REPORT

Tonkin+Taylor

Coastal Inundation in Nelson City

Prepared for
Nelson City Council
Prepared by
Tonkin & Taylor Ltd
Date
November 2020
Job Number
1006718.v7

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Document Control

Title: Coastal Inundation in Nelson City					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
13/07/18	1	Draft for internal review	P Knook Q Hornblow	T Shand D Velluppillai	
20/07/18	2	Draft for external review	P Knook Q Hornblow	T Shand D Velluppillai	
23/07/18	3	Draft for external review with run-up section updated	P Knook Q Hornblow	T Shand D Velluppillai	
10/08/18	4	Final draft including client comment	T Shand	R Reinen-Hamill	R Reinen-Hamill
17/10/18	5	Final draft including effect on future shoreline	T Shand	R Reinen-Hamill	R Reinen-Hamill
05/09/19	6	Final including stage 1 and stage 2 assessment	M Fifield	R Reinen-Hamill	R Reinen-Hamill
06/11/20	7	Spelling corrections only	D Velluppillai	R Reinen-Hamill	R Reinen-Hamill

Distribution:

Nelson City Council	1 PDF copy
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Executive summary

Nelson City Council (NCC) engaged Tonkin & Taylor Ltd (T+T) to undertake a high level or *first-pass* coastal inundation assessment for Nelson City, followed by a more detailed and dynamic assessment. The first pass assessment was completed and reported on in October 2018. This report represents an update of the October 2018 report, to include the more recent dynamic assessment.

First pass assessment

This includes a review of available extreme coastal water level information, derivation of current and future extreme coastal water levels for general areas of Nelson City and mapping of land elevation for low lying areas of Nelson City. By combining both the derived extreme water levels and the elevation mapping, areas susceptible to inundation can be identified. The Nelson City coastline has been split into representative coastal cells within which the assessed extreme water levels are expected to be similar. The present day extreme coastal inundation level has been assessed based on a combination of astronomical tide, storm surge and wave effects with values derived using the updated NIWA (2018) coastal calculator. Coastal water levels with an annual exceedance probability (AEP) of 1% (a 1% AEP event is equivalent to a 100 year ‘return period’ event) have been found to vary between 2.5 and 3.1 m above NZVD2016. The future extreme coastal water levels include allowance for future sea level rise based on guidance provided in MfE (2017). These 1% AEP levels range between 2.8 and 3.6 m NZVD2016 in 2070 and between 3.1 and 4.5 m NZVD2016 in 2130 depending on the adopted sea level rise projection.

The assessment has also mapped land elevation for low lying areas of Nelson City. Areas that are inundated but disconnected from the coastline are differentiated to show the potential total inundated area if the disconnected areas are hydraulically connected (e.g. via culverts or stopbank failure). Inundated areas have been mapped using 0.25 m interval bands for the hard copy maps and using 0.1 m interval bands for the digital inundation layers.

Based on the assessed inundation levels and maps showing inundation extents, areas such as Monaco, Tahunanui and the Wakapuaka lowlands may be subject to inundation during extreme events in the next 50 years. Monaco is likely to be inundated during extreme storms over the next 50 years, with inundation frequency and magnitude increasing over the next 100 years. The Nelson Airport may be subject to coastal inundation in 2130 independent of the adopted sea level rise projection or in 2070 if the sea level rises according to the highest sea level rise projection. The Tahunanui playing fields, campground and adjacent urban area may get inundated during an extreme event in 2070. The inundation extents increase in 2130 to include a large part of the urban area adjacent to Back Beach Inlet. The coastal edge along Nelson Haven may be subject to inundation in 2130 for the mid to higher sea level rise projections. The Wakapuaka lowlands are protected by both the Boulder Bank and Boulder Bank Drive. Because of the relatively low elevation of the Boulder Bank Drive, the Wakapuaka lowlands are subject to inundation during present day extreme events resulting from elevated water levels within Nelson Haven.

Future high tide levels defined by MHWS-6 were also assessed, as these indicate areas that may be subject to inundation more frequently, resulting in more permanent migration of the coastal edge. By 2070, MHWS-6 may reach 2.3 m under a high end (RCP8.5+) SLR scenario. Under this scenario, Tahunanui including the airport may be below the MHWS-6 level but are not necessarily connected to the coastline. By 2130, MHWS-6 may reach 3.2 m under a high end (RCP8.5+) SLR scenario. This would cause more widespread permanent inundation of parts of The Wood, The CBD, Tahunanui, around Monaco, the Airport and business district.

Dynamic assessment

Following the high level inundation assessment, The Wood and Nelson City CBD were identified as being particularly prone to coastal inundation, and as such, a detailed hydrodynamic coastal inundation assessment has also been undertaken for these areas using an existing hydraulic flood model of the Matai River. Modelling was undertaken using the same inundation levels derived for the Nelson Haven coastal cell. However, using a hydrodynamic model provides a refined estimate of coastal inundation through the use of a dynamic tidal boundary, which reduces the overall inundation time from one that was unlimited when assessed with a static inundation level, to one that is limited by peak tidal timing. As such, modelled coastal inundation extents were observed to be less than those derived using static inundation levels. This is particularly evident with peak water levels below 3.4 m NZVD2016, where spill out of bank occurs only briefly, while at more extreme water levels, inundation extents are more similar to static inundation assessments. Inundation of The Wood is observed to occur first when water levels exceed 2.6 m NZVD2016 on the lower Maitai River at Hathaway Terrace. Inundation of The Wood becomes more severe, via spill at Hathaway Terrace, with the severity of climate change influence. Coastal inundation in the south-west of the CBD first occurs as outbreaks of the Saltwater Creek banks, and in extreme/future scenarios, sees much of lower Vanguard Street and the lower part of Washington Valley inundated.

The Port, coastal areas of The Wood and areas south-west of the lower Matai River, are most susceptible to coastal inundation under MHWS-6 and 1% AEP water level scenarios simulated. Modelled inundation extents have been mapped and include maximum inundation depths. Based on the findings of those assessments the following actions are recommended to more accurately assess the effect of coastal inundation on the Nelson region:

- *Post-event data collection.*
  Surveying or capturing static inundation or wave run-up levels after a storm event would provide a calibration/validation of the assessed levels to improve the accuracy and confidence in predicted extreme levels.
- *Wave modelling*
  Numerical wave modelling for the Waimea Inlet, including the inner Tahunanui area, Nelson Haven and Delaware Estuary would provide more detailed information on spatially varying nearshore wave heights along the shoreline.
- *Ground-truth disconnected areas*

  This assessment includes maps of inundated areas that are connected and disconnected from the coastline but could be inundated if they were hydraulically connected. It is recommended to undertake field investigations to confirm hydraulic connectivity of large disconnected areas.
- *Hydrodynamic model for large inundated areas.* As demonstrated in The Wood and CBD, other large inundated areas such as the Wakapuaka lowlands and Tahunanui area are likely to have conservative flood extents using a connected bathtub approach, due to the limited duration of the maximum tidal level and frictional losses across the land. Dynamic (hydrodynamic) modelling could also be undertaken for these sites to better assess the flood extents.
- *Update downstream water levels for catchment flooding*
  This assessment includes coastal inundation levels and does not include flooding due to local rainfall or elevated river levels. Separate assessments that are being or have been undertaken, such as catchment flooding, may require to be reviewed and/or re-assessed using levels assessed in this report.
- *Risk screening assessment*
  This assessment has identified areas which may be susceptible to coastal inundation over different time periods and for different sea level rise scenarios. A comprehensive risk screening assessment would consider the consequences of flooding for different areas and

could incorporate additional aspects such as the likelihood and frequency of flooding and flooding depths. The findings of this assessment could be used for the development of response strategies.

1 Introduction

1.1 Background

The Nelson coastline is varied and complex, being located between steep, tectonically uplifted ranges to the east and the flat Waimea River Floodplain to the west. The coastline is defined by cliff, sand and gravel beaches, spits and barriers, boulder banks and finer estuarine environments within Waimea Inlet (Figure 1-1). Much of the backshore area is low lying and susceptible to flooding from both coastal and terrestrial sources (i.e. as shown in Figure 1-1).

Nelson City Council (NCC) has engaged Tonkin + Taylor (T+T) to undertake a high level or *first-pass* coastal inundation assessment for Nelson City. This includes a review of available extreme coastal water level information, derivation of current and future extreme coastal water levels for general areas of Nelson City and mapping of land elevation for low lying areas of Nelson City. By combining both the derived extreme water levels and the elevation mapping, areas susceptible to inundation can be identified. The advantage of considering these components separately is that it enables significantly more combinations of likelihood, sea level rise and timeframe to be considered. It also allows either the levels or mapping to be independently updated as new data or methods become available.

Following the high level inundation assessment, The Wood and Nelson City CBD were identified as being particularly prone to coastal inundation, and as such, a detailed hydrodynamic coastal inundation assessment has also been undertaken for these areas using an existing hydraulic flood model of the Matai River. The purpose of additional analysis was to provide a more detailed assessment of coastal inundation using dynamic tidal boundary conditions.

Figure 1-1: Aerial view of Monaco, Oyster Island with the airport, Tahunanui Beach and Nelson in the background (source: Boffa Miskell, 2015)

1.2 Statutory considerations

The RMA planning process for the consideration of natural hazard within a district or regional plan requires technical assessment of the hazards and the risk posed by those hazards; and a robust process for developing and testing plan provisions (including objectives, policies and rules) intended to manage the hazard risk to suit the needs of the community.

The Nelson Resource Management Plan (NRMP) includes provisions for managing development within areas affected by coastal inundation. While the current NRMP does not include any coastal inundation overlays, the following excerpts from the NRMP relate to controls for development below a ground level of RL 15.35 m (relative to old NCC datum – approx. 2.95 m NZVD2016).

> **Building on low lying sites**
>
> *REr.58.1; ICr.54.1; SCr.47; INr53.1; OSr.25.1; RUr.29.1*
>
> *Building is permitted if: a) the ground level (excluding waterbodies) is 15.35m NCC Datum or above, or ground level is raised and compacted to at least those levels, and*
>
> **Subdivision (controlled activities)**
>
> *REr.107.2 Subdivision not located in the Services, Natural Hazard, Landscape or Heritage Overlays (excluding Wakefield Quay) shown on the Planning Maps is controlled, if…d) the minimum finished ground level for any land allotment (excluding water bodies) is 15.35m NCC Datum, and…*
>
> *ICr.81.2; SCr.71.2*
>
> *Any subdivision not located in the Heritage Overlay or Heritage Precinct is controlled, if: …d) the minimum finished ground level for any land allotment (excluding water bodies) is 15.35m NCC Datum, except in the Inundation Overlay, and…*
>
> *INr.73.2*
>
> *Any subdivision not located in the Services or Heritage Overlays is controlled, if…d) the minimum finished ground level for any land allotment (excluding water bodies) is 15.35m NCC Datum, except in the Inundation Overlay, and…*

We note that NCC is working on a full review of all of its plans developed under the RMA. Once prepared, the reviewed plan will be called the Whakamahere Whakatū Nelson Plan (the 'Whakamahere', or 'Nelson Plan'). Nelson's RMA Plans currently include the Nelson Regional Policy Statement, Nelson Air Quality Plan and the Nelson Resource Management Plan which incorporates the district plan, regional plan and regional coastal plan. The Nelson Plan will integrate all of these Plans into the one document. While it is currently not known exactly when the Nelson Plan will become operative, it is expected that the coastal hazard information will be incorporated into the Nelson Plan via a Plan Change process, and that when it is, it will supersede the current NRMP provisions.

The New Zealand Coastal Policy Statement (2010) Policy 24 requires the identification of areas that are potentially affected by coastal hazards:

"Identify areas in the coastal environmental that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed…" NZCPS (2010) Policy 24.

This is essentially a technical risk assessment process (Kenderdine et al., 2016) comprising two-levels of assessment: A "*first-pass"* assessment which should take into account the various drivers of hazard as outlined in the NZCPS Policy 24 (1) (a) – (h), should be undertaken at a high level and generally, at a regional-scale and used to identify areas potentially exposed to the effects of coastal hazard. Second-pass more detailed assessments can then be undertaken in areas found to be most exposed to adverse effects.

The MfE (2017) *Coastal Hazards and Climate Change: Guidance for Local Government* provides further guidance for undertaking hazard assessment recommending consideration of a range of hazard likelihoods, sea level rise values and timeframes.

1.3 Scope of works

The scope of works undertaken within this assessment includes:

1. Review of available extreme coastal water level information including the updated coastal calculator for Nelson City developed by NIWA (2018) and statutory guidance.
2. Derivation of current and future extreme coastal water levels for general areas of Nelson City including allowance for a range of sea level rise scenarios as set out by MfE (2017).
3. Mapping of land elevation for low lying areas of Nelson City.
4. Hydrodynamic modelling and inundation mapping of The Wood and CBD within Nelson City.
5. Assessment and discussion of areas affected by coastal inundation by combining the derived extreme water levels, elevation mapping and hydrodynamic modelling.
6. Recommendations for more detailed assessment.

1.4 Report layout

Section two describes the previous studies and background information available to inform a coastal inundation assessment. Sections three and four presents the coastal inundation methodology and assessment and Section five describes the inundation mapping and hydrodynamic modelling. Section six presents results and discussion with conclusions and recommendations presented in Section seven.

1.5 Datum and coordinates

The levels in this report are in terms of New Zealand Vertical Datum 2016 (NZVD2016) unless otherwise specified. A summary of datum levels and offsets are presented in Table 1.1.

Coordinates are presented in terms of New Zealand Transverse Mercator (NZTM).

Table 1.1: Nelson City Datums

Datum	Offset	Mean Sea Level[1]
New Zealand Vertical Datum 2016 (NZVD2016)	12.40	0.43
Nelson Vertical Datum 1955 (NVD-55)	12.07	0.1
Chart Datum at Port Nelson (CD)	9.83	-2.14
Nelson City Datum (NCC Datum)	0	-11.97

[1]MSL (1996-2014) given by NIWA (2015)

2 Previous assessment and values

Several coastal inundation studies have been completed by NIWA between 2009 and 2015. NIWA (2009) assessed the 1% AEP coastal water levels for Nelson City for the present day and allowing for sea level rise up to 1 m. These extreme levels were later mapped overlaying aerial photographs in 2013 (NIWA, 2013). A joint-probability analysis of extreme significant wave heights and storm tide levels for Tasman Bay was undertaken by NIWA in 2012. Mean High Water Spring (MHWS) levels including allowance for several sea level rise scenarios were derived for eight locations along the NCC coastline. A synthesis of the previous four reports was set out by NIWA in 2014 for The Wood, Stoke, Tahunanui Beach and Glenduan including storm-tide elevations, allowance for sea level rise and freeboard.

A larger-scale coastal inundation assessment including wave effects for open coast shorelines was undertaken by NIWA in 2014 covering both Tasman Bay and Golden Bay. In 2015, NIWA updated their joint-probability analysis from 2012 for Nelson City to include eight years of overlapping storm tide and wave data compared to four years in 2012. In 2018, this assessment was updated to include more than 10 years of overlapping storm tide and wave data. This assessment is based on Revision 6 of this calculator, released by NIWA in June 2018.

3 Coastal inundation methodology

The water level at any time is determined by the combination of several components including both deterministic and stochastic components.

Key components that determine water level are:

- Astronomical tides
- Barometric and wind effects, generally referred to as storm surge
- Long-term changes in relative sea level due to climatic or geological changes
- Nearshore wave effects (wave set-up or run-up).

These components combined either form a static extreme water level, which typically includes storm tide and wave set-up, or dynamic extreme water level, which typically include storm tide and wave run-up. Figure 3-1 shows a schematisation of the water level components.

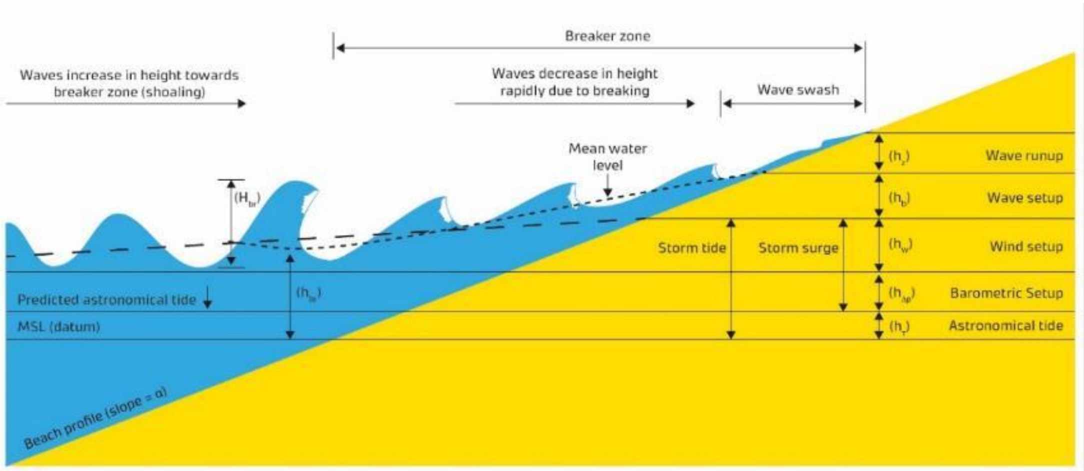

Figure 3-1: Schematisation of water level components

3.1 Astronomical tide

Tides at Nelson are semi-diurnal with fortnightly spring-neap cycles and monthly perigean - apogean cycles apparent. Tides for Port Nelson based on LINZ (2017) and NIWA (2018) analysis are presented in Table 3.1 and show a spring tidal range of approximately 3.9 m with Mean High Water Springs around 2 m above Mean Sea Level.

Table 3.1: Astronomical tide levels at Port Nelson (source: LINZ, 2017)

Tide		CD	NZVD2016
HAT	Highest Astronomical Tide	4.67	2.1
MHWS	Mean High Water Springs	4.32	1.75
MHWS-6[1]	Mean High Water Spring	4.29	1.72
MHWN	Mean High Water Neap	3.29	0.72
MSL	Mean Sea Level	2.34	-0.23
MLWN	Mean Low Water Neap	1.39	-1.18
MLWS	Mean Low Water Spring	0.44	-2.13
LAT	Lowest Astronomical Tide	0.07	-2.5

[1]MHWS exceeded by 6% of tides based on NIWA (2018)

3.2 Storm surge

Storm surge results from the combination of barometric set-up from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide. Storm surge applies to the general elevation of the sea above the predicted tide across a region, but excludes nearshore effects of storm waves such as wave set-up and wave run-up at the shoreline.

Previous studies of storm surge around New Zealand's coastline have concluded that storm surge appears to have an upper limit of approximately 1.0 m (Hay, 1991; Heath, 1979; Bell et. al, 2000). Given the perceived upper limit of storm surge for New Zealand, a standard storm surge of 09 m is considered representative of a return period of 80 to 100 years (MfE, 2004).

However, the actual observed water level observed depends on the superposition of storm surge on astronomical tide and is referred to as *storm tide*. NIWA (2018) used 10 years of sea level data at Port Nelson, separated storm surge from astronomical tide, and re-combined using a Monte Carlo approach to estimate long-term storm tide levels. The assessment found a storm tide with a 1% annual probability of exceedance (1% AEP) during present day sea levels (defined as mean sea level over 2008-2017 period) is 2.34 m NZVD2016 at Nelson Haven. This is some 0.62 m above MHWS-6.

On 1 February 2018 the remnants of Tropical Cyclone Fehi caused water levels to reach 2.35 m NZVD2016 due to a large storm surge on top of a very high tide. This event was found to have a recurrence interval of approximately 100 years (NIWA, 2018).

Table 3.2: Storm tide levels (Source: NIWA, 2018)

ARI (years)	NZVD2016 (m)
1	2.14
2	2.17
5	2.23
10	2.27
20	2.27
50	2.29
100	2.34
Ex-TC Fehi 1 Jan 2018	2.35

3.3 Sea level rise

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/year with Nelson having a slightly lower rate of 1.3 ± 0.25 mm/year (Hannah and Bell, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future. The New Zealand Coastal Policy Statement 2010 (NZCPS, 2010) requires that the identification of coastal hazards includes consideration of sea level rise over at least a 100 year planning period.

