REPORT

Tonkin+Taylor

Otago Climate Change Risk Assessment

Main report

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Executive Summary

This report outlines the findings of the first Otago Climate Change Risk Assessment (OCCRA) that has been developed by Otago Regional Council (ORC). It provides a regional snapshot of current and future climate scenarios and details the highest ranked climate change related risks for the region. As the first summary of climate change scenarios and related risks for the region, this report sets a baseline for the region to collectively build upon and respond to climate change risks over time.

The OCCRA report:

a Provides the first regional summary of the risks to Otago from climate change.

b Groups risks according to five value domains (in alignment with New Zealand's National Climate Change Risk Assessment - NCCRA). These are: natural environment, human, economy, built environment, and governance.

c Highlights opportunities that may be possible in the face of climate changes.

d Identifies some research and knowledge gaps to be filled to better understand the risks.

The purpose of the report is to inform stakeholders about both risks and opportunities faced in the region due to climate change. The report provides context for the next steps and can be utilised by ORC and all stakeholders as a reference to enable adaptation planning.

Limitations

This risk assessment is focused on regional risks, with discussion of national scale and international risks covered in the NCCRA. This risk assessment was conducted utilizing current knowledge and research available at the time, augmented by stakeholders and subject matter experts within the region. The risk rating process was, to a certain extent, subjective on account of uncertainty around climate projections and associated vulnerability. The assessment does not consider socio-economic projections, nor does it consider transition risks, cascading risks and interdependencies, or adaptation approaches in detail. However, it is recognised that many risks between and within the domains are highly interconnected, and in some cases there is a strong connection between mitigation and adaptation, and as such, a short discussion of these issues is provided.

Climate Change Hazards in Otago

In general, climate change projections for the Otago region include warmer temperatures, with more hot days and fewer frosts. Winter and spring are expected to be wetter, but with significant decreases in seasonal snow likely. In essence, the seasonality of climate in the Otago region is expected to become more pronounced.

More severe extreme rainfall events are anticipated, as are the severity and frequency of windy days. Even with dramatic reduction of greenhouse gas emissions, sea level rise is expected for the next 100 years and more. Hazards associated with these changes in climate are likely to include increased flooding and landslides, drought, coastal inundation and erosion, and increased instances of wildfire.

Kāi tahu

It is acknowledged that Kai Tahu Rūnaka were unable to participate in the early stages of the OCCRA to the level at which they and ORC would have desired. The feedback received from Aukaha towards the latter stages of the project identified some limitations to the methodology of this risk assessment, resulting from the lack of mana whenua region-specific knowledge, values and tikaka being incorporated. In particular, the Rūnaka considered that the approach used did not reflect a Māori worldview, particularly as the approach involved assessing risks within discrete domains, thereby creating limitations to assessing the interrelatedness of climate change risks. It is recognised that many risks are inherently interconnected, however a full assessment of interconnected and cascading risks was outside the scope of this assessment. Despite this, a range of risk interactions are presented and discussed within the main body of the report.

ORC is committed to continue working closely in partnership with Rūnaka on both climate change risk assessments and adaptation planning. This could include working with local Rūnaka to undertake a parallel risk assessment, for Māori, by Māori, in order to capture the region-specific values, practices and knowledge. This risk assessment would be informed by tikaka and mātauraka Māori ways of thinking and acting around climate change. It would draw on those Kāi Tahu values already used in other planning documents such at the Regional Policy Statement - for example whakapapa, Whakawhanaukataka, Wairua, Mauri, Ki Uta Ki Tai, Rakatirataka, Kaitiakitaka, Tikaka, Taoka, Mahika Kai, as well as the principle of Manaakitaka.

Risk rating process

The risk assessment involved evaluating risks based on the RCP8.5 scenario across three-time horizons including current, 2040 (mid-century) and 2090 (end of century). RCP8.5 is generally considered a ‘high end’ or in some cases, a ‘business as usual’ emissions scenario, if a significant reduction in emissions does not occur.

A two-step risk assessment process was carried out which included an initial risk screening process (to identify risk areas across the five domains), followed by a qualitative risk assessment and rating. The risk rating process was carried out through workshops with extensive engagement with local subject matter experts, key stakeholders, council staff and Kāi Tahu.

It is noted that the risk rating was only undertaken for the built environment, natural environment and economy domains. For the Human and Governance Domains, risks were identified as part of engagement processes and are discussed within the report.

The following sections summarise the *over-arching, headline risks* within the 5 domains. Further detail and breakdown of sub-risks is provided within the body of the report.

Natural Environment Domain

The Natural Environment Domain refers to all aspects of the natural environment within Otago, which support indigenous species and associated ecosystems in terrestrial, freshwater, wetland, coastal and marine environments.

Six key risks were identified for the Natural Environment Domain. These are shown in Table ES-1 and include risks to the terrestrial, freshwater, wetland, coastal and marine ecosystems, risks to water quality and risks to native ecosystems from invasive plants, pests and diseases.

Table ES-1: Summary of key Natural Environment Domain risks

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
N1	Risks to the terrestrial ecosystems from increasing temperatures, changes in rainfall and reduced snow and ice	H	E	E
N2	Risks to the freshwater (rivers and lakes) ecosystems from increasing temperatures and extreme weather events	M	H	E
N3	Risks to the coastal and marine ecosystems from climate change hazards including ocean acidification and marine heatwaves	L	H	E

N4	Risks to coastal, inland and alpine wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice	H	E	E
N5	Risks to Otago water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice	M	E	E
N6	Risks to native ecosystems posed by increasing threats from invasive plants, pests and disease due to climate change	M	M	E

* Highest risk rating per category and hazard relationship highlighted (L=low, M=medium, H=high, E= extreme). Refer to individual risk discussions for detailed, hazard specific ratings.

Economic Domain

The Economic Domain refers to key economic sectors within Otago, which support people and livelihoods. All of the sectors identified rely heavily on the natural environment to sustain their activities.

Seven key risks were identified for the Economic Domain as set out in Table ES-3. Of these risks, none were rated as high or extreme in the present day, however they are all predicted to increase to extreme, in the long term under RCP8.5.

Table ES-2: Summary of key Economic Domain risks

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
E1	Risks to the livestock farming sector from climate change hazards including drought, increased fire weather, inland flooding, and increased landslides	M	H	E
E2	Risks to horticulture and viticulture from climate change hazards including temperature, drought, changing rainfall patterns and extreme weather	M	H	E
E3	Risks to the forestry sector from climate change hazards including temperature, drought, fire and extreme weather	L	M	E
E4	Risks to the fisheries and aquaculture sector from climate change hazards including marine water temperature and water quality	L	M	E
E5	Risks to primary sector supply chains from climate change hazards including inland flooding, coastal flooding and increased landslides	M	H	E
E6	Risks to cost of doing business from climate change hazards including coastal and inland flooding, landslides, and extreme events	M	H	E
E7	Risks to the tourism sector from climate change hazards including higher temperatures, reduced snow and ice, inland and coastal flooding, landslides and erosion	M	H	E

* Highest risk rating per category and hazard relationship highlighted (L=low, M=medium, H=high, E= extreme). Refer to individual risk discussions for detailed, hazard specific ratings.

Built environment domain

The Built Environment Domain refers to the set and configuration of buildings, physical infrastructure, and transport.

Nine key risks were identified for the Built Environment Domain as set out in Table ES-4. Risks to buildings and open spaces, risks to water supply infrastructure and irrigation systems and risks to stormwater and wastewater networks from climate hazards were all rated as high in the present day and are expected to increase with time.

Table ES-3: Summary of key Built Environment Domain risks

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
B1	Risk to buildings and open spaces from climate change hazards including inland and coastal flooding, coastal erosion, and sea level rise and salinity stress	H	E	E
B2	Risk to flood management schemes from inland and coastal flooding, and sea level rise and salinity stress	M	E	E
B3	Risk to water supply infrastructure and irrigation systems due to drought, fire weather, flooding and sea level rise and salinity stress	H	E	E
B4	Risk to stormwater and wastewater networks from increased temperature, sea level rise and salinity stress, extreme weather events and flooding	H	H	E
B5	Risks to linear transport (roads and rail) from flooding, coastal erosion, extreme weather events and landslides	M	E	E
B6	Risk to airports and ports from flooding and extreme weather events	M	E	E
B7	Risk to solid waste (landfills and contaminated sites) to flooding and sea level rise and salinity stress	M	E	E
B8	Risks to electricity (generation, transmission and distribution) networks from changes in rainfall, extreme weather events and flooding	M	H	E
B9	Risks to telecommunications infrastructure due to sea level rise and salinity stress and extreme weather events	L	M	H

*Highest risk rating per category and hazard relationship highlighted (L=low, M=medium, H=high, E= extreme). Refer to individual risk discussions for detailed, hazard specific ratings.

Human Domain

The Human Domain encompasses people's skills, knowledge, and physical and mental health (human), the norms and institutions of society (social), and the knowledge, heritage and customs of society (cultural).

Direct impacts on communities may include increased exposure to hazards such as heat waves and weather events, flooding and fires. Indirect social impacts include disruption to health services, social and economic factors including migration, housing and livelihood stresses, food security, socioeconomic deprivation and health inequality including mental health and community health effects. The effects of climate change will not be spread evenly across the Otago, exacerbating existing socioeconomic and health inequalities.

Key risks summarised in Table ES-5 have not been individually rated. These include risks to community cohesion, physical and mental health, increased inequities and costs of living, and specific risk to both Kāi Tahu sites, identity and practices as well as non-Kāi Tahu cultural heritage sites.

Table ES-4: Summary of key Human Domain risks

Risks	
H1	Risks to Kāi Tahu sites, identity and practices, and non-Kāi Tahu cultural heritage sites, due to climate change.
H2	Risks to community cohesion and resilience from climate change.
H3	Risk to mental wellbeing and health from climate change.
H4	Risk to physical health due to climate change.
H5	Risk to increased inequities and cost of living due to climate change.

Governance Domain

The Governance Domain refers to the governing structures, frameworks and processes for decision making that exist in and between governmental, economic and social institutions. Governance sits across all aspects of New Zealand society, from the Treaty partnership between Māori and the Government (the Crown) to the relationships between local government and communities, the economy, the built environment and natural ecosystems.

The governance risks have not been specifically rated, however they have been categorised in relation to whether local government, central government, or a combination of both may have primary influence in responding to the risks.

Table ES-6 provides a summary of the five key Governance Domain risks.

Table ES-5: Summary of key Governance Domain risks

Risks		Local vs central government influence
G1	Risk that existing planning, decision making, and legislative frameworks are inadequate for responding to long-term climate change risks and result in maladaptive responses, and potential liability.	Combination of local and central influence
G2	Risk of local authorities lacking capacity to effectively respond to climate change.	Local direct influence
G3	Risk that the national, regional and local governance/institutional structures for managing climate change are inadequate.	Combination of local and central influence
G4	Risk that a low level of community awareness and engagement hinders communication of climate risk and uncertainty, and leads to de-prioritisation.	Local direct influence
G5	Risk that climate change will result in increasing damage costs, with insufficient financing for adaptation and risk reduction.	Combination of local and central influence
G6	Risk that public services will be impacted by climate change.	Combination of local and central influence

Opportunities

Climate change may result in a number of opportunities for the Otago region. These have been identified where climate change has the potential to *directly* lead to positive or beneficial outcomes.

Opportunities are likely to arise in parallel with risks, as both are driven by the same climate variables. Opportunities may also present other risks, as new or increased activity in some areas have consequences for others, for example increased agricultural production may place further pressure on the natural environment, such as increased irrigation demand and agricultural runoff.

Opportunities that were identified for Otago include those for the primary sector, businesses, health, and heating. These opportunities were identified in the risk assessment process, but do not constitute a comprehensive list of all the potential benefits that may result from climate change. Further research in this area is required to understand the potential benefits of climate change across all elements, sectors and domains.

Table ES-6: Summary of opportunities identified

Domain	Opportunity
Human	HO1: Opportunity for reduction in cold weather-related mortality due to warmer temperatures.
Natural	No opportunities identified.
Economic	EO1: Opportunity for increased primary sector productivity due to warmer temperatures and increased annual rainfall, including:
	EO2: Opportunity for businesses to provide adaptation related goods and services.
Built	BO1: Opportunity for reduction in winter heating demand due to warmer temperatures.
	B02: Opportunity for increased capacity from renewable energy sources:
Governance	No opportunities identified.

Knowledge gaps and future research

A wide range of climate change research is currently ongoing across a broad range of organisations in New Zealand, and also within Otago. These include ORC, Universities and Crown Research Institutes, as well as many of the National Science Challenges.

The OCCRA has identified risks relevant to Otago, and through this process a range of knowledge and research gaps were identified. These are listed within the main body of the report, and include research gaps within climate science/hazard research as well as exposure, vulnerability and impact research relating to a wide number of specific domains and risk elements discussed within this report.

Next steps

The partnership and collaborative approach taken in developing this assessment has been important, and will be required to be maintained going forward into risk prioritisation and action planning – if the region is to respond effectively to the report findings.

The next step is to consider the risks highlighted within this report and agree on those which are either priorities for adaptation planning or which require further research. Following this, those parties responsible for responding to identified risks (Councils, utilities, others) will need to develop appropriate plans and programmes to respond. Consideration is being given by ORC to building collaboration with stakeholders in supporting and developing these responses and a regional climate change adaptation approach. It is noted that some of these considerations of specific risks are already underway or are planned to be undertaken.

This OCCRA is an initial step in an ongoing process of understanding climate change risks in the Otago region and how they might change in the future. Some information gaps were identified during this process and filling these gaps will be an important step in improving subsequent assessments.

Over time, further research will be undertaken by various parties and information will improve. As the climate changes, the risk scape will also evolve, and as a result, the risk scorings will need to be reviewed and updated to reflect this. The risk assessment will need to be repeated at appropriate intervals in order to update the risk ratings and to reflect changes in information available. This should be done in a timeframe that aligns with updates to the NCCRA. The next NCCRA will be completed by the Climate Change Commission within the next 6 years as the Climate Change Response (Zero Carbon) Amendment Act 2019 requires a risk assessment at least every six years.

Prioritisation

Prioritisation of high risks for response / further research will need to be undertaken by ORC, Kāi Tahu and regional stakeholders following the OCCRA. Criteria for prioritisation will vary and could include: level of risk relative to time horizon (i.e. earlier risks more urgent); level of agreement on risk priority; gaps in information; potential for cascading impacts; potential for lock-in or maladaptation; potential for tipping points or thresholds to be reached; or potential for opportunistic implementation due to alignment with other investment.

Next step, further studies and gaps

This report has highlighted a range of information gaps and areas for further research. Some of these will fall under the responsibility of ORC to investigate while others will be more industry and sector targeted. Various bodies and organisations will help to fill these information gaps and this will likely involve partnerships between Universities, CRIs, councils, Kāi Tahu and stakeholders. Increasing understanding in these areas will help inform decision making and improve future iterations of the risk assessment.

