NIWA
Taihoro Nukurangi

Climate change implications for the Manawatū-Whanganui Region

Prepared for Horizons Regional Council

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Prepared by:
Paula Holland
Petra Pearce
Jordan Luttrell
Ryan Paulik

For any information regarding this report please contact:

Petra Pearce
Climate Scientist
Climate and Environmental Applications
+64-9-375 2052
petra.pearce@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

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	Reviewed by:	Dr Sam Dean Principal Scientist - Climate
	Formatting checked by:	Petra Pearce
	Approved for release by:	Dr Andrew Tait Chief Scientist – Climate, Atmosphere and Hazards

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Executive summary

Climate change is already affecting the Manawatū-Whanganui Region, and current impacts are likely to continue and intensify into the future. The region will be affected by increasing temperatures, changes to rainfall patterns, river flows, increased drought, and ongoing sea-level rise.

This report considers how climate change may impact different sectors in the Manawatū-Whanganui Region. It brings together regionally specific climate change projection data (including sea-level rise and flood hazard information) and assesses this against sectoral information from the region. Asset data from the RiskScape database is used to assess exposure of buildings, infrastructure, land, and population to coastal inundation and flood hazards.

Climate change impacts for four of the most important sectors in the region were analysed: agriculture, forestry and fishing; public administration and safety; retail trade; and healthcare and social assistance. Additionally, the impact of climate change on four cross-cutting areas was considered: infrastructure, housing, water, and environment and tourism. There are data gaps for some of the largest sectors (e.g. manufacturing, education and training) so analysis of climate change impacts on these sectors could not be carried out.

Overall, climate change is likely to lead to increased costs in most sectors. For example, increased prevalence of droughts, increased temperatures and changes to rainfall patterns is likely to increase costs for water management, feed preparation and pest control in the agriculture sector. Sea-level rise will differentially impact parts of the region, with assets in Horowhenua District being the most exposed. Considerably larger parts of the region are exposed to flood hazards, particularly in the Manawatū, Rangitikei and Tararua Districts. Significant amounts of infrastructure, buildings and population are exposed to both flooding and sea-level rise.

This assessment has not explicitly considered climate change mitigation and adaptation options for the Manawatū-Whanganui Region. However, it provides examples of possible implications for Council as a means to stimulate discussion among Horizons Regional Council and stakeholders about potential impacts and implications so that informed decisions can ultimately be made around climate change strategy.

1 Introduction

Horizons Regional Council commissioned NIWA to provide a report to understand how climate change could impact the Manawatū-Whanganui Region and Horizons Regional Council's business. This will inform a regional climate change strategy and prioritisation of work programmes by the Council and the community into the future.

This report collates what is currently known about the region in terms of climate change projections and physical impacts (following a climate change projections report produced for the Council by NIWA in 2016 (Pearce et al., 2016)), and further assesses the impacts of climate change on the Council's business and responsibilities, including sectoral impacts. The new knowledge created by this report will support decision-making and local adaptation discussion, as well as revealing some information gaps.

This report provides a synthesis of information for the Council to consider how climate change could affect different sectors and locations within the region as well as Council business and responsibilities. Numerical information derived from model projections is provided where available, and qualitative information and expert opinion summarises potential issues.

This report has several parts:

- A summary of key trends, issues and obligations related to climate change globally and nationally that may impact the Council in the future.
- Background information on the key stakeholders (resource users, sectors) and assets in the region to illustrate key resources potentially at risk from climate change impacts.
- A summary of climate change projections for the Manawatū-Whanganui Region (based on the climate change projections report written for Horizons Regional Council in 2016 and updated with more recent guidance on extreme rainfall, sea-level rise and river flows).
- Assessment of climate change impacts on sectors and asset classes in the Manawatū-Whanganui Region, in light of knowledge of current regional characteristics.

In combination, these strands provide insights into the impacts of a changing climate on Council business and responsibilities.

2 Obligations for climate change mitigation and adaptation

2.1 New Zealand obligations to global agreements

New Zealand has committed to action on climate change as a part of its role on the international stage and in addressing adaptation as a country experiencing ongoing impacts. This section outlines existing commitments related to climate change that Horizons Regional Council – as part of New Zealand – will be subject to. The global commitments of New Zealand are noted because – while signed by Central Government – they have wide ranging implications for local government.

2.1.1 Global commitments

New Zealand is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), the global framework for addressing the impacts of climate change. Within the Convention, New Zealand has signed up to numerous agreements including:

- The Kyoto Protocol – a legally binding agreement to reduce greenhouse gas emissions and a framework for international emissions trading. The Kyoto Protocol devises units to measure emissions, which can be traded internationally. New Zealand ratified the Kyoto Protocol in December 2002. In 2015 New Zealand reported enough emission units to account for gross emissions for the first commitment period (Ministry for the Environment, 2015).

- The Paris Agreement – a legal framework for signatories to commit to taking ambitious action to address climate change (New Zealand Parliament, 2016). The Paris Agreement was ratified by New Zealand on 4 October 2016. Contributions are nationally determined (NDC). Signatories agree to pursue lower greenhouse gas (GHG) emissions without threatening food production, foster climate resilience and apply financing to these efforts, including for the support of developing countries' efforts towards climate change mitigation and adaptation (Paris Agreement, Article 2. 1.a) b) c). The Paris Agreement also calls for parties to communicate transparently about their efforts, including regular detailed reporting of contributions and adaptation planning, and sharing of knowledge (ibid, Article 3 13, Article 7; National Interest Analysis).

As a signatory of the Convention, New Zealand agrees to national contribution targets including:

- a 2020 target, under the UNFCCC, to reach 5 percent below the 1990 greenhouse gas emission levels;

- a 2030 target, a commitment to the Paris Agreement, to reduce emissions to 30 per cent below 2005 levels by 2030. This target is equivalent to 11 percent below 1990 levels; and

- a 2050, long-term target, to reduce emissions to 50 percent below 1990 levels (Ministry for the Environment, 2017d).

It is important to recognise that these targets are for **net** emissions, which is the difference between the total amount of greenhouse gases emitted into the atmosphere (gross emissions) and the amount taken up through approved carbon sinks, such as forestry. At the time of writing this report, New Zealand's net position was on track to meeting the 2020 emissions reduction target, owing to a surplus of units from the first commitment period of the Kyoto Protocol (Ministry for the

Environment, 2019a). As of 2017, New Zealand's gross emissions to the atmosphere have increased by 23.1 per cent since 1990.

Maintaining support for GHG research remains a priority for taking serious action to decrease emissions, particularly given the dominance of biological methane in agriculture (New Zealand Parliament, 2015).

Additionally, the New Zealand Emissions Trading Scheme (NZ ETS) is a key tool in the effort to meeting global obligations for acting to decrease emissions. The NZ ETS, operating since 2008, defines an emission unit and places a financial value upon it. ETS units can be regulated through government allocation, trading in the emissions market, and businesses and households, through incentivised changes in behaviour (Leining and Kerr, 2018a). The ETS has been reviewed three times, in 2008, 2011 and 2015, and changes were proposed in 2017, but not legislated before the change in government (Leining and Kerr, 2018b). In 2015 NZ stopped accepting Kyoto units, operating under the NZ ETS (Ministry for the Environment, 2017d).

In early 2019, the Zero Carbon Amendment Bill (the Bill) was introduced to the House of representatives. The New Zealand Government decided to introduce the Bill as an amendment to the Climate Change Response Act 2002. It will set a new greenhouse gas emissions reduction target that will bring New Zealand's targets more in line with the over-arching objective set under the Paris Agreement of keeping the global average temperature well below 2° C above pre-industrial levels, while pursuing efforts to limit the temperature increase to 1.5° C. The proposed targets are:

- To reduce all greenhouse gases (excluding biogenic methane) to net zero by 2050
- To reduce biogenic methane emissions within the range of 24-47 percent below 2017 levels by 2050, including 10 percent below 2017 levels by 2030

Additionally, the Bill requires the setting of emissions budgets which work towards the longer-term target. The Government will be required to develop and implement policies for climate change adaptation and mitigation. Specifically, the Minister for Climate Change will regularly prepare and publish a plan setting out the policies and strategies for meeting an emissions budget, and this must include:

- sector-specific policies to reduce emissions and increase removals; and
- a multi-sector strategy to meet emissions budgets and improve the ability of those sectors to adapt to the effects of climate change; and
- a strategy to mitigate the impacts that reducing emissions and increasing removals will have on workers, regions, iwi and Māori, and wider communities, including the funding for any mitigation action.

The government will also be required to undertake national-scale climate change risk assessments every five years. The Minister must also prepare a national adaptation plan that sets out the Government's strategies, policies, and proposals for meeting adaptation objectives. It is the contents of these two plans that are likely to have the greatest implications for the ongoing operations of local government.

The Bill also establishes a new Climate Change Commission to advise and monitor successive governments in these goals. The NDC for 2030 under the Paris Agreement does not change, and the ETS will continue to be used as a tool to meet these goals. New Zealand will need to determine and record its second NDC under the Paris Agreement in 2025. As of June 2019, the Government is seeking public submissions to the Bill, and it may pass into law in late 2019 (Ministry for the Environment, 2019b).

2.2 National activities

Together with its global commitments to address climate change, New Zealand is developing policies and practices to withstand the effects of climate change locally. As an example, at a broad level, New Zealand's Resource Management Act (1991) requires regional policy statements give effect to the New Zealand Coastal Policy Statement (NZCPS) (Department of Conservation, 2010), specifically Objective 5, "To ensure that coastal hazard risks taking account of climate change are managed by:

- Locating new development away from areas prone to such risks;
- Considering responses, including managed retreat, for existing development in this situation; and,
- Protecting or restoring natural defences to coastal hazards"

Other requirements on regional or local councils embrace adaptation through sectoral work. For example, the National Policy Statement for Freshwater Management (Ministry for the Environment, 2014, Updated 2017) requires regional councils to recognise *Te Mana o te Wai*, the connection between water and the broader environment, water quality and quantity, in planning. In so doing, it becomes the responsibility of regional councils to – among other things – identify, manage and plan for "the reasonably foreseeable impacts of climate change" (2014) while improving, maximising and encouraging efficient water use and integrating water management.

National and local level guidance for coastal adaptation have also been developed. For example, the Ministry for the Environment released guidance for local governments in 2017 on adaptation to and accommodating climate change in coastal regions (Ministry for the Environment, 2017b). The guidance includes information on potential impact to climate change, planning horizons and approaches to adaptation. A summary of sea-level rise projections from this guidance document is provided in Section 9.1.3.

At the local level, the Manawatū-Whanganui Emergency Management Group (2016) established a regional Civil Defence Emergency Management Group Plan, detailing the region's risk profile for hazards, identifying the process of risk reduction on local levels and how these relate to Central Government. The overarching aim is to create resilient regional communities. Other local governance guides include Local Government New Zealand's infrastructure guide (Simonson and Hall, 2019) which guides local governments on preparation and action for coastal exposure and the impacts of climate change on infrastructure over time.

In summary, the Council has numerous obligations and commitments to be cognisant of as the region's climate change strategy evolves. Particular attention will be required to navigate the interrelated and simultaneous challenges of international and national greenhouse gas mitigation obligations and local-scale adaptation.

3 Horizons Regional Council overview

Climate change may impact a variety of services or resources. Some of these are responsibility of local government (through regional or city councils[1]); others are the responsibility of the private sector. The difference in responsibility is important because it affects in what way councils may respond to climate change risks. For instance:

- where services or resources may be harmed by climate change that are their responsibility, councils will need to be prepared to act to minimise or address harm caused by climate change. By comparison,
- where services or resources may be harmed by climate change that fall outside their responsibility, the ability of councils to function well may be indirectly harmed. This may happen if local constituents lose income and pay less tax, eroding the council revenue base. In these cases, councils will need to consider opportunities to enhance local (or even national) policy so that their communities can adapt positively to climate change and enable councils to continue to serve communities effectively.

In light of these issues, this section considers:

- The services and resources, where climate change may be relevant, under the responsibility of the Horizons Regional Council, the local government authority responsible for the oversight and servicing of the Manawatū-Whanganui Region of the North Island.
- The key natural and economic features of the Manawatū-Whanganui Region.

3.1 Responsibilities of Horizons Regional Council

Known for trading purposes as Horizons Regional Council, Horizons Regional Council covers the 22,200km^2 area from Ruapehu District in the north to Horowhenua District in the south, to Whanganui District in the west and Tararua District in the east (Horizons Regional Council, 2019). Horizons is the second-largest local government region in the North Island and the sixth-largest in New Zealand (Wikipedia, 2019) (Figure 3-1).

The roles of local government across New Zealand are articulated in the Local Government Act (2002), complemented by a range of other Acts, from the Resource Management Act (RMA 1991) to the Civil Defence Emergency Management Act. Generally speaking, local government is responsible to meet the needs of communities for good-quality local infrastructure, local public services and performance of regulatory functions in a way that is most cost-effective for households and businesses (Local Government Act 2002, section 10 (1)). In so doing, local governments are expected to embed four key aspects of well-being to their work – social, economic, environmental, and cultural. In so doing, regional councils' responsibilities include:

- Sustainable regional well-being.
- Managing the effects of using freshwater, land, air and coastal waters, by developing regional policy statements and the issuing of consents.

1 The powers and responsibilities of city and district councils are the same. Both are territorial authorities. The only difference is that city councils serve a population of more than 50,000 in a predominantly urban area (see Local Government in New Zealand 2011).

- Managing rivers, mitigating soil erosion and flood control.
- Regional emergency management and civil defence preparedness.
- Regional land transport planning and contracting passenger services.
- Harbour navigation and safety, oil spills and other marine pollution (Local Government in New Zealand, 2011).

Figure 3-1: Manawatū-Whanganui Region, administered by Horizons Regional Council. Source: Wikipedia (2019).

Horizons Regional Council observes its responsibilities as including the management of its region's natural resources, leading regional land transport planning, contracting passenger transport services and coordinating the region's response to natural disasters. Some of the Council's activities span several city and district council boundary lines (Figure 3-2) and its jurisdiction extends 12 nautical miles out to sea. As a result, the Council works closely with these councils and other agencies on some issues to ensure they are managed to benefit the entire region (Horizons Regional Council, 2019).

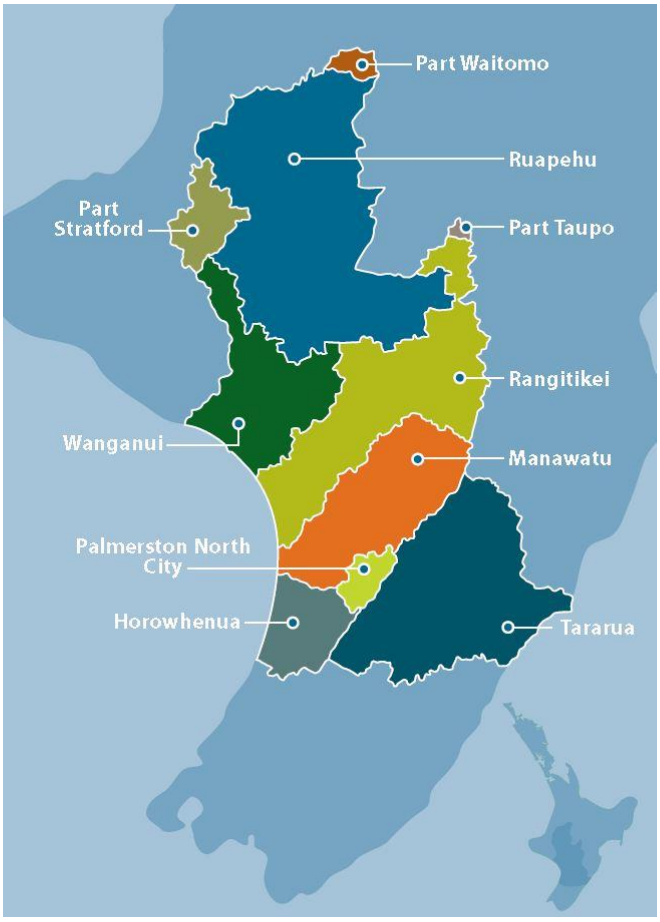


Figure 3-2: Territorial authorities making up the Horizons Region. Source: http://www.horizons.govt.nz/about-our-region-and-council/our-role-and-goals

3.2 Summary of regional characteristics

Regional land use is dominated by the agriculture sector, which also provides a considerable income for the region (fifth-largest GDP earner). Other primary industries such as horticulture (particularly vegetable growing) and exotic forestry are important land uses in the region. About one-fifth of the region is under indigenous forest cover. The highest concentration of population is Palmerston North, but over half of the region's people live outside urban centres in small towns or rural areas. Compared with the national picture, the people of Manawatū-Whanganui have lower incomes and fewer tertiary qualifications. Unemployment is slightly higher than the national average. The largest sectors by employment are healthcare and social assistance, education and training, and retail. Manufacturing is the largest sector by GDP, with much of the sector dominated by agriculture-related businesses. Most sectors are showing increasing trends of GDP, however agriculture has been declining in recent years. Several areas have been indicated as potential growth markets in the region, including tourism, land use optimisation, and care of older people. Climate change may have significant impacts on the region's sectors and population. The following sections explore the interaction between climate change projections and impacts and implications for specific sectors and areas of the Manawatū-Whanganui Region. Detailed information on regional characteristics (including statistics of demographics, land use, economic profile, and environmental assets) is presented in Section 9 (Appendix).

4 Climate change trends in the Manawatū-Whanganui Region

In 2016, Horizons Regional Council contracted NIWA to produce climate change projections for the region (Pearce et al., 2016). This report contained projections (maps and tables) for several climate variables, as well as discussion about potential climate change impacts on physical processes such as hill country erosion, sea-level, river flows, and ocean acidification. Table 4-1 summarises the potential changes for the region from the 2016 report. For more detail, see Pearce et al. (2016) (available at https://www.horizons.govt.nz/CMSPages/GetFile.aspx?guid=5414ca9a-1b04-481c-bb21-3a185c9c4b8a). Due to updates to projections of extreme rainfall, sea-level rise and river flows following the 2016 report, expanded information about those variables is considered in Section 10 (Appendix).

Table 4-1: Climate change projections and impacts for the Manawatū-Whanganui region. Based on (Pearce et al., 2016, Ministry for the Environment, 2017c, Ministry for the Environment, 2018a, Ministry for the Environment, 2018b)

Climate variable/ physical process	Direction of change	Magnitude of change	Spatial and seasonal variation
Average temperature	Progressive increase with greenhouse gas concentration. Temperature increase flattens off for RCP2.6 but keeps increasing for other scenarios.	By 2040, annual increases from +0.7°C [RCP2.6] to +1.1°C [RCP8.5] By 2090, annual increases from +0.7°C [RCP2.6] to +3.1°C [RCP8.5]	Greatest warming in summer/autumn and least in winter/spring.
Growing degree-days	Increase	Specific analysis of GDD has not been carried out for the Manawatū-Whanganui Region at this stage.	Largest increase in areas and seasons with greatest warming (above).
Water temperature	Increase	Unknown, further work needed to understand magnitude of change.	Amount of warming depends on river elevation, catchment size, water source (e.g. snow melt or not).
Hot days	Increase in hot days (days with maximum temperature >25°C)	Currently 19 (average across region below 500m). By 2040, from +10 [RCP4.5] to +12 [RCP8.5]. By 2090, from +18 [RCP4.5] to +47 [RCP8.5].	Larger increases in the western Manawatū-Whanganui Region (increase of 50-60 hot days per year between Taumarunui and Whanganui under RCP8.5 by 2090).
Frosts	Decrease in frosts/cold nights (nights with minimum temperature <0°C)	Currently 18 (average across region below 500m). By 2040, from -7 [RCP4.5] to -11 [RCP8.5]. By 2090, from -11 [RCP4.5] to -16 [RCP8.5].	Larger decreases at higher elevations of the Central Plateau (reduction of >50 frosts per year for Tongariro National Park under RCP8.5 by 2090).
Rainfall	Mixed direction of change for most seasons, RCPs and time periods but consistent increases for winter.	Whanganui: By 2040, from -1% (autumn) to +5% (winter) [RCP8.5]. By 2090, from -5% (autumn) to +10% (winter) [RCP8.5]. Palmerston North: By 2040, from 0% (summer) to +6% (winter) [RCP8.5]. By 2090, from -3% (autumn) to +13% (winter) [RCP8.5].	Larger increases for the western half of the region in winter. Decreases in rainfall for the eastern part of the region (east of the Ruahine Ranges).

Climate variable/ physical process	Direction of change	Magnitude of change	Spatial and seasonal variation
Extreme rainfall intensity[2]	Increasing. Larger increases for shorter duration, rare events compared to longer duration, common events.	Shorter duration rare events undergo the largest increases in intensity (up to ~14% increase per degree of warming for a 1 hour, 1-in-100-year event). Longer duration more common events undergo the smallest increases in intensity (~5% increase per degree of warming for a 120 hour, 1-in-2-year event).	Large regional variability in changes to intensity across NZ. However, there is not enough confidence to provide regional projections so national augmentation factors are provided.
Potential evapo-transpiration deficit (a drought indicator)	Increasing everywhere, larger increases with time and RCP scenario. Generally, the region becomes more drought prone, particularly the eastern half.	Changes for 2090 under RCP8.5: Northern (Taumarunui to Feilding): up to +80 mm/yr Central (Waiouru to Fielding): around +160 mm/yr Western (Whanganui to Levin): +80-100 mm/yr Eastern (east of the ranges): +120-140 mm/yr	Largest increases east of Taihape under RCP8.5 by 2090. The area between Taumarunui and Ohakune undergoes the smallest increases (i.e. drought potential there does not change much).
Hill country erosion	Increase with larger extreme rainfall events, more rainfall in winter.		Increased land sliding: western Manawatū-Whanganui Region Increased gully erosion: Whanganui area Increased earthflow erosion: eastern Manawatū-Whanganui Region Increased sheet erosion: Volcanic Plateau, Ohakune cropping areas
Sediment loads	Increased extreme rainfall expected to increase fluvial sediment loads		
Solar radiation	Small increases in summer, decreases in winter.		

[2] The extreme rainfall projections presented in Pearce et al. (2016) have since been updated by NIWA. This report includes only the updated information presented in MINISTRY FOR THE ENVIRONMENT 2018a. Climate change projections for New Zealand: atmospheric projections based on simulations undertaken for the IPCC 5th Assessment, 2nd edition.

Climate variable/ physical process	Direction of change	Magnitude of change	Spatial and seasonal variation
Sea-level rise[3]	Increasing	0.5 m of SLR projected for NZ between 2060 (RCP8.5 83rd percentile scenario) and 2110 (RCP2.6 scenario). 1.0 m of SLR projected between 2100 and after 2200 for the same scenarios.	Subsidence is occurring in the south and west of the North Island (incl. Manawatū-Whanganui Region coastline) so relative SLR may be higher than projected national amount.
Coastal hazards[3]	Increasing	More frequent and severe coastal inundation events with increasing sea levels and more intense storms.	Most assets at risk from a 1-in-100-year storm tide event + sea level rise in Horowhenua and Whanganui Districts.
Manawatū river flows[4]	Decreases to mean annual low flow.	Mean annual discharge: minimal change (less than 5%) Mean annual flood: increases for all RCPs and time periods. +21% [RCP8.5, 2040], +18% [RCP8.5, 2090]. Mean annual low flow: decreases for most RCPs and time periods, e.g. -19% [RCP8.5, 2090].	Larger increases to mean annual flood by 2040 than 2090 (natural variability signal).

[3] The sea-level rise information presented in Pearce et al. (2016) has since been updated and is covered in Appendix 4. This report includes only the updated information presented in MINISTRY FOR THE ENVIRONMENT 2017c. Coastal hazards and climate change: Guidance for local government. Lead authors: Bell, R.; Lawrence, J.; Allan, S.; Blackett, P.; Stephens, S. Ministry for the Environment Publication ME-1292. Accessed at: http://www.mfe.govt.nz/publications/climate-change/preparing-coastal-change-summary-of-coastal-hazards-and-climate-change.

[4] The river flow information presented in Pearce et al. (2016) has since been updated by NIWA. This report includes only the updated information presented in MINISTRY FOR THE ENVIRONMENT 2018b. Hydrological projections for New Zealand rivers under climate change, NIWA client report 2018193CH prepared for the Ministry for the Environment, 107pp.

5 Methodology

This report considers implications of climate change for the Manawatū-Whanganui Region based on:

1. Assessments of climate change trends affecting the Manawatū-Whanganui Region (Section 4)
2. Modelling of potential impacts of sea-level rise and extreme flooding on the Manawatū-Whanganui Region and key assets
3. Linking of climate change findings from 1 and 2 to the region, with particular reference to key sectors and its socioeconomic profile. Linking and inference is informed by key documents describing the expected impacts of climate change generally (globally) as well as specifically for New Zealand and Manawatū-Whanganui Region.

Note that it was outside the scope of this project to differentiate the impact of climate change on iwi, hapu, whanau and Māori business from the more general social and economic impacts in the region.

5.1 RiskScape exposure modelling – coastal and flood hazards

Research for the Deep South National Science Challenge covered national, regional and district-level risk exposure to inundation in low-lying coastal areas (Paulik et al., 2019b) and areas exposed to fluvial and pluvial (rainfall) flooding (Paulik et al., 2019a). The RiskScape asset database was used to measure exposure. RiskScape[5] is a tool used to predict exposure to natural hazards. Exposure to coastal inundation was expressed as built assets (e.g. buildings, roads, railways, three-waters infrastructure etc.), land cover, and usually resident population present in the zone inundated by 100-year return period storm-tide event (1% AEP) at the present day and with different levels of sea-level rise (0.5m, 1m, 1.5m and 2m of SLR are considered here). The same asset database was intersected with a flood hazard area map (FLHA) that was created using publicly-available flood hazard maps from local government organisations and flood-prone soil maps from Landcare Research. This exercise included all areas inundated by past floods and areas considered to be at risk from flooding. Some flood prone areas may not be correctly identified and there was no specific return period assigned to this area. This exercise did not consider potential changes to flood events with climate change, due to the unavailability of extreme flood projections at present. However, it provides a useful baseline for understanding all areas currently exposed to flood hazards in the Manawatū-Whanganui Region. Refer to Paulik et al. (2019a) and Paulik et al. (2019b) for details about the methodology.

Elements exposed to coastal and flood hazards include both tangible and intangible assets. Included in these studies were:

- Population (#)
- Buildings
  - Total number (#)
  - Replacement value (NZD 2016)

[5] https://www.niwa.co.nz/natural-hazards/research-projects/riskscape

- Transport Infrastructure
  - Roads (km)
  - Railways (km)
  - Airports (total number)
- Electricity Infrastructure
  - Transmission Lines (km)
- Three-waters Infrastructure (stormwater, wastewater, potable water)
  - Nodes (#)
  - Pipelines (km)
- Land Cover
  - Built Land (km^2)
  - Production Land (km^2)
  - Natural/Undeveloped Land (km^2)

Results from this analysis giving the exposure of these asset classes is considered in detail for the Manawatū-Whanganui Region in Section 6.

5.2 Key sectors around which to consider climate change impacts for Horizons Regional Council

For key sectors, we have identified the top five to six sectors according to GDP and employment in the region (Table 5-1 and Table 5-2).

Table 5-1: Top employment sectors in the Manawatū-Whanganui Region.

Sector	Manawatū-Whanganui Region	% regional employment	% national sectoral employment
Agriculture, Forestry and Fishing	9100	8.8	7.5
Public Administration and Safety	9300	9	7.5
Retail Trade	10300	10	4.8
Education and Training	11100	10.8	5.9
Manufacturing	11500	11.1	4.9
Health Care and Social Assistance	13100	12.7	5.5
Total employment			62.4

Table 5-2: Top GDP-earning sectors in the Manawatū-Whanganui Region (2016).

Sector	Millions NZD	% of regional GDP
Agriculture	674	7
Health care and social assistance	723	7.5
Public administration, defence, and safety	758	7.8
Primary manufacturing	792	8.2
GST on production, import duties, and other taxes	819	8.5
Total regional GDP		39

A lack of detailed information on the Education and Training and Manufacturing sectors means that it is not possible within the resources of the project to assess the potential impacts of climate change in these sectors. Outside of these, we have selected the following key sectors from this analysis to consider the implications of climate change for Horizons Regional Council:

- Agriculture, Forestry and Fishing
- Public Administration and Safety
- Retail Trade
- Health Care and Social Assistance.

6 Climate change impacts for the Manawatū-Whanganui Region

A review was conducted of expected climate change impacts on New Zealand generally (MBIE, Undated, Ministry for the Environment, 2017a, Clothier et al., 2012, Reisinger et al., 2014) and considered in terms of:

- Expected climate changes noted in Section 4
- The socioeconomic profile of the region (Section 3, Section 9 (Appendix)); and
- RiskScape exposure modelling for coastal inundation and flood hazards

Based on these, climate change impacts to be anticipated in the Manawatū-Whanganui Region are considered in terms of the following selected key sectors of economic activity in the Manawatū-Whanganui area:

- Agriculture, Forestry and Fishing
- Public Administration and Safety
- Retail Trade
- Health Care and Social Assistance

Additionally, the impact of climate change on cross cutting areas has been considered:

- Infrastructure
- Housing
- Water
- Environment and tourism.

Based on the risk exposure modelling for coastal inundation and flooding undertaken for Parliamentary Commissioner for the Environment (2015) and Paulik et al. (in preparation), NIWA estimates the exposure of assets in the Manawatū-Whanganui Region from:

- a 1-in-100-year storm tide event at present day sea level and future levels of SLR; and
- the total flood hazard area (FLHA) identified from flood hazard and flood prone soil maps (see Section 5.1 for more detail).

A detailed breakdown of district-level exposure by asset type is presented in Section 11.

A summary of climate change-related impacts for the different sectors and cross-cutting areas is presented in Table 6-1 at the end of this chapter.

6.1 Areas exposed to coastal inundation and river flooding

Maps of areas exposed to sea-level rise and storm tide events in the Manawatū-Whanganui Region are presented in Figure 6-1 to Figure 6-3 and a map of the flood hazard area in the Manawatū-Whanganui Region is presented in Figure 6-4. The largest areas exposed to coastal inundation are around Foxton/Shannon, Tangimoana, and Whanganui. The Rangitikei and Manawatū catchments have the largest areas exposed to flood hazards.

Relative to other parts of New Zealand, Manawatū-Whanganui has lower exposure to coastal inundation than most other regions. For 0.9 m of sea-level rise (as an example) with a 100-year return period storm tide event, the region is ranked 12th in terms of population exposed (out of 14 regions), 9th in terms of numbers of buildings exposed, and 7th for production land exposed (Paulik et al., 2019b). However, for flood hazards, Manawatū-Whanganui is relatively more exposed compared with most other regions. The region is 6th in terms of population exposed and 5th for numbers of buildings exposed. It ranks 4th for production land area exposed to flooding (Paulik et al., 2019a). A full breakdown of region-by-region exposure to the different asset classes is provided in Section 11.

