KiwiRail Physical Climate Change Risk Assessment

Prepared for: KiwiRail Ltd

Prepared by: Tonkin & Taylor Ltd

16 Oct 2024

www.tonkintaylor.co.nz

Tonkin+Taylor

KiwiRail Physical Climate Change Risk Assessment

Authors

Alex Cartwright
Tessa Allan
Morgan Lindsay

Approved by

Richard Reinen-Hamill

Job Number

1094423.0010

Version 2.0

Tonkin+Taylor

Document control and review

Document control and review

Date	Version	Description	Prepared by:	Authorised by:
11/09/2024	0.1	DRAFT for client review	T. Allan M. Lindsay A. Cartwright	R. Reinen-Hamill
23/09/2024	1.0	Final for client	T. Allan M. Lindsay A. Cartwright	R. Reinen-Hamill
16/10/2024	2.0	Final for client (including yards)	T. Allan M. Lindsay A. Cartwright	R. Reinen-Hamill

Quality management

To ensure alignment with our Quality Management System, technical review of differing elements within this report is documented below.

Quality management

Element:	Prepared by:	Reviewed by:
Geospatial analysis	Rachael Nilsson	Josie Robison
Map outputs	Josie Robison	Rachael Nilsson
Risk framework	Tessa Allan	Alex Cartwright

16 Oct 24

T:\Christchurch\TT Projects\1094423\1094423.0010\IssuedDocuments\20241016_Report.V2\20241016.KiwiRailPhysicalCCRA.Report.V2.FINAL.docx

Table of contents

Executive summary

KiwiRail undertook a Resilience Programme Business Case (PBC) in 2023 to identify national resilience improvements related to the rail network and developed a Draft Climate Resilience Strategy. Identified as an objective in the Draft Climate Resilience Strategy, this KiwiRail Physical Climate Change Risk Assessment (CCRA) is an extension of the Resilience PBC. This CCRA assesses more KiwiRail assets, along with increased physical climate-related hazards, to better understand the risks that may result from climate change for KiwiRail's assets now and in the future.

The risk assessment framework used to understand risk to KiwiRail railway infrastructure and property aligns with both the ISO 31000 'Risk Management' and the Intergovernmental Panel on Climate Change (IPCC). Risk is defined by hazard exposure and vulnerability (together forming likelihood), and consequence. The risk assessment focuses on three timeframes (present day, mid-century, end of century) and two Shared Socio-economic Pathways (SSPs).

The risk assessment is high-level in nature, looking at a picture of risk across KiwiRail's national network. Data quality has been considered for both KiwiRail asset information along with climate-related hazard information. Assessment rating tables have been created based on available information for each risk criteria.

A total of 10 KiwiRail asset types were assessed against three climate-related 'acute' hazards (coastal inundation, coastal erosion, river and surface flooding) along with three climate variables 'chronic' hazards (hot days, heavy rainfall, strong winds). All asset types are found to have assets at high or extreme risk to coastal erosion, coastal inundation, and river and surface flooding. The below table summarises assets identified as exposed and at risk from these three hazards (by asset type).

Summary of at risk assets by asset type, hazard and timeframe

Asset/ measure	Total assessed	Coastal erosion		Coastal inundation		River/ surface flooding	
		Present day	End of century	Present day	End of century	Present day	End of century
Tracks (km)	5099	295 (6%)	362 (7%)	84 (2%)	354 (7%)	1586 (31%)	1586 (31%)
Private sidings (km)	22	0.5 (2%)	0.6 (3%)	0.1 (0%)	1.2 (6%)	8.4 (38%)	8.4 (38%)
Bridges (No.)	1,393	77 (6%)	97 (7%)	143 (10%)	179 (13%)	779 (56%)	779 (56%)
Signals (No.)	2,969	217 (7%)	265 (9%)	36 (1%)	268 (9%)	899 (30%)	899 (30%)
Culverts (No.)	11,614	604 (5%)	690 (6%)	136 (1%)	353 (3%)	2925 (25%)	2925 (25%)
Tunnels (No.)	148	29 (20%)	31 (21%)	1 (1%)	1 (1%)	18 (12%)	18 (12%)
Container sites (No.)	15	4 (27%)	8 (53%)	1 (7%)	11 (73%)	7 (47%)	7 (47%)
Yards (No.)	98	30 (31%)	36 (37%)	42 (43%)	56 (57%)	77 (79%)	77 (79%)
Structures (No.)	943	76 (8%)	97 (10%)	33 (3%)	197 (21%)	357 (38%)	357 (38%)
Landholdings (km^2)	182	8.6 (5%)	11 (6%)	4.4 (2%)	9.3 (5%)	52 (29%)	52 (29%)

Note: table depicts summary of at risk assets, with varied units of measure.

This work has been completed concurrently with work by KiwiRail looking at their organisational climate risks and opportunities, aligned to reporting requirements under NZ CS 1. There are a range of recommendations that KiwiRail should consider following this work, including reviewing risk assessment criteria for climate variables, incorporation of slope data and heavy rainfall data, further assessment of culvert hydraulic capacity, and integration of outputs of this assessment into KiwiRail's asset and risk management processes.

1 Introduction

In 2020 the Government established a new planning and funding framework for rail under the Land Transport Management Act 2003. The Rail Network Investment Programme (RNIP) was developed under the framework to *achieve a resilient and reliable rail network that also improves safety*. In 2023, KiwiRail undertook a Resilience Programme Business Case (PBC) to identify national resilience improvements related to the rail network. They also developed a Draft Climate Resilience Strategy.

Identified as an objective in the Draft Climate Resilience Strategy, this KiwiRail Physical Climate Change Risk Assessment (CCRA) is an extension of the Resilience Programme Business Case undertaken in 2023. The extension seeks to assess more KiwiRail assets, along with increased physical climate-related hazards. The assessment seeks to understand the risks that may result from climate change for KiwiRail's assets now and in the future.

The latest climate change projection data has been used for nine climate hazards and variables to assess all KiwiRail infrastructure and property assets as outlined in priority below:

1. KiwiRail National Rail Network
2. KiwiRail Container Sites and Depots
3. KiwiRail Container Transfer Sites
4. KiwiRail Rolling Stock Depots
5. KiwiRail Property.

It is understood that KiwiRail would like to utilise outputs from this assessment to inform potential future reporting on climate-related risks and opportunities as part of Aotearoa New Zealand Climate Standard 1: Climate-related Disclosures (NZ CS 1). Climate reporting falls outside the scope of work.

Paragraph 14 (NZ CS 1) states that:

> *An entity must include the following information when describing the climate-related risks and opportunities it has identified (see paragraph 11(c)):*
>
> *(a) how it defines short, medium and long term and how the definitions are linked to its strategic planning horizons and capital deployment plans;*
>
> *(b) whether the climate-related risks and opportunities identified are physical or transition risks or opportunities, including, where relevant, their sector and geography; and*
>
> *(c) how climate-related risks and opportunities serve as an input to its internal capital deployment and funding decision-making processes.*

Understanding KiwiRail's physical risk to climate change gives the organisation information to develop an informed climate change adaptation plan. This helps KiwiRail achieve the objective of managing resilience of their railway infrastructure and property assets as outlined in the RNIP.

This project was completed concurrently with an organisational CCRA to understand the transitional climate change risks to KiwiRail. To ensure consistency across both pieces of work, the climate change projections and timeframes have been aligned to the Transport Sector Scenarios, where appropriate.

2 Risk assessment framework

The risk assessment framework used to understand risk to KiwiRail railway infrastructure and property, aligns with both the ISO 31000 'Risk Management' and the Intergovernmental Panel on Climate Change (IPCC). ISO 31000 is used as the overarching framework, while the criteria is associated with the IPCC risk definition. This enables close alignment to KiwiRail's Enterprise risk framework and terminology[1].

Although this CCRA may be used as an input for the NZCS 1, the reporting does not require a specific risk assessment approach to be outlined. Other organisations reporting on NZCS 1 have tended to align with the method described above.

The IPCC utilise hazard, exposure, and vulnerability to define risk. Whereas ISO 31000 utilises likelihood and consequence to measure risk. For this assessment, risk is defined by hazard exposure and vulnerability (together forming likelihood), and consequence (Figure 2.1).

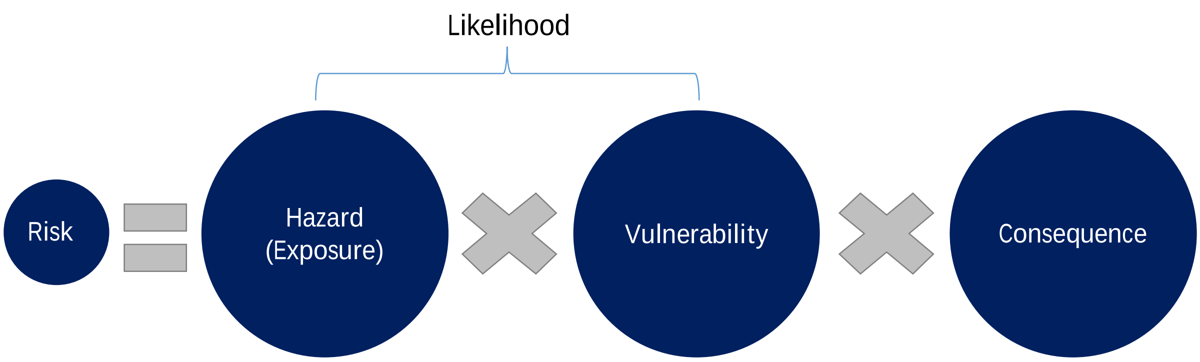


Figure 2.1: Alignment between KiwiRail's enterprise risk framework and the IPCC methodology

Likelihood gives context to the frequency and potential level of damage caused to the asset by the hazard. Consequence is determined by the importance of the assets in the national KiwiRail network. These terms and how they are used in the CCRA are discussed below.

Risk identification for this assessment is focused on KiwiRail assets and their interaction with physical climate hazards.

2.1 Assessment timeframes

Three generic timeframes were utilised for this assessment:

1 Present day (now)
2 Mid-century (2050 – 2080)
3 End of century (2100 – 2130).

These timeframes were chosen and are longer than the organisational risk assessment to ensure the asset lifecycles were accounted for in the assessment. The range for each timeframe is to enable matching of publicly available climate variable and hazard information. Organisations that own climate hazard information use differing projections and timeframes. Given the uncertainty associated with climate projections, grouping of timeframe ranges can provide simplicity without reduction in confidence. The matching of these timeframes is discussed further in Section 3.

[1] KiwiRail's Enterprise Risk Management Manual October 2023

2.2 Climate scenarios

The IPCC's Sixth Assessment Report, AR6 (2021–22) has produced a new set of representative scenarios, based on Shared Socio-economic Pathways (SSPs). These comprise of different socio-economic assumptions that drive future greenhouse gas emissions, including population, economic growth, education, urbanisation, and the rate of technological development. Five SSP pathways have been developed by the IPCC and NIWA has downscaled three of these for New Zealand.

For this CCRA, two scenarios that align with the Transport Sector Scenarios published in 2024[2] have been utilised:

- SSP1-2.6 (median)
- SSP3-7.0 (median).

These scenarios do not align with the Coastal Hazards and Climate Change Guidance[3], which outlines to assess against SSP2-4.5 and SSP5-8.5. To best position this CCRA for when NIWA release the SSP5-8.5 scenario (not currently available), the sea level rise increments have been recorded in the geospatial data. This means future consideration of relative sea level rise (including accounting for Vertical Land Movement) can be made when nationally applicable datasets are available.

These scenarios are primarily utilised for establishing assessment information for hazard exposure (within likelihood) and for subsequent reporting.

[2]https://static1.squarespace.com/static/62439881aa935837b9ad6ac9/t/66788f014f07162c0ddbd83e/1719177096225/Transport+Sector+Climate+Scenarios+-+Master+File+-+FINAL+-+2024.06.24.pdf.
[3] https://environment.govt.nz/publications/coastal-hazards-and-climate-change-guidance/

3 Data review

This assessment was dependent on the availability and quality of both climate-related hazard data and KiwiRail's asset data. A summary of the data review is documented below, focused on information utilised within this physical CCRA.

3.1 Climate-related hazards data

This CCRA involved undertaking an assessment of seven climate-related hazards that may impact KiwiRail assets. These hazards are outlined in Table 3.1, where river and surface flooding, coastal erosion, coastal inundation, and landslides are all high-energy, 'acute' hazards, and temperature, rainfall, and wind are more 'chronic' climate variables/ hazards.

Table 3.1: Climate-related hazards description

Climate variable/ hazard	Description
River and surface flooding	Flooding that occurs on normally dry land, caused by the overflow of waterbodies or when rainfall cannot be absorbed into the ground surface, creating runoff.
Coastal erosion	Coastal erosion is the loss or displacement of land, dependent on sediment supply, climate and ocean conditions.
Coastal inundation	Flooding that occurs on normally dry, low-lying coastal land, due to sea level rise, storm surges, and/ or high tides.
Change in temperature	Increasing temperatures (means and extremes) focus in this assessment was given to number of days within one year where the maximum daily temperature exceeds 25°C (known as hot days).
Changes in rainfall intensity	A large amount of rainfall that falls within a short period of time. This can overwhelm drainage systems, leading to flash flooding, along with cause damage due to the intensity of the rain.
Strong wind	Strong winds occur from high-pressure systems and storms. These are very geographically specific, and hard to project into the future. Trends for larger geographic areas are more reliable than localised projections of wind change.
Changes in landslide frequency	Change in the rate of landslides occurring in a particular area, which is influenced by rainfall, vegetation, slope, and human activity.

The climate-related hazard data has been gathered from a range of sources, with the purpose of informing the exposure assessment. Prioritisation was given to publicly available datasets, primarily sourced from Councils and NIWA. This included the updated climate projections for Aotearoa New Zealand (AR6), released June 2024, providing climate variable information for: temperature, rainfall, and winds. These have consistent timeframes and scenarios with national coverage at a 5x5 km resolution. Other datasets were sourced for inland flooding, coastal inundation, and coastal erosion. These have varied timeframes and scenarios. Table 3.2 summarises the data sources and associated timeframe and scenario information available by hazard. The climate-related hazards outlined in the table are as they were originally described in the Assessment Method Statement (AMS) but will be referred to as their data sources for the remainder of the report.

This assessment focuses on direct risks associated with physical climate change. Indirect risks have not been assessed in detail, nor those direct risks that have limited spatial information to assess assets against (e.g. prevalence of pests and diseases).

Table 3.2: Climate-related hazards assessed

Climate variable/ hazard	Data source	Timeframes and scenarios
River and surface flooding*	Amalgamation of open-source datasets from Regional, Unitary and Territorial Authorities (collated by NIWA and T+T)	Varied timeframes and scenarios used nationally
Coastal erosion	LINZ coastal boundary (to provide coastal edge proximity as proxy)	Proxy provides ability to consider range of timeframes and scenarios
Coastal inundation	NIWA 1% AEP coastal dataset (2019) and NIWA Mean High Water Springs dataset (2016), both excluding allowance for vertical land movement	Increments of sea level rise can be joined to differing timeframes and scenarios
Change in temperature	NIWA downscaled NZ number of hot days (>25°C) projections (AR6)	Scenarios: SSP1-2.6, SSP2-4.5 and SSP3-7.0 Timeframes: 2021-2040, 2041-2060, and 2081-2100 Absolute values can be calculated from historic baseline (1986-2005)
Changes in rainfall intensity	NIWA downscaled NZ heavy rainfall (99th percentile, >25mm) projections (AR6)	
Extreme wind	NIWA downscaled NZ strong wind (99th percentile) projections (AR6)	
Changes in landslide frequency	KiwiRail slope risk dataset** and NIWA downscaled NZ heavy rainfall (99th percentile) projections	Rainfall information as above
Groundwater	No national (and limited local) datasets available	No scenarios or timeframes
Increased fire hazard/ risk	Scion projected fire risk – proposed but not available until 2025 (being updated)	No accessible datasets.

* River and surface flooding generally does not include overland flow paths due to no national and limited local datasets of suitable assessment quality. There is limited variability in frequency of flood data currently.

** Slope risk has been established by KiwiRail, with heavy rainfall data used to consider changes to this risk profile.

With the variance in available climate-related information, NIWA's downscaled climate variable information 2021-2040 SSP 1-2.6 has been considered as present day. This provides best comparison with the less frequent modelled hazard events (e.g. inland flooding and coastal inundation).

While the hazard and climate variables assessed are interrelated, the available hazard vary in their relationship to each other. While downscaled climate variable datasets are sourced from the same models, more acute hazard datasets (e.g. flooding) have been produced independently, and at differing times resulting in differing climatic inputs. This means that while all areas of New Zealand have been modelled for changes in rainfall intensity, not all areas have been modelled for flood hazard. This means some areas that are modelled to experience high rainfall intensities may not be shown to flood. This can create trends in the assessment that are the result of data bias, rather than actual expected projections (e.g. areas identified at high rainfall intensity but not at risk to flooding).

3.2 KiwiRail asset data

KiwiRail has supplied spatial and non-spatial asset information. All information received is related to four broad asset types:

1. Rail network
2. Container sites and yards
3. Rolling stock depots
4. Property (landholdings).

Further consideration of Yards is desired, however currently there is no existing Yards dataset. KiwiRail's asset information was provided in both spatial and non-spatial formats, exported from KiwiRail's data management systems such as ESRI ArcGIS and Maximo, respectively.

The spatial location of assets was used for assessing exposure to specific climate hazards. The asset metadata received was used to inform the assessment of vulnerability and consequence. Where suitable information was available, assets could be assessed at a sub-asset level (using data to provide granularity between each asset). Where suitable sub-asset information was not available, assessment of vulnerability and/or consequence occurred at the asset level (standard rating by asset type).

The asset datasets varied in completeness and assessment quality (discussed below), with numerous datasets and wider information received throughout the assessment process. Consideration of each asset dataset, and the associated metadata, was undertaken to assess its value within the assessment. KiwiRail staff were engaged with to aid this assessment.

Table 3.3: List of corridors that were assessed

Line name	Acronym	Location
Bluff	BLUFF	South Island
Castlecliff	CASLF	North Island
Dargaville	DGAVL	North Island
Waharoa-Tauranga	ECMT	North Island
Gracefield	GRCFD	North Island
Hokitika	HKTKA	South Island
Hautapu	HTAPU	North Island
Johnsonville	JVILL	North Island
Kinleith	KNLTH	North Island
Kapuni	KPUNI	North Island
Manukau	MANUK	North Island
Midland	MDLND	South Island
Mission Bush	MISBS	North Island
Melling	MLING	North Island
Main North Line	MNL	South Island
Marton to New Plymouth	MNPL	North Island
Main South Line	MSL	South Island
Mt Maunganui	MTMNG	North Island
Kawerau-Murupapa	MUPRA	North Island

Line name	Acronym	Location
North Auckland	NAL	North Island
North Island Main Trunk	NIMT	North Island
Newmarket	NWMKT	North Island
Southern South Island	OHAI	South Island
Onehunga	ONHGA	North Island
Palmerston North to Gisborne	PNGL	North Island
Port Chalmers Branch	PTCHS	South Island
Rapahoe Branch	RPHOE	South Island
Stillwater Ngākawau	SNL	South Island
Stratford-Okahukura	SOL	North Island
Wanganui Beach	WGIFT	North Island
Morrinsville-Waitoa	WITOA	North Island
Upper Hutt-Masterton	WRAPA	North Island

3.3 Data completeness (quality)

The completeness and quality of information used in the assessment impacts the overall confidence in the risk assessment process and associated results.

To account for this, data completeness (quality) ratings have been established to assess climate data and KiwiRail attribute information (Table 3.4). For climate-related hazards, information relating to national coverage, available timeframes and scenarios can be considered for assessing data quality (Table 3.5).

For KiwiRail asset information, the rating relates to the availability of relevant attribute data and does not consider the source or quality of the specific information (Table 3.6). This means that data completeness may present a higher value than the corresponding data quality, should the data be based on incomplete or incorrect information. Focus is given to the level of information available to complete a sub-asset level assessment.

Table 3.4: Levels of data completeness

Rating	Climate related hazard information	KiwiRail information
Good	Nationally consistent datasets with range of scenarios and timeframes	Relevant attribute information for sub-asset level assessment with >70 % completeness
Average	Inconsistent spatial coverage or lack of range of scenarios and timeframes	Relevant attribute information for sub-asset level assessment with >40% completeness
Poor	Inconsistent spatial coverage and lack of range of scenarios and timeframes	Asset level assessment only or <40 % of relevant attribute data complete

Data completeness should be considered when looking at the resulting risk score, to better understand the underlying information that it is based on.

Table 3.5: Climate-related hazards information

Climate variable/ hazard	Data quality/ completeness	Considerations
River and surface flooding	Average	Inconsistencies of scenarios and timeframes reduce ability to assess range of exposures
Coastal erosion	Average	Proxy provides ability to assess coastal edge proximity across all timeframes, limited variation for differing scenarios (SSPs)
Coastal inundation	Good	Sea level rise increments provide good national analysis, noting some variance in the 2019 and 2016 methodologies
Number of hot days (>25°C)	Good	Consistent national dataset with range of timeframes and scenarios. Resolution of 5x5 km grid provides coarse analysis applicable to the uncertainties in projections. Note some grids may not show increasing trend with increasing timeframes and SSPs – this is a product of climate modelling and associated uncertainty rather than reduced data quality. Due to the coarseness of the NIWA downscaled data, there are small portions of the coast that are not captured. Assets that are outside of these extents have been classified as "outside of the hazard layer".
Heavy rainfall		
Strong wind		
Changes in landslide frequency	Average	Dependent on quality of KiwiRail slope dataset and above rainfall information
Groundwater	Poor	No national or local datasets, qualitative commentary only
Increased fire hazard/ risk	Poor	Lack of acceptable dataset for use in assessment

Table 3.6: KiwiRail asset information

Asset type	Data quality/ completeness	Considerations
Tracks	Average	Nationally consistent track, with inconstant overlay of sleeper material and tonnage (reduction in quality due to spatial join). Good coverage of sub-asset attribute data (sleeper material, condition).
Private sidings	Poor	Limited information beyond geospatial location. Asset-level assessment undertaken with attributes derived from nearest track.
Bridges	Good	Sub-asset level attribute information available including: number of spans, pier material, class description, replacement costs.
Signals	Poor	No sub-asset level attribute information resulting in no differentiation by individual asset. Assumptions made regarding design & condition.
Culverts	Average	Varied level of information, including condition ratings and material/ design information in varied formats. Good hydraulic information for limited number of culverts.
Tunnels	Average	Limited sub-asset level information relating to tunnel design, construction and condition. Assumptions made based off age.
Container sites	Good	Simple summary of prioritisation, good geographic areas.
Yards	Poor	Limited information, assessed at asset level. Dataset was delineated from KiwiRail's landholding dataset, and the extents may not be a true reflection of actual yards. KiwiRail verified the dataset used.