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) has concluded that human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans, with climate related impacts able to be distinguished from other possible causes (Bilir et al., 2014).

There are two modes of reducing and managing impacts and risks related to climate change: *mitigation* and *adaptation*. While mitigation is focussed on reducing greenhouse gas emissions to limit further climate change, adaptation is the process of adjusting to the actual and expected changes in the environment resulting from greenhouse gas emissions already released into the atmosphere and those that may be released in the future (IPCC, 2014). This report relates primarily to *adaptatio*n (enabled via this risk assessment), and does not focus on mitigation.

All stakeholders including local territorial authorities, regional council, communities and the business sector recognise that a changing climate will present risks to the region, and Otago Regional Council (ORC) has identified climate change as a priority as part of their 2018-28 long-term planning. An understanding of climate change related risks and vulnerabilities within the region will enable future prioritisation of risks for adaptation planning. Highlighted risks within this assessment will help direct further information gathering and help to plan for adaptation. Note, further context around relevant climate change legislation is provided in Appendix A.

ORC have therefore commissioned the Otago Climate Change Risk Assessment (OCCRA), with the following objectives:

1. Describe Otago's climate and how it may change in the future.
2. Undertake a stocktake of knowledge and initiatives relating to climate change.
3. Provide a broad understanding of climate risks and opportunities within the Otago region and how risks may change over time.
4. Rank risks to identify the highest risks per domain.
5. Support decision makers to better understand regional risks and inform preparation of ORC's long-term plan and other planning activities.
6. Align, where relevant, with the National Climate Change Risk Assessment (NCCRA) (MfE, 2020).

Additionally, this project provides an opportunity to engage with a wide range of stakeholders around Otago's current and future climate risks, thereby raising awareness.

The OCCRA has been undertaken in a number of phases, with the first phase involving project definition/scoping, a second phase around designing the risk assessment framework, and a final phase relating to undertaking the risk assessment. Tonkin & Taylor Ltd (T+T) was engaged by ORC to complete the first phase (Tonkin & Taylor, 2019) and complete this final phase, in accordance with our contract dated 13 August 2020.

This report provides an overview of how Otago may be affected by climate change related hazards, and documents the highest ranked risks to the region, as well as some opportunities - identified through stakeholder elicitation and subsequent literature review.

The report is structured as follows:

Section 1: Introduction

Section 2: Overview of climate change projection for the Otago Region

Section 3: Methodology

Section 4: Human Domain risks

Section 5: Natural Environment Domain risks

Section 6: Economic Domain risks

Section 7: Built Environment Domain risks

Section 8: Governance Domain risks

Section 9: Interacting risks

Section 10: Opportunities

Section 11: Future research

Section 12: Summary and next steps

Section 13: References

Appendices A (Legislative context); B (Climate change within Otago – details), C (Glossary); D (Risk long list), E (Stakeholder engagement list), and F (Copy of survey questions).

Purpose Statement

This report is an outline of the findings of the OCCRA, providing a regional snapshot of current and future climate scenarios and the highest ranked climate change related risks for the region. The purpose of the report is to inform stakeholders about both risks and opportunities faced in the region due to climate change. The report provides context for the next steps and can be utilised by ORC and all stakeholders as a reference to enable adaptation planning.

As the first summary of climate change scenarios and related risks for the region, this report sets a baseline for the region to collectively build upon and respond to climate change risks.

Intentions of the report

What the OCCRA report provides:

- e The first regional, collective summary of the risks to Otago from climate change assigning a risk value (based on exposure and vulnerability).
- f Groups risks according to five value domains (in alignment with the NCCRA) these are: natural environment, human, economy, built environment, and governance.
- g Highlights opportunities that may be possible in the face of climate changes.
- h Identifies some research and knowledge gaps to be filled to better understand the risks.
- i Identifies some interactions between risks (however does not provide a comprehensive assessment of cascading impacts).
- j Identifies the need for adaptation to mitigate the impact of climate change.

How the report can be used:

- a All stakeholders will be able to utilise the list of risks from this report to guide both current and planned work programmes. For example, the findings from this assessment may be used in the development of long-term plans.
- b The report has developed a baseline of climate change related risk understanding that can be used to track changes to these risks and improve understanding over time.
- c The findings can help to guide development of a regional adaptation approach.
- d The report can help inform councils, stakeholders, organisations and individuals within the region on the climate change risks we may face. It can be used as a guide to understand what risks might need further research or understanding both at a regional and local scale.

What the report doesn't provide:

- As the report is based at a regional scale it does not provide an assessment of the identified risks at a local or community level scale. The identified risks do not provide a breakdown of components, for example specific species, locations or infrastructure elements at risk, other than certain examples that are used to explain and illustrate the risks within the discussion sections.
- The identified risks have not been prioritised beyond the direct climate change related risk ranking. Prioritisation is a multi-faceted process that is best undertaken through other processes and will consider different factors for each domain.

This report does not plan a way forward for adaptation or comment on specific adaptation actions, as this forms part of the next steps (this is consistent with the National approach - with the National Adaptation Plan (NAP) set for release within the next two years following the release of the NCCRA).

2 Climate change for the Otago Region

The global climate system is exhibiting unprecedented changes over short and long periods (decades to millennia) (IPCC (ed), 2013). This indicates that human induced greenhouse gas emissions are driving changes in natural climate processes (Bilir et al., 2014). There is a high level of natural variability within the climate system. Some key patterns in New Zealand climate are linked to phenomena including the El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) which describe changes in sea surface temperatures occurring every few years (ENSO) to decades (IPO). These cause predictable changes in wind, temperature and rainfall patterns.

The natural variability in climate patterns means that long-term trends are not easily observable without statistical analyses, and that future changes in local climate may be both dampened and exaggerated for periods of time over the next century (Macara et al., 2019). Gradual changes are being observed within New Zealand, where atmospheric temperatures have increased, on average by 1 ^{o}C per century since 1909, in addition to rising sea levels and increased frequency of severe weather extremes (Ministry for the Environment, 2018).

Changes in our future climate are dependent on atmospheric greenhouse gas concentrations. However, these concentrations are dependent on global efforts as well as local efforts to reduce greenhouse gas emissions. This uncertainty is captured through the development of four emissions scenarios (Figure 2-1), where the lowest emissions scenario, RCP2.6 (Representative Concentration Pathway), represents significant global reduction in greenhouse gasses, RCP4.5 and RCP6.0 are mid-range scenarios, and RCP8.5 is a 'business as usual' scenario with global greenhouse gas emissions continuing at current rates (Macara et al., 2019). Projected changes based on these forecast scenarios are referenced to the average climate of the Otago region (Macara, 2015).

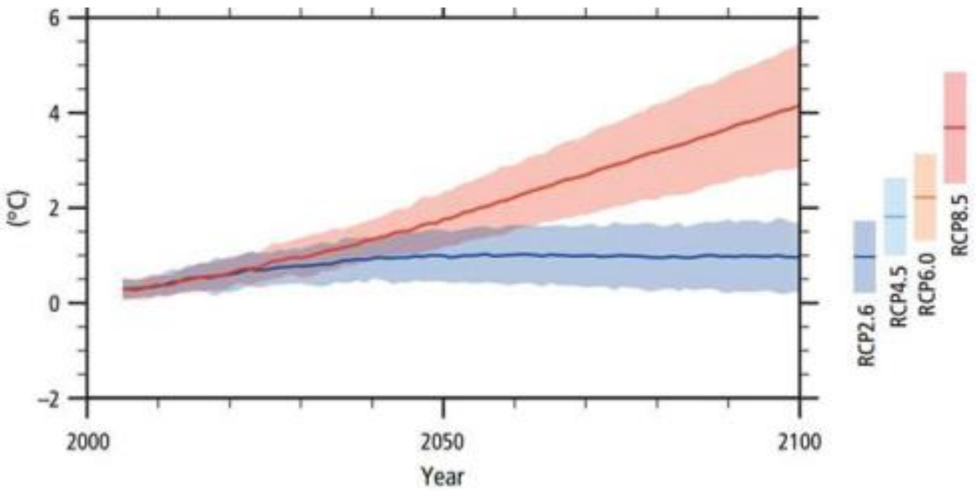

Figure 2-1: Global average surface temperature change from 2006 to 2100 as determined by multi-model simulations relative to 1986 – 2005. Shaded areas show uncertainty associated with RCPs (IPCC, 2014).

NIWA have developed national and regional projections based on the IPCC Fifth Assessment Report (2014), that form the basis of climate change projections used within this report. This report and the risk assessment herein is based on RCP8.5, a high greenhouse gas emissions scenario. This is considered to be a reasonable upper level scenario, and therefore supports the objective to identify the most significant climate related risks (Macara et al., 2019).

In general, climate change projections for the Otago region include warmer temperatures, with more hot days and fewer frosts. Winter and spring are expected to be wetter, but with significant decreases in seasonal snow likely. In essence, the seasonality of climate in the Otago region is expected to become more pronounced, with larger seasonal differences through much of the region. More severe extreme rainfall events are anticipated, as is the severity and frequency of windy days. Even with intervention, sea level rise is expected for the next 100 years and more (Macara et al., 2019).

Table 2-1 and Figure 2-2 provide an overview of the climate change projections for the Otago region in the mid to long term. These projected changes to climate variables can create hazards in their own right, or exacerbate related natural hazards associated with these changes in climate. These natural hazards include increased flooding and landslides, drought, coastal inundation and erosion, and increased instances of wildfire.

Table 2-2 below outlines these related natural hazards that contribute to climate risk. These form the basis of the risks identified and assessed within this climate risk assessment.

Table 2-1: Overview of climate projections for the Otago Region under RCP8.5 summarised from Macara et al., (2019)

Symbol	Climate variable / hazard	Description of change	Change in 2040	Change in 2090
Temperature				
	Annual mean	Seasonal mean temperatures are projected to increase across the Otago region.	0.5-1.5°C	1.5-3.5°C
	Minimum and maximum	Both minimum and maximum temperatures are expected to increase across the Otago Region.	Maximum temperatures increase by 1.5°C. Minimum temperatures increase between 0-1.0°C.	Maximum temperatures increase by 3.5°C. Summertime mean maximum temperature are projected to increase up to 5°C in central and western Otago. Minimum temperatures are also projected to increase throughout the region by up to 2°C.
	Number of hot days (>25 °C)	Central Otago and inland areas are likely to experience significant increases in the number of extreme hot days. Coastal and southern parts of Otago are likely to experience slight increases in the number of extreme hot days.	6-10 more extreme hot days for parts of Central Otago. Dunedin is projected to observe a slight increase to 0.5 extreme hot days.	30-40 more extreme hot days in parts of Central Otago. 10-30 more hot days per year for remaining inland areas. Increasing of 0.1-4 days for coastal and southernmost parts of Otago.
	Number of cold nights / frost (<0 °C)	The number of cold nights resulting in frost are expected to decrease across the region, with larger reductions projected for further inland areas.	10-15 fewer frost days for inland areas.	20-40 fewer frost days per year for inland areas.

Rainfall				
	Annual mean	Annual rainfall is expected to increase across the region.	0-10% annual increase.	Increases of 10-20% for the majority of Otago with smallest increases expected near Ranfurly 0-5%.
	Extreme rainfall events	Extreme, rare rainfall events are likely to increase in intensity in Otago.	From 8% higher for a 1:100 year 1-hour duration rainfall event.	Up to 35% higher for a 1:100 year 1-hour duration rainfall event.
	Snowfall	The number of snow days are also projected to reduce, with the greatest reductions projected to occur in the coldest, mountainous areas.	The number of snow days is likely to decrease between 0-15 days.	The number of snow days is likely to decrease between 0-20 days.
	Number of dry days	The number of dry days are likely to decrease near the coast and parts of Central Otago, with the remaining parts of Otago experiencing increases. Seasonally fewer winter dry days for western Otago and more summer dry days for western and inland parts of Otago.	Decreases in annual dry days of 1-4 days are projected for coastal and some central parts of Otago, with increases of 2-8 more dry days per year for many remaining parts of Otago.	Decreases in annual dry days of 2-6 days are projected for coastal and some central parts of Otago, with increases of 2-10 more dry days per year for many remaining parts of Otago.
	Flooding	In general Otago is projected to experience an increase in Mean Annual Flood (MAF). This is consistent with increased mean annual rainfall.	Between-5 to 100% reductions in MAF are projected to occur in parts of the Catlins, North Otago and Wanaka / Hawea area. With the remaining areas projected to increase by up to 50-100% in some places.	Generally greater than 20% increase across whole region with some areas over 100% increase in MAF.
Sea level rise				
	Sea level rise	Sea level rise is occurring throughout New Zealand. Storm surges, waves, winds and the frequency and intensity of storms are also affected by climate change. These will generate higher extreme water levels which are variable along the coast of Otago.	Mean SL is projected to increase by 0.21m across New Zealand.	Up to 0.9-1.2m increase in SL.
	Groundwater	Groundwater projections are highly variable across the region. Detailed information is currently not available for future timeframes.		
Extreme weather				

	Wind	Daily mean wind speed is projected to decrease about the eastern coast of Otago, and increase for inland areas about Central Otago and the Southern Lakes.	Inland areas about Clyde, Cromwell and Queenstown are projected to observe an increase in extreme wind of 4-6%. Coastal areas likely to experience a decrease of 0-4%.	Inland areas about Clyde, Cromwell and Queenstown are projected to observe an increase in extreme wind of 6-12%. Southern coastal areas likely to experience an increase of 0-2% with northern coastal areas experiencing a decrease of 0-4%.

For further detail and definitions of climate change projections for Otago refer Appendix B.