MfE (2017) provides guidance on predicted sea level rise based on a range of Representative Concentration Pathways (RCP). Table 3.2 and Figure 3-2 show sea level rise projections up to 2130 for the Nelson region relative to present day (2008-2017) MSL based on NIWA (2018). Over the next 100 year planning period (taken to be 2130) the sea level is projected to rise between 0.53 m and 1.45 m above the 2008-2017 MSL baseline depending on the adopted RCP scenario.

Table 3.3: Sea level rise projections (m) relative to 2008-2017 MSL baseline for the Nelson region

Year	NZ RCP2.6 *M* (median)	NZ RCP4.5 *M* (median)	NZ RCP8.5 *M* (median)	NZ RCP8.5+ (83rd percentile)
2008–2017	0	0	0	0
2020	0.01	0.01	0.02	0.04
2030	0.06	0.06	0.08	0.11
2040	0.11	0.12	0.14	0.2
2050	0.16	0.17	0.21	0.3
2060	0.2	0.23	0.29	0.41
2070	0.25	0.29	0.38	0.54
2080	0.3	0.35	0.48	0.68
2090	0.35	0.42	0.6	0.83
2100	0.39	0.48	0.72	0.98
2110	0.44	0.54	0.86	1.13
2120	0.48	0.6	0.99	1.29
2130	0.53	0.67	1.11	1.45

Source: MfE (2017)

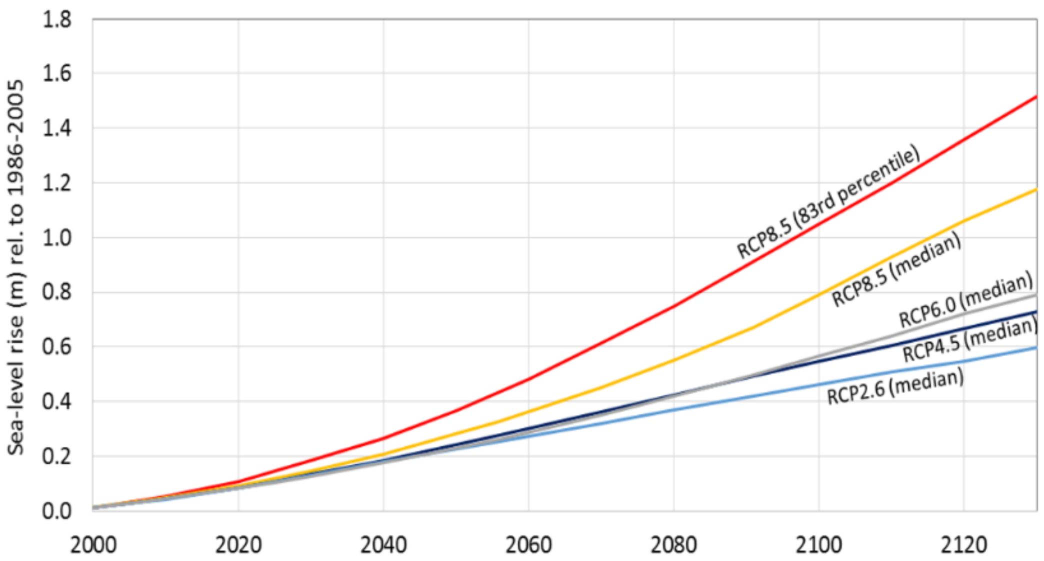

Figure 3-2: Range of sea level rise scenarios for New Zealand (source: MfE, 2017)

3.4 Wave effects

Waves along the Nelson open coast arrive from a northerly quarter, generated primarily from strong north-westerly to north-easterly winds in Tasman Bay and the South Taranaki Bight, although northerly swell (periods > 12s) from low pressure systems in the Tasman Sea can penetrate into the Nelson shoreline.

Wave conditions (height, period and direction) are measured by the Fairway Gauge, which is situated offshore of the Boulder Bank. The Fairway wave-gauge data was used by NIWA (2018) to derive extreme wave heights. Table 3.4 shows these extreme wave heights, with the 1% AEP wave height at 4.39 m. The wave conditions during Ex-Tropical Cyclone Fehi were measured at 3.85 m, with an average annual recurrence interval of approximately 23 years (NIWA, 2018). The joint probability of the wave height and storm tide for the event was estimated at approximately 300 years (Figure 3-3; NIWA, 2018).

Table 3.4: Extreme significant wave heights at the Fairway Gauge (Source: NIWA, 2018)

ARI (years)	Significant wave height, H_s (m)
1	2.53
2	2.83
5	3.21
10	3.49
20	3.78
50	4.13
100	4.39
Ex-TC Fehi 1 Feb 2018	3.85

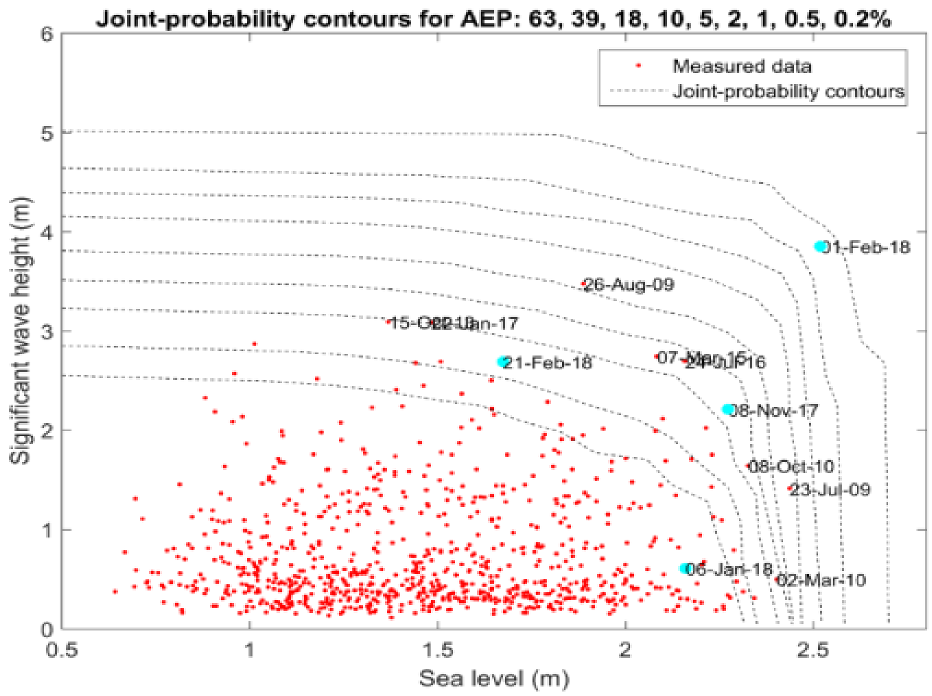

Figure 3-3: Observed wave and water levels measured at Port Nelson and the Nelson-Fairway gauge together with joint probability contours (source: NIWA, 2018)

Within the sheltered water bodies of Waimea Inlet, Nelson Haven and the estuary at Delaware Bay waves are generated by winds blowing locally across the water surface. Their height is limited by the wind speed and distance over which they blow (the fetch length) and also by the water depth with depths of less than around twice the wave height causing waves to break and dissipate energy. Therefore, waves will be largest when wind blows along the longest dimension during the highest water levels.

Waves can both super-elevate the mean water level at the shoreline due to the breaking process (termed wave set-up) and cause wave run-up above this level and overtop where the run-up level exceeds the backshore crest level. To evaluate the contribution of wave processes to extreme coastal water levels, wave heights have been assessed along different parts of the Nelson coastline. On *open coasts* this is based on results presented by NIWA (2018), while for *sheltered coasts*, waves generated locally within the enclosed waterway have been assessed.

3.4.1 Wave set-up

Wave set-up is the increase of the mean water level induced by breaking waves. When waves approach the shoreline the water depth becomes shallower and waves become too high relative to the water depth, become unstable and start to break. During this process wave energy is released and this is compensated by an increase in water level. Figure 3-1 shows a schematisation of how wave set-up increases the mean water level.

3.4.1.1 Open coast wave set-up

Wave set-up (η) for the open coast is assessed by NIWA (2018) using the formula by Stockdon et al. (2006). The formula by Stockdon et al. (2006) is as follows:

$$\eta = 0.35\beta_s\sqrt{H_0 L_0} \tag{3-1}$$

Where:

H_0 = offshore wave height (m)

L_0 = deep water wave length (m)

β_s = beach slope (from mean water to mean high water)

NIWA (2018) have assessed offshore wave conditions at several locations along the Nelson City coastline (i.e. Tahunanui, Fairway Gauge, Delaware Bay and Oananga Bay). Wave set-up for open coast shorelines can be assessed using the coastal calculator by specifying the relevant wave output location and beach slope, which can be derived based on LiDAR information.

However, the Stockdon et al. (2006) empirical formula can result in low set-up values for low gradient shorelines such as Tahunanui. The nearshore processes have therefore been re-assessed for this assessment using a numerical model with site-specific cross-shore bathymetric data rather than the empirical formula with a single typical slope. The 2D numerical wave transformation model, Unibest-LT, has been used. The model transforms offshore wave data to the coast, taking into account the principal wave transformation processes including shoaling and dissipation by wave breaking and bottom friction (Delft Hydraulics, 1994).

A combination of 2015 LiDAR information and LINZ depth contours has been used to generate typical cross-shore profiles for the open coast. The NIWA (2018) joint probability storm water level and wave height have been used as input at the offshore boundary of the 2D numerical model. As wave period is not provided in NIWA (2018), we have adopted the wave period provided in the 33 year MetOcean hindcast model (metoceanview.com). This modelling showed a peak wave period of around 11s for the largest waves and this has been adopted. An example of Unibest-LT modelling output for Tahunanui Beach is shown in Figure 3-4.

This example for Tahunanui shows maximum wave set-up of around 0.5 m simulated by Unibest-LT. For comparison the coastal calculator finds wave set-up of 0.14 m. Due to the lack of validation data available for the Nelson Region, the larger numerical model-based values have been adopted for this present assessment. This could be reassessed with site-specific data.

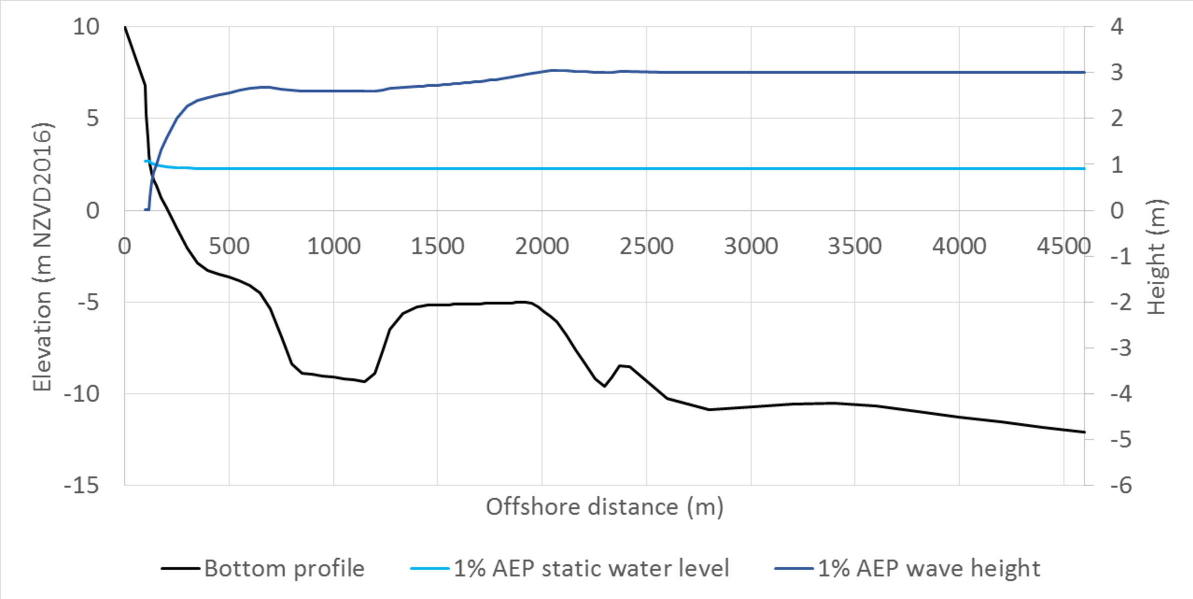

Figure 3-4: Example of Unibest-LT model output for Tahunanui Beach

3.4.1.2 Sheltered coastline wave set-up

For coastlines within a sheltered environment the offshore wave conditions as assessed by NIWA (2018) are not applicable. The significant wave height (H_s) for sheltered coastlines has been based on the 1% AEP 3 second gust wind speed as set out in AS/NZS 1170.2:2011 Part 2 Wind Actions. These three second gust wind speeds have then been converted to average wind speeds of an assumed duration of 60 minutes using procedures in the Coastal Engineering Manual (CEM) 1110-2-1100 (USACE, 2006).

The growth of wind waves are limited by the minimum wind duration (60 minutes) and fetch distance. Fetch-limited waves have been calculated based on the methods according to Wilson (1965) and revisited by Goda (2003) with the maximum directional wave height adopted.

For the sheltered coast wave set-up is calculated based on the simple empirical model of Thornton & Guza (1982). The expression is as follows:

$$\overline{\eta_{max}} = 0.17H_s \qquad (3\text{-}2)$$

This has been adopted due to the wide variation in bed slopes within harbour environments meaning that using either the Stockdon et al. (2006) empirical approach or Unibest-LT numerical model are not practical. Table 3.5 shows both the fetch-limited wave height and wave set-up for different fetch distances.

Table 3.5: Significant wave height and wave set-up by fetch distance

Fetch (km)	Significant wave height, H_s (m)	Wave set-up (m)
<0.5	0.6	0.1
0.5-1	0.8	0.15
1-2	1.1	0.2
2-4	1.5	0.25

The sheltered coastlines within the Nelson region typically have a fetch between 1 km and 4 km. However, due to the shallow water depth (typically with depths of less than 2 m at high tide) waves are not expected to reach a height larger than approximately H_s=1.1 m. Therefore, a wave height of H_s=1.1 m and corresponding wave set-up height of 0.2 m has been adopted for this assessment.

3.4.2 Wave run-up

Wave run-up occurs as waves travel across the surf zone and are then carried by momentum above the still water level until such forces are exceeded by gravity. Although the extreme wave run-up level is higher than the extreme static inundation, it is dynamic and confined to the coastal edge but may contribute to overtopping flows. Wave run-up decreases with distance inland. Figure 3-5 shows a photograph taken during the 1 February 2018 storm with debris mobilised by previous wave run-up events left dry as run-up flows have receded.

Figure 3-5: Photograph at Glenduan (taken 1 February 2018) showing extent of previous wave run-up

3.4.2.1 Open coast wave run-up

The NIWA Coastal Calculator (2018) uses the empirical formula by Stockdon et al. (2006) to calculate wave run-up:

$$R_{2\%} = 1.1\left(0.35\beta_s\sqrt{H_0L_0} + \frac{\left[H_0L_0\left(0.563\beta_s^2+0.004\right)\right]^{1/2}}{2}\right) \qquad (3\text{-}3)$$

Where:

$R_{2\%}$ = run-up exceeded by 2% of the time

H_0 = offshore wave height (m)

L_0 = deep water wave length (m)

β_s = beach slope (from mean water to mean high water)

Wave run-up calculated using the Coastal Calculator has been compared with run-up observed during the 1 February 2018 event at Glenduan (Figure 3-5). The waves reached and overtopped the crest of the beach and road further north along the shoreline during this event. A topographic survey was undertaken following the storm event, and picked up the swash/run-up extents along the beach. The survey showed run-up to reach a level of 6.2 m NZVD2016. Based on NIWA (2018) the storm tide was 2.27 m NZVD2016 on 1 February, which means that the run-up height was 3.9 m above storm tide level.

In order to calculate the wave run-up using the coastal calculator, the upper beach slope is required. The wave height and wave length are implicitly included within the calculator. Beaches typically comprise of composite slopes including flatter and steeper slopes, with the beach slope depending on at what part of the beach the slope is taken. Therefore, wave run-up has been assessed for three different beach slopes and includes the steepest slope (1V:6H), beach slope above the storm tide (1V:10H) and composite slope from MSL to the crest (1V:10H). Figure 3-6 shows the cross section of the beach at Glenduan.

Table 3.6 shows the calculated wave run-up heights for different beach slopes, and observed wave run-up. This table shows that using the flatter composite slope (1V:10H) significantly under-predicts the observed wave run-up (by approximately 50%). The calculated wave run-up using a steeper beach slope (1V:10H) still under-predicts the observed run-up (by approximately 30%). This is supported by findings of Shand et al. (2011) who found that the Stockdon et al. (2006) formula, used by the coastal calculator, has a tendency to under-predict wave run-up for storm events and that the upper beach slope should be used to calculate wave run-up using empirical formula to best match observation.

Table 3.6: Calculated and observed wave run-up at Glenduan for 1 February 2018 storm

Calculated $R_{2\%}$ (m)for beach slope 1V:10H	Calculated $R_{2\%}$ (m) for beach slope 1V:6H	Observed run-up (m)
2.1	2.8	3.9

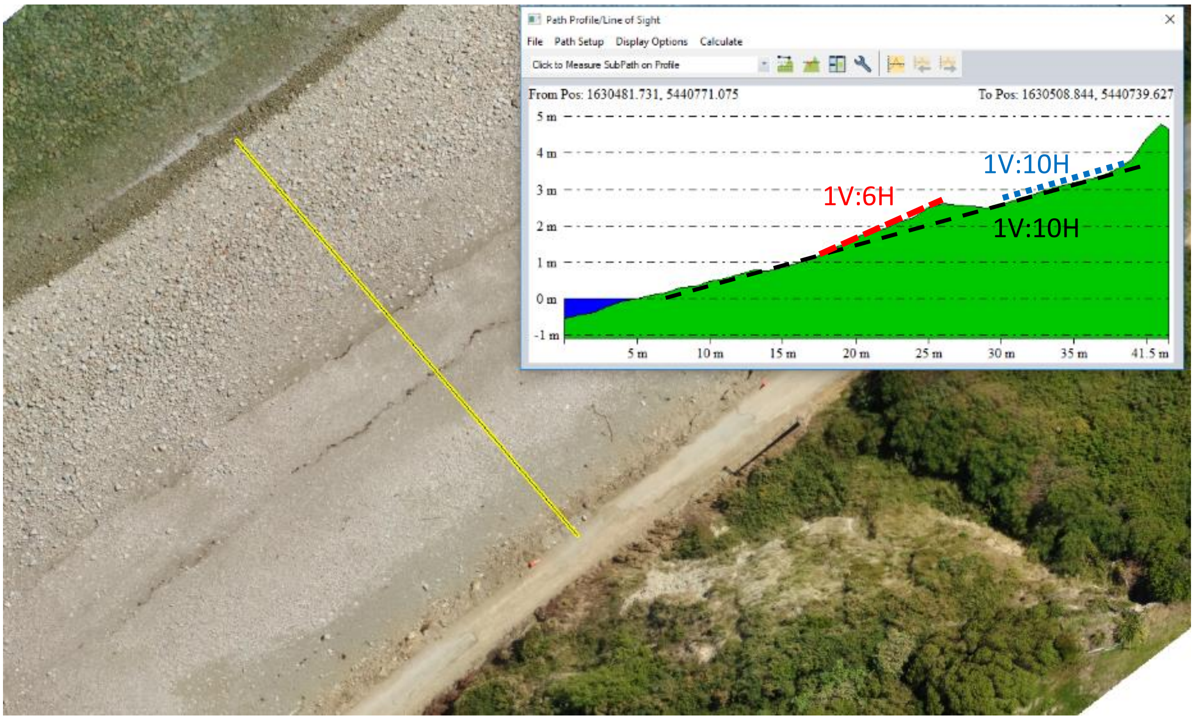

Figure 3-6: Cross-section of beach at Glenduan including beach slopes

Based on this, the coastal calculator seems likely to under-predict wave run-up during storm events. Without additional storm run-up data it is not possible to undertake a more detailed comparison using different empirical formulas. Therefore, wave run-up has been calculated using the coastal calculator and the steepest beach slope for each location. It should be noted that this may not be conservative for very steep upper beach slopes or where structures are located on the coastal edge and site-specific assessment is recommended.