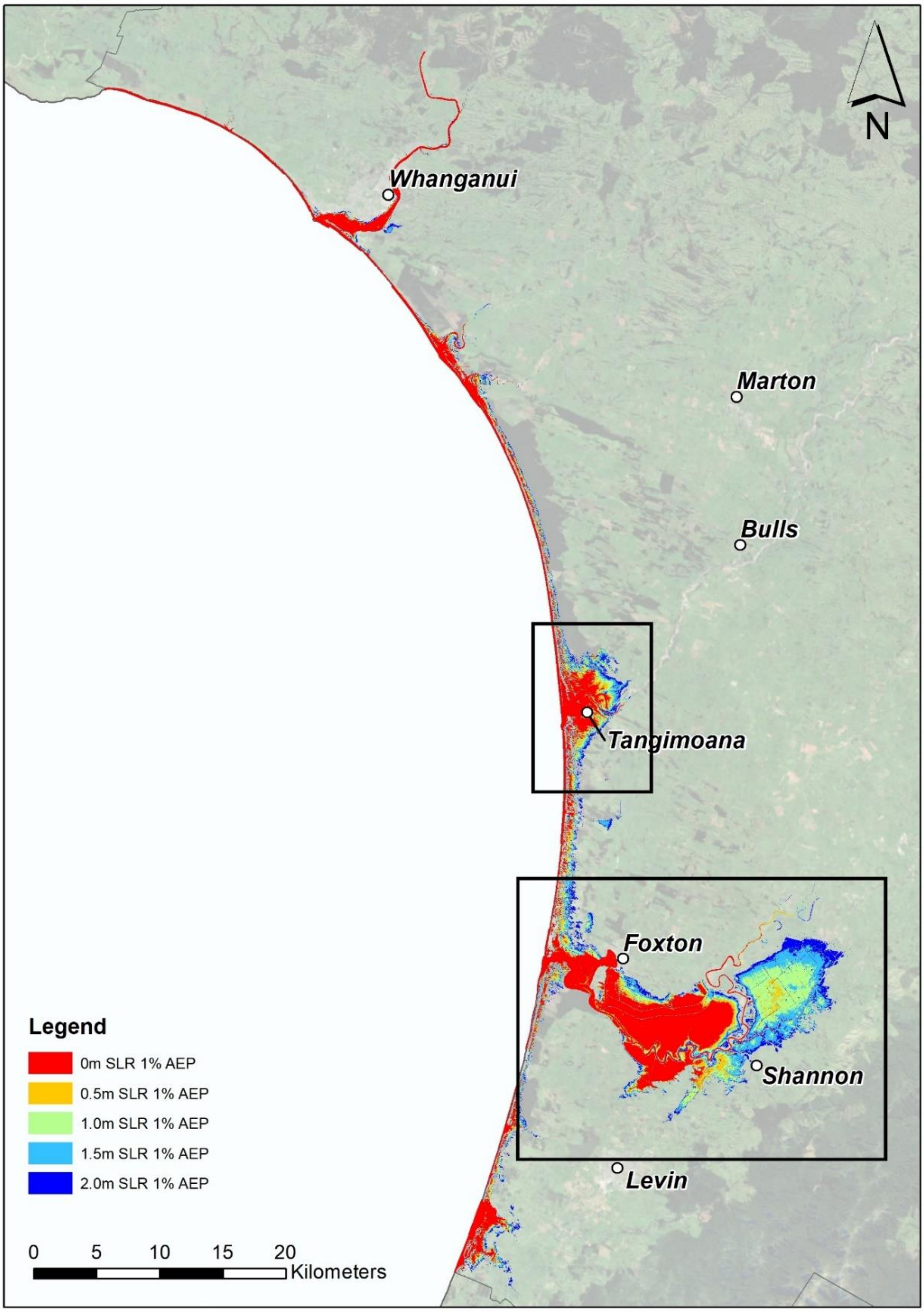


Figure 6-1: 1% AEP storm tide + sea-level rise elevations exposure in the western Manawatū-Whanganui Region. The top boxed area is Tangimoana, see Figure 6-3 for detail. Bottom boxed area is Foxton, see Figure 6-2 for detail. Source: Paulik et al. (2019b). The eastern half of the region is not shown as there is minimal exposure on that coastline.

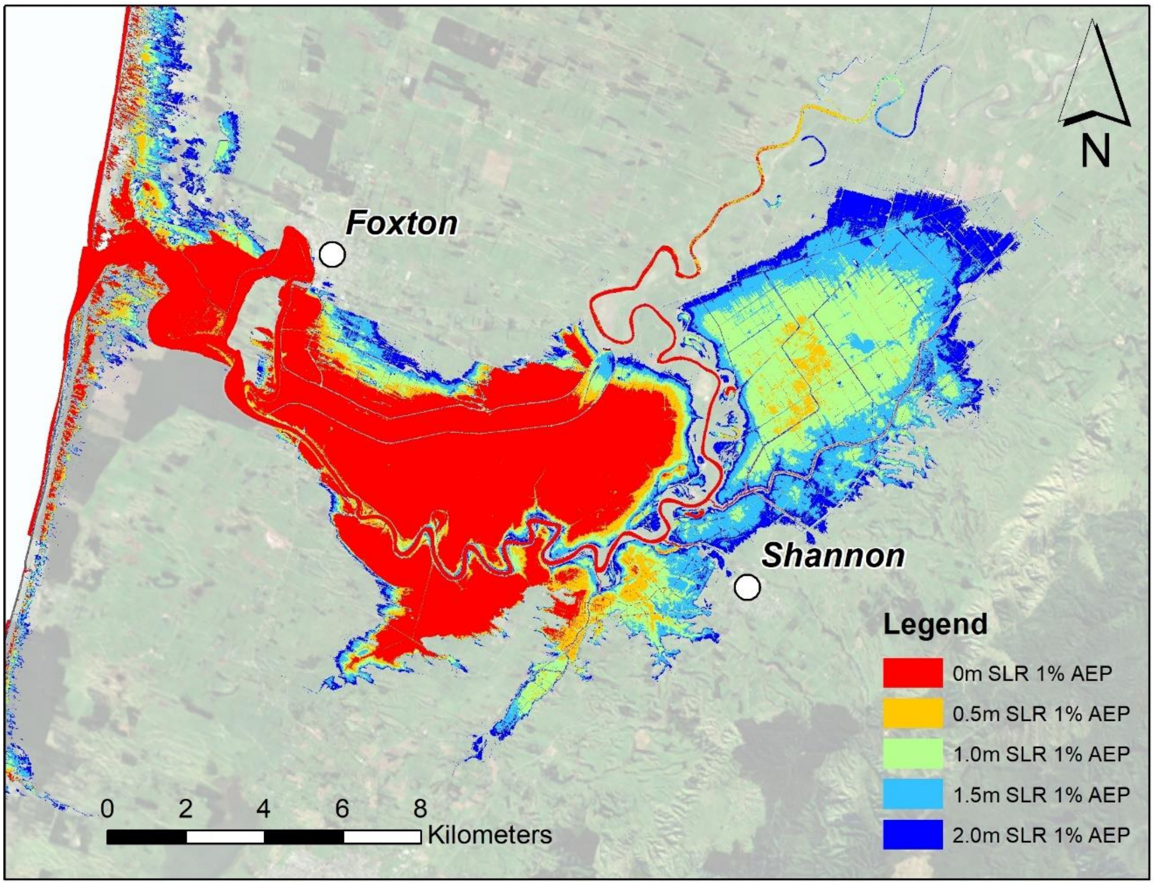


Figure 6-2: 1% AEP storm tide + sea-level rise elevations exposure in the Foxton area. Source: Paulik et al. (2019b).

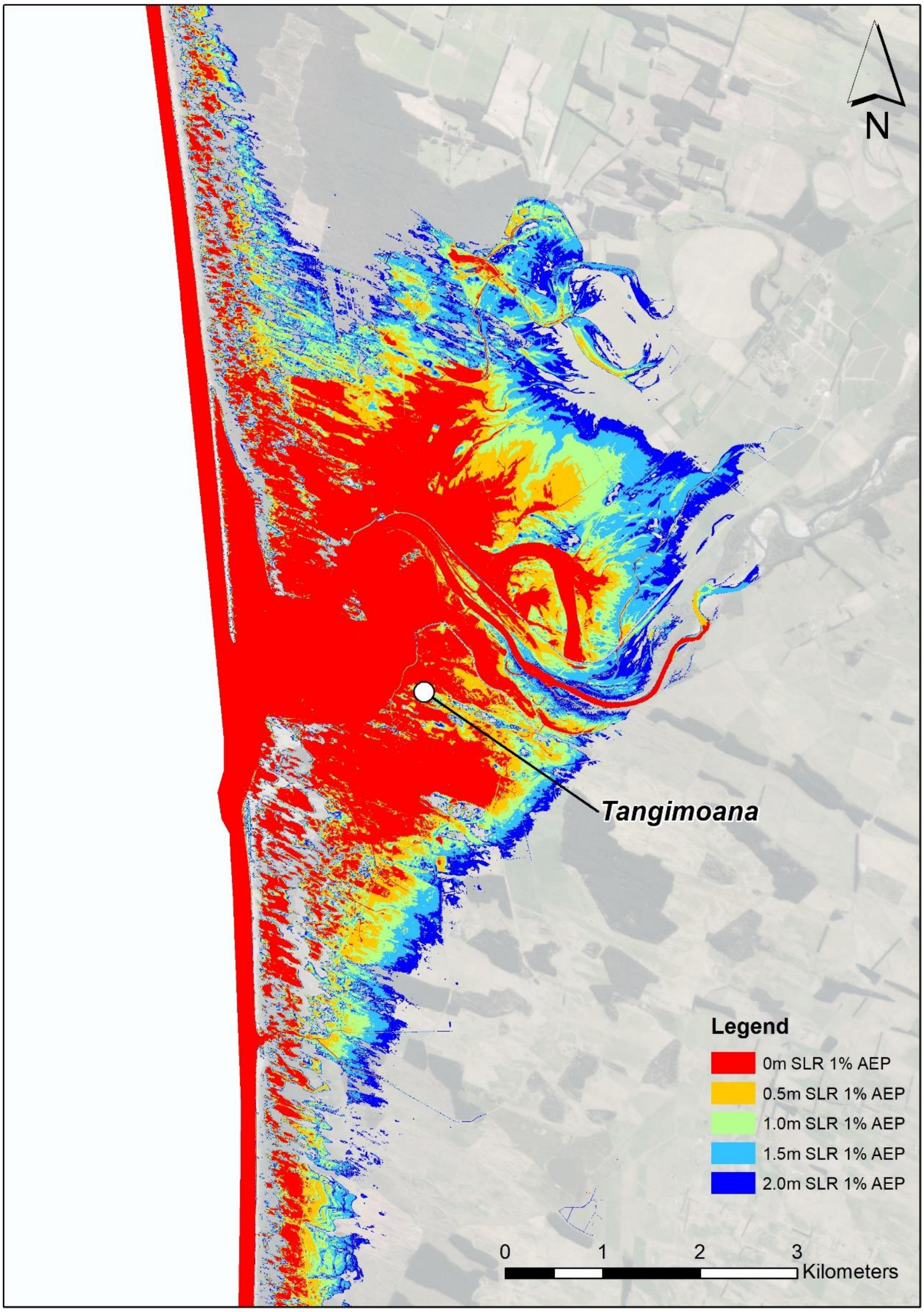


Figure 6-3: 1% AEP storm tide + sea-level rise elevations exposure in the Tangimoana area. Source: Paulik et al. (2019b).

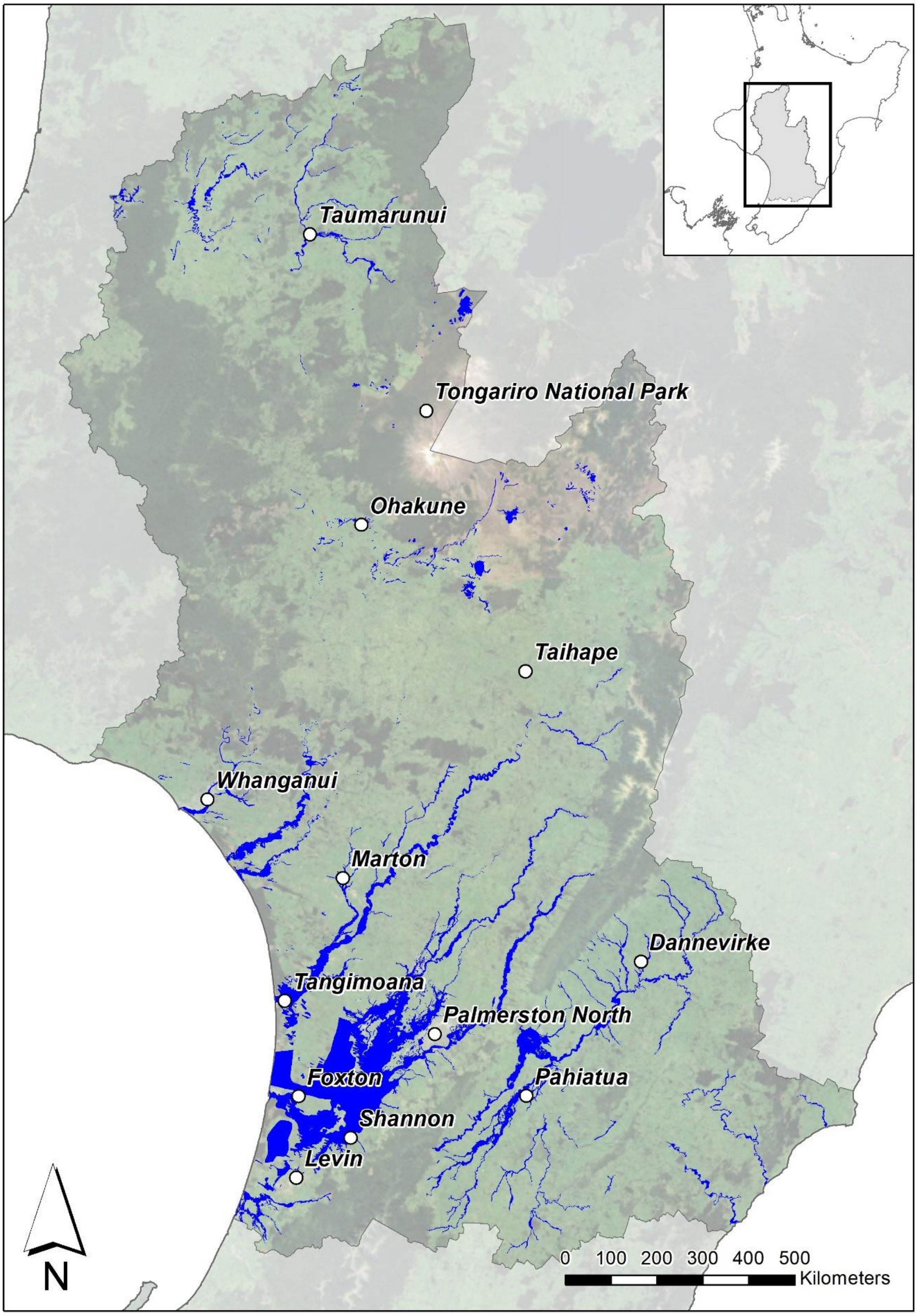


Figure 6-4: Flood Hazard Area for the Manawatū-Whanganui Region (top: northern part of the region; bottom: southern part of the region). Blue shading indicated areas currently identified as exposed to flooding. Source: Paulik et al. (2019a).

6.2 General impacts upon the population

Depending on the severity of sea level rise, the degree of inundation affecting the Manawatū-Whanganui Region – as well as related harm – varies. For example, we estimate that – in the event of a 1:100-year storm tide event, the number of people in the Manawatū-Whanganui Region inundation zone could range from 902 today (based on present day sea level) to 3778 (assuming 2 m sea level rise). Additionally, 27,000 people are in the flood hazard area (Figure 6-5). Manawatū District has the largest amount of people in the flood hazard area, followed by Palmerston North City.

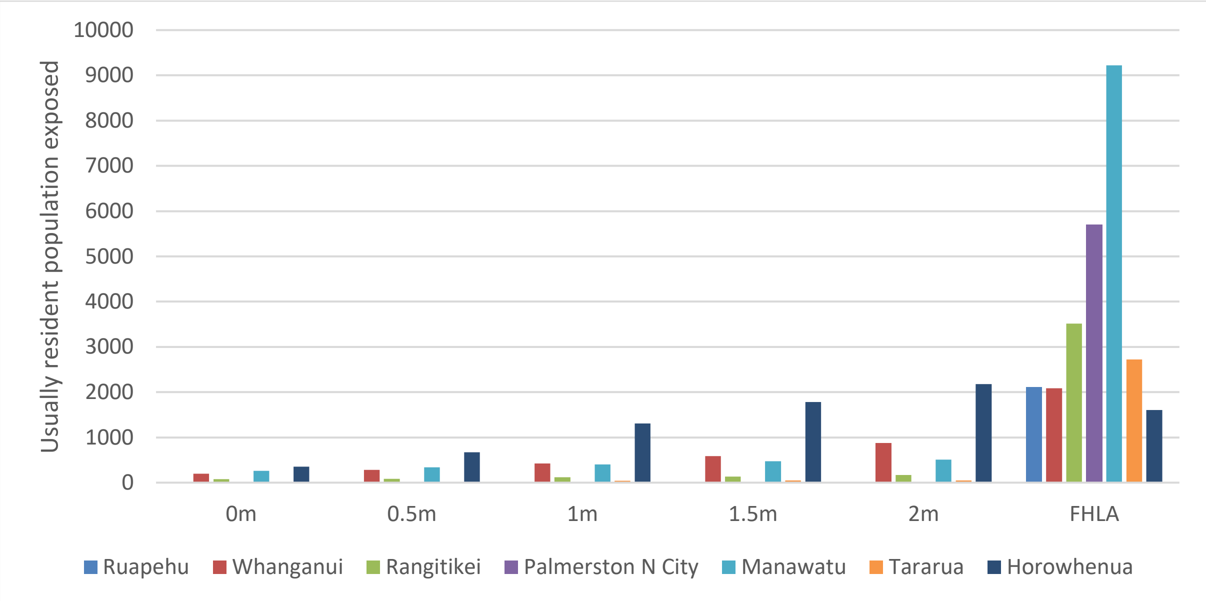


Figure 6-5: Population in territorial areas of Manawatū-Whanganui Region exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.3 Impact on built environment

For a 1:100-year storm tide inundation event, around 1500-5400 buildings overall would be in the impact zone (depending on the severity of sea level rise), while over 25,000 buildings overall would be in the flood hazard area. The distribution of exposure is uneven, with Horowhenua consistently most at risk of coastal impact and Manawatū District most at risk of impact by flood events (Figure 6-6). The exposure to flood hazards is considerably larger than exposure to coastal inundation in all districts, except for Horowhenua at high SLR elevations.

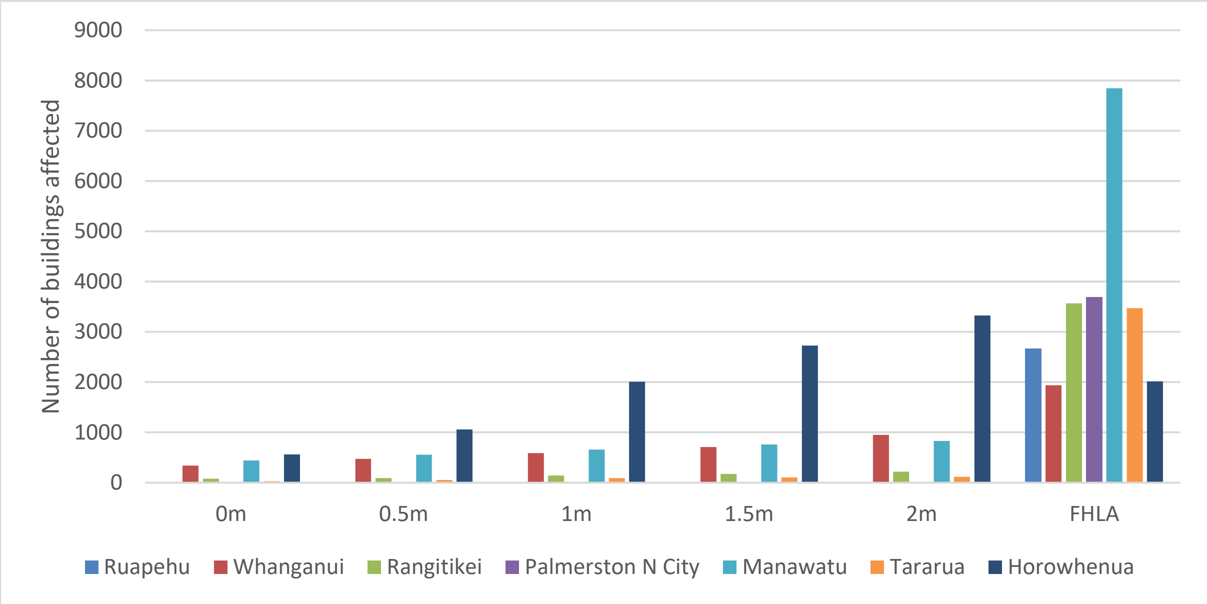


Figure 6-6: Number of buildings in territorial areas of Manawatū-Whanganui Region exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

The cost of coastal inundation-related damage is expected to be the greatest risk for Whanganui and Horowhenua (Figure 6-7) as sea level rise increases. The cost from flooding would pose the greatest risk to Manawatū, however the cost from flood-related damage is higher in all districts (except Horowhenua at high SLR elevations) than coastal inundation.

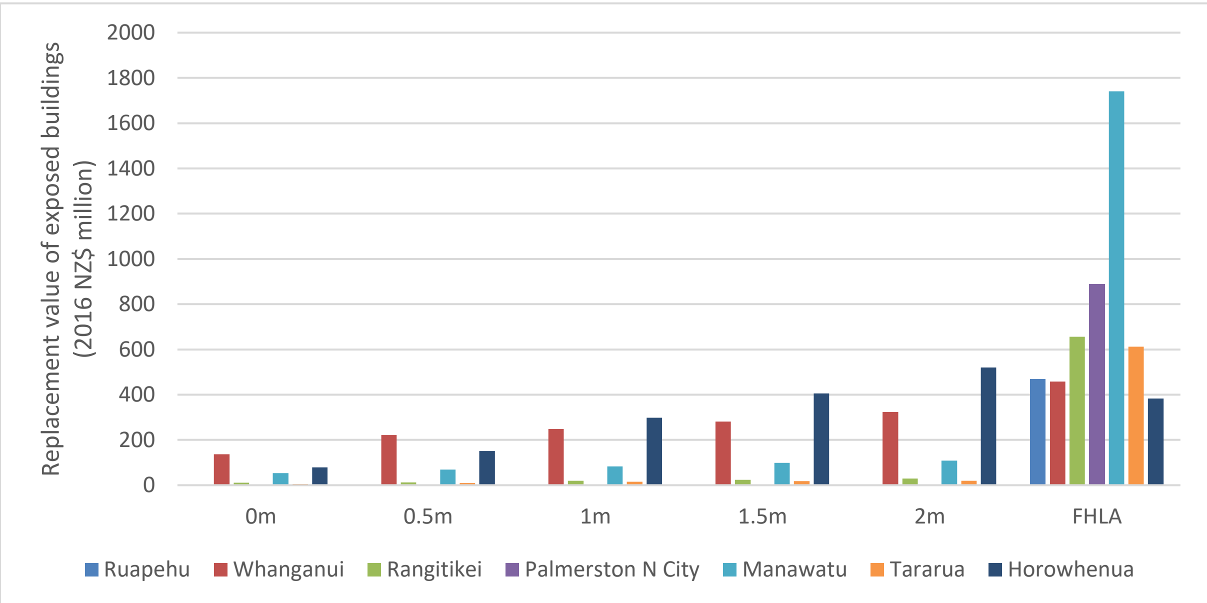


Figure 6-7: Replacement value of buildings (2016 NZ$ million) in territorial areas of Manawatū-Whanganui Region exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.3.1 Ownership of impacted buildings

The proportion of building types at risk from coastal inundation and flooding varies by district. Different types of buildings include, for example, residential, commercial, industrial and critical buildings (such as hospitals). Based on the modelling, residential buildings will consistently be the buildings most at risk from a potential flood or coastal inundation event (Figure 6-8). Accordingly, the cost of replacing or repairing these buildings will be a risk mostly faced by families, with potential repair/ replacement costs for exposed buildings estimated:

- to range between NZD $153-645 million for a single coastal inundation event, depending on the rate of sea level rise; and
- to be around NZD $3805 million for the flood hazard area (Figure 6-9).

The district with residential buildings most exposed to coastal inundation is expected to be Horowhenua, with 1810 buildings exposed at a replacement cost of around NZ $418 million (for 2m of SLR). As sea level rise continues, the impact upon industry in the area will be expected to increase (Figure 6-8). The number of buildings exposed to flood hazards is much higher than for coastal inundation – the flood hazard area is modelled to expose around 12,300 residential buildings (with a replacement cost of around NZ $3805 million). 4800 industrial buildings are exposed to flooding (Figure 6-8), with an estimated repair/replacement cost of around NZ $678 million (Figure 6-9), potentially affecting the economic performance of the region (this would likely be compounded by simultaneous impacts on transport and power infrastructure – see below.)

Considering that the average incomes in the Manawatū-Whanganui Region are already below the national average, the potential impact on families to recover from flooding and coastal inundation would be felt disproportionately.

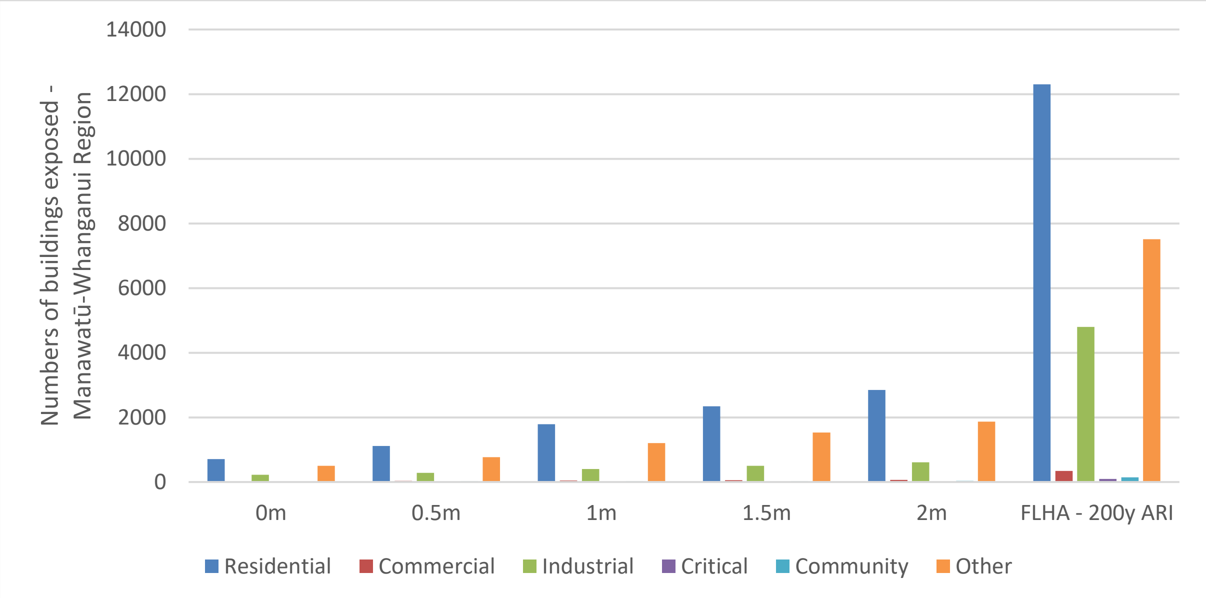


Figure 6-8: Different types of buildings exposed (for Manawatū-Whanganui Region as a whole) to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

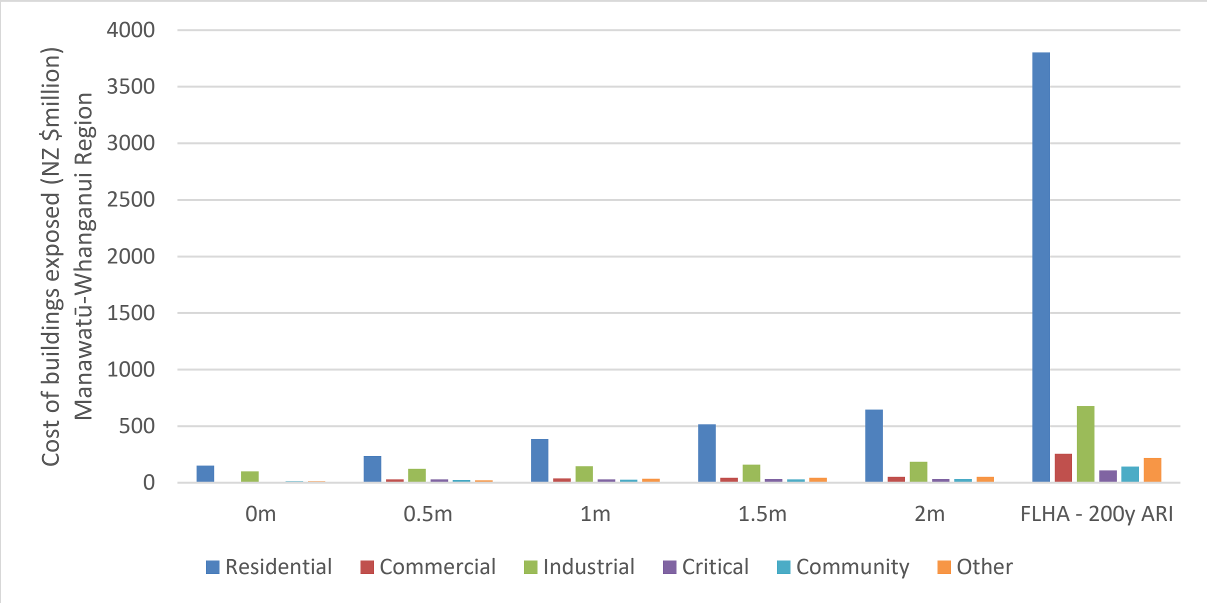


Figure 6-9: Replacement cost of different types of buildings exposed (for Manawatū-Whanganui Region as a whole) to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.4 Impacts on infrastructure

6.4.1 Roads

Regardless of the rate of sea level rise, Horowhenua contains the greatest extent (length) of road in the impact zone for a 1:100-year coastal inundation event compared with other districts (Figure 6-10), while Tararua District contains the greatest length of road (459 km) exposed to flood hazards (38% of the region's flood-exposed roads are in Tararua). The district with the next highest level of exposure is estimated to be Manawatū, containing an estimated 226 km of road exposed to flooding (19% of the region's flood-exposed roads are in Manawatū). Overall, the length of road exposed to flooding is significantly higher than road exposed to coastal inundation.

Roading infrastructure is also particularly at risk from slips and landslides associated with heavy rainfall. Although there is no quantitative data to draw upon regarding exposure to slips in the Manawatū-Whanganui Region, heavy rainfall events are likely to increase in intensity (Section 4). Therefore, it is likely that the parts of the region which already have geology susceptible to slips and landslides may be more at risk in the future.

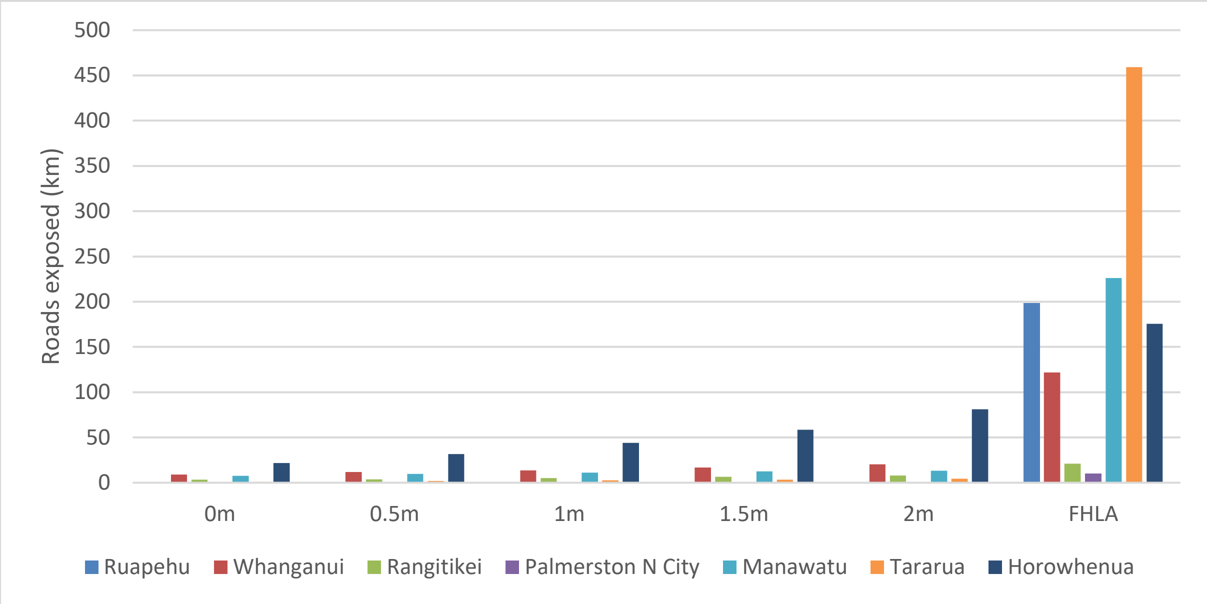


Figure 6-10: Length of road in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.4.2 Railway

Regardless of the severity of sea level rise, around 10km of rail around Whanganui are estimated to be vulnerable to inundation in the event of a 1:100-year coastal inundation event. The length of railway exposed to flooding is much higher than for coastal inundation. For flood hazards, the greatest degree of rail exposure is around Rangitikei and Tararua, with 58 km and 47 km of railway estimated to be in the impact zone respectively (Figure 6-11).