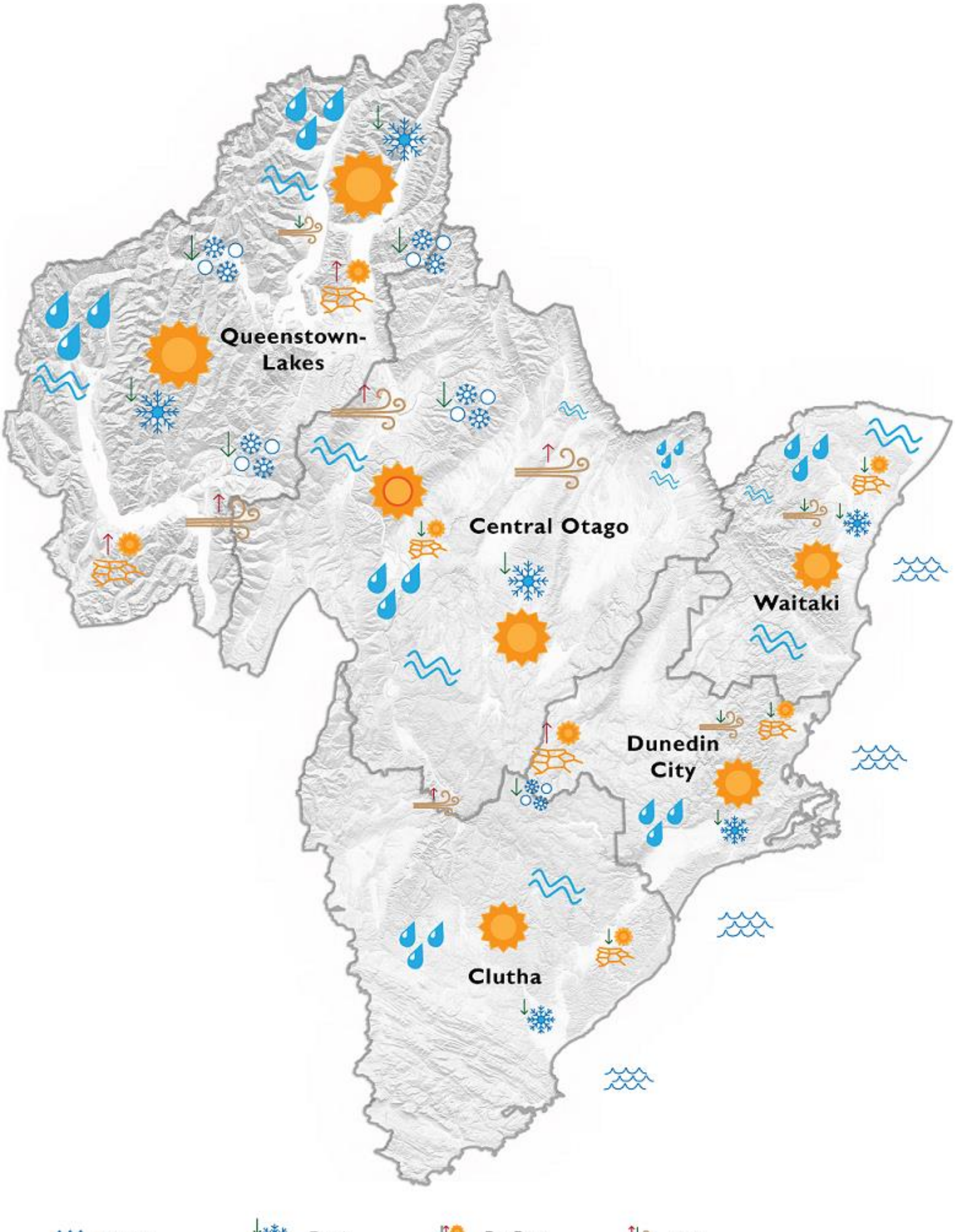

Figure 2-2: Summary of expected climatic changes for the Otago Region (source: provided by ORC summarised from Macara et al., (2019)). Location of symbol is not specific it refers to the general locality. The larger the symbol the more significant the impact, an upwards arrow means an increase, a downwards arrow means a decrease.

Table 2-2: Regional climate hazards used in risk assessment

Climate hazard	Description
Temperature increases, extreme temperatures	Increased average or peak atmospheric temperatures, where hot days are defined as a day with a maximum over 25°C and extremely hot day is defined as a day with a maximum temperature over 30°C (Macara et al., 2019).
Reduced snow and ice	Warmer temperatures resulting in warmer alpine conditions leading to reduced snow and ice.
Changing rainfall patterns	Warmer temperatures causing a range of changes in rainfall patterns including periods of more intense rainfall, and extended periods of dry weather.
Drought	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 (Macara et al., 2019).
Increased fire weather	The weather (climatic) conditions that allow for the propagation of wildfire. This includes factors such as: temperature, humidity, soil moisture, rainfall, solar radiation.
Extreme weather events	Weather events (storms and ex-tropical cyclones) that are a combination of extreme rainfall and extreme wind.
Inland flooding	The overflowing of the normal confines of a stream/river/lake, or the accumulation of water over areas not normally submerged. Usually resulting from heavy or sustained rainfall. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, and glacial lake outburst floods (Macara et al., 2019).
Landslides	Land instability typically resulting from saturated soil.
Coastal flooding/ inundation	A combination of sea level rise, tide, storm surge, and wave characteristics causing sea water to encroach beyond the usual coastal zone.
Coastal erosion	The loss or displacement of land, or the long term removal of sediment and rocks along a coastline due to the action of waves, currents, tides, or other impacts of storms.
Ocean acidification	Excess atmospheric carbon dioxide which dissolves in ocean water, causing increased acidification.
Marine heatwaves	Unusually warm oceanic temperatures within a specific region. Usually defined as sea surface temperature that is greater than the 90th percentile of 30 year local measurements for a duration of 5 days (Hobday, et al., 2016).
Salinity stress	Exposure to salinity through coastal inundation or groundwater

3 Methodology

In order to align with the NCCRA framework (Ministry for the Environment, 2020), risks across the Otago Region have been assessed across five 'value domains' (Table 3-1). The process included a qualitative risk assessment method which evaluated a risk element's degree of exposure to a climate hazard and its vulnerability to that hazard (as a function of sensitivity and adaptive capacity). In addition, opportunities for the region were identified.

3.1 Overview of value domains

As outlined in the NCCRA, the five domains represent groups of values, assets and systems that could be either at risk from climate-related hazards or beneficially affected. They are a hybrid of the New Zealand Treasury's Living Standards Framework and those used in the National Disaster Resilience Strategy (The Treasury, 2018; Ministry of Civil Defence and Emergency Management, 2019). The domains are interconnected, apply at individual, community and national levels, and include tangible and intangible values. Each value domain consists of a series of 'elements at risk'. These divide the domains into subcategories that can then be assessed by their exposure and vulnerability to climate hazards (Table 3-1).

Table 3-1: Description of value domains and elements at risk, adapted from the NCCRA (Ministry for the Environment, 2020)

Domain	Description	Elements at Risk
Human	People's skills, knowledge and physical and mental health (human); the norms, rules and institutions of society (social); and the knowledge, heritage, beliefs, arts, morals, laws and customs that infuse society, including culturally significant buildings and structures (cultural).	Community wellbeing, social cohesion and social welfare (urban, rural and coastal communities); health, education, sports, recreation, cultural heritage (archaeological sites, museums, arts, theatre), ahurea Māori, tikaka Māori – Māori culture, values and principles, cultural taoka.
Natural	All aspects of the natural environment that support the full range of our indigenous species, he kura taiao (living treasures), and the ecosystems in terrestrial, freshwater and marine environments.	New Zealand's indigenous species, including he kura taiao – living treasures, terrestrial ecosystems, freshwater ecosystems, coastal, estuarine and marine ecosystems, biosecurity.
Economy	The set and arrangement of inter-related production, distribution, trade and consumption that allocate scarce resources.	Primary industries (forestry, agriculture, horticulture, arable land, viticulture, fisheries, aquaculture, marine farming); land use, tourism, technology and business, whakatipu rawa – Māori enterprise, insurance and banking.
Built	The set and configuration of physical infrastructure, transport and buildings.	Built infrastructure across sectors including housing, public amenity, water, wastewater, stormwater, energy, transport, communications, waste and coastal defences.
Governance	The governing architecture and processes in and between governments, and economic and social institutions. Institutions hold the rules and norms that shape interactions and decision-making and the agents that act within their frameworks.	Treaty partnerships, adaptive capacity, all governing and institutional systems, all population groups, including vulnerable groups.

3.2 Principles

The risk assessment process was guided by the following broad principles:

- Collaborative, qualitative approach, with input from key specialists and stakeholders.
- Transparency of process to inform the risk assessment.
- Alignment with and acknowledgement of NCCRA process and outcomes.
- Clear recording of the process so that it can be readily understood by others (and therefore is replicable).
- An iterative approach, with mechanisms for reviewing the process if basic assumptions change through initially unforeseen circumstances or if new information is presented.
- Consistency with international and national standards and guidelines, and clear recording and justification of where departures have been made.

3.3 Risk assessment methodology

The risk assessment involved evaluating risks based on the RCP8.5 scenario across three-time horizons including current, 2040 and 2090. RCP8.5 is generally considered a 'high end' or in some cases, a 'business as usual' emissions scenario (Macara et al., 2019).

This scenario therefore is considered useful, in order to support the identification of the most significant climate related risks that may occur if warming continues unabated. It should not, however, be considered a 'most likely' scenario (Hausfather, 2019). Predicting emissions trajectories going forward, and their relative likelihoods, is extremely complex and relates to a wide range of factors including climatic and atmospheric science, socio-economic and technological change over time, and international / national climate policies. Most, if not all, of these are extremely hard to predict with certainty, and as such, the RCP8.5 'high end' scenario was chosen to provide an underpinning assumption for the risk assessment.

A two-step risk assessment process was carried out which included an initial risk screening process (to identify risk areas across the five domains), followed by a qualitative detailed risk assessment (and rating). It is noted that the detailed risk rating was only undertaken for the Built Environment, Natural Environment and Economy Domains. The Human and Governance Domain risks were not rated, for the following reasons:

- **Human Domain**: Given the lack of relevant data on which to evaluate risks, plus the fact that risks in the Human Domain are cross-cutting, there was deemed to be little value in ranking/prioritising the risks. The risks identified are quite different from each other and very much interrelated. Social vulnerability indicators were developed based on available data relating to socio-economic factors such as social-deprivation, immigrant communities and people living in rental housing. This allows identification of communities which may be more predisposed to the risks identified and therefore may help focus subsequent actions. In summary, all five of the risks identified are of equal relevance and should be managed as such.
- **Governance Domain**: Similarly, there was deemed to be little value in ranking or prioritising the Governance risks. Again, they are quite different from each other and would require a range of interventions from various levels of government. In summary, all six of the governance risks identified are of equal relevance and should be managed as such.

When reading through the report therefore, there are differences between the domain sections. For the Built, Natural and Economy Domains, summary risk tables are provided at the start of each Domain section, followed by detailed breakdown tables of sub-risk elements within each sub-section. These risk rating tables are not provided for the Human and Governance Domains, for reasons explained above.

It should also be noted that in places the discussion may reference general research, nationally focused reports or research from other focus areas but that the risk assessment component (scoring) was focused on Otago through the use of sector leads and experts in the region with local knowledge and experience.

Note: The risk assessment is based on a qualitative methodology as set out below. This risk rating will generally guide and set out risks which are priorities for adaptation action (that is, those risks which may be rated high or extreme). In some cases, however, a current low-rated risk may be considered a higher priority for other reasons, for example to ensure the risk element isn't under higher risk in the future. These discussions and decisions will need to be considered following the completion of this risk assessment (refer Section 12 for further discussion).

3.3.1 Step 1: Risk identification and screening

Initially, a broad, high level literature review was undertaken to identify risk elements, across the five value domains. These were then utilised within a two-day workshop which was held on 5 and 6 December 2019, involving stakeholders from the region. The outcomes of the workshop were documented within a summary report (Tonkin & Taylor, 2020). The workshop involved:

1. Identifying and validating key risk elements through a mind mapping exercise, building on the initial literature review.
2. For the *Built Environment, Natural Environment and Economy* Domains, the workshop attendees then worked through the regional climate hazards to confirm and rate vulnerabilities and consequences over the three-time horizons for the identified risk elements.
   - Elements which demonstrated low vulnerability over the time frames were excluded from the detailed assessment. For example, storm and wind impacts on the forestry sector.
3. Across all domains (*including Human and Governance*), for the risk elements that were included, the following information was discussed / obtained:
   a. A description of the risk.
   b. Commentary around spatial distribution of the risk.
   c. Commentary on the broader consequences of the risk, for including within reporting.
4. Vulnerability was ranked based on the vulnerability descriptors outlined in Table 3-2. Note, this was only done for the *built environment, natural environment and economy* domains. For the human and Governance Domains, risks were discussed and further detail was documented to inform reporting.
5. Consequences were also ranked at a high level, however these were not included within the detailed risk rating (Step 2, Section 3.3.2).
6. Potential opportunities were discussed.

Table 3-2: Step 1 Vulnerability levels and descriptions

Vulnerability Level	Vulnerability Definition
Extreme	Extremely likely to be adversely affected, because the element/asset is extremely sensitive to a given hazard, and has a very low capacity to adapt.
High	Highly likely to be adversely affected, because the element/asset is highly sensitive to a given hazard, and has a very low capacity to adapt.
Moderate	Moderately likely to be adversely affected, because the element/asset is moderately sensitive to a given hazard, and has a low, or moderate capacity, to adapt.
Low	Low likelihood of being adversely affected, because the element/asset has low sensitivity to a given hazard, and has a high capacity to adapt.

Note, a full 'long list' of risks is included within Appendix D.

3.3.2 Step 2: Detailed risk assessment

The detailed risk assessment involved targeted engagement / conversations with key stakeholders and specialists (refer Appendix E) within each Domain, as well as a detailed literature review relating to each risk element. As discussed above, risks for Built Environment, Natural Environment and Economy Domains were rated. This risk rating was based on a qualitative assessment of exposure and vulnerability, which is discussed further below.

The risk assessment process was drawn from the IPCC conceptual risk framework as shown in Figure 3-1. This shows that risks from climate change impacts arise from the interaction between hazard (triggered by an event or trend related to climate change), vulnerability (susceptibility to harm) and exposure (people, assets or ecosystems at risk). Refer to the glossary for definitions.

In order to assess risk, the terms *exposure* and *vulnerability* were rated.

Exposure is defined as *the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected* (IPCC, 2007).

Vulnerability is defined as *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** (*IPCC, 2014d).

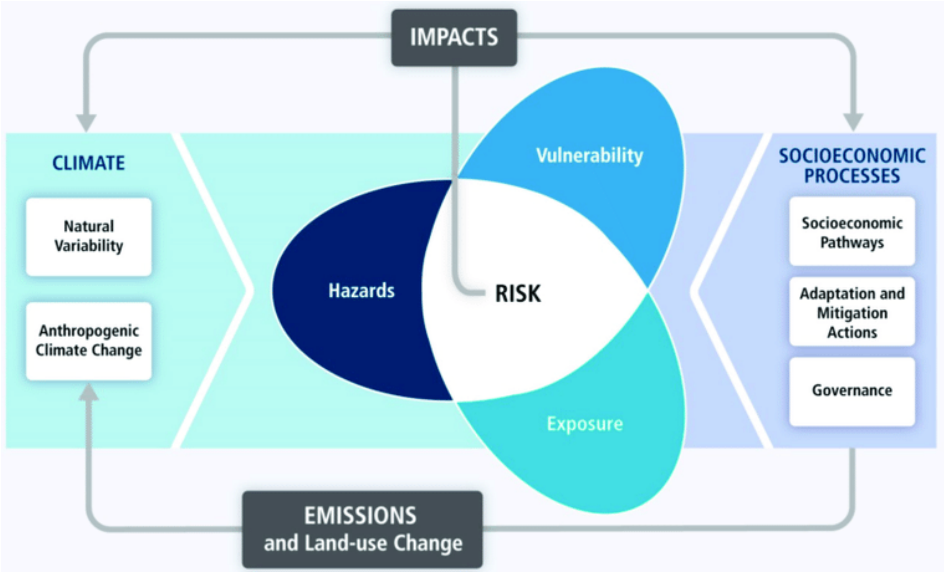

Figure 3-1: The IPCC AR5 conceptual framework with risk at the centre (IPCC, 2014).