The reduction in run-up height with distance from the coastal edge can be assessed using empirical formula if the crest elevation and backshore slope is known, but is generally restricted to 15-30 m from the coastal edge (NIWA, 2018).

3.4.2.2 Sheltered coastline wave run-up

Open coast wave conditions are not applicable to sheltered coastlines where waves are both fetch and depth limited. Wave run-up in these environments has been assessed using a simplified approach. It has been assumed that the wave run-up in these environments is similar to the nearshore wave height. A wave run-up height of 1 m above the still water level has therefore been adopted for sheltered coastlines. In reality the run-up will be highly dependent on the actual exposure, the nearshore slope and the shoreline type (i.e. whether the shoreline is protected by a seawall or revetment). These should be assessed on a site-specific basis. As above, the reduction in run up height with distance from the coastal edge can be assessed if the crest elevation and backshore slope is known, but is generally restricted to 15-30 m from the coastal edge.

4 Coastal inundation assessment

4.1 Overview

The Nelson City coastline has been split in representative coastal cells within which the assessed extreme water levels are expected to be similar. Cells have been defined based on:

- similar exposure
- nearshore beach slope
- wave and water level conditions (based on NIWA (2018) output locations)
- connection to coastline.

The coastline has been split up where the exposure to wave action or the nearshore beach slope significantly varies, or where a different NIWA (2018) output location is applicable. The landward extent of the coastal cells have been based on an estimation of what area is inundated that is connected to the coastline of each coastal cell. Figure 4-1 shows the extents of the coastal cells.

The joint-probability assessment undertaken by NIWA (2018) includes joint-probability storm tide levels and wave conditions (i.e. Figure 3-3). This study has been used to derive 1% AEP joint-probability storm tide levels, wave conditions and effects for the present day and future timeframes for each coastal cell. Wave set-up for open coast shorelines have been assessed using a numerical model rather than the empirical formulas used by NIWA (2018) as set out in Sections 3.4.1.

Section 4.2 includes the extreme water level components and total water levels for the present day for each coastal cell.

Note that the 1% AEP storm tide may slightly vary between coastal cells due to the joint probability of water levels and wave height (e.g. a lower water level and higher wave height combination may be result in a higher extreme static water level).

Figure 4-1: Overview map of coastal cells

4.2 Assessment for coastal cells

4.2.1 Waimea Inlet

The Waimea Inlet coastal cell includes Stoke, Monaco and the remaining coastline within the Waimea Inlet, but excluding the Airport spit coastline along the Blind Channel (refer to Figure 4-1). The coastlines within the coastal cell are situated within the estuary and are therefore sheltered from direct exposure of ocean swell. Waves are generated by wind blowing over the water surface within the estuary and limited by fetch length and depth.

Wave set-up and run-up have been assessed using the formulas applicable for a sheltered coast (refer to Section 3.4.1.2 and 3.4.2.2). The coastline is typically comprised of embankments with a typical beach slope around 0.03 based on 2015 LiDAR information.

Table 4.1 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for the Waimea Inlet coastal cell. Note that the non-joint-probability has been adopted for this site, because wave effects have been assessed separately. The present day 1% AEP static water level is 2.5 m NZVD2016 and 1% AEP run-up water level is 3.3 m NZVD2016.

Table 4.1: Present day 1% AEP water level components and total water levels for the Waimea Inlet

MHWS-6 (m NZVD2016)	1.72
Storm tide (m NZVD2016)	2.34
Wave height[1] (m)	1
Wave set-up (m)	0.2
Wave run-up (m)	1
Extreme static water level (m NZVD2016)	**2.54**
Extreme run-up water level (m NZVD2016)	**3.34**

[1]Fetch-limited wave height

4.2.2 Tahunanui

The Tahunanui coastal cell includes the coastline along the Blind Channel from the Airport spit to Tahunanui Back Beach, and Tahunanui Beach to the transition with the Rocks Road seawall (refer to Figure 4-1). The Tahunanui Beach coastline is exposed to open ocean swell. The coastline along the Blind Channel (including Back Beach estuary) may be somewhat sheltered by the Waimea Inlet ebb tidal delta. However, without a 3D hydrodynamic/wave model this effect could not be assessed. It has been assumed that the exposure along the Blind Channel coastline is similar to the exposure of Tahunanui Beach.

The coastline of this cell is typically comprised of sandy beaches and embankments with a typical beach slope for the Tahunanui coastal cell of 0.025-0.045 m/m between MHWS and MSL based on 2015 LiDAR information. A value of 0.025 m/m has been used for the purposes of this assessment. Wave set-up has been assessed using the Unibest-LT numerical model, and Stockdon et al. (2006) to assess wave run-up.

Table 4.2 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for the Tahunanui coastal cell. The present day 1% AEP static water level is 2.7 m NZVD2016 and 1% AEP run-up level is 3.5 m NZVD2016.

Table 4.2: Present day 1% AEP water level components and total water levels for Tahunanui

MHWS-6 (m NZVD2016)	1.72
Joint-Probability storm tide (m NZVD2016)	2.16
Wave height[1] (m)	3.0
Wave set-up (m)	0.5
Wave run-up (m)	1.36
Extreme static water level (m NZVD2016)	**2.66**
Extreme run-up water level (m NZVD2016)	**3.52**

[1]Joint-Probability offshore wave height

4.2.3 Rocks Road

The Rocks Road coastal cell includes the coastline from the transition with Tahunanui Beach to the Nelson Port (refer Figure 4-1). This coastline has been separated from the Tahunanui coastal cell because of the presence of a seawall along the entire section.

The typical beach slope just offshore of the seawall is 0.04 m/m based on 2015 LiDAR information and has been used to assess wave set-up. Waves are unlikely to fully break offshore of the seawall and therefore a relatively low set-up height due to a relatively flat slope is expected. Wave run-up has not been assessed, because the seawall may get overtopped during extreme events for which overtopping rates rather than run-up levels should be assessed.

Table 4.3 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for the Rocks Road coastal cell. The present day 1% AEP static water level is 2.5 m NZVD2016.

Table 4.3: Present day 1% AEP water level components and total water levels for Rocks Road

MHWS-6 (m NZVD2016)	1.72
Joint-Probability storm tide (m NZVD2016)	2.16
Wave height[1] (m)	3.0
Wave set-up (m)	0.36
Wave run-up (m)[2]	N/A
Extreme static water level (m NZVD2016)	**2.52**
Extreme run-up water level (m NZVD2016)[2]	**N/A**

[1]Joint-Probability offshore wave height
[2]Not assessed for this site

4.2.4 Nelson Haven

The Nelson Haven coastal cell includes the coastline situated within the Nelson Haven estuary (refer to Figure 4-1). The coastline is sheltered from direct exposure of ocean swell due to the protection of the Boulder Bank. Wave effects contributing to elevating water levels are due to locally generated wind waves within the estuary.

Wave effects for this coastal cell have been assessed using the formulas applicable to sheltered coastlines. The typical beach slope just offshore of the embankment is around 0.025 m/m based on 2015 LiDAR information.

Table 4.4 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for the Nelson Haven coastal cell. Note that the non-joint-probability has been adopted for this site, because wave effects have been assessed separately. The present day 1% AEP static water level is 2.5 m NZVD2016 and 1% AEP run-up level is 3.3 m NZVD2016.

Table 4.4: Present day 1% AEP water level components and total water levels for Nelson Haven

MHWS-6 (m NZVD2016)	1.72
Storm tide (m NZVD2016)	2.34
Wave height[1] (m)	1
Wave set-up (m)	0.2
Wave run-up (m)	1
Extreme static water level (m NZVD2016)	**2.54**
Extreme run-up water level (m NZVD2016)	**3.34**

[1]Fetch-limited wave height

4.2.5 Boulder Bank to Pepin Island

This coastal cell includes the coastline from the Boulder Bank north to Pepin Island (refer to Figure 4-1). The coastline is typically comprised of a gravel beach and is exposed to open ocean swell. The exposure within this relatively long coastal cell is expected to be similar.

The typical beach slope between MHWS and MSL for this coastal cell is around 0.1 m/m derived from 2015 LiDAR information. Wave set-up has been assessed using the Unibest-LT numerical model, and Stockdon et al. (2006) to assess wave run-up.

Table 4.5 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for this coastal cell. The present day 1% AEP static water level is 3.1 m NZVD2016 and 1% AEP run-up level is 4.9 m NZVD2016.

Table 4.5: Present day 1% AEP water level components and total water levels for Boulder Bank to Pepin Island

MHWS-6 (m NZVD2016)	1.72
Joint-Probability storm tide (m NZVD2016)	2.13
Wave height[1] (m)	3.7
Wave set-up (m)	0.92
Wave run-up (m)	2.8
Extreme static water level (m NZVD2016)	**3.05**
Extreme run-up water level (m NZVD2016)	**4.93**

[1]Joint-Probability offshore wave height

4.2.6 Delaware Bay estuary

The Delaware Bay estuary coastal cell includes the coastlines that are situated within the estuary that is sheltered by the Delaware Bay spit, Pepin Island and Cable Bay barrier (refer to Figure 4-1). The coastline is sheltered from direct exposure of ocean swell with wave effects due to locally generated wind waves within the estuary contributing to elevated water levels.

Wave effects for this coastal cell have been assessed using the formulas applicable to sheltered coastlines. The typical beach slope just offshore of the embankment is around 0.025 based on 2015 LiDAR information.

Table 4.6 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for the Delaware Bay estuary coastal cell. Note that the non-joint-probability has been adopted for this site, because wave effects have been assessed separately. The present day 1% AEP static water level is 2.5 m NZVD2016 and 1% AEP run-up level is 3.3 m NZVD2016.

Table 4.6: Present day 1% AEP water level components and total water levels for the Delaware Estuary

MHWS-6 (m NZVD2016)	1.72
Storm tide (m NZVD2016)	2.34
Wave height[1] (m)	1
Wave set-up (m)	0.2
Wave run-up (m)	1
Extreme static water level (m NZVD2016)	**2.54**
Extreme run-up water level (m NZVD2016)	**3.34**

[1]Nearshore wave height significantly attenuated

4.2.7 Delaware Bay open coast

The Delaware Bay open coast cell includes the coastline from the Delaware Bay spit to Hori Bay (refer to Figure 4-1). The coastline is typically comprised of a gravel beach and is exposed to open ocean swell.

The typical beach slope between MHWS and MSL for this coastal cell is 0.08 m/m derived from 2015 LiDAR information. Wave set-up has been assessed using the Unibest-LT numerical model, and Stockdon et al. (2006) to assess wave run-up.

Table 4.7 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for this coastal cell. The present day 1% AEP static water level is 2.9 m NZVD2016 and 1% AEP run-up water level is 4.3 m NZVD2016.

Table 4.7: Present day 1% AEP water level components and total water levels for the Delaware Bay open coast

MHWS-6 (m NZVD2016)	1.72
Joint-Probability storm tide (m NZVD2016)	2.12
Wave height[1] (m)	3.8
Wave set-up (m)	0.74
Wave run-up (m)	2.23
Extreme static water level (m NZVD2016)	**2.86**
Extreme run-up water level (m NZVD2016)	**4.34**

[1]Joint-Probability offshore wave height

4.2.8 Oananga Bay open coast

The Delaware Bay open coast cell includes the coastline from Hori Bay to Oananga Bay (refer to Figure 4-1). The coastline is typically comprised of a gravel beach and is exposed to open ocean swell.

The typical beach slope between MHWS and MSL for this coastal cell is 0.07 m/m derived from 2015 LiDAR information. Wave set-up and run-up have been assessed using the formulas applicable for an exposed open coast.

Table 4.8 shows the 1% AEP water level components, adopted wave height and extreme total water levels for the present day for this coastal cell. The present day 1% AEP static water level is 2.6 m NZVD2016 and 1% AEP run-up water level is 4.3 m NZVD2016.

Table 4.8: Present day 1% AEP water level components and total water levels for the Oananga Bay open coast

MHWS-6 (m NZVD2016)	1.72
Joint-Probability storm tide (m NZVD2016)	2.12
Wave height[1] (m)	3.8
Wave set-up (m)	0.5
Wave run-up (m)	2.22
Extreme static water level (m NZVD2016)	**2.62**
Extreme run-up water level (m NZVD2016)	**4.34**

[1]Joint-Probability offshore wave height

4.3 Summary of future coastal water levels

4.3.1 Astronomical tide

Future astronomical tidal levels will be higher than present as sea levels rise. Table 4.10 presents the assessed MHWS-6 water levels for present and future sea levels for all sites.

Table 4.9: MHWS-6 for present day and future time frames (m NZVD2016)

		Future MHWS-6 water level							
		2070				**2130**			
Site	**Present Day MHWS-6**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP8.5+**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP8.5+**
All sites	1.72	1.97	2.01	2.10	2.26	2.25	2.39	2.83	3.17

4.3.2 Extreme static water levels

Table 4.10 presents the assessed 1% AEP present day static coastal water levels for each coastal cell rounded up to the nearest 0.1 m. This table shows extreme static water levels of around 2.5 m within sheltered areas and up to 3.1 m along the open coast. Extreme water levels for future timeframes include allowance for sea level rise (refer to Section 3.3) for both 2070 (~50 yr) and 2130 (~100 yr) are also presented. These show future extreme water levels reaching up to 4 m within sheltered areas and up to 4.5 m along the open coast.

Table 4.10: Extreme coastal water levels for present day and future time frames (m NZVD2016)

Site	Present Day 1% AEP coastal water level	Future 1% AEP coastal water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Waimea inlet	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Tahunanui Beach	2.7	3.0	3.0	3.1	3.2	3.2	3.4	3.8	4.2
Rocks Road	2.6	2.8	2.9	2.9	3.1	3.1	3.2	3.7	4.0
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Boulder Bank to Pepin Island	3.1	3.3	3.4	3.5	3.6	3.6	3.8	4.2	4.5
Delaware Estuary	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Delaware Bay open coast	2.9	3.2	3.2	3.3	3.4	3.4	3.6	4.0	4.4
Oananga Bay open coast	2.7	2.9	3.0	3.0	3.2	3.2	3.3	3.8	4.1

4.3.3 Extreme wave run up levels

Table 4.11 presents the assessed 1% AEP extreme wave run up levels for each coastal cell rounded up to the nearest 0.1 m. This table shows extreme run up levels of up to 3.3 m within sheltered areas and up to 4.9 m along the open coast. It should be noted that these levels are confined to the coastal edge and are highly dependent on site-specific factors such as exposure and conditions at the coastal edge with very steep upper beaches and coastal structures likely having higher run up elevations than indicated. Extreme run-up levels for future timeframes include allowance for sea level rise reach up to 4.8 m within sheltered areas and up to 6.4 m along the open coast.

Table 4.11: Extreme wave run-up levels for present day and future time frames (m NZVD2016)

Site	Present Day 1% AEP wave run-up level	Future 1% AEP wave run up level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Waimea inlet	3.4	3.6	3.7	3.8	3.9	3.9	4.1	4.5	4.8
Tahunanui Beach	3.6	3.8	3.9	4.0	4.1	4.1	4.2	4.7	5.0
Rocks Road	N/A								
Nelson Haven	3.4	3.6	3.7	3.8	3.9	3.9	4.1	4.5	4.8
Boulder Bank to Pepin Island	5.0	5.2	5.3	5.4	5.5	5.5	5.6	6.1	6.4
Delaware Estuary	3.4	3.6	3.7	3.8	3.9	3.9	4.1	4.5	4.8
Delaware Bay open coast	4.4	4.6	4.7	4.8	4.9	4.9	5.1	5.5	5.8
Oananga Bay open coast	4.4	4.6	4.7	4.8	4.9	4.9	5.1	5.5	5.8

5 Coastal inundation mapping – bathtub approach

5.1 Methodology

Areas inundated under extreme static inundation levels have been mapped using two methods:

- a simple bathtub model (all land below a specified elevation shown as inundated); and
- a connected bathtub model where areas are flooded only where they connect to the coastal water body.

Areas that are inundated but disconnected from the coastline (e.g. all land below MHWS), are mapped with a different colour to show the potential total inundated area if the disconnected areas are hydraulically connected (e.g. via culverts).

Digital elevation models (DEMs) have been constructed for Nelson City using NCC LiDAR data from 2014/2015. DEMs have been constructed at a 0.5 m grid resolution and represent the bare earth (i.e. with buildings and vegetation removed).

For the purposes of this report, inundated areas have been mapped using 0.25 m interval bands starting from 1.5 m NZVD2016 up to 4.5 m NZVD2016 to allow for sea level rise to 2130 adopting the highest projection. We understand that NCC intend to present this information to users via a WebGIS application accessible on the internet. For this end use, inundated areas have been mapped using 0.1 m interval bands over the same range of levels as above, and will be supplied to NCC at the completion of this study.

5.2 Inundation maps in combination with extreme water level tables

This section summarises how to use the maps in combination with the results of Table 4.10 (included on the maps). Each map includes inundated areas at 0.25 m intervals and a table showing the extreme static water levels for the relevant location. Water levels are shown for both the present day as well as future time frames (2070 and 2130) including allowance for the four sea level rise scenarios as recommended by MfE (2017).

For each extreme water level the inundation extents can be found on the map. The advantage of this is that in the event that estimates of extreme water levels change it is only the tables of extreme water levels that need to be changed; the inundation maps remain the same. Additionally, if site-specific information is available which supersedes the LiDAR then this can be used in conjunction with the levels.

The disconnected inundation areas are shaded with a different colour and show the potential for inundation if hydraulically connected. This method was adopted to trigger a more detailed assessment required to assess the potential connectivity to the ‘connected’ inundated areas.

5.3 Results of inundation mapping

Table 5.1 below presents a summary of static inundation levels across Nelson City. A short summary on the implications of these results follows. Note that run up levels may extend higher than this along the coastal edge.

Table 5.1: Summary of selected 1% AEP inundation levels (m RL NZVD2016)

Location/Zone	Present day	2070[1]	2130[1]
Waimea inlet	2.6	2.8 to 3.1	3.1 to 4.0
Tahunanui	2.7	2.9 to 3.2	3.2 to 4.2
Rocks Road	2.6	2.8 to 3.1	3.1 to 4.0
Nelson Haven	2.6	2.8 to 3.1	3.1 to 4.0
Boulder Bank/Glenduan	3.1	3.3 to 3.6	3.6 to 4.5
Delaware Estuary	2.6	2.8 to 3.1	3.1 to 4.1

[1] Ranges given from RCP2.6m to RCP8.5+

5.3.1 Waimea Inlet

In a present day 100 year ARI event, parts of Monaco and the Nelson Airport are expected to experience inundation from elevated sea levels. In this event, the capacity of the lower part of the Arapiki Stream becomes constrained as sea water intrudes beyond Quarantine Road, causing minor inundation of industrial land.

By 2070, at a water level of around 3 m NZVD2016, airport runways would be compromised and flooding through the lower industrial area would be more widespread. The extremity of the Monaco peninsula would be inundated, in some places by around 1 m depth.

By 2130 (up to 4 m NZVD2016) the majority of properties at Monaco and Quarantine Road are expected to be inundated, and significant sections of Whakatu Drive are overtopped resulting in a corridor of industrial land becoming flooded. The airport site would be almost completely inundated, as would the area of industrial land between Whakatu Drive and Arapiki Stream – in some places by over 1.5 m.

5.3.2 Tahunanui

In the present day 100 year ARI event, inundation is expected in property around the lower parts of Maire Stream, as well as the Tahunanui playing fields, camp ground and property near Bolt Road. Mapping shows the modelling pond underwater during this event, as well as flooding in Waikare St properties (assuming these are hydraulically connected through the reticulated stormwater network).