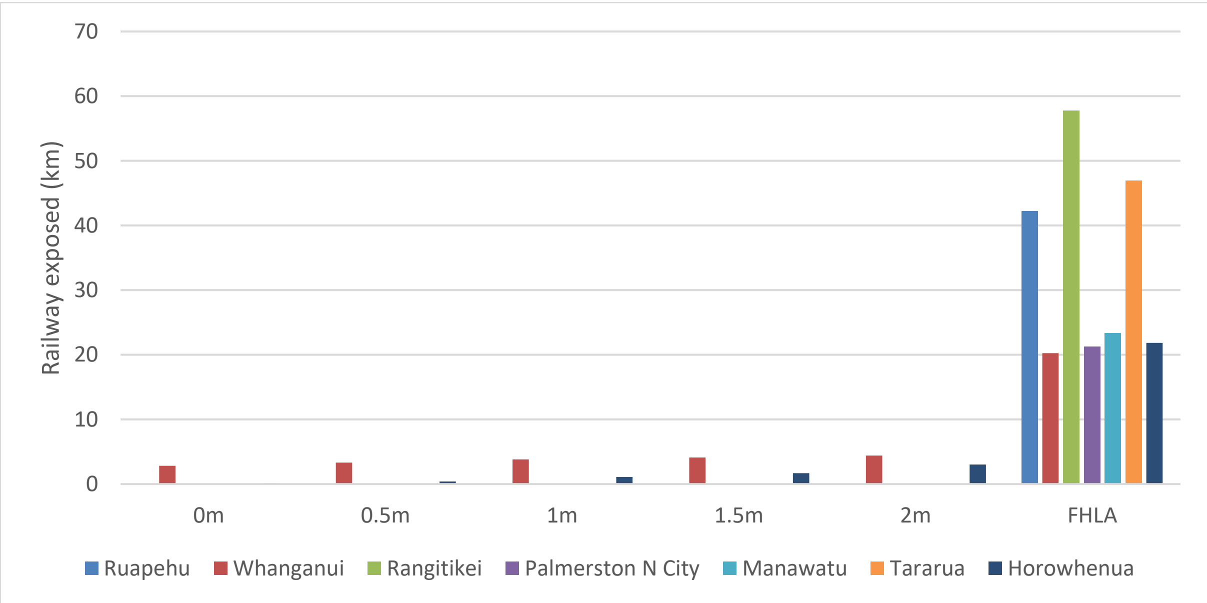


Figure 6-11: Length of railway in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.4.3 Airports

Three airports exist in Manawatū-Whanganui Region (Whanganui, Manawatū and Palmerston North). Whanganui airport is estimated to fall inside the impact zone of 1:100-year storm-tide events with current sea levels and future sea-level rise, whereas all three airports can be expected to fall into the flood hazard area.

6.4.4 Electricity transmission lines

Based on the risk exposure models, coastal inundation will have little immediate impact on electricity transmission lines. However, exposure to flooding is much more pronounced. Around 388 km of electricity transmission lines in Manawatū-Whanganui Region can be expected to be located in the flood hazard area. The majority of affected lines are in the Manawatū district, where it is estimated that 184km (47% of the region's lines) of lines are exposed (Figure 6-12).

The impact on electricity has a number of implications. In the immediate aftermath of an extreme weather event, power is needed to reach communities who may be cut off as well as to clean up impacted areas. Additionally, power outages during summer (when demand for air conditioning is at its highest) and winter (when heating is needed) may impact the vulnerable. This is important for the population generally, but also specifically for the aged whose care is a key target of economic growth for the Manawatū-Whanganui Region. Power outages can also be expected to have implications for water security as piped water to homes, businesses, factories and irrigations systems will rely on power.

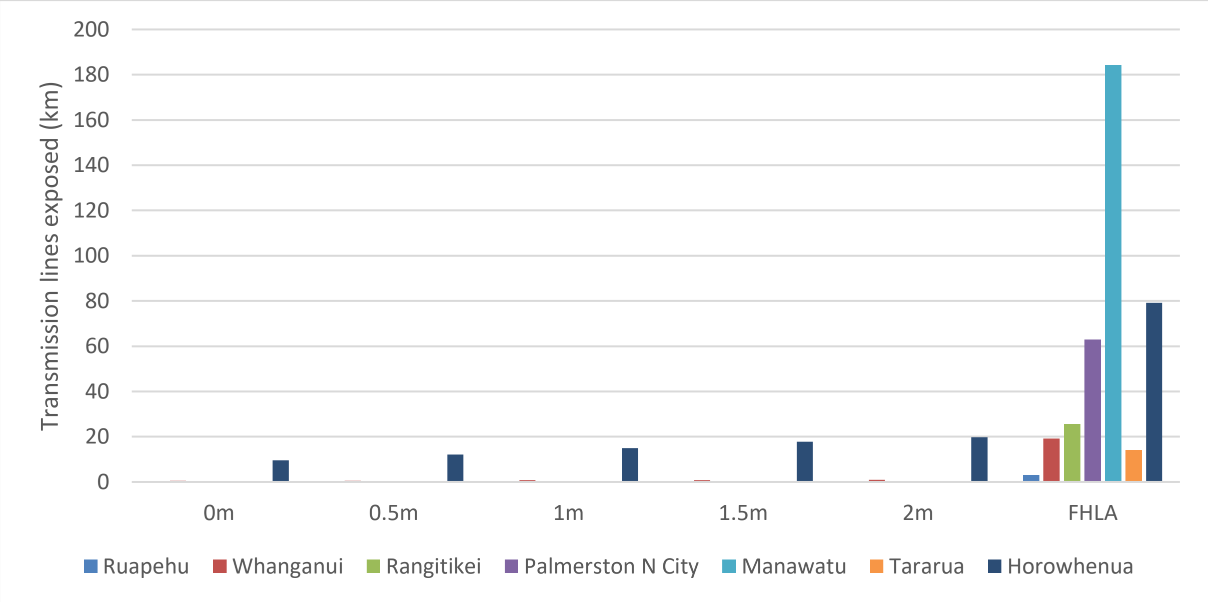


Figure 6-12: Length of transmission lines in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

6.4.5 Water related infrastructure

The exposure of drinking water, storm water and waste water nodes and pipelines has been modelled. Nodes are links in the distribution system, such as junction points in pipes. In the case of water for consumption, water nodes in only Whanganui and Horowhenua are expected to fall into the coastal inundation impact zone, with the number of nodes increasing as sea level rise increases (Figure 6-13). In the case of the flood hazard area, water nodes in all districts except for Ruapehu and Tararua would be expected to fall into the flood zone. Palmerston North City and Rangitikei District contain the greatest number of nodes exposed in this case.

Water pipelines are vulnerable to both sea level rise-induced coastal inundation and freshwater flooding. Whanganui and Horowhenua host the largest length of pipelines exposed to damage from a coastal inundation event, with up to 32.5 km and 28.5 km respectively of piping exposed in Horowhenua and Whanganui, depending on the severity of sea level rise (Figure 6-14). By comparison, the flood hazard area would be expected to expose around 196 km of pipelines across the region, with Rangitikei and Palmerston North City most exposed, with around 77 km and 71 km respectively of piping exposed to harm.

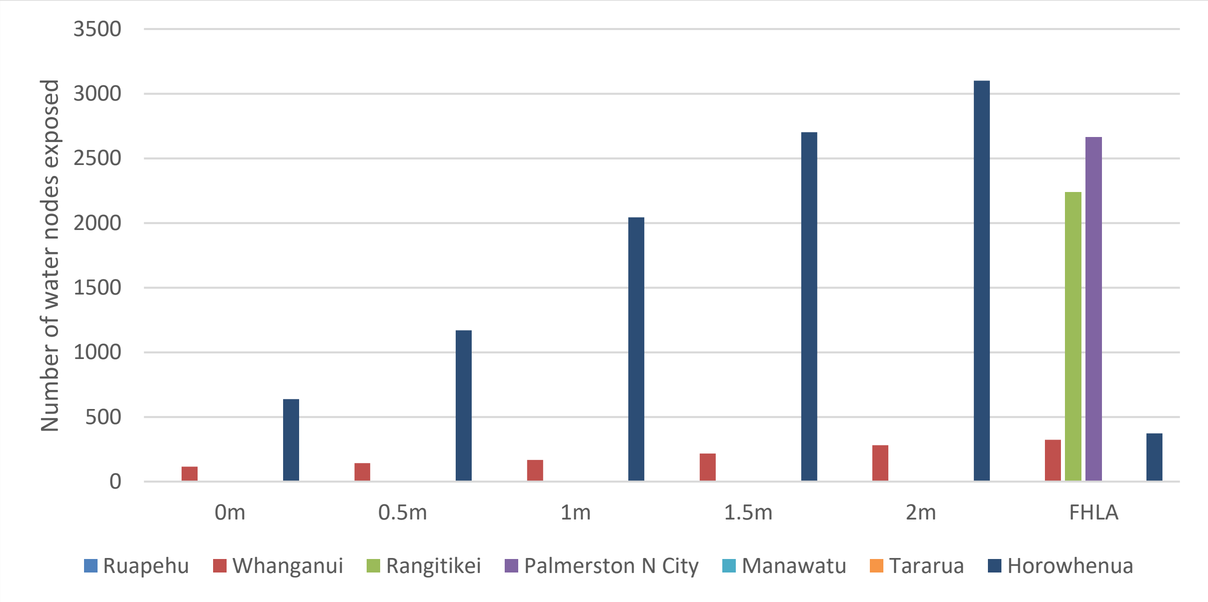


Figure 6-13: Number of water nodes in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

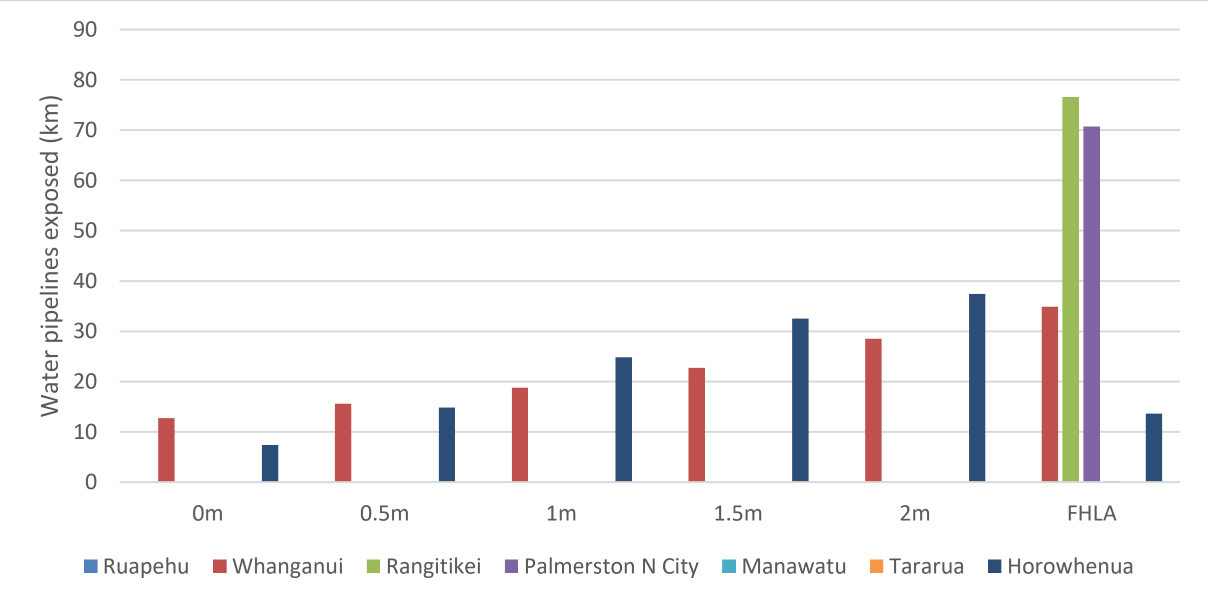


Figure 6-14: Length of water pipelines in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

Wastewater infrastructure is likely to be highly exposed around Horowhenua, in the event of major coastal inundation (Figure 6-15). However, most other districts could remain largely unaffected. By comparison, wastewater infrastructure nodes would be exposed to flooding for Rangitikei, Palmerston North and Horowhenua. Wastewater pipelines are only expected to be exposed in a severe coastal event in Whanganui and Horowhenua. By comparison, the flood hazard area would be estimated to expose around 150 km of wastewater pipelines across the region. 56 km of pipeline in the Palmerston North City territory is estimated to be exposed, and 45 km in the Rangitikei area. 30 km of pipeline is estimated to be exposed to flooding in the Whanganui district, and 19 km in Horowhenua (Figure 6-16).

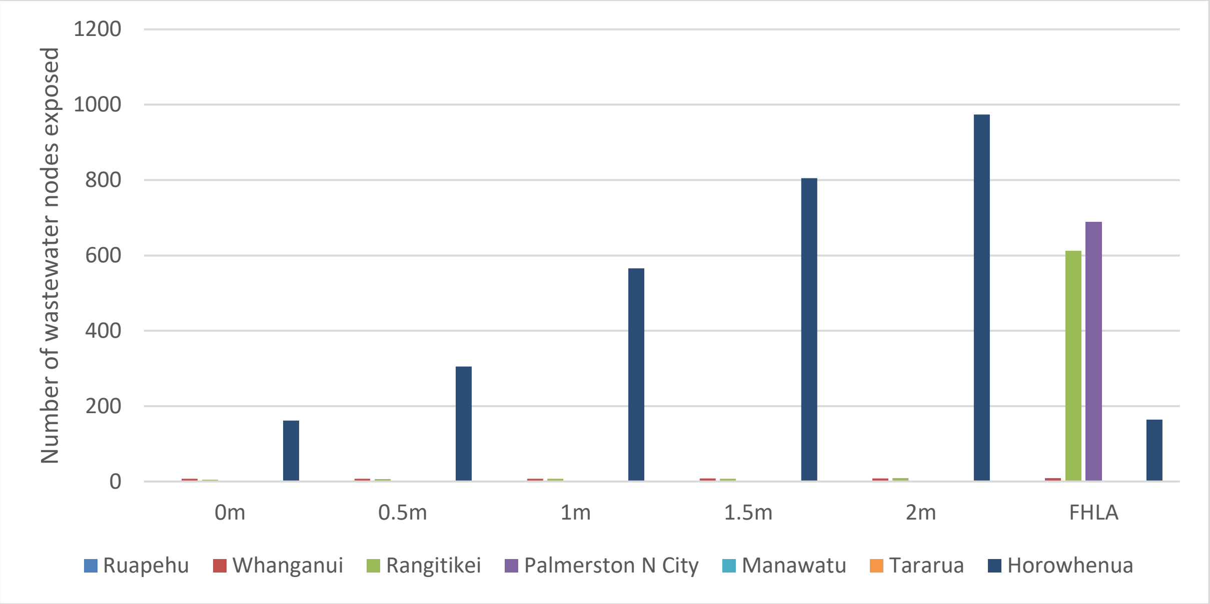


Figure 6-15: Number of waste water nodes in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

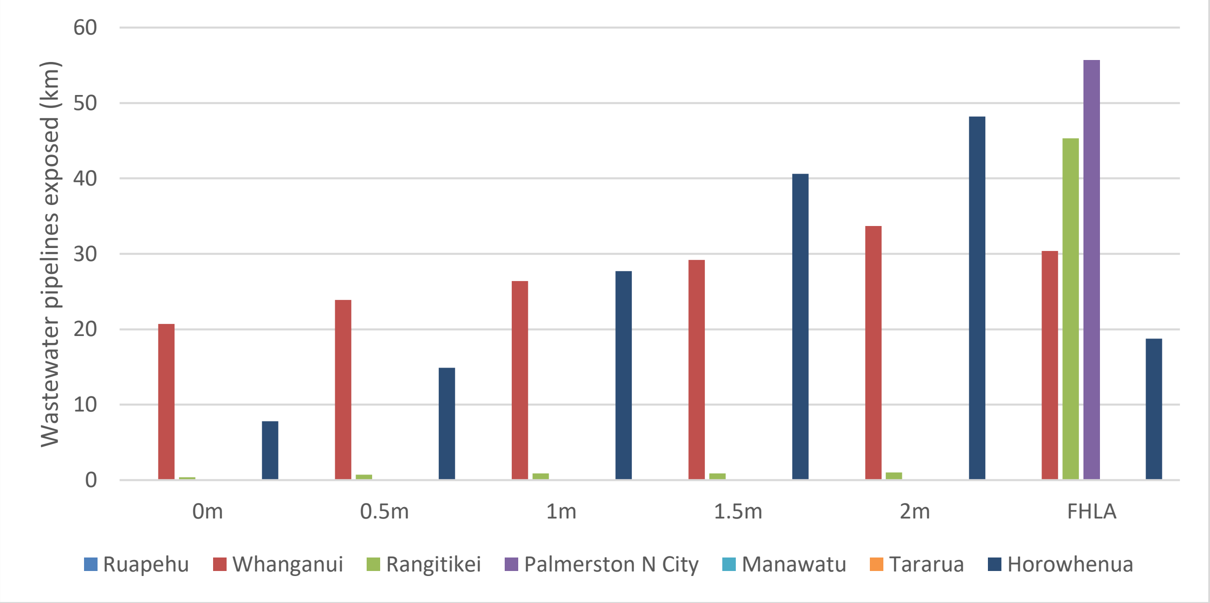


Figure 6-16: Length of waste water pipelines in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

Horowhenua contains the greatest number of stormwater nodes exposed to coastal inundation although Whanganui also contains nodes that are exposed (Figure 6-17). By comparison, flood events expose more extensively. As many as 2400 stormwater nodes would fall into the flood hazard area, potentially most impacting Palmerston North City and Rangitikei (exposing 1140 and 1017 nodes respectively).

Between 13 and 35 km of stormwater pipelines would fall into the exposure zone of a 1:100-year storm-tide event, depending on the district (Figure 6-18). However, flood events expose more stormwater infrastructure. As many as 225 km of stormwater pipe in the Manawatū-Whanganui Region are in the flood hazard area. 121 km of pipeline estimated in this flood hazard area are located in Palmerston North City, accounting for 54% of the total exposure in the region. A further 86 km of pipeline is located in the flood hazard area of Rangitikei district.

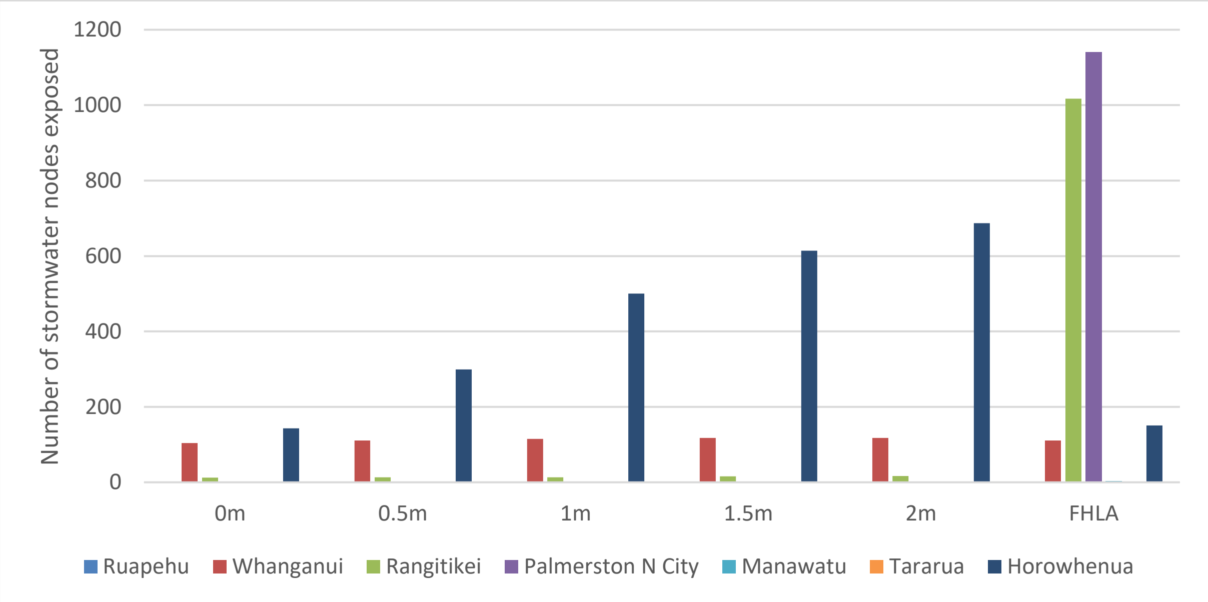


Figure 6-17: Number of stormwater nodes in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

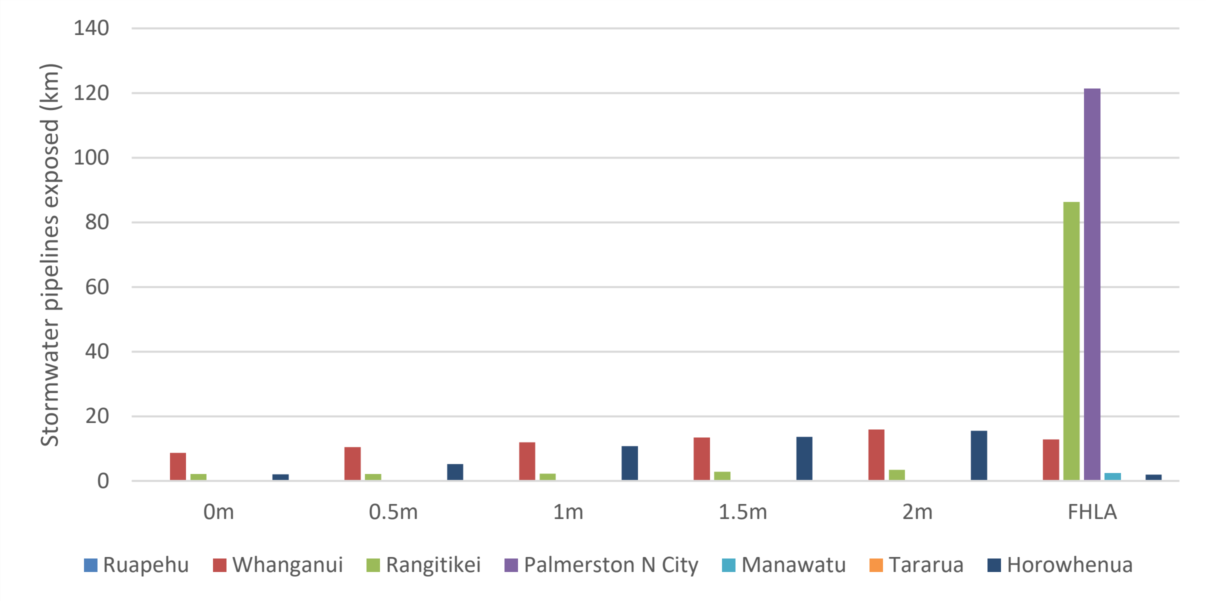


Figure 6-18: Length of stormwater pipelines in territorial areas exposed to a 1:100-year storm tide event at present day and future levels of SLR, as well as in the flood hazard area.

Any damage to nodes and pipelines would impact economic productivity of the area over time, where industries are reliant on water supply and removal of wastewater and stormwater. As an example, Section 6.5 will consider the impact of extreme weather (coastal inundation or flood) events on primary production. In this case, not only might Horowhenua be expected to face the greatest risk to its pipelines, but it would be expected to host the greatest amount of arable and dairy farming in the impact zone. Any outages of water supplies would then compound this.

Risks from floods will be expected to be more evenly distributed, with Horowhenua, Manawatū and Tararua districts facing considerable exposure.

Generally, water infrastructure in the flood hazard area is concentrated in Palmerston North City or Rangitikei districts. It is estimated that no water infrastructure in the Ruapehu district would fall into the impact zone, and other districts would only contain a limited number of exposed nodes and pipelines for the three waters.

Horizons Regional Council manages over 490 km of stopbanks, 1090 km of drains, 23 pumping stations and 53 dams (Horizons Regional Council, Undated). These flood protection schemes are potentially exposed to future changes in the magnitude and frequency of large floods. However, most of these assets were not specifically included in the RiskScape asset database.

The dams explicitly included in the asset database for the region are:

- Okehu Stream/Waitahinga Dam (Rangitatau Weir) – Whanganui (supplying water)
- Upper and Lower Turitea - Palmerston North (supplying water)
- Mangahao Dam (30 MW) – Tararua (generating energy).

All three dams are expected to be in the flood hazard area. However, it is not possible at this point to determine the risk of damage to the dams or their impacts on water or power security.

Further work is required to understand the exposure of the region's flood protection infrastructure to climate change-related impacts.

6.5 Agriculture, forestry and fishing

At a general level, changes in climate will have impacts on the agricultural sector on which employment in the Manawatū-Whanganui Region is heavily reliant. Increased temperatures and number of hot days is expected to increase the incidence of drought over time. This will be harmful for livestock (directly) and – in some cases – may increase the incidence of weeds or pests. At the same time, an increased intensity in severe rainfall events and high storm surge/ coastal inundation events can be expected to affect water quality, harm grazing areas and risk the safety of farm buildings, machinery, staff and livestock.

As an indication of exposure to agricultural production in the area, we have estimated the area of land that would be expected to be inundated in the case of a 1:100-year storm tide event and land that is within the flood hazard area. The main forms of agriculture practiced in the region are arable, dairy and pastoral farming. Some other activities occur such as market gardening, horse, pig, chicken and deer rearing, although these make up only a small proportion of total land use. Focusing on the main production types, it is estimated that – depending on the severity of sea level rise (between 0 and 2 m) – the following areas of agricultural land would be in the impact area:

- 3-16 km^2 of arable land
- 45-100 km^2 of dairy land
- 10-28km^2 of pastoral land[6] (Figure 6-19 to Figure 6-24).

For the flood hazard area, it is estimated that the following agricultural land could be exposed:

- 40 km^2 of arable land
- 562 km^2 of dairy land
- 700 km^2 of pastoral land.

As climate change progresses, the severity of agricultural impacts from extreme events is expected to be harmful to the economic performance and employment base of the area. It is important to note the risk to Horowhenua production in the event of severe coastal inundation. More of this district will be in the impact area than other districts. The impact area of flooding will be expected to be much larger and more evenly distributed across the districts, with Horowhenua, Manawatū and Tararua districts containing extensive agricultural lands in the impact zone.

Over time, these events – plus the effect of increased drought and or pest incidence – can be expected to affect water quality, harm grazing areas and risk the safety of farm buildings, machinery, staff and livestock. This can be expected to:

- Increase production costs (weed management, water planning and supply, feedstock planning/pre-positioning/storage of feed, shelter, loss of livestock) resulting in a reduction over time of profitability in some areas
- For some areas, warmer temperatures will provide a more supportive environment for livestock, as higher temperatures increase the number of growth days for feed. This is

[6] Lowest estimates are for 0 metres increase in sea level rise while highest values are for a 2.0 metre rise in sea level

considered for upland and lowland areas. Nevertheless, the increasing incidence of droughts, flooding, slips, and coastal inundation mean that farmers will face increased operating costs for advanced water and feed planning (above).

- Warmer temperatures may also contribute to heat stress on farm animals. In dairy cattle, heat stress results in reduced feed intake, which in turn results in lower milk production (DairyNZ, no date). Heat can also affect milk composition in terms of proportions of fats and proteins. Farmers may have to consider adaptation strategies like providing more shade, water, and shorter walking distances to milk sheds.

The risks of severe events or pest outbreaks notwithstanding, climate change can be reasonably expected to have some positive impacts. For example, the increase in temperatures over time is expected to favour wheat yields (Reisinger et al., 2014, MBIE, Undated). Additionally, climate change can be expected to benefit the production of export crops, such as onions, potatoes and other vegetables, in the horticulture industry as increased temperature and rainfall over time will extend the growing season for many vegetable crops. Negative impacts may include seasonal changes to planting and harvest times, such as increased frequency of severe rainfall waterlogging soils, leading to a delay in planting. There is also likely to be an increased risk of pest and disease with increased temperature, humidity and pest generation times owing to prolonged seasons (Clothier et al., 2012).

Impacts on forestry are likely to be mixed, but conditions for pine forestry may improve due to carbon dioxide fertilisation and warmer temperatures, and this is an area of potential economic growth. Nevertheless, there will be a higher risk of fires and weeds due to an increase in the number of hot days and increases in wind (Pearce et al., 2010). As a result, operating costs (fire management, weed management and water management) will be expected to increase somewhat over time. The increase in temperatures over time is expected to favour the growth of native and exotic forests in coastal regions, but the risk of inundation will also increase.

It is important to recognise that – for all agriculture – the reliance on an effective transportation system is critical for operations. Box 1 notes that transport infrastructure (roads, rail and air) can be negatively impacted by climate change because of increased risk of inundation from several coastal events or freshwater flooding. The need to maintain the connectivity of the region to maintain or resume commercial operations following extreme events applies for all sectors.

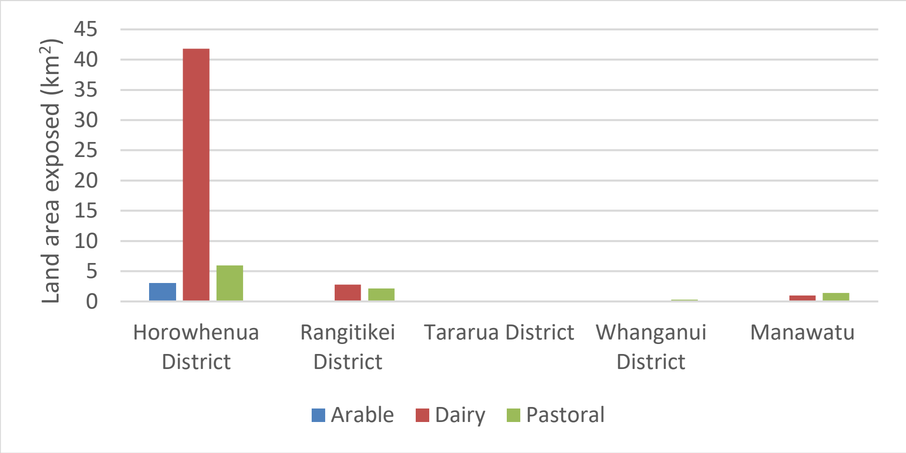


Figure 6-19: Total land area exposed for key production in a 1:100-year storm tide event at present day sea levels.