The *exposure* of the risk elements to the climate hazards (within the Built Environment, Natural Environment and Economy Domains) were ranked over the three-time frames. This was undertaken in a qualitative manner based on stakeholder and specialist knowledge and the exposure definitions in Table 3-3.

The Step 1 *vulnerability* ratings were refined to give a qualitative rating for both *sensitivity* and *adaptive capacity* over the three-time horizons, and combined based on the matrix in Table 3-4.

An overall risk rating was then generated for each risk based on *exposure* and *vulnerability* (Table 3-5). Figure 3-2 illustrates the risk equation and the various parameters discussed.

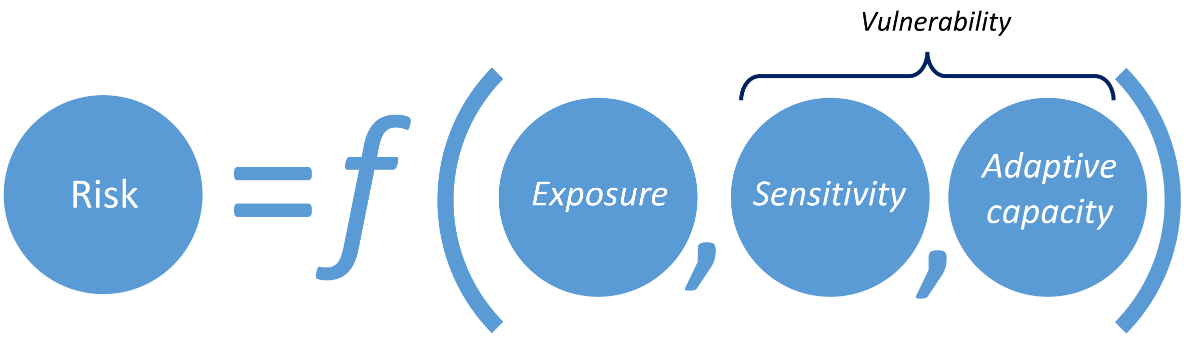

Figure 3-2: Risk equation based on exposure, sensitivity and adaptive capacity.

Table 3-3: Exposure level and descriptor

Exposure Level	Exposure Definition
Extreme	Significant and widespread exposure of elements to the hazard.
High	High exposure of elements to the hazard.
Moderate	Moderate exposure of elements to the hazard.
Low	Isolated elements are exposed to the hazard.

Table 3-4: Vulnerability matrix

Adaptive Capacity	Sensitivity: Low	Moderate	High	Extreme
Low	L3	M3	H3	E3
Medium	L2	M2	H2	E2
High	L1	M1	H1	E1

Vulnerability Key
Extreme
High
Moderate
Low

Table 3-5: Risk matrix

Vulnerability	Exposure: Low	Moderate	High	Extreme
Extreme	4L	4M	4H	4E
High	3L	3M	3H	3E
Moderate	2L	2M	2H	2E
Low	1L	1M	1H	1E

Risk Key
Extreme
High
Medium
Low

Table 3-6 shows example risk ratings, illustrating the risk statement (incorporating the risk element and climate hazard), and individual ratings for exposure, sensitivity, adaptive capacity and risk, based on the matrices above.

Table 3-6: Example risk rating table

Risk No.	Risk statement	Exposure			Vulnerability: Sensitivity			Adaptive Capacity	Risk		
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N1.1	Risk to native ecosystems and species due to higher temperature	L	M	H	L	H	E	M	L	M	E
N1.2	Risk to native ecosystems and species due to change in rainfall	L	M	H	L	H	H	M	L	M	H
N1.3	Risk to native ecosystems and species due to drought	M	M	H	L	M	H	M	L	M	H

3.4 Kā Rūnaka

There are seven Kāi Tahu Rūnaka who represent the hapū who hold mana whenua rakatirataka across the ORC region (to one degree or another), these are:

- Te Rūnanga o Moeraki.
- Kāti Huirapa Rūnaka ki Puketeraki.
- Te Rūnanga o Ōtākou.
- Hokonui Rūnanga.
- Te Rūnanga o Ōraka Aparima.
- Te Rūnanga o Waihōpai.
- Te Rūnanga o Awarua.

ORC engaged with Aukaha in January 2020, building an approach for involvement of local Rūnaka.

During this initial engagement, the Ngāi Tahu Climate Change Strategy (Ngāi Tahu, 2018) and the ongoing work being done with each Rūnaka were acknowledged. An open invitation was provided for any level of engagement sought by the Rūnaka (from simple recognition and transfer of existing knowledge through to full in-depth engagement via working groups and multi-day workshops). The relevant Rūnaka were sent a pānui in February about the work and their possible involvement.

It is acknowledged that Rūnaka were unable to participate in the early stages of the OCCRA and were subsequently sent a draft risk assessment in August and were provided a further opportunity to be involved in the risk scorings at this stage. In response, initial feedback was received from Aukaha in August 2020. Based on the recommendations in this feedback we sought to develop the work required to adjust the risk assessment with Aukaha. Further feedback was received from Aukaha in late December 2020 and subsequent changes have been made to the risk assessment report where possible.

The feedback received from Aukaha identified some limitations to the methodology of this risk assessment, resulting from the lack of mana whenua region-specific knowledge, values and tikaka being incorporated. In particular, the Rūnaka considered that the approach used did not reflect a Māori worldview, particularly as the approach involved assessing risks within discrete domains, thereby creating limitations to assessing the interrelatedness of climate change risks. Rather, the Māori worldview acknowledges the interconnectedness and complexity of the environmental and human systems, including intergenerational connections. These interdependencies are an important part of the Māori worldview and are therefore considered by the Rūnaka to be vital to the overall risk assessment.

It is recognised that many risks are inherently interconnected, however a full assessment of interconnected and cascading risks was outside the scope of this assessment (Section 3.7). Despite this, a range of risk interactions are presented and discussed within Section 9.

ORC is committed to continue working closely in partnership with Rūnaka on both climate change risk assessments and adaptation planning. Future work could include working with local Rūnaka to undertake a parallel risk assessment, for Māori, by Māori, in order to capture the region-specific values, practices and knowledge. This future risk assessment would be informed by tikaka and mātauraka Māori ways of thinking and acting around climate change. Future work would draw on those Kāi Tahu values already used in other planning documents such at the Regional Policy Statement - for example whakapapa, Whakawhanaukataka, Wairua, Mauri, Ki Uta Ki Tai, Rakatirataka, Kaitiakitaka, Tikaka, Taoka, Mahika Kai, as well as the principle of Manaakitaka.

3.5 Stakeholder Engagement Process

A variety of engagement activities were undertaken to inform the risk screening and subsequent detailed risk assessment processes. These included:

- A two-day workshop with key local government stakeholders, to identify and screen risks (refer (Tonkin & Taylor, 2020) for summary). This was facilitated by T+T with ORC support. The workshop involved:
  - Brainstorming and identifying elements at risk in the region, screening these to highlight the elements most at risk and the climate variables that put them at risk.
  - By identifying an element at risk, it was assumed 'screened' for exposure.
  - Vulnerability was then considered over the three timeframes; present day, 2040 and 2090, along with a discussion of consequences.
- Targeted requests for information and engagement with stakeholders/sector leads across all domains (this was led by ORC).
  - This involved ORC contacting stakeholders/sector leads to request information about their sectors and risks in relation to climate change.
  - ORC received feedback through email responses, phone calls and virtual meetings.
  - Feedback included a range of responses including direct information about specific risks, general information about the sector and climate change and links to relevant research.
- Collective online engagement with key lifelines stakeholders.
- Due to the range of organisations within the lifelines sector, ORC undertook collective online engagement with this sector via an online survey through *Your Say* (refer Appendix F for copy of survey). Individual phone calls with stakeholders, sector leads and topic experts to confirm detailed risk ratings (this was led by T+T with ORC support).
- All this information was utilised in the detailed risk assessment step when scoring exposure, vulnerability and risk.

3.6 Link between climate adaptation and climate change mitigation

A number of greenhouse gas emissions reductions and other mitigation actions have clear links with the complementary need to adapt to the expected impacts of climate change. At a fundamental level, the extent of emissions reductions at a global scale will help to reduce the severity of impacts that we experience due to climate change, and the corresponding extent to which we must adapt (Climate Change Commission, 2021a). Co-benefits may also arise from mitigation related decisions, that could change the vulnerability of communities or ecosystems or from adaptation actions which may lead to the reduction in greenhouse gasses.

Measures to mitigate GHG emissions such as carbon budget allocation, and the relative prioritisation of reduction and sequestration activities at both the national and regional/ local level may impact upon the risk landscape within each domain by influencing their future exposure, sensitivity or adaptive capacity. Below are some examples of how these links may play out:

- The adaptive capacity of certain sectors may increase due to incentives for carbon mitigation activities offered by central government. For example, household insulation subsidies that are targeted in reduced energy consumption have the added benefit of reducing vulnerability to temperature extremes (Ministry for the Environment, 2005).
- Carbon mitigation measures are likely to increase the use of carbon sinks (i.e. native and exotic forestry risks) as a tool for use in emissions reduction. This is likely to result in a range of benefits including increased biodiversity, soil conservation, improved water quality,

hydrological benefits and bioenergy (Ministry for the Environment, 2005). However, may also lead to adverse impacts such as increased fire risk.

- The impact of carbon mitigation on (current and future) renewable energy projects (i.e. hydro, solar and wind electricity generation risks) within the Built Domain. Distributed energy sources that use renewable energy such as household solar can increase resilience against weather related power outages (Climate Change Commission, 2021a).

For the purpose of the current OCCRA mitigation / adaptation linkages have not been considered further. Similarly the assessment does not consider transition risks, that is – those risk that arrive due to the need to rapidly decarbonise our societies.

3.7 Limitations

Key limitations of the OCCRA are as follows:

- The OCCRA utilised current knowledge and research that was available at the time of this study, and that the project team were aware of. This was augmented by engagement with stakeholders and subject matter experts within the region.
- There are likely to be additional risks not identified due to both limitations in our knowledge and understanding, and limitations in the breadth and depth of engagement with local subject matter experts. A 'long list' of risks identified is included within Appendix D.
- The inherent uncertainty in both our knowledge of climate change projections and the associated vulnerability of risk elements, means that there is subjectivity associated with the risk ratings. Involvement of key sector and subject matter experts was used, as far as practical, to provide as much context and insight as possible and to reduce the subjectivity.
- The ratings and assessments are generally based on expert opinion and sometimes there was limited research and peer reviewed information to support these rankings.
- In many cases, risks have been aggregated into themes to allow for consistent and clear reporting. Only material risks (where climate hazards were deemed by stakeholder groups and research to have potential for impact) have been discussed.
- Responses were not received from all stakeholders. This may partly have been due to COVID-19 (a large part of the engagement occurred during COVID-19 level 3 and level 4 restrictions limiting some stakeholders availability).
- Similar to the NCCRA the OCCRA does not consider cascading impacts and interdependencies in detail[1]. There has been little research on how the impacts of climate change cascade across human systems, and even less on how to consider such cascades when assessing climate change risk. Therefore, these have not been considered in this iteration of the risk assessment, as knowledge and processes develop they can be considered for future iterations of the risk assessment. However, it is recognised that many risks between and within the domains are highly interconnected, and some examples are provided within Section 9.
- Similar to the NCCRA the OCCRA does not consider socio-economic projections, such as future changes in population, gross domestic product and other economic, land use or employment variables. The uncertainty in how these variables may project out to mid and end century timeframes is too high to allow for their meaningful incorporation into the risk assessment.
- Similar to the NCCRA the OCCRA does not consider transition risks. These are risks that may emerge from the transition to a lower-carbon economy and may relate to policy, legal, technology and market changes to address mitigation and adaptation (Task Force on Climate-related Financial Disclosures, 2017). Climate change mitigation (and subsequent transition

[1] Refer Section 9.

risks) consideration is outside the scope of this assessment, however there are some clear links between adaptation and mitigation, refer Section 3.6.

- The OCCRA does not consider international and transboundary issues as this was considered best approached at the National level and is addressed in the NCCRA.
- The OCCRA does not document current approaches to adaptation within the region. Adaptation considerations is outside the scope of this report.
- Engagement with Kā Rūnaka identified some limitations to the methodology of this risk assessment, resulting from the lack of mana whenua region-specific knowledge, values and tikaka being incorporated, as well as a need to more fully consider interconnected risks - as discussed further in Section 3.4.

Human

4 Human Domain

4.1 Introduction

The Human Domain encompasses people's skills, knowledge, and physical and mental health (human), the norms and institutions of society (social), and the knowledge, heritage and customs of society (cultural). Climate change is expected to have major implications for the health of communities, for amenity, and for maintaining cultural continuity[2] (MfE, 2020). As outlined in the Methodology (Section 3.3), due to the cross-cutting nature of climate risk to human values, the Human Domain risks were not subject to a ranking or prioritisation process as discussed in Section 3.3. Further, discussion of the exposure and vulnerability of communities living within the Otago Region is presented for the domain as a whole, rather than by specific risk.

Direct impacts on communities may include increased exposure to hazards such as heat waves and weather events, flooding and fires (Royal Society, 2017). Indirect social impacts include disruption to health services, social and economic factors including migration, housing and livelihood stresses, food security, socioeconomic deprivation and health inequality including mental health and community health effects (Royal Society, 2017). The effects of climate change will not be spread evenly across the population, exacerbating existing socioeconomic and ethnic health inequalities.

Otago is a region with an ethnically, geographically, and economically diverse population of 240,000 people. According to the 2018 census 85% of the population identified as NZ / European, 9% identified as Māori, 8% as Asian, 3% as Pacifica, and 3% as other[3].

The highest risks identified within the Human Domain include the following, these are discussed further below:

Table 4-1: Summary of risk ratings in the Human Domain

Risks	
H1	Risks to Kāi Tahu sites, identity and practices, and non-Kāi Tahu cultural heritage sites, due to climate change.
H2	Risks to community cohesion and resilience from climate change.
H3	Risk to mental wellbeing and health from climate change.
H4	Risk to physical health due to climate change.
H5	Risk to increased inequities and cost of living due to climate change.