By 2070, inundation of residential and industrial property during a 100 year ARI event would be expected to be more widespread. The Maire Stream areas is inundated, including Chandler, Otterson and Beatty St properties. Most property on the north side of Golf Road are inundated, and Beach Road would be completely inundated.

By 2130, the majority of land west of Muritai St and Pascoe St would be inundated. Tahunanui School and the Nelson Waste Transfer Station stay at or slightly above the inundation level. Approximately 150 m of Tahunanui Drive around the Bisley Ave intersection could be expected to flood.

Figure 5 in Appendix A has been included to show areas that may become inundated at a level lower than what is anticipated by overland flow. For clarity only the 2.5 m NZVD2016 level is shown. The blue areas have been marked to show inland areas that are below the 2.5 m NZVD2016 level but not connected to the coast. The probability of any one of these areas being hydraulically connected has not been assessed.

5.3.3 Rocks Road

Sections of Rocks Road between Richardson Street and the Nelson Settlers Memorial are expected to become inundated at around 3.75 m NZVD2016 (upper 2130 100 year ARI prediction) while the area south between Richardson Road and Bisley Avenue does not become inundated until at least 4.0 m NZVD2016, i.e. in events greater than the 100 year ARI out to 2130.

5.3.4 Nelson Haven

In a present day 100 year ARI event, inundation mapping shows that the state highway and most of the Port remains dry. The tide level extends up the Maitai River until around Hardy Street, and depending on whether they are hydraulically connected or not, areas within the Wood (including Hathaway Terrace and lower Trafalgar Street), Washington Valley and Vanguard/Gloucester Streets experience inundation. The Trafalgar Park turf level of around 2.3 m NZVD2016 is lower than the 100 year ARI event level of 2.5 m NZVD2016. The Trafalgar Centre and surrounding land is above the inundation level, and the Maitai River banks are not expected to be overtopped.

By 2070, the 100 year ARI level of 2.8 to 3.1 m NZVD2016 is expected to cause flooding of Haven Road in the vicinity of the water fountain, as well as shallow flooding within Auckland Point School. Widespread flooding across the lower parts of the Wood and Rutherford/Vanguard/St Vincent Streets as well as Washington Valley. Trafalgar St is inundated between SH6 and Nelson City Council building (except at Trafalgar St Bridge). Wakatu and Montgomery Square carparks are both expected to be completely inundated during this event, as are Anzac Park and the Warehouse carpark. Both Countdown supermarkets and the library and associated carparks would be inundated.

By 2130, the 100 year ARI level of up to 4.1 m NZVD2016 is expected to cause widespread flooding across the Wood and Lower CBD. Access to the city would be cut off from Rocks Road and from the north via SH6. Flood depths within the CBD and Wood would approach (and in some places exceed) 2 m. Flooding would extend as far inland as the Harvey Norman building on St Vincent Street, Selwyn Place to the south and Founders Park to the east. Flood depths over SH6 along the Wood and Neale Park would be around 0.5 m with the road acting as a weir. The Nelson Port and all property north of SH6 (Akersten Street, etc.) would be underwater. Auckland Point School would experience inundation depths of approx. 1 m depths.

5.3.5 Boulder Bank / Glenduan

Due to its exposed nature, assessed extreme tide levels are approximately 0.5 m higher in this area than elsewhere along the Nelson coast.

In a present day 100 year ARI event, sea levels are expected to reach 3.1 m NZVD2016, approximately the level of Boulder Bank Drive. The majority of floodplain land between Boulder Bank Drive and Glenduan is well below this level, i.e. if the Boulder Bank Drive road embankment did not exist, inundation would be expected across the Wakapuaka Floodplain in this event, including over Glen Road. The water level would exceed the level of the lower (newer) two Wakapuaka oxidation pond embankments, and a number of structures associated with the treatment plant would be flooded. The Cawthron Aquaculture site would be expected to be significantly inundated. The crest of the Boulder Bank itself is above this level, typically ranging between 4.5 m and 5 m NZVD2016.

By 2070, with 100 year ARI tide levels up to 3.6 m NZVD2016, the overall flood extents are not expected to be dramatically different, though flood levels are expected to be 0.5 m higher than in the present day climate. In the present day, the Boulder Bank is overtopped by waves at certain locations several times a decade on average. This frequency is expected to increase by 2070. This saltwater intrusion through wave overtopping, combined with elevated ground water levels due to sea level rise, is expected to affect the viability of some existing land use activities across the floodplain. The level of SH6 at Todd Valley is approximately 3.6 m NZVD2016. The crest level of the largest of the Wakapuaka oxidation ponds is also approximately 3.6 m NZVD2016, and therefore both assets would be expected to be compromised by this time during a 100 year ARI event.

By 2130, with 100 year ARI tide levels up to 4.5 m NZVD2016, flood levels around the floodplain are typically over 3 m deep. Inundation would be widespread, including up above SH6 at Todd Valley road. The oxidation ponds would be completely submerged, as would SH6 from the Wakapuaka Tennis Club south.

5.3.6 Delaware Estuary and open coast, Oananga Bay

Coastal inundation levels are presented for Delaware Estuary, the Delaware Bay open coast, and Oananga Bay. Present day and projected 100 year ARI tide levels range between 2.5 m NZVD2016 and 4.0 m NZVD2016. At 2.5 m NZVD2016, the Pepin Island access road would remain open; at 4.0 m NZVD2016, the access road would be significantly inundated at either end, with only a middle section of road remaining above the static inundation level.

Development in areas likely to be affected by these levels is limited, though an inspection of NCC's LiDAR, aerial photos and building footprint layers indicates that low-lying buildings/structures may be affected at the following locations:

- Several buildings at 642 Maori Pa Road
- Two to three buildings at 574 Cable Bay Road
- One building (possibly habitable) at 796 Cable Bay Road that is above the 2.5 m NZVD2016 contour but below the 4.0 m NZVD2016 contour
- One dwelling at 816 Cable Bay Road that is located approximately on the 2.5 m NZVD2016 contour
- One dwelling at 875 Cable Bay Road (on Pepin Island) that is located approximately on the 2.5 m NZVD2016 contour
- Various private boat sheds/jetties located in Cable Bay Road properties
- The lower part of the Cable Bay campground would be inundated by a 4.0 m NZVD2016 sea level (2130 100 year ARI event, assuming RCP8.5+ scenario).

6 Nelson Haven coastal inundation hydrodynamic modelling

A more detailed assessment of coastal inundation has been undertaken for The Wood and CBD, located within the Nelson Haven coastal cell, using dynamic tidal boundary conditions. The main difference between a bathtub assessment (described in Section 5) and a dynamic assessment is that the dynamic assessment models the movement of seawater through low-lying coastal land during the tidal event, rather than making the assumption that the peak of the tide remains high enough for long enough to completely inundate any land below the peak tide water level.

As agreed with NCC, inundation was required to coincide with low flows in the river system, so as to assess the impact of sea inundation only.

6.1 Hydraulic Modelling

6.1.1 Model domain and status

Coastal inundation modelling has been undertaken using the Maitai River flood model created using the 2014 version of the DHI software.

The model was originally developed by T+T and peer-reviewed by Stantec in 2013. In 2017, the model was updated to a flexible mesh model, and extended to include the York Stream and Brook Stream and to extend further up the Maitai Valley.

In 2019, NCC engaged T+T to update the model to incorporate:

- Latest guidance from NIWA and MfE relating to present day sea levels and climate change effects on sea level and rainfall,
- Latest (2015) LiDAR data for cross sections and floodplain bathymetry,
- Pipe network upgrade in the York Stream catchment.

The 2019 model has been submitted to Stantec for peer review, and at the time of reporting, T+T are currently awaiting their review comments before finalising the model. However, the model is considered suitable for use for the current study of coastal inundation.

It is important to note that the urban stormwater pipe network is NOT modelled (except for the main/arterial line in the York sub-catchment). NCC does not currently have a stormwater reticulation model to use for this purpose. This means that in the model, seawater can only travel across surface flowpaths, and is restricted from backing up through the reticulated stormwater network. In reality, Nelson does experience seawater inundation in some inland areas (e.g. Wakatu Carpark) due to back up through the stormwater system during periods of elevated tidal conditions. It is likely that as sea levels rise, pipe outlets from the stormwater network would be retrofitted with flap-gates to prevent tidal backflow.

Figure 6.1 shows the extent of the model domain and its relation to the Nelson Haven coastal cell, while more details on model build are presented in T+T (2017) and T+T (2019).

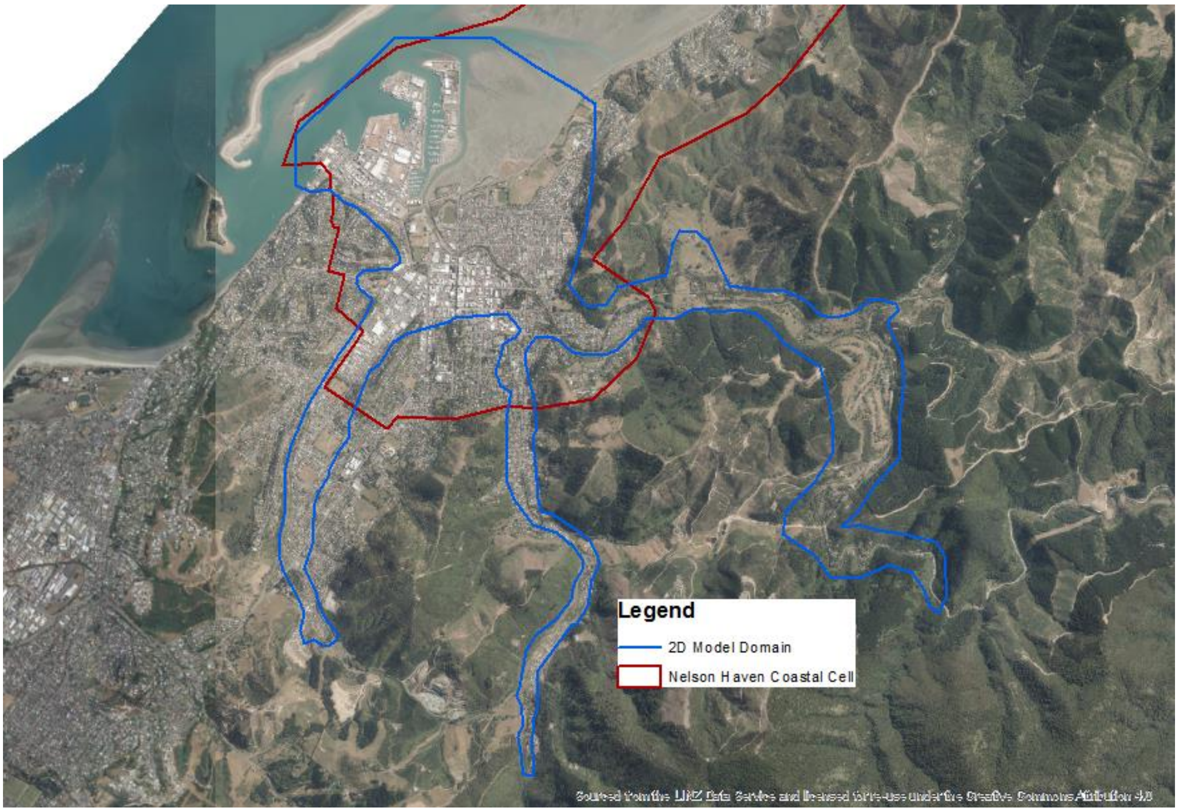

Figure 6.1: MIKEFLOOD Maitai 2D Model Domain and Nelson Haven Coastal Cell

6.1.2 Coastal inundation levels

Coastal inundation levels, described in Section 4.3 and summarised in Table 6.1, were used to create dynamic (sinusoidal) tidal boundaries, and these were applied to the model for one complete tidal cycle. The assessment focused on the following levels:

- MHWS-6 (a mean high water springs tidal level defined as that exceeded by 6% of all tides);
- 1% average exceedance probability (AEP) sea level rise.

In addition to the inclusion of the above tidal boundaries, linear inflow time series hydrographs from 0-0.1 m^3/s replaced the existing inflow boundaries in the model, so as to remove the impact of river flow on peak inundation levels, while keeping the models stable. The same inflow boundaries were applied to all modelled scenarios. No other changes were made to the existing model.

A total of twenty one scenarios were completed. Details of these are shown, as presented in Table 6.1.

Table 6.1: Summary of selected MHWS-6 and 1% AEP inundation levels (m NZVD2016)

Tide	Sea level rise	Present day	Year 2070	Year 2130
1% AEP	No SLR	2.6		
	RCP2.6		2.80	3.10
	RCP4.5		2.90	3.30
	RCP6.0		2.95	3.40
	RCP8.5		3.00	3.70
	RCP8.5+		3.10	4.00

Tide	Sea level rise	Present day	Year 2070	Year 2130
MHWS-6				
	RCP2.6		1.97	2.25
	RCP4.5		2.01	2.39
	RCP6.0		2.05	2.50
	RCP8.5		2.10	2.83
	RCP8.5+		2.26	3.17

6.1.3 Results of inundation modelling

6.1.3.1 MHWS-6 events

Model outputs are presented on Figures 1 and 2 in Appendix B. They show minor coastal inundation for most of the modelled future MHWS-6 events, with effects confined to isolated areas of the port. The exception to this is the 2130 RCP8.5 and RCP8.5+ scenario, where a MHWS-6 tidal cycle with a peak water level of 2.83 m NZVD2016 and 3.17 m NZVD2016 respectively results in tidal flow outbreak along the true right bank (TRB) of the Maitai River adjacent to Hathaway Terrace and into the Wood – refer Figures 1 and 2 in Appendix B.

The TRB at this location sits at a level of approximately 2.6 m NZVD2016 and controls the flows between the Matai River and The Wood to the east of the Maitai River. Other bank elevations along the lower Maitai River sit above this estimated future MHWS-6 water level and modelling indicates no other outbreak locations.

Peak water depths range from 0.1 m to 1 m at The Wood, as shown on Figure 1 in Appendix B.

Figure 2 in Appendix B presents flood extents for all MHWS-6 scenarios modelled.

6.1.3.2 1% AEP events

Model outputs are presented on Figures 3 - 13 in Appendix B. Coastal inundation caused by the ingress of tidal water up the Matai River initially occurs at the TRB adjacent to Hathaway Terrace, with peak water levels greater than 2.6 m NZVD2016 inundating areas of The Wood, east of the Matai River. Spill occurs at this location for all 1% AEP water level scenarios, with inundation extents and peak water depths increasing with the severity of climate change influence.

For the 2070 RCP2.6 scenario (peak tidal level of 2.8 m NZVD2016), the modelling indicates outbreaks from Saltwater Creek and heading upstream, inundating areas along Vanguard Street, Gloucester Street and St Vincent Street. In the modelled 2070 RCP6.0 scenario (peak tidal level of 2.95 m NZVD2016), water spills at the true left bank (TLB) of the Maitai River immediately downstream of the Trafalgar Street Bridge (i.e. along the Maitai River Walkway), joining outbreak flows from Saltwater Creek in the more severe climate change scenarios modelled.

In the modelled 2130 RCP4.5 scenario (peak tidal level of 3.3 m NZVD2016), landward inundation through the Port begins to encroach on urban areas where water is observed to cross State Highway Six (SH6) north-west of the Haven Road roundabout. In the modelled 2130 RCP8.5 scenario (peak tidal level of 3.7 m NZVD2016), inundation also crosses SH6 into The Wood, joining with flows that first breach at Hathaway Terrace.

Maximum inundation extents are observed to reach Atawhai Drive in the north-east and the Harvey Norman building on Vanguard Street, in the south-west.

Floodplain inundation peak water depths range from 0.1 m to greater than 1 m in the modelled 2130 RCP8.5+ scenario. Peak water depths and flood extents for all 1% AEP scenarios are shown on Figures 4 to 13 in Appendix B.

7 Discussion

7.1 Coastal edge migration by permanent inundation

A shoreline is defined by the landward extent of typical marine processes such as tides and waves. The potential increase in future sea level may cause the shoreline to migrate landward as areas are permanently inundated (i.e. every high tide) as shown in Figure 7-1. This process differs from extreme coastal inundation where the event is rare and temporary. The effects of coastal edge migration by permanent inundation are likely to be similar to erosion where the marine-land boundary is shifted landward.

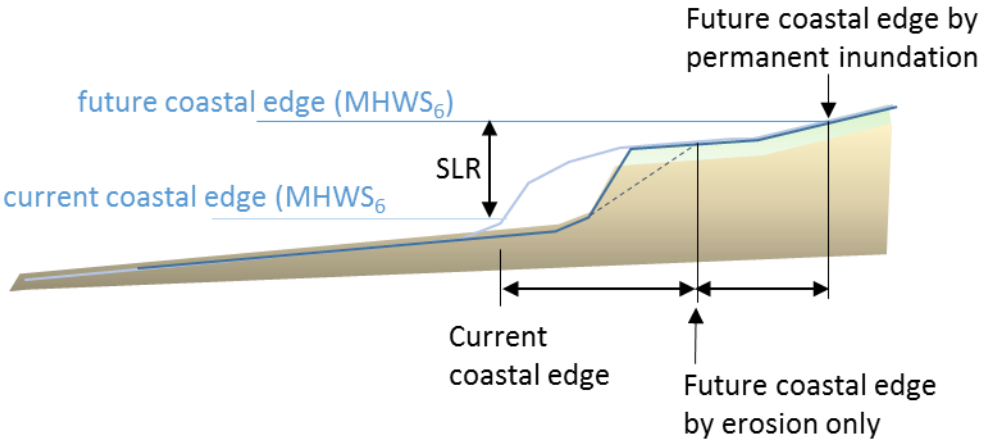

Figure 7-1: Effect of future astronmical tide on the coastal edge due to permanent inundation

This coastal edge migration by permanent inundation can be *estimated* by using the connected bathtub inundation maps in combination with the future MHWS-6 values presented in Table 4.9. However, it should be noted that the current coastal edge may also be affected by wave and swash processes and coastal vegetation and may therefore be slightly lower or higher than the MHWS-6. Results for this first-pass estimate show that this coastal edge migration would primarily affect low-lying estuarine areas such as around The Wood, the CBD and Tahunanui.

By 2070, MHWS-6 may reach 2.3 m NZVD2016 under a high end (RCP8.5+) SLR scenario. Under this scenario, the first past-inundation assessment shows parts of The Wood and CBD and Tahunanui including the airport may be below the MHWS-6 level, but not necessarily connected to the coastline (Figure 7-2). However, more detailed hydrodynamic modelling of The Wood and CBD shows no inundated by the MHWS-6 level as bank levels in the Matai River sit higher at approximately 2.6 m NZVD2016 (Figure 7-3).

By 2130, MHWS-6 may reach 3.2 m NZVD2016 under this high end (RCP8.5+) SLR scenario. This would cause widespread permanent inundation of parts of The Wood, The CBD, Tahunanui, around Monaco, the Airport and business district.