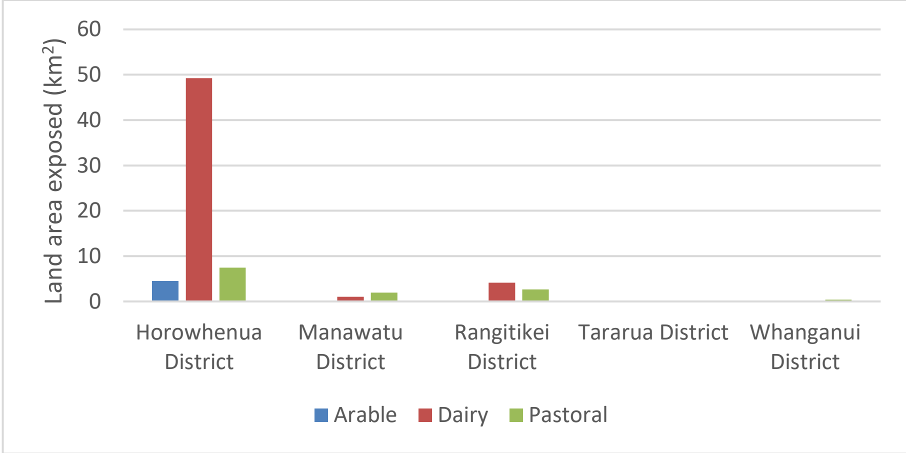


Figure 6-20: Total land area exposed for key production in a 1:100-year storm tide event with 0.5 m of sea-level rise.

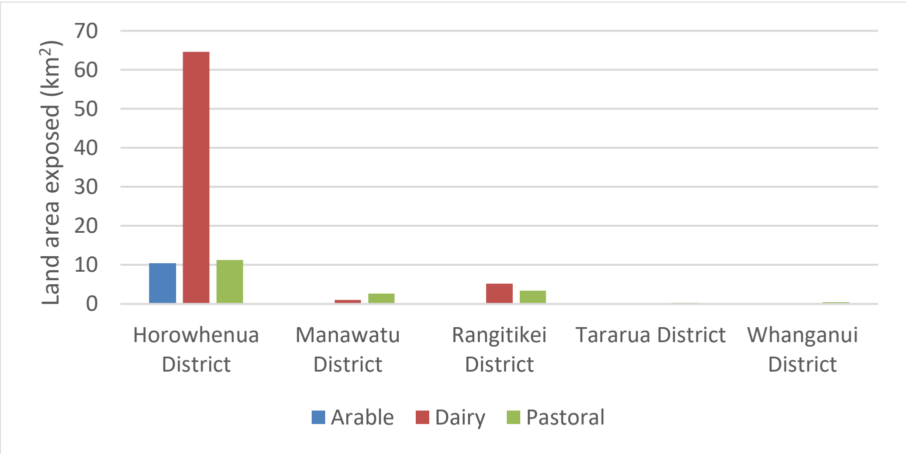


Figure 6-21: Total land area exposed for key production in a 1:100-year storm tide event with 1 m of sea-level rise.

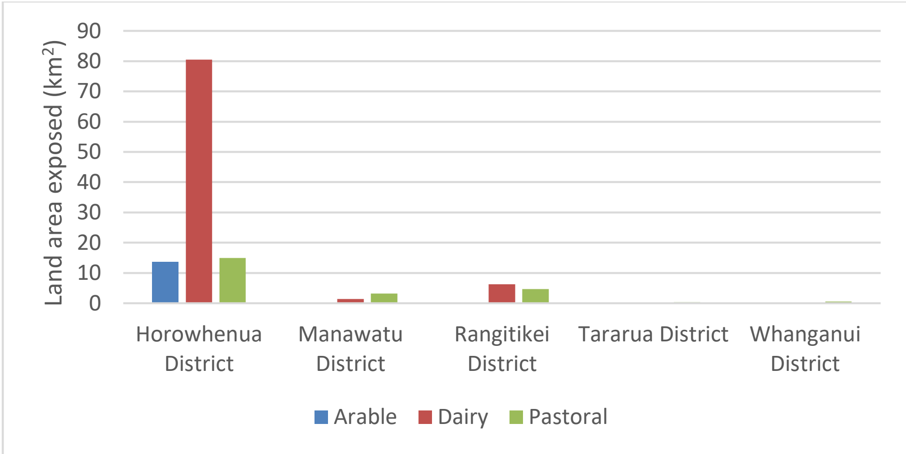
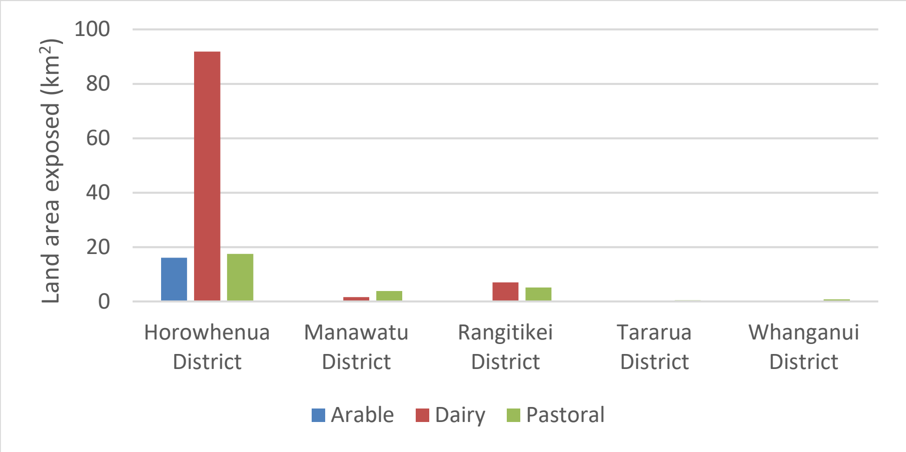


Figure 6-22: Total land area exposed for key production in a 1:100-year storm tide event with 1.5 m of sea level rise.



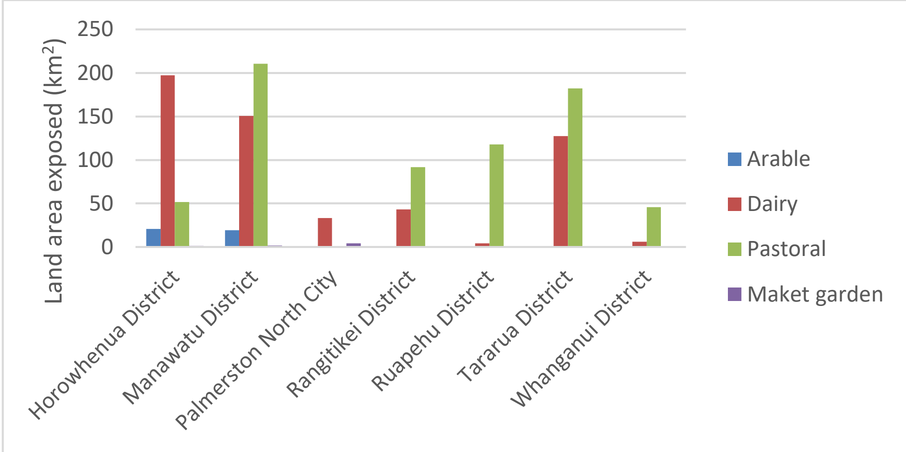


Figure 6-23: Total land area exposed for key production in a 1:100-year storm tide event with 2 m of sea-level rise.

Figure 6-24: Total land area exposed for key production in the flood hazard area.

Fisheries in the area may expect negative impacts as over time as warming sea temperatures affect habitats and potentially reduce yields. Warming ocean temperatures may also bring warm-water pests to the New Zealand region, which may compete with local species (Law et al., 2018). Ocean acidification may have impacts on the development of fish species, particularly juvenile fish, as well as shellfish with calciferous shells (Law et al., 2017).

6.6 Public safety and administration

Increased incidence of drought, fires, flooding and coastal inundation events can be expected to increase pressure on emergency services and resource planners to monitoring, anticipate severe events, respond and underpin recovery.

6.7 Retail trade

Retail centres are reliant upon effective transport infrastructure to enable transactions. Modelling by NIWA indicates that harm to transport infrastructure from coastal inundation and flooding is likely to be a particular risk to Horowhenua and Tararua (Box 1). Air links for Whanganui are also likely to be exposed as a result of severe coastal inundation and severe flood. As well as risking the profitability of the transport sector over time, ongoing and/or increasing climate change would be expected to reduce the ability of traders to reach market and for clients, customers and staff to reach employment centres. This is important for the region considering its role in providing contact centres (business process outsourcing) which is a targeted area for regional growth.

Box 1: Impacts of climate change on transport

According to modelling by NIWA:

- Of all the territorial areas in the region, the road systems of Horowhenua are most exposed to harm from coastal inundation events while the road system around Tararua is most exposed to harm from flooding. At present, the models on the exposure of road systems to hazard events used by NIWA do not distinguish between local roads and state highways. Harm to both is important, although the effects can be different. Harm to local roads, for example, can negatively impact local access to businesses (such as farms), communities (for example, providing support to the elderly) and amenities (such as hospitals) in severe events; while harm to highways can affect the provision of external support as well as the wider supply of goods and services, including tourism.
- Rail networks may be negatively impacted by coastal inundation with Whanganui’s networks most exposed, while the rail networks around Rangitikei, Tararua and Ruapehu are extensively exposed by floods.
- Transmission lines around Horowhenua are at risk of coastal inundation while lines around Manawatū are particularly exposed to flooding, potentially cutting off electricity in an extreme event.
- A disproportionately high share of nodes and pipelines for potable water, wastewater and stormwater are at risk of harm from coastal inundation in Horowhenua (although nodes and pipes around other areas are still at risk, e.g., Whanganui). In the event of severe flooding, water nodes for Palmerston North and Rangitikei are highly at risk. The greater area of pipelines at risk of harm are wastewater pipelines where – in the event of a 1:100-year coastal inundation event with 2 m of sea level rise – 83 km of wastewater piping are at risk of harm, while 150 km are in the flood hazard area. The risk of water contamination and threat to human health, agricultural production systems and transport in this case are high.

6.8 Health care and social assistance

Increased temperatures over time can have some beneficial impacts to humans with reduced need for heating in winter. This may be expected to reduce the risk of cold related illnesses and deaths. On the other hand, IPCC (Reisinger et al. 2014) and the Royal Society of New Zealand (2017) suggest that the risk of respiratory illness, such as asthma, heat-related death and water and food borne disease can be expected to increase. Considering the reliance on the Manawatū-Whanganui Region for aged care and the expectation of growth in this area, this will be important.

Also critical at this point is the risk of (i) transport links being jeopardised due to flood or coastal inundation, affecting access to critical services such as hospitals, medicines, support services (ii) interruptions to water service due to harm to infrastructure; and (iii) cuts to electricity distribution due to flood or inundation.

6.9 Housing

Along with infrastructure, housing is at risk of harm from climate change due to ongoing sea level rise and coastal inundation as well as exposure to freshwater flooding. As noted in Section 6.2, as many as 3778 people and 2845 homes can be expected in the impact zone during a 1:100-year coastal inundation event with 2 m of sea level rise, while around 27,000 people and over 12,300 homes would be expected to be in the flood hazard area. Moreover, with harm to transport infrastructure from severe events, the risk exists that homes may become cut off from transport and critical amenities.

6.10 Water

Generally speaking, the Manawatū-Whanganui Region can anticipate a small increase in average rainfall. This does not necessarily translate to an increase in freshwater availability, as there will be varied distribution of rainfall across the region, as well as a likely increase in the incidence of heavy rainfall events and drought. Warmer temperatures can also drive greater evaporation, leading to less water availability in rivers. The region is projected to receive more rainfall on average during the winter period, and less rainfall during summer (Pearce et al., 2016). This may lead to increased water availability during winter, but less during the time of year when water availability is already limited (summer). Warmer temperatures in the summer will likely drive greater demand for freshwater, particularly for irrigation. In addition, rainfall intensity is projected to increase for extreme, rare events (see Section 10.2).

River flow projections (Section 10.2) generally do not show confident directions of change for the Manawatū-Whanganui Region aside from low flow levels being projected to decline. This may affect primary industries and other sectors that use river water for irrigation and other uses, as allocations may change over time in response to declining low flow levels. Projections for large floods have not yet been produced, so although extreme rainfall is projected to increase in intensity, this cannot be reliably connected to riverine flooding at this time.

For coastal and estuarine areas, sea-level rise may cause saline intrusion into groundwater reserves and drive brackish water further upstream than at present. This may have impacts on water availability for primary industries and municipal water supply, increasing operating and delivery costs.

6.11 Environment, culture and tourism

Much of the tourism in the Manawatū-Whanganui Region is reliant upon the natural environment. This includes an expectation of snow for skiing and clean attractive environments for tramping and sightseeing.

Climate change is expected to be a stressor on terrestrial, freshwater, coastal and marine ecosystems, particularly under high-warming scenarios. Many indigenous New Zealand species are already and will be at further risk from climate-related impacts such as river water abstraction for irrigation (in response to reductions in rainfall and higher drought incidence), hydroelectric power schemes (a potential mitigation response to greenhouse gas emissions), and non-climate-related impacts such as predation, habitat loss and fragmentation from land use change, urban area and infrastructure expansion, and pollution (McGlone and Walker, 2011). Many species will be at risk from new and existing pests that are able to colonise and spread further in New Zealand because of climate change (Kean et al., 2015).

Wetlands are highly sensitive areas and are amongst the most threatened ecosystems in New Zealand. In the future, wetlands will be threatened by changes to rainfall patterns, drought and surface and groundwater hydrology. Wetlands close to the coast will also be at risk from sea-level rise (inundation and erosion) and changes to salinity of groundwater which may impact the distribution and assemblage of species.

The direct responses of terrestrial biodiversity to future climate changes will be challenging to predict, due to uncertainty about climate projections, species' responses to climate change and the ability of species to adapt (McGlone and Walker, 2011; Christie, 2014). This is particularly because of the existing pressures of invasive species and human-related habitat loss on native biodiversity. The capacity of native species and ecosystems to adapt to a changing climate is unknown, especially given New Zealand's oceanic setting and existing highly variable climate regime. However, the indirect responses of terrestrial biodiversity to climate change can be predicted with more certainty. Indirect impacts involve the exacerbation of existing invasive species problems and human-related threats, such as habitat loss (Christie, 2014). Land use and land management practice change in anticipation of climate change may result in further restrictions of native species abundance and distribution.

Some mitigation aspects of climate change might have negative impacts on terrestrial biodiversity. Afforestation with exotic tree species (e.g. *Pinus radiata*) may lead to reductions in catchment water yield, with negative impacts on stream flow and freshwater biodiversity, stabilisation of previously dynamic systems (e.g. pines on coastal dunes) with consequent loss of indigenous flora, invading areas where native forest was either absent or limited, and creating flammable forest communities (McGlone and Walker, 2011). The conversion of native scrub and shrub land to forestry may also cause the direct loss of native ecosystems.

Changes to rainfall patterns and river flows, as well as the human impact of greater abstraction of freshwater for irrigation and increasing storage (in the form of reservoirs) for hydroelectricity and urban water supply, will lead to impacts on freshwater ecosystems (Parliamentary Commissioner for the Environment, 2012). The role of floods in New Zealand rivers is extremely important maintaining ecological integrity, so changes to the hydrological regime may have dramatic impacts on biological communities (Death et al., 2016, Crow et al., 2013). Altered natural flow patterns may result in invasive predators gaining increased access to habitats crucial for sensitive life cycle stages (e.g. islands in river channels used by nesting birds) and changes in habitat type, and some aquatic species (e.g. invertebrates) are likely to be impacted more than others, depending on their life cycles (McGlone and Walker, 2011). Habitat size, availability and quality may be reduced for some species, and drought may threaten already isolated fish and invertebrate populations.

Sea-level rise may increase salinity at river mouths and further upstream than at present, thereby reducing freshwater habitats, particularly in short catchments. Increases in extreme rainfall intensity may lead to more sedimentation and turbidity in waterways, with consequent habitat loss. Banded kokopu (*Galaxias fasciatus*) have been found to have reduced abundance in turbid streams, so increasing runoff and sediment flowing into streams could limit their distribution (Rowe et al., 2000). Other oceanic changes (e.g. changes to salinity, sea temperatures, and pH (Law et al., 2018)) may also have an impact on diadromous fish species and their migration patterns.

Coastal systems are particularly sensitive to three key drivers related to climate change: sea level, ocean temperature, and ocean acidity (Wong et al., 2014). Soft shorelines (beaches and estuaries) are likely to be more severely affected by sea-level rise than hard (rocky and consolidated cliffs) shores. Due to the extensive development near beaches, estuaries and marshes, it is unlikely that natural adjustment of the coast will be readily allowed in the future (i.e. coastal retreat and reconfiguration as sea level rises). A potential human response to sea-level rise will be by building hard barriers, protecting sand dunes, replenishing beaches, and infilling estuaries to prevent erosion and to protect property and infrastructure. This scenario (often termed 'coastal squeeze') means that rising sea levels will destroy large areas of habitat at the current coastal margin (McGlone and Walker, 2011).

Loss of productive estuarine habitats and biota is likely to accelerate, with the more visible ecological effects being reduced populations and altered migratory patterns of coastal birds, and declines in certain marine fishes (e.g. snapper, *Pagrus auratus*). Loss of ecosystems and species habitats by coastal squeeze is already apparent in some places where coastal dunes have been developed upon or forested. The effects of changes in waves and freshwater inputs will also have significant adverse impacts for coastal ecosystems (Hewitt et al., 2016). Warming oceans are likely to have impacts on the distribution of marine species as well as pests from warmer areas. Marine species are likely to be affected by ocean acidification. Growth rates and shell development of oyster and paua larvae are reduced in more acidic waters (Cummings et al., 2013). The behaviour of Australian reef fish is affected by ocean acidification, with olfaction, hearing, visual risk assessment and activity altered due to the impact on neurotransmitter function (Munday et al., 2014). Work is ongoing at NIWA to understand the impacts of ocean acidification on New Zealand's fish species.

Climate change and sea-level rise impacts on locations and practices that are important to Māori were out of scope for this report, but these are important considerations that should form part of future research.

For tourism, the expected warmer temperatures are likely to have an impact on the ski industry. In the short term, the impact is likely to be beneficial, as snow cover in Australia is reducing more rapidly than New Zealand and New Zealand should be able to absorb the market (Reisinger et al., 2014, Ministry for the Environment, 2017a). Nevertheless, higher temperature and fewer snow days will be detrimental to the Manawatū-Whanganui Region in the long term, causing rising natural snowlines (Hendrikx et al., 2012). However, modelling carried out by Hendrickx and Hreinsson (2012) showed that snowmaking on current ski field sites at Mt Ruapehu would still be possible by the 2090s, even under a high emission scenario.

The risk of harm to transport and other infrastructure will be an issue for the tourism sector.

6.12 Other issues

The cost of wear and tear on major infrastructure over time can be expected to rise due to increased risks from coastal inundation, flooding and/or demands on the energy system (e.g., the need for more cooling during summer time and increased demand through electrification of the vehicle fleet). Moreover, interconnected infrastructure networks mean that there are increased compound effects (Ministry for the Environment, 2017a).

Hazard events may occur together. For example, it is possible that coastal inundation and flooding may occur in close succession, leading to more severe impacts. Similarly, flooding may be accompanied by landslides induced by intense rainfall. Moreover, the probability of harm over time may increase such that, what was once a 1:200-year event, may in the end become a 1:100-year event or even 1:50 year event. The risk of harm can be expected to continue to rise for the foreseeable future.

Table 6-1: Potential impacts of climate change on key sectors in the Manawatū-Whanganui Region.

Sector	Impact	Comment – over time, anticipate:
Agriculture, fisheries and forestry • Sheep farming • Sheep and cattle farming • Beef cattle farming • Dairy cattle farming	• Increased temperatures leading to increased drought risk will cause economic losses in direct and off-farm output (Reisinger et al. 2014) • Increased risk of river erosion driven by increased rainfall and extreme events. However greater development of flooding projections is needed to understand the extent of risk. • Changes in temperature and humidity will alter the production zones and timing – some will benefit, and some will become more vulnerable (Ministry for the Environment, 2017a) • Increased risk of erosion on farms (Ministry for the Environment, 2017a) • Increased risk of flooding (Ministry for the Environment, 2017a) • Increased flooding and ponding will increase the risk of contamination of water (Ministry for the Environment, 2017a) • Projected changes in national pasture production (dairy/sheep/beef) = range from an average reduction of 4% across climate scenarios for the 2030s, to increases of up to 4% for two scenarios in the 2050s (Reisinger et al. 2014) – note these numbers are for NZ as a whole so production may be different for Horizons. Increases broadly consistent with this are projected by Ausseil et al. (2017) • As with all primary industries, the risk of biosecurity hazards increases (Kean et al., 2015) • Increased risk of heat stress on farm animals • Increased agricultural reliance on water driven by increased risk of drought and more competition over scarcely available water, for example, water abstraction per capita is increasing in NZ, where over half is used in irrigation (Reisinger et al. 2014) • Improved pasture farming due to increased number of growing degrees days for feed, but increased number of hot days and increased risk of droughts will lead to need for advanced planning (access to water) (Pearce et al. 2016) • If farming occurring in uplands, beneficial although need for improved planning of feedstock to cope with increased seasonal variability (Rutledge et al., 2017) • If farming occurring in lowlands, beneficial although higher risk of drought will mean the need for improved planning (Ausseil et al., 2017) • If farming occurring in coastal regions, harmful due to increased coastal inundation (McBride et al., 2016)	• increase costs (planning, water quantity and quality, land loss, weed management) for farming and reduced profits • This may impact employment, equity and tax base • Some production will benefit but some may suffer • Increased physical and safety risks for farm infrastructure, livestock and staff (flood, inundation, drought, high temperatures)

Sector	Impact	Comment – over time, anticipate:
• Forestry (exotic and native)	• As with all primary industries, the risk of biosecurity hazards increases (Kean et al., 2015) • Warmer temperatures and higher snowline have implications for weed & pest management (Rutledge et al., 2017) • Pine forestry may benefit due to increased *Pinus radiata* growth in cooler regions (Ministry for the Environment, 2017a) • However, higher risk of pine species disease (Reisinger et al. 2014) • Increased risk of fire – post fire regeneration of forests requires water, reducing water yields (Reisinger et al. 2014, Ministry for the Environment, 2017a, Pearce et al., 2010) • Long production cycles expose forestry industry to climate change impacts over longer periods (Ministry for the Environment, 2017a) • Increased risk of pest and disease because of rising temperatures, and habitat loss via erosion and unstable land are key risks to the industry (Ministry for the Environment, 2017a) • Increase in native and exotic forests in the coastal regions (Reisinger et al. 2014)	• Improved opportunities for pine forestry, but an increased risk of fire (increased temperatures, drought) • Improved opportunities for forestry in coastal areas (improved climate) • Increased risk of coastal inundation
• Other	• Potential to increase wheat yields (Reisinger et al. 2014) • Increased temperatures extending the growing season for many vegetable crops, a boon for horticulture • Increased risk of pest and disease with increased temperature, humidity and pest generation times, exacerbated by prolonged growing seasons (Clothier et al., 2012) • Seasonal changes will impact planting and harvest times, and the authors note here that there is a risk that waterlogged soils will delay planting in a heavy rainfall (Clothier et al., 2012)	• Opportunities to increase wheat yields • Opportunities for warmer climate vegetable varieties to be grown • Increased costs of pest management
• Fishing (sea and freshwater)	• Some cold-water-adapted fish are at increased risk due to warming (Reisinger et al. 2014) • Ocean acidification impacts on fish and shellfish development (Law et al., 2017) • Decline in yield (habitat harm and decreased food for fish) (Law et al., 2016) • Increased risk of pests and diseases due to warmer water temperatures (ocean and freshwater) (Kean et al., 2015)	• Changes in distribution and abundance of marine and freshwater species • Increased costs of pest management
Public Administration and Safety	• Need for increased fire management, particularly clarifying objectives for different responses, for example, preserving biodiversity versus protecting buildings (Reisinger et al. 2014) will increase management costs • Increased resourcing pressure on emergency services – including the flow on effect of damage to infrastructure considering the amount of regional pop in rural areas (Ministry for the Environment, 2017a)	• Increased costs • Increased monitoring for fires

Sector	Impact	Comment – over time, anticipate:
Retail Trade	• Risks to infrastructure (from inundation and flooding) imply increased risk of being cut off from transport and associated impacts on the sector (Pearce et al. 2016) • Tourism related retail will be harmed over time for alpine areas (reduced snowfall impacts the ski industry. Reduced snow may result in a gradual tourism shift over time to the South Island (see Tourism)	• Reduced ski related retail profits • Potential impact on employment
Education and Training	• Risks to infrastructure (from inundation and flooding) imply increased risk of being cut off from transport and associated impacts on the sector (Pearce et al. 2016)	• Increased operating costs
Manufacturing	• Risks to infrastructure (from inundation and flooding) imply increased risk of being cut off from transport and associated impacts on the sector (Pearce et al. 2016)	• Increased operating, maintenance and replacement costs
Health Care and Social Assistance	• Increased risk of respiratory illness, such as asthma (Reisinger et al. 2014) • Heat related deaths at risk of increase, but reduced deaths to cold conditions (Reisinger et al. 2014) • Water- and food-borne diseases to increase, but connection to climate is complex = low confidence in specific projections (Reisinger et al. 2014) - Direct impacts include increased heat related deaths – vulnerable populations such as the elderly (Ministry for the Environment, 2017a) - Indirect impacts include increased incidence of existing and new diseases – more frequent pandemics, increased stress and mental health issues (Ministry for the Environment, 2017a) • Risks to infrastructure (from inundation and flooding) mean implication of being cut off from transport and associated impacts on the sector (Pearce et al., 2016)	• More heat-related illness and less cold-related illness
Other		
Infrastructure	• Risk for low-lying airports • Sea level rise will hinder the drainage capability of storm water pipes (Ministry for the Environment, 2017a) • Sewer networks may overflow with more intense and frequent heavy rain events (Ministry for the Environment, 2017a) • Wind energy generation will benefit from increased mean westerlies, but risk damage and shutdown in extreme winds plus variability in these increase risk (Reisinger et al. 2014) • Transmission lines damage risk increased (Ministry for the Environment, 2017a)	• Increased maintenance and replacement costs • Increased costs to service rural users due to infrastructure failure (e.g., roads under water)

Sector	Impact	Comment – over time, anticipate:
	• Greater variability of wind makes this energy generation vulnerable (Ministry for the Environment, 2017a) • Seasonal changes in electricity demand, for example, increased demand for air conditioning in summer, but decreased demand for heating in winter (Ministry for the Environment, 2017a) • Increased risk of landslides and damage to infrastructure and safety (Basher et al., 2012) • For coastal areas, increased likely harm to infrastructure from increased coastal inundation, wear and tear and increased maintenance costs	
Housing	• Increased risk of landslides and damage to housing and safety with increased extreme rainfall intensity • Implication for being cut off from transport and associated impacts • For coastal areas, increased inundation of communities with sea-level rise and storm surge	• Increased maintenance and replacement costs • Increased insurance costs
Water	• Increased risk of landslides and damage to infrastructure (Pearce et al. 2016) • Increased precipitation over winter (Pearce et al. 2016) • Reduction in river levels for low flows on the Manawatū River • Increase in extreme rainfall events. As well, increased sediment loads all leading to increased risk of flooding (Pearce et al. 2016) • For lowland areas, likely increased demand for water due to increased risk of drought – especially from agriculture (Ausseil et al., 2017) • For coastal areas, increased salinity due to sea-level rise (McBride et al., 2016)	• Increased costs for infrastructure maintenance and replacement
Environment/ tourism	• Unclear about the climate change effects on ecosystems services provided by soils (Reisinger et al. 2014) • Increased incidence of pests and diseases likely to impact native biodiversity (Kean et al., 2015) • Limited evidence, but high agreement that the alpine biodiversity is at risk (Reisinger et al. 2014) • Coastal habitats are at risk from sea-level rise and 'coastal squeeze' (McGlone and Walker, 2011) • Bird species with braided-river habitats are at risk because of predation (McGlone and Walker, 2011) • Freshwater species are at risk from increased water temperatures and lower river flow levels. • Marine species are at risk from increased ocean temperatures, ocean acidification and sea-level rise.	• Reduced ski tourism income and increased costs • Increased costs for infrastructure maintenance and development • Increased costs for pest management

Sector	Impact	Comment – over time, anticipate:
	• Coastal areas such as Horowhenua (Otaki, Foxton, Levin) and Whanganui which are important cultural heritage sites (food gathering) at risk of inundation and harm (Ministry for the Environment, 2017a) • Communications infrastructure increased vulnerability, increased maintenance and repair costs – are not easily forecasted due to variability of events (Ministry for the Environment, 2017a) • Interconnected infrastructure networks mean that there are increased compound effects (Ministry for the Environment, 2017a) • Snow cover is reducing more rapidly in Australia than NZ, so there may be an increase in ski-tourism). However, in the longer term, the higher temperature and fewer snow days will cause rising natural snowlines, however snowmaking is still possible (Hendrickx and Hreinsson, 2012). • Implication for being cut off from transport and associated impacts on the tourism and industry sector (Pearce et al. 2016)	

7 Considerations for Horizons Regional Council

This report has brought together multiple sources of data and information to understand potential climate change implications for the Manawatū-Whanganui Region administered by Horizons Regional Council. Climate change is likely to have wide ranging impacts on people, sectors, and environments across the region. Some of these impacts may not be felt immediately but may compound over time.

Some considerations for Horizons Regional Council, concerning how climate change may impact the Council's responsibilities, include:

- Infrastructure (e.g. transport, water-related infrastructure) is likely to be adversely impacted in coastal areas during large storm tides, and particularly in the Horowhenua District. A significant amount of infrastructure is exposed to river flooding in most districts.
- Increased intensity of extreme rainfall may cause more slips and landslides, impacting transport networks and services.
- Changes to floods and extreme rainfall may impact the council's flood protection schemes.
- Impacts on resource consent holders (e.g. dairy farming, forestry, horticulture) through climatic changes or coastal/fluvial inundation may affect the council's ability to manage the impacts on the environment.
- Changing frequency and magnitude of extreme events (e.g. storm-tides, floods) may affect the council's ability to respond and manage emergencies.

For future ratepayers, these impacts on the council's responsibilities as well as for different sectors in the Manawatū-Whanganui Region as a whole (as outlined throughout this report), will potentially affect the cost of living in general and may cause some areas to become unsuitable for their current land use (whether housing, agriculture, and so on). Impacts on various sectors and environments as discussed in this report may affect residents' incomes and therefore their ability to pay rates – a downstream consequence of this being that the council's tax base may be eroded over time (which will likely also be used to pay for climate change-related costs).

As noted in Section 3, while the effects of climate change may be felt by different sectors, they may or may not fall directly under the responsibility of the Regional Council. Some services or resources affected by climate change may be the responsibility of local government, but others may be the responsibility of the private sector. Based on the potential impacts, possible implications of climate change for local government and the private sector might include the need for Horizons Regional Council to either:

- directly adapt services or facilities under its jurisdiction (either through structural or policy work); or
- support communities to better adapt, thereby lessening the effect of climate change on the Manawatū-Whanganui Region.

This assessment has not explicitly considered climate change mitigation and adaptation options for the Manawatū-Whanganui Region. However, examples of possible implications for council are provided in Table 7-1 as a means to stimulate discussion among Horizons Regional Council and stakeholders about potential impacts and implications so that informed decisions can ultimately be made around climate change strategy.

Table 7-1: Examples of potential council responsibilities in different impact areas.

Impact area	Impact areas of council responsibility – considerations for council to act to minimise or address harm	Impact areas of private sector responsibility – considerations for council to enhance local (or even national) policy to support communities
People and their safety	Increased availability of emergency services and resource planners to monitor, anticipate severe events, respond and underpin recovery	General and seasonal awareness campaigns for personal safety and preparedness
Critical buildings such as hospitals	Options to minimise the impact need to be considered e.g., retrofitting of road infrastructure or buildings, walk ways	Support to communities and businesses for preparation for possible reductions in access to at-risk areas or reductions in service availability (advertising and awareness campaigns etc), especially in relation to key/ remote tourist facilities
Road infrastructure (submergence and increased risk of landslips, potentially cutting off access to airports, services)		
Rail		
Electricity and water infrastructure in the event of extreme floods, coastal inundation	Options to minimise the impact need to be considered e.g., targeted monitoring and management of key public resources, retrofitting of water and or power infrastructure or development of back-up systems, support to communities and businesses for preparation for possible power outages (advertising and awareness campaigns, outreach with the commercial and agricultural sector (esp. those reliant upon irrigation) etc)	
Agriculture and environment (fire risks and weeds, flooding, inundation, power outages, water outages risk of pests etc.)	Targeted fire, weed and water monitoring and management on key public lands, reserves and resources	Encouragement of responsible/ adaptive agriculture and forward planning for changes in climate
Private buildings, especially residential but also commercial and industrial		Strengthening of the enabling policy such as updating and enforcement of building codes, revised planning and zoning, promotion of asset insurance.