Further, the NCCRA report identifies the following risks within the Human Domain that are of particular significance to Māori:

- H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae, due to ongoing sea-level rise, changes in rainfall and drought.
- H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity, due to greater climate variability and ongoing sea-level rise.
- H8 Risks to Māori and European cultural heritage sites, due to ongoing sea-level rise, extreme weather events and increasing fire weather.

[2] Cultural continuity refers to the sharing of cultural heritage from one generation to another (Hall, 2005).
[3] Note: Total percentage is greater than 100% as a person may identify as belonging to more than one ethnic group and therefore are counted within both categories.

Commentary of these risks to Māori identified in the national scale assessment is incorporated into the risks identified in this domain. Specifically, risks H5 and H6 in the NCCRA are addressed primarily within risks H2, H3, and H5 of the current assessment, and risk H8 in the NCCRA is addressed primarily within risk H1 of the current assessment.

Exposure and vulnerability to climate change risks are largely dependent on where people live within Otago. Most of the population is urban, with approximately 80% living in main urban or independent urban areas. The remaining 20% live in small towns or rural / remote areas with little urban influence (Stats NZ, 2020a).

The impacts of climate change will be felt most strongly by those already marginalised in society, or those with higher levels of social vulnerability due to factors such as lower socioeconomic status and therefore less able to access / pay for resources. It is expected that new vulnerabilities and inequities are likely to emerge as climate change impacts are experienced more widely.

Ultimately the effects of climate change in any domain can impact on humans, with ramifications for their wellbeing, identity, autonomy and sense of belonging. For simplicity, impacts can generally be divided into *direct* and *indirect* risks as a result of a climate driver (Figure 4-1). For example, direct risks on physical health may include risks associated with being swept away when driving or walking through floodwaters due to increased frequency in rainfall, floods and storm tides. An indirect risk may include impacts on human health due to flooding of residential properties leading to increased dampness and mould and increased mental health impacts from stress (Royal Society, 2017).

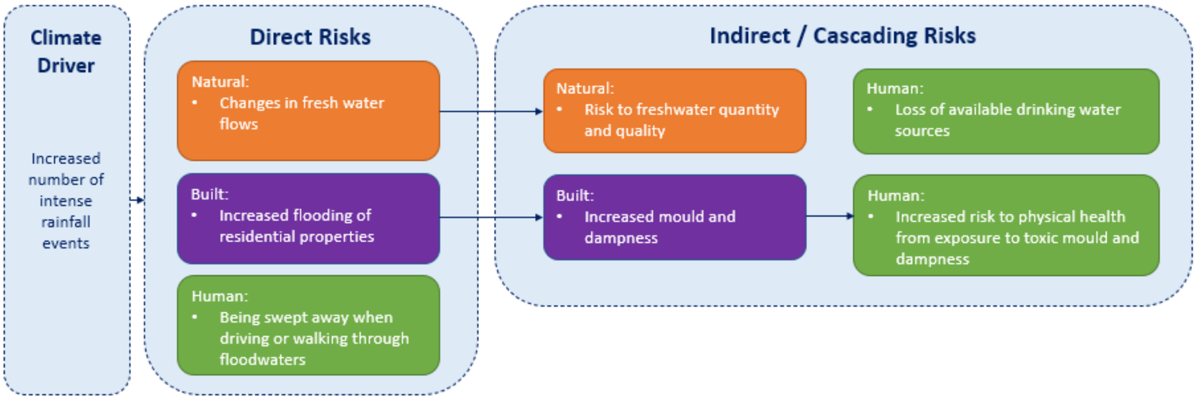

Figure 4-1: Direct and indirect effects of climate change examples.

The majority of the identified Human Domain risks are indirect or result from 'cascading' impacts[4], such as risk to cultural identity due to loss of culturally important land located within close proximity to the coastline, or risk to social cohesion due to migration as a result of climate drivers such as sea level rise or coastal erosion. Another example of cascading impacts includes loss or changes to livelihoods (refer to economy domain), which is likely to have an impact on the overall mental wellbeing of communities. A detailed assessment of cascading impacts is outside the scope of this study, however some examples are provided within Section 9.

Human Domain risks are influenced by community *exposure* to hazards, as well as their inherent *vulnerability* (sensitivity or adaptive capacity). The following sections provide an overview of the main exposed communities, an overview of each of the identified Human Domain risks and detail on vulnerable communities.

[4] Cascading impacts include those impacts which can propagate within, between and across multiple areas or sectors (Lawrence J. , Blackett, Cradock-Henry, & Niston, 2018). Cascading effects in disasters are those where the impact of a physical event or a technological or human failure, generates a sequence of events in human sub-systems that result in physical, social, or economic disruption (Pescaroli & Alexander, 2016).

4.2 Exposure

The Otago region is likely to experience a number of significant climate-related changes over time, as discussed within Section 2. These include more frequent intense rainfall events, increasing flood risk, drought, coastal erosion and inundation - and will result in the exposure of a wide range of communities throughout the region.

An increase in the number of intense rainfall events is likely to result in increased risk of flooding and landslides, particularly in western Otago (Macara et al., 2019). Communities located along western and central lakesides and river flood plains, such as Lakes Wakatipu and Wanaka and the Clutha River, could face an increase in risk from flood waters.

Historically, rainfall events have resulted in widespread flooding throughout the region such as events in Lower Clutha in 2020, Lower Taieri in 2017, Roxburgh in 2017 and South Dunedin in 2015 and led to evacuations, road closures, damage to infrastructure and associated power outages (Otago Daily Times, 2018; NZ Herald, 2020a; Stuff, 2017; NZ Herald, 2020b; Hughes et al., 2019). Similarly, Henley, located on the Taieri Flood Plain, is regularly isolated due to significant flood events (Otago Regional Council, 2015; Otago Daily Times, 2018).

The following areas in the Dunedin City District are located within a flood hazard area and are therefore potentially exposed to the impacts of flooding: South Dunedin, St Clair, St Kilda, Green Island, Mosgiel, Taieri flood plain, North Dunedin, Dunedin CBD, Brighton, Hardwood, Aramoana, Long beach, Waitati, Orokonui, Karitane, coastal sides of Waikouaiti, Middlemarch and Sutton (Paulik et al., 2019).

Approximately 2,400 people live on the low-lying parts of Clutha River Delta, where stopbanks protect much of the Balclutha and Kaitangata settlements. This represents approximately 15% of the Clutha District's population (Otago Regional Council, 2016). Given the characteristics of the river at Balclutha, such as tight river bends, high flow volumes and predominant urban land use, failure of the stopbanks is a significant risk for the community (Otago Regional Council, 2016). Other communities within the Clutha District located within a flood hazard area include but are not limited to; western parts of Tapanui and Kelso, Clarksville, Milton and Waihola (Paulik et al., 2019).

Within the Central Otago and Queenstown Lakes Districts, a range of townships are located within flood hazard areas. These include Alexandra, Kingston, Jacks Point, western parts of Lake Hayes Estate along the Shotover river, Frankton and Queenstown waterfronts, Glenorchy, Wanaka, Albert Town and parts of Hawea (Paulik et al., 2019).

Parts of Queenstown, Glenorchy, Kingston and Wanaka are developed on land that lies within the natural ranges of the surfaces of Lakes Wakatipu and Wanaka (Otago Regional Council, 2006). Flooding of the urban areas (as a result of elevated lake levels) has occurred over recent years, including the 2019 floods in Wanaka.

Flooding is also a known issue in the Waitaki District affecting rural areas as well as urban townships such as Oamaru (Waitaki District Council, 2017).

Droughts are likely to occur more frequently due to projected higher temperatures, resulting in increased water supply shortages, increased need for irrigation and increased risk of wildfires, particularly in the higher and drier areas of the region (Ministry for the Environment, 2018). Droughts have occurred on numerous occasions, including 2010 and 2018 across large parts of Otago including Queenstown Lakes, Central Otago and Clutha Districts (Otago Daily Times, 2018; Otago Daily Times, 2010). This significantly impacted rural farming communities who were unable to grow enough feed for their livestock for the winter months and had limited ability to get water to affected stock resulting in lower milking productivity (Otago Daily Times, 2018; Stuff, 2018).

Sea levels are projected to rise by up to 0.9 m by 2100 under RCP8.5 throughout New Zealand (Ministry for the Environment, 2017). This will result in increased coastal flooding of low-lying areas within the Clutha, Dunedin City and Waitaki Districts - including South Dunedin, lower Clutha Delta, Aramoana, Taieri Mouth, Pounawea, Toko Mouth, Long Beach, Karitane and Kakanui (ORC., 2012).

Other low lying coastal communities include but are not limited to parts of Papatowai, eastern parts of Kaka Point, Brighton, Dunedin CBD, Ocean Grove, Harwood, Aramoana, Long Beach, Macandrew Bay, Sawyers Bay, Port Chalmers, Waitati, Waikouaiti, Karitane, Kakanui and Oamaru waterfront (Paulik et al., 2019a).

4.3 Summary of social vulnerability

As discussed above, the concept of social vulnerability can provide some insight and help identify where the above risks may manifest within Otago.

There are several factors which contribute to social vulnerability or reduced (lack of) resilience. These include, but are not limited to: rapid population growth, aging population, poverty, hunger, poor health, low levels of education, and lack of resources and services (Fischer et al., 2002; Jenson, 2010).

Sensitivity and *adaptive capacity* are also concepts which can be used to describe social vulnerability. Sensitivity may refer to an individual or community's age distribution and overall health, and adaptive capacity or resilience is then used to describe factors such as socio-economic status as outlined in Figure 4-2 (Mason et al., 2019).

For the purpose of this assessment three social vulnerability indicators have been chosen that have potential to influence and exacerbate the climate change risks summarised above. These include the 2018 New Zealand Deprivation Index[5] (Salmond et al., 2005) as well as a proportion of older adults and social connectedness from the Social Vulnerability Indicators for Flooding (Mason et al., 2019). Each of these indicators is discussed further below.

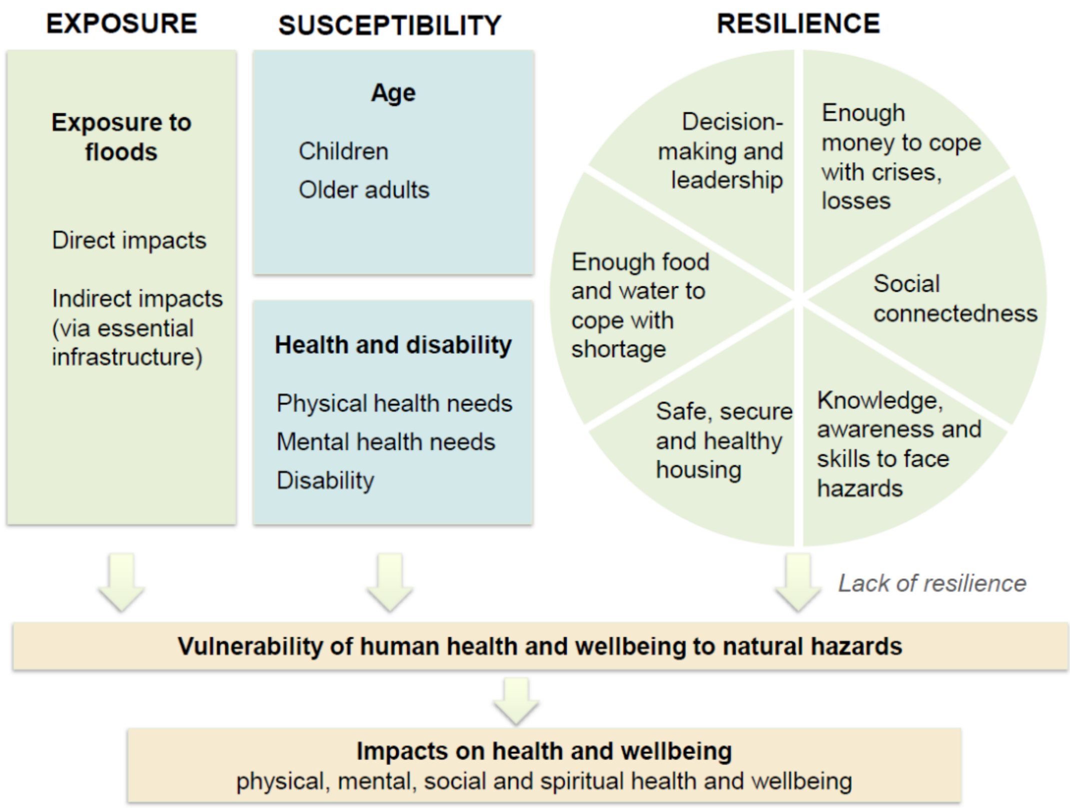

Figure 4-2: Social vulnerability framework and dimensions relating to flooding in Aotearoa, New Zealand (Mason et al., 2019).

4.3.1 Social deprivation index

The New Zealand Index of Social Deprivation provides one example of a measure of social vulnerability across communities (note that these are averages based data from the previous

[5] We note that the NZ Deprivation Index covers a range of factors that are also partially covered in the older adults and social connectedness factors.

census). The Index ranks locations on a scale of decile 1 (least deprived) to decile 10 (most deprived) based on a number of prescribed criteria including:

- People with no access to the Internet at home.
- People aged 18 - 64 receiving a means tested benefit.
- People living in equivalised[6] households with income below an income threshold.
- People aged 18 - 64 unemployed.
- People aged 18 - 64 without any qualifications.
- People not living in own home.
- People aged < 65 living in a single parent family.
- People living in equivalised[6] households below a bedroom occupancy threshold.
- People living in dwellings that are always damp and/or always have mould greater than A4 size.

In general, people who live in more deprived areas (for example, decile 9 and 10) are more susceptible to environmental risks. This is generally because they have less capacity to cope with the effects of environmental risks, and fewer resources to protect themselves from environmental hazards (EHINZ, 2018).

The New Zealand Index of Social Deprivation provides one example of a measure of social vulnerability across communities by Statistical Area 2[7]. The Index ranks locations on a scale of decile 1 (least deprived) to decile 10 (most deprived) based on a number of prescribed criteria.

Areas of high deprivation within Otago include Harbourside, Hillside-Portsmouth Drive and Bathgate Park in Dunedin City, which have all been categorised as decile 10 or high deprivation (Figure 4-3 a and b). These three high deprivation areas are also all located within a low lying coastal area and flood hazard area (Paulik et al., 2019a; Paulik et al., 2019).

[6] Equivalisation: Equivalisation is a term that describes the measurement of household income by giving the members of a household different weightings. Equivalisation is a standard methodology in economics in which the household income is modified to account for the different financial needs of different household sizes and composition. The incomes of different household types are made comparable by accounting for shared consumption benefits.

[7] Statistical area geographies are aggregations of meshblocks optimised to be of similar population sizes to enable the release of low-level data (StatsNZ, 2018).

