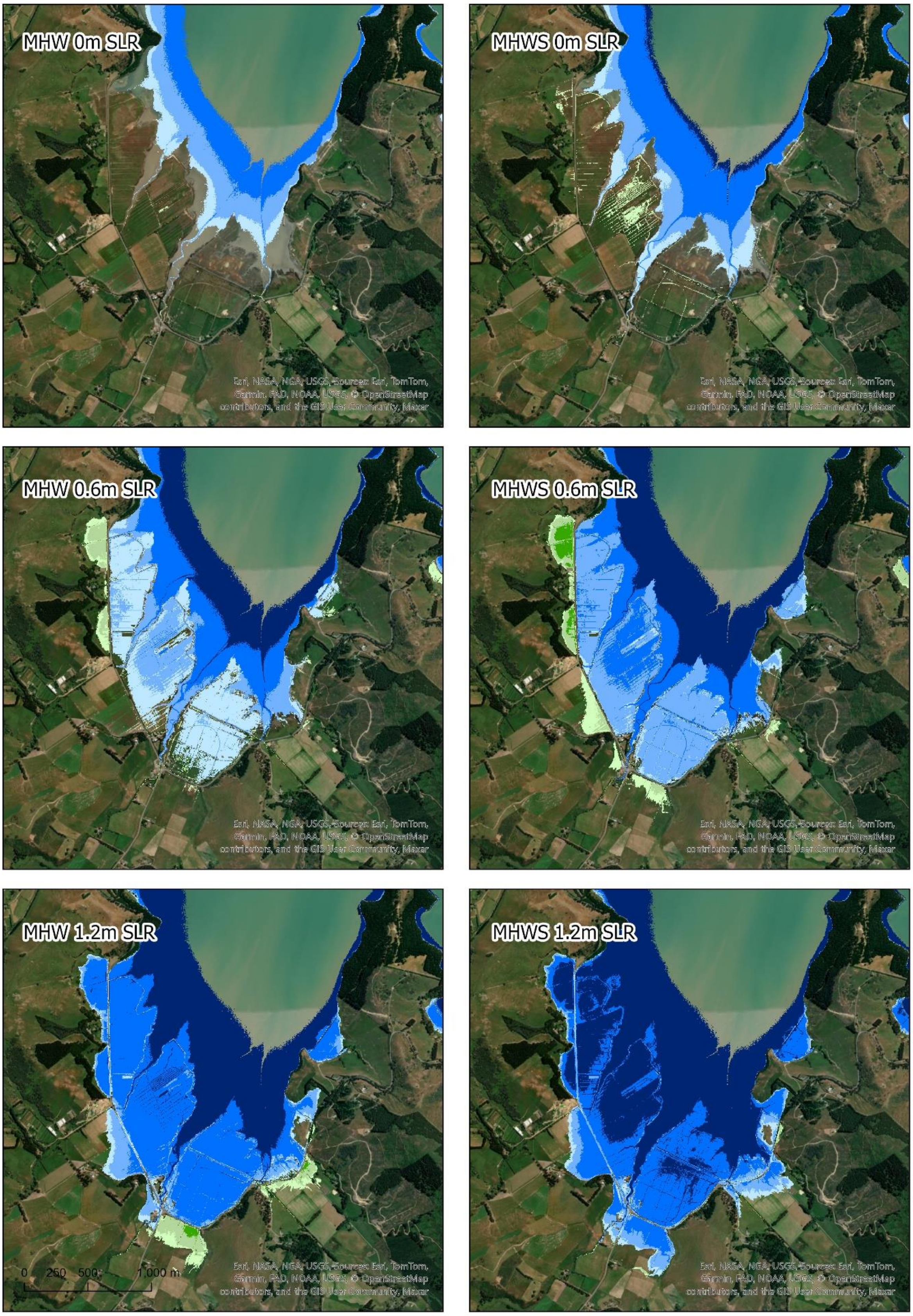

MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR
0
50
100
200 m

B.17 Governors Bay

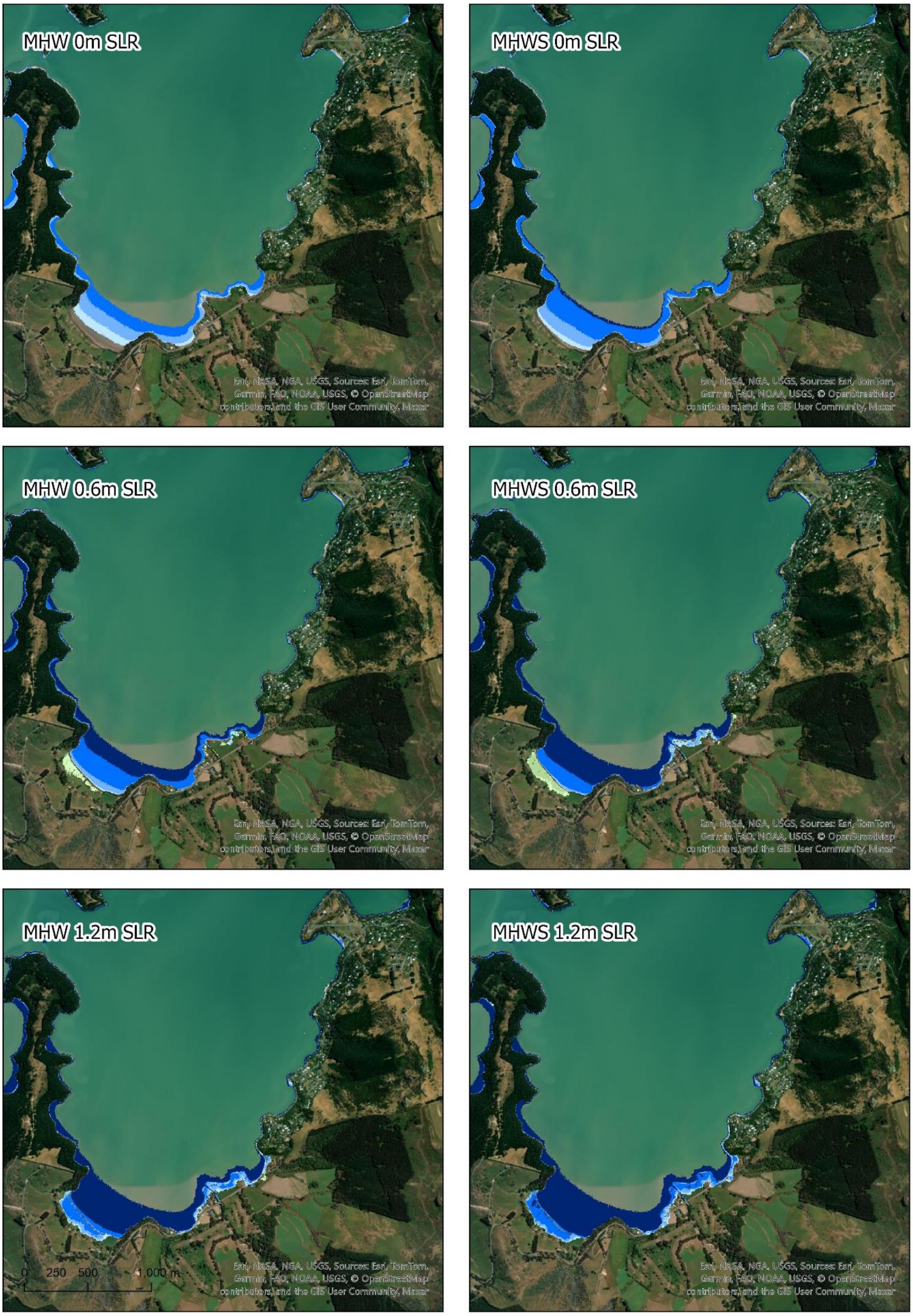
B.18 Allandale



B.19 Teddington



B.20 Charteris Bay



B.21 Diamond Harbour

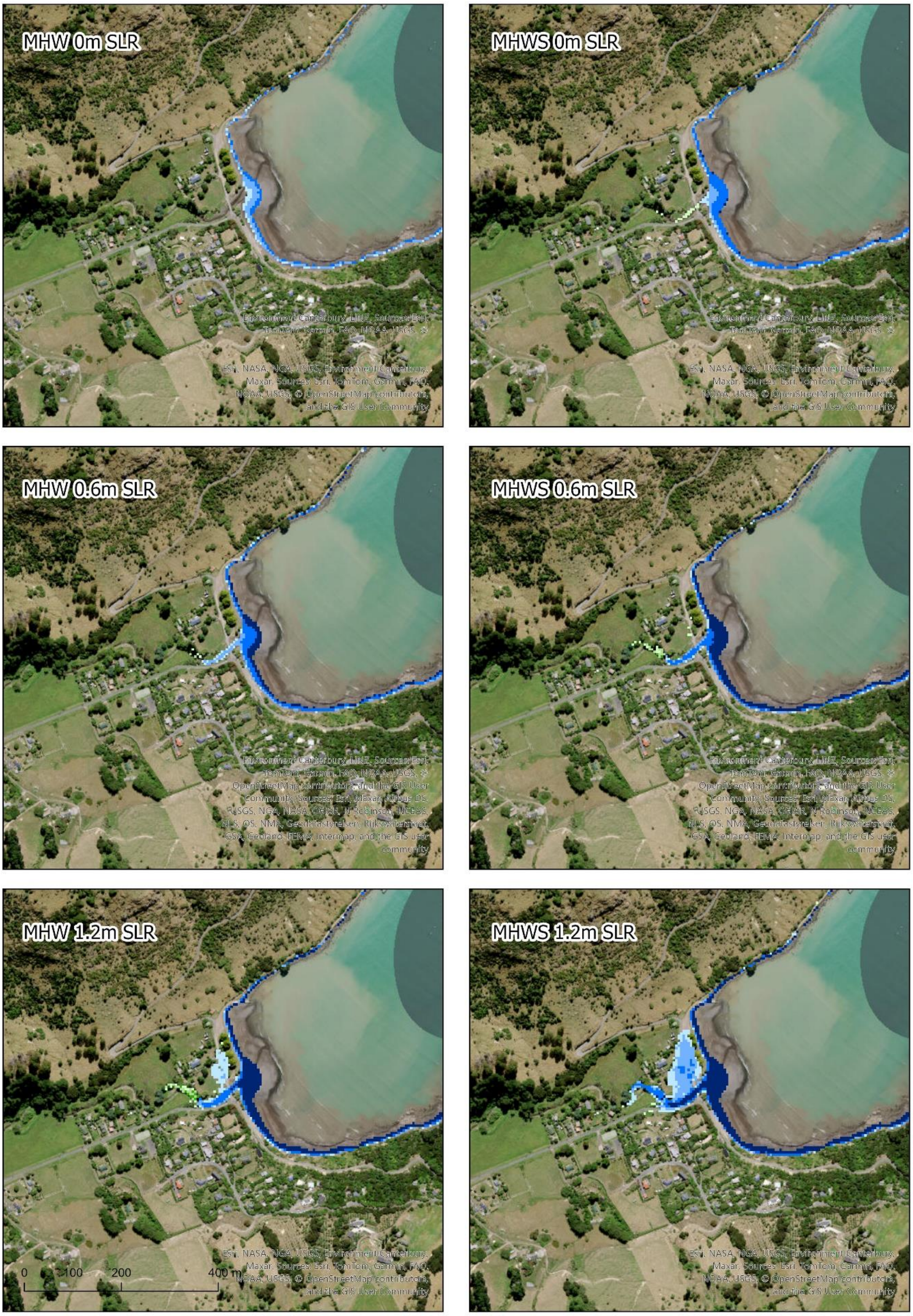
B.22 Purau


MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR

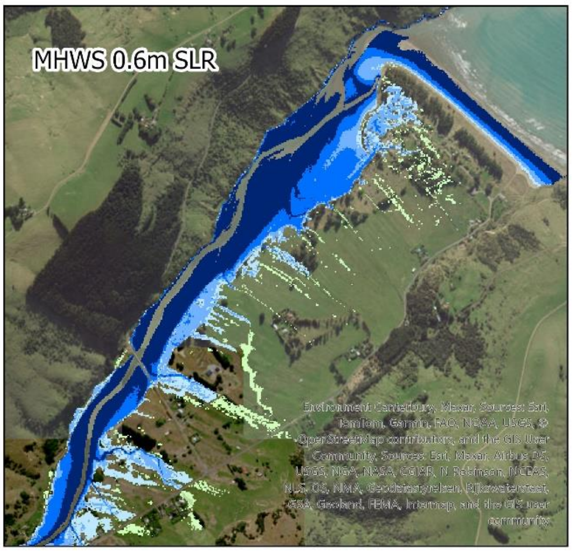