This research identified gaps in knowledge and areas outside the scope of this project which would be desirable to gain a full understanding of implications of climate change on the Manawatū-Whanganui Region.

Considering the resources and time available for the work in this project, it was agreed that analysis of the impacts of climate change on the local Māori community would not be explicitly addressed as this would require appropriate design, consultation and coordination with key interest groups. In the future, opportunities exist to include special consideration of Māori implications in modelling, provided that enough time and resources are available to design this. Work could include, for example, consultation and collaboration with iwi on cultural assets to include these in the exposure database. This would allow the impact of extreme events on key cultural assets to be explicitly noted in impact models.

It was identified that the Manawatū-Whanganui Region has a relatively high level of exposure to riverine flooding, with significant amounts of infrastructure located in known floodplains. While comprehensive guidance on likely changes to rainfall extremes is now available, comprehensive understanding of how this hazard projects onto flood risk for the Manawatū-Whanganui Region is not yet available.

Other areas of potential for future analysis include Education and Training, Manufacturing, and Healthcare and Social Assistance, around which only limited data was available for this analysis. Considering the importance of these sectors to the economic base of the region, there is value in investigating the nature these sectors in more detail in the future, in order to better understand the risks they face from climate change.

8 References

ACKERLEY, D., BELL, R. G., MULLAN, A. B. & MCMILLAN, H. 2013. Estimation of regional departures from global-average sea-level rise around New Zealand from AOGCM simulations. *Weather and Climate,* 33**,** 2-22.

AUSSEIL, A.-G., BODMIN, K., DAIGENAULT, A., TEIXEIRA, E. I., KELLER, E., BAISDEN, T., KIRSCHBAUM, M., TIMAR, L., DUNNINGHAM, A., ZAMMIT, C., STEPHENS, S., BELL, R. G., CAMERON, M., BLACKETT, P., HARMSWORTH, G., FRAME, B., REISINGER, A., TAIT, A. & RUTLEDGE, D. 2017. Climate Change Impacts and Implications for New Zealand to 2100: Synthesis report RA2 lowland case study. Synthesis Report LC2714. Climate Change Impacts and Implications for New Zealand to 2100. MBIE contract C01X1225, Wellington: 60p. Available online at: https://ccii.org.nz/app/uploads/2017/03/RA2-Lowland-Case-Study-Synthesis-report.pdf. .

BASHER, L., ELLIOTT, S., HUGHES, A., TAIT, A., PAGE, M., ROSSER, B., MCIVOR, I., DOUGLAS, G. & JONES, H. 2012. Impacts of climate change on erosion and erosion control methods - A critical review. MPI Technical Paper No: 2012/45, 216pp.

BEAVAN, R. J. & LITCHFIELD, N. J. 2012. Vertical land movement around the New Zealand coastline: implications for sea-level rise. GNS Science report, retrieved from www.kapiticoast.govt.nz/contentassets/a933446e8c094de8a946d20b9f36a1de/vertical-land-movement-around-the-nz-coastline.pdf.

CAREY-SMITH, T., HENDERSON, R. & SINGH, S. 2018. High Intensity Rainfall Design System Version 4, NIWA Client Report 2018022CH.

CHRISTIE, J. E. 2014. Adapting to a changing climate: a proposed framework for the conservation of terrestrial native biodiversity in New Zealand. Department of Conservation, Wellington, 23 p.

CHURCH, J. A., CLARK, P. U., CAZENAVE, A., GREGORY, J. M., JEVREJEVA, S., LEVERMANN, A., MERRIFIELD, M. A., MILNE, G. A., NEREM, R. S., NUNN, P. D., PAYNE, A. J., PFEFFER, W. T., STAMMER, D. & UNNIKRISHNAN, A. S. 2013a. Sea-level rise by 2100. *Science,* 342**,** 1445.

CHURCH, J. A., CLARK, P. U., CAZENAVE, A., GREGORY, J. M., JEVREJEVA, S., LEVERMANN, A., MERRIFIELD, M. A., MILNE, G. A., NEREM, R. S., NUNN, P. D., PAYNE, A. J., PFEFFER, W. T., STAMMER, D. & UNNIKRISHNAN, A. S. 2013b. Sea Level Change. *In:* STOCKER, T. F., QIN, D., PLATTNER, G.-K., TIGNOR, M., ALLEN, S., BOSCHUNG, J., NAUELS, A., XIA, Y., BEX, V. & MIDGLEY, P. M. (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

CHURCH, J. A. & WHITE, N. J. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics,* 32**,** 585-602.

CLARK, P. U., SHANKUN, J. D., MARCOTT, S. A., MIX, A. C., EBY, M., KULP, S., LEVERMANN, A., MILNE, G. A., PFISTER, P. L., SANTER, B. D., SCHRAG, D. P., SOLOMON, S., STOCKER, T. F., STRAUSS, B. H., WEAVER, A. J., WINKELMANN, R., ARCHER, D., BARD, E., GOLDNER, A., LAMBECK, K., PIERREHUMBERT, R. T. & PLATTNER, G.-K. 2016. Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. *Nature Climate Change,* 6**,** 360-369.

CLOTHIER, B., HALL, A. & GREEN, S. 2012. Chapter 6 - Horticulture: Adapting the horticulture and vegetable industries to climate change. *In:* CLARK, A. & NOTTAGE, R. (eds.) *Impacts of climate change on land-based sectors and adaptation options. Technical Report to the Sustainable Land Management and Climate Change Adaptation Technical Working Group, Ministry for Primary Industries, 408 p.*

CROW, S. K., BOOKER, D. J. & SNELDER, T. H. 2013. Contrasting influence of flow regime on freshwater fishes displaying diadromous and nondiadromous life histories. *Ecology of Freshwater Fish,* 22**,** 82-94.

CUMMINGS, V., HEWITT, J., ALLEN, S., MARRIOTT, P., BARR, N. & HEATH, P. 2013. Ocean acidification: impacts on key NZ molluscs, with a focus on flat oysters (Ostrea chiliensis). Final Research Report for the NZ Ministry of Primary Industries on project ZBD200913. 18 p.

DAIRYNZ. no date. *Heat Stress* [Online]. Available: https://www.dairynz.co.nz/animal/cow-health/heat-stress/ [Accessed].

DANGENDORF, S., MARCOS, M., MULLER, A., ZORITA, E., RIVA, R., BERK, K. & JENSEN, J. 2015. Detecting anthropogenic footprints in sea level rise. *Nature Communications,* 6.

DEATH, R., BOWIE, S. & O'DONNELL, C. 2016. Vulnerability of freshwater ecosystems due to climate change. *In:* ROBERTSON, H., BOWIE, S., DEATH, R. & COLLINS, D. (eds.) *Freshwater conservation under a changing climate. Proceedings of a workshop hosted by the Department of Conservation, 10-11 December 2013, Wellington.* Christchurch: Department of Conservation.

DEPARTMENT OF CONSERVATION 2010. New Zealand Coastal Policy Statement. Wellington: Department of Conservation.

FIGURES NZ 2019. Total agricultural land area in New Zealand. Available online at: https://figure.nz/chart/EF7EZQePFodPVKNW-OqC0ii4i2Vms8pxD. .

FIGURES NZ Undated. Available online at: https://figure.nz/chart/qHcXwvXcwlBE3MEL-D9ztKQs1unwP5Ove.

FISCHER, E. M. & KNUTTI, R. 2016. Observed heavy precipitation increase confirms theory and early models. *Nature Clim. Change,* 6**,** 986-911, doi:10.1038/nclimate3110.

HANNAH, J. & BELL, R. G. 2012. Regional Sea Level Trends in New Zealand. *Journal of Geophysical Research: Oceans,* 117**,** 1-7.

HENDERSON, R., COLLINS, D., DOYLE, M. & WATSON, J. 2018. Regional Flood Estimation Tool for New Zealand Final Report Part 2. NIWA Client Report, 2018177CH for Envirolink Tools (MBIE): 44.

HENDRICKX, J. & HREINSSON, E. O. 2012. The potential impact of climate change on seasonal snow in New Zealand: part II—industry vulnerability and future snowmaking potential. *Theor Appl Climatol,* 110**,** 619-630.

HENDRIKX, J., HREINSSON, E. O., CLARK, M. P. & MULLAN, A. B. 2012. The potential impact of climate change on seasonal snow in New Zealand: part I - an analysis using 12 GCMs. *Theoretical and Applied Climatology,* 110**,** 607-618.

HEWITT, J., ELLIS, J. I. & THRUSH, S. F. 2016. Multiple stressors, nonlinear effects and the implications of climate change impacts on marine coastal ecosystems. *Global Change Biology,* 22**,** 2665-2675.

HORIZONS REGIONAL COUNCIL 2016. Manawatu-Whanganui Economic Action Plan. Available online at: http://www.horizons.govt.nz/HRC/media/Media/Accelerate%2025/Manawat_-Whanganui-Economic-Action-Plan-August-2016-WEB.PDF.

HORIZONS REGIONAL COUNCIL 2018. Annual Plan 2017-2018. Available online at: http://www.horizons.govt.nz/publications-feedback/the-annual-plan.

HORIZONS REGIONAL COUNCIL 2019. About our region and Council. Available online at: https://www.horizons.govt.nz/about-our-region-and-council.

HORIZONS REGIONAL COUNCIL Undated. River and Drainage Schemes, Accessed online at: http://www.horizons.govt.nz/flood-emergency-management/flood-protection/river-drainage-schemes.

IPCC (ed.) 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC 2018. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Available online at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf.

KEAN, J. M., BROCKERHOFF, E. G., FOWLER, S. V., GERARD, P. J., LOGAN, D. P., MULLAN, A. B., SOOD, A., TOMPKINS, D. M. & WARD, D. F. 2015. Effects of climate change on current and potential biosecurity pests and diseases in New Zealand. Prepared for Ministry for Primary Industries, MPI Technical Paper No: 2015/25. 100p.

KOPP, R. E., HORTON, R. M., C.M., L., MITROVICA, J. X., OPPENHEIMER, M., RASUMUSSEN, D. J., STRAUSS, B. H. & TEBALDI, C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future,* 2**,** 383-406.

KOPP, R. E., KEMP, A. C., BITTERMANN, K., HORTON, B. P., DONNELLY, J. P., GEHRELS, W. R., HAY, C. C., MITROVICA, J. X., MORROW, E. D. & RAHMSTOR, S. 2016. Temperature-driven global sea-level variability in the Common Era. *Proceedings of the National Academy of Sciences,* 113**,** E1434-E1441.

LAW, C. S., BELL, J. J., BOSTOCK, H. C., CORNWALL, C. E., CUMMINGS, V. J., CURRIE, K., DAVY, S. K., GAMMON, M., HEPBURN, C. D., HURD, C. L., LAMARE, M., MIKALOFF-FLETCHER, S. E., NELSON, W. A., PARSONS, D. M., RAGG, N. L. C., SEWELL, M. A., SMITH, A. M. & TRACEY, D. M. 2017. Ocean acidification in New Zealand waters: trends and impacts. *New Zealand Journal of Marine and Freshwater Research***,** 1-41.

LAW, C. S., RICKARD, G. J., MIKALOFF-FLETCHER, S. E., PINKERTON, M., GORMAN, R. G., BEHRENS, E., CHISWELL, S. M., BOSTOCK, H. C., ANDERSON, O. & CURRIE, K. 2016. The New Zealand EEZ and the South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100. MBIE Contract C01X1225. 41pp.

LAW, C. S., RICKARD, G. J., MIKALOFF-FLETCHER, S. E., PINKERTON, M. H., BEHRENS, E., CHISWELL, S. M. & CURRIE, K. 2018. Climate change projections for the surface ocean around New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 52**,** 309-335.

LEINING, C. & KERR, S. 2018a. A Guide to the New Zealand Emissions Trading Scheme. Report prepared for the Ministry of the Environment. Wellington: Motu Economic and Public Policy Research.

LEINING, S. & KERR, S. 2018b. A Guide to the New Zealand Emissions Trading Scheme. Report prepared for the Ministry of the Environment. Retrieved from Wellington: https://motu.nz/assets/Documents/our-work/environment-and-agriculture/climate-change-mitigation/emissions-trading/ETS-Explanation-August-2018.pdf.

LOCAL GOVERNMENT ACT, N. S. 2002. Available online at: http://www.legislation.govt.nz/act/public/2002/0084/173.0/DLM170873.html.

LOCAL GOVERNMENT IN NEW ZEALAND 2011. Local Government in New Zealand - Local Councils, available online at: http://www.localcouncils.govt.nz/lgip.nsf/wpg_url/About-Local-Government-Local-Government-In-New-Zealand-Councils-roles-and-functions#RegionalCouncils.

MANAWATŪ-WHANGANUI EMERGENCY MANAGEMENT GROUP 2016. Civil Defence Emergency Management Group Plan 2016-2021. Retrieved from http://www.horizons.govt.nz/HRC/media/Media/Emergency%20Management/Manawatu-Wanganui-Civil-Defence-Group-Plan-v1-3.pdf.

MBIE 2018. Beyond commodities: Manufacturing into the future. NEW ZEALAND SECTORS REPORT SERIES, New Zealand. Available online at: https://www.mbie.govt.nz/assets/f0f81b6194/new-zealand-manufacturing-sector-report-2018.pdf.

MBIE Undated. About CCII (Climate Changes, Impacts and Implications for New Zealand). Available online at: https://ccii.org.nz/climate-changes-impacts-and-implications-nz/.

MCBRIDE, G., REEVE, G., PRITCHARD, M., LUNDQUIST, C., DAIGENAULT, A., BELL, R. G., BLACKETT, P., SWALES, A., WADWHA, S., TAIT, A. & ZAMMIT, C. 2016. The Firth of Thames and Lower

Waihou River. Synthesis Report RA2, Coastal Case Study. Climate Changes, Impacts and Implications for New Zealand to 2100. MBIE contract CO1X1225, 50pp.
MCGLONE, M. & WALKER, S. 2011. Potential effects of climate change on New Zealand's terrestrial biodiversity and policy recommendations for mitigation, adaptation and research. *Science for Conservation,* 312**,** 1-80.
MILLNER, J. P. & ROSKRUGE, N. R. 2013. The New Zealand arable industry. In Dymond, J. R. ed. Ecosystem services in New Zealand – conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand.
MINISTRY FOR THE ENVIRONMENT 2014. National Policy Statement for Freshwater Management.
MINISTRY FOR THE ENVIRONMENT 2015. Report on expiration of the additional period for fulfilling commitments by New Zealand. Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/true-up_period_report_by_New_Zealand_2015.pdf.
MINISTRY FOR THE ENVIRONMENT 2017a. Adapting to climate change in New Zealand: Stocktake report from the Climate Change Adaptation Technical Working Group. Retrieved from Wellington: http://www.mfe.govt.nz/sites/default/files/media/adapting-to-climate-change-stocktake-tag-report-final.pdf.
MINISTRY FOR THE ENVIRONMENT 2017b. Coastal Hazards and Climate Change: Guidance for local government. Wellington: Ministry for the Environment.
MINISTRY FOR THE ENVIRONMENT 2017c. Coastal hazards and climate change: Guidance for local government. Lead authors: Bell, R.; Lawrence, J.; Allan, S.; Blackett, P.; Stephens, S. Ministry for the Environment Publication ME-1292. Accessed at: http://www.mfe.govt.nz/publications/climate-change/preparing-coastal-change-summary-of-coastal-hazards-and-climate-change.
MINISTRY FOR THE ENVIRONMENT 2017d. New Zealand's Seventh National Communication: Fulfilling reporting requirements under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Wellington: Minsitry for the Environment.
MINISTRY FOR THE ENVIRONMENT 2018a. Climate change projections for New Zealand: atmospheric projections based on simulations undertaken for the IPCC 5th Assessment, 2nd edition.
MINISTRY FOR THE ENVIRONMENT 2018b. Hydrological projections for New Zealand rivers under climate change, NIWA client report 2018193CH prepared for the Ministry for the Environment, 107pp.
MINISTRY FOR THE ENVIRONMENT 2019a. Latest update on New Zealand's 2020 net position [Online]. Available: https://www.mfe.govt.nz/climate-change/climate-change-and-government/emissions-reduction-targets/reporting-our-targets-0 [Accessed 27 May 2019].
MINISTRY FOR THE ENVIRONMENT 2019b. Proposed Climate Change Response (Zero Carbon) Amendment Bill [Online]. https://www.mfe.govt.nz/climate-change/zero-carbon-amendment-bill [Accessed 31 May 2019].
MUNDAY, P. L., CHEAL, A. J. & DIXSON, D. L., ET AL. 2014. Behavioural impairment in reef fishes caused by ocean acidification at CO2 seeps. *Nature Climate Change* 4**,** 487-492.
NEW ZEALAND PARLIAMENT 2015. New Zealand's Intended Nationally Determined Contribution
NEW ZEALAND PARLIAMENT 2016. *National Interest Analysis: The Paris Agreement*.
NZ TRADE AND ENTERPRISE 2016. Manawatu Whanganui Regional Highlights, available online at: https://www.betterbydesign.org.nz/-/media/NZTE/Downloads/Investment-and-funding/Regional-investment-profiles/Manawatu-Wanganui-investment-profile.pdf.
PALMERSTON NORTH CITY COUNCIL 2018. Regional Economic Report - Manawatu-Whanganui Region. Accessed online at: https://www.pncc.govt.nz/media/3131105/regional-economic-report-manawatu-whanganui-horizons-region-june-2018.pdf.
PARLIAMENTARY COMMISSIONER FOR THE ENVIRONMENT 2012. Hydroelectricity or wild rivers? Climate change versus natural heritage. Wellington: Parliamentary Commissioner for the

Environment. Retrieved from: http://www.pce.parliament.nz/media/1277/wild-riversweb.pdf.
PAULIK, R., CRAIG, H. & COLLINS, D. 2019a. New Zealand fluvial and pluvial flood exposure. Prepared for the Deep South National Science Challenge, NIWA Client Report Number 2019118WN, 58pp.
PAULIK, R., STEPHENS, S., WADWHA, S., BELL, R. G., POPOVICH, B. & ROBINSON, B. 2019b. Coastal flooding exposure under future sea-level rise for New Zealand. Prepared for the Deep South National Science Challenge, NIWA Client Report Number 2019119WN, 76pp.
PEARCE, H. G., KERR, J., CLARK, A., MULLAN, A. B., ACKERLEY, D., CAREY-SMITH, T. & YANG, E. 2010. Improved estimates of the effect of climate change on NZ fire danger, Prepared for Ministry of Agriculture and Fisheries by Scion and NIWA, Scion Report No. 18087. 83p.
PEARCE, P. R., PAUL, V., MULLAN, A. B., ZAMMIT, C., SOOD, A., BELL, R. G. & LAW, C. S. 2016. Climate change and variability - Horizons Region. NIWA Client Report AKL2016-011, 91 pp.
REISINGER, A., KITCHING, R. L., CHIEW, F., HUGHES, L., NEWTON, P. C. D., SCHUSTER, S. S., TAIT, A. & WHETTON, P. 2014. Australasia. *In:* BARROS, V. R., FIELD, C. B., DOKKEN, D. J., MASTRANDREA, M. D., MACH, K. J., BILIR, T. E., CHATTERJEE, M., EBI, K. L., ESTRADA, Y. O., GENOVA, R. C., GIRMA, B., KISSEL, E. S., LEVY, A. N., MACCRACKEN, S., MASTRANDREA, P. R. & WHITE, L. L. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, and New York, NY, USA: Cambridge University Press.
RESOURCE MANAGEMENT ACT, N. S. 1991. Available online at: http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html.
ROWE, D. K., HICKS, M. & RICHARDSON, J. 2000. Reduced abundance of banded kokopu (Galaxias fasciatus) and other native fish in turbid rivers of the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 34**,** 545-556.
ROYAL SOCIETY OF NEW ZEALAND 2017. Human health impacts of climate change for New Zealand: Evidence summary. 18 pp. Available from: https://royalsociety.org.nz/assets/documents/Report-Human-Health-Impacts-of-Climate-Change-for-New-Zealand-Oct-2017.pdf.
RUTLEDGE, D., BAISDEN, T., CRADOCK-HENRY, N. A., KELLER, E., MASON, N., MULLAN, A. B., OVERTON, J., SOOD, A., STUART, S., TAIT, A., TIMAR, T., VETROVA, V., ZAMMIT, C. & DUNNINGHAM, A. 2017. Upper Waitaki Catchment. Synthesis Report RA2, Uplands Case Study. Climate Change Impacts and Implications (CCII) for New Zealand to 2100. Available online at: https://ccii.org.nz/app/uploads/2017/08/RA2-Uplands-Case-Study-Synthesis-report1.pdf.
SIMONSON, T. & HALL, G. 2019. Vulnerable: the quantum of local government infrastructure exposed to sea level rise. *In:* LOCAL GOVERNMENT NEW ZEALAND (ed.).
SLANGEN, A. B. A., CHURCH, J. A., AGOSTA, C., FETTWEIS, X., MARZEION, B. & RICHTER, K. 2016. Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change,* 6**,** 701-705.
STEPHENS, S., BELL, R. G. & LAWRENCE, J. 2017. Applying principles of uncertainty within coastal hazard assessments to better support coastal adaptation. *Journal of Marine Science and Engineering,* 5**,** 40, http://www.mdpi.com/2077-1312/5/3/40.
STRAUSS, B. H., KULP, S. & LEVERMANN, A. 2015. Carbon choices determine US cities committed to futures below sea level. *Proceedings of the National Academy of Sciences,* 112**,** 13508-13513.
TRENBERTH, K. E. 1999. Conceptual framework for changes of extremes of the hydrological cycle with climate change. *Climatic Change,* 42**,** 327-339, doi:10.1023/A:1005488920935.
WIKIPEDIA 2019. Manawatū-Whanganui, available online at: https://en.wikipedia.org/wiki/Manawatū-Whanganui.

WONG, P. P., LOSADA, I. J., GATTUSO, J.-P., HINKEL, J., KHATTABI, A., MCINNES, K. L., SAITO, Y. & SALLENGER, A. 2014. Coastal systems and low-lying areas. *In:* BARROS, V. R., FIELD, C. B., DOKKEN, D. J., MASTRANDREA, M. D., MACH, K. J., BILIR, T. E., CHATTERJEE, M., EBI, K. L., ESTRADA, Y. O., GENOVA, R. C., GIRMA, B., KISSEL, E. S., LEVY, A. N., MACCRACKEN, S., MASTRANDREA, P. R. & WHITE, L. L. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY, USA: Cambridge University Press.

9 Appendix: Characteristics of the Manawatū-Whanganui Region

This appendix details the characteristics of the Manawatū-Whanganui Region in terms of land use, demographics, environmental assets, and economic profile. The information here expands on the summary in Section 3.

9.1 Land use in the Manawatū-Whanganui Region

Land use in the Manawatū-Whanganui Region is dominated by agriculture. The region is the fourth largest agricultural region of the country (Figures NZ, 2019) with agriculture accounting for around two thirds of all its land (Staci Boyte, Horizons Regional Council, personal communication, May 2019). Agriculture is dominated by pastoral farming (see Table 9-1 on the level of high producing exotic grassland), although there is also extensive beef and sheep production, alongside dairy and arable (crop) farming. There is also a significant horticulture industry which produces potatoes and other vegetables. Exotic forestry is an important land use in the Manawatū-Whanganui Region.

Table 9-1: Key land cover types over time in hectares for the Manawatū-Whanganui Region. Source: New Zealand Land and Water Database (https://www.lawa.org.nz/download-data/#land-cover)

Detailed Category	1996	2001	2008	2012	% of total land cover (2012)
Transport infrastructure	446	446	503	503	0.0
Surface mine or dump	370	364	378	393	0.0
Sand or gravel	1887	1833	1817	1817	0.1
Landslide	637	662	655	655	0.0
Gravel or rock	12350	12350	12360	12360	0.6
Permanent snow and ice	272	272	272	272	0.0
Alpine grass/herb field	2172	2172	2172	2172	0.1
Built-up area (settlement)	10747	10855	11133	11178	0.5
Urban parkland/open space	3096	3103	3126	3125	0.1
Short-rotation cropland	15532	16599	17156	17222	0.8
Orchards, vineyards or other perennial crops	470	495	543	515	0.0
Forest – harvested	9570	7083	4105	15991	0.7
Exotic forest	110729	136252	145032	135703	6.1
Deciduous hardwoods	8071	8150	8186	8128	0.4
Indigenous forest	400329	400130	400069	400048	18.0
Broadleaved indigenous hardwoods	116146	115519	115995	116266	5.2
Depleted grassland	2936	2936	2936	2936	0.1
High producing exotic grassland	1219316	1202149	1198114	1196174	53.8
Low producing grassland	60025	55053	54124	56437	2.5
Herbaceous freshwater vegetation	5919	5864	5849	5849	0.3
Flaxland	1404	1404	1394	1394	0.1
Herbaceous saline vegetation	244	244	244	244	0.0
Tall tussock grassland	58040	57894	57906	57906	2.6
Gorse and/or Broom	15164	14068	13230	12694	0.6
Mixed exotic shrubland	983	961	1200	1218	0.1
Manuka and/or Kanuka	117200	117010	115235	112532	5.1
Matagouri or Grey scrub	588	589	589	589	0.0
Fernland	683	839	937	935	0.0
Sub-alpine shrubland	36311	36311	36311	36311	1.6
Lake or pond	2250	2284	2294	2294	0.1
River	8072	8070	8098	8102	0.4
Estuarine open water	99	99	99	99	0.0
Total regional area	2222059	2222059	2222059	2222059	100.0

9.2 Demographics

We have referred to the Horizons Region Annual Plan 2017-2018 for the most recent estimated population, given the most recent census data is from 2013 (Horizons Regional Council, 2018). Palmerston North is the largest population centre, followed by Whanganui. Other urban centres in the region are Levin, Feilding, Dannevirke, Taumarunui, Foxton, and Marton. Over half of the region's population live outside of these large towns and cities in small towns and rural areas (Table 9-2).

Table 9-2: Population distribution of Manawatū-Whanganui Region. Source: Horizons Annual Plan 2017-2018

District	Estimated population
Ruapehu District	12, 700
Whanganui District	43, 800
Manawatū-Rangitikei District	36, 900
Palmerston North City	86, 300
Tararua District	17, 550
Horowhenua District	39, 600
Total	**236, 800**

* May be subject to rounding errors.

We refer to the census data for more specific demographic information. According to the 2013 census, just over 220,000 people live in the Manawatū-Whanganui Region, accounting for around 5% of the national population generally (Table 9-3), and around 7% of the Māori population specifically (Table 9-4). Locally, Māori represent around 20% of the population. The region is very close in age structure to that of the national profile (Table 9-5).

Table 9-3: Population of Manawatū-Whanganui Region. Source: Statistics New Zealand

Sex	Manawatū-Whanganui Region	New Zealand	% national population
Male	107,820	2,064,015	5.22
Female	114,852	2,178,033	5.27
Total people	222,672	4,242,051	5.2

Table 9-4: Māori population of Manawatū-Whanganui Region. Source: Statistics New Zealand

Sex	Manawatū-Whanganui Region	New Zealand	% national population
Male	21,093	288,639	7.3
Female	22,503	309,966	7.3
Total people	43,596	598,602	7.3

Table 9-5: Age breakdown of Manawatū-Whanganui Region population. Source: Statistics New Zealand

Age	% of total Manawatū-Whanganui Region	National average
0-14	21%	20%
15-24	14%	14%
25-64	49%	51%
65+	16%	14%

9.2.1 Broad socioeconomic profile

Based on the 2013 census, conventional economic wealth in the Manawatū-Whanganui Region is below the national average. A lower proportion of individuals in the population have education to tertiary level and personal and household income is on average 10-20% below the national average (Table 9-6).

Table 9-6: Skills, income and work. Source: Statistics New Zealand

	Manawatū-Whanganui Region	New Zealand
% population tertiary educated	23%	29%
Personal income NZD pppy	25,000	28,500
Annual household income	50,000	63,800
Employment rate	59%	62%
Unemployment rate[7]	8%	7%
Housing ownership rate	65%	65%

9.2.2 Employment

Employment in the Region accounts for around 5% of national employment. The largest employment sectors in the region are Health Care and Social Assistance (12.7% of employed), Education and Training (10.8%) and Retail (10%) (Table 9-7).

Table 9-7: Employee count by sector. Source: Statistics New Zealand (data extracted 1 March 2019)

	Total New Zealand	Manawatū-Whanganui Region	% regional employment	% national sectoral employment
Agriculture, Forestry and Fishing	121200	9100	8.8	7.5
Mining	5300	100	0.1	1.9
Manufacturing	233700	11500	11.1	4.9
Electricity, Gas, Water and Waste Services	16500	830	0.8	5.0
Construction	170500	7100	6.9	4.2
Wholesale Trade	114600	4900	4.7	4.3
Retail Trade	216300	10300	10.0	4.8
Accommodation and Food Services	168800	6300	6.1	3.7
Transport, Postal and Warehousing	94000	3550	3.4	3.8
Information Media and Telecommunications	35800	840	0.8	2.3
Financial and Insurance Services	55300	1200	1.2	2.2
Rental, Hiring and Real Estate Services	34600	1300	1.3	3.8
Professional, Scientific and Technical Services	186400	4350	4.2	2.3
Administrative and Support Services	120100	3150	3.1	2.6
Public Administration and Safety	123700	9300	9.0	7.5
Education and Training	188600	11100	10.8	5.9

[7] Unemployed share of labour force (from Statistics New Zealand)

	Total New Zealand	Manawatū-Whanganui Region	% regional employment	% national sectoral employment
Health Care and Social Assistance	236200	13100	12.7	5.5
Arts and Recreation Services	42700	1700	1.6	4.0
Other Services	73700	3450	3.3	4.7
Total	**2237900**	**103200**	**100.0**	**4.6**

Unemployment hovers around eight per cent, marginally higher than a national average (Table 9-8).

Table 9-8: Unemployment rate by district. Source: Statistics New Zealand

	Unemployment rate, 2013 census
Ruapehu	8.1
Whanganui	9.6
Rangitikei	6.1
Manawatū	5.8
Palmerston North	7.5
Tararua	6.1
Horowhenua	10.1
Manawatū-Whanganui region	7.8
New Zealand	7.1

9.3 Environmental assets

The Manawatū-Whanganui region is predominantly rural. The region is dominated by two significant river catchments, the Whanganui and the Manawatū. In addition to its extensive water resources, the region has extensive fertile lands around the rivers that have underpinned considerable agricultural production. While occupied by Māori, the region was settled by Europeans in the 1800s, with the Manawatū Plains being more densely settled than the plains around the Manawatū River. Land around the Manawatū River remains heavily forested (Wikipedia, 2019).

The Manawatū-Whanganui region is around one fifth indigenous forest (Table 9-1). According to Wikipedia (2019), it contains areas of great ecological significance, reflected in the designation of approximately a seventh of its land area as part of the nation's conservation estate. The largest park in the region is Tongariro National Park, which – established in 1887 – is the oldest national park in the country. Whanganui National Park is slightly smaller and was established 99 years later. There are two state forest parks in the rugged, bush-clad Ruahine and Tararua Ranges. The four parks offer skiing, tramping, jetboating and white-water rafting and the opportunity to appreciate the environment (Wikipedia, 2019).