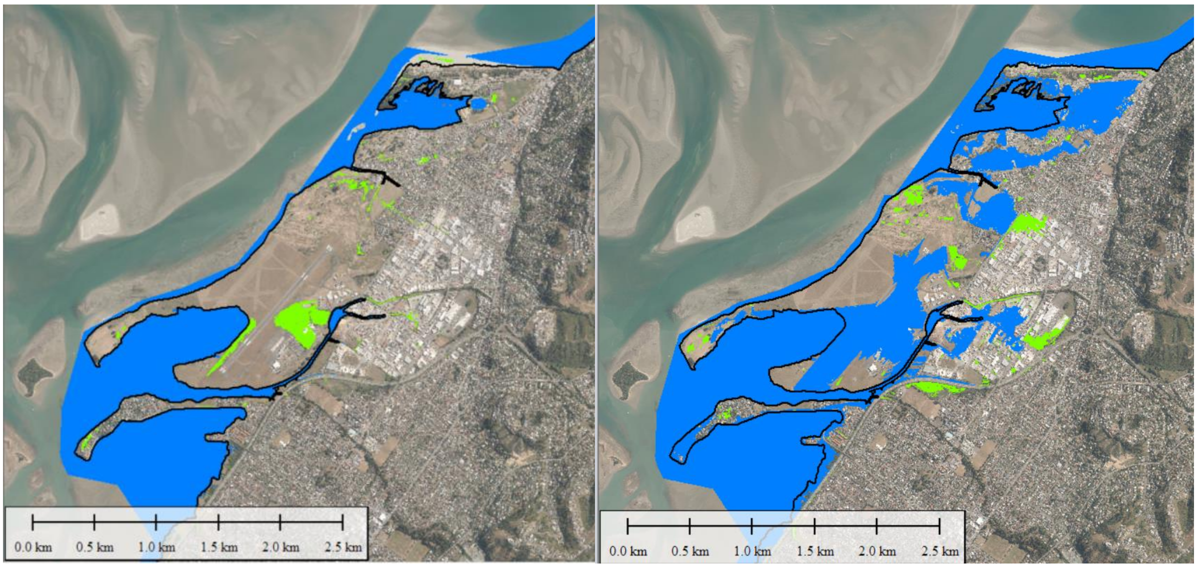

Figure 7-2: Areas of Tahunanui to Monaco inundated by a MHWS-6 water level under a RCP8.5+ SLR scenario by 2070 (left) and 2130 (right) with connected areas shown in blue and non-connected in green

Figure 7-3: Areas of The Wood and CBD inundated by a MHWS-6 water level under a RCP8.5+SLR scenario by 2070 (left) and 2130 (right)

7.2 Site specific assessments

The static inundation levels and wave run-up levels presented in this report have been assessed on a district-wide scale. Site specific inundation levels may therefore slightly vary from these and can be assessed based on site specific and more detailed information.

A site specific assessment could include:

- collection of additional site-specific topographic data to supersede or augment the LiDAR used in mapping in the assessment,
- reassessment of the extreme coastal water levels,
- reassessment for the potential for extreme coastal water levels to reach the site based on flow paths and connection.

If a site specific re-assessment of extreme coastal water levels is undertaken, the static inundation level is calculated as follows:

Static inundation level = Storm Tide + wave set-up + sea level rise

The storm tide can be derived using the coastal calculator. The wave set-up component depends on whether the coastline is situated along the open coast or within an estuary. For an open coast shoreline the wave height can be determined using the coastal calculator and wave set-up can be calculated using an empirical formula or numerical model. For sheltered coastlines within an estuary the wave set-up can be calculated using Table 3.5 for the relevant fetch distance (longest offshore distance to another coastline). The sea level rise value can be determined based on Table 3.3 and depends on the adopted timeframe. All four sea level rise projections should be assessed for a site specific assessment.

The wave run-up level for a site specific assessment is calculated as follows:

Wave run-up level = Storm Tide + wave run-up + sea level rise

The storm tide and sea level rise components can be calculated as described above. Wave run-up for an open coast shoreline can be calculated using the coastal calculator, an empirical formula or numerical model, with wave conditions determined using the coastal calculator. For sheltered shorelines, wave height should be assessed based on the maximum fetch distance and wave run-up should be calculated using an appropriate empirical formula and site-specific topography.

7.2.1 Wave run-up attenuation

Wave run-up level may exceed the crest level of the coastal edge. If this occurs, waves will overtop the edge and run inland, with wave height attenuating over distance.

The attenuation of wave run-up with distance inland is highly site-specific and is dependent on the run-up elevation, backshore height and slope (i.e. Figure 7-4). This section sets out how to undertake a site specific self-assessment of wave run-up attenuation distance.

Wave attenuation with distance from the coastal edge can be assessed following the following steps:

i Determine extreme run-up level using empirical methods and add to relevant storm tide level.

ii Assess the dune crest or backshore elevation using Council LiDAR or site-specific topographic survey.

iii If run-up level exceeds the dune crest, calculate run-up attenuation according to Equation 6-1, modified from FEMA (2005).

$$X = \frac{\sqrt{R-Y_0} \cdot A(1-2m) \cdot gT^2}{5\sqrt{gT^2}} \qquad (6\text{-}1)$$

Where:

X = Wave run-up attenuation distance (m)

R = Wave run-up level including the storm tide (m RL)

Y_0 = Dune crest elevation (m RL)

T = Wave period (sec)

g = 9.81m/s^2

A = Inland slope factor (default = 1, can be adjusted at own preference)

m = Positive upward inland slope valid for -0.5 < m < 0.25 (e.g. for 1(V):10(H), m = 0.1)

iv Offset the calculated distance from the dune crest/coastal edge.

The distance between the coastal edge and the offset line represents the coastal run-up hazard zone. These steps should be repeated if the beach slope, wave conditions or dune crest level vary alongshore.

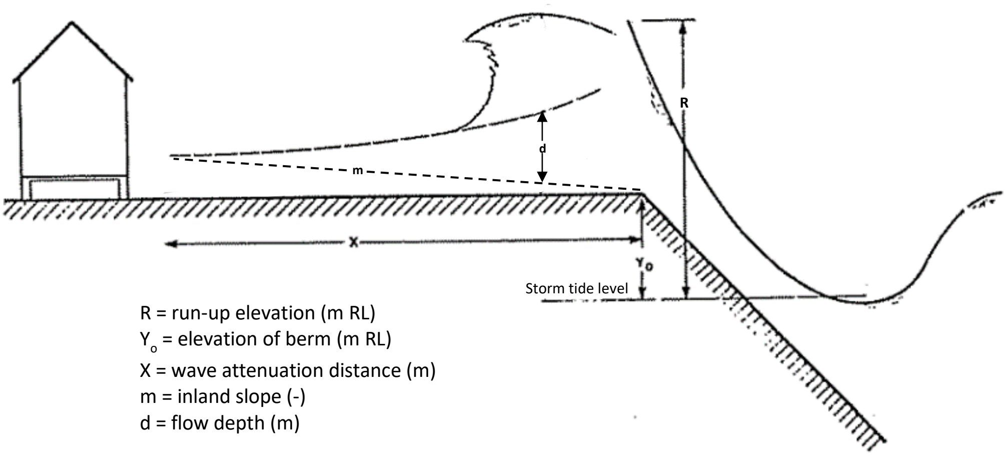

Figure 7-4: Run-up attenuation definition sketch (modified from Cox and Machemehl, 1986)

8 Conclusion and recommendations

8.1 Summary

Nelson City Council (NCC) has engaged T+T to undertake a high level or *first-pass* coastal inundation assessment for Nelson City. This includes a review of available extreme coastal water level information including the updated coastal calculator for Nelson City developed by NIWA (2018) and derivation of current and future extreme coastal water levels for general areas of Nelson City.

The extreme water levels have been derived using the coastal calculator where applicable, with additional numerical modelling to assess wave set-up for open coast shorelines. For shoreline situated within estuaries wave set-up and run-up have been calculated using a simple empirical approach due to the wide variation in bed slopes meaning that using either the coastal calculator or numerical model are not practical.

The Nelson City coastline has been split in representative coastal cells within which the assessed extreme water levels are expected to be similar. The present day 1% AEP static inundation levels vary between 2.5 to 3.1 m NZVD2016 for the Nelson region (refer to Table 4.10). The future extreme water levels allow for the sea level to rise with inundation levels between 2.8 and 3.6 m NZVD2016 in 2070 and between 3.1 and 4.5 m NZVD2016 in 2130 depending on the adopted SLR projection.

The assessment also includes mapping of land elevation for low lying areas of Nelson City. By combining both the derived static inundation levels and the elevation mapping, areas susceptible to inundation can be identified. Areas that are inundated but disconnected from the coastline (e.g. all land below MHWS), are mapped with a different colour to show the potential total inundated area if the disconnected areas are hydraulically connected (e.g. via culverts). Inundated areas have been mapped at using 0.25 m interval bands for the hard copy maps and using 0.1 m interval bands for the digital inundation layers. Based on the assessed inundation levels and inundation maps showing inundation extents, areas such as Monaco, Tahunanui and the Wakapuaka lowlands may be subject to inundation in the next 50 years. Monaco is likely to be inundated during extreme storms over the next 50 years, with increasing inundation extents over the next 100 years. The Nelson Airport may be subject to coastal inundation in 2130 independent of adopted sea level rise projection or in 2070 if the sea level rises according to the highest sea level rise projection. The Tahunanui playing fields, camp ground and adjacent urban area may get inundated during an extreme event in 2070. The inundation extents increase in 2130 to include a large part of the urban area adjacent to Back Beach Inlet. Future high tide levels, as defined by the MHWS-6, were also assessed, as these indicate areas that may be subject to inundation more frequently, resulting in more permanent migration of the coastal edge. By 2130, MHWS-6 may reach 3.2 m NZVD2016 under a high end (RCP8.5+) SLR scenario. This would cause more widespread permanent inundation of parts of The Wood, The CBD, Tahunanui, around Monaco, the Airport and business district.

Following the high level inundation assessment, The Wood and Nelson City CBD were identified as being particularly prone to coastal inundation, and as such, a detailed hydrodynamic coastal inundation assessment has also been undertaken for these areas using an existing hydraulic flood model of the Matai River. Modelling was undertaken using the same inundation levels derived for the Nelson Haven coastal cell, however, using a hydrodynamic model provides a refined estimate of coastal inundation through the use of a dynamic tidal boundary, which reduces the overall inundation time from one that was unlimited, when assessed with a static inundation level, to one that is limited by peak tidal timing. As such, modelled coastal inundation extents were observed to be less than those derived using static inundation levels. This is particularly evident with peak water levels below 3.4 m NZVD2016, where spill out of bank occurs only briefly, while at more extreme water levels, inundation extents are more similar to static inundation assessments.

Inundation of The Wood is observed to occur first when water levels exceed 2.6 m NZVD2016 on the lower Matai River at Hathaway Terrace. Inundation of The Wood becomes more severe, via spill at Hathaway Terrace, with the severity of climate change influence. Coastal inundation in the south-west of the CBD first occurs as outbreaks of the Saltwater Creek banks, and in extreme/future scenarios, sees much of lower Vanguard Street and the lower part of Washington Valley inundated.

The port, coastal areas of The Wood and areas south-west of the lower Matai River, are most susceptible to coastal inundation under MHWS-6 and 1% AEP water level scenarios simulated.

8.2 Recommendations

Based on the findings of this assessment the following are recommendations to more accurately assess the effect of coastal inundation on the Nelson region:

- *Post-event data collection.*
  Surveying or capturing static inundation or wave run-up levels after a storm event would provide a calibration/validation of the assessed levels to improve the accuracy and confidence in predicted extreme levels. This should be undertaken using survey grade GPS (accuracy to +/- 1 cm) and based on debris lines or other evidence. It is important to note the difference between flooding caused by rainfall, by catchment flows or by coastal inundation.
- *Wave modelling*
  Numerical wave modelling for the Waimea Inlet, including the inner Tahunanui area, Nelson Haven and Delaware Estuary would provide more detailed information on spatially varying nearshore wave heights along the shoreline. This information would be used to assess wave set-up and therefore static inundation levels varying along the shoreline could be assessed in more detail.
- *Ground-truth disconnected areas*

  This assessment includes maps of inundated areas that are connected to the coastline and example maps including areas that are disconnected from the coastline that could be inundated if they were hydraulically connected. An example is the urban area in the vicinity of the lower Maitai near Trafalgar Park, which is shown to be inundated during a present day extreme event if it was hydraulically connected to the coastline (see Figure 4 in Appendix A). For large areas such as this example an investigation should be undertaken to confirm whether it is hydraulically connected (e.g. culvert) and is recommended to be included for a detailed assessment.
- *Hydrodynamic model for large inundated areas*
  As demonstrated in The Wood and CBD, other large inundated areas such as the Wakapuaka lowlands and Tahunanui area are likely to have conservative flood extents using a bathtub approach, due to the limited duration of the maximum tidal level and frictional losses across the land. Dynamic (hydrodynamic) modelling could also be undertaken for these sites to better assess the flood extents.

Update downstream water levels for catchment flooding
This assessment includes coastal inundation levels and does not include flooding due to local rainfall or elevated river levels. Separate assessments that are being or have been undertaken, such as catchment flooding, may require to be reviewed and/or re-assessed using levels assessed in this report. For example, we are aware that NCC's existing modelling of Nelson Urban Streams is based on a coastal boundary of a 1 year ARI sea level with up to 1 m sea level rise, and that NCC are currently mapping catchment inundation assuming up to 1.5 m of sea level rise. We note that the 1 year ARI sea level adopted for the purposes of flood modelling was given to NCC by NIWA in 2012 as RL 14.43 m (relative to NCC datum – approx. 2.03 m NZVD2016). We note that as per Table 3.2 of

this report, the 1 year ARI sea level is now assessed as 2.14 m NZVD2016 – i.e. approximately 0.11 m higher.

- *Risk screening assessment*
  This assessment has identified areas which may be susceptible to coastal inundation over different time periods and for different sea level rise scenarios. A comprehensive risk screening assessment would consider the consequences of flooding for different areas and could incorporate additional aspects such as the likelihood and frequency of flooding and flooding depths. The findings of this assessment could be used for the development of response strategies.

9 Applicability

This report has been prepared for the exclusive use of our client Nelson City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

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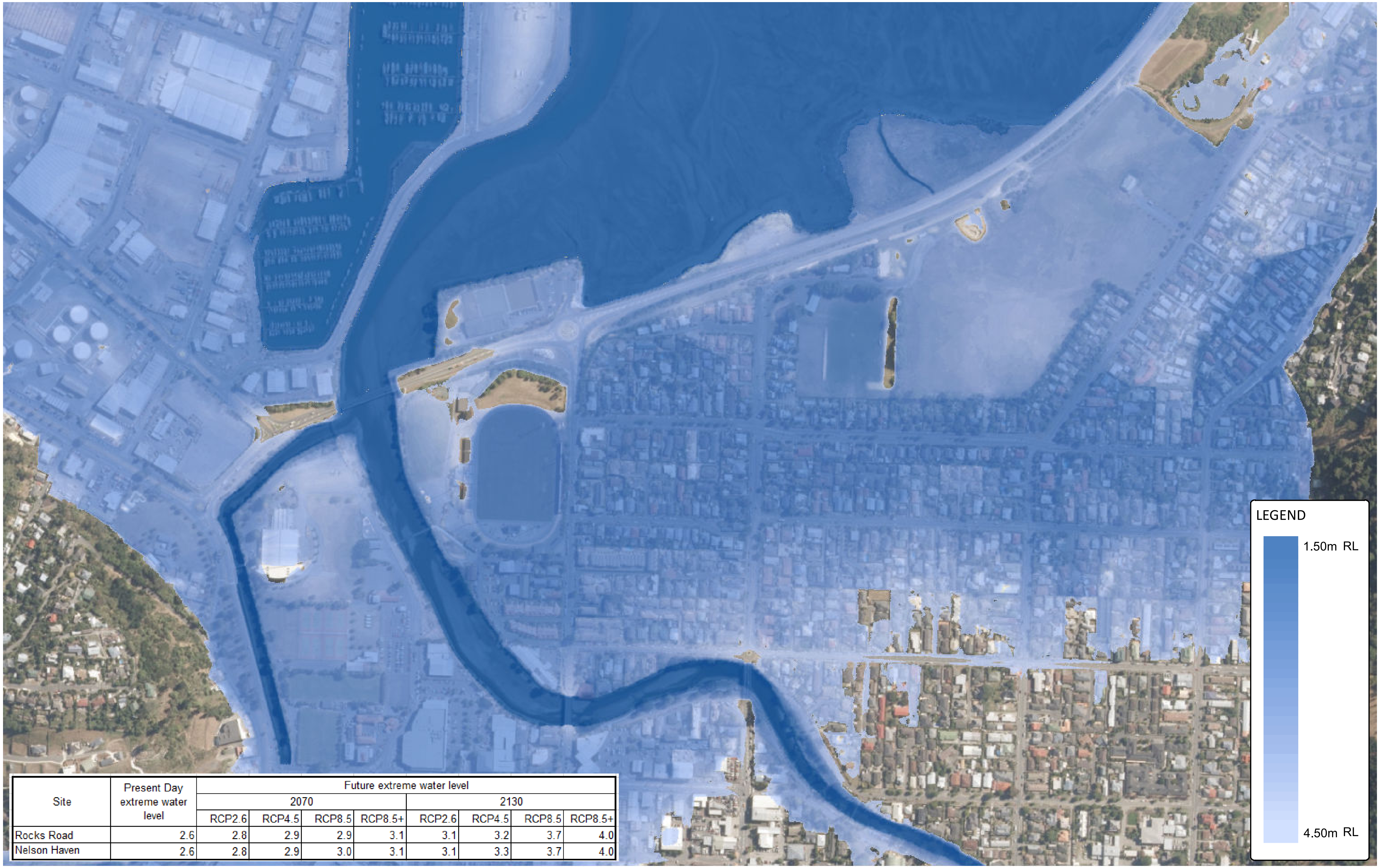
Appendix A: Extent of Inundation for Elevated Coastal Water Levels – Bathtub Approach



Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Rocks Road	2.6	2.8	2.9	2.9	3.1	3.1	3.2	3.7	4.0
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000

0 50 100 150 200 250 Meters

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DRAWN	QUHO	Aug.18
CHECKED	TDS	Oct. 18
APPROVED		
ARCFILE	quho_20180808_0.1m.mxd	
SCALE (AT A3 SIZE)	1:5,000	
PROJECT No.	1006718.000	

NELSON CITY COUNCIL

Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 1. Lower Maitai

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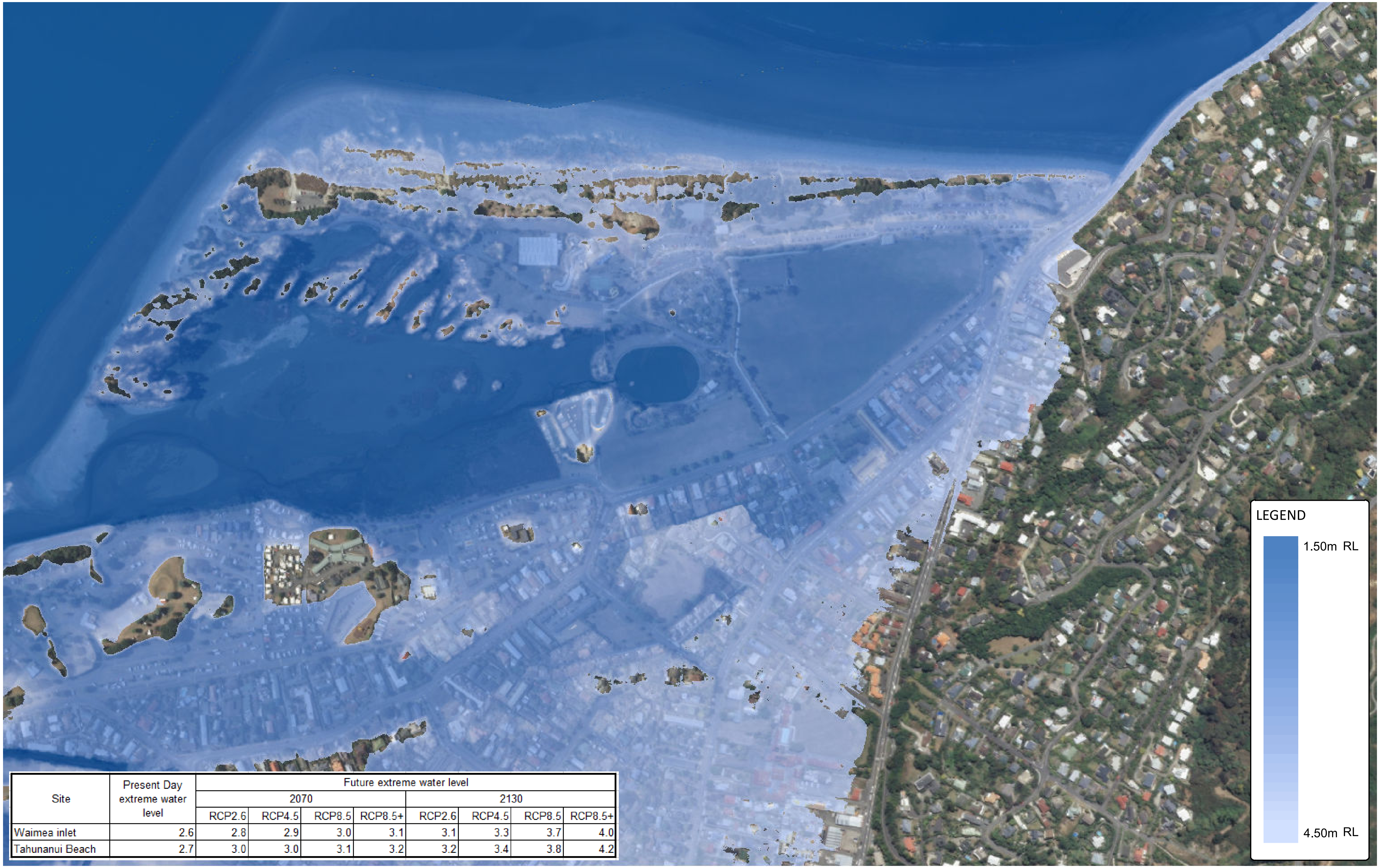
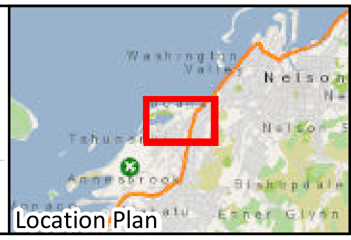


Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Waimea inlet	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Tahunanui Beach	2.7	3.0	3.0	3.1	3.2	3.2	3.4	3.8	4.2

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000
0 50 100 150 200 250 Meters



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Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 2. Tahunanui
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Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Waimea inlet	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Tahunanui Beach	2.7	3.0	3.0	3.1	3.2	3.2	3.4	3.8	4.2

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000
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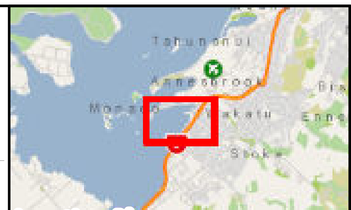
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Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 3. Monaco

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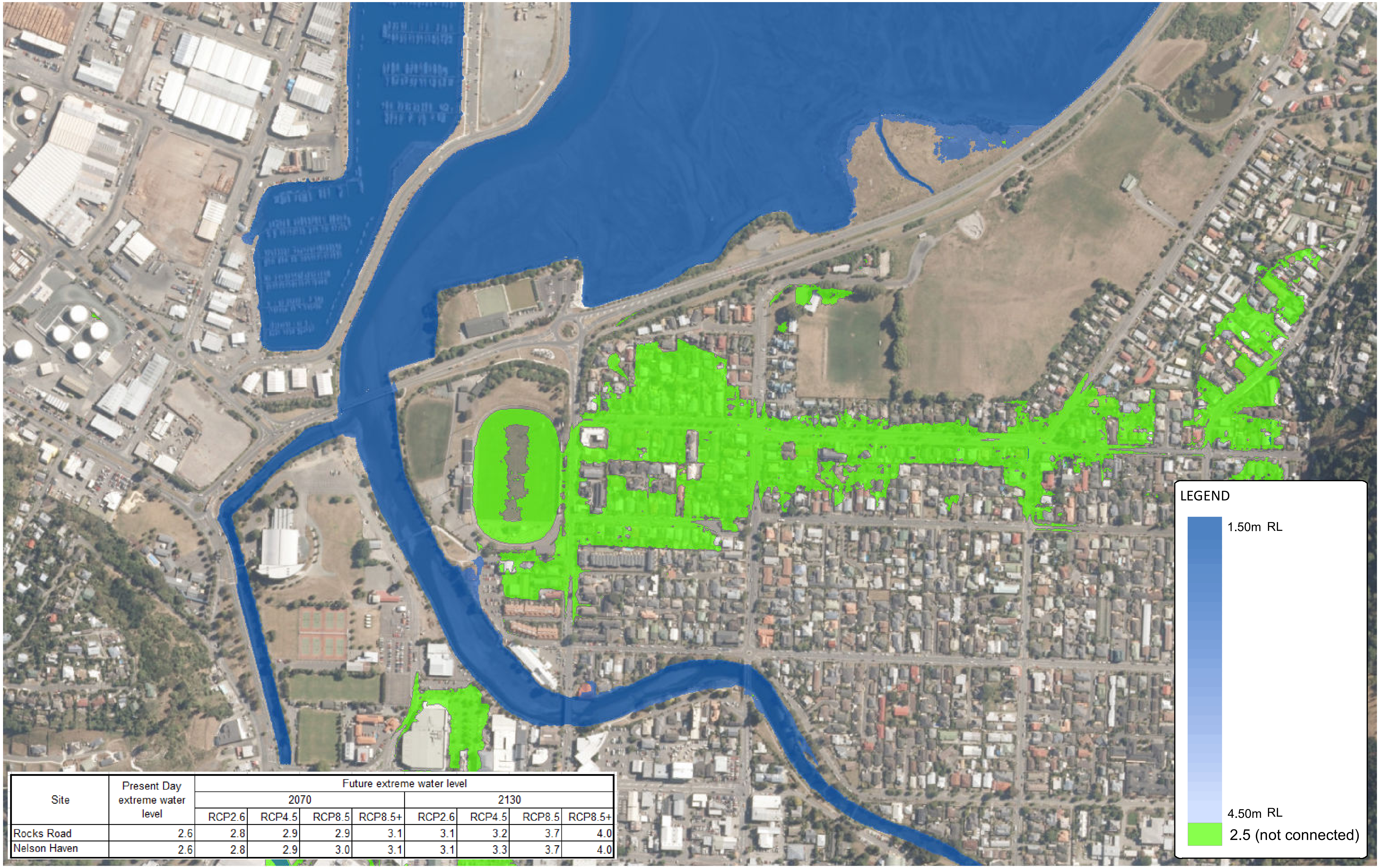

Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Rocks Road	2.6	2.8	2.9	2.9	3.1	3.1	3.2	3.7	4.0
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000

0 50 100 150 200 250 Meters

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ARCFILE quho_20180808_0.1m.mxd		
SCALE (AT A3 SIZE) 1:5,000		
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Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 4. Lower Maitai, 2.5m non-connected

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Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Waimea inlet	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Tahunanui Beach	2.7	3.0	3.0	3.1	3.2	3.2	3.4	3.8	4.2

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000
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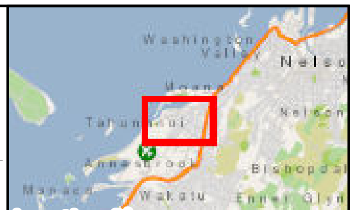
Location Plan

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Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 5. Tahunanui, 2.5m non-connected

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Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0
Boulder Bank / Pepin Island	3.1	3.3	3.4	3.5	3.6	3.6	3.8	4.2	4.5

Notes: Levels in terms of NZVD 2016
Aerial imagary sourced from LINZ Data Service

A3 SCALE 1:5,000
0 50 100 150 200 250 Meters

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Extent of Inundation for Elevated Coastal Water Levels

FIGURE No. Figure 6. Glenduan

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Appendix B: Hydraulic Model Coastal Inundation Maps

- Figure 1 - MHWS-6 2130 RCP8.5+ modelled inundation depths
- Figure 2 - MHWS-6 modelled inundation extents
- Figure 3 - 1% AEP present-day modelled inundation depths
- Figure 4 - 1% AEP RCP2.6 2070 modelled inundation depths
- Figure 5 - 1% AEP RCP2.6 2130 modelled inundation depths
- Figure 6 - 1% AEP RCP4.5 2070 modelled inundation depths
- Figure 7 - 1% AEP RCP4.5 2130 modelled inundation depths
- Figure 8 - 1% AEP RCP6.0 2070 modelled inundation depths
- Figure 9 - 1% AEP RCP6.0 2130 modelled inundation depths
- Figure 10 - 1% AEP RCP8.5 2070 modelled inundation depths
- Figure 11 - 1% AEP RCP8.5 2130 modelled inundation depths
- Figure 12 - 1% AEP RCP8.5+ 2070 modelled inundation depths
- Figure 13 - 1% AEP RCP8.5+ 2130 modelled inundation depths

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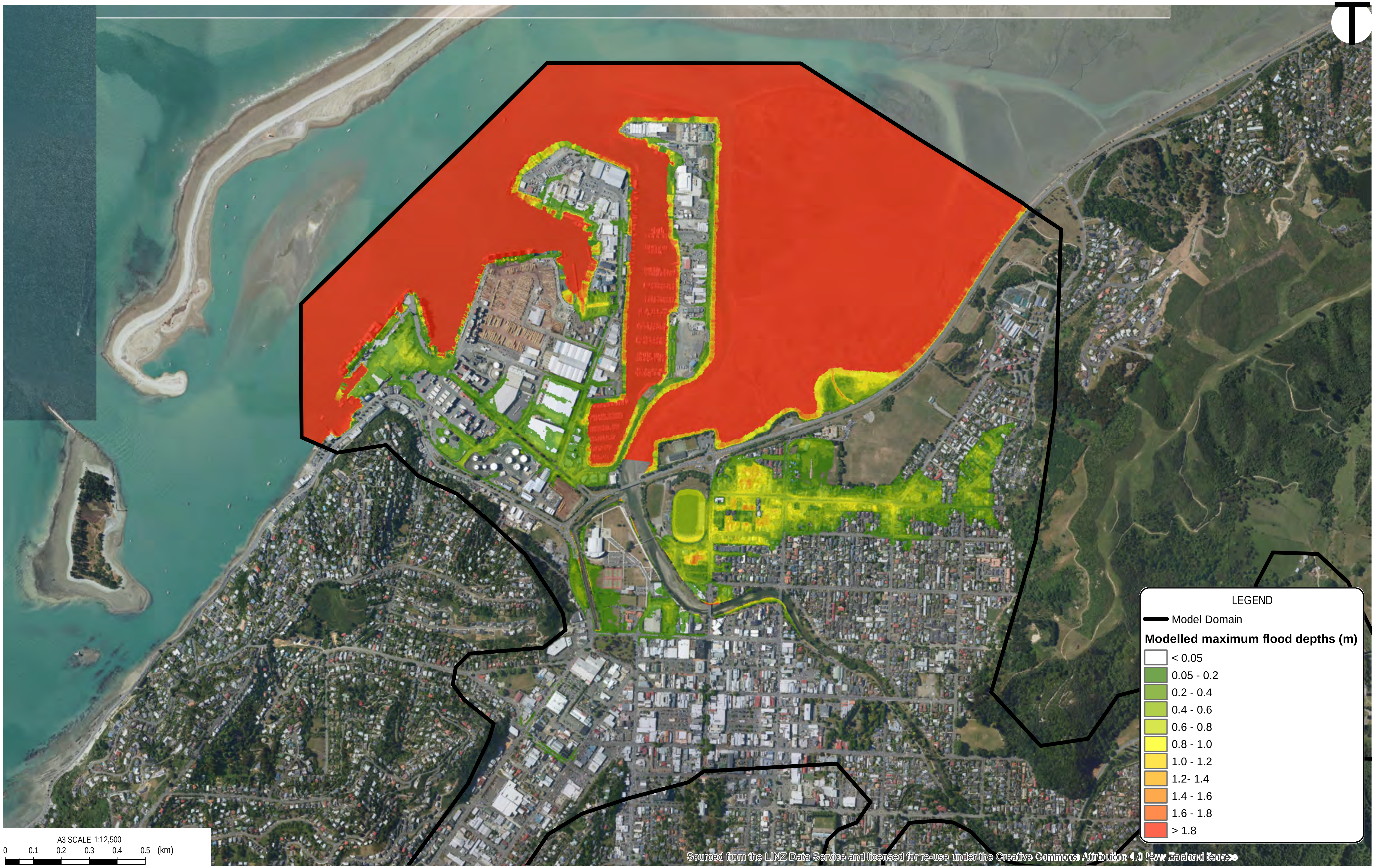

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NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. MHWS-6 = mean high water springs, exceeded by 6% of tides
3. RCP8.5+ = Representative concentration pathway 8.5+ for future sea level rise

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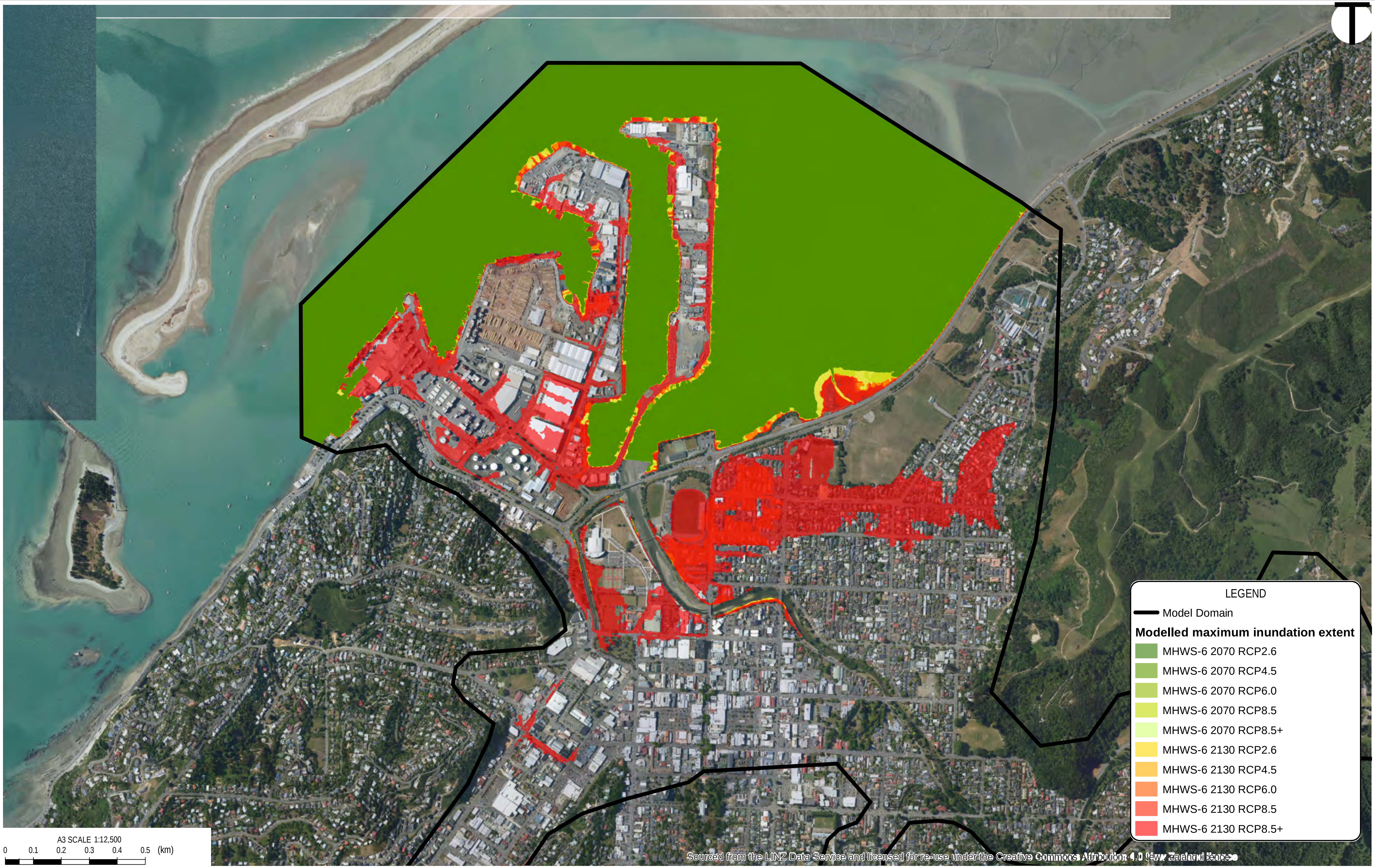
PROJECT DYNAMIC COASTAL INUNDATION MODELLING
TITLE Modelled Maximum Inundation Depths - MHWS-6 (2130 RCP8.5+)

SCALE (A3) 1:12,500 FIG No. Figure 1 REV 0



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NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. MHWS-6 = mean high water springs, exceeded by 6% of tides
3. RCP = Representative concentration pathway for future sea level rise

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TITLE Modelled Maximum Inundation Extents- MHWS-6

SCALE (A3) 1:12,500 FIG No. Figure 2 REV 0

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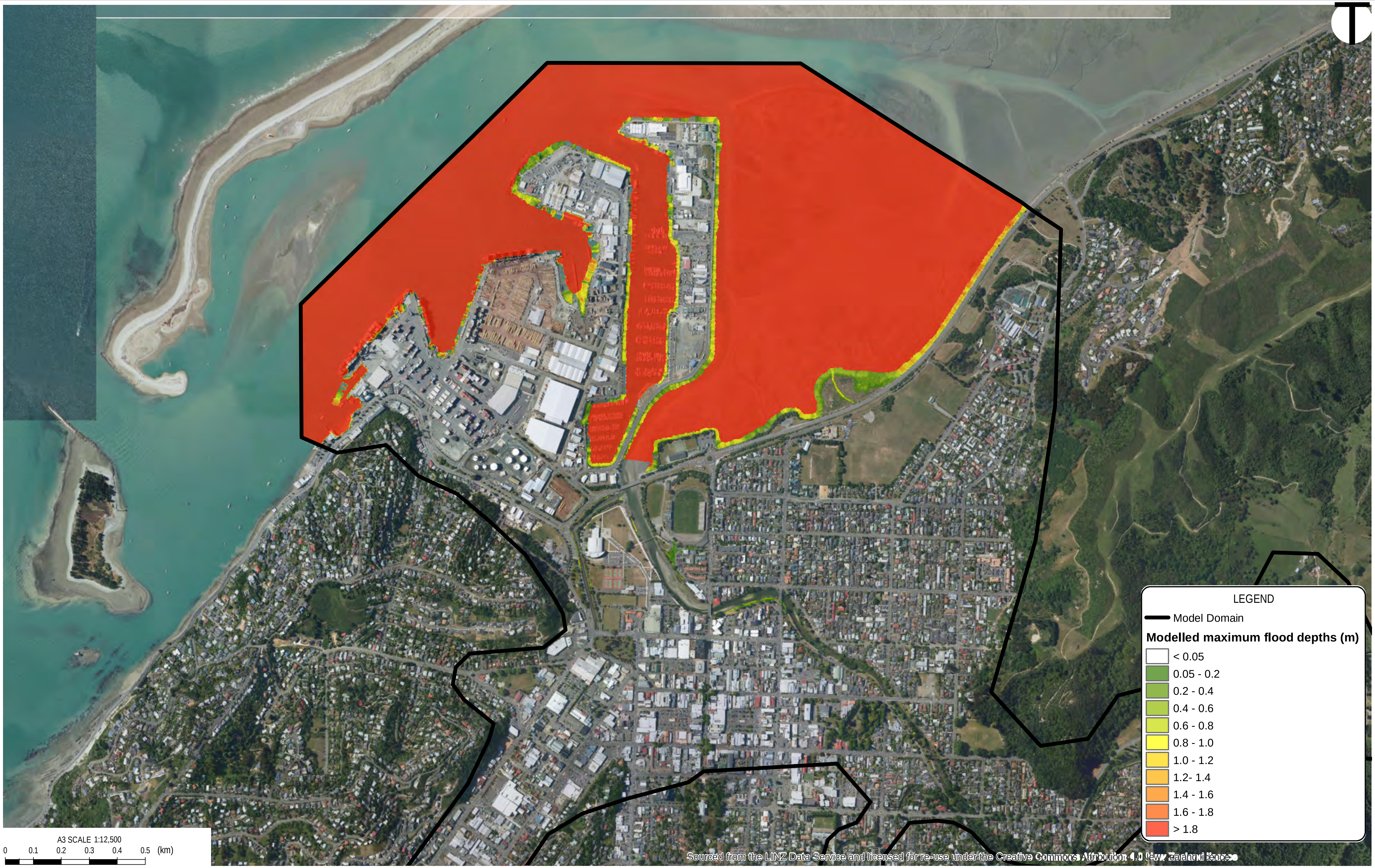

NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability

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TITLE Modelled Maximum Inundation Depths- 1% AEP (Present Day)

SCALE (A3) 1:12,500 FIG No. Figure 3 REV 0

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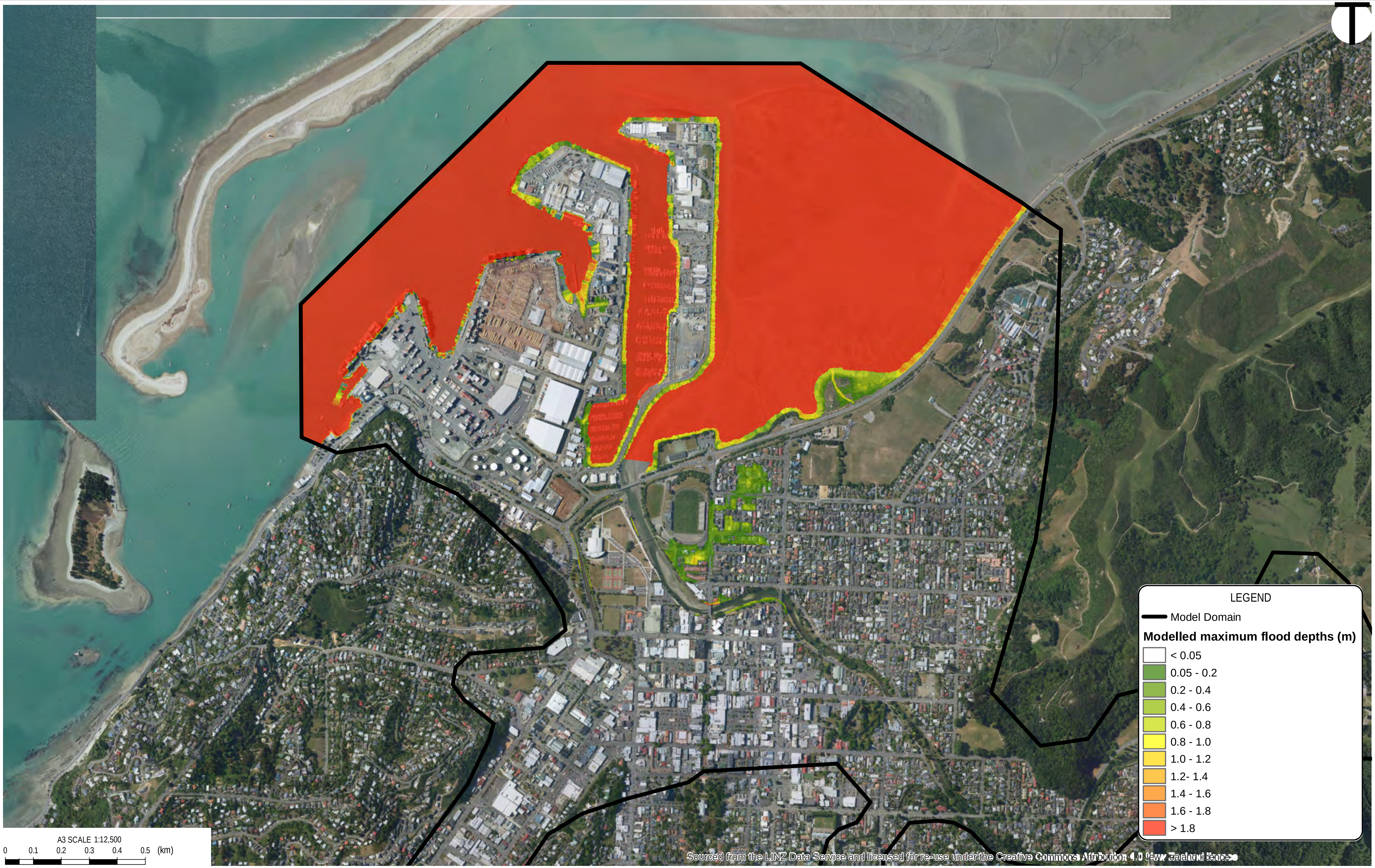

NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP2.6 = Representative concentration pathway 2.6 for future sea level rise

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PROJECT DYNAMIC COASTAL INUNDATION MODELLING

TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP2.6 2070)

SCALE (A3) 1:12,500 FIG No. Figure 4 REV 0

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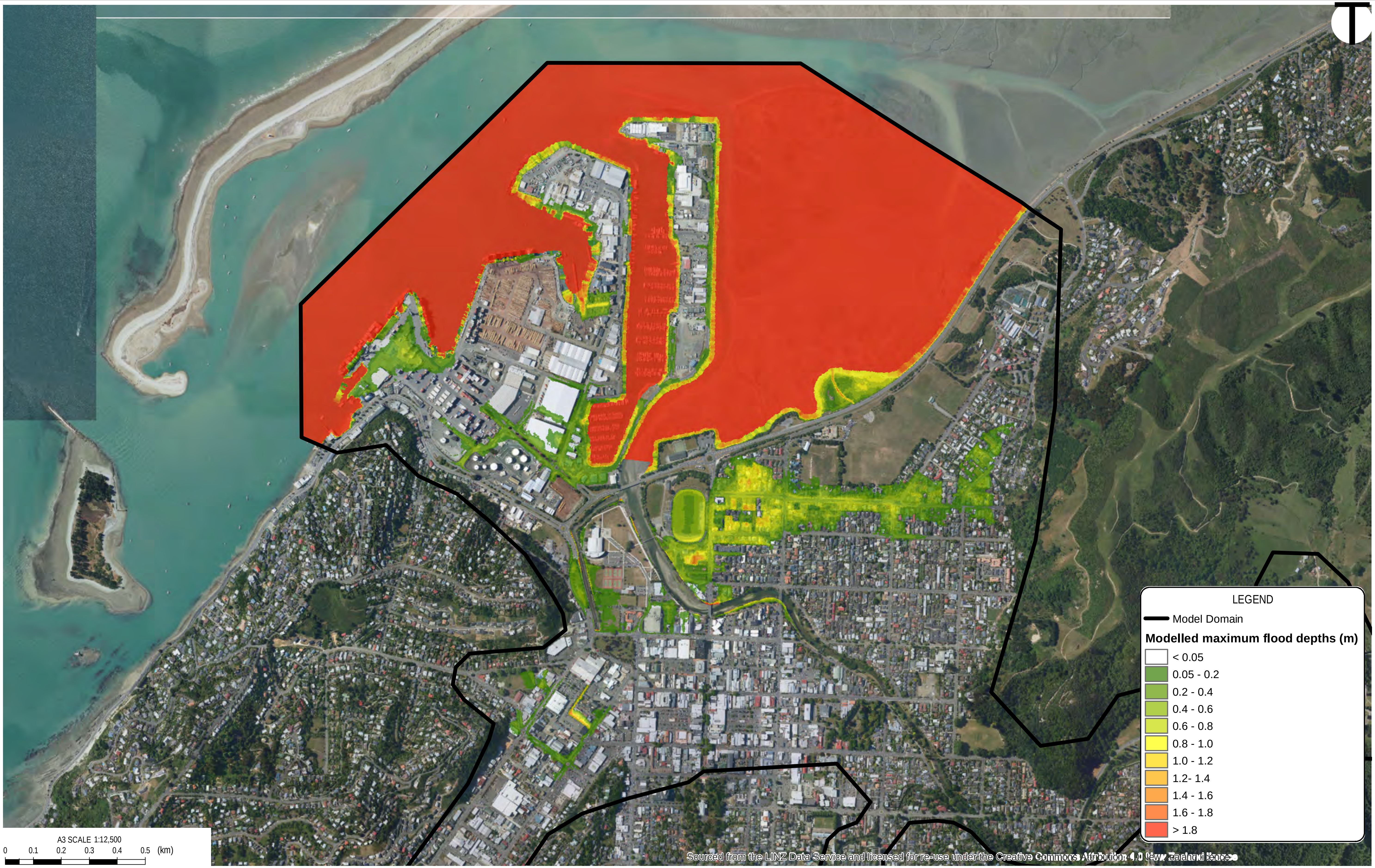

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NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP2.6 = Representative concentration pathway 2.6 for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP2.6 2130)

SCALE (A3) 1:12,500 FIG No. Figure 5 REV 0

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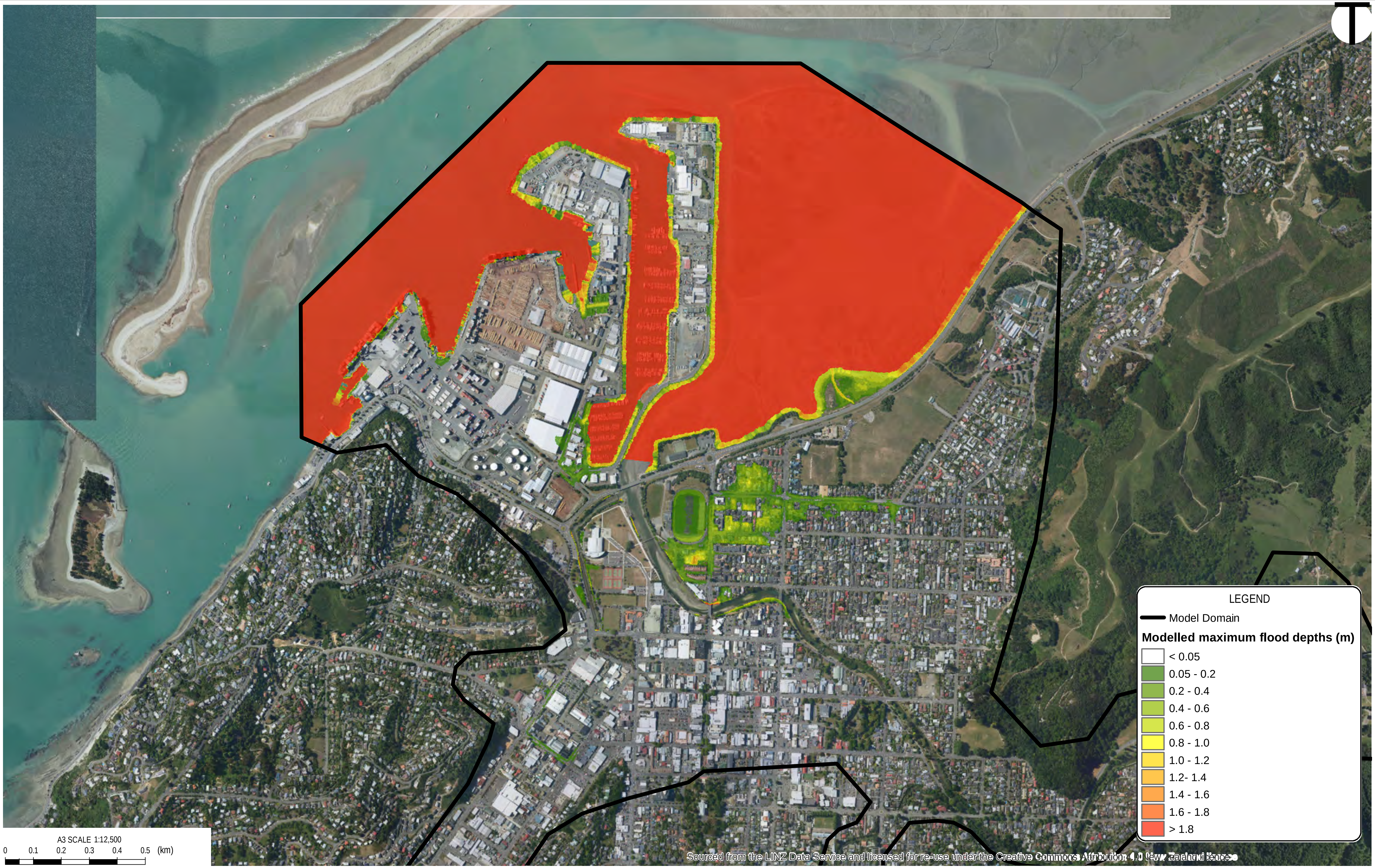

NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP4.5 = Representative concentration pathway 4.5 for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP4.5 2070)
SCALE (A3) 1:12,500 FIG No. Figure 6 REV 0

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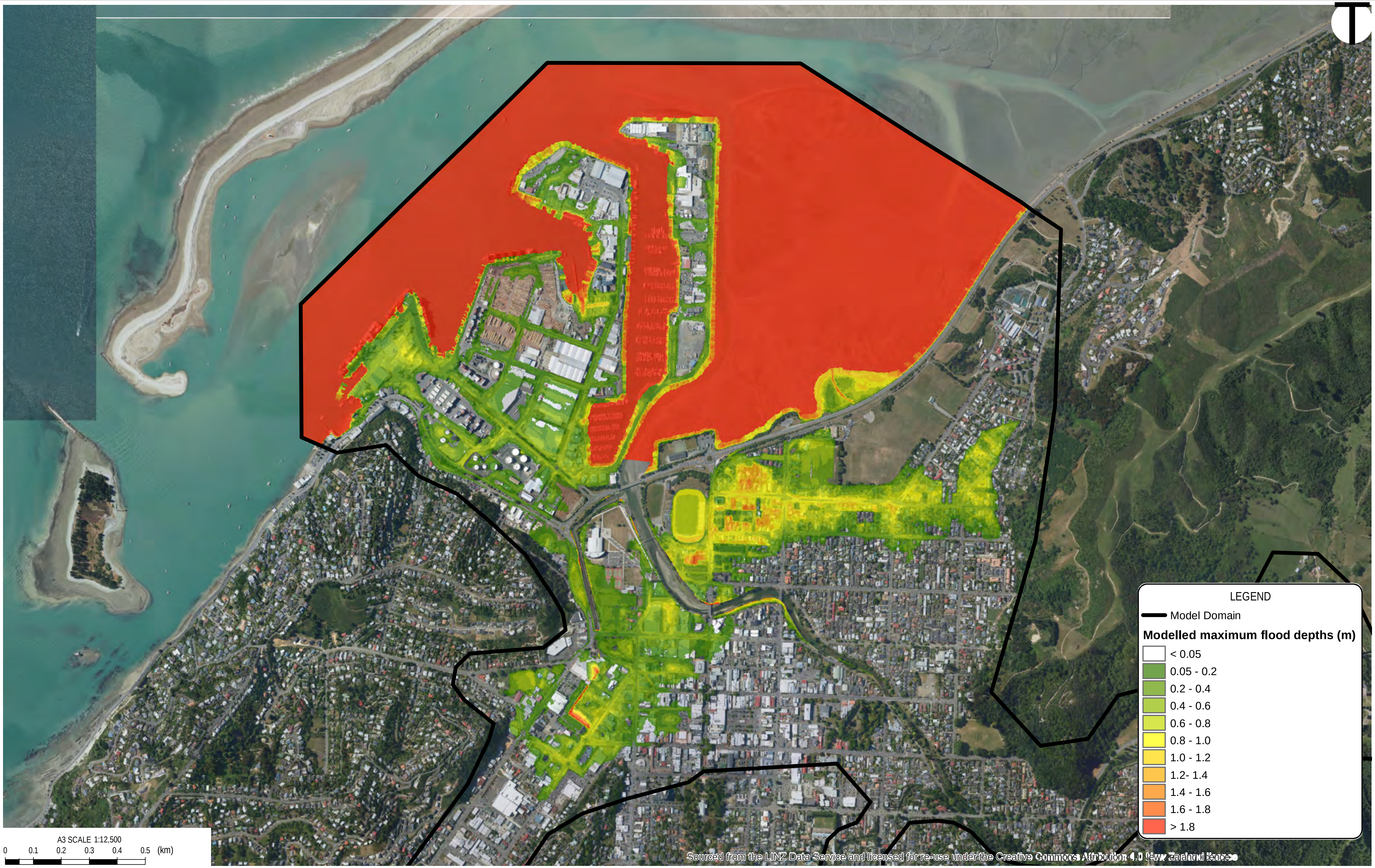

NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP4.5 = Representative concentration pathway 4.5 for future sea level rise

LOCATION PLAN

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP4.5 2130)
SCALE (A3) 1:12,500 FIG No. Figure 7 REV 0

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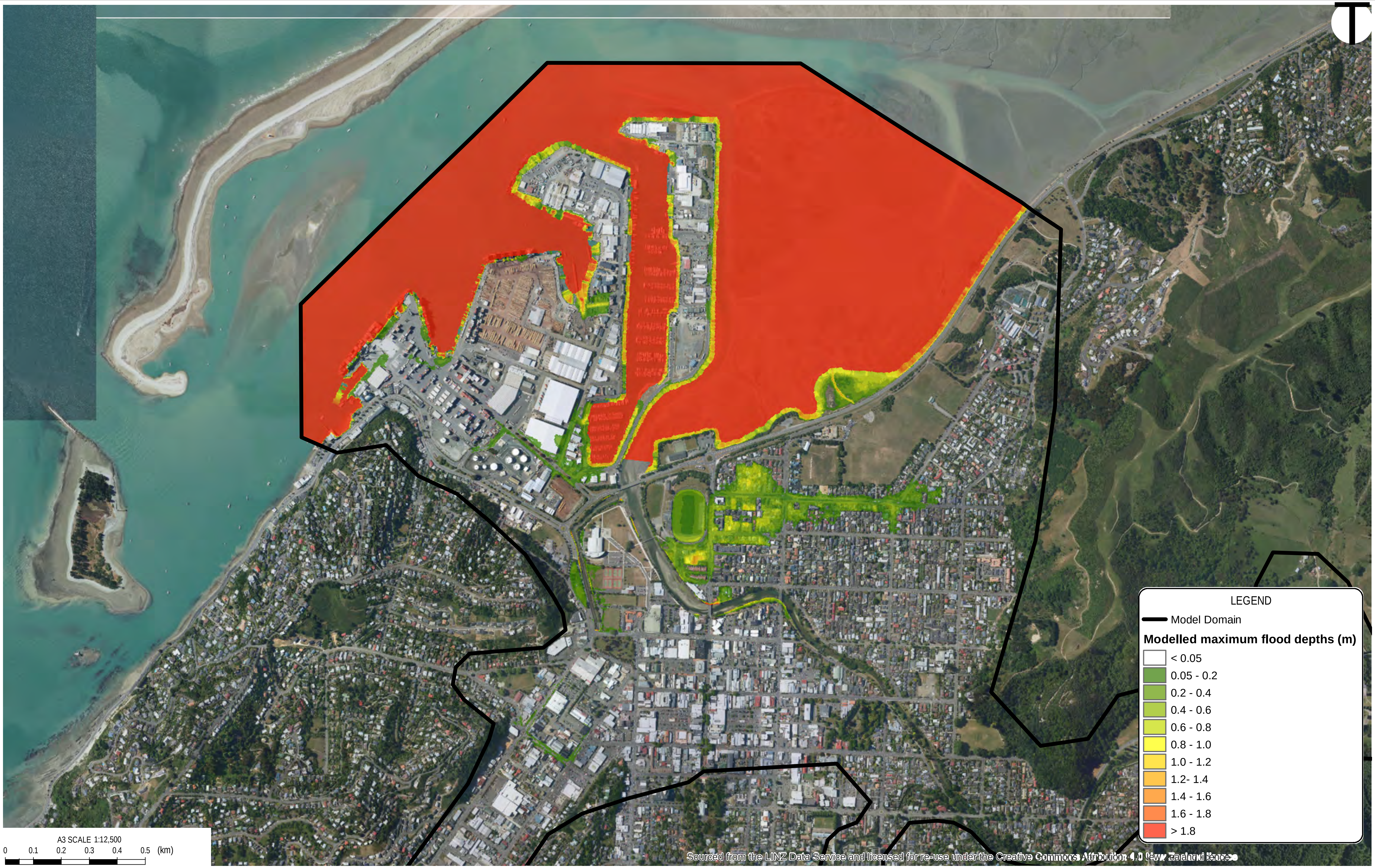

NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP6.0 = Representative concentration pathway 6.0 for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP6.0 2070)
SCALE (A3) 1:12,500 FIG No. Figure 8 REV 0