B.23 Port Levy

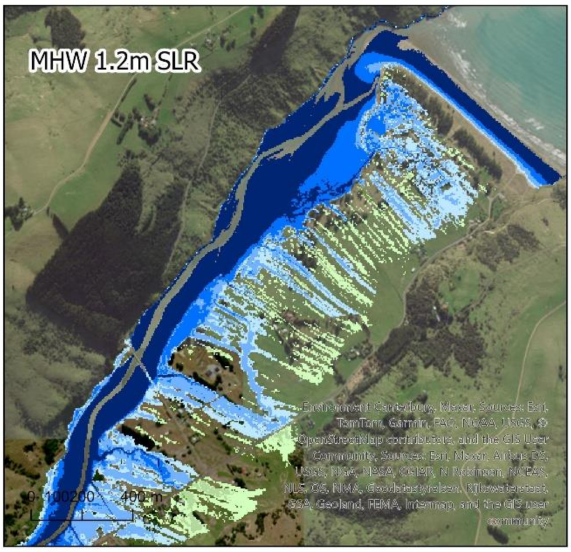
B.24 Pigeon Bay

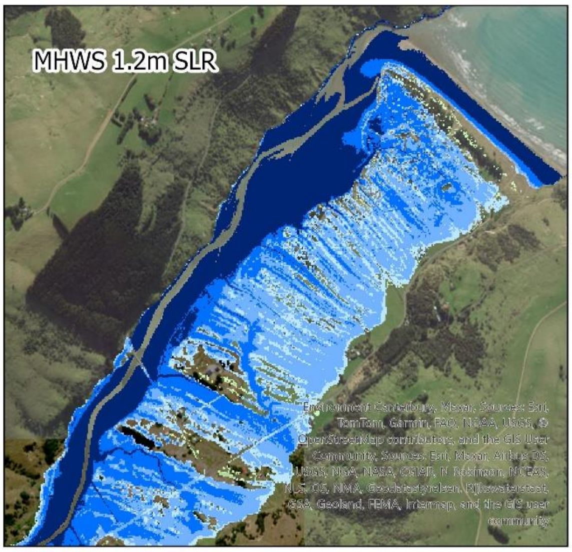
B.25 Little Akaloa



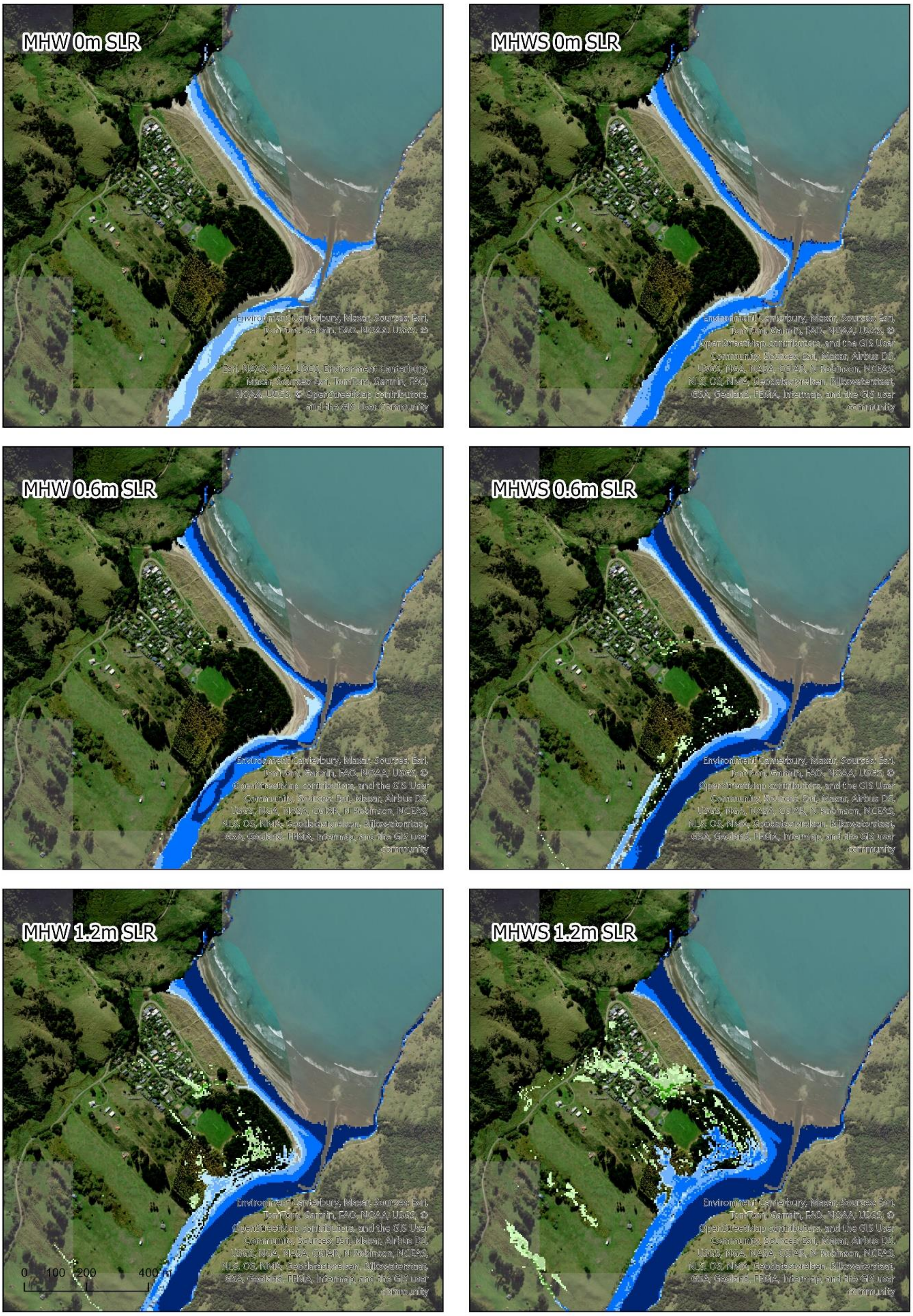
B.26 Okains Bay







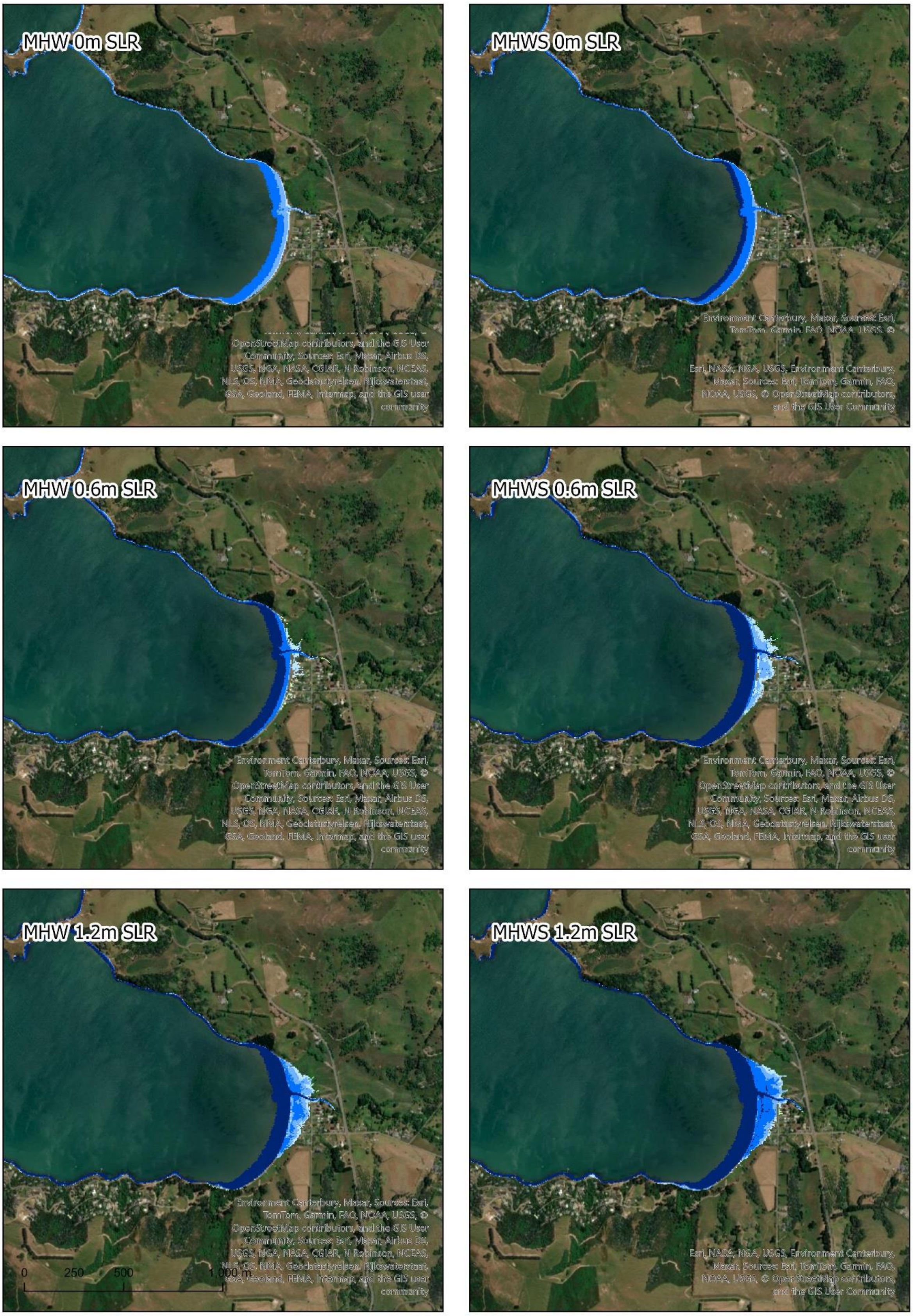
B.27 Le Bons Bay



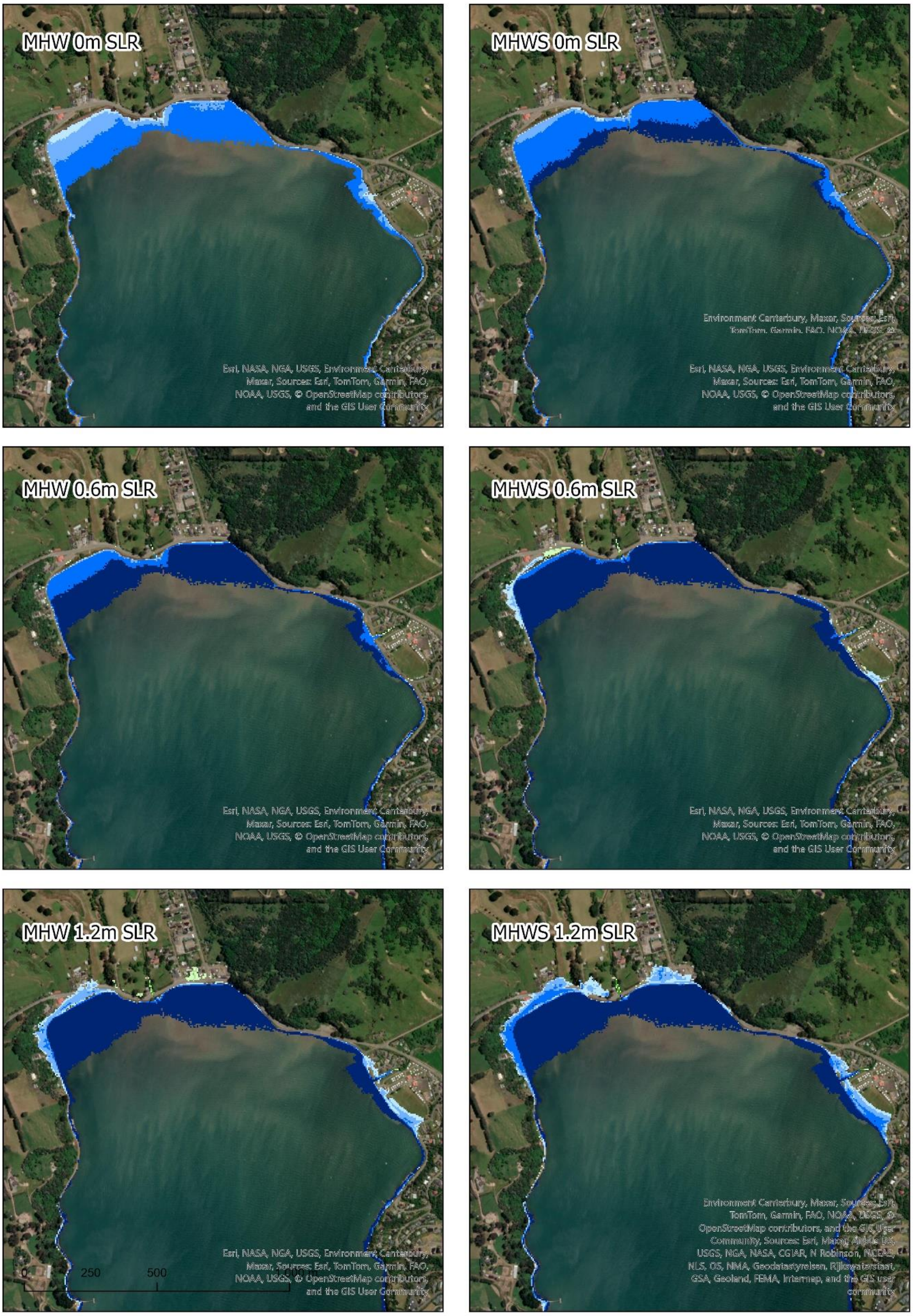
B.28 Akaroa


MHW 0m SLR
MHWS 0m SLR
MHW 0.6m SLR
MHWS 0.6m SLR
MHW 1.2m SLR
MHWS 1.2m SLR