9.4 Economic profile

The greatest economic contributors to GDP in the Manawatū-Whanganui Region in 2016 (last year of data available) were manufacturing, public administration and safety, and healthcare and social assistance (Table 9-9). Services are the main economic contributor. Virtually all sectors are demonstrating growth trends. Apart from agriculture which was the fifth largest GDP contributor (decreasing substantially in value in recent years), natural resource industries did not feature highly in the GDP profile of the region, although they are important for employment purposes. For example, electricity, gas, water, and waste services were the 16th largest contributor to GDP in the region, while fishing, forestry, and mining were the 18th largest contributor (Table 9-9). Tourism is active in the region (see Table 9-9– food services and accommodation), targeting environment related activities such as skiing, tramping, jetboating and white-water rafting. However, it was only the 20th largest contributor of GDP at the last count (Table 9-9).

The next few sections highlight the most important sectors (for GDP) for the Manawatū-Whanganui Region.

Table 9-9: Gross domestic product, by industry (2011-2016 NZD millions), for the Manawatū-Whanganui Region. Source: Statistics New Zealand (data extraction March 2019)

Industry	**2011R**	**2012R**	**2013R**	**2014R**	**2015R**	**2016**	**General trend**	**2016 % GDP**	**Rank**
Agriculture	889	899	747	1,024	686	674	Decreasing	7.0	5
Forestry, fishing, mining, electricity, gas, water, and waste services:								0.0	
• Fishing, forestry, and mining	177	176	170	200	212	231	Increasing	2.4	18
• Electricity, gas, water, and waste services	228	226	266	287	288	307		3.2	16
Manufacturing:								0.0	
• Primary manufacturing	498	484	486	571	735	792		8.2	2
• Other manufacturing	282	276	274	284	328	329		3.4	15
Construction	507	515	493	462	491	511		5.3	9
Wholesale trade	361	384	391	421	441	436		4.5	11
Retail trade	456	472	483	494	498	492		5.1	10
Accommodation	37	46	34	33	35	38	Stable/ decreasing	0.4	21
Food services	101	108	106	112	117	124	Increasing	1.3	20
Transport, postal, and warehousing	291	289	303	315	339	360		3.7	14
Financial and insurance services	212	224	242	243	284	258		2.7	17
Rental, hiring, and real estate services	529	573	590	601	590	626		6.5	7
Owner-occupied property operation	528	555	582	586	599	616		6.4	8
Professional, scientific, and technical services	390	387	399	414	391	421		4.4	12
Administrative and support services	115	116	112	117	129	137		1.4	19
Public administration, defence, and safety	690	651	657	664	709	758		7.8	3
Education and training	602	610	616	608	632	642		6.6	6
Health care and social assistance	625	621	641	659	686	723		7.5	4
Information media and telecommunications and other services	378	329	330	345	367	379		3.9	13
GST on production, import duties, and other taxes	674	728	736	763	781	819		8.5	1
Gross domestic product	**8,571**	**8,670**	**8,659**	**9,204**	**9,339**	**9,675**		100.0	

Footnotes:

- R = revised
- Figures may not sum to totals due to rounding.
- Some ANZSIC 2006 industries have been combined to maintain data quality standards.
- The Accommodation and Food Services (RNAA.SG01NAC34B01__GH2) series have been discontinued and replaced by Accommodation (RNAA.SG01NAC34B01__GH3) and Food and Beverage Services (RNAA.SG01NAC34B01_GH4), for all years from 2000.

9.4.1 Manufacturing

Nationally, the Manawatū-Whanganui Region is the sixth largest region for manufacturing, accounting for 4.6% of manufacturing firms across the country and five per cent of all manufacturing employees (Figure 9-1 and Figure 9-2) (MBIE, 2018). According to MBIE (2018), Manawatū-Whanganui employment in manufacturing declined over 2008-2012 but has increased slightly and steadily until 2017.

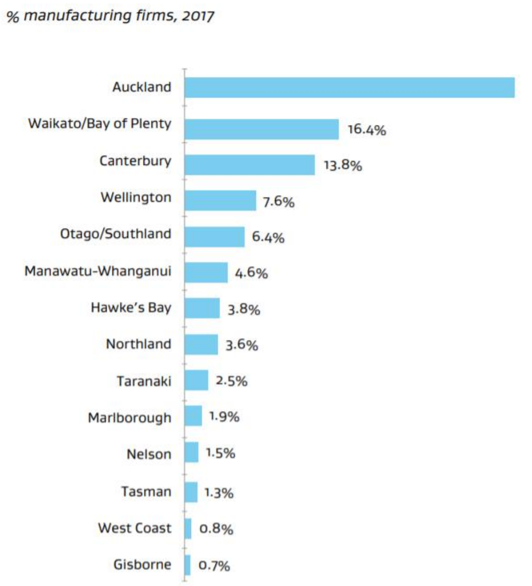


Figure 9-1: Share of manufacturing firms by region. Source: MBIE (2018)

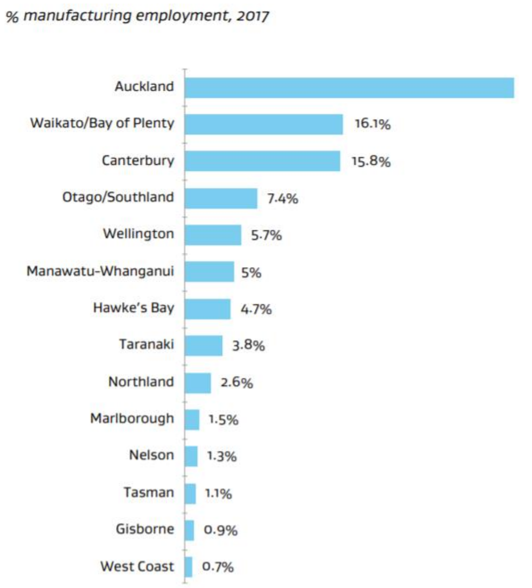


Figure 9-2: Share of manufacturing employment by region. Source: MBIE (2018)

Most businesses in the region are related to the agricultural sector (Wikipedia, 2019). This includes, for example, manufacturing of forestry products (such as paper) as well as the production of bio-pharmaceutical, agribusiness and food industries. Nevertheless, the region is also host to, and targeting, contact centre operations (NZ Trade and Enterprise, 2016). The latter relies on ongoing access to New Zealand's other main centres and high-speed digital connections to international markets.

9.4.2 Public Administration and Safety

Public Administration and Safety Division refers to units mainly engaged in Government legislative, executive and judicial activities; in providing physical, social, economic and general public safety and security services; and in enforcing regulations (Central, State or Local government services, policy development and enforcement, law, police, courts and public funds etc.).

9.4.3 Health Care and Social Assistance

Health care and social assistance in the region refers to hospital provision (major regional centre for hospital-based services) and residential care services, especially aged care. (This sector also includes Hospices, refuges, respite residential care, and other residential care facilities such as for cancer.)

9.4.4 Agriculture, forestry and fishing

Agriculture was the fifth largest GDP contributor in the region. Land use in the region is dominated by high producing grass, accounting for over half of all land (Table 9-1). According to Statistics New Zealand (https://figure.nz/chart/fdspH3Xo7XrlJb62-wVJN3ufOSOxnU58c), the key forms of agriculture in the region– in order of farm numbers – are:

- Sheep farming
- Sheep and cattle farming
- Beef cattle farming
- Dairy cattle farming; and
- Forestry (exotic and native).

Key farm types are sheep and cattle (including beef and dairy) farming. As well, there is a significant horticulture industry which produces vegetables (predominantly potatoes, squash and sweetcorn), as well as some cereal crops (Millner and Roskruge, 2013). Historically the region has been a key producer of wheat, although there has been a decrease in this crop. Other cereal crops are produced in the region, including 8% of the national barley harvest and 15% of the national maize harvest (area harvest in hectares). The Manawatū-Whanganui region is the main barley producer in the North Island (Millner and Roskruge, 2013).

Some of the agriculture in the region is reliant upon irrigation, particularly dairy where over 16,000 hectares of dairy land in the region is reportedly under irrigation. Other forms of agriculture may also draw on irrigation, but less so. For example, around 1600 hectares of non-dairy livestock land is irrigated, along with around 900 hectares of vegetable crop land (Figure 9-3).

Forestry has declined in recent years (Wikipedia, 2019) but includes both exotic and native forestry. Fishing in the region includes both freshwater fish (e.g. trout) and sea fish (e.g. snapper, blue cod and crayfish).

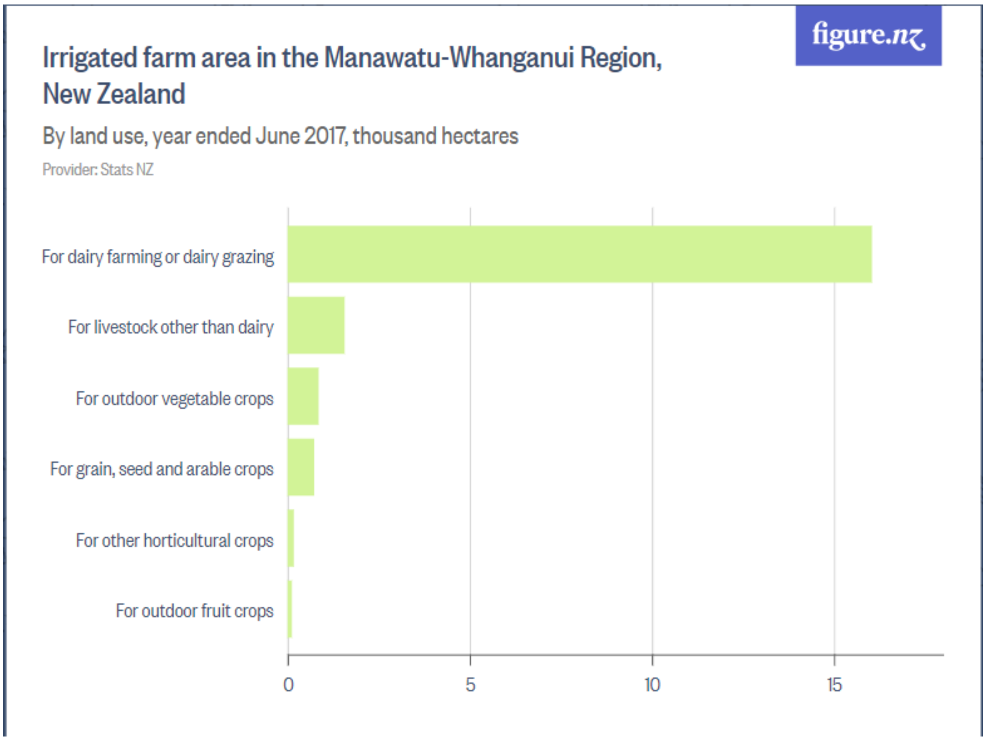


Figure 9-3: Irrigated farm area in the Manawatū-Whanganui Region. Source: Figures NZ (Undated), drawing on Stats NZ.

9.4.5 Tourism

Tourism in the region focuses on nature-based activities such as trekking, enjoyment of natural parks and skiing. In Palmerston North, the largest settlement, tourism is increasingly important, with Palmerston North City Council (2018) observing a 6% increase in spending over 2017-2018. This is higher than national average increase in income on the previous year (Table 9-10).

Table 9-10: Increases in tourism spending 2017-2018. Source: Palmerston North City Council (2018)

Manawatū-Whanganui Region	National tourism	International tourism
Domestic	4.4	6.9
International	13.9	11.0

Source: Palmerston North City Council (2018).

9.4.6 Areas of growth and development

According to Horizons Regional Council's 2018 Annual Plan (Horizons Regional Council, 2018), key issues highlighted for investment in the immediate future are:

- Transport
- Biodiversity and biosecurity
- Land and water use (including river schemes).

In the longer term, Horizons is to target several specific sectors to underpin future economic growth and wellbeing:

- Tourism (especially nature-based activities such as tramping, use of natural parks)

- Land use optimisation (via farming)
- Manuka honey
- Poultry meat and fresh vegetable production
- Care and lifestyle for older people
- Business process outsourcing (contact centres, food HQ)
- Realisation of Māori potential
- Enablers (Horizons Regional Council, Undated).

Agriculture and Food Innovation were two key industries in the Manawatū-Whanganui region which were presented as investment opportunity areas in an investment profile prepared by New Zealand Trade and Enterprise (NZ Trade and Enterprise, 2016). Manuka honey production and Tourism are areas of opportunity identified in the Manawatū-Whanganui Economic Action Plan (Horizons Regional Council, 2016).

Individual cities within the region also have targeted areas for economic growth. For example, Palmerston North City Council (2018) considers tourism and housing as areas for economic growth in its area in the last year, noting that housing increases have been driven by an increase in regional population. The total value of consents issued for Palmerston North over 2017-2018 was reported as NZD $593 million, an increase of NZD $140 million from the previous year (Table 9-11).

Table 9-11: Building consents issued in the Manawatū-Whanganui Region. Source: Palmerston North City Council (2018)

	Year ended 2017	Year ended 2018	Annual change
Residential consents (new dwellings, additions, alterations)			
• Horizons North West	75	84	13.0
• Horizons South East	256	314	23.0
Horizons total	330	398	21.0
New Zealand	12779	14203	11.0
Non-residential consents (new dwellings, additions, alterations)			
• Horizons North West	41	30	-26.0
• Horizons South East	82	164	101.0
Horizons total	123	195	59.0
New Zealand	6240	6883	
Total consents (new dwellings, additions, alterations)			
• Horizons North West	116	115	-1.0
• Horizons South East	338	478	42.0
Horizons total	453	593	31.0
New Zealand	19019	21086	11.0

Source (including internal inconsistencies): Statistics New Zealand, cited in Palmerston North City Council (2018).

10 Appendix: Climate change projections and impacts updated since 2016

10.1 Extreme rainfall projections

Key messages

- Extreme, rare rainfall events are likely to increase in intensity in New Zealand because a warmer atmosphere can hold more moisture.
- Augmentation factors (percentage increases per degree of warming) are provided which allow calculation of increases in rainfall depths for events of different durations.
- Short duration, rare rainfall events have the largest relative increases which approach 14% increase per degree of warming, while the longest duration events increase by 5-6% per degree of warming.
- Extreme rainfall projections for any New Zealand location can be viewed at www.hirds.niwa.co.nz
- Increases in extreme rainfall events may cause more flooding, particularly for parts of the region where average annual and seasonal rainfall is projected to increase.

Extreme rainfall projections for New Zealand have been updated by Carey-Smith et al. (2018) and Ministry for the Environment (2018a). This section summarises the updated projections.

Extreme, rare rainfall events may cause significant damage to land, buildings, and infrastructure. This section analyses how these rainfall events may change in the future for New Zealand.

Extreme rainfall events (and floods) are often considered in the context of return periods (e.g. 1-in-100-year rainfall events). A return period, also known as a recurrence interval, is an estimate of the likelihood of an event. It is a statistical measure typically based on historic data and probability distributions which calculate how often an event of a certain magnitude may occur. Return periods are often used in risk analysis and infrastructure design.

The theoretical return period is the inverse of the probability that the event will be exceeded in any one year. For example, a 1-in-10-year rainfall event has a 1/10 = 0.1 or 10% chance of being exceeded in any one year and a 1-in-100-year rainfall event has a 1/100 = 0.01 or 1% chance of being exceeded in any one year. However, this does not mean that a 1-in-100-year flood will happen regularly every 100 years, or only once in 100 years. The events with larger return periods (i.e. 1-in-100-year events) have larger rainfall amounts for the same duration as events with smaller return periods (i.e. 1-in-2-year events) because larger events occur less frequently (on average).

A warmer atmosphere can hold more moisture, so there is potential for heavier extreme rainfall with global increases in temperatures under climate change (Fischer and Knutti, 2016, Trenberth, 1999). The frequency of heavy rainfall events is 'very likely' to increase over most mid-latitude land areas (this includes New Zealand (IPCC, 2013)). Given the mountainous nature of New Zealand, spatial patterns of changes in rainfall extremes are expected to depend on changes in atmospheric circulation and storm tracks.

NIWA's High Intensity Rainfall Design System (HIRDS) allows rainfall event recurrence intervals to be calculated for any location in New Zealand. HIRDS calculates historic recurrence intervals as well as future potential recurrence intervals based on climate change scenarios. The 2018 HIRDS version 4 (Carey-Smith et al., 2018) updated the scenarios to those presented in this report (i.e. the IPCC's Fifth Assessment Report scenarios). The future rainfall increases calculated by the HIRDS v4 tool are based on a percent change per degree of warming. The expected percentage change in rainfall depth per degree of warming for an event with a 50-year return period is shown in Figure 10-1. This figure shows that, for this return period, the change in magnitude is positive throughout New Zealand and for all durations. It is also clear that as the event duration decreases, the increase in magnitude becomes more pronounced. There is also an indication that for shorter durations, regions in the north of the North Island and southeast of the South Island have larger increases than elsewhere in New Zealand. However, Carey-Smith et al. (2018) found the large regional variability between the regional climate model simulations does not provide enough confidence in these regional patterns and recommended that until further information suggests otherwise, climate change rainfall augmentation factors should be assumed to be uniform over New Zealand.

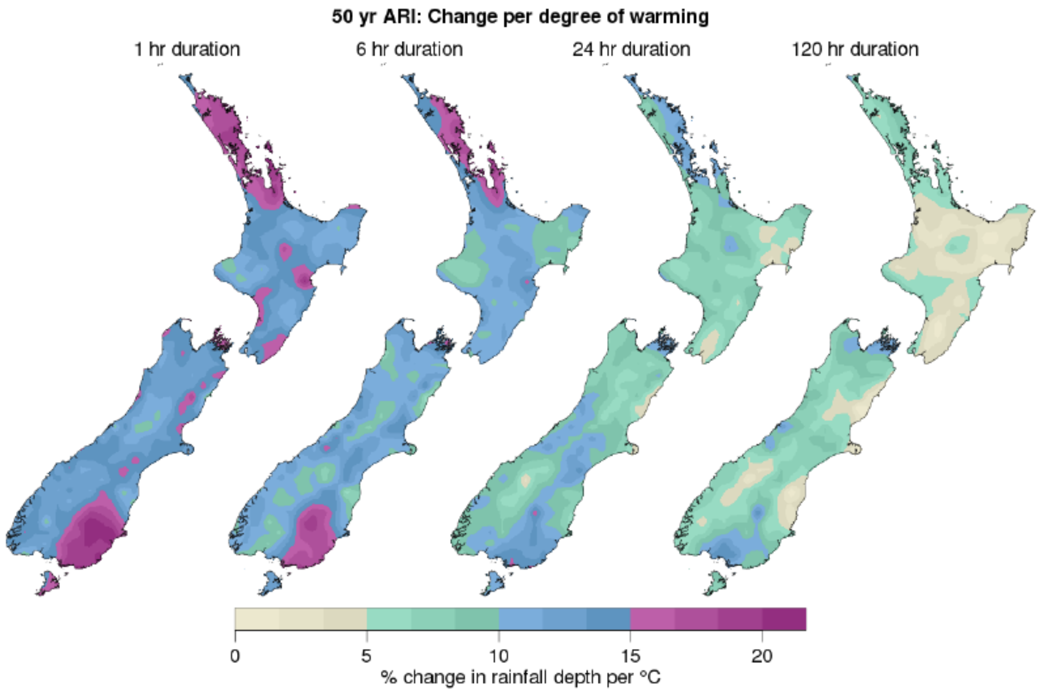


Figure 10-1: Change in the 50-year rainfall event magnitude for four different event durations. Each map combines all 24 different RCM simulations and shows the percentage change per degree of warming. Source: Ministry for the Environment (2018a).

Augmentation factors can be used to take a rainfall depth valid for the current climate and estimate the expected increase in this depth due to the projected temperature increase in a future climate. The augmentation factors provided in Table 10-1 have been estimated by taking an average over New Zealand. For each event duration and return period the median over New Zealand has been taken as the most likely estimate, and the 5th and 95th percentiles have been used to indicate the range of values that might be expected.

It is important that any projected temperature increase used in conjunction with the augmentation factors be from the same source as that used to estimate the augmentation factors. For this purpose,

Table 10-2 contains the mean temperature change for each RCP at three future time periods relative to 1986-2005 derived from the New Zealand regional climate model.

Table 10-1: Percentage change factors to estimate the increase in rainfall depth that is expected to result from a 1 degree increase in temperature. Source: Ministry for the Environment (2018a). The most likely percentage change is shown on the top of each row and the range provided below it shows the variability that could be expected across New Zealand based on the RCM results. To obtain change factors for a temperature change that is not 1 degree, the values in this table should be multiplied by the projected temperature change.

ARI: Duration	2 yr	5 yr	10 yr	20 yr	30 yr	50 yr	100 yr
1 hour	12.2 9.8 – 17.5	12.8 10.6 – 18.1	13.1 10.7 – 18.5	13.3 10.7 – 18.8	13.4 10.7 – 18.9	13.5 10.7 – 19.1	13.6 10.7 – 19.4
2 hours	11.7 9.2 – 18.0	12.3 9.9 – 18.4	12.6 10.0 – 18.7	12.8 10.1 – 19.0	12.9 10.1 – 19.1	13.0 10.1 – 19.3	13.1 10.1 – 19.6
6 hours	9.8 7.5 – 14.9	10.5 8.0 – 15.4	10.8 8.3 – 15.9	11.1 8.4 – 16.4	11.2 8.5 – 16.6	11.3 8.5 – 17.0	11.5 8.5 – 17.4
12 hours	8.5 5.7 – 13.5	9.2 6.5 – 13.9	9.5 6.8 – 14.2	9.7 7.1 – 14.5	9.8 7.2 – 14.8	9.9 7.3 – 15.1	10.1 7.3 – 15.4
24 hours	7.2 4.0 – 11.9	7.8 4.6 – 12.0	8.1 4.8 – 12.1	8.2 4.9 – 12.2	8.3 5.0 – 12.3	8.4 5.1 – 12.5	8.6 5.2 – 12.8
48 hours	6.1 2.6 – 11.0	6.7 3.1 – 11.1	7.0 3.3 – 11.2	7.2 3.4 – 11.3	7.3 3.4 – 11.3	7.4 3.4 – 11.4	7.5 3.5 – 11.5
72 hours	5.5 2.1 – 10.5	6.2 2.6 – 10.6	6.5 2.7 – 10.8	6.6 2.8 – 10.9	6.7 2.9 – 11.0	6.8 2.9 – 11.1	6.9 2.9 – 11.2
96 hours	5.1 1.7 – 10.0	5.7 2.2 – 10.2	6.0 2.4 – 10.5	6.2 2.5 – 10.7	6.3 2.6 – 10.9	6.4 2.6 – 11.0	6.5 2.7 – 11.2
120 hours	4.8 1.3 – 9.6	5.4 1.9 – 9.7	5.7 2.1 – 10.0	5.8 2.3 – 10.2	5.9 2.3 – 10.4	6.0 2.4 – 10.5	6.1 2.4 – 10.7

Table 10-2: New Zealand average temperature increases, in degrees, relative to 1986-2005 for four future emissions scenarios to be used with percentage change factors for extreme rainfall.

	2031-2050 "2040"	2081-2100 "2090"
RCP2.6	0.59	0.59
RCP4.5	0.74	1.21
RCP6.0	0.68	1.63
RCP8.5	0.85	2.58

HIRDS v4 can be freely accessed at www.hirds.niwa.co.nz.

10.2 River flow projections

Key messages

- River flow projections for 20 New Zealand rivers (including the Manawatū River) were produced by the Ministry for the Environment in 2018.
- Mean annual low flow is projected to decline in the Manawatū River
- Flow exceedance percentiles of 25%, 50%, 75% and 95% are projected to decline in the Manawatū River.
- Minor changes are projected for the other hydrological variables considered.
- Very few hydrological changes are apparent by mid-century, with most emerging by late-century.

River flow projections for New Zealand have been updated since the climate change projections for Manawatū-Whanganui Region were compiled in 2016 (Pearce et al., 2016), by Ministry for the Environment (2018b). This report, *Hydrological projections for New Zealand rivers under climate change* is accessible at: https://mfe.govt.nz/publications/climate-change/hydrological-projections-new-zealand-rivers-under-climate-change. This section summarises river flow projections for Manawatū-Whanganui Region from this report.

The report examined the potential impacts of climate change on hydrological conditions at 20 river mouths around New Zealand. River hydrology was simulated from 1971-2099 under climate conditions derived from six Global Climate Models and four scenarios of future greenhouse gas emissions, taken from the IPCC Fifth Assessment. A suite of hydrological variables was examined, together describing seasonal variations in average conditions as well as high and low flow extremes. Differences between baseline conditions (1986-2005) and mid-century (2031-2050) or late-century (2080-2099) were examined for any patterns with the different emissions scenarios that would suggest a climate change effect.

The hydrological variables analysed included:

- Mean annual and seasonal discharge = the mean discharge over the analysis period.
- Mean annual flood (MAF) = the mean of the series of each year's highest daily flow. Such a flow can be expected to have a recurrence interval of once every two to three years.
- Mean annual 7-day low flow (MALF) = the mean of the series of each year's lowest 7-day discharge.
- Frequency of ecologically important floods (FRE3) = the mean number of floods per year above a given threshold. The threshold is defined as three times the median discharge during the baseline period, and floods become distinct when separated by at least five days. This statistic is a general indicator of several in-stream ecological values, most importantly periphyton accrual. As such, changes in FRE3 under climate change must be assessed with respect to the same threshold flow.

- Flow percentiles = the flows equalled or exceeded 5%, 25%, 50%, 75% and 95% of the time. 5% exceedance probability corresponds to a high flow, 50% to the median flow, and 95% to a low flow.

The only river in the Manawatū-Whanganui Region considered in this study was the Manawatū River. The projected directions of change for different hydrological variables for all 20 rivers considered in New Zealand are displayed in Table 10-3, with the Manawatū River emphasised. Overall, mean annual low flow is projected to decline in the Manawatū River, as well as the flow exceedance percentiles of 25%, 50%, 75% and 95%. Minor changes are projected for the other hydrological variables considered. Very few hydrological changes are apparent by mid-century, with most emerging by late-century.

Table 10-3: Summary of the projected hydrological changes (direction indicated by the arrow/colour) for 20 rivers around New Zealand. Gaps with no arrows mean there was no discernible change detected in river flow. Source: Ministry for the Environment (2018b).

River	Mean flow					Flow extremes			Flow exceedance percentiles				
	Summer	Autumn	Winter	Spring	Annual	MALF	MAF	FRE3	5%	25%	50%	75%	95%
Wairoa			↓	↓	↓	↓		↓		↓	↓	↓	↓
Hoteo			↓	↓	↓	↓		↓		↓	↓	↓	↓
Waihou						↓							↓
Waikato				↓		↓				↓	↓	↓	↓
Rangitaiki						↓							↓
Waipaoa					↓	↓		↓		↓	↓	↓	↓
Waiapu		↓	↓	↓	↓	↓		↓		↓	↓	↓	↓
Waiongana			↑			↓							
Manawatu						↓				↓	↓	↓	↓
Tukituki		↓	↓	↓	↓	↓		↓		↓	↓	↓	↓
Ruamāhanga						↓				↓	↓	↓	↓
Motueka			↑		↑		↑	↑	↑	↑			↓
Maitai			↑		↑		↑		↑	↑			↓
Awatere			↑										
Buller			↑		↑	↓	↑	↑	↑	↑	↑		
Haast	↑	↑	↑	↑	↑		↑	↑	↑	↑	↑	↑	
Rakaia			↑				↑	↑	↑	↑	↑	↑	
Clutha			↑		↑		↑	↑	↑	↑	↑	↑	
Waiau			↑		↑		↑	↑	↑	↑	↑	↑	
Mataura			↑		↑		↑	↑	↑	↑	↑		

When interpreting these projections, it is important to consider several caveats:

- The results apply only to the coastal outlets of the studied rivers, not to individual upstream sub-catchments or nearby rivers (so the behaviour of the studied rivers cannot necessarily be extrapolated to other rivers in the region)
- The Mean Annual Flood metric reflects an event that is expected to occur once every two to three years and cannot be interpreted as robustly describing the effect climate change will have on rare flood events.
- Identification of a climate change effect is made difficult by inter-annual variability, variations among GCMs, and non-linearity of RCP effects.
- Not all hydrological differences are statistically or practically significant, even when averaged over 20-year periods. It is recommended that future assessments of climate change effects employ repeatable and objective tests of significance.

Detailed projections for the Manawatū River are presented in Table 10-4 and Table 10-5. Changes in mean flows (Table 10-4) show no discernible pattern with RCP. However, mean annual low flow (Table 10-5) tends to decline by late-century.

Table 10-4: Projected changes for the Manawatū River in seasonal and annual mean discharge (in %) between 1986-2005 and 2031-2050 "mid-century" and 2080-2099 "late-century". The changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

RCP	Summer	Autumn	Winter	Spring	Annual
Mid-century					
RCP8.5	-1 (-23, 13)	4 (-12, 6)	0 (-5, 13)	-2 (-11, 7)	1 (-9, 6)
RCP6.0	0 (-14, 25)	4 (-11, 9)	2 (-10, 8)	2 (-8, 15)	3 (-6, 10)
RCP4.5	-9 (-13, 32)	1 (-22, 12)	1 (-7, 5)	3 (-4, 12)	0 (-10, 10)
RCP2.6	-1 (-9, 29)	-1 (-6, 19)	3 (-7, 14)	1 (-4, 25)	2 (-2, 14)
Late-century					
RCP8.5	-16 (-27, 11)	-9 (-23, 3)	5 (-8, 9)	5 (-8, 9)	-3 (-15, 4)
RCP6.0	2 (-37, 11)	-5 (-16, 10)	3 (-3, 9)	3 (-3, 9)	0 (-9, 6)
RCP4.5	3 (-15, 17)	-8 (-15, 12)	-2 (-4, 10)	-2 (-4, 10)	-5 (-6, 10)
RCP2.6	-6 (-21, 23)	0 (-15, 11)	3 (0, 5)	3 (0, 5)	2 (-2, 5)

Table 10-5: Projected changes for the Manawatū River in mean annual 7-day low flow (MALF), mean annual flood (MAF), and the frequency of floods three times the median flow (FRE3) (in %) by mid-century and late-century. The changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

RCP	MALF	MAF	FRE3
Mid-century			
RCP 8.5	-8 (-20, 11)	21 (0, 29)	-3 (-26, 35)
RCP 6.0	-3 (-20, 4)	13 (3, 21)	4 (-27, 10)
RCP 4.5	-13 (-16, 0)	14 (-1, 44)	-8 (-24, 26)
RCP 2.6	7 (-12, 9)	28 (-18, 75)	-6 (-10, 33)
Late-century			
RCP 8.5	-19 (-31, -9)	18 (-8, 45)	-15 (-31, 22)
RCP 6.0	-11 (-28, 1)	8 (-18, 75)	-9 (-20, 14)
RCP 4.5	-6 (-19, 12)	7 (-28, 58)	-15 (-25, 14)
RCP 2.6	-12 (-14, 14)	7 (-15, 26)	-7 (-22, 3)

Analysis of flow records indicates that MAF has a strong correspondence with observed mean annual rainfall (Henderson et al., 2018). It is noteworthy that flood design standards for significant infrastructure are usually made based on events with annual exceedance probabilities much smaller than that represented by MAF. Analysis of regional climate model rainfall projections undertaken for the High Intensity Rainfall Design project (Carey-Smith et al., 2018), has shown that events with small annual exceedance probability are projected to increase ubiquitously across the country in a way that scales with increasing temperatures. As such, the MAF number shown here should not be considered a comprehensive metric for the possible impact of climate change on New Zealand flooding. The median and ranges presented highlight the noisiness of climate projections when shown as output for a single river from short twenty-year time slices of single model runs.

Projected differences in the exceedance probabilities of baseline flows are summarised in Table 10-6. They show whether historical flow thresholds calculated over the baseline period (1986-2005) for each global climate model, chosen to correspond to the 5%, 25%, 50%, 75%, and 95% exceedance probabilities, are exceeded more or less frequently in the future.