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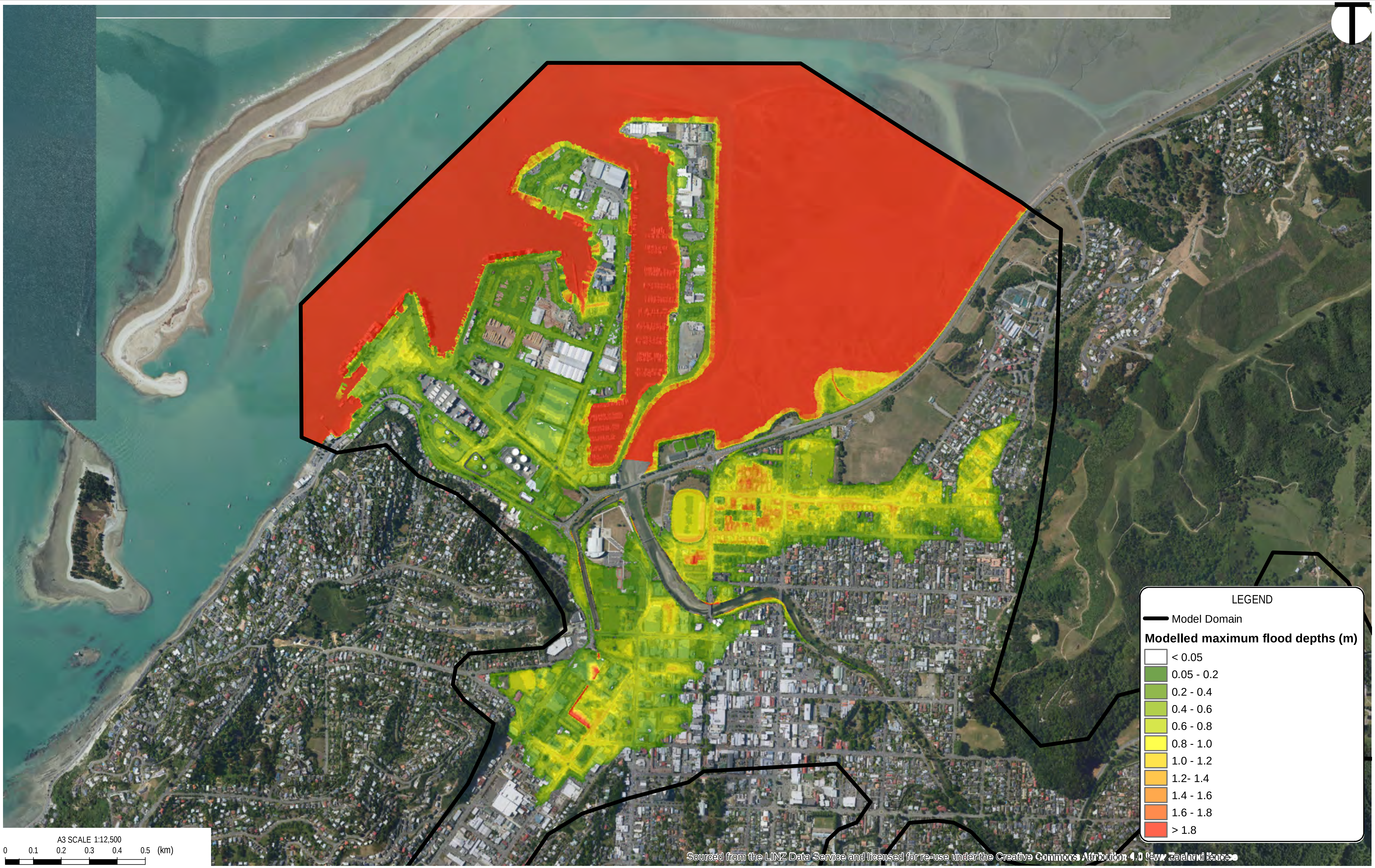

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NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP6.0 = Representative concentration pathway 6.0 for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP6.0 2130)

SCALE (A3) 1:12,500 FIG No. Figure 9 REV 0

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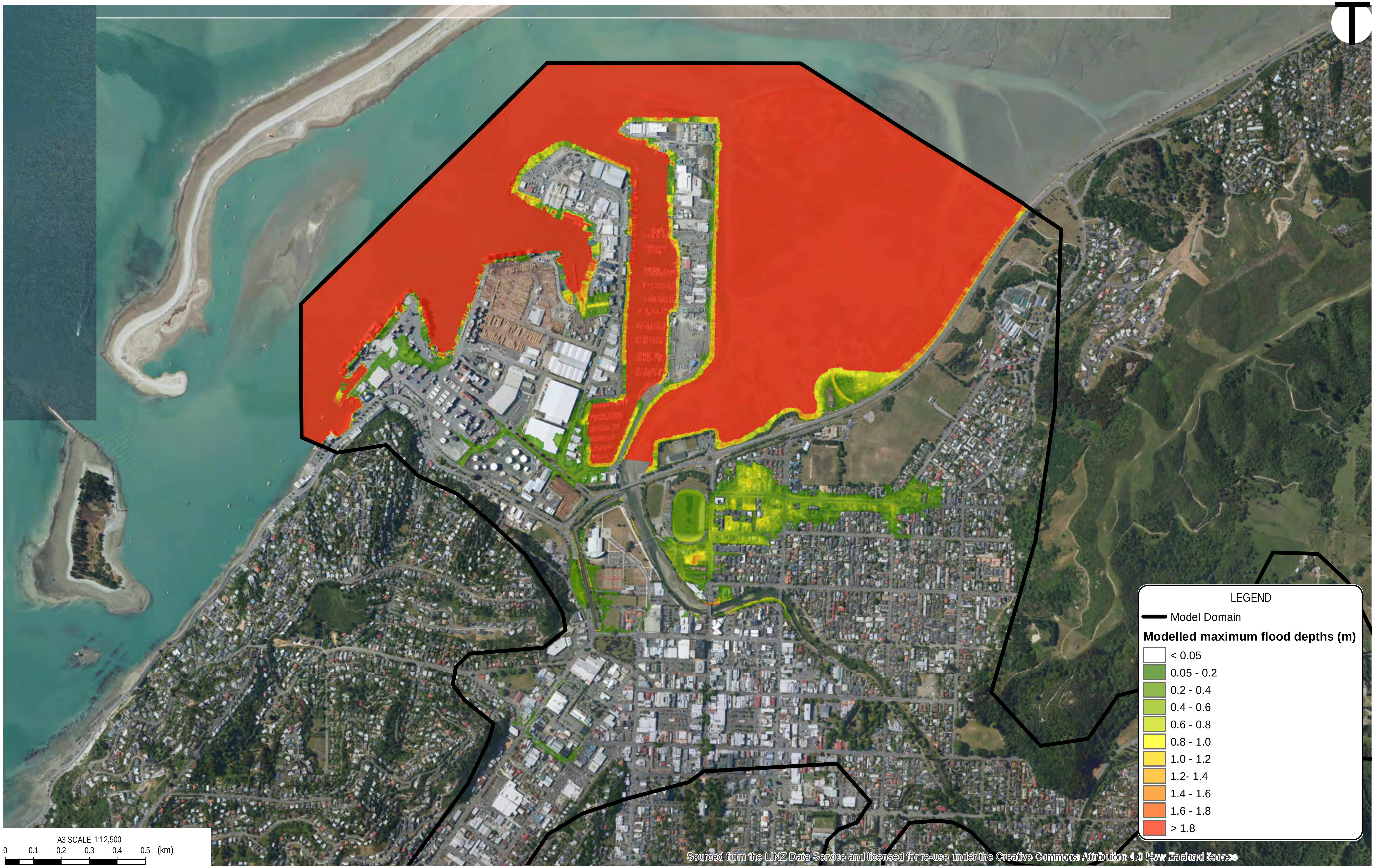

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NOTES

1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP8.5 = Representative concentration pathway 8.5 for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP8.5 2070)

SCALE (A3) 1:12,500 FIG No. Figure 10 REV 0

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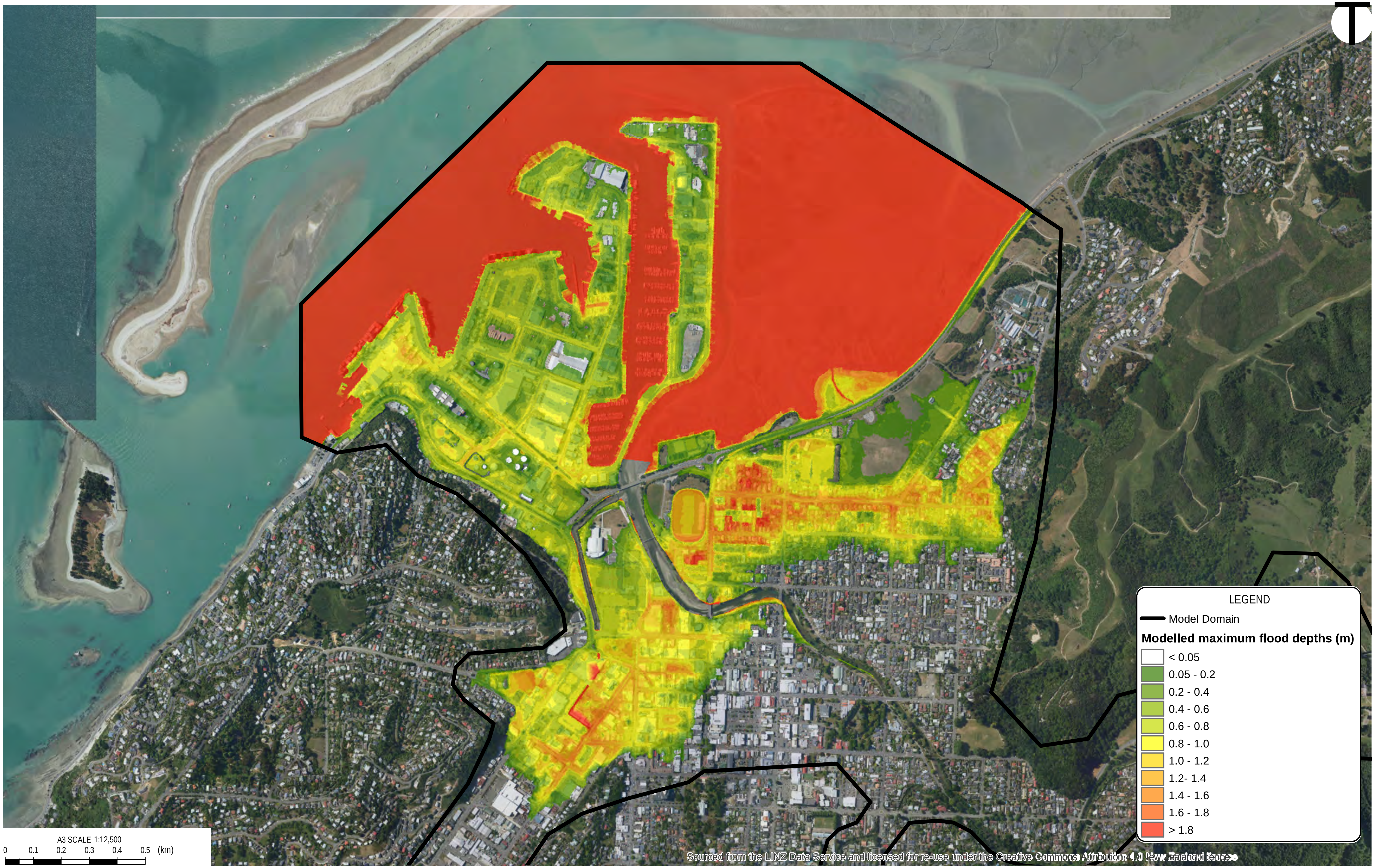

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NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedance probability
3. RCP8.5 = Representative concentration pathway 8.5 for future sea level rise

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PROJECT **DYNAMIC COASTAL INUNDATION MODELLING**

TITLE Modelled Maximum Inundation Depths - 1% AEP (2130 RCP8.5)

SCALE (A3) 1:12,500 FIG No. Figure 11 REV 0

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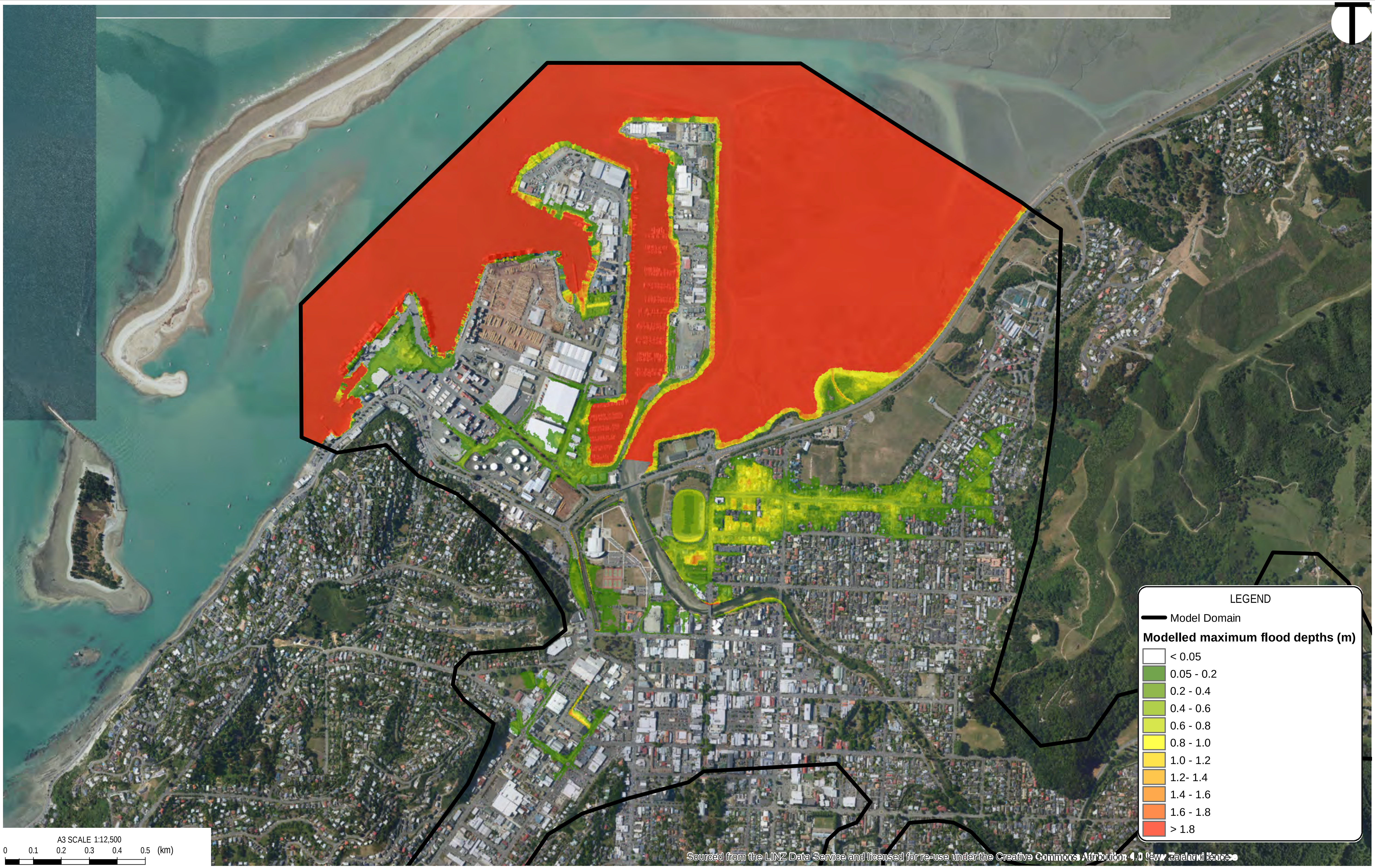

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NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP8.5+ = Representative concentration pathway 8.5+ for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP8.5+ 2070)
SCALE (A3) 1:12,500 FIG No. Figure 12 REV 0

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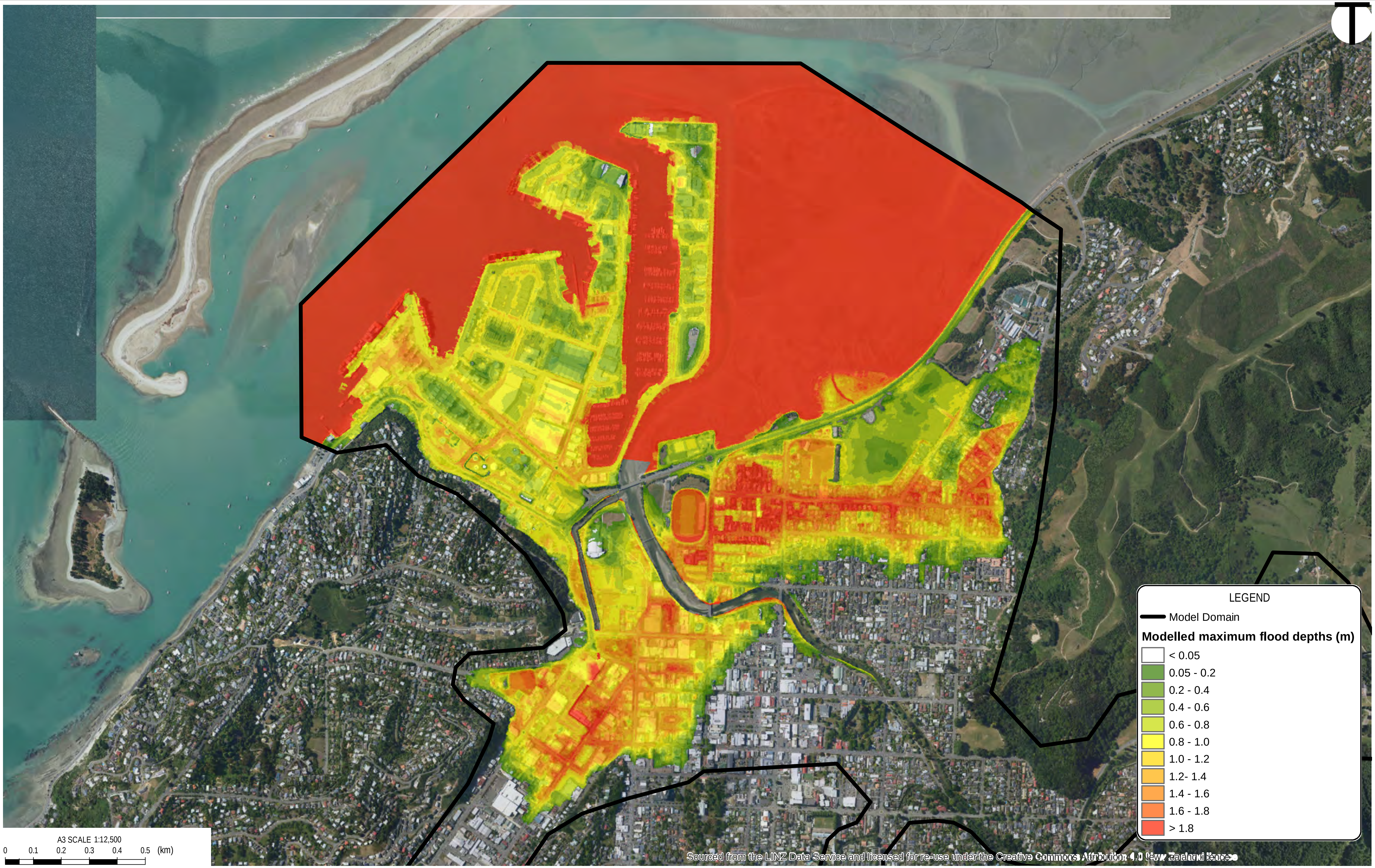

NOTES
1. Inundation due to elevated tidal levels only - no river flooding
2. 1% AEP = 1% average exceedence probability
3. RCP8.5+ = Representative concentration pathway 8.5+ for future sea level rise

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TITLE Modelled Maximum Inundation Depths- 1% AEP (RCP8.5+ 2130)
SCALE (A3) 1:12,500 FIG No. Figure 13 REV 0

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