Structures	Poor	Limited information beyond building type, assessed at asset level.
Landholdings	Average	Limited information, overall grouping provided for usage of non-track connected landholdings enabling individual assessment of consequence.

4 Assessing risk

Risk is established using exposure, vulnerability, and consequence (Figure 2.1). These three components are individually assessed and then combined to provide a risk rating across timeframes and scenarios. Rating tables and criteria were developed to assess each of the components. The following sub-sections provide a summary of how the methodology was applied.

4.1 Likelihood

KiwiRail's Enterprise Risk Management Manual[1] describes likelihood as the probability of damage or harm to occur. KiwiRail has a likelihood matrix, which is based on the return period of the hazard. Included in the return period are factors that could increase the likelihood of damage, e.g. material, methods of construction, and financial climate.

This assessment uses a similar overarching likelihood concept, with two separate components: exposure (hazard) and asset vulnerability. These are assessed individually, then combined using the likelihood matrix outlined in Section 4.3.

4.1.1 Exposure (hazard)

Hazard exposure refers to the presence of an element (e.g. railway asset) in a place that could be adversely affected by a climate-related hazard (e.g. river and surface flooding). This includes the extent of the hazard area and the probability of that hazard occurring (e.g. Annual Exceedance Probabilities). Exposure is established on a four-point scale for all hazards (Table 4.1).

Table 4.1: Exposure levels and associated indicative frequency descriptions

Exposure (hazard)	Indicative frequency
Very low	Very often, often nuisance type events.
Low	Quite often, a good chance of occurring every year.
Medium	May happen, an event may have occurred in the last 5 or so years.
High	Rare, larger scale event, infrequent in nature.

Note: Exposure provides a scale for potential damage, with less frequent events generally having increased scale, and therefore higher exposure. It's not possible to identify 'not exposed' areas, therefore 'outside the assessed area' is used.

Consideration of assets as "not exposed" is difficult due to a lack of confidence in available datasets. For example, mapped river flood hazard areas, model extents, and areas modelled to have no flooding, are limited in availability. As such, assets that are not identified to be in a specific hazard layer are considered classed as being "outside" of assessed hazard layers, rather than "not exposed". The exception for this is coastal edge proximity (as a proxy for coastal erosion), where assets that are inland of the coast (> 500m) can be considered not exposed across the assessment timeframes.

For climate variables: number of hot days (>25°C), heavy rainfall, strong wind; standalone assessment of hazard exposure is not possible, as everywhere is "exposed" through time. Instead, the scale of change (e.g. from 10 hot days to 30 hot days by end of century) can be considered in relation to how an element could respond. This incorporates both exposure and also vulnerability to provide likelihood of damage for a given element/ asset. The climate variables have also been scored on a 4-scale basis, with the values being presented as absolute values.

The type and quality of available hazard information dictates how it can be used within our assessment. These are outlined below (Table 4.2).

Table 4.2: Assessment approach

Assessment type	Hazards	Method
Quantitative	Coastal inundation River and surface flooding	Tagging all KiwiRail assets with an Annual Exceedance Probability (AEP) for differing scenarios (e.g. SLR)
	Coastal erosion	Tagging all KiwiRail assets with distances from the coastal edge as a proxy for coastal erosion
	Number of hot days (>25°C) Heavy rainfall Strong wind	Tagging all KiwiRail assets with the AR6 downscaled climate variable projections
Semi-quantitative	Landslide frequency	Tagging all KiwiRail assets with the KiwiRail slope risk dataset and modifying with the downscaled heavy rainfall (99th percentile) projections – not achieved
Qualitative	Groundwater	Commentary of potential impacts of groundwater for susceptible areas by observation
Not assessed	Increased fire risk	No data available for assessment of hazard currently

Exposure assessment tables for individual climate-related hazards can be found in Appendix A.

4.1.2 Vulnerability

Vulnerability is the component that considers factors which could increase the likelihood of damage, as aligned with KiwiRail's Enterprise likelihood description[1]. Asset characteristics are used to assess vulnerability, such as:

- Condition
- Design/ material
- Age/ construction year and design life (as a proxy for condition).

Vulnerability ratings are different for each asset, depending on the asset type, availability of data, data quality, and the hazards assessed. For example, average span length of bridges was utilised to provide understanding of vulnerability to debris flow with flood events.

Vulnerability ratings for all assets and hazards are provided below in Table 4.3 with Appendix B providing further commentary. Tracks, bridges, culverts, and tunnels are assessed at a sub-asset level given the availability of more detailed information.

Table 4.3: Vulnerability ratings

Asset	Sub-asset	Hot days (>25°C)	Heavy rainfall	Increased fire risk	Strong wind	Coastal inundation	Coastal erosion	River and surface flooding
Tracks	Overall	Low	Very low	Medium	Very low	High	High	High
	Timber sleepers AND good (1-3) condition			High		Medium		Medium
	Timber sleepers AND poor (4-5) condition			High				
	Non-timber sleepers AND good (1-3) condition					Medium		Medium
	Non-timber sleepers AND poor (4-5) condition							Medium
Private Sidings	Overall	Vulnerability rating derived from the connected track.						
Bridges	Overall	Low	Very low	Low	Medium	Medium	High	Medium
	Low average span length OR Timber pier OR >100yr old					High		High
	High average span length AND < 75 yr old							
	Timber pier OR > 75 yr old			Medium				
	Non-timber pier AND < 75 yr old							
Signals	Overall	Low	Low	Medium	Medium	High	High	High
Culverts	Overall	Very low	Very low	Very low	Very low	Medium	High	Medium
	Undersized culverts (KiwiRail Hydraulic Results, <300mm diameter) OR poor (4-5) condition		Medium			High		High
Tunnels	Overall	Very low	Medium	Very low	Very low	Medium	High	Medium
	< 100 years		Low					
	> 100 years				High	High		High
Container sites/ Yards	Overall	Low	Very low	Medium	Very low	High	High	High
Structures	Overall	Very low	Very low	Medium	Low	High	High	High
Landholdings	Overall	Very low	Low	Low	Very low	Medium	High	Medium

Note: Increased vulnerability of culverts proximal to high-risk slopes has been requested. Assessment of the analysis approach will be undertaken, and if possible, identified culverts will have increased vulnerability equivalent to undersized culverts.

4.2 Consequence

Consequence considers the importance of the individual asset and reflects the asset's position in the wider network (impacts to the network if the assets are damaged). Consequence and importance are represented by asset values and/ or asset types. Examples include:

- Replacement cost
- Redundancy ability
- Criticality ratings
- Culvert diameter
- Asset type (e.g. railway has higher importance than a stock underpass).

Consequence has been assessed at either asset level or sub-asset level, depending on the available information for the given assets. These two levels of assessment provide consideration for the interconnected nature of the network, whilst acknowledging the high-level nature of this assessment.

The two levels for assessment of consequence are:

1. Sub-asset level assessment (using data to provide granularity between each asset)
   - The track consequence rating is based on 'type' and 'tonnage'.
   - Bridges, culverts, container sites, yards, and structures are assessed based on their importance, derived from sub-asset level data, then modified depending on the track consequence rating.
2. Asset level assessment (standard rating for the asset type)
   - Private sidings, signals, and landholdings are based on the track consequence because they have no sub-asset level data that is appropriate to assess consequence.

Table 4.4 reflects these differences in the consequence ratings and outlines how each asset is assessed. Appendix C Table 7.5 further details the consequence methodology specific to the asset and the level of assessment granularity.

Table 4.4: Consequence ratings

Asset	Sub-asset assessment	Consequence rating					
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)	Adjustment method
Tracks	Net tonnage + track type	<50,000 tonnes	50,000 - 199,999 tonnes OR loop	200,000 - 799,999 tonnes OR crossover	800,000 - 1,500,000 tonnes	>1,500,000 tonnes	No adjustments made
Private sidings		*Derived from the connected track*					No adjustments made
Bridges	Rail/ road and rail bridges replacement value	Stock underpass (all) OR Subway < $1,000,000	Subway > $1,000,000	Rail/ road OR rail bridge <$10,000,000 Subway on Major OR Critical rail lines	Rail/ road OR rail bridge $10,000,000 - $25,000,000	Rail/ road OR rail bridge > $25,000,000	+/- 1 point of the track
Signals		Signals on an insignificant track	Signals on a minor track	All other signals			No adjustments made
Culverts	Diameter + Depth to pipe (D2P)	< 300 mm	300 - 599 mm	600 - 1049 mm OR <3m D2P	1050 - 2100 mm	> 2100 mm OR >1050 mm AND <3m D2P	+/- 1 point of the track
Tunnels					All other tunnels	Tunnels on a critical track	No adjustments made
Container sites/ Yards	Criticality/ importance rating	5 rating	4 rating OR container sites/ yards on insignificant track	3 OR container sites/ yards on a minor track	2	1	+/- 1 point of the track
Structures	Use type	Platform	All other buildings	Container site building	Rolling Stock buildings		Track consequence sets the maximum rating.
Landholdings	Usage type (adhoc categorisation by KiwiRail)		Mothballed line sections (green)	Yet to be mothballed not in service	Existing lines or future lines		No adjustments made

4.3 Calculating risk

To calculate the likelihood of a hazard causing damage to an asset, exposure and vulnerability ratings are combined, as shown in Table 4.5.

Table 4.5: Likelihood matrix

		Vulnerability			
		Very low	Low	Medium	High
Exposure	High	P	L	AC	AC
	Medium	UL	P	L	AC
	Low	R	UL	P	L
	Very low	R	R	UL	P

Likelihood matrix

R - Rare	UL - Unlikely	P - Possible	L - Likely	AC – Almost certain

Following the calculation of likelihood, risk can be established through combining the likelihood and consequence ratings (Table 4.6). KiwiRail have an existing risk rating matrix they use within their organisation. This matrix is applied to the CCRA to ensure transferability and consistency across the organisation. The previous likelihood and consequence ratings also apply this terminology.

Table 4.6: Risk rating table

		Consequence				
		Insignificant	Minor	Moderate	Major	Critical
Likelihood	Almost certain	M	H	H	E	E
	Likely	M	M	H	H	E
	Possible	L	M	M	H	H
	Unlikely	L	L	M	M	H
	Rare	L	L	L	M	H

Risk rating key

Rating	Descriptor
Low (L)	Low risk, manage by routine procedures.
Medium (M)	Moderate risk, management responsibility must be specified.
High (H)	Significant risk, senior management attention needed.
Extreme (E)	Extreme, immediate action required; Board/shareholder notification required.

5 Summary of physical risks

A total of 10 KiwiRail asset types were assessed against three climate-related 'acute' hazards (coastal inundation, coastal erosion, river and surface flooding) along with three climate variables 'chronic' hazards (increasing hot days, heavy rainfall, strong wind).

All asset types are found to have assets at high or extreme risk to coastal erosion, coastal inundation, and river and surface flooding. The total assets identified as exposed and at risk for these three hazards, by asset type and timeframe, is shown in Table 5.1. A full summary of results, including risk ratings across rail corridors, timeframes, and SSP scenarios can be found in Appendix E, while the list of corridors is shown in Table 3.3.

Table 5.1: Summary of at risk assets by asset type, hazard and timeframe (acute hazards)

Asset/ measure	Total assessed	Coastal erosion		Coastal inundation		River/ surface flooding	
		Present day	End of century	Present day	End of century	Present day	End of century
Tracks (km)	5099	295 (6%)	362 (7%)	84 (2%)	354 (7%)	1586 (31%)	1586 (31%)
Private sidings (km)	22	0.5 (2%)	0.6 (3%)	0.1 (0%)	1.2 (6%)	8.4 (38%)	8.4 (38%)
Bridges (No.)	1,393	77 (6%)	97 (7%)	143 (10%)	179 (13%)	779 (56%)	779 (56%)
Signals (No.)	2,969	217 (7%)	265 (9%)	36 (1%)	268 (9%)	899 (30%)	899 (30%)
Culverts (No.)	11,614	604 (5%)	690 (6%)	136 (1%)	353 (3%)	2925 (25%)	2925 (25%)
Tunnels (No.)	148	29 (20%)	31 (21%)	1 (1%)	1 (1%)	18 (12%)	18 (12%)
Container sites (No.)	15	4 (27%)	8 (53%)	1 (7%)	11 (73%)	7 (47%)	7 (47%)
Yards (No.)	98	30 (31%)	36 (37%)	42 (43%)	56 (57%)	77 (79%)	77 (79%)
Structures (No.)	943	76 (8%)	97 (10%)	33 (3%)	197 (21%)	357 (38%)	357 (38%)
Landholdings (km^2)	182	8.6 (5%)	11 (6%)	4.4 (2%)	9.3 (5%)	52 (29%)	52 (29%)

Note: Table depicts summary of at risk assets, with varied units of measure.

When considering rail corridors (using tracks), river and surface flooding presents a key risk, with nearly a third of the track identified at risk in the present day. Signals and yards showcase a similar percentage at risk, which is expected given that they are located proximal to tracks. [redacted] 9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities

The proportion of the corridor that is at risk to the acute hazards is smaller than that of the chronic hazards: heavy rainfall, hot days (>25°C), strong wind. This is from these climate variables affecting all of New Zealand, resulting in a large proportion of assets being recorded as exposed and at risk. Generally, the risk profiles for these chronic hazards are lower, given the overall reduced vulnerability of assets to these variables.

The corridors that showcase larger proportions of extreme or high risk from most hazards typically are the longer corridors, which have a larger number of assets associated with them, along with more varied geography, increasing the potential for risk. These corridors are:

- NIMT, ECMT, MNL, MSL, MDLND, MTMNG.

A small corridor that was identified as having extreme and high risks to coastal erosion, coastal inundation and strong winds, was the PTCHS and associated assets.

9(2)(i) - Commercial Activities [redacted]

Despite the assumption that bridges have been engineered to withstand environmental hazards, in the present day, 10% of KiwiRail's bridges are subject to extreme risk from flooding. These bridges tend to be located on high consequence lines, and have lower average span lengths, increasing their vulnerability to blockages. There are also undersized culverts which has also driven the risk score up for these assets, in association with river and surface flooding.

Acute hazards posed the highest risk to tunnels across KiwiRail's network, alongside increased heavy rainfall at the tunnel entrances. There were no low risks identified for tunnels, due to their higher consequence rating and importance on the network. Flooding (coastal and inland) posed the more extreme risk to KiwiRail structures, due to the assumed floor levels and higher vulnerability to these hazards.

Rising groundwater levels as a result of sea level rise can cause impacts to KiwiRail assets. They can cause sustained saturation of subsurface foundations of tracks, private sidings, and buildings, which may impact their integrity over time. container sites and landholdings may become more regularly flooded in storm events due to lower thresholds and sub-surface storage capacities. Some areas where groundwater rise may be an issue for KiwiRail, include East Coast Main Trunk (Matata), MTMNG, Palmerston North- Gisborne Line (Napier), MSL (Dunedin) and other low-lying areas that are connected to the sea.

5.1 Uncertainty and data bias

The datasets used to complete the CCRA vary in data completeness and quality as discussed in Section 3.3. The differences in data completeness have created trends in the results that are more likely a result of the data limitations and bias, rather than a true reflection of exposure and risk.

For all asset datasets there was limited sub-asset level information that enabled a detailed assessment of each asset. For the vulnerability assessment, private sidings, signals, container sites, structures, and landholdings had no sub-asset level information available, while others had incomplete sub-asset data. This resulted in limited differentiation of asset vulnerability to each hazard. For the consequence assessment, private sidings, signals and tunnels, all solely relied on the track criticality for their consequence due to know appropriate sib-asset level data available. This again resulted in limited differentiation of all assets. The means that variation in risk for these asset types is primarily driven by changes in exposure rating.

The exposure of assets to river and surface flooding does not change throughout time, as seen in Table 5.1. Given the inconsistent and incomplete flood hazard information across New Zealand, flood layers are amalgamated and treated as one scenario. Therefore, the number of total assets exposed and at risk to river and surface flooding will remain constant through time.

Exposure to heavy rainfall and strong wind remain consistent across all timeframes, as they are predominantly based on the climate variable exposure table in Appendix A and are not given a minimum threshold. The datasets cover almost all of New Zealand, resulting in high proportions of assets exposed. Due to the coarseness of the NIWA downscaled datasets, there are gaps along the coastlines, resulting in the assets in these areas to be classified as "outside" of the hazard area.

6 Physical risks by asset

The following section provides a summary of risk across the six assessed climate-related hazards and variables, delineated by the 10 asset types:

- Tracks
- Private sidings
- Bridges
- Signals
- Culverts
- Tunnels
- Container sites
- Yards
- Structures
- Landholdings.

A selection of summary tables and figures are provided through this section, with further tabulated results found in Appendix E, and additional supporting maps in Appendix G. The histograms in the following sections show the differences in risk through time, with present day (PD) on the left, then mid-century (MC), and end of century on the right (EOC). For coastal inundation SSP1-2.6 end of century is first, then SSP3-7.0.

6.1 Tracks

A total of 5,099 km of track was assessed across the KiwiRail network nationally, distributed over 32 corridors (rail lines). Tracks are at extreme risk from coastal erosion, coastal inundation, river and surface flooding, and hot days above 25°C.

Approximately 20 km of the total track length is at extreme risk to coastal erosion in the present day (Figure 6.1). This increases to approximately 62 km (1% of total length) by the end of the century (SSP3-7.0) with increased inland exposure. Of the 62 km, 23% is on the NIMT and 21% is on the MNL. PTCHS has the highest proportion of its rail line length affected by coastal erosion, with 54% at high or extreme risk in the present day, increasing to 65% by the end of century.

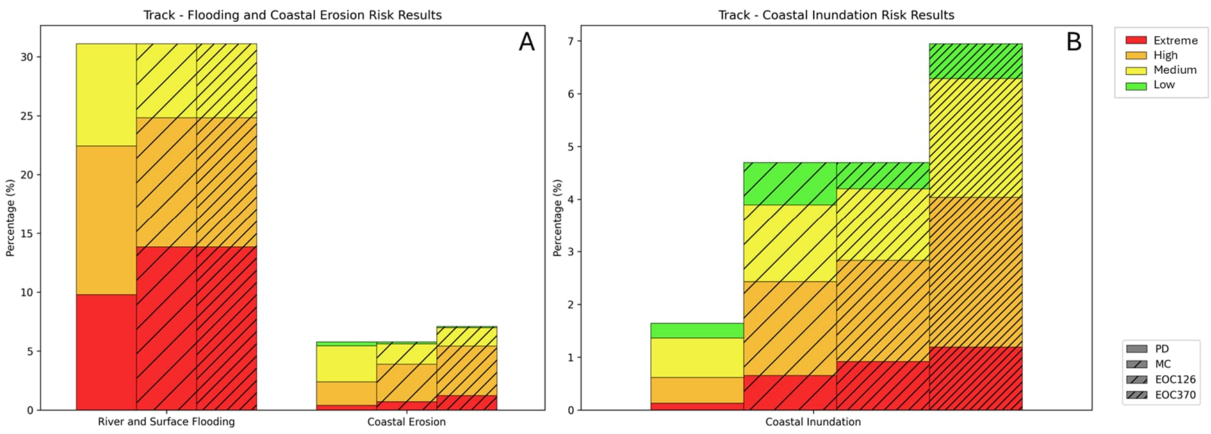


Figure 6.1: Percentage of KiwiRail's track at risk to acute hazards

For coastal inundation, track exposure increases through time, with approximately 84 km (2% of total tracks) exposed in the present day, and 354 km (7%) exposed by the end of century in a SSP3-7.0 scenario (Figure 6.1). Exposed tracks are distributed around New Zealand's coastline. Risk increases through time, with approximately 7 km of track at extreme risk in the present day, 33 km in the mid-century, and 61 km by end of century in a SSP3-7.0 scenario. Tracks at extreme risk are predominantly located the Bay of Plenty, Dunedin, and near Porirua.

There are approximately 500 km (10%) of tracks nationally at extreme risk to river and surface flooding in the present day (Figure 6.2). This increases to 705 km (14%) in the mid-century and end of century in an SSP3-7.0 scenario, predominately associated with tracks south of Dunedin, between Greymouth and Westport, and between Wellington and Palmerston North (Figure 6.2). Among the 705 km at extreme risk, 46% is within the NIMT, while 22% in the MSL. All tracks with extreme ratings have a net tonnage >800,000, with most tracks being rated as 'good' condition.