To illustrate how to interpret these results, consider a baseline flow percentile of 25% for the Manawatū River. This flow is a mid-to-high range flow exceeded 25% of the time during the simulated baseline period. During the mid-century period, the flow is exceeded 26% of the time for RCPs 2.6, 4.5 and 8.5, but for RCP6.0 the exceedance is 27%. That means that for RCP6.0 the flow threshold is exceeded slightly less often; i.e., the range of flows above this threshold become rarer.

For the Manawatū River, all exceedance flows except for the very highest (5% exceedance), are exceeded less often by late-century.

Table 10-6: Projected flow percentiles for baseline flow exceedance percentiles of equivalent discharge for the Manawatū River, by mid-century and late-century. The new percentiles are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

RCP	Baseline flow exceedance percentiles				
	5% (high flow)	25%	50%	75%	95% (low flow)
Mid-century					
RCP 8.5	5 (4, 7)	26 (21, 28)	51 (44, 53)	74 (68, 77)	94 (93, 96)
RCP 6.0	5 (4, 7)	27 (22, 30)	51 (48, 56)	76 (71, 77)	95 (93, 97)
RCP 4.5	5 (4, 7)	26 (21, 30)	50 (44, 56)	74 (69, 80)	94 (92, 96)
RCP 2.6	5 (5, 7)	26 (23, 32)	50 (48, 58)	75 (71, 79)	96 (94, 97)
Late-century					
RCP 8.5	5 (4, 7)	25 (17, 27)	47 (38, 52)	71 (67, 74)	93 (90, 95)
RCP 6.0	5 (4, 6)	25 (21, 27)	48 (42, 52)	73 (65, 75)	93 (91, 96)
RCP 4.5	5 (4, 7)	23 (22, 30)	47 (45, 54)	72 (70, 76)	95 (93, 97)
RCP 2.6	5 (4, 6)	26 (23, 27)	50 (47, 54)	75 (71, 77)	95 (92, 97)

Some notes about the use of mean annual flood and mean annual low flow projections:

Two of the variables chosen for the analysis – MAF and MALF – are typical variables used in hydrological analysis and either hazard management or water resource management. They are both indicators of only moderately extreme flow conditions. As such, it would be inaccurate to connect modelled differences in these variables to differences in either flood or drought hazard.

In the first case, the mean annual flood (MAF) is a flood, but not a large flood. This magnitude flood occurs, on average, every two to three years and is of a similar magnitude to the flow necessary to fill a river up to the top of its banks. This size of flood is rarely a nuisance or a hazard but is used in flood hazard analysis as a reference for the size of floods that could occur. Changes in MAF alone cannot be used to infer changes in flood hazard. For this, research would need to address the more extreme floods, in terms of both size and frequency, and both discharge and inundation extent. Translating the hazard into a risk would require the further consideration of social, cultural, economic, and environmental vulnerability of flood-prone areas.

In the second case, the mean annual low flow (MALF) is an indicator of low flow conditions (e.g., Ministry for the Environment 2008), widely used as a rule-of-thumb for setting minimum flows, but rivers with flows equal to MALF are not typically considered to be in drought. This magnitude of flow occurs, on average, every two to three years. MALF is used as an indicator of how low river flows can drop but does not describe the most extreme low flows that may occur, nor the implications. For this, research would need to address the more extreme low flow events and examine how these droughts affect social, cultural, economic, and environmental uses of water, whether in-stream or extractive.

10.3 Coastal hazards and climate change

Since the climate change projections report for Horizons Regional Council was produced in 2016 (Pearce et al., 2016), updated coastal hazards and climate change guidance has been published Ministry for the Environment (2017c). This report can be accessed from: http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government. This section provides a summary of recent sea-level rise trends and future projections for New Zealand.

Rising sea level in past decades is already affecting human activities and infrastructure in coastal areas, with a higher base mean sea level contributing to increased vulnerability to storms and tsunami. Key impacts of rising sea level are:

- gradual inundation of low-lying marsh and adjoining dry land on spring high tides
- escalation in the frequency of nuisance and damaging coastal flooding events
- exacerbated erosion of sand/gravel shorelines and unconsolidated cliffs (unless sediment supply increases)
- increased incursion of saltwater in lowland rivers and nearby groundwater aquifers, raising water tables in tidally-influenced groundwater systems.

These impacts will have increasing implications for development in coastal areas, along with environmental, societal and cultural effects. Local government road and 'three waters' infrastructure will also be increasingly affected, such as wastewater treatment plants and potable water supplies, besides capacity and performance issues with stormwater and overland drainage systems. Public transportation infrastructure and roads will also be affected, both by nuisance shallow flooding of saltwater (e.g. vehicle corrosion) and more disruptive flooding and damage from elevated storm-tides and wave overtopping.

There are three types of sea-level rise (SLR) in relation to observations and projections:

- absolute (or eustatic) rise in ocean levels, measured relative to the centre of the Earth, and usually expressed as a global mean (which is used in most sea-level projections e.g. IPCC).
- offsets (or departures) from the global mean absolute SLR for a regional sea, e.g. the sea around New Zealand. Significant variation can occur in response to warming and wind patterns between different regional seas around the Earth.
- local (or relative) SLR, which is the net rise from absolute, regional-sea offsets and local vertical land movement, measured relative to the local landmass. Local or regional adaptation to SLR needs to focus on this local rise.

The first two types of sea-level change are measured directly by satellites, using radar altimeters, or by coalescing several tide-gauge records after adjusting for local vertical land movement and ongoing changes in the Earth's crust following ice loading during the last Ice Age[8].

Local SLR is measured by tide gauges. One advantage of knowing the local SLR from these gauge measurements is that this directly tracks the SLR that has to be adapted to locally, or over the wider region represented by the gauge. If, for instance, the local landmass is subsiding, then the local (relative) SLR will be larger than the absolute rise in the adjacent ocean level acting alone (Figure 10-2).

[8] Scientific term is glacial isostatic adjustment (GIA)

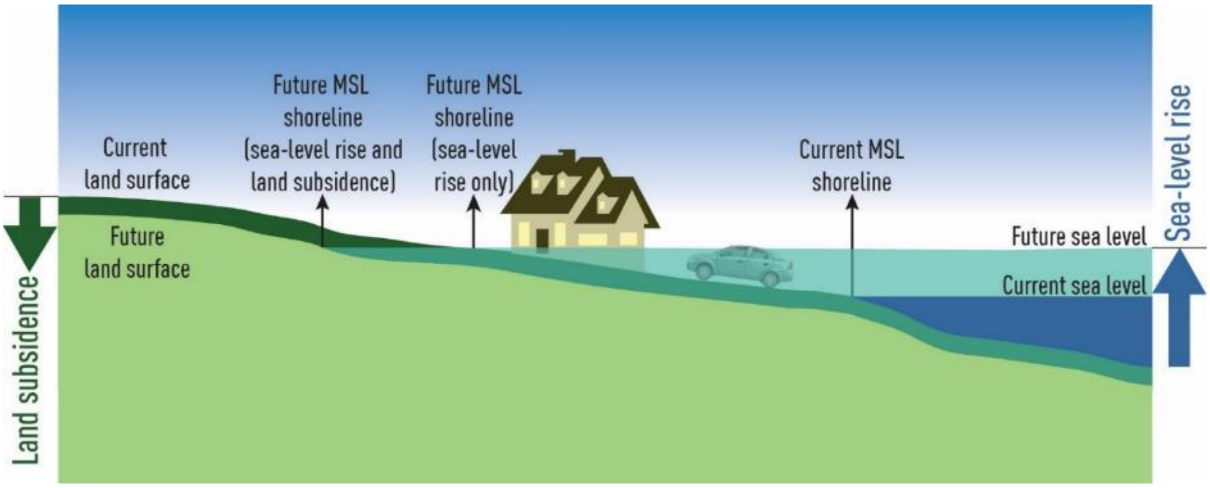


Figure 10-2: Difference in mean sea level (MSL) shoreline between absolute and local (relative) SLR where land subsidence occurs.

Changes in rate of rise

After a period of relative local stability over the past 2000–3000 years, with small rates of sea-level change of up to ±0.2 mm/year (Kopp et al., 2016), global sea level began to rise in the late 1800s. The steady rise in global mean sea level (MSL) since then is shown in Figure 10-3, based on updates of the data from Church and White (2011).

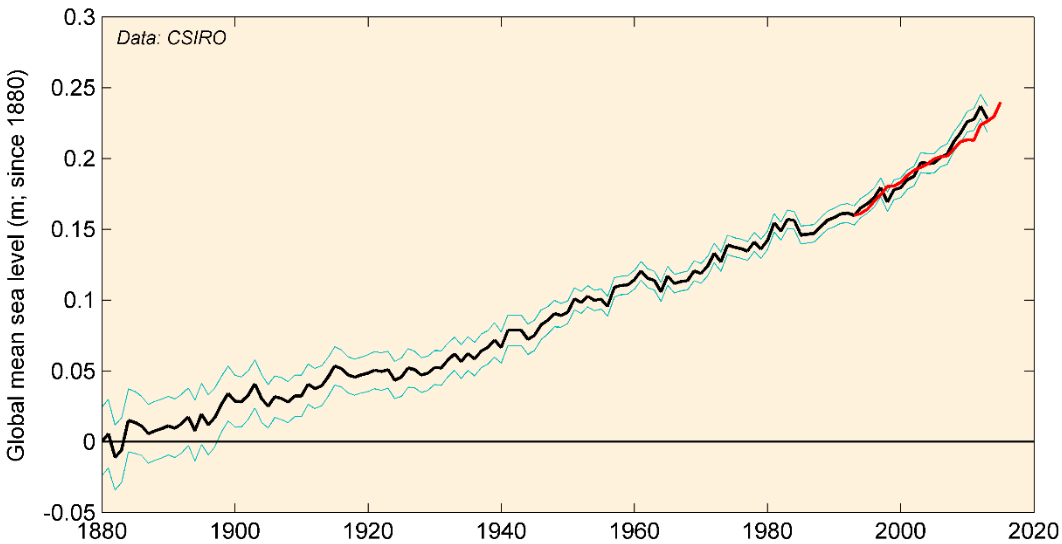


Figure 10-3: Cumulative changes in global mean sea level (MSL) since 1880, based on a reconstruction of long-term tide gauge measurements to end of 2013 (black) and recent satellite measurements to end 2015 (red). Lighter lines are the upper and lower bounds of the likely range (± 1 standard deviation) of the MSL from available tide gauges, which is a function of the number of measurements collected and the precision of the methods. Tide gauge data from Church and White (2011), updated to 2013; satellite data from CSIRO (2016).

From a synthesis of scientific publications, the Intergovernmental Panel on Climate Change determined that it is very likely that the mean rate of globally averaged sea-level rise was 1.7 ± 0.2 mm/year between 1901 and 2010, producing a total rise in global sea level over that period of 0.19

metres (±0.02 metres). A slightly higher annual rise of 2.0 ± 0.3 mm/year occurred in the 40-year period from 1971 to 2010 (Church et al., 2013b).

Contributors to global sea-level rise

As the temperature of the Earth's atmosphere changes so does sea level, although with a lagged response. Rising atmospheric temperature and sea-level change are linked by two main processes:

- Volume increase: As ocean water warms, its volume expands slightly – an effect that is cumulative over the entire depth of the oceans. This is converted mainly into a height increase as the oceans are largely constrained by continental coastlines (despite inundation of low-lying land areas).

- Mass increase: Changes in the land-based volumes of ice and water on land (namely glaciers and ice sheets, and to a lesser extent the net change in freshwater budgets) have led to an increase in the mass of water in the ocean, especially as ice stores diminish with increasing surface and ocean temperatures.

Recent studies have demonstrated that the anthropogenic contribution to the observed global SLR in the 20th century has been around 45–50% (Kopp et al., 2016, Dangendorf et al., 2015). The anthropogenic contribution since 1970 has risen to 69% [±31%] of the observed increase in global mean sea level (Slangen et al., 2016).

For the satellite era (from 1993 onwards, Figure 10-4), the recent trend in global-average MSL to July 2017, based on the CSIRO analysis of satellite altimeter data[9], is 3.4 ± 0.1 mm/year. This rate of increase, averaged over the past 24 years, is nearly double the global-average rate over the historic rate over the entire 20th century of 1.7-1.8 mm/year (Church et al., 2013b, Church and White, 2011). Natural climate variability from inter-annual to decadal climate cycles, especially the 20–30-year Interdecadal Pacific Oscillation (IPO) (which changed phase around 1999, partway into the satellite era), has contributed to part of the increased rate of rise. However, it is clear that anthropogenic climate change is also contributing an increasing proportion of this more recent increase in global SLR (Slangen et al., 2016).

[9] www.cmar.csiro.au/sealevel/sl_hist_last_decades.html - Rate includes adjustments for both inverse barometer and glacial isostatic adjustment.

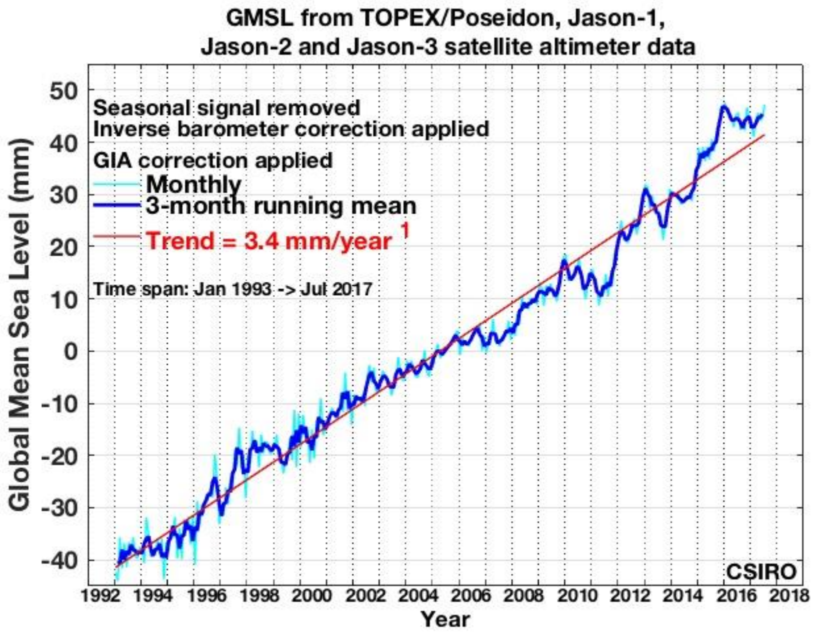


Figure 10-4: Time series and trend in global average sea level over the satellite era from January 1993 to July 2017. Adjustments for glacial isostatic adjustment (GIA), following crustal response to the last Ice Age, and inverted barometer (annual air pressure differences) have been made. Retrieved from CSIRO web site: http://www.cmar.csiro.au/sealevel/sl_hist_last_decades.html

Sea-level rise for New Zealand waters

Changes in annual local MSL at the four main ports in New Zealand from 1900 to 2015 are shown in Figure 10-5. MSL is plotted relative to the average for each time series over the same 1986–2005 baseline period used for IPCC AR5 projections. The initial period of IPCC global-mean projections of SLR for RCP8.5 and RCP2.6 scenarios are also shown for a general comparison.

Considerable variability occurs from year to year, influenced by seasonal changes, the two- to four-year El Niño-Southern Oscillation and the IPO over 20-30-year cycles. The notable rapid rise in SLR in 1999 across all port sites is a result of a regime shift to the negative phase of the IPO. Climate variability masks the underlying rise caused by climate change, so long records are needed to extract robust trends.

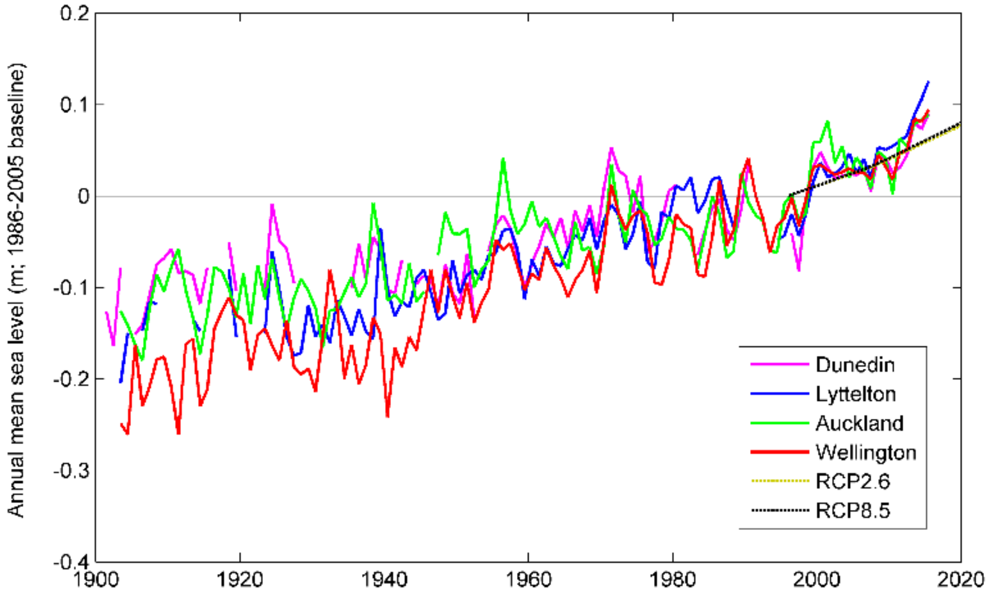


Figure 10-5: Change in annual local MSL for the four main ports from 1900–2015, and initial global-mean SLR projections for RCP2.6 and RCP8.5 to 2020 (dashed lines). Relative to the average MSL over the baseline period 1986–2005 (used for IPCC AR5 projections of SLR, with mid-point at 1996). (Source data: Hannah and Bell (2012), updated to 2015; Church et al. (2013a)).

Trends from these long-term port records, along with inferred trends from six other gauge sites used to establish local survey datums last century, were derived by Hannah and Bell (2012) for records up to and including 2008. The average trend for the local or relative SLR at the four main ports up to 2008 was 1.7±0.1 mm/yr, ranging from a local rate of 1.3 mm/yr at Dunedin to 2.0 mm/yr in Wellington.

Adding on the average glacial isostatic adjustment (GIA) for New Zealand, due to post-Ice Age rebound of the Earth's crust of around 0.3 mm/yr (Hannah and Bell, 2012) yields an absolute SLR of around 2.0 mm/yr for New Zealand ocean waters. This is at the upper end of observations of global mean SLR of 1.7±0.2 mm/yr from 1900 to 2010 from the IPCC AR5 (Church et al, 2013).

Local sea-level or RSLR trends over the past 60-100 years with standard deviations were analysed at 10 gauge sites by Hannah and Bell (2012), with an average rise of 1.7 mm/year from early last century up to 2008. The trends were updated to 2015 (except for Whangarei), as shown in Figure 10-6, with the national average rate now closer to 1.8 mm/year.

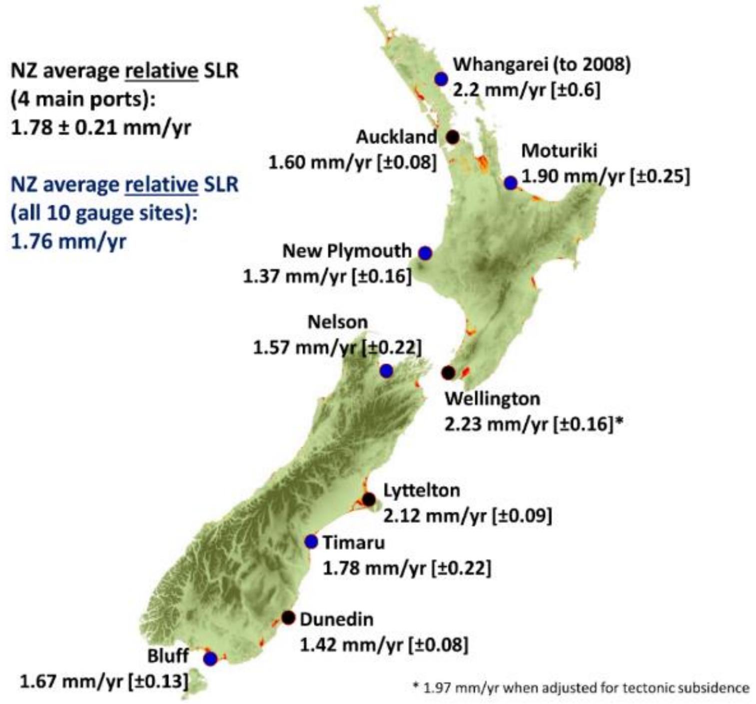


Figure 10-6: Historic long-term RSLR rates for the 20th century up to and including 2015 (excluding Whangarei), determined from longer sea-level gauge records at the four main ports. Note: Standard deviations of the trend are listed in the brackets. Sources: analysis up to end of 2008 from Hannah and Bell (2012) updated with seven years of MSL data to end of 2015 (J Hannah, pers. comm., 2016); sea-level data from various port companies is acknowledged.

Adaptation to SLR requires knowledge on why and how local SLR around New Zealand is affected by ongoing vertical land movement. Of most concern is the presence of any significant ongoing subsidence of the landmass, which will exacerbate the absolute ocean SLR (Figure 10-2).

Future projections of SLR at some locations or regions in New Zealand will need to factor in estimates of ongoing vertical land movement. Measurements of vertical (and horizontal) land movement have been undertaken by continuous GPS (cGPS) stations around New Zealand over the past decade or more. Vertical land movement was analysed by Beavan and Litchfield (2012), who determined that the lower North Island (including sites in Manawatū-Whanganui Region) is subsiding presently on average at 1-3 mm/yr due to interseismic slow-slip activity (Figure 10-7). It is not clear whether subsidence will continue at this rate. Any significant long-term vertical land movement (beyond ±0.5 mm/yr, the accuracy of the rate at which trends can be extracted from 10-year records) should be factored into local SLR projections, especially if the land is subsiding, because this will exacerbate the local net rise in sea level that will need to be adapted to (Figure 10-2).

Future major earthquake displacements for a particular locality are deeply uncertain (both when and by how much). Unlike the ongoing sea-level rise, they could be either subsidence or uplift, other than those areas with a clear geological history of only uplift or subsidence (Beavan and Litchfield, 2012).

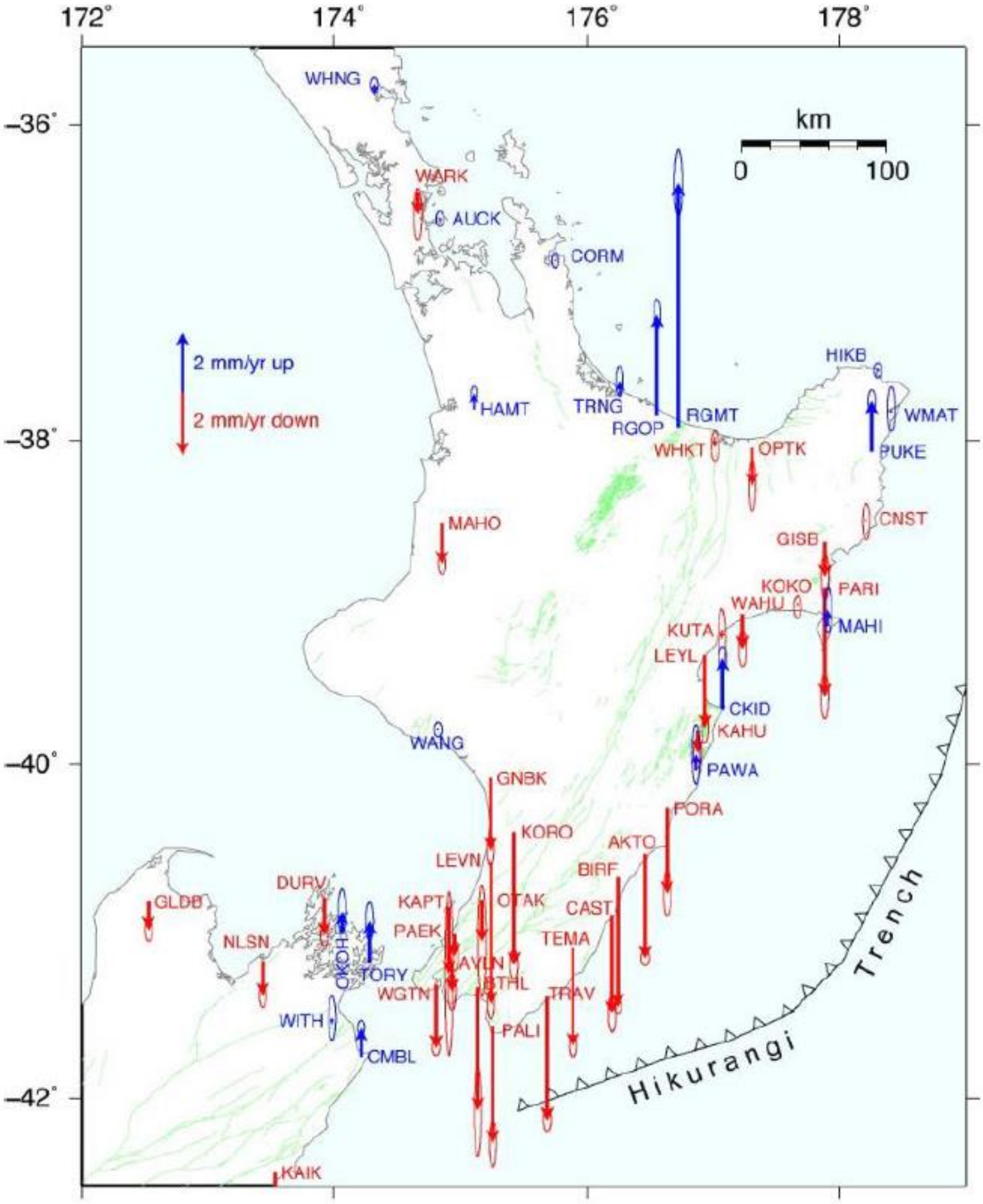


Figure 10-7: Average vertical land movements (mm/yr) for near-coastal continuous GPS sites across central New Zealand regions. Source: Beavan and Litchfield (2012).

Projections for sea-level rise

The primary climate driver for SLR is global and regional surface temperature, which is strongly influenced by greenhouse gas emissions. With the greenhouse gases currently in the atmosphere and the heat stored in the ocean, the world is already committed to further temperature increases, and an ongoing lagged response to SLR, because of the inertia in warming the deep oceans and the melting of the vast polar ice sheets. Cumulative global emissions to date have already committed the Earth to an eventual 1.6–1.7 m of global SLR relative to the present level (Strauss et al., 2015, Clark et al., 2016), even if no further net global emissions occur. However, depending on how continuing emissions track during the rest of this century (particularly the next few decades), realising this present commitment to SLR could take one to two centuries.

The IPCC AR5 (Church et al., 2013a) projections out to 2100 are provided in Figure 10-8. These projections cover the likely range of variability for the lowest and highest RCP2.6 and RCP8.5 scenarios out to 2100, and all four RCPs for the averaging period 2081-2100. The zero baseline for these projections is the averaging period for MSL from 1986–2005 (same as for Figure 10-5).

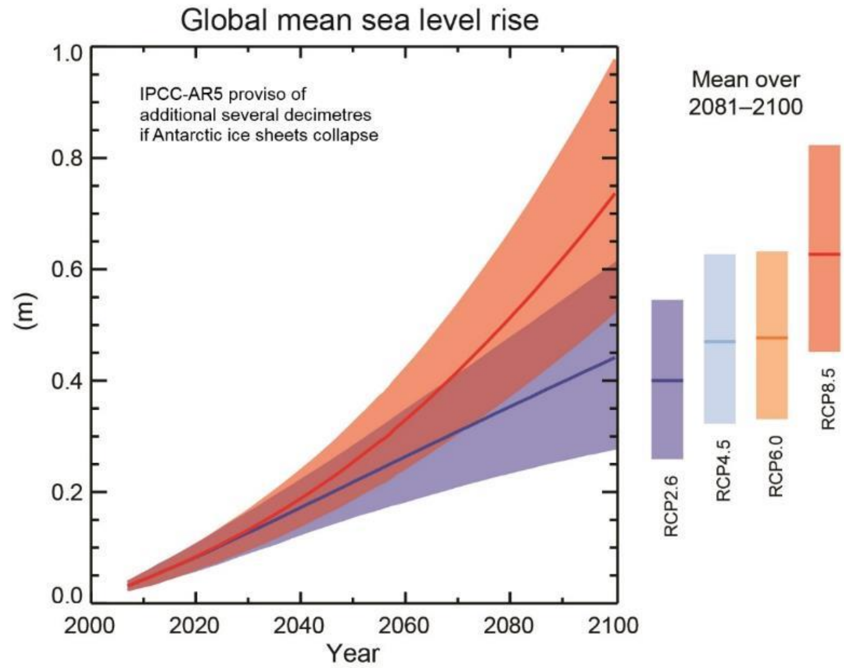


Figure 10-8: IPCC AR5 projections of global-average MSL rise (metres, relative to a base MSL of 1986-2005) covering the range of scenarios from RCP2.6 to RCP8.5. The heavy line shows the median estimate for that RCP, while the shaded area covers the "likely range" projections for the RCP, with a 33% chance SLR could be outside that range. The bars on the right show the median and "likely range" for all four RCPs averaged over the last two decades of this century (2081–2100), hence are lower than projections ending at 2100 in the main plot. (From IPCC (2013)).

Key statements on SLR in the IPCC AR5 (using the calibrated language for uncertainty and confidence in italics), include (Church et al., 2013a):

- Global mean SLR will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010.
- By 2100, global-average SLR will *likely* (i.e. 66% chance) be in the range 0.28–0.61 m [RCP2.6], 0.36–0.71 m [RCP4.5], 0.38–0.73 m [RCP6.0] and 0.52–0.98 m [RCP8.5].
- Onset of the collapse of the marine components of the Antarctic ice sheets could cause global MSL to rise substantially above the *likely* range (Figure 10-8) during this century. While the contribution cannot be precisely quantified, there is *medium confidence* that it would not exceed several tenths of a metre[10] of SLR by 2100.
- It is *virtually certain* that global mean SLR will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.

[10] Or decimetres (one-tenth of a metre).

- The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated SLR of up to 7 metres, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures.
- Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment.

Additional key statements in the IPCC Special Report on Global Warming of 1.5 degrees (IPCC, 2018) have strengthened the level of concern for the stability of polar ice sheets. These include that marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (medium confidence).

Use of global projections to generate New Zealand SLR scenarios

A set of all four RCP projections for New Zealand is shown in Figure 10-9, based on the median projections from IPCC (Church et al., 2013b). An additional scenario is presented here, which is the 83rd percentile of RCP8.5 (i.e., upper end of the "likely range"). This more extreme scenario is presented to cover the possibility of polar ice sheet instabilities not factored into the IPCC projections (Stephens et al., 2017). Small offsets have been added to the global average SLR projections to account for a slightly higher (5-10%) increase in SLR in seas around New Zealand compared to the global average projections (Ackerley et al., 2013). The base set of global SLR projections is extended to 2120, to align with the planning timeframe of at least 100 years stipulated in the New Zealand Coastal Policy Statement 2010.