B.29 Takamatua

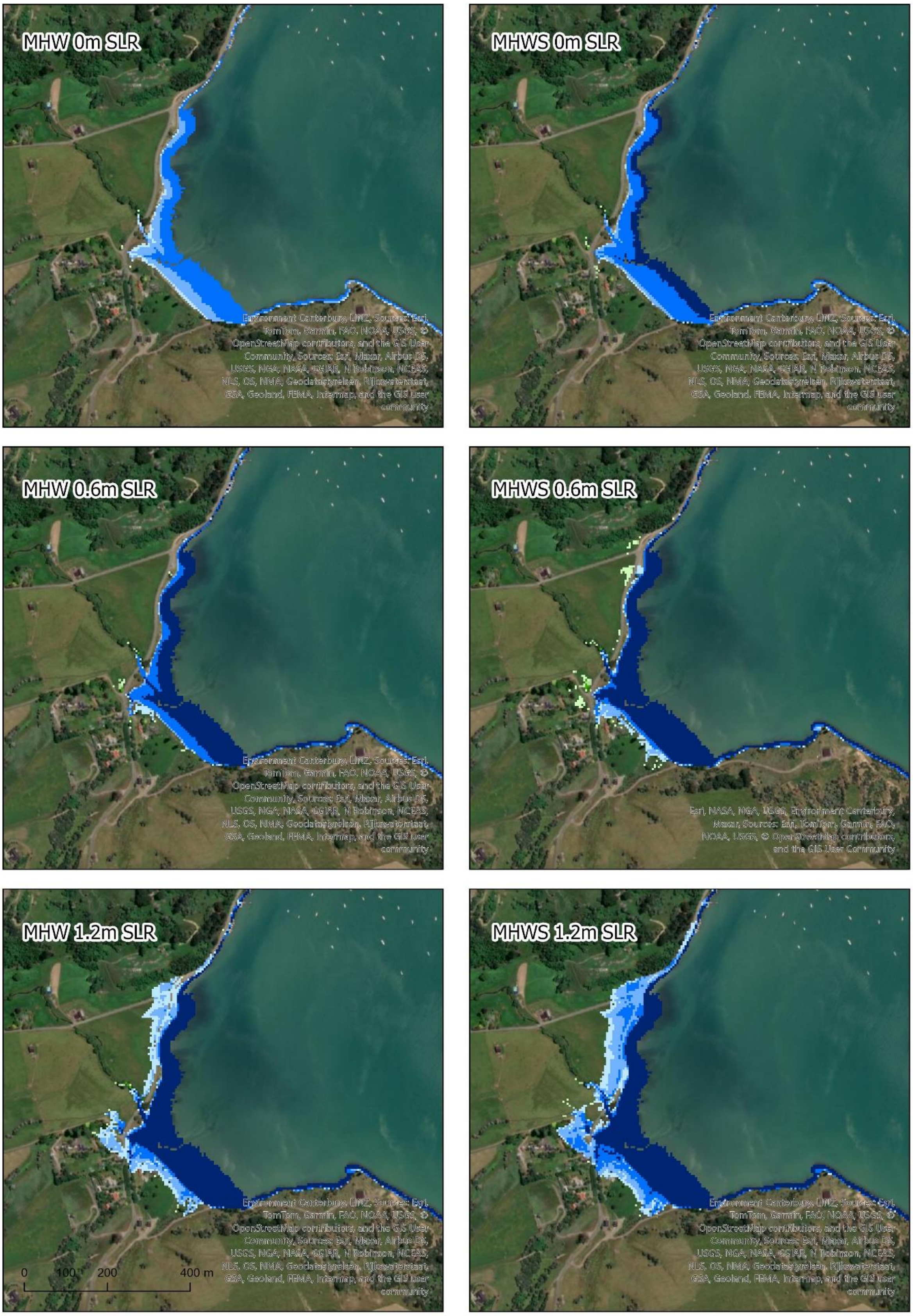


B.30 Duvauchelle

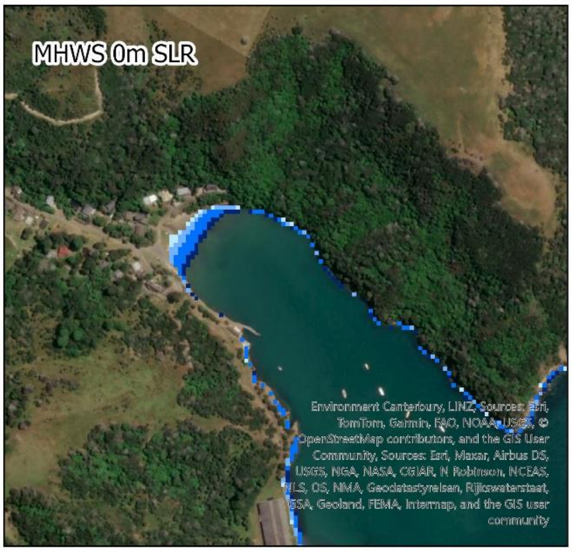


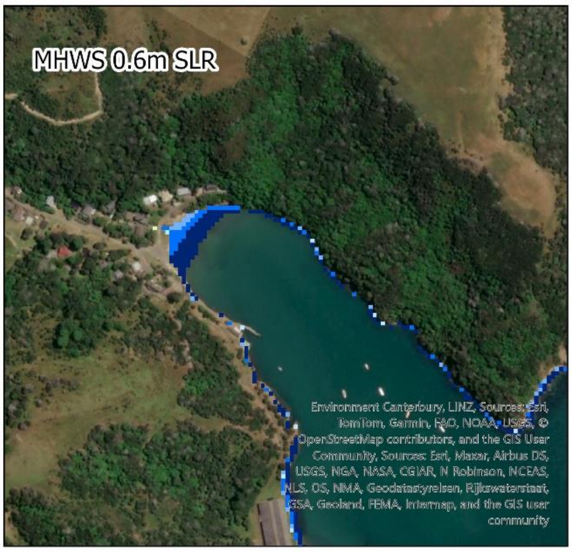
B.31 Barrys Bay

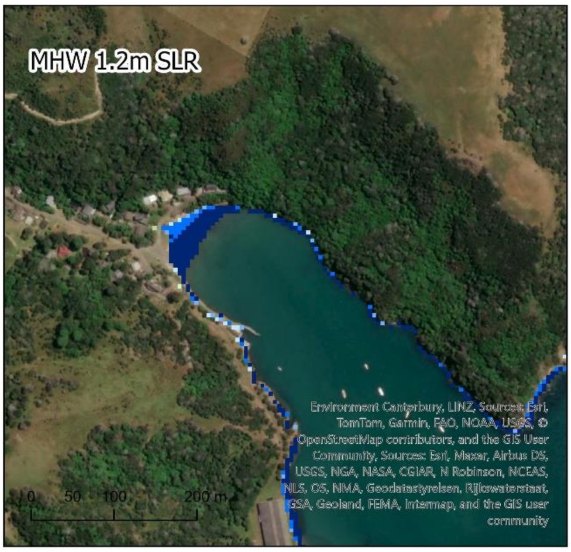
B.32 French Farm



B.33 Tikao Bay



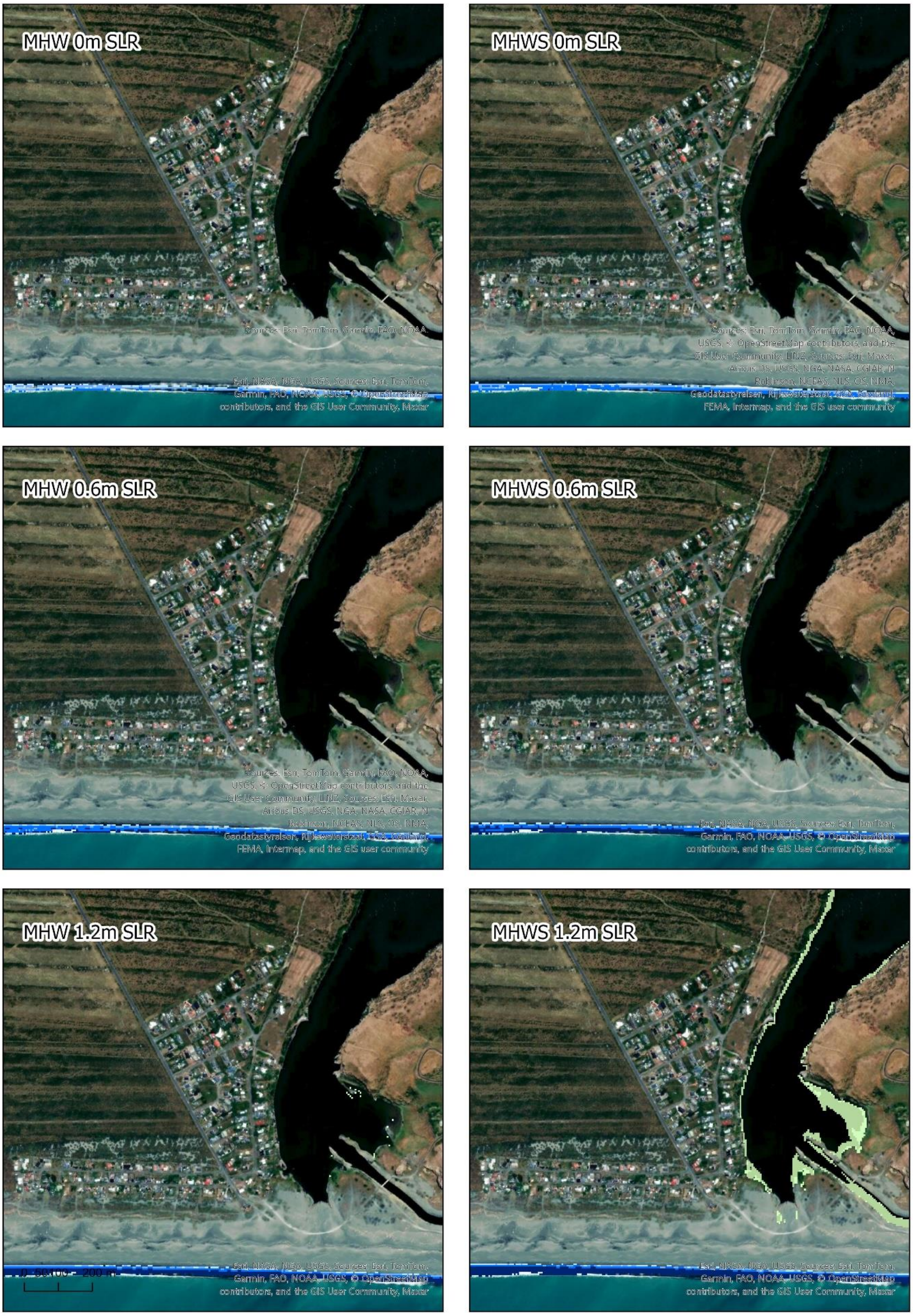




B.34 Wainui


MHW 0m SLR
Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community
MHWS 0m SLR