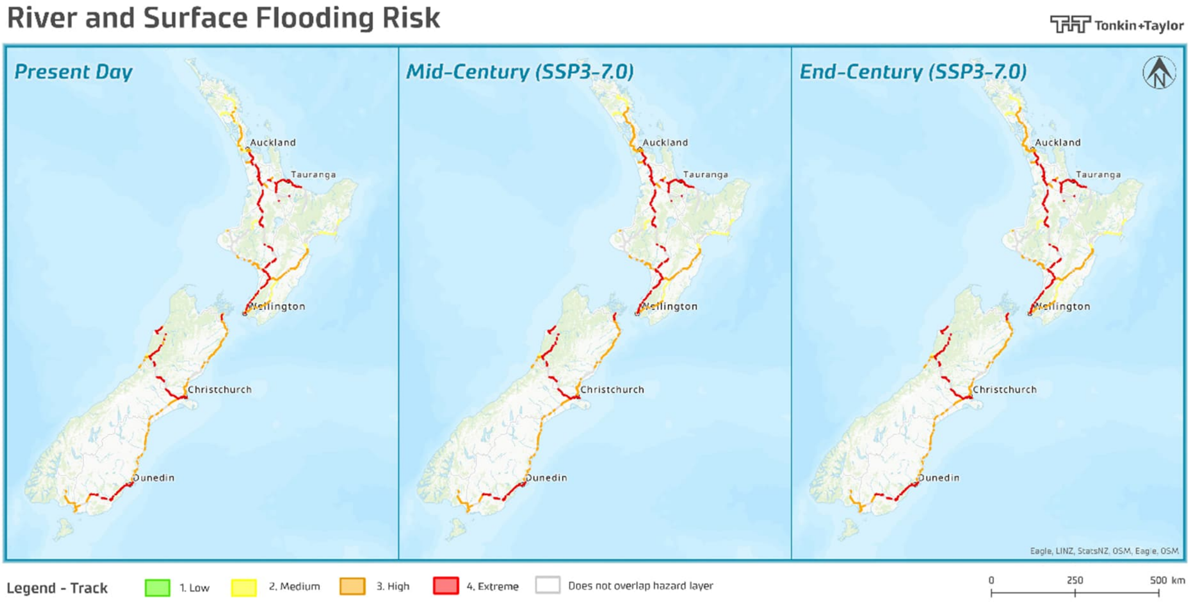


Figure 6.2: River and surface flooding for tracks across three timeframes (SSP3-7.0)

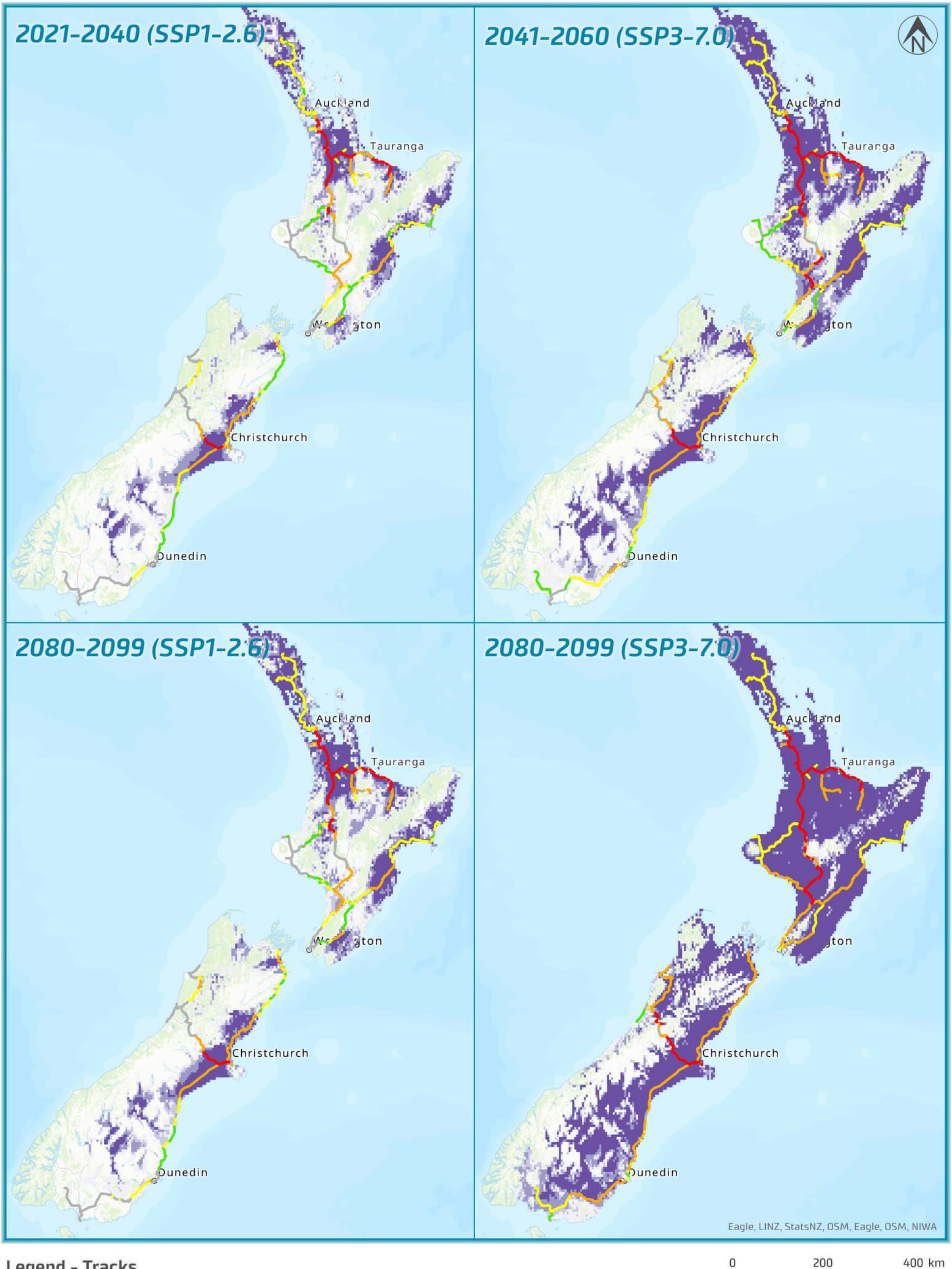
There is a total of 4,643 km of track exposed to heavy rainfall in all timeframes and SSPs, however there is little variation in risk profile through time. By the end of century (SSP3-7.0), risk increases for a small proportion of tracks (10 km – located in Greymouth) from low to medium, with the majority (2,608 km) remaining low risk. This is predominantly driven by the low likelihood of damage to tracks, along with a default very low vulnerability. This results in no tracks having extreme risk to heavy rainfall. Tracks between Christchurch and Greymouth, and through the central North Island between Auckland-Tauranga-Palmerston North have high risk to heavy rainfall, primarily driven by their increased criticality.

The risk profile for tracks to strong winds is not shown to change through time and SSPs as explained in Section 5.1. The 26% of tracks at high risk to strong winds are mostly due to the tracks having a critical net tonnage greater than 1,500,000 tonnes. Wind speeds are projected to remain less than 100 km/hour across New Zealand by end of century under SSP3-7.0. It is noted that while this is less than the prescribed wind speed for trains, expectation would be that there would be increases in third party damage at similar rates to increases in wind speeds.

When considering hot days, 10% of assessed tracks are identified at extreme risk presently, predominately between Christchurch and Sheffield, and between Te Kuiti-Auckland-Tauranga (see the next page). By the end of century (SSP3-7.0), the length of track identified at extreme risk increases to just over 1,000 km (21%) including the central North Island (Auckland to Palmerston North) and Christchurch to Greymouth. Extreme risk from hot days (>25°C) occurs due to there being >40 hot days annually, and these tracks having a net tonnage greater than 1,500,000 tonnes.

Temperature Risk

Tonkin+Taylor



Legend - Tracks

1. Low
2. Medium
3. High
4. Extreme

Does not overlap hazard layer

Average number of hot days (>25°C): 15-25 days; 25-30 days; 30-40 days; >40 days

6.2 Private sidings

A total of 22 km of KiwiRail private sidings has been assessed in this CCRA, distributed over six corridors.

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities

[redacted]

[redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities

[redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities

[redacted]

6.3 Bridges

Prioritisation of KiwiRail owned bridges was made during this CCRA, with 1,393 bridges assessed across the network. These are distributed across 24 of the 32 corridors. Coastal erosion, river and surface flooding, and increased temperatures all result in extreme risks to bridges by the end of century.

Over half of KiwiRail owned bridges are identified as exposed and at risk to river and surface flooding (779 bridges). This is expected, with bridges by default 'exposed' to flood datasets given their purposeful location within watercourses. Consideration of average span distance within the vulnerability rating elevated the risk of bridges with a low average span length. A total of 133 bridges (10%) are assessed as at extreme risk in the present day, increasing to 241 (17%) by mid and end of century (Figure 6.4). Along with high vulnerabilities, these bridges are also located on high consequence track corridors. Distribution of these extreme risk bridges include 35% within the NIMT, 15% along the ECMT, and a further 15% on the MSL.

When considering coastal erosion, 77 bridges (6%) are exposed and at risk in the present day, increasing to 97 (7%) by the end of century (Figure 6.4). Of these, 14 bridges are identified at extreme risk by end of century, with a further 65 bridges identified at high risk by end of century. Notably, the Bluff, Johnsonville, and ECMT lines have a significant proportion of bridges at risk, ranging from 20% to 25% by end of century.

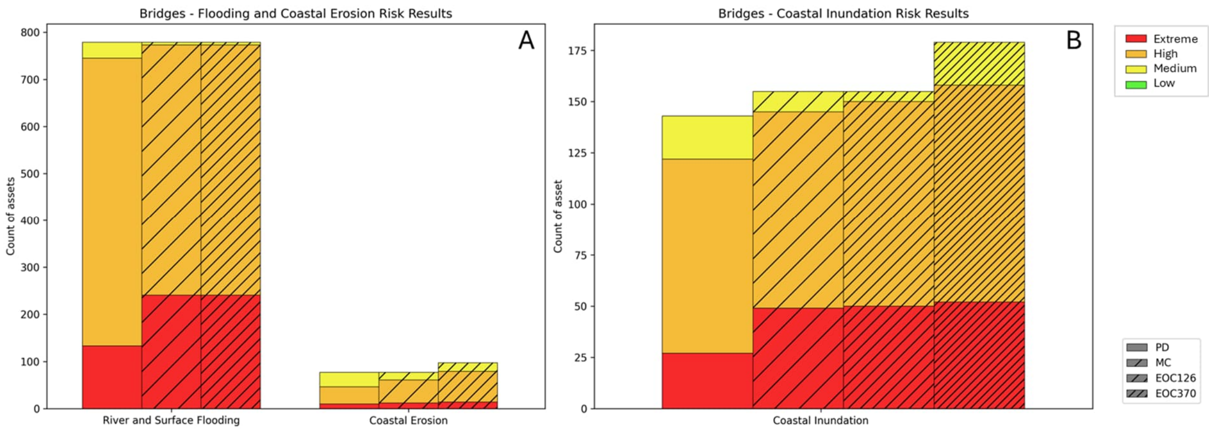


Figure 6.4: Percentage of bridges at risk to acute hazards

Heavy rainfall does not result in extreme risk across all timeframes and scenarios. A total of 86 bridges were found to be at high risk across all timeframes and scenarios. There are four bridges at extreme risk to increased temperatures in the present day. These are located in the upper central North Island on the ECMT and NIMT lines. This increases to 34 bridges (2%) by the end of century under a SSP3-7.0 scenario, in the central South Island and central North Island from the Kapiti Coast to Auckland.

Strong wind poses a consistent risk across all timeframes, with no bridges at an extreme risk level. Out of 22 wind-impacted corridors, ten have 100% of their bridges at low or medium risk across all durations. The risk to bridges from strong winds does not change throughout time. There are nearly 1,100 bridges (78%) at medium risk and 43 bridges (3%) at high risk. These are mostly attributed to the default vulnerability rating, and they are classed as rail bridges with a replacement value in excess of $25,000,000.

6.4 Signals

A total of 2,969 signals were assessed across the KiwiRail network nationally, distributed over all 32 corridors (rail lines). Signals have no extreme risks to any hazards, driven primarily by relatively lower consequence ratings (maximum rating 3-moderate). A moderate consequence is the threshold for high risks.

For coastal hazards, roughly 10% of signals are exposed by the end of century. For coastal erosion, 217 signals are exposed in the present day, increasing to 265 by end of century (SSP3-7.0). The majority are at medium risk present day, increasing to high risk by end of century (Figure 6.5). For coastal inundation, 36 signals are exposed in the present day, increasing to 161 at end of century (SSP1-2.6), and 268 signals exposed and at risk under SSP3-7.0. All signals have high vulnerability to coastal inundation due to having ground level electrical equipment. Key areas of higher risk are the CASLF corridor (with all signals at high risk from coastal inundation by the end of century under SSP3-7.0), and PTCHS (with all signals at high risk from coastal erosion in the present day).

For river and surface flooding, 30% of the national signals are identified as exposed. The majority of these (835) are at high risk in the present day, with the risk profile remaining the same through all future timeframes (Figure 6.5). Again, 100% of the signals in the CASLF and OHAI corridors are at high risk from river and surface flooding. This is followed by SNL with 50% of its signals at high risk.

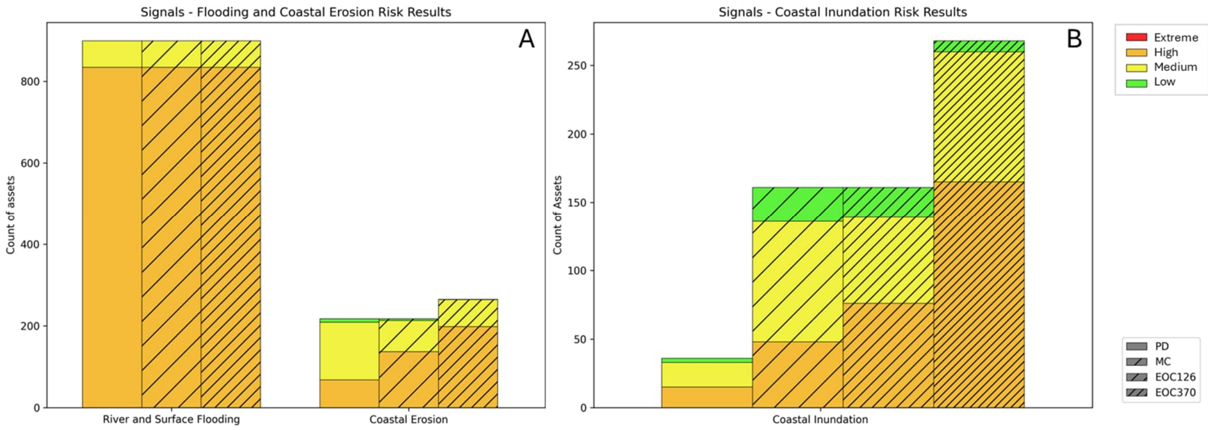


Figure 6.5: Count of signals at risk to acute hazards

Of the 2,969 signals assessed, 92% are at low or medium risk to strong wind in all timeframes, with no high or extreme risks (Figure 6.6). These ratings are associated with the lesser wind speeds (very low exposure) and medium vulnerability. Consequence is the driving factor for whether it has a low or medium risk. The KNLTH, MURPA, SNL and PTCHS lines have 100% of their signals at medium risk from strong wind.

There are more than 2,500 signals (approximately 85%) that are at low risk to increased heavy rainfall over all timeframes across New Zealand (Figure 6.6). This is mostly attributed to signals having high vulnerability to water-based hazards due to ground level electrical equipment. the risk profile has minimal change through the assessed timeframes. The MDLND and SNL are the only corridors that have signals at high risk to increased heavy rainfall (>2% of the total network), due to the high heavy rainfall (>100 mm per 24 hours) that occurs over the Southern Alps with steep slopes. This means these signals may have a higher likelihood of damage from landslide deposits compared to other KiwiRail signals across New Zealand.

In the present day, there are more than 1,900 signals (65%) at risk to increased temperatures, and 572 (19%) of these having a high-risk rating (Figure 6.6). The number of signals with a high risk increases to 45% (total at risk is 75%) in the mid-century under a SSP3-7.0 scenario, and 64% (total at risk is 90%) by the end of century SSP3-7.0 scenario. These risks are predominantly driven by an increasing number of hot days (>25 °C). Both the KNLTH and MURPA corridors have 100% of their signals at high risk by the end of the century in the SSP3-7.0 scenario.

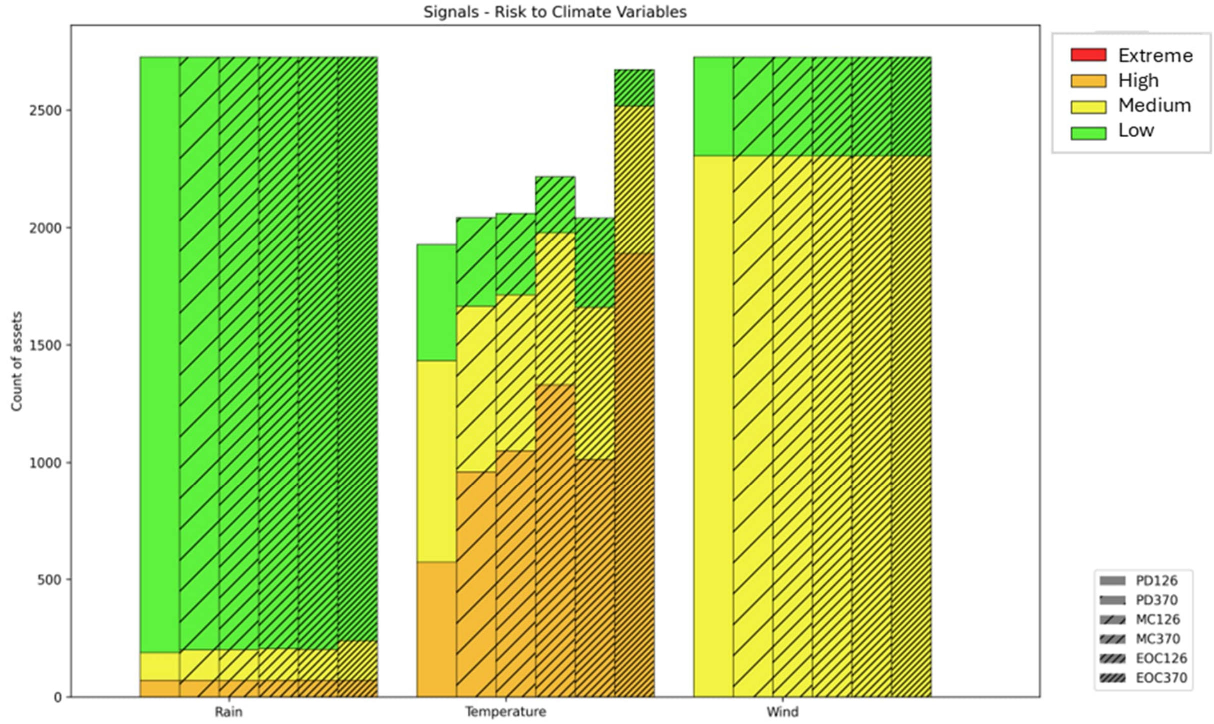


Figure 6.6: Count of signals at risk to chronic hazards

6.5 Culverts

There were 11,614 culverts assessed in this CCRA, with the MNPL having the most culverts across the network (752), followed by SNL (555). Culverts are at extreme risk from river and surface flooding, coastal erosion, and coastal inundation.

River and surface flooding is the hazard that results in the largest exposure of culverts (2,925) in all time periods (Figure 6.7). This is expected, because they are designed to perform in a water environment, so by default exposed when spatially assessed against flood hazard. There are just over 2,100 culverts (18%) at high risk, while approximately 730 (6%) are at extreme risk from river and surface flooding from mid-century onwards. The extreme risks are driven by those culverts that are undersized and therefore have high vulnerabilities. Most of the extreme risks are for culverts along the NIMT (477), MDLND (105), and ECMT (47) corridors.

For coastal erosion, there are 604 culverts exposed in the present day, with 14 culverts at extreme risk presently, increasing to 33 culverts by the end of century (Figure 6.7). These culverts are on the ECMT, MNL, MSL, NIMT and PTCHS lines. More than 50% of culverts (25) on the Bluff line are at high risk from coastal erosion by the end of century. On the PTCHS line, nearly 60% of culverts are at extreme risk from coastal erosion by the end of century.

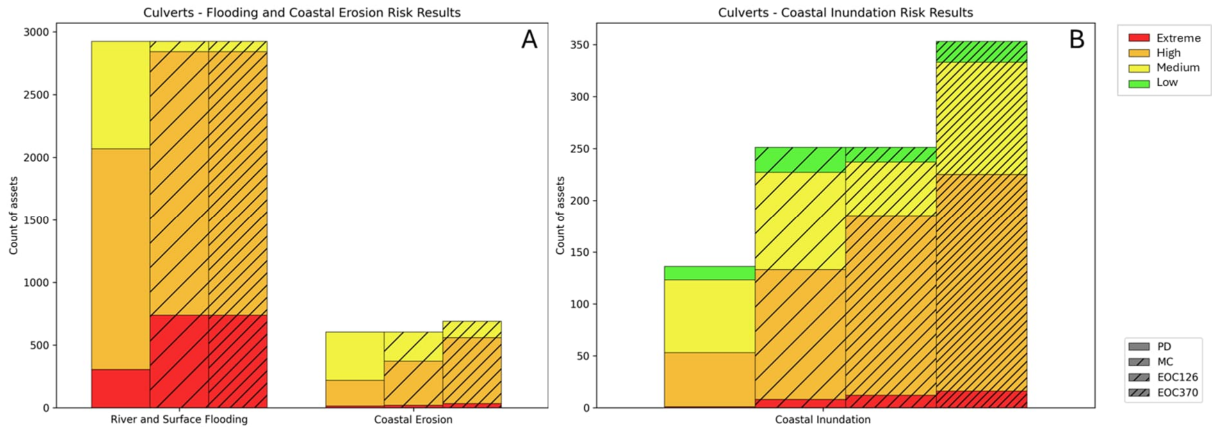


Figure 6.7: Count of culverts at risk to acute hazards

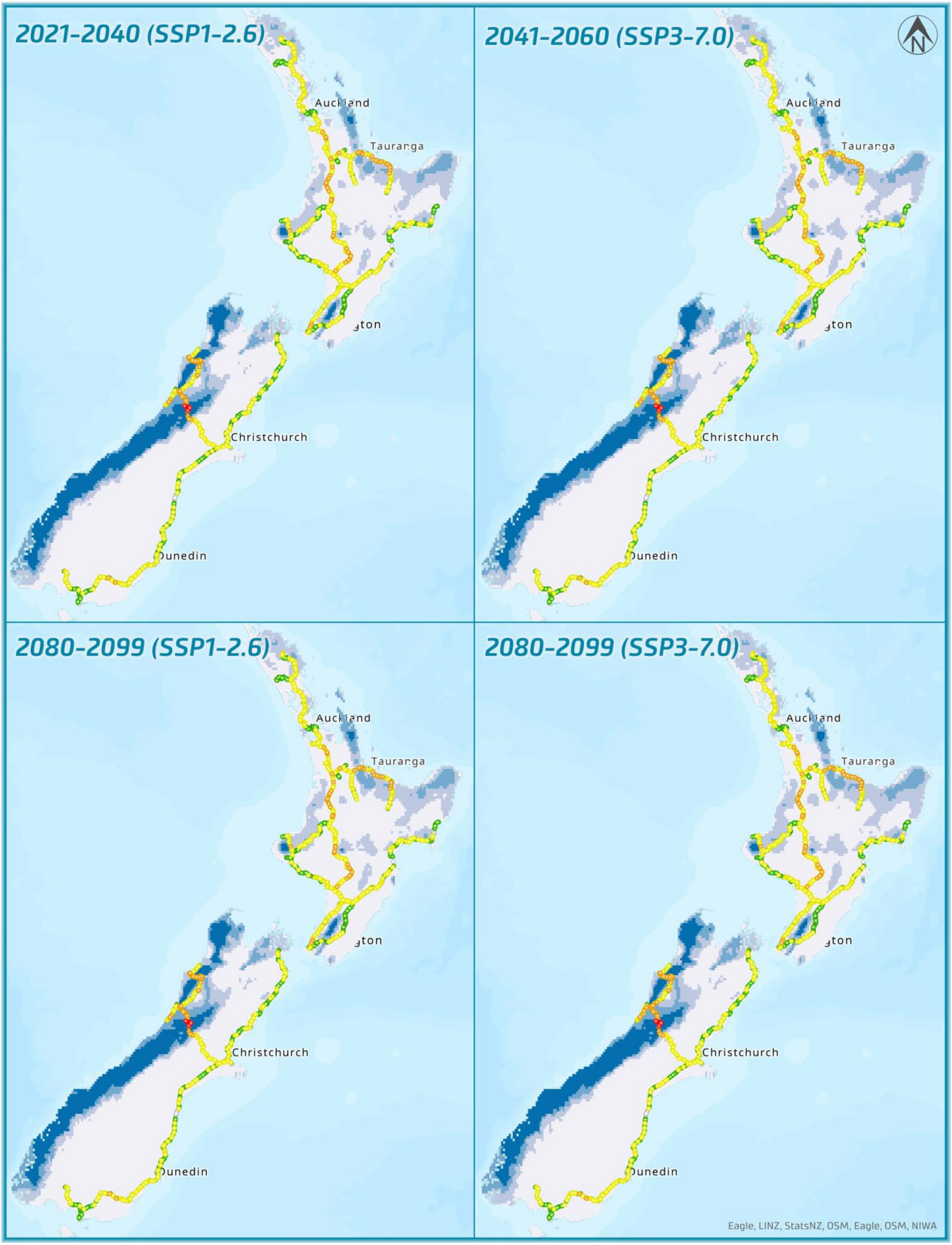
Of all hazards assessed, culverts have the lowest exposure to coastal inundation, with a total of 353 culverts (3%) identified as exposed and at risk by end of century under SSP3-7.0. The majority of exposed culverts have a risk rating of medium or high through all timeframes. When considering culverts at the corridor level, the PTCHS line has more than 50% at high risk by the end of century.