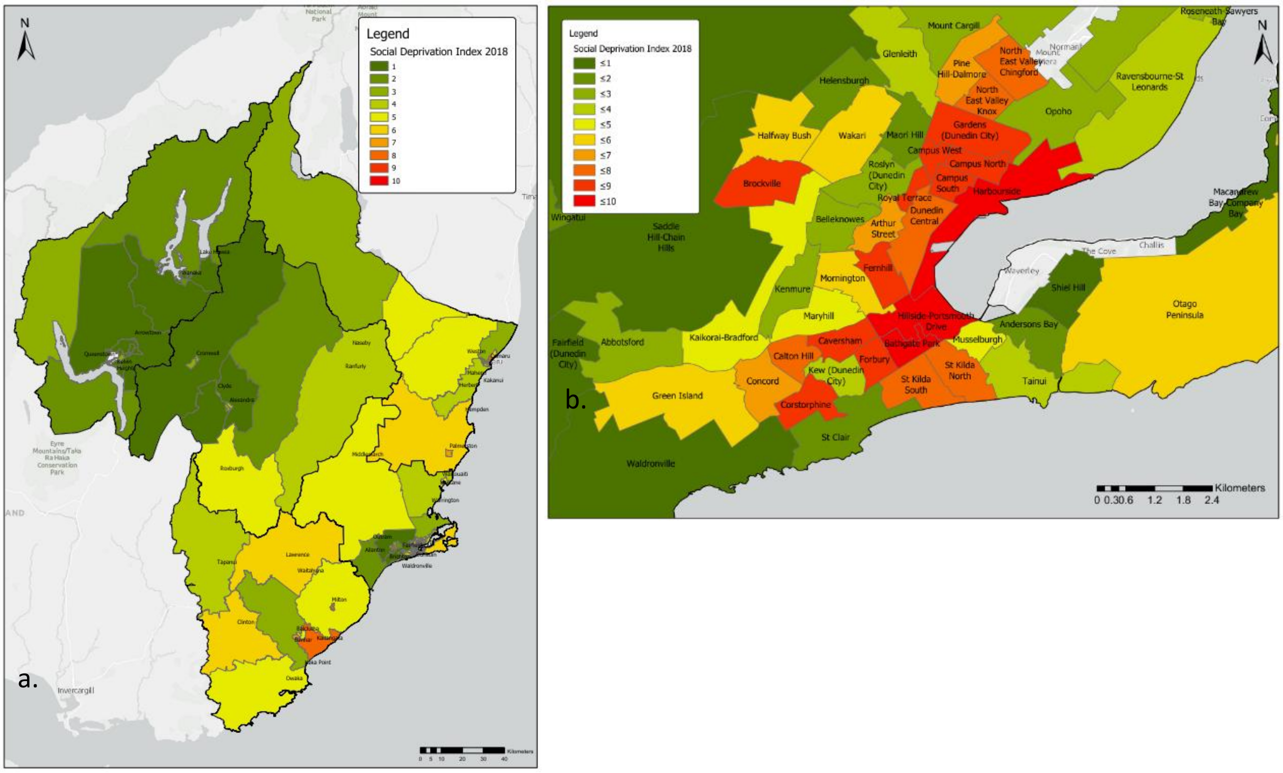

Figure 4-3: a. Social Deprivation Index by statistical area 2 for Otago region, b. Social Deprivation Index by statistical area for Dunedin City.

Other communities which were indicated by stakeholders as having higher levels of social deprivation include the Taieri Plains (particularly areas at risk of coastal and flood hazards), Harrington Point and Aramoana at the entry to Otago harbour, Long Beach, Inch Clutha, and Karitane (Stakeholder Consultation, 2019/2020). It was noted that these coastal areas are also often comprised of low-income families, low-key holiday homes/cribs, and retirees (Stakeholder Consultation, 2019/2020). Therefore, these households likely lack adaptive capacity and do not have a strong financial base for undertaking adaptation.

4.3.2 Older adults

Older adults tend to be less mobile and are more likely to be physically impaired and have ailments such as hearing or vision loss. Older adults are also more likely to have chronic health conditions such as heart disease and diabetes, which make them more susceptible to health impacts related to heat stress or during and after a flood (Environmental Health Indicators Programme, 2019). They may have limited social networks and be socially isolated, particularly if they live alone, as well as needing more help to evacuate during a flood, and during the clean-up phase after a flood (Mason et al., 2019).

Information on older adults is based on the 2018 census. For the purposes of this assessment has included the percentage of people older adults (70+ and 60+ for Māori) across the Otago Region by Statistical Area 2 and shown in Figure 4-4.

Oamaru central has the greatest percentage of older adults with 37%, followed by Seddon Park in Dunedin City, Wanaka Central, Mosgiel Central and Mosgiel East with 25-30% of their population as older adults (Figure 4-4 b, c and d). Of these areas with a high percentage of older adults, Seddon Park, Mosgiel Central, Mosgiel East and parts of Wanaka Central are located within a flood hazard area (Paulik et al., 2019), whereas parts of Oamaru Central are located in a low lying coastal area

(Paulik et al., 2019a). Higher concentrations of vulnerable groups can be an advantage as it allows a targeted approach to specific communities.

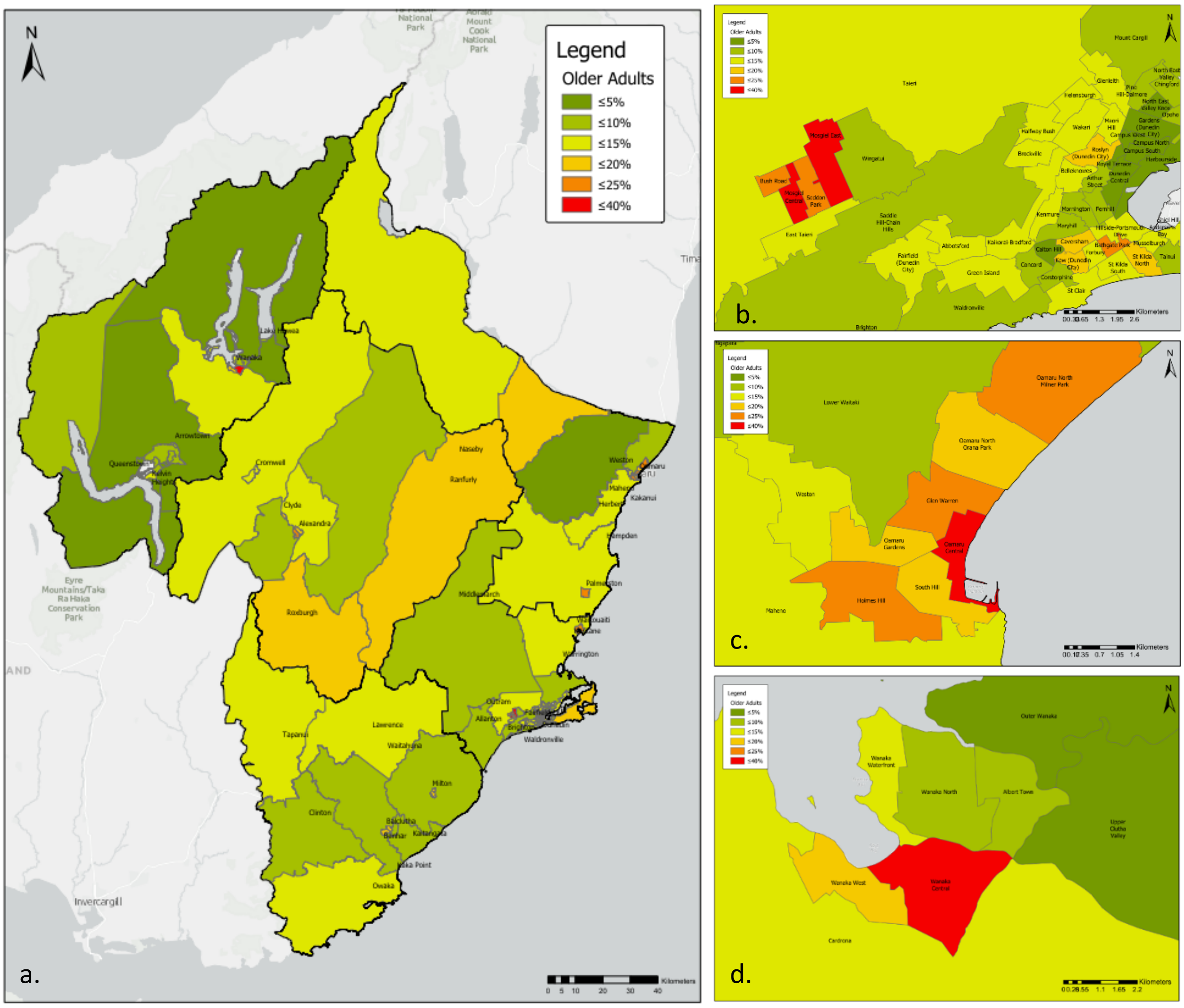

Figure 4-4: a. Percentage of older adults by statistical area 2 for the Otago region, b. percentage of older adults by statistical area 2 in Dunedin City, c. percentage of older adults by statistical area 2 in Oamaru, d. percentage of older adults by statistical area 2 in Wanaka.

4.3.3 Social connectedness

Having strong social connections and networks can be beneficial for coping during and after a natural hazard (refer section 4.4.2). By contrast, social isolation is an important aspect of vulnerability for people, as it means that people may not have others to help them if needed, including for evacuation, and clean-up (Mason et al., 2019).

Social connectedness is based on the 2018 census and includes (Mason et al., 2019):

- **People living in rental housing:** People living in rental housing may move from place to place more regularly than people who own a house. For this reason, people who live in rental housing may not know other people in their neighbourhood. When a local area has a high percentage of rental houses, if many of these people move each year, it may be difficult to build social connectedness in the area.

- **Recent immigrants:** People who are new to New Zealand may not yet have a strong social network. They may also not know where to go to access information, support services and other important services.

Dunedin City Council area has the highest percentage of people living in rented dwellings across the five districts (Figure 4-5 a). Specific areas of note are Campus North with 99%, Campus South with 97%, Gardens with 96% and Campus West with 91% (Figure 4-5 b). This is likely due to the significant number of university students living close to Otago University. The majority of Campus South as well as parts of Campus North, Gardens and Campus West are located within a flood hazard area (Paulik et al., 2019). Eastern parts of Campus North and Campus South are located within a low-lying coastal area (Paulik et al., 2019a).

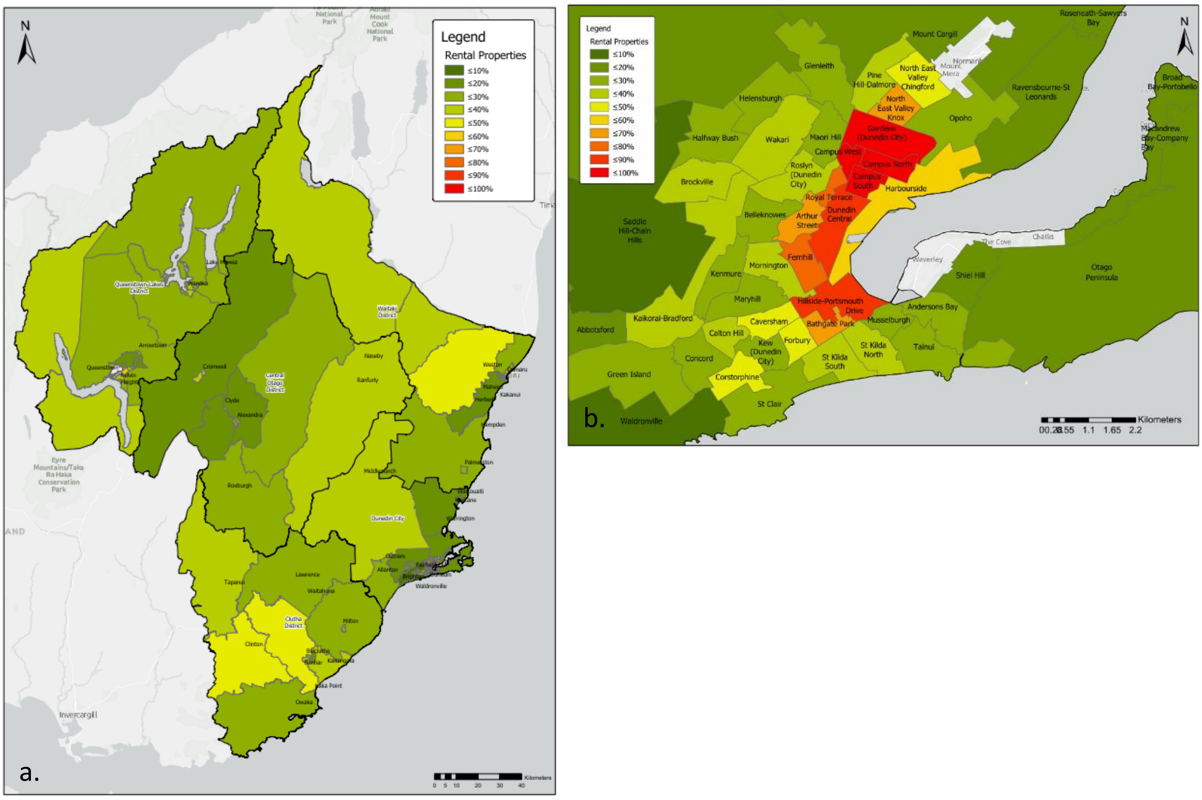

Figure 4-5: a. Percentage of total population living in rented dwellings by statistical area 2, b. percentage of people living in rented dwellings by statistical area 2 in Dunedin City.

Figure 4-6 shows the percentage of the population who have recently migrated within the last year. Warren Park and Queenstown Central in Queenstown Lakes District have the greatest number of recent immigrants with 33% of their total population having immigrated in the last 0-1year (Figure 4-6 a and b). This is followed by Sunshine Bay-Fernhill and Queenstown East with over 20% of their population having immigrated in the last year. Waterfront areas of Queenstown Central are within a flood hazard area, as well as small parts of Warren Park (Paulik et al., 2019).

A recent report by the Salvation Army 'The State of Our Communities' (Salvation Army, 2020), highlighted the hardships currently being faced by migrant communities in Queenstown, as a result primarily of the COVID 19 pandemic. This was related to long term employment uncertainty, high housing costs and lack of access to social support and mental health services. These led to economic hardship, and increased instances of stress and anxiety being experienced.