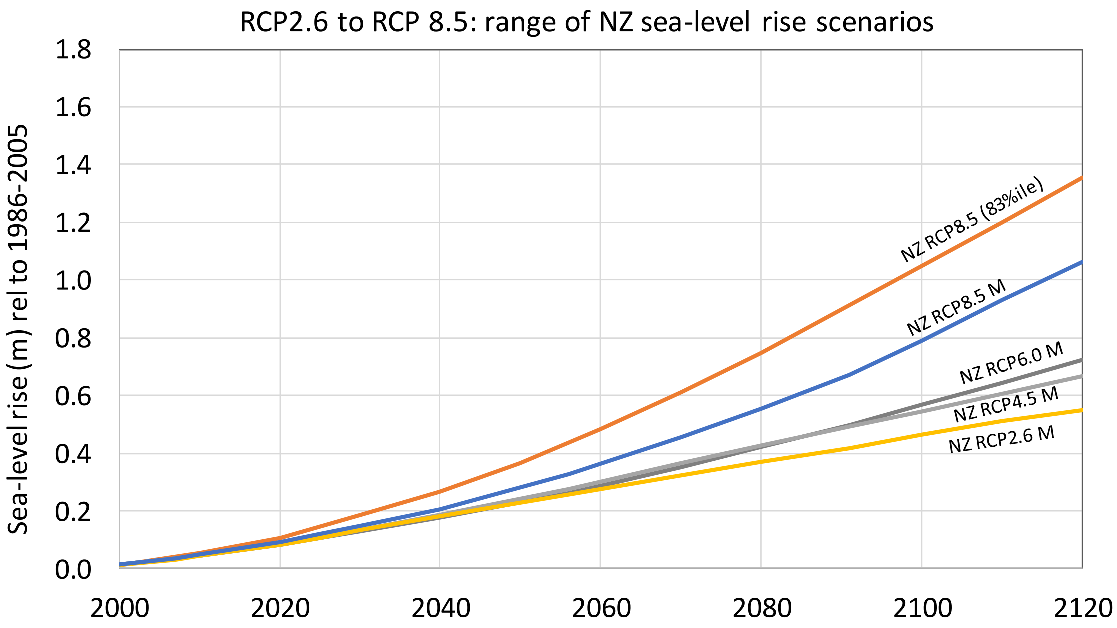


Figure 10-9: SLR scenarios for New Zealand seas, based on a set of median projections for all four RCPs (based on Church et al., 2013b) plus a higher 83rd percentile RCP8.5 projection (based on (Kopp et al., 2014)). The M next to the RCP on the plot stands for median. Note: for New Zealand seas, SLR projections will be around 5-10% higher than the global mean SLR published by IPCC, so between 2.5 to 5 cm by 2100 has been added to the median global average projections, and 7.5 cm to the higher scenario.

To assist with adaptive approaches to planning, the bracketed time window (approximate earliest to latest) when various SLR increments will be reached is shown for all scenarios in Table 10-7 (except for NZ RCP6.0 which is similar to NZ RCP4.5). For example, 0.5 m of SLR for New Zealand is projected to occur by 2060 at the earliest (assuming a RCP8.5 83rd percentile scenario described above) and 2110 at the latest (under the low-emission RCP2.6 scenario). Even earlier exceedance of the specific SLR increment cannot be entirely ruled out (depending on the future emission controls and possible runaway polar ice sheet responses). Exceedance of a 1 m SLR is projected by 2100 for a possible earliest (based on the RCP8.5 83rd percentile scenario) and after 2200 at the latest.

Table 10-7: Approximate years, from possible earliest to latest, when specific SLR increments (metres above 1986-2005 baseline) could be reached for various projection scenarios of SLR for the wider New Zealand region. From Stephens et al. (2017)

SLR (metres)	Year achieved for RCP8.5 (83%ile)	Year achieved for RCP8.5 (median)	Year achieved for RCP4.5 (median)	Year achieved for RCP2.6 (median)
0.3	2045	2050	2060	2070
0.4	2055	2065	2075	2090
0.5	2060	2075	2090	2110
0.6	2070	2085	2110	2130
0.7	2075	2090	2125	2155
0.8	2085	2100	2140	2175
0.9	2090	2110	2155	2200
1.0	2100	2115	2170	>2200
1.2	2110	2130	2200	>2200
1.5	2130	2160	>2200	>2200
1.8	2145	2180	>2200	>2200
1.9	2150	2195	>2200	>2200

11 Appendix: Assets at risk from sea-level rise and flood hazards

This information is additional to that presented in Section 5 and 6. Table 11-1 shows a region-by-region breakdown of RiskScape asset class exposure for coastal inundation, using 0.9 m of sea-level rise and a 100-year return period storm-tide event as an example (more sea-level elevation breakdowns can be found in Paulik et al. (2019b). Table 11-2 shows a region-by-region breakdown of asset class exposure for flood hazard area. Table 11-3 shows the exposure to each level of coastal inundation and flood hazard for each asset class, for the different districts of the Manawatū-Whanganui Region as well as the region as a whole.

Table 11-1: National and regional level exposure of elements at risk to a 100-year return period storm-tide event +0.9 m sea-level rise above present-day MSL on land with available LIDAR DEM coverage (Manawatu-Whanganui region highlighted). Source: Paulik et al. (2019b)

Region*	Population (#)	Buildings		Transport			Electricity (National Grid)			Three-Waters		Land Cover (km²)		
		Building (#)	Replacement Value (2016 NZD$ Billion)	Roads (km)	Railway (km)	Airports (#)	Transmission Lines (km)	Structures (#)	Sites (#)	Pipelines (km)	Nodes (#)	Built	Production	Natural or Undeveloped
Northland	4,084	5,265	1.33	153.7	11.4	0	7.6	11	0	227.0	7,323	5.5	86.2	17.7
Auckland	8,890	5,371	3.22	136.6	16.2	1	35.4	45	0	424.3	16,140	6.9	112.0	32.3
Waikato	10,561	10,663	2.20	503.5	8.9	4	17.2	13	0	276.7	6,903	9	629.7	162.8
Bay of Plenty	19,549	15,828	3.81	379.9	28	2	49.8	116	0	910.9	27,844	10.3	307.7	38.6
Gisborne	505	649	0.18	34.9	11	1	0	0	0	50.3	1,200	1.2	36.2	7.9
Hawke's Bay	24,207	19,066	4.36	208.1	5	1	1.3	1	0	1,051.1	38,433	12.2	70.7	35.3
Taranaki	703	695	0.13	22.2	1.9	0	0.8	7	2	58.6	961	0.8	9.4	8.7
Manawatu-Whanganui	2,094	3,212	0.61	72.8	4.6	1	15	16	0	116.1	3,126	3.4	110.0	29.8
Wellington	20,775	13,330	5.59	157.1	7.7	2	4	3	0	1,009.7	22,210	8.2	110.8	114.5
Canterbury	47,777	27,224	7.68	497.2	19.1	0	19.4	39	1	1,226.9	No Data**	29.4	179.3	96.7
Otago	12,553	7,312	2.56	286.8	48.1	1	11.9	18	2	616.6	16,300	7.3	165.0	58.9
Southland	4,685	2,578	1.16	66.8	12.4	0	0	0	0	233.6	3,963	4.2	8.3	8.8
Tasman	5,512	2,979	0.87	102	0	0	0	0	0	224.6	7,840	4.1	35.7	12.8
Nelson	3,288	2,752	1.07	39.9	0	1	0	0	0	355.4	9,884	3.4	0.8	2.2
Marlborough	1,615	1,016	0.32	52.1	1.9	0	24.9	36	0	3.8***	6***	1.1	54.5	14.4
NZ Total	**166,789**	**117,940**	**35.1**	**2,713**	**176**	**14**	**187**	**305**	**5**	**6,786**	**162,130**	**107**	**1,916**	**641**

* No LIDAR available for West Coast region.
** No three-waters infrastructure node data available for Canterbury region.
*** Limited three-waters infrastructure pipeline and node data available for Marlborough region.

Table 11-2: National and regional level exposure of elements at risk within identified New Zealand flood hazard areas (Manawatu-Whanganui region highlighted). Source: Paulik et al. (2019a)

Region*	Population (#)	Buildings		Transport			Electricity (National Grid)			Three-Waters		Land Cover (km^2)		
		Total (#)	Replacement Value (2016 NZD$ Billion)	Roads (km)	Railway (km)	Airports (#)	Transmission Lines (km)	Structures (#)	Sites (#)	Pipelines (km)	Nodes (#)	Built	Production	Natural or Undeveloped
Northland	15,237	14,263	3.4	1,141	163	0	51	53	0	515	15,619	9	896	141
Auckland	118,172	48,167	27.6	1,259	196	3	214	243	4	4,409	146,165	29	622	177
Waikato	89,012	60,008	15	2,542	176	1	583	1,262	8	1,614	25,228	58	2,288	391
Bay of Plenty	18,322	13,450	3.3	667	36	2	57	119	0	1,269	37,034	15	310	223
Gisborne	15,455	11,804	2.2	371	18	1	0	0	0	417	8,663	9	228	31
Hawkes Bay	17,788	13,942	3.5	681	86	1	270	116	3	796	22,489	10	531	117
Taranaki	2,145	2,195	0.4	74	7	0	43	14	1	114	1,683	4	97	23
Manawatu-Whanganui	26,975	25,206	5.2	1,213	234	3	388	1,006	4	571	9,503	12	1,544	232
Wellington	77,675	43,360	13.8	1,515	37	0	93	138	6	3,453	73,053	34	511	184
Tasman	20,740	11,072	2.9	789	0	0	38	2	0	620	19,063	10	424	118
Nelson	12,029	6,873	2.1	130	0	1	3	85	1	895	24,336	7	21	12
Marlborough	4,674	3,760	1.0	387	25	1	205	160	1	8**	126**	3	394	140
West Coast	9,136	5,901	1.5	1,025	212	2	247	180	5	281	7,885	6	1,038	1,207
Canterbury	189,012	116,713	40	3,947	156	2	808	672	10	4,177	No Data	112	2,991	949
Otago	41,447	21,684	8.7	1,386	136	1	126	1,355	2	1,782	47,482	23	1,111	410
Southland	17,672	13,118	4.2	1,971	95	2	268	443	4	250	4,170	15	2,180	979
NZ Total	**675,491**	**411,516**	**135**	**19,098**	**1,577**	**20**	**3,397**	**8,848**	**49**	**21,173**	**442,499**	**358**	**15,190**	**5,335**

*2016 regional council boundaries.
** Limited data.

Table 11-3: Exposure of RiskScape asset classes to inundation by a 100-year return period storm-tide event with different elevations of sea-level rise and river flood hazards (FLHA; Flood Hazard Area) in the Manawatū-Whanganui Region and districts within the region.

RiskScape Asset Class	1% AEP storm tide + sea-level rise elevation exposure					Flood hazard area exposure
POPULATION COUNT	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FHLA**
Ruapehu District	0	0	0	0	0	2117
Whanganui District	199	283	424	586	874	2089
Rangitikei District	78	85	118	137	166	3514
Manawatū District	262	338	402	476	511	9225
Palmerston North City	0	0	0	0	0	5702
Tararua District	10	12	40	50	52	2725
Horowhenua District	353	673	1307	1779	2175	1603
Manawatū-Whanganui Region	902	1391	2291	3028	3778	26975
BUILDINGS COUNT	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	2673
Whanganui District	339	475	591	711	952	1936
Rangitikei District	81	92	144	176	218	3567
Manawatū District	445	555	658	763	828	7846
Palmerston North City	0	0	0	0	0	3697
Tararua District	31	53	90	106	115	3471
Horowhenua District	563	1062	2006	2725	3328	2016
Manawatū-Whanganui Region	1459	2237	3489	4481	5441	25206
BUILDINGS $2016 MILLION	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	469
Whanganui District	137	222	248	281	324	458
Rangitikei District	11	12	19	24	30	656
Manawatū District	54	70	83	98	109	1741
Palmerston North City	0	0	0	0	0	888
Tararua District	5	9	15	18	19	611
Horowhenua District	79	151	298	405	520	383
Manawatū-Whanganui Region	286	463	663	825	1003	5207
ROADS KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	199
Whanganui District	9	12	14	17	20	122
Rangitikei District	3	4	5	7	8	21
Manawatū District	8	10	11	13	13	226
Palmerston North City	0	0	0	0	0	10
Tararua District	1	2	3	4	5	459
Horowhenua District	22	32	44	59	81	175

RiskScape Asset Class	1% AEP storm tide + sea-level rise elevation exposure					Flood hazard area exposure
Manawatū-Whanganui Region	43	59	77	98	127	1213
RAILWAY KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	42
Whanganui District	3	3	4	4	4	20
Rangitikei District	0	0	0	0	0	58
Manawatū District	0	0	0	0	0	23
Palmerston North City	0	0	0	0	0	21
Tararua District	0	0	0	0	0	47
Horowhenua District	0	0	1	2	3	22
Manawatū-Whanganui Region	3	4	5	6	7	234
AIRPORTS COUNT	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
South Taranaki District	0	0	0	0	0	0
Ruapehu District	0	0	0	0	0	0
Whanganui District	1	1	1	1	1	1
Rangitikei District	0	0	0	0	0	0
Manawatū District	0	0	0	0	0	1
Palmerston North City	0	0	0	0	0	1
Tararua District	0	0	0	0	0	0
Horowhenua District	0	0	0	0	0	0
Manawatū-Whanganui Region	1	1	1	1	1	3
TRANSMISSION LINES KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	3
Whanganui District	1	1	1	1	1	19
Rangitikei District	0	0	0	0	0	25
Manawatū District	0	0	0	0	0	184
Palmerston North City	0	0	0	0	0	63
Tararua District	0	0	0	0	0	14
Horowhenua District	10	12	15	18	20	79
Manawatū-Whanganui Region	10	13	16	19	21	388
WATER NODES	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	115	143	168	218	282	324
Rangitikei District	0	0	0	0	0	2239
Manawatū District	0	0	0	0	0	5
Palmerston North City	0	0	0	0	0	2664
Tararua District	0	0	0	0	0	0
Horowhenua District	638	1170	2044	2701	3100	374

RiskScape Asset Class	1% AEP storm tide + sea-level rise elevation exposure					Flood hazard area exposure
Manawatū-Whanganui Region	753	1313	2212	2919	3382	5606
WASTEWATER NODES	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	7	7	7	8	8	9
Rangitikei District	5	6	7	7	9	612
Manawatū District	0	0	0	0	0	0
Palmerston North City	0	0	0	0	0	689
Tararua District	0	0	0	0	0	0
Horowhenua District	162	305	566	805	974	164
Manawatū-Whanganui Region	174	318	580	820	991	1474
STORMWATER NODES	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	104	111	115	118	118	111
Rangitikei District	12	13	13	16	17	1017
Manawatū District	0	0	0	0	0	4
Palmerston North City	0	0	0	0	0	1140
Tararua District	0	0	0	0	0	0
Horowhenua District	143	299	500	614	687	151
Manawatū-Whanganui Region	259	423	628	748	822	2423
STORMWATER PIPELINES KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	9	11	12	13	16	13
Rangitikei District	2	2	2	3	3	86
Manawatū District	0	0	0	0	0	2
Palmerston North City	0	0	0	0	0	121
Tararua District	0	0	0	0	0	0
Horowhenua District	2	5	11	14	16	2
Manawatū-Whanganui Region	13	18	25	30	35	225
WATER PIPELINES KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	13	16	19	23	29	35
Rangitikei District	0	0	0	0	0	77
Manawatū District	0	0	0	0	0	0
Palmerston North City	0	0	0	0	0	71
Tararua District	0	0	0	0	0	0
Horowhenua District	7	15	25	33	37	14
Manawatū-Whanganui Region	20	30	44	55	66	196

RiskScape Asset Class	1% AEP storm tide + sea-level rise elevation exposure					Flood hazard area exposure
WASTEWATER PIPELINES KM	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	21	24	26	29	34	30
Rangitikei District	0	1	1	1	1	45
Manawatū District	0	0	0	0	0	0
Palmerston North City	0	0	0	0	0	56
Tararua District	0	0	0	0	0	0
Horowhenua District	8	15	28	41	48	19
Manawatū-Whanganui Region	29	40	55	71	83	150
BUILT LAND KM2	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	0
Whanganui District	1	2	2	2	2	2
Rangitikei District	0	0	0	0	0	3
Manawatū District	0	0	1	1	1	4
Palmerston North City	0	0	0	0	0	2
Tararua District	0	0	0	0	0	1
Horowhenua District	0	1	1	2	2	0
Manawatū-Whanganui Region	2	3	4	4	5	12
PRODUCTION LAND KM2	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	134
Whanganui District	1	1	1	1	2	68
Rangitikei District	7	11	15	20	23	157
Manawatū District	5	7	9	11	13	454
Palmerston North City	0	0	0	0	0	86
Tararua District	0	0	0	0	0	357
Horowhenua District	52	64	92	117	136	289
Manawatū-Whanganui Region	65	83	117	149	174	1544
NATURAL UNDEVELOPED LAND KM2	**0m**	**0.5m**	**1m**	**1.5m**	**2m**	**FLHA**
Ruapehu District	0	0	0	0	0	65
Whanganui District	6	7	7	7	8	17
Rangitikei District	4	4	4	4	5	25
Manawatū District	2	2	2	3	3	41
Palmerston North City	0	0	0	0	0	14
Tararua District	1	1	1	1	1	36
Horowhenua District	14	15	16	17	18	35
Manawatū-Whanganui Region	26	28	30	33	34	232

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13 Glossary of abbreviations and terms

Term/abbreviation	Definition
Adaptation	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.
Afforestation	Planting of new forests on lands that historically have not contained forests, or have not recently contained forests.
Annual exceedance probability (AEP)	The probability of a given event (e.g. flood or sea level or wave height) being equalled or exceeded in elevation, in any given calendar year. AEP can be specified as a fraction (e.g., 0.01) or a percentage (e.g., 1%).
Anomaly	The deviation of a variable from its value averaged over a reference period.
Anthropogenic	Human-induced; man-made. Resulting from or produced by human activities.
Anthropogenic emissions	Emissions of greenhouse gases, greenhouse gas precursors, and aerosols caused by human activities. These activities include the burning of fossil fuels, deforestation, land use changes, livestock production, fertilization, waste management, and industrial processes.
AR4	IPCC Fourth Assessment Report 2007.
AR5	5th Assessment Report of IPCC – published in 2013/14 covering three Working Group Reports and a Synthesis Report.
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains the greenhouse gas water vapour, whose amounts are highly variable but typically around 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.
Augmentation factor	The percentage increase of rainfall per degree of warming contained within depth-duration-frequency tables in this report.
Average recurrence interval (ARI)	The average time interval (averaged over a very long time period and many "events") that is expected to elapse between recurrences of an infrequent event of a given large magnitude (or larger). A large infrequent event would be expected to be equalled or exceeded in elevation, once, on average, every "ARI" years, but with considerable variability.
Baseline/reference	The baseline (or reference) is the state against which change is measured. A baseline period is the period relative to which anomalies are computed.
Business as Usual (BAU)	Business as usual projections assume that operating practices and policies remain as they are at present. Although baseline scenarios could incorporate some specific features of BAU scenarios (e.g., a ban on a specific technology), BAU scenarios imply that no practices or policies other than the current ones are in place. RCP8.5 is known as the 'business as usual' climate change scenario.
Carbon dioxide (CO_2)	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal of burning biomass, of land use changes and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas that affects the Earth's radiative

	balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.
Carbon dioxide (CO_2) fertilisation	The enhancement of the growth of plants because of increased atmospheric carbon dioxide (CO_2) concentration
Carbon sequestration	Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide. Carbon sequestration involves long-term storage of carbon dioxide or other forms of carbon to mitigate or defer global warming.
Clausius–Clapeyron equation/relationship	The thermodynamic relationship between small changes in temperature and vapour pressure in an equilibrium system with condensed phases present. For trace gases such as water vapour, this relation gives the increase in equilibrium (or saturation) water vapour pressure per unit change in air temperature.
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, rainfall and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.
Climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.
Climate change scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.
Climate model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented or the level at which empirical parametrizations are involved. Coupled Atmosphere–Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near or at the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a

	research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal and inter-annual climate predictions.
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/ radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.
Climate system	The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land use change.
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
Climate variable	An element of the climate that is liable to vary or change e.g. temperature, rainfall.
CMIP5	Coupled Model Inter-comparison Project, Phase 5, which involved coordinating and archiving climate model simulations based on shared model inputs by modelling groups from around the world. This project involved many experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Fifth Assessment Report, Working Group I. The CMIP5 dataset includes projections using the Representative Concentration Pathways.
Coastal squeeze	A narrowing of coastal ecosystems and amenities (e.g., beaches, salt marshes, mangroves, and mud and sand flats) confined between landward-retreating shorelines (from sea level rise and/or erosion) and naturally or artificially fixed shorelines including engineering defences (e.g., seawalls), potentially making the ecosystems or amenities vanish.
Cold nights	In this report, a cold night (or frost) is defined when the daily minimum temperature is below 0°C.
Confidence	The validity of a finding based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement. Confidence is expressed qualitatively.
Depth duration frequency table	Rainfall depth-duration-frequency (DDF) curves or tables describe rainfall depth as a function of duration for given return periods and are important for the design of hydraulic structures.
Disease vector	In epidemiology, a disease vector is any agent that carries and transmits an infectious pathogen into another living organism; most agents regarded as vectors are organisms, such as intermediate parasites or microbes, but it could be an inanimate medium of infection such as dust particles.

Downscaling (statistical, dynamical)	Deriving local climate information (at the 5 kilometre grid-scale in this report) from larger-scale model or observational data. Two main methods exist – statistical and dynamical. Statistical methods develop statistical relationships between large-scale atmospheric variables (e.g., circulation and moisture variations) and local climate variables (e.g., rainfall variations). Dynamical methods use the output of a regional climate/weather model driven by a larger-scale global model.
Drought (meteorological, hydrologic)	A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term; therefore, any discussion in terms of rainfall deficit must refer to the rainfall-related activity that is under discussion. For example, shortage of rainfall during the growing season impinges on crop production or ecosystem function in general (due to soil moisture drought, also termed agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by increases in actual evapotranspiration in addition to reductions in rainfall. A period with an abnormal rainfall deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.
Ecosystem	An ecosystem is a functional unit consisting of living organisms, their non-living environment, and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases, they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems, and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment.
Emission scenario	A plausible representation of the future development of emissions of substances that act as radiative forcing factors (e.g., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.
Ensemble	A collection of model simulations characterizing a climate prediction or projection. Differences in initial conditions and model formulation result in different evolutions of the modelled system and may give information on uncertainty associated with model error and error in initial conditions in the case of climate forecasts and on uncertainty associated with model error and with internally generated climate variability in the case of climate projections.
Eustatic sea-level rise	Absolute level of sea-level rise, measured relative to the centre of the earth. In contrast to relative sea-level rise which is measured relative to the land nearby.
Evapotranspiration	The combined process of evaporation from the Earth's surface and transpiration from vegetation.
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

Global mean surface temperature	An estimate of the global mean surface air temperature. However, for changes over time, only anomalies, as departures from a climatology, are used, most commonly based on the area-weighted global average of the sea surface temperature anomaly and land surface air temperature anomaly.
Greenhouse effect	The radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers. This is because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a greenhouse gas concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere.
Greenhouse gas (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are many entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Groundwater recharge	The process by which external water is added to the zone of saturation of an aquifer, either directly into a geologic formation that traps the water or indirectly by way of another formation.
Growing degree-days (GDD)	Growing degree-days (GDD) express the sum of daily temperatures above a selected base temperature (e.g. 10˚C) that represent a threshold of plant growth. The daily GDD total is the amount the daily average temperature exceeds the threshold value (e.g. 10°C) per day. For example, a daily average temperature of 18°C would have a GDD base 10°C value of 8 and a GDD base 5°C value of 13. The daily GDD values are accumulated over the period 1 July to 30 June to calculate an annual GDD value.
Gully erosion	The removal of soil along drainage lines by surface water runoff. Once started, gullies will continue to move by headward erosion or by slumping of the side walls unless steps are taken to stabilise the disturbance.
Hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.

HIRDS	High Intensity Rainfall Design System (http://hirds.niwa.co.nz). HIRDS uses a regionalized index-frequency method to predict rainfall intensities at ungauged locations and returns depth-duration-frequency tables for rainfall at any location in New Zealand. Temperature increases can be inserted and corresponding increases in rainfall for each duration and frequency are calculated.
Hot days	In this report, a hot day is defined as a day with a maximum temperature over 25°C.
Hydrologic drought	Hydrologic drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after an extended period of meteorological drought.
Ice sheet	A mass of ice of continental size that is sufficiently thick to cover most of the underlying bed, so that its shape is mainly determined by its dynamics (the flow of the ice as it deforms internally and/or slides at its base). An ice sheet flows outward from a high central ice plateau with a small average surface slope. The margins usually slope more steeply, and most ice is discharged through fast flowing ice streams or outlet glaciers, in some cases into the sea or into ice shelves floating on the sea. There are two main ice sheets in the modern world, one over Greenland and one over Antarctica. Ice sheets that are grounded below sea level, including consideration of isostatic rebound, are called marine ice sheets. West Antarctica is primarily a marine based ice sheet.
Impacts (Consequences, Outcomes)	Effects on natural and human systems. In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.
Industrial Revolution	A period of rapid industrial growth with far reaching social and economic consequences, beginning in Britain during the second half of the 18th century and spreading to Europe and later to other countries including the United States. The invention of the steam engine was an important trigger of this development. The industrial revolution marks the beginning of a strong increase in the use of fossil fuels and emission of, in particular, fossil carbon dioxide.
Interglacial	An interglacial period is a geological interval of warmer global average temperature lasting thousands of years that separates consecutive glacial periods within an ice age. The current Holocene interglacial began at the end of the Pleistocene, about 11,650 years ago.
Invasive species	A species introduced outside its natural past or present distribution (i.e., an alien species) that becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.

IPCC	Intergovernmental Panel on Climate Change. This body was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human induced climate change, its potential impacts and options for adaptation and mitigation. Its latest reports (the Fifth Assessment) were published in 2013/14 (see www.ipcc.ch/).
Land use and Land use change	Land use refers to the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus give rise to radiative forcing and/or other impacts on climate, locally or globally.
Likelihood	The chance of a specific outcome occurring, where this might be estimated probabilistically.
Mean annual flood	The average of the maximum flood discharges experienced in a river over a period, which should have a recurrence interval of once every 2.33 years.
Mean annual low flow	The mean of the lowest 7-day average flows in each year of a projection period.
Mean discharge	The average annual streamflow or discharge of a river.
Mean high water springs (MHWS)	The high tide height associated with higher than normal high tides that result from the beat of various tidal harmonic constituents. Mean high water springs occur every 2 weeks approximately.
Mean sea level (MSL)	The surface level of the ocean at a point averaged over an extended period such as a month or year. Mean sea level is often used as a national datum to which heights on land are referred. Mean sea level changes with the averaging period used, due to climate variability and long-term sea-level rise.
Meteorological drought	A period with an abnormal rainfall deficit; when dry weather patterns dominate an area, and resulting rainfall is low.
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Ocean acidification	Ocean acidification refers to a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.
Open coast	Coastline located outside of sheltered harbours and estuaries, in locations subject to ocean waves and swell.
Paris agreement	The Paris Agreement aims to respond to the global climate change threat by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C.

PED	Potential evapotranspiration deficit. PED can be thought of as the amount of water needed to be added as irrigation, or replenished by rainfall, to keep pastures growing at levels that are not constrained by a shortage of water. The unit of PED is millimetres.
Percentiles	The set of partition values which divides the total population of a distribution into 100 equal parts, the 50th percentile corresponding to the median of the population.
pH	pH is a dimensionless measure of the acidity of water (or any solution) given by its concentration of hydrogen ions (H^+). pH is measured on a logarithmic scale where pH = –log10(H^+). Thus, a pH decrease of 1 unit corresponds to a 10-fold increase in the concentration of H^+, or acidity.
Phenology	The relationship between biological phenomena that recur periodically (e.g., development stages, migration) and climate and seasonal changes.
Potable water	Water that is safe to drink.
Precipitation	Describes all forms of moisture that falls from clouds (rain, sleet, hail, snow, etc). 'Rainfall' describes just the liquid component of precipitation.
Pre-industrial	Conditions at or before 1750. See also Industrial revolution.
Projection	A numerical simulation (representation) of future conditions. Differs from a forecast; whereas a forecast aims to predict the exact time-dependent conditions in the immediate future, such as a weather forecast a future cast aims to simulate a time-series of conditions that would be typical of the future (from which statistical properties can be calculated) but does not predict future individual events.
Radiative forcing	A measure of the energy absorbed and retained in the lower atmosphere. More technically, radiative forcing is the change in the net (downward minus upward) irradiance (expressed in W/m^2, and including both short-wave energy from the sun, and long-wave energy from greenhouse gases) at the tropopause, due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the sun.
Regional Climate Model (RCM)	A numerical climate prediction model run over a limited geographic domain (here around New Zealand), and driven along its lateral atmospheric boundary and oceanic boundary with conditions simulated by a global climate model (GCM). The RCM thus downscales the coarse resolution GCM, accounting for higher resolution topographical data, land-sea contrasts, and surface characteristics. RCMs can cater for relatively small-scale features such as New Zealand's Southern Alps.
Relative sea level	Sea level measured by a tide gauge with respect to the land upon which it is situated. Relative sea-level rise (RSLR) is the sea-level rise relative to the land adjacent.
Representative Concentration Pathways (RCPs)	Representative concentration pathways. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively)
Resolution	In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations.

Return period	An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity.
Riparian	The interface between land and a river or stream.
Scenario	In common English parlance, a 'scenario' is an imagined sequence of future events. The IPCC Fifth Assessment describes a 'climate scenario' as: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. The word 'scenario' is often given other qualifications, such as 'emission scenario' or 'socio-economic scenario'. For the purpose of forcing a global climate model, the primary information needed is the time variation of greenhouse gas and aerosol concentrations in the atmosphere.
Sea ice	Ice found at the sea surface that has originated from the freezing of seawater. Sea ice may be discontinuous pieces (ice floes) moved on the ocean surface by wind and currents (pack ice), or a motionless sheet attached to the coast (land-fast ice).
Sea level change	Sea level can change, both globally and locally due to (1) changes in the shape of the ocean basins, (2) a change in ocean volume as a result of a change in the mass of water in the ocean, and (3) changes in ocean volume as a result of changes in ocean water density.
Sea surface temperature (SST)	The sea surface temperature is the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys and drifters.
Simulation	Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics, behaviours and functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.
SLR	Sea-level rise
Soil moisture	Water stored in the soil in liquid or frozen form.
Spatial and temporal scales	Climate may vary on a large range of spatial and temporal scales. Spatial scales may range from local (less than 100,000 km^2), through regional (100,000 to 10 million km^2) to continental (10 to 100 million km^2). Temporal scales may range from seasonal to geological (up to hundreds of millions of years).
Storm surge	The rise in sea level due to storm meteorological effects. Low-atmospheric pressure relaxes the pressure on the ocean surface causing the sea-level to rise, and wind stress on the ocean surface pushes water down-wind (onshore winds) and to the left up against any adjacent coast (alongshore winds). Storm surge has timescales of sea-level response that coincide with typical synoptic weather motions; typically 1–3 days.
Storm-tide	Storm tide refers to the total observed sea level during a storm, which is the combination of storm surge (caused by low atmospheric pressure and by high winds pushing water onshore) and normal high tide
Stormwater	The runoff of water from urban surfaces generated by rainfall or melting snow.
Surface temperature	Air temperatures measured near or 'at' the surface (usually 1.5 m above the ground).

Tide gauge	A device at a coastal or deep-sea location that continuously measures the level of the sea with respect to the adjacent land. Time averaging of the sea level so recorded gives the observed secular changes of the relative sea level
TopNet	A semi-distributed hydrological model for simulating catchment water balance and river flow, developed by NIWA.
Trend	In this report, the word trend designates a change, generally monotonic in time, in the value of a variable.
Tropical cyclone	A strong, cyclonic-scale disturbance that originates over tropical oceans. Distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. A tropical storm is a tropical cyclone with 1-minute average surface winds between 18 and 32 m s^{-1}. Beyond 32 m s^{-1}, a tropical cyclone is called a hurricane, typhoon, or cyclone, depending on geographic location.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts).
VCSN	Virtual Climate Station Network. Made up of observational datasets of a range of climate variables: maximum and minimum temperature, rainfall, relative humidity, solar radiation, and wind. Daily data are interpolated onto a 0.05° longitude by 0.05° latitude grid (approximately 4 kilometres longitude by 5 kilometres latitude), covering all New Zealand (11,491 points). Primary reference to the spline interpolation methodology is Tait et al (2006).
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
W/m^2	Watts per square meter (a measure of radiation intensity).
Wastewater	Used water from any combination of domestic, industrial, commercial or agricultural activities.
Wind erosion	Damage of land as a result of wind removing soil from an area.