Unsurprisingly, heavy rainfall is identified as a risk for culverts. Over 10,800 culverts were identified as exposed and at risk to increasing heavy rainfall, equivalent to 93% of all culverts assessed (see next page). The risk profile increases through time, associated with increasing heavy rainfall. A total of 16 culverts are identified at extreme risk in the present day, all of which are in the Southern Alps along the MDLND line.

Risk ratings for strong wind and hot days (>25°C) are lower for culverts, driven by very low default vulnerability ratings. More than 1,000 culverts are at high risk from hot days (>25°C) in mid-century under SSP1-2.6 and SSP3-7.0, and more than 2,000 by end of century under the SSP3-7.0. Many of these culverts are in the North Island, centred around areas such as Hawke's Bay, Bay of Plenty, Waikato, and Auckland. More than 2,500 culverts (23%) are at medium risk to strong wind, and 58 at high risk through all timeframes. The central North Island is where most of the high risks to strong wind is located, with patches also in Wellington, south of Dunedin, and on the West Coast of the South Island.

Rain Risk

Tonkin+Taylor



Legend - Culverts

1. Low
2. Medium
3. High
4. Extreme

Does not overlap hazard layer

Average maximum heavy rainfall (mm): <50mm, 50-70mm, 70-100mm, >100mm

0 200 400 km

6.6 Tunnels

The nationwide KiwiRail network has approximately 148 tunnels distributed over 15 rail lines. Coastal erosion, coastal inundation, river and surface flooding, and increased heavy rainfall result in extreme risks to tunnels. No tunnels are at low risk to any hazard due to all tunnels having net tonnage >800,000 and as they are a pinch point in the rail network.

There are no tunnels are at low and medium risk to coastal erosion, coastal inundation, or river and surface flooding (Figure 6.8). Coastal erosion results in 20% of tunnels at high risk in the present day which changes to 3% at high risk and 18% at extreme risk by the end of century. Those affected include MNL, MSL, NAL, NIMT, and PTCHS.

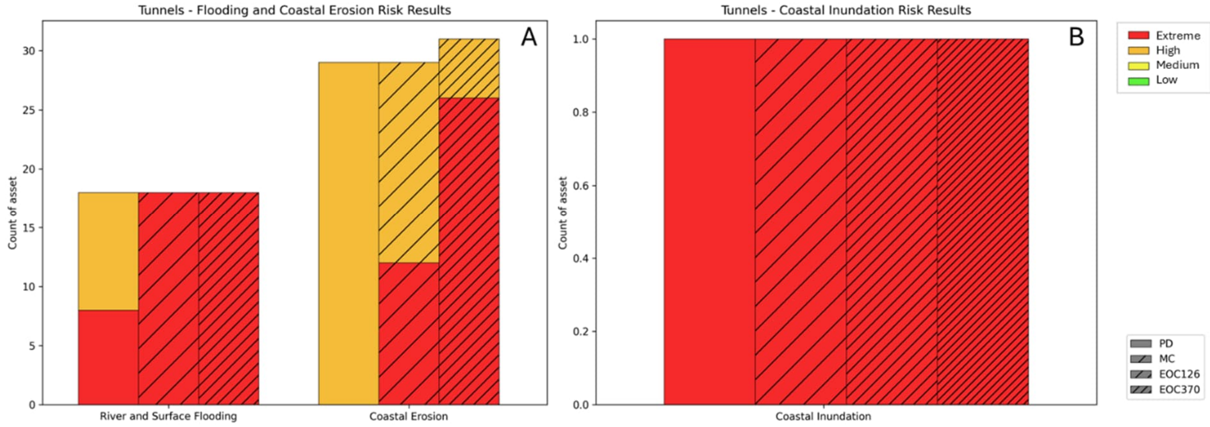


Figure 6.8: Count of tunnels at risk to acute hazards

The tunnel in Britomart on the NIMT corridor is the only tunnel exposed and at risk to coastal inundation (Figure 6.8). The tunnel is less than 100 years old, situated on a track with a consequence rating less than critical, and is frequently inundated. These result in the tunnel being at extreme risk to coastal inundation in all time periods. This same tunnel is at high risk to coastal erosion.

River and surface flooding has no additional tunnels that become exposed throughout time, but the 10 tunnels (7%) at high risk in the present day increases to extreme risk by mid-century (Figure 6.8). These tunnels have a net tonnage is >800,000 tonnes.

Of the 148 tunnels assessed, 124 are at risk from increased heavy rainfall over all timeframes. There are four tunnels at extreme risk in all timeframes from the MSL and SNL. This is mostly attributed to critical and major consequence, and high exposure.

Tunnels have medium to high risks from the number of hot days (>25°C) and strong wind, none at extreme risk. This is due to having a default vulnerability rating of very low as there was no sub-asset data appropriate for assessment of the number of hot days (>25°C) and strong wind. Risk from hot days (>25°C) increased through time, changing from 58 tunnels at medium risk and 30 tunnels at high risk in the present day to 19 tunnels at medium risk and 100 at high risk by the end of century SSP3-7.0. Risk to tunnels from strong wind is likely only to occur when the wind is blowing in the same direction as the tunnel length, as that would affect the train stability on the track.

6.7 Container sites

Nationally, 15 container sites were assessed with a total area of approximately 573,500 m^2.

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities [redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities [redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities [redacted]

[redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities [redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities [redacted]

9(2)(b)(ii) - Commercial position, 9(2)(i) - Commercial Activities

[redacted]

6.8 Yards

Nationally, 98 yards were assessed with a total area of approximately 15.4 km^2. Yards are at extreme risk from river and surface flooding, coastal inundation, coastal erosion, and hot days (>25°C) in the present day. Yard consequence was based off the importance matrix received from KiwiRail which included factors such as total inbound and outbound tonnage, operational services, and complexity (e.g., simultaneous train movements).

For river and surface flooding, 77 of KiwiRail's yards are exposed in the present day. More than a third of the total area is exposed, with their risk profile not changing through time as outlined in Section 5.1 (Figure 6.10). Yards have been identified as only being at high or extreme risk to river and surface flooding, with 49 at high risk across all timeframes and 31 at extreme risk. Of these, there are six yards with fully exposed sites to river and surface flooding through all timeframes in Gore, Greymouth, Mataura, Milton, Spring Creek, and Wairoa.

For coastal erosion in the present day, 1.8 km^2 across 30 yards is exposed and at risk. Of the area exposed and at risk, none is at low risk, 1.2 km^2 is at medium risk, 0.6 km^2 at high risk, and <0.05 km^2 at extreme risk. By the end of century this increases to a total of 2.3 km^2 across 36 yards, with 0.5 km^2 at medium risk, 1.7km^2 at high risk, and 0.1 km^2 at extreme risk (Figure 6.10). Two yards (Oaro and Sawyers Bay) are fully exposed to coastal erosion by the end of century, while three others (Kaikoura, Lyttleton, and Oamaru) have more than 90% of the yard areas exposed.

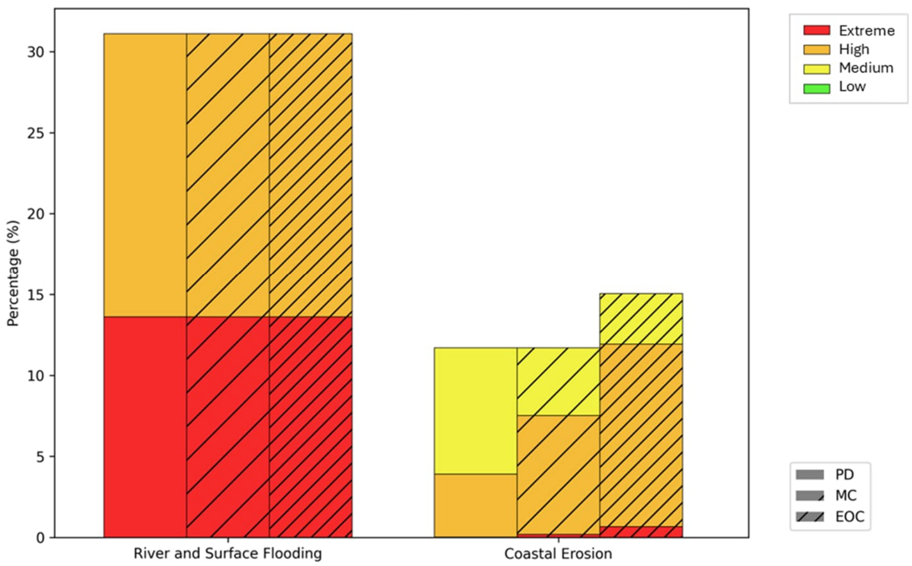


Figure 6.10: Percentage of KiwiRail's yards at risk to river and surface flooding and coastal erosion

Exposure to coastal inundation is generally similar to coastal erosion, with approximately 3% of the total yard area (0.5 km^2) exposed in the present day. This increases to 13% (2 km^2) by the end of century under SSP3-7.0. There are no yards at low risk to coastal inundation and the risk profile is generally spread across the medium, high, and extreme risk levels. There is a total of 0.1 km^2 at extreme risk in the present day, which increases by 20% by the end of century under SSP1-2.6. Under SSP3-7.0, extreme risk increases to 0.4 km^2 (Figure 6.11). By the end of century (SSP3-7.0), only Helensville yard is fully exposed to coastal inundation, while 12 others have more than 80% of the yard areas exposed.

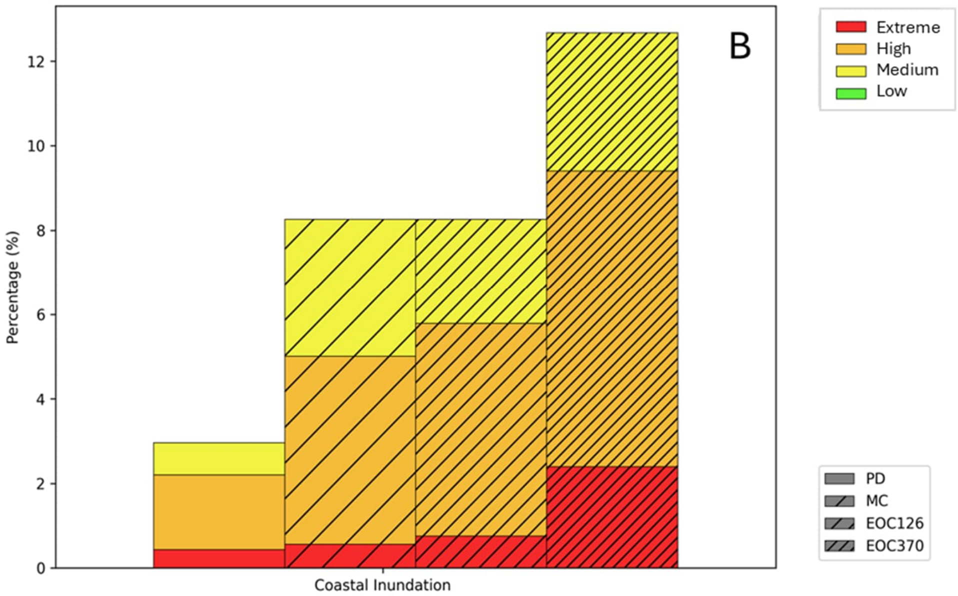


Figure 6.11: Percentage of KiwiRail's yards at risk to coastal inundation

When considering the climate variables, strong winds present the highest exposure with 87 yards exposed through all time periods. However, strong winds present the lowest risk, alongside heavy rainfall, when compared to the other hazards. All yards exposed are in areas of a very low wind speed (<100 km/ hour) and have a low default vulnerability rating. Therefore, the variance in the risk comes from the consequence ratings, which are associated with the *importance rating* assigned by KiwiRail. There are seven yards with a high-risk rating, based in Christchurch, SH73 on the eastern side of the Southern Alps, Wellington, Hamilton, Tauranga, and Auckland.

There are 79 yards exposed to increased heavy rainfall through all time periods. Similarly to wind, these are of low risk which is driven by low exposure, and low default vulnerability ratings. Yards with high-risk ratings have critical consequence ratings, associated with the *importance rating* KiwiRail previously assigned it. There are three yards located in medium heavy rainfall areas (75-100 mm per 24 hours) on the West Coast of the South Island, and two yards in high heavy rainfall areas (>100 mm per 24 hours) in the Southern Alps. They are all located in river valleys, near steep slopes, therefore may have a higher likelihood of damage from rainfall induced landslides compared to other KiwiRail yards in New Zealand.

There are 68 yards (69%) exposed to more than 15 hot days (>25°C) in the present day, increasing to 90 yards (92%) by the end of century under SSP3-7.0. There are 6 at extreme risk by the end of century SSP3-7.0, which are located in Christchurch, SH73 on the eastern side of the Southern Alps, Hamilton, Tauranga, Auckland, and the central North Island. This is generally attributed to having more than 40 days a year with temperatures above 25°C and it being an important yard to KiwiRail.

6.9 Structures

There are 943 KiwiRail structures that were assessed in the CCRA. Over a third of the structures assessed were found to be exposed to river and surface flooding, and 20% exposed to coastal inundation, both of which had structures rated at extreme risk by end of century. The majority of structures identified at risk to heavy rainfall, hot days (>25°C), and strong wind were low to medium risk.

Of the 357 structures identified as exposed to river and surface flooding no structures are at low risk, 13% are at medium risk, 22% at high risk, and 3% at extreme risk (Figure 6.12). This means the risk profile remains constant through time as explained in Section 5.1 . All of the structures at extreme risk are noted as critical rolling stock depots, with half located in Bay of Plenty along the MTMNG corridor. All structures are presumed to have finished floor levels flush to ground, increasing their vulnerability to flood events.

For coastal inundation, 33 structures are identified as exposed and at risk in the present day, increasing to 142 in the mid-century, and nearly 200 exposed and at risk by end of century (under SSP3-7.0). A total of seven structures are identified at extreme risk in the present day, with no increase in extreme risk through time (Figure 6.12). All of these structures are critical rolling stock depots, with majority located in Dunedin and one in Wellington. Ten structures are identified at high risk from coastal inundation in the present day (none being critical rolling stock depots). This increases to 43 structures in a SSP1-2.6 end of century scenario with 32% being critical rolling stock depots. When considering SSP3-7.0 at the end of century, 77 structures are at high risk with 35% as critical rolling stock depots.

Coastal erosion has the least number of structures exposed, with 76 (8% of total structures) exposed in the present day and mid-century, increasing to 97 (10%) by the end of century (Figure 6.12). Structures, like other assets, have a high vulnerability to coastal erosion, which drives higher risk profiles. By end of century 44 structures are identified at high risk, with 13 being the critical rolling stock depots. There are a further 46 at medium risk, but only 3 as critical rolling stock. These structures are located mostly in Wellington, Auckland, Oamaru, and Kaikoura. There are no structures at extreme risk to coastal erosion.

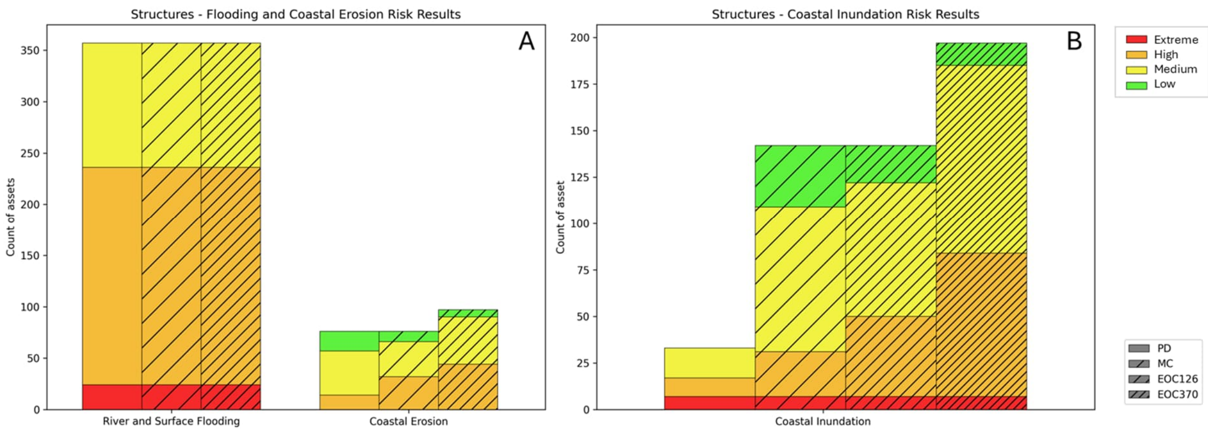


Figure 6.12: Count of structures at risk to acute hazards

Increased heavy rainfall and strong winds have the highest proportion of structures exposed (78%) through all time periods, but are the lowest risk compared to the other hazards (Figure 6.13). This is driven by low wind speed and less rainfall, and a low default vulnerability rating. Structures with medium risk ratings for both hazards have higher consequence ratings, associated with structure type (e.g. rolling stock buildings) and their connected track tonnage. There are seven structures located in high heavy rainfall areas (>100 mm per 24 hours) in the Southern Alps. They are generally located on flat land but near steep slopes, and therefore may have a higher likelihood of damage from rainfall induced landslides compared to other KiwiRail structures in New Zealand.

There are 498 structures (53%) exposed to more than 15 hot days (>25°C) in the present day with 63 being critical rolling depots. This increases to 771 structures (82%) with 110 critical rolling stock depots by the end of century (Figure 6.13). There are 15 (3%) at high risk by the end of century SSP3-7.0, all of which are critical rolling stock depots. These are mostly located in Christchurch and the central North Island, where the number of hot days exceeds 40 days a year, along with these structures having higher consequence ratings. No structures are at extreme risk to hot days (>25°C).

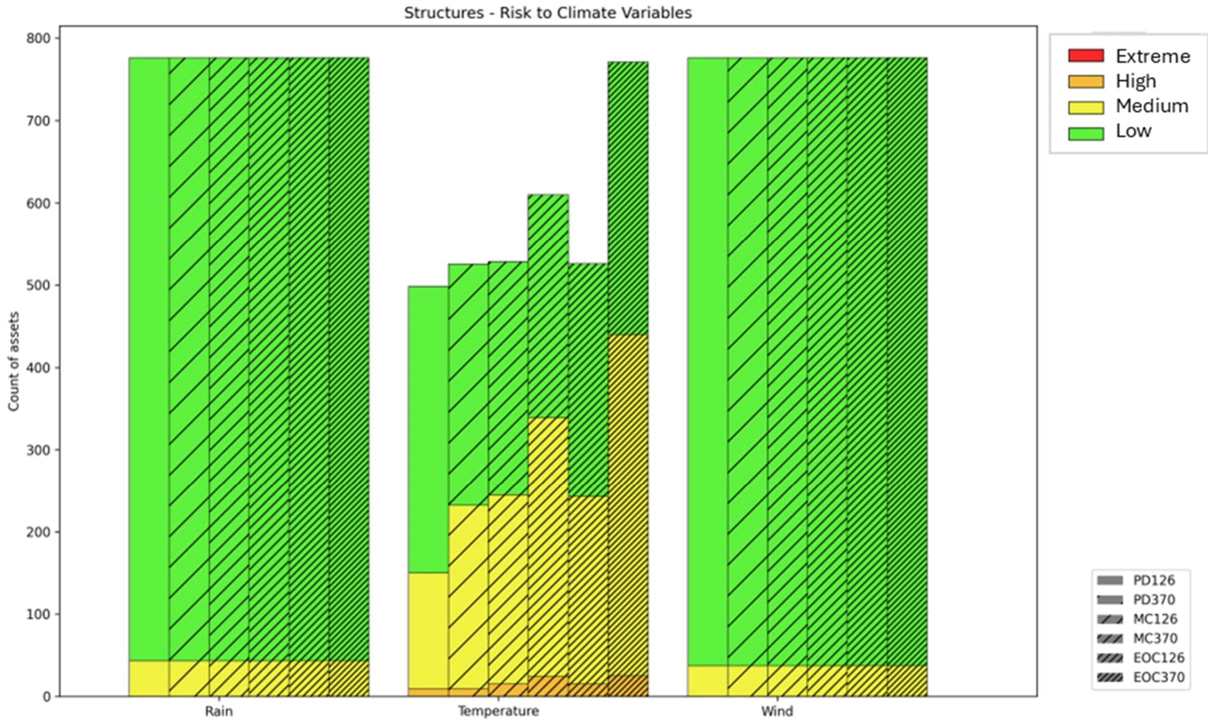


Figure 6.13: Count of structures at risk to chronic hazards

It is noted that there are further indirect environmental implications of climate change, including changes in flora and fauna distribution, along with the prevalence of pests and diseases. These will impact on assets in differing ways. For structures, consideration of fungus growth in timber structures could be worthy of further investigation with increasing temperatures and higher precipitation levels. Impacts could include further spread of Toredo worm into the South Island, where there is a larger proportion of timber structures.