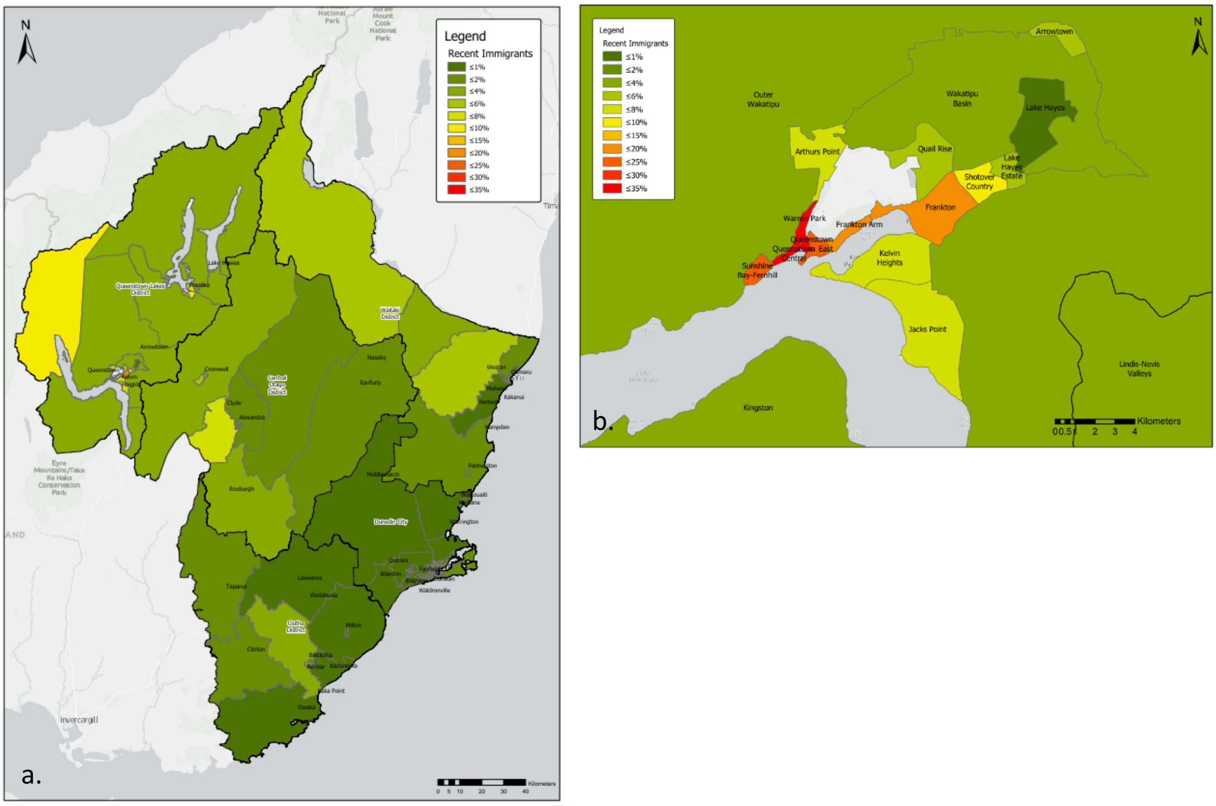

Figure 4-6: a. Percentage of the total population who have recently migrated in the last 0-1year by statistical area 2 for the Otago Region, b. percentage of the people migrated in the last 0-1 year by statistical area 2 for Queenstown.

4.4 Summary of key risks

The following sections detail the top risks identified across the Human Domain and their associated consequences. These risks can be read in conjunction with the high-level indicators of social vulnerability (Section 254.3) which can provide some insight into sub-regional differences.

4.4.1 H1: Risks to Kāi Tahu sites, identity and practices, and non-Kāi Tahu cultural heritage sites, due to climate change

The loss of access to, and quality of, cultural sites such as tapu land and water ways can result in a loss of cultural identity for Māori communities, as they often play a key role in narratives and shared stories of societies (Downing & Cuerrier, 2011; Carmichael et al., 2018; Voyde & Morgan, 2012; Royal Society, 2017).

Māori communities have strong connections to their turangawaewae[8] or place, through whakapapa (genealogical connections) that include physical and spiritual connections. This leads to a deeper connection to land and place, even if this results in increased exposure to hazards such as flooding (King et al., 2010a). The strong connection to turangawaewae makes Māori more vulnerable to loss of land or displacement, as this loss will sever the spiritual relationship with traditionally occupied places (Koppel Maldonado et al., 2013).

Kāi Tahu in Otago traditionally settled mostly in coastal areas but travelled extensively inland according to the seasonal hunting and gathering economy that was a distinctive feature of the

[8] Home grounds through rights of kinship and whakapapa, place to stand.

southern Kāi Tahu lifestyle. Travel routes often followed rivers and lakes, with routes and inland settlements typically based around mahika kai areas (Anderson, 1998).

Mahika kai refers to the customary gathering of food and natural materials and the places where those resources are gathered or produced. Maintaining mahika kai sites, gathering resources, and continuing to practice the tikaka that governs each resource, is an important means of passing on cultural values and mātauraka to the next generation. For southern Māori, mahika kai is the basis of culture, and the unrelenting cultural imperative is to keep the mahika kai intact, to preserve its productivity and the diversity of species (Kāi Tahu ki Otago Natural Resource Management Plan 2005).

A warming climate and therefore warmer water temperatures is likely to have implications for water quality, leading to impacts such as loss of ecosystem functioning due to a loss of biodiversity (Ministry for the Environment & Stats NZ, 2017; Bassem, 2020). For Māori, this could mean the mauri of the water would be impacted, and the ability of Māori to interact with the ecosystem would be diminished, in turn impacting on opportunities to practice mahika kai (Morgan, 2006; Durette et al, 2009; Ministry for the Environment, 2019). The health and capacity of waterways is a significant part of expressing ahikāroa and kaitiakitaka (Ministry for the Environment, 2019).

In addition to impacts on mahika kai and the mauri (life force) of water, climate change may impact on other resources significant to Kāi Tahu, such as tapu (sacred) sites, wāhi tūpuna (cultural landscapes), taoka (treasured) species and habitats and the coastal environment in general. Kāi Tahu are connected to all of these elements through whakapapa (genealogy), kaitiakitaka (customary authority) and associated tikaka (customs) which govern how kaitiaki is exercised. Any diminishment of the mauri of these elements through the impacts of climate change is felt as a diminishment of the mana (spiritual life force energy) of Kāi Tahu mana whenua (Carter, 2020). This point is reinforced and acknowledged by Heritage New Zealand, in that they recognise that the loss of cultural heritage will impact on identity and cultural wellbeing (Stakeholder engagement, 2020).

More broadly, cultural heritage sites (including buildings, infrastructure and landscapes) provide a sense of identity and continuity for a place (UKEssays, 2018). Cultural heritage can also play a significant role in economic development for an area or community and if impacted by climate change, can result in a number of economic, mental health and social cohesion impacts (Alexandrakis et al, 2019). Increasing flooding and sea level rise may reduce access along narrow coastal or riverine reserves.

A number of heritage sites and buildings are known to be at risk. These include sites on the New Zealand Heritage List (Rārangi Kōrero) as well as Heritage NZ properties. Examples include Clark's Mill (Maheno); Hayes Engineering and Homestead (Oturehua); Matanaka (Waikouiti). The Oamaru Victorian Precinct will potentially be recognised as a National Historic Landmark, and this is low lying and thought to be at risk from flooding (Stakeholder engagement, 2020).

There are also a number of New Zealand Archaeological Association sites in Otago (both recorded and unrecorded) which are known to be at physical risk to coastal erosion and sea level rise. Due to past settlement patterns, a significant proportion of these sites are of Māori origin and some are already experiencing damage due to coastal erosion (Stakeholder engagement, 2020). However it is noted that exposure of Māori and non- Māori heritage sites is considered poorly understood, and requires further investigation.

4.4.2 H2: Risks to community cohesion and resilience from climate change

Understanding a community's level of social cohesion is key to understanding the social vulnerability to climate related hazards (Vega-López, 2012). Social cohesion can be impacted in a number of ways such as loss of national, regional or community level identity, or through lack of integration of migrants into the host communities (Saggar et al., 2012).

At the national level, it has been identified that Māori communities are at risk of displacement due to climate related hazards. This risk is relevant to Kāi Tahu in the Otago region. Many Māori communities are concentrated around coastal areas, which are particularly vulnerable to rising sea levels (Ministry for the Environment, 2020). For Māori, culture forms the basis of social cohesiveness, which in turn contributes to wellbeing and resilience including adaptive capacity of the collective (Ministry for the Environment, 2020). The potential displacement of individuals, families and communities due to climate-related hazards will erode sense of community, social cohesion, and community wellbeing. These factors are paramount for resilience and adaptive capacity (Ministry for the Environment, 2020; Jakes and Langer, 2012; Tompkins and Adger, 2004).

Human migration has been deemed one of the greatest consequences of climate change (International Organisation for Migration, 2008). The cultural and social impacts of community relocation or migration may be severe for: the communities receiving or hosting migrants, the migrants themselves, and the communities they leave behind (UNESCAP, 2014).

In terms of migrants, the Otago region has received 3% of New Zealand's Skilled Migrant Category based on the latest Migration Trend Overview (MBIE, 2017). The Otago region was the third largest employer of Essential Skill workers in the country with a significant number of temporary migrants to Queenstown and has 5% of total number of international students (MBIE, 2017).

Rapid urban growth can also have an impact on social resilience and social cohesion. Prior to the impacts of COVID-19, Queenstown Lakes District was growing twice as fast as any other city in New Zealand (PWC, 2019). This has led to significant capacity and infrastructure constraints whilst significantly impacting the local community to the point where residents are moving out of the area (Martin Jenkins, 2018; Newshub, 2019).

The Queenstown District has the greatest percentage of migrants who have arrived within the last 0-1 year within the Otago region. The Central Dunedin area (Campus South, Campus West, Campus North and Gardens), have a significant proportion of their population living in rental properties. As previously mentioned, both of these factors contribute to lowering social cohesion within communities, that may be exacerbated by the impacts of climate change. It is also possible that the areas close to the University Campus may have communities with stronger cohesion through this link which may counter the above.

The impacts of climate change have potential to exacerbate these issues such as increasing strain on infrastructure (refer built domain), in turn resulting in lower social cohesion and resilience, for both the remaining community and those who may retreat or move out of the area (Boas et al. 2019).

4.4.3 H3: Risk to mental wellbeing and health from climate change

Along with the obvious physical disruption climate change will likely cause, there is also the potential for increasing impacts on the mental health of communities living within exposed areas. 'Climate anxiety' is an increasing issue caused from both experiencing a significant hazard event as well as the ongoing stress of worrying about the uncertain future (The Guardian, 2020).

The degree of distress a person feels about climate change is often related to how directly and significantly their environment is altered or threatened (Ingle & Mikulewicz, 2020). Therefore, communities which are more regularly exposed to significant climate related events are more likely to experience increased mental health impacts - something which is already occurring within Otago. An example is that of the Taieri Plains which is an area regularly impacted due to flooding. This has resulted in the threat of heavy rainfall or high river flows causing regular anxiety for local residents (Otago Regional Council, 2015). It is worth noting that impacts on people's livelihoods and finances (see economic domain) is likely to, in turn, impact the overall mental wellbeing of the community – for example through loss of livelihoods or loss/damage to property as a result of climate change.

Additionally, climate change hazards can result in the loss of amenity (for example open space which is flooded or eroded at the coast). This can lead to a variety of mental and physical health impacts (through loss of connection or ability to engage in recreation) and may have a disproportionate impact on more socially disadvantaged community groups who may have higher needs for publicly available recreation and play spaces provided, or local iwi who may have historical and traditional connections to certain amenity areas.

For Kāi Tahu, climate change has potential to destabilise cultural foundations and contribute to a loss of identity, and thus will result in stress-related health issues. Māori understandings of health emphasize a holistic persepctive that incorporates spritual, intellectual, physical, social and emotional dimensions, and includes relationships with the environment (Jones, et al., 2014). Changes to landscapes and waterways will adversely impact on wāhi tūpuna and marae, cultural practices such as mahika kai, and access to resources. This will weaken cultural values and connections to whakapapa, and add to the existing higher rates of mental illness and suicidal behaviour experienced by Māori (Jones, et al., 2014).

The risks of coastal hazards (leading to potential retreat) and extreme temperatures have been identified as risks which can significantly affect people's mental health (Royal Society, 2017). Coastal retreat is likely to cause uncertainty for vulnerable populations and lead to mental health issues from the trauma of leaving familiar surroundings, the breaking of social ties, and the difficulty of resettlement as well as financial impacts of loss of property or diminishing value (Royal Society, 2017). Extreme temperatures have been shown to result in increased incidences of aggressive behaviour, violence and suicide, particularly in individuals with established mental health or psychiatric conditions (Royal Society, 2017).

Priority should therefore be given to promoting community resilience through well-planned approaches, involving community-based adaptation that engages stakeholders in proactive problem solving processes to enhance social capital (Ebi & Semenza, 2008). In addition to grassroots actions undertaken at the community level, reducing vulnerability to current and projected climate change will also require top-down interventions implemented by public health organizations and agencies (Ebi & Semenza, 2008).

4.4.4 H4: Risk to physical health due to climate change

Climate hazards can result in a range of potential physical health impacts. Extreme events, such as the June 2015 flooding in South Dunedin present immediate physical risks associated with being swept away when driving or walking through floodwaters, injury by electrocution, debris or rainfall induced landslides, or being injured by fire (Vardoulakis et al., 2015; Royal Society, 2017; WHO, 2013). With temperature extremes (including an increase in the number of hot days) expected to increase, there will likely also be an increase in heat-related mortality (Royal Society, 2017). Increasing temperatures pose an increased risk of heat stress, as well as increased occurrence of gastrointestinal infections, infectious diseases, respiratory problems and cardiac problems. Populations that are vulnerable to these increasing risks are older adults, those with chronic disease, young children and those who are on low incomes or predominantly work outdoors (Environmental Health Indicators Programme, 2019).

Air quality is also likely to change as a result of changing climate due to the strong dependence on weather (Jacob and Winner, 2009). The nature of changes in air quality across the Otago region will vary with local atmospheric responses to the predicted changes in wind speeds, temperature and rainfall for the region (Macara et al., 2019). If the sources and relative emission volumes of air-borne pollutants (e.g. particulate matter and toxic gases) remains comparable to the present then a high level assessment of the impact of projected climate changes on air quality over the next 100 years can be made. Air quality may be expected to generally improve in those areas that experience increases in wind speeds (due to the more rapid dispersal of pollutants and air mixing rates).

However, increasing temperature and water vapour (linked to increasing rainfall) are associated with worsening air quality. During seasons and regional-scale weather patterns where wind speeds are low, air quality is expected to become worse over time (Jacob and Winner, 2009; Ebi and McGregor, 2008).

Indirect physical health risks include impacts from living and working in damp indoor environments. This may result in an increase in respiratory diseases such as asthma, hypersensitivity pneumonitis, rhinosinusitis, bronchitis and respiratory infections (WHO, 2013; Zang, 2010; The National Institute for Occupational Safety and Health, 2012). Impacts on wastewater and stormwater infrastructure may result in impacts to water quality and exposing communities to unsafe contaminated water (Hughes et al , 2019). This may result in increasing risk of infection or disease, as well as water shortages (Vardoulakis et al., 2015; Ahern et al , 2005). It is also thought that changes in the climate may lead to an increasing amount of pollen and extending the duration of pollen season having an impact of allergic disorders such as rhinitis, conjunctivitis, asthma and hay fever (AAAAI, 2020).