Environment Canterbury, LINZ, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community
MHW 0.6m SLR
Environment Canterbury, LINZ, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community
MHWS 0.6m SLR
Environment Canterbury, LINZ, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community
MHW 1.2m SLR
0 50 100 200 m
Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community
MHWS 1.2m SLR
Environment Canterbury, Maxar, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, Maxar, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community

B.35 Birdlings Flat



Appendix C. MHW and MHWS level with 1, 10, and 100 year ARI

Table C.1. Comparison table of Mean High Water and Mean High Water Spring levels developed for this study, compared to static inundation levels used to map coastal flooding in storms in the Tonkin and Taylor (2021) Coastal Hazard Assessment. Static inundation levels including wave set up for 1-, 10-, and 100-year ARIs are currently shown on the Coastal Hazards Portal.

Name	Mean High Water (m) (this study)	Mean High Water Spring (m) (this study)	1-year ARI Storm tide (m) – Excludes Wave Setup (T&T, 2021)	Static Inundation levels 1-year ARI – Includes Wave Setup (T&T, 2021)	Static Inundation levels 10-year ARI – Includes Wave Setup (T&T, 2021)	Static Inundation levels 100-year ARI – Includes Wave Setup (T&T, 2021)
Brooklands Lagoon	0.66	1.00	1.4	1.4	1.6	1.8
Christchurch Open Coast	0.50	0.88	1.37	1.8	2.0	2.3
Avon-Heathcote Estuary North	0.54	0.87	1.32	1.5	1.7	2.0
Avon-Heathcote Estuary South	0.54	0.87	1.32	1.5	1.6	1.8
Sumner	0.52	0.86	1.37	1.8	2.0	2.3
Taylors Mistake	0.52	0.87	1.37	1.8	2.0	2.3
Lyttleton Harbour	0.63	0.91	1.31	1.6	1.7	1.8
Banks Peninsula North	0.52	0.88	1.37	2.2	2.5	2.8
Banks Peninsula South	0.52	0.88	1.37	2.9	3.4	3.9
Akaroa Harbour	0.74	1.05	1.55[(1)]	1.9	2.1	2.3
Lake Forsyth	0.52	0.86				
Kaitorete Spit	0.52	0.86	1.37	2.6	2.9	3.3
Lake Ellesmere	0.52	0.86	1			
Note (1) Corrected from T&T (2021) in T&T (2022) Addendum.						