6.10 Landholdings

A total of 182 km^2 of land holdings was assessed nationally. Landholdings were categorised into three groups: mothballed line sections, yet to be mothballed not in service, existing lines or future lines. Landholdings either have existing lines or identified as future investments were given the highest consequence ratings. Nearly a third of landholdings (by area) is exposed to river and surface floodings, with approximately 5% exposed to coastal erosion and coastal inundation by end of century, of which result in extreme risk for landholdings within the present day (Figure 6.14).

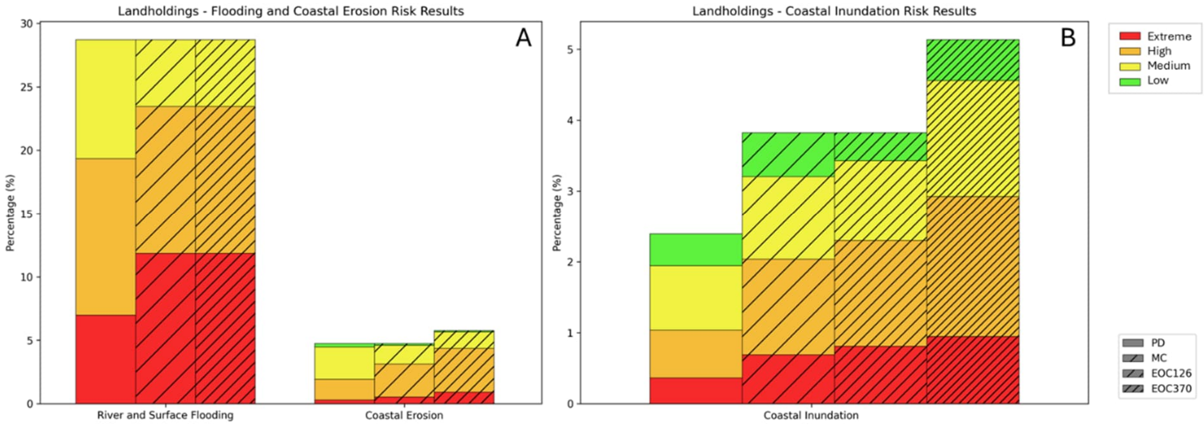


Figure 6.14: Percentage of landholdings at risk to acute hazards

For coastal erosion, 8.6 km^2 (5%) of landholdings is identified at risk in the present day, with the half of this land area rated at medium risk. A total of 3.5km^2 is rated at high or extreme risk in the present day, increasing to over 5.5 km^2 by mid-century (Figure 6.15). For future investment areas, where no lines are currently present, there is no exposure to coastal erosion on the South Island, and limited exposure on the North Island (0.71 km^2).

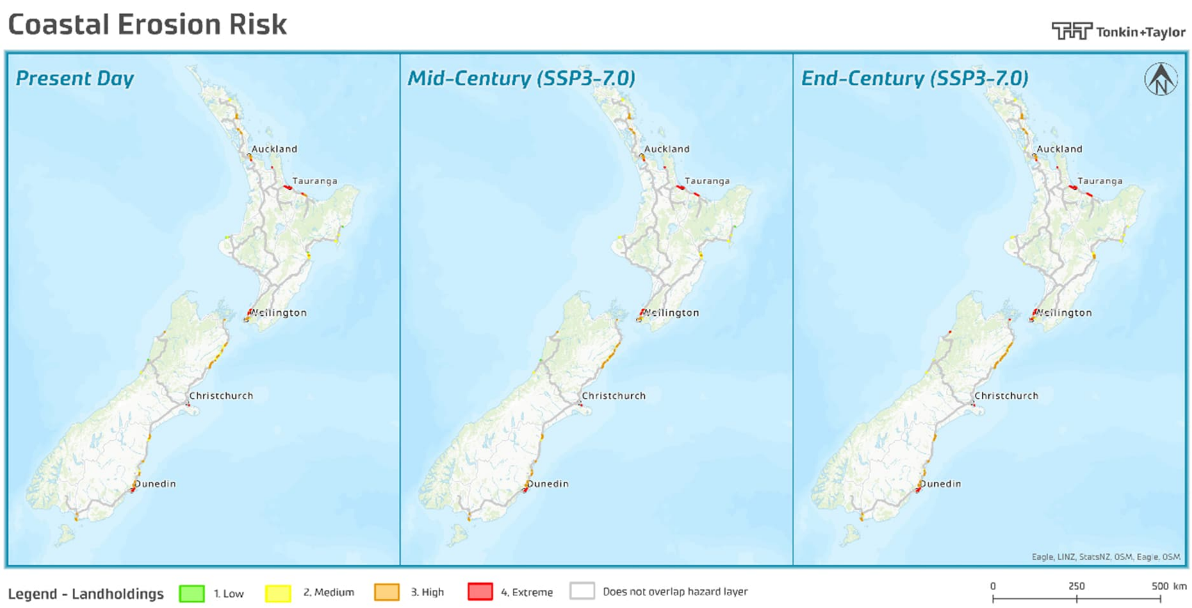


Figure 6.15: Coastal erosion risk for landholdings across three timeframes (SSP3-7.0)

Over 52 km^2 of landholdings are exposed to river and surface flooding (Figure 6.16). A fifth of this is at extreme risk in the present day, increasing to over 40% (21.5 km^2) by the end of century. NIMT, SNL, MSL and MDLND corridors have the largest land holding areas at extreme risk. The PTCHS and

MTMNG lines have more than 30% of their land holdings at extreme risk from river and surface flooding. This is followed by SNL and ECMT with roughly 25% of their lines at extreme risk. For future investment areas, exposure is predominantly concentrated to the North Island (4.2 km^2), with some exposure in the South Island (0.003 km^2) by end of century.

Exposure to coastal inundation is generally low, with present day exposure at 2%, increasing to 5% by the end of century (SSP3-7.0). The risk profile is generally spread across the four risk levels, with a total of 0.66 km^2 at extreme risk in the present day, increasing to 1.47 km^2 at the end of century under SSP1-2.6, and 1.72 km^2 under SSP3-7.0 (Figure 6.16). There is limited exposure for future investment areas in the South Island, with the North Island future investments showing 0.91 km^2 exposed and at risk in the present day, increasing to 1.46 km^2 by end of century (SSP3-7.0). This is equivalent to 15% of the total area of future investment landholdings in the North Island.

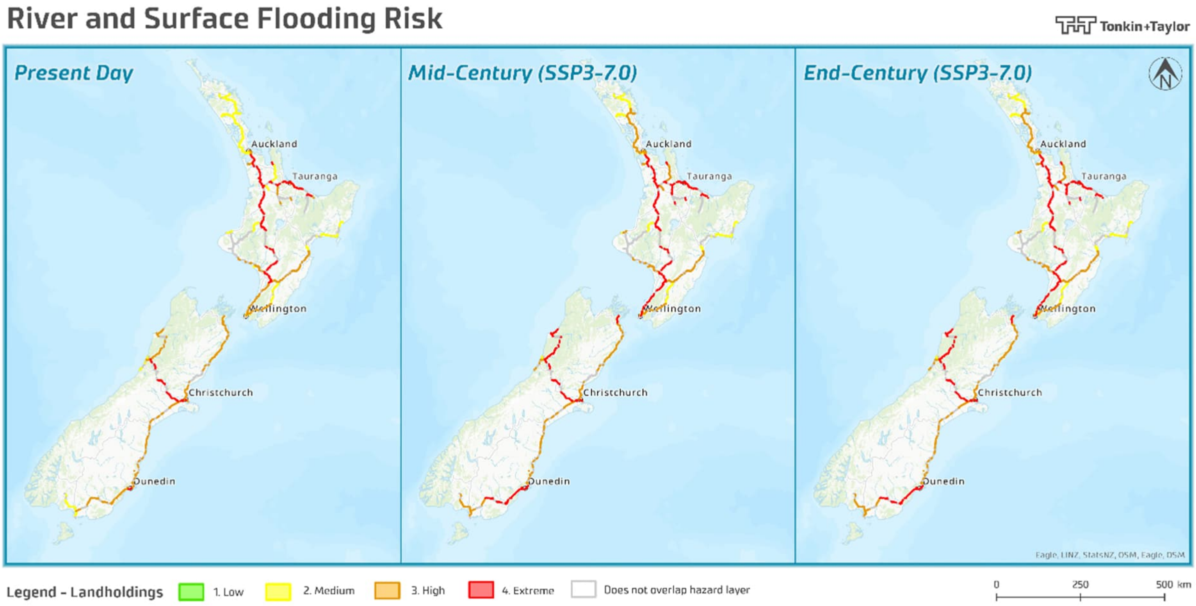


Figure 6.16: River and surface flooding risk for landholdings across three timeframes (SSP3-7.0)

When considering climate variables, the number of hot days is shown to affect the majority (90%) of the total area assessed. Risk in the present day is predominantly low and medium, with 20% of exposed land identified at high risk. This increases to nearly 65 km^2 (36%) of landholdings identified as high risk by end of century (SSP3-7.0). Risk ratings of landholdings against strong winds and increased heavy rainfall do not change over time, driven by no change in exposure ratings. Both result in 93% of the total landholdings areas at risk. Of the 26% of the landholding areas at high risk from strong winds, the NIMT accounts for 60% of the high risks. There is 2% of the landholdings areas at extreme risk to increased heavy rainfall, all within the MDLND corridor. These are mostly associated with heavy rainfall greater than 100 mm per 24 hours and are amongst steep sloped terrain, increasing the likelihood for rainfall induced landslide impacting the landholdings.

7 Recommendations

This KiwiRail Physical Climate Change Risk Assessment (CCRA) is an extension of the Resilience Programme Business Case undertaken in 2023. This extension has assessed more KiwiRail assets, along with increased physical climate-related hazards. This work has been completed concurrently to work by KiwiRail looking at their organisational climate risks, aligned to reporting requirements under NZ CS 1.

There are a range of recommendations that KiwiRail should consider following this work, including:

a Review and refinement of risk assessment criteria to ensure effective weighting of consequence, along with appropriate criteria for climate variables by individual asset types (e.g. max wind speeds for asset types other than rolling stock).

b Incorporation of slope data and heavy rainfall data to better understand the impact of climate change on slope failure. This could also include assessment of higher risk slope areas on nearby assets (e.g. culverts).

c Further assessment of hydraulic capacity of culverts across all major and critical consequence lines to further refine risk ratings.

d Extending the CCRA out to include other climate related hazards that are direct and indirect in nature. This could include prevenance of pests and disease, changes in flora and fauna, etc.

e Integration of assessment information within KiwiRail asset management systems. This is key to be able to visualise and interrogate the key deliverable –assessed information – further.

f Integration of assessment information within KiwiRail risk management systems to ensure that identified risks are added to risk registers and monitoring and reporting processes are established to track risk over time.

g Development of an asset information inventory, including attribute completeness and associated quality. In time this would seek to be used to increase consistency of asset metadata (i.e. attribute information) records in a centrally accessible location.

Appendix A Exposure (hazard) assessment tables

Appendix A Table 7.1: Criteria for assessing hazard exposure

Timeframe	Hazard	Hazard exposure ratings			
		Very low	Low	Medium	High
Present day	*River & surface flooding*	< 0.1% AEP	0.1% AEP or greater	1% AEP or greater	5% AEP or greater
	Coastal flooding	1% AEP + 0.4 m SLR	1% AEP + 0 m SLR	MHWS + 1 m	MHWS + 0.5 m
	Coastal edge proximity (erosion)	50 m or greater from coastal edge up to 150m	20 m – 50 m from coastal edge	-	Within 20 m from coastal edge
Mid-century (SSP 3-7.0)	*River & surface flooding*	< 0.1% AEP + CC	0.1% AEP + CC or greater	1% AEP + CC or greater	5% AEP + CC or greater
	Coastal flooding	1% AEP + 1.0 m SLR	1% AEP + 0.6 m SLR	1% AEP + 0.4 m SLR	1% AEP
	Coastal edge proximity (erosion)	100 m or greater from coastal edge up to 150m	50 m – 100 m from coastal edge	20 m – 50 m from coastal edge	Within 20 m from coastal edge
End of century (SSP 3-7.0)	*River & surface flooding*	< 0.1% AEP + CC	0.1% AEP + CC or greater	1% AEP + CC or greater	5% AEP + CC or greater
	Coastal flooding	1% AEP + 1.6 m SLR	1% AEP + 1.2 m SLR	1% AEP + 0.8 m SLR	1% AEP + 0.6 m SLR
	Coastal edge proximity (erosion)	150 m or greater from coastal edge up to 200m	100 m – 150 m from coastal edge	50 m – 100 m from coastal edge	Within 50 m from coastal edge
End of century (SSP 1-2.6)	*Coastal flooding*	1% AEP + 1.0 m SLR	1% AEP + 0.8 m SLR	1% AEP + 0.6 m SLR	1% AEP + 0.4 m SLR

Note: hazard datasets limit the granularity that exposure levels can be assessed at over a range of timeframes and scenarios where there would be material differences. As such, only SSP 3-7.0 has been used for mid-century, and SSP 1-2.6 has been used for coastal inundation only at end of century. 'CC' refers to relevant climate change allowances for the time period (e.g. 2050-2080 for mid-century). With limited AEPs available, river flood datasets have been rated 'medium' in the present day, and 'high' in future timeframes.

Appendix A Table 7.2: Climate-variable likelihood assessment

Timeframe	Variable	Very low	Low	Medium	High
All timeframes	*Temperature* *Average # of hot days (>25 °C)*	>15	>25	>30	>40
	Average maximum heavy rainfall (mm)	< 50 mm in 24 hrs	50 mm in 24 hrs OR >75 mm in 48 hrs	>75 mm in 24 hrs OR >100 mm in 48 hrs	>100 mm in 24 hrs OR >200 mm in 48 hrs
	Wind *Average strong wind (99^{th} percentile) (m/s)*	<100 km/h wind gusts	>100 km/ h wind gusts	>120 km/ h wind gusts	>140 km/h wind gusts

Note: Where possible likelihood metrics have been aligned with defined triggers within KiwiRail TARPs. Average maximum heavy rainfall used to establish daily (24hr) totals, as 48hr periods are not available. Timeframes were compared to the baseline 1986-2005, with future period 2021-2040 SSP 1-2.6 used to represent present day.

Appendix B Vulnerability assessment tables

Appendix B Table 7.3: Vulnerability assessment detailing whether a sub-asset level assessment or an asset level assessment by climate-related hazard

Asset type	Sub-asset level assessment	Asset level assessment
Tracks (line)	• Sleeper material and condition provides detail for sub-asset level assessment for increased fire risk, coastal inundation, and river and surface flooding: – Tracks with concrete sleepers have lower relative vulnerability. – Tracks with timber sleepers have higher relative vulnerability due to being weaker, and at the end of life, hence lower design standards. – Tracks with lower conditions have increased vulnerability. *Note: The specific methodology used to assess sleeper material and condition is outlined in the additional commentary table below.*	• Sleeper materials does not impact track vulnerability to the number of hot days (>25°C), heavy rainfall, strong winds, and coastal erosion.
Private sidings (line)		• Private sidings assessed at asset-hazard level for all hazards. • Private sidings are equivalent to the track it joins to as there is no further information on the asset's characteristics.
Bridges (line)	• Pier material and age provides detail for sub-asset level assessment for increased fire risk. • Span length, pier material, and age provides detail for sub-asset level assessment for coastal inundation and river and surface flooding. – Timber has increased vulnerability due to generally being older, in poorer condition, and structurally more fragile. – Piers made of other material such as concrete and steel have lower vulnerabilities, due to generally being younger, in better condition, and has higher structural integrity. – Bridges with earlier origin years have increased vulnerability due to having lower design standards that do not meet current standards that consider climate change hazards.	• Pier materials and ages do not impact bridge vulnerability to the number of hot days (>25°C), heavy rainfall, strong winds, and coastal erosion. • Average span length does not impact bridge vulnerability to the number of hot days (>25°C), heavy rainfall, increased fire risk, strong winds, or coastal erosion.

Asset type	Sub-asset level assessment	Asset level assessment
Signals (point)		• Signals are assessed at an asset-hazard level, as there is no further information.
Culverts (point)	• Undersized culverts and condition provide detail for sub-asset level assessment for heavy rainfall, coastal inundation, and river and surface flooding: – Culverts that are undersized have increased vulnerability to water-based hazards. – Culverts in poorer condition will have increased vulnerability.	• Undersized culverts and condition does not impact culvert vulnerability to the number of hot days (>25°C), increased fire risk, strong winds, or coastal erosion.
Tunnels (line)	• Year of construction provides detail for sub-asset level assessment for heavy rainfall, coastal inundation, and river and surface flooding: – Tunnels that were constructed at an earlier date have an increased vulnerability due to being built at lower standards than present day and are likely less stable.	• Year of construction does not impact the number of hot days (>25°C), increased fire risk, strong winds, and coastal erosion.
Track structure (point)	• Layer excluded due to its features already captured in the Tracks (line) dataset.	• Layer excluded due to its features already captured in the Tracks (line) dataset.
Container sites/ yards		• Container sites/ yards are assessed at an asset-hazard level for all hazards and are all treated equally, as there is no further information.
Major Stations (point)	• Layer used as a reference point, as it is just a descriptor: – It does not denote an actual railway station with platforms. This information is captured in the Structures (polygon) dataset.	• Layer used as a reference point, as it is just a descriptor: – It does not denote an actual railway station with platforms. This information is captured in the Structures (polygon) dataset.
Structures (polygon)		• Structures are assessed at an asset-hazard level, as there is no further information.
Landholdings (polygon)		• Landholdings are assessed at an asset-hazard level, as there is no further information.

Appendix B Table 7.4: Additional commentary for vulnerability ratings

Asset	Additional commentary
Tracks	• Baseline vulnerability is dependent primarily on ballast (susceptibility to deformation): – High-energy hazards (i.e. flooding and landslides) can reduce/remove ballast. These hazards can also deposit fine material, reducing ballast capability to free drain and ability to interlock, resulting in decreased stability. – The ballast retainer is a key component for vulnerability to hot days (>25°C). • Ballast structure/ condition varies significantly over shorter timeframes than the assessment timeframes, resulting in limited ability to assess contribution of ballast to vulnerability over time. Information relating to sleepers is available. • Sub-asset vulnerability uses sleeper information for specific hazards. For example: – Increased vulnerability for steel/concrete sleepers to coastal hazards with corrosion. – Increased vulnerability for timber sleepers to fire hazard. – Increased vulnerability for sleepers with low condition. • The track sleeper GIS file contained up to four groupings of materials, conditions, and percentages for each feature. The data could be processed in one of three ways, depending on the information supplied: – Where material and condition were the same, but percentage varied, they were combined. – Where material and percentage are the same, but condition varies, the worst condition is used. – Where all percentage, material, and condition are different, the highest percentage is used.
Private sidings	• Without further information on private sidings, the vulnerability rating established based on the track it is joined to.
Bridges	• Vulnerability is reduced to medium for flooding and landslides as bridges are assumed to have been designed to consider the hazards in the environment (e.g. retaining walls). • Increased vulnerability for smaller span lengths, as it is more susceptible to debris accumulating in watercourses. • Medium vulnerability to strong winds as trains may become unstable while travelling in valley, where wind is funnelled through. This would result in closure of the rail line.
Signals	• The vulnerability assessment assumes that all signals have ground level electrical equipment, resulting in higher vulnerabilities to flooding hazards.
Culverts	• Culverts designed to be in a water environment, reducing the vulnerability to flooding. • Overall condition ratings are available for many culverts, based on KiwiRail's Civil Standard Culvert Condition Assessment. This considers individual design elements (e.g. headwalls, wingwalls, apron, design event standard). • Undersized culverts increase vulnerability. Any culvert under 300mm diameter is considered to be undersized. KiwiRail has completed hydraulic assessments for some line culverts. Where available this will be used to further identify undersized culverts.

Asset	Additional commentary
Tunnels	• Tunnels were primarily assessed at an asset level. • Age of tunnel was used as proxy for vulnerability, with those commissioned over 100 years ago more susceptible to damage. Where age is unknown, the tunnel is assumed to be older. • Tunnels generally designed to withstand some slope deformation, resulting in reduced vulnerability to landslides. It has a higher vulnerability to heavy rainfall than tracks, due to the potential for penetration through tunnel roof, creating mud spots.
Container sites / yards	• Increased vulnerability to flooding hazards, due to depressed areas within loading zones.
Structures	• Structure assessed at an asset level given the limited information regarding design (e.g. material, finished floor levels). • Building finished floor levels assumed to be at ground level. • Increased vulnerability rating for fire damaging buildings.
Landholdings	• Reduced vulnerability to fire due to grass/ vegetation having relatively higher adaptive capacity for regrowth. • Higher vulnerability to flood hazards due to erosion and deposition of material.

Appendix C Consequence assessment tables

Appendix C Table 7.5: Consequence assessment detailing whether a sub-asset level assessment or an asset level assessment by climate-related hazard

Asset type	Consequence assessment	Example
Tracks (line)	• Track consequence is assessed at the sub-asset level by 'type' and 'tonnage': – Larger tonnage results in higher consequences. – Track types that do not have redundancy (multiple rail lines) have higher consequences. *Note majority of other asset consequence ratings will be relative to the Track consequence, as this will provide a network level assessment which considers the network interdependencies.*	
Private sidings (line)	• Default rating is equivalent to the track it is connected to.	
Bridges (line)	• Bridge consequence is assessed at sub-asset level by 'replacement costs' and 'class description', then adjusted by the tracks rating: – Subways and stock underpasses have lower consequence ratings compared to rail and road bridges. • The bridge consequence is required to be within 1 point of the track consequence rating, due to bridges creating a pinch point in the network.	• If Bridge = Moderate (3), and Track = Critical (5), then Bridge = Major (4). • If Bridge = Critical (5), and Track = Minor (2), then Bridge = Moderate (3).
Signals (point)	• Signals are all treated equally at an asset level assessment, with a default (and maximum) consequence rating of Moderate (3). Then adjusted by the tracks rating. • The tracks consequence rating sets the maximum consequence rating for signals.	• If Signals = Moderate (3), and Track = Critical (5), then Signals = Moderate (3). • If Signals = Moderate (3), and Track = Minor (2), then Signals = Minor (2).
Culverts (point)	• Culvert consequence is assessed at the sub-asset level by 'diameter' and 'depth to pipe', then adjusted by tracks rating: – Larger diameters and smaller depth to pipe have higher consequences. • The culvert consequence is required to be within 1 point of the track consequence rating, due to culverts creating a pinch point in the network. For example, a blowout or blockage could occur, resulting in the track being closed.	• If Culvert = Moderate (3), and Track = Critical (5), then Culvert = Major (4). • If Culvert = Major (4), and Track = Minor (2), then Culvert = Moderate (3).

Asset type	Consequence assessment	Example
	• Multiple diameter fields were available to use between the received datasets and varied in data completeness. They are prioritised in order below: 1 Diameter values from the two hydraulic files. If not available; 2 The updated culvert_point dataset was used. Within this dataset there were four diameter fields. a "Diamter Nosec" was prioritised. If not populated then; b Whichever of the other three fields were populated, was used	
Tunnels (line)	• Tunnels are all treated equally at an asset level assessment, with a default (and minimum) consequence rating of Major (4). Then it is adjusted by the tracks rating. • The tunnel consequence is required to be within 1 point of the track consequence rating, due to tunnels creating a pinch point in the network. – Therefore, all tunnel consequence ratings will either be Major (4) or Critical (5).	• If Tunnel = Major (4), and Track = Critical (5), then Tunnel = Major (4). • If Tunnel = Major (4), and Track = Minor (2), then Tunnel = Major (4).
Track structure (point)	• Layer excluded.	
Container sites/ yards (polygon)	• Container sites and yards consequence are assessed at sub-asset level by the criticality/ importance ranking list supplied by KiwiRail, then adjusted by the tracks rating. • The container sites and yards consequence are required to be within 1 point of the track consequence rating, due to container sites creating a pinch point in the network.	• If container site/ yard = Major (4), and Track = Critical (5), then container site/ yard = Major (4). • If container site/ yard = Critical (5), and Track = Insignificant (1), then container site/ yard = Minor (2)
Major Stations (point)	• Layer used as a reference point.	
Structures (polygon)	• Structures consequence is assessed at sub-asset level by 'asset type'. – Structures that are related to container sites are given the same consequence rating as the container site. – Workshops have a higher consequence rating than offices. • The track's consequence rating sets the upper/maximum consequence rating for structures.	• If the Structure is a container site building, then structure = container site rating. • If structure = Critical (5), and the track = Minor (2), then the structure is modified to Minor (2).
Landholdings (polygon)	• Landholdings consequence is assessed at an asset level. • Where the landholding overlaps with the track, the consequence rating is required to be within 1 point of the track.	• If there is overlap with track, which has a Moderate (3) rating, then the landholding will have a Moderate (3) rating.

Asset type	Consequence assessment	Example
	• Where landholdings do not overlap the track, KiwiRail will provide a consequence rating based on the proposed usage.	• If there is no overlap with track, then the landholding is given to KiwiRail to assess criticality.

Appendix D Datasets received and used in the CCRA

Appendix D Table 7.6: Information received and used within the assessment, including desired asset information

Asset type	Dataset received	Received format	Dataset used?	Desired data for vulnerability	Data received and used to assess vulnerability	Desired data for consequence	Data received and used to assess consequence
Track	Track_line (original)	GIS	Yes	• Condition of ballast, sub-ballast, and rail. • Material of ballast, sub-ballast, and rail. • Age of ballast, sub-ballast, and rail. • Rail height above ground level.	• Sub-asset level assessment – Sleeper material. – Sleeper condition.	• Tonnage. • Track type. • Customer volume.	• Sub-asset level assessment – Tonnage. – Track type.
	Sleeper Upload Format	Excel	No				
	Track RAMP Sleeper Count	Excel	No				
	Sleepers Upload Format	GIS	Yes				
	Gross_tonnage_ data_FY23_line	GIS	Yes				
Private sidings	PrivateSidings_line (original)	GIS	Yes	• Condition of ballast, sub-ballast, and rail. • Material of ballast, sub-ballast, and rail. • Age of ballast, sub-ballast, rail. • Rail height above ground level.	• Asset level assessment – No data was received.	• Customer connection.	• Asset level assessment – No data received.
	PrivateSidings_point (original)	GIS	No				
Bridges	Bridges_line (original)	GIS	Yes	• Number of piers. • Material of piers. • Condition of piers.	• Sub-asset level assessment – Number of spans (and length of bridge). – Material of piers.	• Class description. • Replacement costs.	• Sub-asset level assessment – Class description. – Replacement costs.
Signals	Signals_point (original)	GIS	Yes	• Material of poles. • Condition of poles.	• Asset level assessment	• Signal type.	• Asset level assessment

Asset type	Dataset received	Received format	Dataset used?	Desired data for vulnerability	Data received and used to assess vulnerability	Desired data for consequence	Data received and used to assess consequence
					– No data was received.		– No data received.
Culverts	Culverts_point (original)	GIS	No	• Construction of culvert • Material of culvert. • Suitability (sizing). • Age of culvert.	• Sub-asset level assessment – Suitability (sizing) – partial – Condition	• Diameter.	• Sub-asset level assessment – Diameter. – Depth to pipe.
	Culverts_point (updated with more features and fields)	GIS	Yes				
	KiwiRail – Culvert Spreadsheets Processed	Excel	Yes				
	NAL Hydraulic_Results_ Overview	Excel	Yes				
Tunnel	Tunnels_line (original)	GIS	Yes	• Condition of tunnel.	• Sub-asset level assessment – Tunnel age.	• Replacement cost.	• Asset level assessment – No data received.
	Tunnel Data Specification	Excel	No				
Track structure	Trackstructure_ point (original)	GIS	No	• Not assessed - already captured in other datasets.	• Not assessed	• Not assessed	• Not assessed.
Container sites	Yard_polygon (original)	GIS	Yes		• Asset level assessment – No data received.	• Area (m^2). • Number of railroad tracks.	• Sub-asset level assessment – Criticality/ importance rating.
	Yard_Sidings Importance Matrix_V7_Final	Excel	Yes				
Yards	Landholding_ Polygon (original)	GIS	Yes		• Asset level assessment • No data received	• Area (m^2). • Number of railroad tracks.	• Sub-asset level assessment • Criticality/ importance rating.

Asset type	Dataset received	Received format	Dataset used?	Desired data for vulnerability	Data received and used to assess vulnerability	Desired data for consequence	Data received and used to assess consequence
Major stations	StationsMajor_ point (original)	GIS	No	• Layer used as a reference point.	• Layer used as a reference point.	• Layer used as a reference point.	• Layer used as a reference point.
Structures	Structures_polygon (original)	GIS	Yes	• Cladding type. • Floor levels.	• Asset level assessment – No data received.	• Structure type/ use.	• Sub-asset level assessment – Structure type/ use (but limited information).
	RSAS Depot Data	Excel	Yes				
Landholdings	Landholding_ Polygon (original)	GIS	Yes	• Soil type. • Topography.	• Asset level assessment – No data received.	• Whether it is occupied by buildings. • Type/ use. • Area (m^2). • Land value.	• Asset level assessment – No data received.

Note: “Original” indicates those datasets that were first received.

Appendix E Risk results

Table 7.7: Risk results for 'acute hazards'

Assets	Total assets assessed	Risk category	Coastal erosion			Coastal inundation				River and surface flooding		
			Present day	Mid century	End of century	Present day	Mid century	End of century		Present day	Mid century	End of century
								SSP1-2.6	SSP3-7.0			
Tracks	5,099 km	Low	17	9	5	14	41	25	34			
		Medium	156	88	80	38	74	70	115	442	320	320
		High	102	162	214	25	91	98	145	645	561	561
		Extreme	20	36	62	7	33	47	61	499	705	705
Private sidings	22.2 km	Low										
		Medium	1	1	1							
		High		1	1			1	1	8	8	8
		Extreme								1	1	1
Bridges	1,393 count	Low										
		Medium	31	16	18	21	10	5	21	34	6	6
		High	36	49	65	95	96	100	106	612	532	532
		Extreme	10	12	14	27	49	50	52	133	241	241
Signals	2,969 count	Low	8	4	1	3	25	22	8			
		Medium	141	76	66	18	88	63	95	65	65	65
		High	68	137	198	15	48	76	165	834	834	834
		Extreme										
Culverts	11,614 count	Low	1			13	24	14	20			
		Medium	385	234	132	70	94	52	108	857	82	82
		High	204	350	525	52	125	173	209	1764	2104	2104

		Extreme	14	20	33	1	8	12	16	304	739	739
Tunnels	148 count	Low										
		Medium										
		High	29	17	5					10		
		Extreme		12	26	1	1	1	1	8	18	18
Container Sites	15 count	Low										
		Medium	3	3	3	1	3	3	4			
		High	1	2	5		3	3	5	5	5	5
		Extreme						1	2	2	2	2
Yards	98 count	Low										
		Medium	15	15	14	18	20	20	22			
		High	15	19	20	21	28	28	29	49	49	49
		Extreme	1	4	4	5	5	5	7	31	31	31

Table 7.8: Risk results for 'chronic hazards'

Assets	Total assets assessed (units)	Risk category	Rainfall intensity					Change in temperature					Extreme wind				
			Present day	Mid century		End of century		Present day	Mid century		End of century		Present day	Mid century		End of century	
			SSP1-2.6	SSP1-2.6	SSP3-7.0	SSP1-2.6	SSP3-7.0	SSP1-2.6	SSP1-2.6	SSP3-7.0	SSP1-2.6	SSP3-7.0	SSP1-2.6	SSP1-2.6	SSP3-7.0	SSP1-2.6	SSP3-7.0
Tracks	5,099 km	Low	2618	2618	2618	2618	2608	728	410	427	495	126	2626	2626	2626	2626	2626
		Medium	756	756	756	756	766	1145	1325	1493	1213	1399	772	772	772	772	772
		High	1313	1313	1313	1313	1313	952	1077	1239	1048	1997	1289	1289	1289	1289	1289
		Extreme						483	737	884	712	1093					
Private sidings	22.2 km	Low	6	6	6	6	6						6	6	6	6	6
		Medium	1	1	1	1	1	6				1	1	1	1	1	1
		High	7	7	7	7	7	5	6	6	6	6	7	7	7	7	7
		Extreme						2	7	7	7	7					
Bridges	1,393 count	Low	816	816	807	813	788	240	186	163	203	39	145	145	145	145	145
		Medium	384	384	393	387	412	278	295	324	279	264	1098	1098	1098	1098	1098
		High	86	86	86	86	86	294	398	527	380	894	43	43	43	43	43
		Extreme						4	8	20	7	34					
Signals	2,969 count	Low	2536	2523	2519	2522	2484	494	348	238	380	154	420	420	420	420	420
		Medium	117	130	134	131	169	860	664	648	648	629	2304	2304	2304	2304	2304
		High	71	71	71	71	71	572	1049	1330	1013	1888					
		Extreme															
Culverts	11,614 count	Low	6210	6199	6177	6161	6064	3535	2904	2652	3023	987	8032	8032	8032	8032	8032
		Medium	4227	4247	4253	4272	4342	3273	4128	5141	3933	7342	2713	2713	2713	2713	2713
		High	350	341	357	354	381	686	1078	1445	990	2236	58	58	58	58	58
		Extreme	16	16	16	16	16										

Tunnels	148 count	Low															
		Medium	72	73	72	69	68	65	53	25	57	19	104	104	104	104	104
		High	55	54	55	58	59	30	46	79	42	107	27	27	27	27	27
		Extreme	4	4	4	4	4										
Container Sites	15 count	Low	6	6	6	6	6	1	1	2	1		6	6	6	6	6
		Medium	3	3	3	3	3	5	3	1	3	4	3	3	3	3	3
		High	2	2	2	2	2	1	3	5	3	6	2	2	2	2	2
		Extreme						1	1	1	1	1					
Yards	98 Count	Low	56	56	56	56	56	12	10	12	10	3	56	56	56	56	56
		Medium	26	26	26	26	26	34	30	29	32	29	28	28	28	28	28
		High	9	9	9	9	9	23	30	29	29	55	7	7	7	7	7
		Extreme						2	5	5	5	6					

Appendix F Exposure results

There were 10 KiwiRail asset types assessed in the CCRA. All 10 asset types are found to have assets that are exposed to the three climate-related ‘acute’ hazards assessed: river and surface flooding, coastal erosion, and coastal inundation. The total assets identified as exposed to these three climate-related ‘acute’ hazards is shown in Table Appendix F.1 and Table Appendix F.2.

All asset types are the most exposed to river and surface flooding, with all assets having more than 10% of their totals exposed (Table Appendix F.1). Bridges are the most exposed asset to any of the three high-energy hazards with 56% exposed to river and surface flooding (expected given their location generally across rivers). This is followed by private sidings and structures with 38% exposed, then tracks and yards with 31% exposed to river and surface flooding.

As coastal erosion and coastal inundation move further inland through time, the number of assets exposed increases. Although tunnels, container sites, and private sidings are not exposed to coastal erosion within 20 m of the coast in the present day, they end up being the most at risk with 21% of tunnels exposed to coastal erosion within 200 m, followed by container sites (13%), and structures and private sidings (10%).

Table Appendix F.1 : Exposure results of total assets to river and surface flooding and coastal erosion

		River and surface flooding	Coastal Erosion				
Asset	Exposed measure	Exposed to flooding	Within 20 m	Within 50 m	Within 100 m	Within 150 m	Within 200 m
Track	Length (km)	1586 (31%)	46 (1%)	100 (2%)	205 (4%)	294 (6%)	361 (7%)
Private Sidings	Length (km)	8.4 (38%)	0 (0%)	0.1 (1%)	0.4 (2%)	1.5 (7%)	2.2 (10%)
Bridges	Count	779 (56%)	31 (2%)	39 (3%)	59 (4%)	77 (6%)	97 (7%)
Culverts	Count	2925 (25%)	112 (1%)	263 (2%)	497 (4%)	604 (5%)	690 (6%)
Signals	Count	899 (30%)	41 (1%)	76 (3%)	150 (5%)	217 (7%)	265 (9%)
Structures	Count	357 (38%)	10 (1%)	31 (3%)	58 (6%)	76 (8%)	97 (10%)
Tunnels	Count	18 (12%)	0 (0%)	12 (8%)	25 (17%)	29 (20%)	31 (21%)
Landholdings	Area (km^2)	52.2 (29%)	1.3 (1%)	3.0 (2%)	6.1 (3%)	8.6 (5%)	10.5 (6%)
Container Sites	Area (km^2)	0.14 (25%)	0 (0%)	< 0.01 (1%)	0.02 (3%)	0.03 (6%)	0.07 (13%)
Yards	Area (km^2)	0.48 (31%)	0.02 (2%)	0.06 (4%)	0.1 (8%)	0.2 (12%)	0.2 (15%)

Table Appendix F.2. shows the total number of assets exposed to coastal inundation with associated storm events such as MHWS + 0.5m and 1% AEP 0.6 m. These sea levels can be matched to those in A s. For example, AEP 0.6 m sea level rise occurs in 2130 for the SSP2-1.6 scenario, but it occurs in 2090 for the SSP3-7.0 scenario. This shows that different socio-economic assumptions that drive future greenhouse gas emissions, result in different severities of sea level rise.

In a MHWS + 0.5 m event, bridges are the most exposed (5%) to coastal inundation, or 10% in a 1% AEP 0 m event. This slowly increases with sea level rise to 13% in a 1% AEP + 1.6 m scenario. However, in the 1% AEP + 1.6 m scenario, container sites and structures are the most exposed assets to coastal inundation, with 21% exposed. Container sites have a sudden exposure increase from a 1% AEP + 1.0 m event where 9% are exposed, then 15% with 1.2 m sea level rise, and 21% with 1.6 m sea level rise. This indicates more container sites are located slightly further from the coast. On the other hand, exposure to structures slowly increases through sea level increments from 0.4 m sea level rise.

Table Appendix F.2 : Exposure results of total assets to coastal inundation

		Coastal Inundation								
Asset	Exposed measure	MHWS + 0.5m	MHWS + 1m	AEP 1% + 0m	AEP 1% + 0.4m	AEP 1% + 0.6m	AEP 1% + 0.8m	AEP 1% + 1m	AEP 1% + 1.2m	AEP 1% + 1.6m
Track	Length (km)	5 (0%)	28 (1%)	26 (1%)	56 (1%)	87 (2%)	133 (3%)	211 (4%)	258 (5%)	326 (6%)
Private Sidings	Length (km)	0.00 (0%)	0.05 (0%)	0.00 (0%)	0.04 (0%)	0.21 (1%)	0.23 (1%)	0.64 (3%)	0.89 (4%)	1.20 (5%)
Bridges	Count	65 (5%)	99 (7%)	134 (10%)	143 (10%)	146 (10%)	152 (11%)	155 (11%)	163 (12%)	179 (13%)
Culverts	Count	8 (0%)	44 (0%)	41 (0%)	92 (1%)	133 (1%)	174 (1%)	207 (2%)	247 (2%)	309 (3%)
Signals	Count	2 (0%)	10 (0%)	16 (1%)	36 (1%)	54 (2%)	87 (3%)	161 (5%)	208 (7%)	268 (9%)
Structures	Count	6 (1%)	24 (3%)	29 (3%)	33 (3%)	49 (5%)	85 (9%)	142 (15%)	170 (18%)	197 (21%)
Tunnels	Count	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)
Landholdings	Area (km^2)	1.08 (1%)	1.99 (1%)	1.54 (1%)	2.36 (1%)	2.97 (2%)	3.87 (2%)	4.95 (3%)	5.87 (3%)	7.34 (4%)
Container Sites	Area (km^2)	0 (0%)	0 (0%)	0 (0%)	<0.01 (0%)	0.01 (2%)	0.02 (3%)	0.05 (9%)	0.09 (15%)	0.12 (21%)
Yards	Area (km^2)	0.02 (1%)	0.03 (2%)	0.01 (0.5%)	0.02 (1%)	0.03 (2%)	0.05 (3%)	0.1 (6%)	0.1 (8%)	0.2 (11%)

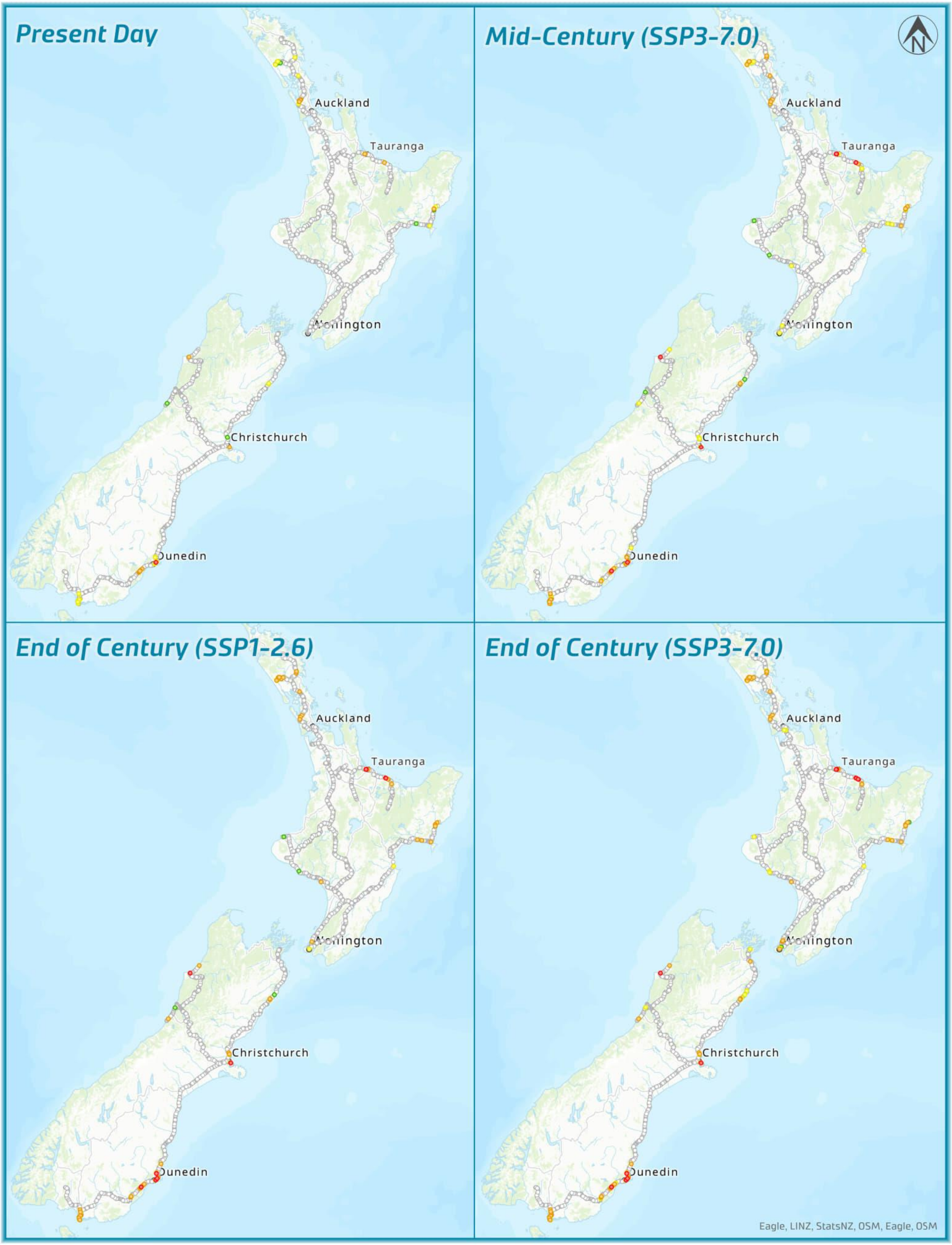
MHWS and AEP datasets have different modelling approaches as they are different scenarios. The AEP dataset allows for a 1% AEP storm surge, while the MHWS is the average water height during a spring tide and does not include a storm surge. This results in different levels of flooding, e.g., MHWS + 1m vs AEP + 1m will contain different exposure results, but the 1 m sea level rise will still occur at the same time.

A summary of approximate year when absolute sea-level rise heights could be reached was established from the updated 2024 Coastal hazards and climate change guidance.

Appendix G Additional maps

Coastal Inundation Risk

Tonkin+Taylor

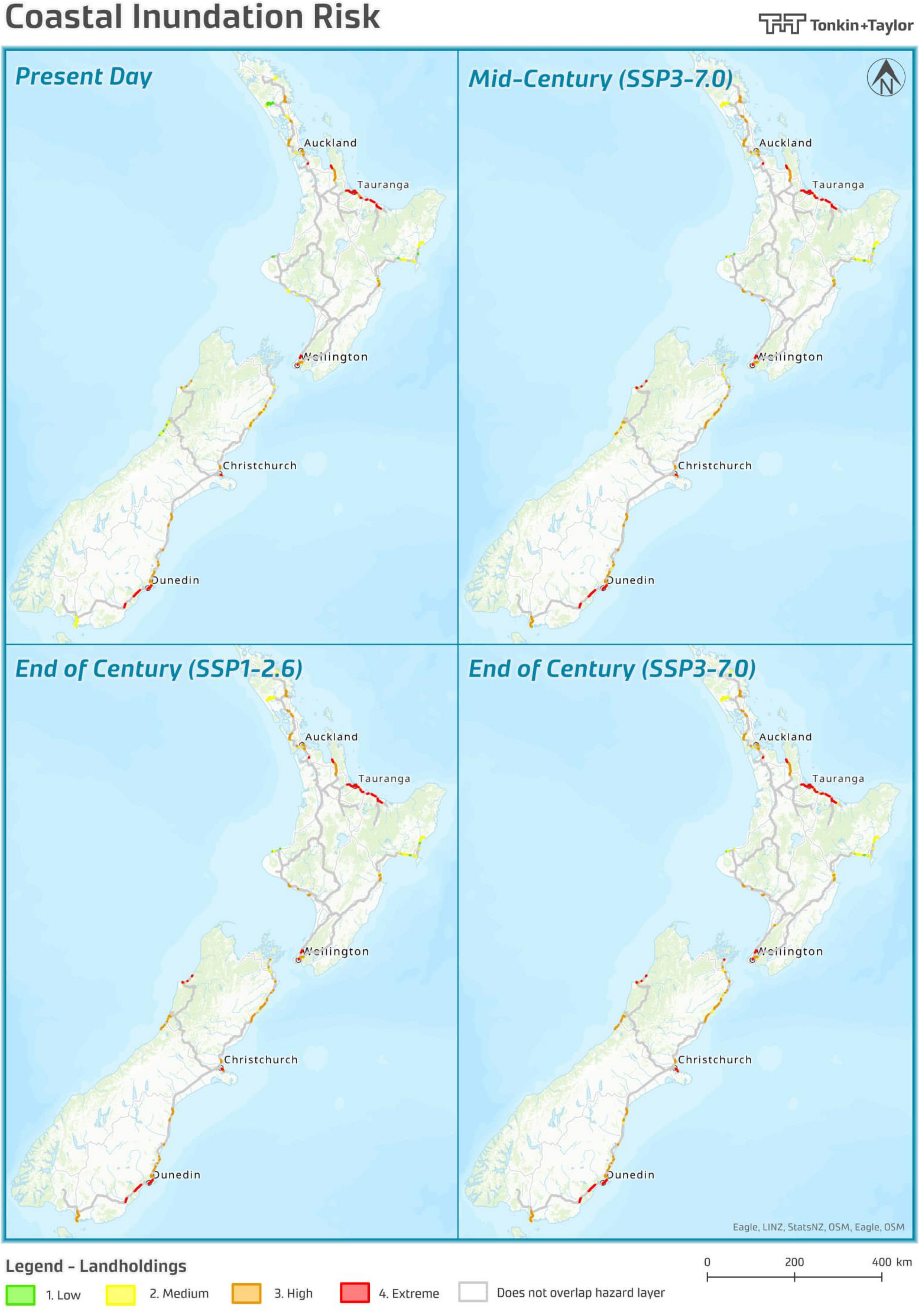


Legend - Culverts

- 1. Low
- 2. Medium
- 3. High
- 4. Extreme
- Does not overlap hazard layer

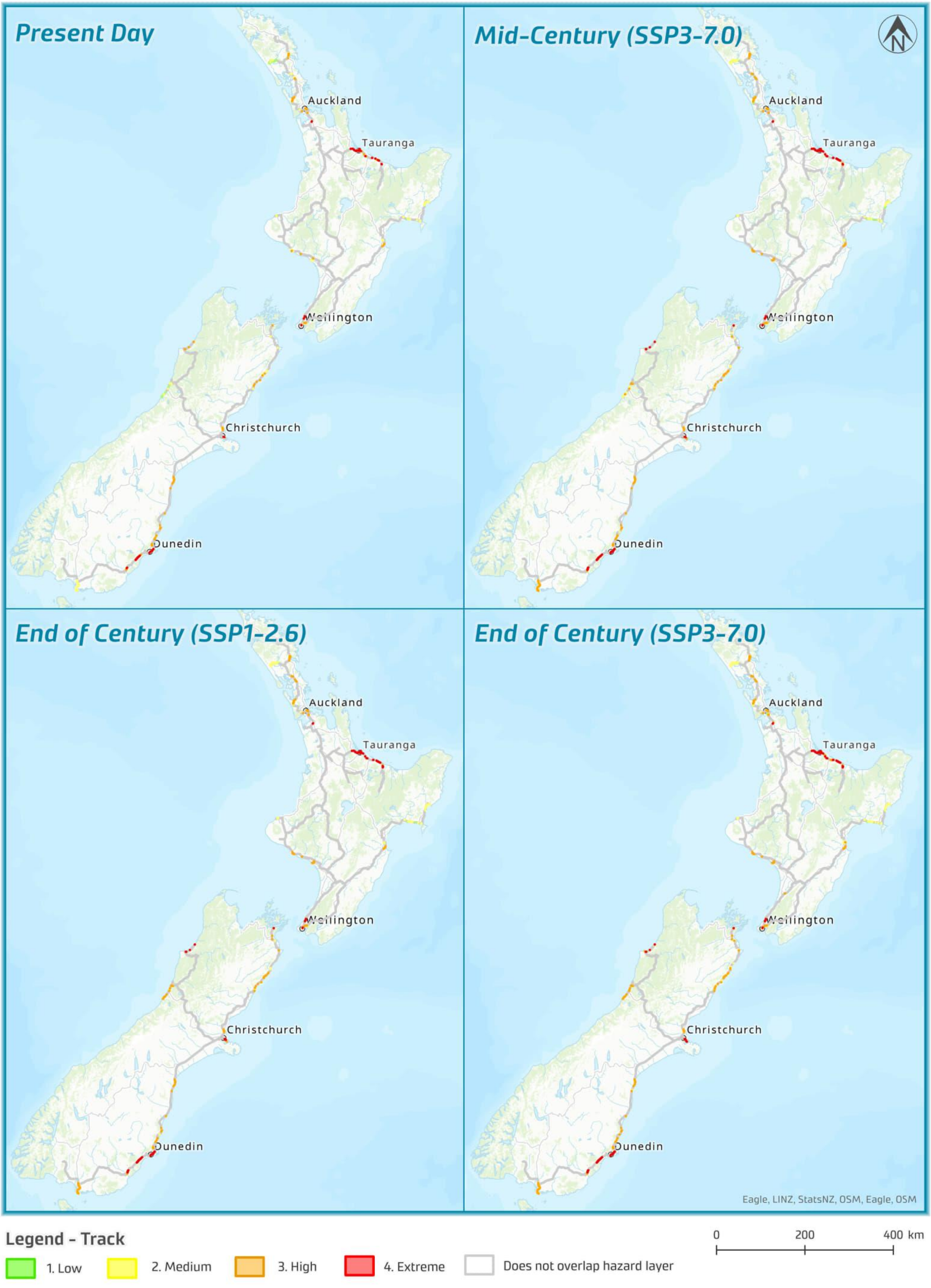
0 200 400 km

Coastal Inundation Risk



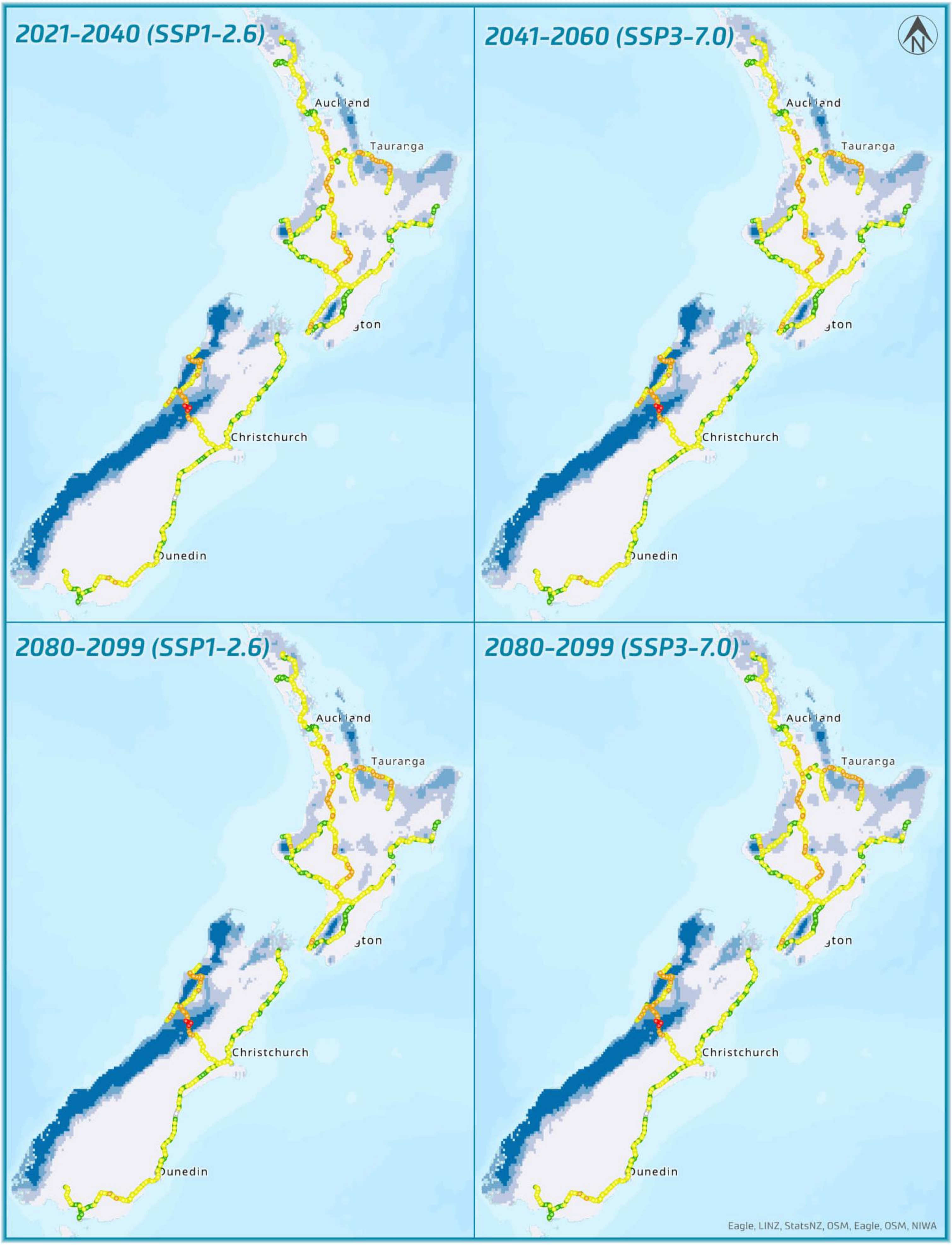
Coastal Inundation Risk

Tonkin+Taylor



Rain Risk

Tonkin+Taylor



Legend - Culverts

1. Low
2. Medium
3. High
4. Extreme

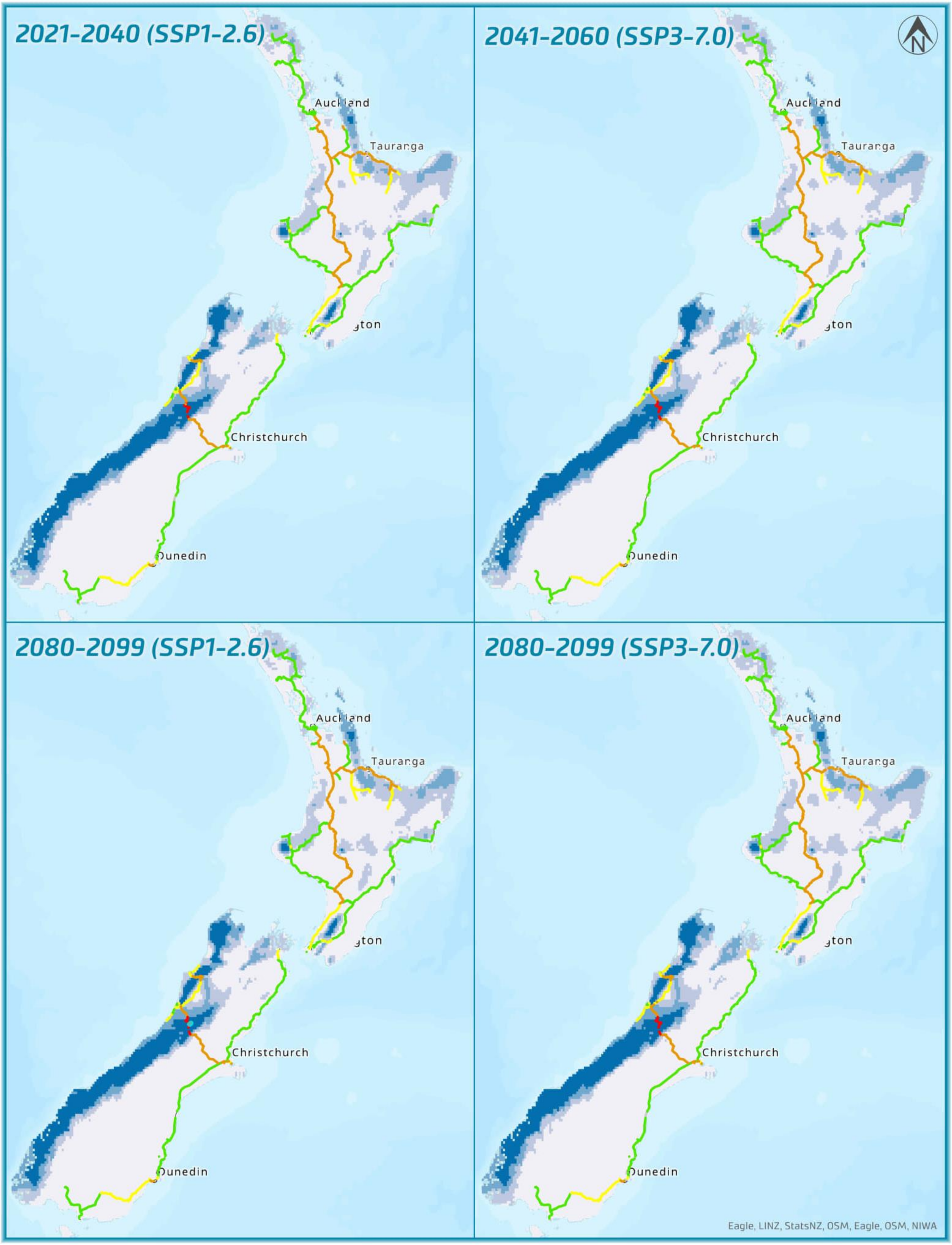
Does not overlap hazard layer

Average maximum heavy rainfall (mm) <50mm 50-70mm 70-100mm >100mm

0 200 400 km

Rain Risk

Tonkin+Taylor



Legend - Landholdings

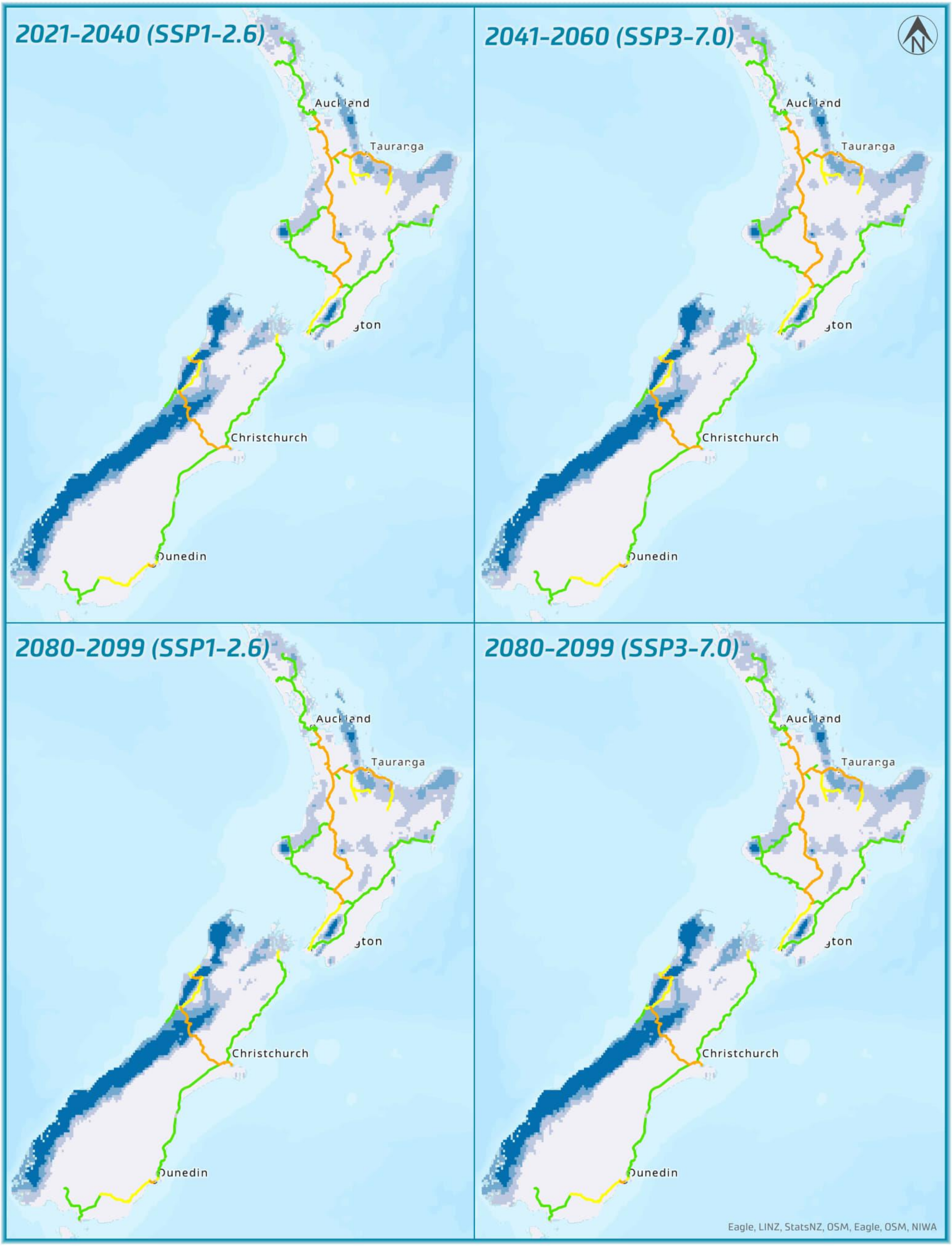
1. Low | 2. Medium | 3. High | 4. Extreme | Does not overlap hazard layer

Average maximum heavy rainfall (mm): <50mm | 50-70mm | 70-100mm | >100mm

0 | 200 | 400 km

Rain Risk

Tonkin+Taylor



0 200 400 km

Legend - Track

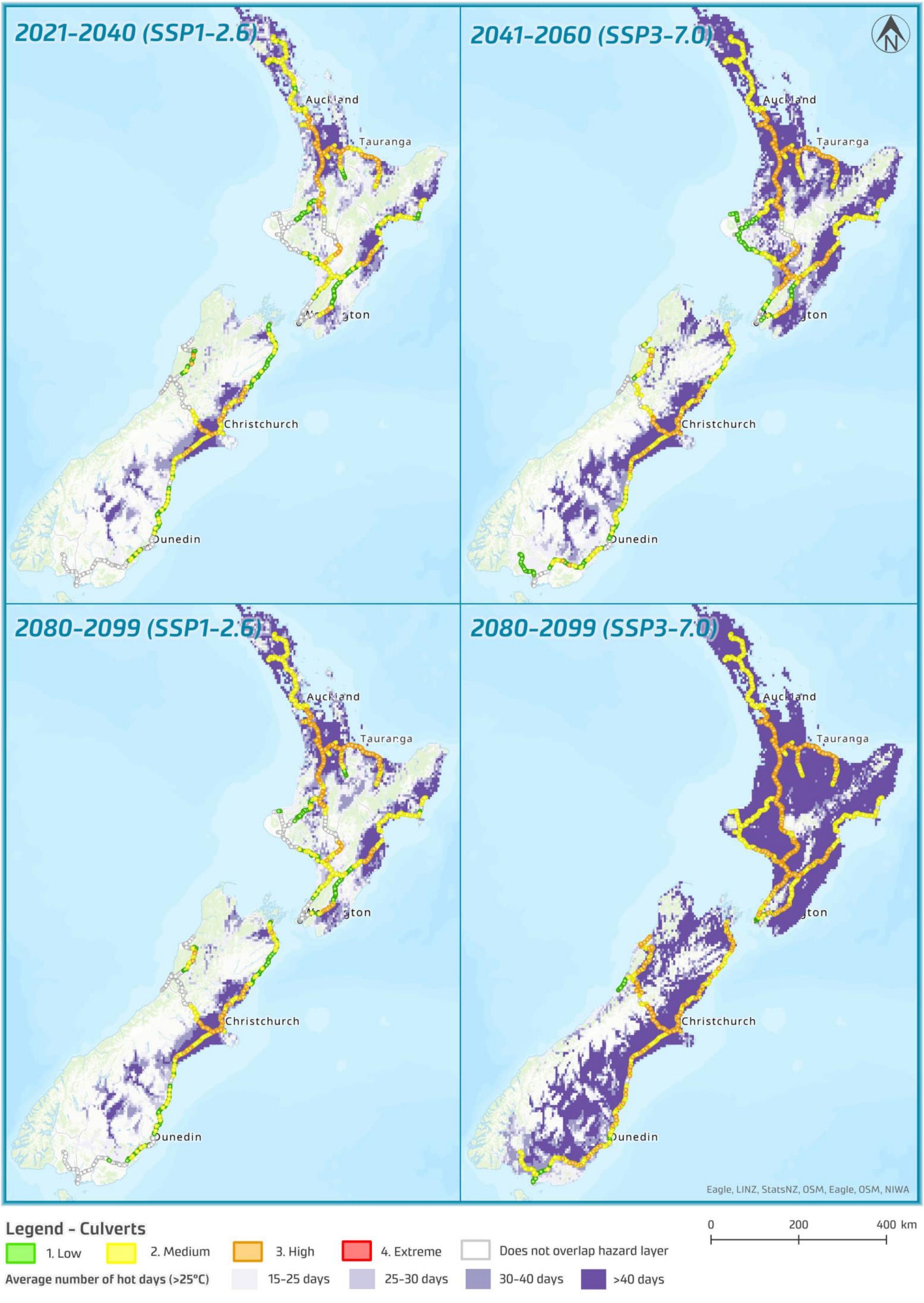
1. Low
2. Medium
3. High
4. Extreme

Does not overlap hazard layer

Average maximum heavy rainfall (mm): <50mm, 50-70mm, 70-100mm, >100mm

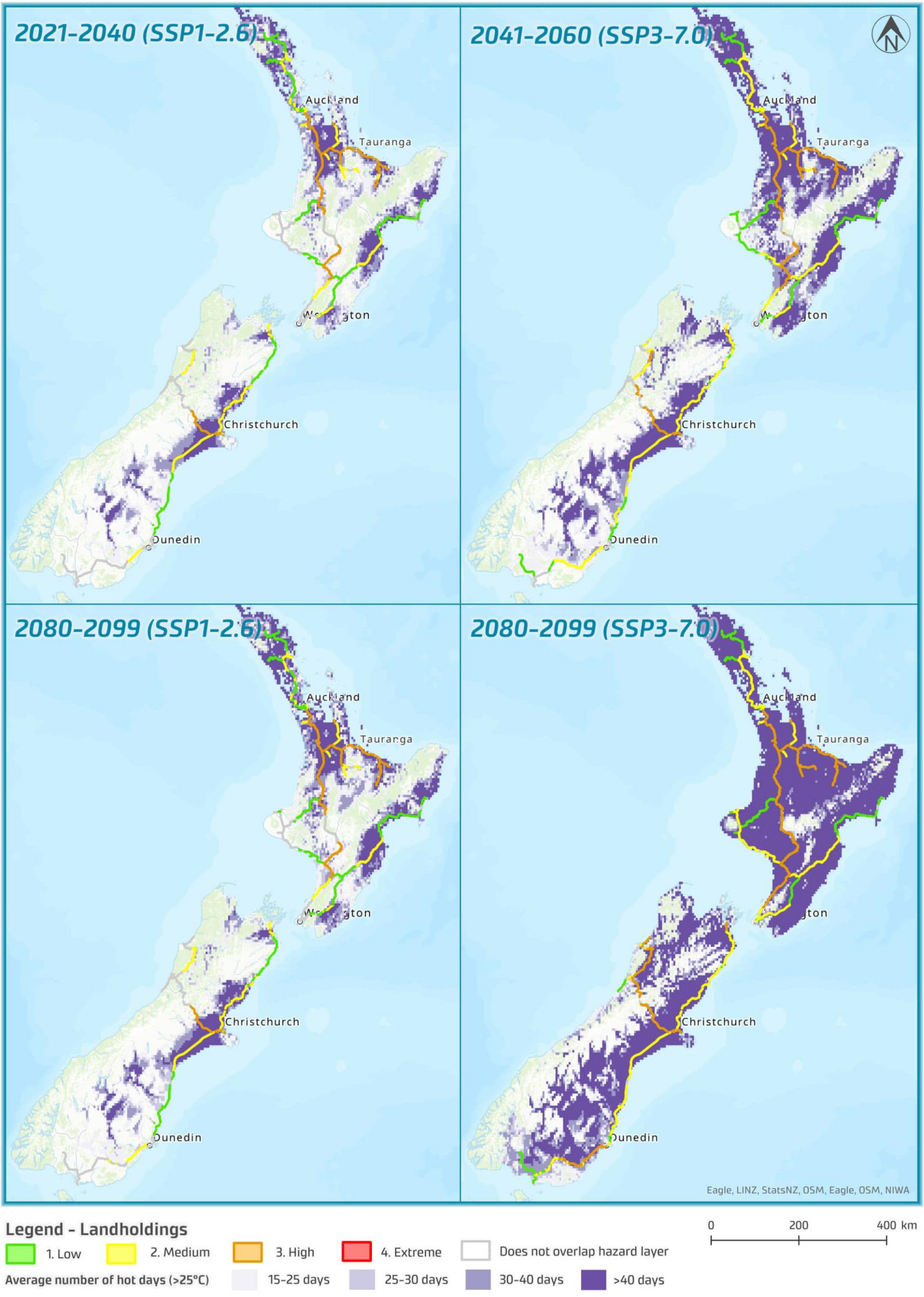
Temperature Risk

Tonkin+Taylor

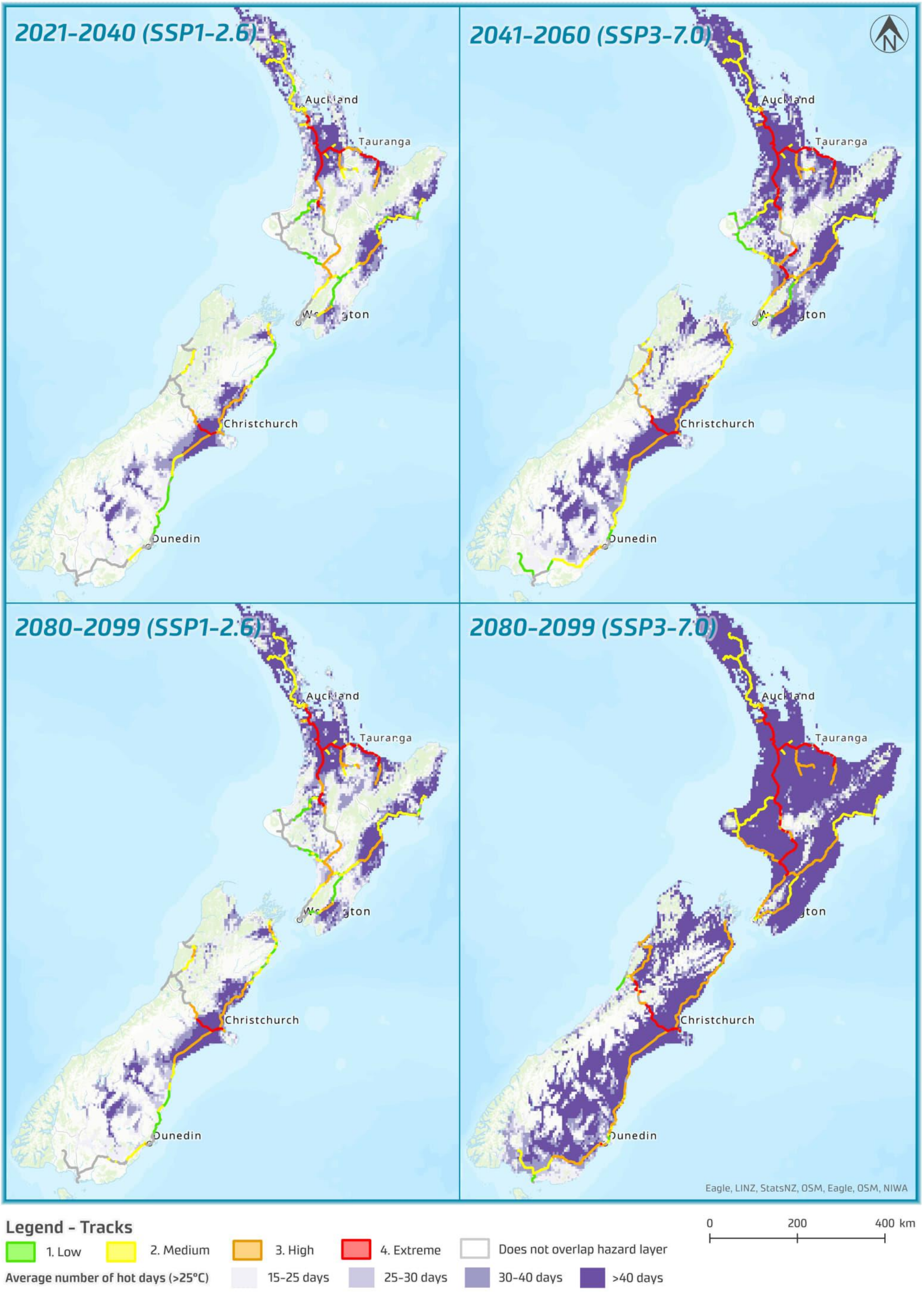


Temperature Risk

Tonkin+Taylor

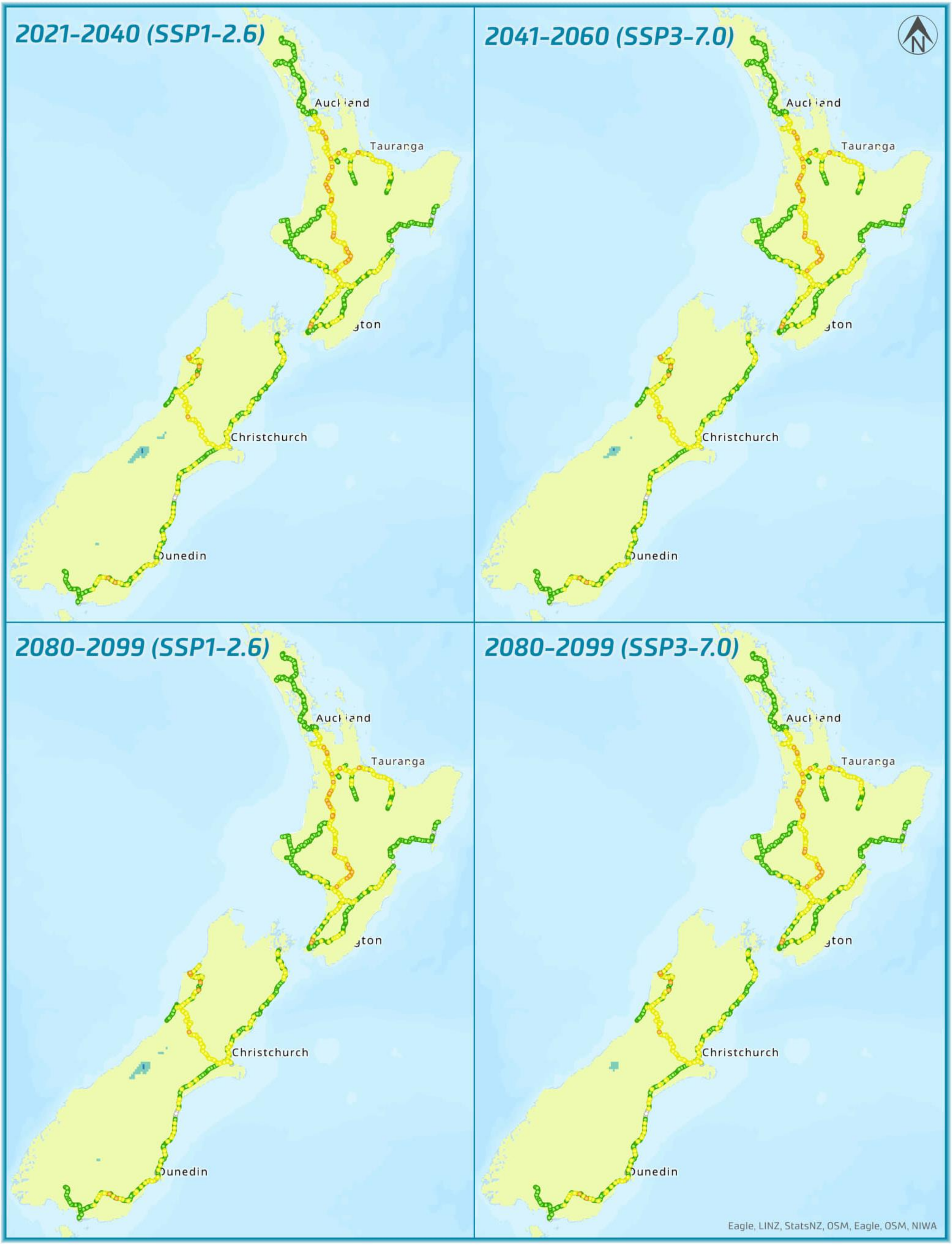


Temperature Risk



Wind Risk

Tonkin+Taylor



Legend - Culverts

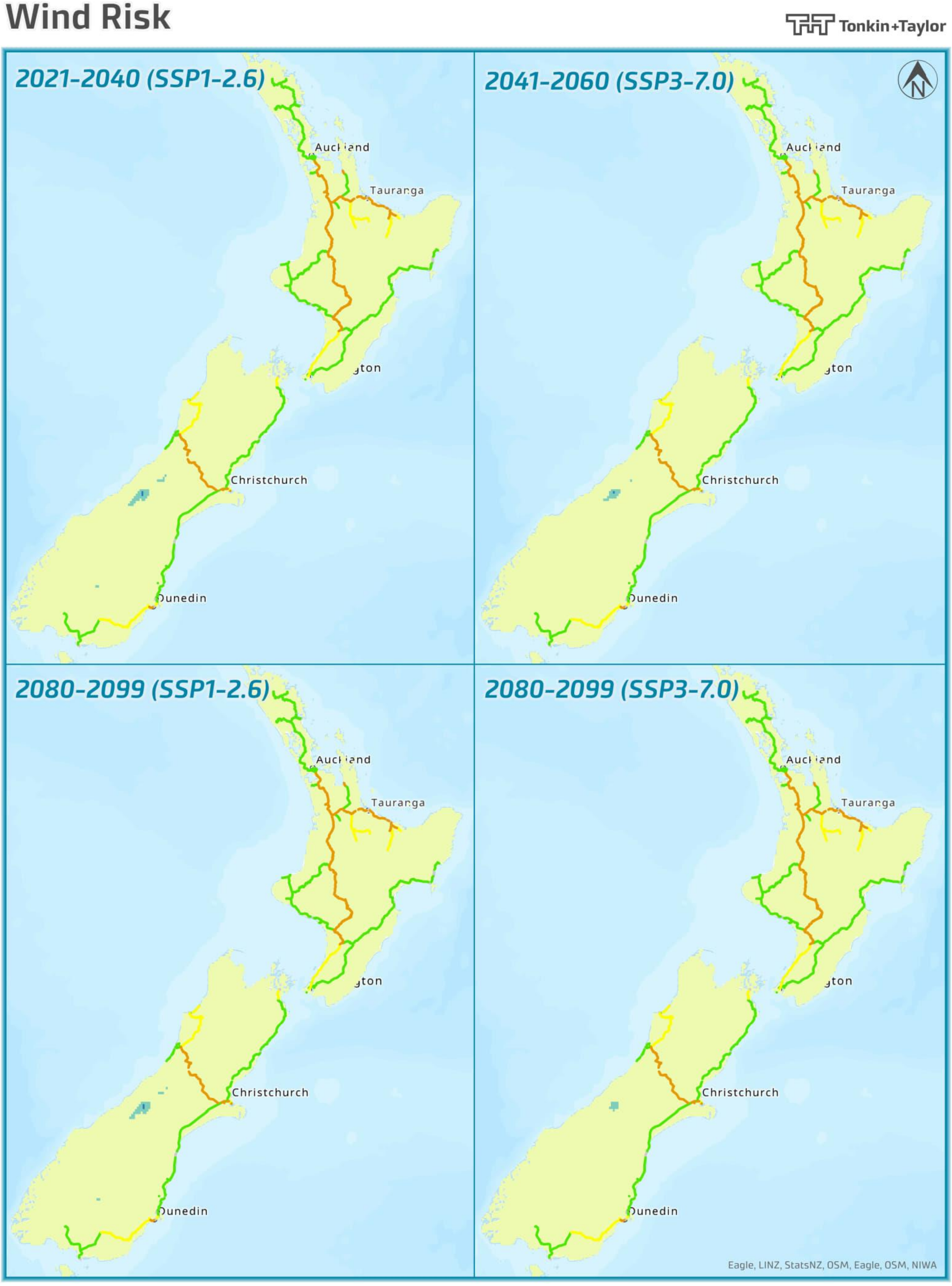
1. Low
2. Medium
3. High
4. Extreme

Does not overlap hazard layer

Average strong wind (99th percentile): <100km/h; 100-120km/h; 120-140km/h

0 200 400 km

Wind Risk



Legend - Landholdings

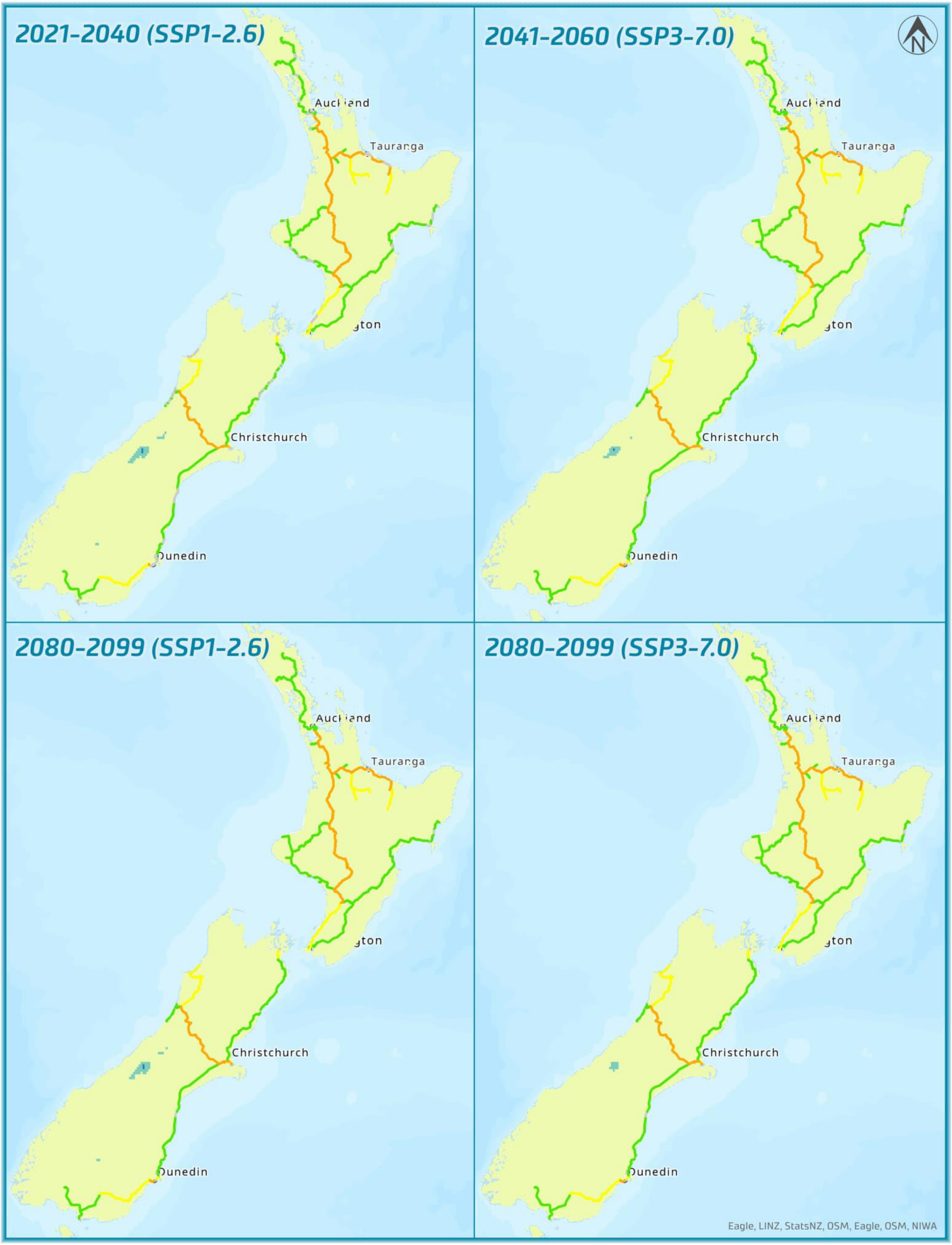
1. Low
2. Medium
3. High
4. Extreme

Does not overlap hazard layer

Average strong wind (99th percentile) <100km/h | 100-120km/h | 120-140km/h

Wind Risk

Tonkin+Taylor



Legend - Track

1. Low
2. Medium
3. High
4. Extreme
Does not overlap hazard layer

Average strong wind (99th percentile): <100km/h, 100-120km/h, 120-140km/h

0 200 400 km