As previously mentioned, older adults are also more likely to have chronic health conditions such as heart disease and diabetes, which make them more susceptible to health impacts during and after a flood (Mason et al., 2019). Oamaru central, Seddon Park, Wanaka Central, Mosgiel Central and Mosgiel East statistical areas have the highest proportions of older adults within their community and are therefore at higher risk of exacerbated physical health impacts due to climate change.

Māori currently face many health inequities, which are likely to be exacerbated by changing climate conditions. This will demand careful societal responses that do not exacerbate these (Ministry for the Environment, 2020; Manning, Lawrence, King and Chapman, 2015). Māori are disproportionately exposed to adverse social and economic conditions, with consequently higher morbidity and mortality. Nationwide studies suggest that life expectancy for Māori is already seven years lower than for non-Māori, and Māori have significantly higher rates of most major diseases. These factors will increase vulnerability to the health effects of climate change for Māori in Otago (Jones, et al., 2014).

4.4.5 H5: Risk to increased inequities and cost of living due to climate change

Climate change exacerbates inequalities, not only in poor, developing countries, but also in industrialised, wealthy ones (Ruiz, 2019). Those marginalised by age, race, ethnicity, socioeconomic status, gender, literacy or health may be unable to access resources to respond to climate risks (Ton et al., 2019; Ellis, 2018; Ingle & Mikulewicz, 2020).

Climate change is likely to increase the cost of living due to more frequent community disruption, as well as disruptions to primary industries, supply chains, and raising the cost of doing business (refer Section 6.7). These impacts may, in turn, compromise food security and increase consumer costs. Risks to communities, buildings and open spaces (risk B1), energy and telecommunications, and other culturally important places can lead to cascading implications such as financial and personal distress, social deprivation, lack of work security, public health concerns and a loss of community (Stephenson et al., 2018) – all of which can increase inequities and raise living costs.

As discussed in detail within Section 4.3, there are a range of indicators which can be utilised to identify communities which may be vulnerable within Otago. These include those with lower incomes, immigrant communities, elderly etc. This increases the risk of inequality resulting from climate change, particularly for those populations who may lack the financial, social, or community resilience needed to cope, manage, and recover from new environmental hazards or climate stress.

The socio-economic disparities between Māori and non-Māori communities are likely to increase sensitivity to climate change impacts and risks for Māori society (Ministry for the Environment, 2020; Manning, Lawrence, Ngaru King and Chapman, 2015). For example, Māori communities are more sensitive to climate change impacts on ecological systems, due to dependence on primary industries for livelihoods, and the impacts of climate change on cultural and spiritual wellbeing, as well as on mahika kai, food security, and proximity of housing and infrastructure (Ministry for the Environment, 2020; Stephenson et al, 2018).

4.5 Summary

Climate change is expected to have major implications for the health of communities, for amenity, and for maintaining cultural continuity.

The impacts of climate change will be felt most strongly by those already marginalised in society, or those with higher levels of social vulnerability. It is noted that new vulnerabilities and inequities are likely to emerge as climate change impacts are experienced more widely.

The effects of climate change can impact on people and communities in a number of ways, both directly and indirectly, with ramifications for their wellbeing, identity, autonomy and sense of belonging. Interacting and cascading implications are significant, and some examples are provided within Section 9.

Risks to people and communities is driven by their exposure to climate hazards and the degree of their social vulnerability. Therefore, any adaptation responses must necessarily address this exposure and/or reduce social vulnerability. This last point is key and underscores the need to address broader social cohesion / inequities / deprivation within communities if we are to effectively adapt to climate change.

Natural Environment

5 Natural Environment Domain

The Natural Environment Domain refers to all aspects of the natural environment within Otago, which support indigenous species and associated ecosystems in terrestrial, freshwater, wetland, coastal and marine environments. Some commentary is also made around climate impacts on landforms and landscapes[9]. The links between the natural environment and other domains, particularly the human and economic domains, mean that impacts on Otago's natural environment can have a range of interacting and cascading impacts in other domains. A detailed assessment of cascading impacts is outside the scope of this study, however some examples are provided within Section 9.

The natural environment within the Otago region is at risk from a range of climate change hazards including, increased temperature, changes in rainfall, reduced snow and ice, coastal and inland flooding, extreme weather events, drought, ocean acidification and others. This assessment focuses on the exposure, vulnerability and potential impacts to the natural environment from selected climate change hazards that have been identified as being of elevated importance. It is noted that the risk assessments provided are not exhaustive but focus on the key risks that are predicted to occur as a result of climate change.

5.1 Summary of risks

The estimated impacts to Otago's natural environment and ecosystems resulting from the identified climate change hazards in Section 2 have been described in terms of habitat and geographic range changes, biodiversity changes, species success (population changes), and the interaction with compounding stressors (human development and land-use and invasive pest pressures). Fifty five individual risk have been identified, across six categories – as summarised within categories in Table 5-1 below, and illustrated in Figure 5-1 and Figure 5-2.

The natural environment risk categories at highest risk are risks to the terrestrial ecosystems from increasing temperatures, changes in rainfall and reduced snow and ice (N1), and risks to coastal, inland and alpine wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice (N4).

A number of risks within the Natural Environment Domain are of particular significance to Māori – reflecting the mātauraka-a-Kāi Tahu in the context of the natural environment, and an integrated economic, environmental, social, and cultural world view. While specific risks have not been explored in detail as part of this report, it is acknowledged that this could be investigated further as part of a Te Ao Māori climate risk assessment.

Risk examples include risks to mahika kai and taoka species. There are a wide number of listed taoka species - many covered within Schedules 97 and 98 of the Ngāi Tahu Claims Settlement Act 1998 (Government of New Zealand, 1998), including birds, plants, marine mammals, fish and shellfish. Further assessments will be required to understand specific risks to individual species. Furthermore, it is noted that many taoka and mahika kai species are diadromous, so they are especially at risk

[9] Note that while this assessment primarily focusses on key natural ecosystems across the Otago region, high level impacts on significant natural landforms and landscapes are also identified, where relevant. A wide range of outstanding and significant natural landforms and features are recognised in district plans across Otago (for example the Wakatipu Basin, the Catlins, and the Rock and Pillar Range). While the climate related changes in vegetation and fauna found in significant landform areas is discussed in the following sections, the primary change-mechanism for landforms is erosion (Ministry for Primary Industries, 2012). Some natural landforms composed of weather-resistant rock will be highly resistant to projected increases in erosion (due to increased rainfall/extreme weather events), while landforms such as the sea cliffs south of Sandymount may have an elevated risk of erosional damage due to increased rainfall, increasing sea-level, and increased frequency of extreme storm events (Moore, 2015).

because climate change will affect the multiple environments they occupy at different parts of their life cycle.

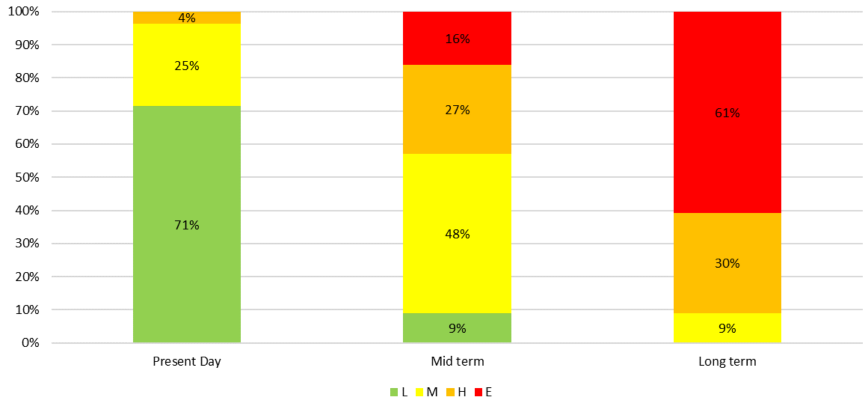

Figure 5-1: Summary of natural environment risks by risk rating.

Table 5-1: Summary of risk ratings in the Natural Environment Domain

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
N1	Risks to the terrestrial ecosystems from increasing temperatures, changes in rainfall and reduced snow and ice.	H	E	E
N2	Risks to the freshwater (rivers and lakes) ecosystems from increasing temperatures and extreme weather events.	M	H	E
N3	Risks to the coastal and marine ecosystems from climate change hazards including ocean acidification and marine heatwaves.	L	H	E
N4	Risks to coastal, inland and alpine wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice.	H	E	E
N5	Risks to Otago water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice.	M	E	E
N6	Risks to native ecosystems posed by increasing threats from invasive plants, pests and disease due to climate change.	M	M	E

*Individual risk rating per category and hazard relationship highlighted. Refer individual risk discussions for detailed ratings.

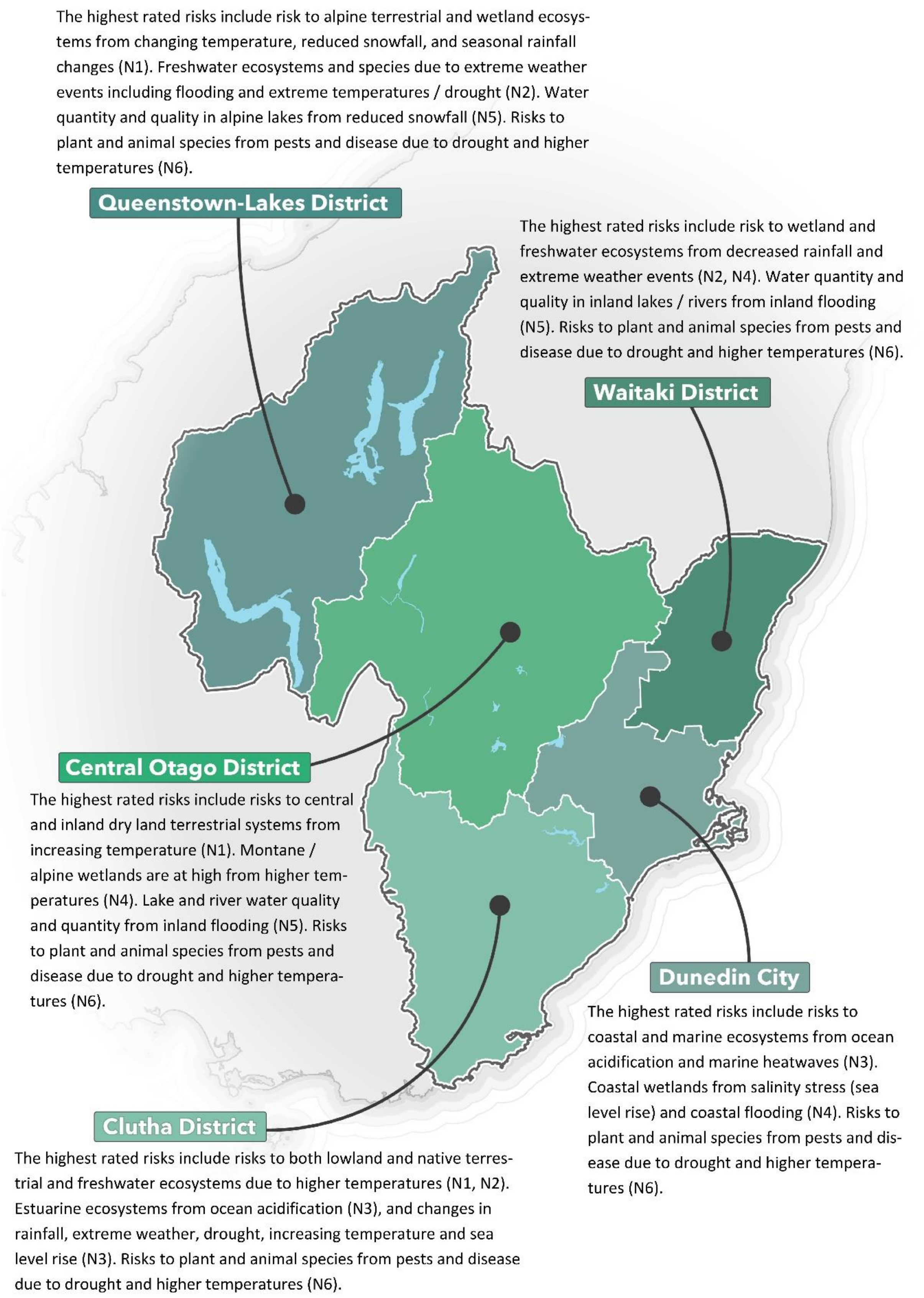

Figure 5-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the natural domain.

5.2 N1: Risks to the terrestrial ecosystems from increasing temperatures, changes in rainfall and reduced snow and ice

5.2.1 Introduction

Terrestrial ecosystems are comprised of communities of land-based organisms that are constantly responding to changing processes in the physical environment. Terrestrial ecosystems are often described by abiotic (usually climatic) characteristics and predominant vegetation types (Singers & Rogers, 2014). The response of these communities to change is often difficult to measure, and predictions of the changes that might occur as a direct result of changing climate are caveated with compounding uncertainty.

The forecast response of the physical environment to these predicted changes is considered, and the estimated response of terrestrial ecosystems and communities between present day and 2090 is summarised. Terrestrial ecosystems in Otago have been broadly grouped into alpine, montane/hill country, and low-land communities for the purposes of this risk assessment.

Alpine ecosystems are found only in the Queenstown-Lakes district, and much of the land supporting these ecosystems is protected in public conservation land. Alpine ecosystems are characterised by communities of cold-adapted species, occurring above the tree line and below the permanent snow line.

Montane/hill country communities are found through much of the Otago region. East of the Southern Alps the Otago region contains a series of basin and range landforms with ranges becoming progressively lower in elevation towards the east coast. Montane/hill country ecosystems are found in these ranges outside of the Southern Alps and are characterised by habitats adapted to the lack of water forming unique dryland communities. These communities are home to approximately 90% of Otago's threatened species, though at present only 3% of dryland habitat has formal conservation protection (Department of Conservation, 2016).

Low-land environments in the Otago region typically retain a very small percentage of indigenous vegetation cover (<10%) (refer Figure 5-3). The low percentage of remaining native vegetation cover contributes to the high threatened environment classification for much of these landscapes, see Figure 5-34 (Walker et al. 2015). A large proportion of these landscapes has been converted to agricultural production land, and the pockets of native vegetation remaining typically comprise coastal forests and shrubs supporting small populations of native fauna.

Approximately 47% of land in the Otago region has been converted from native vegetation cover to exotic grassland, 26% of the land area comprises tussock species vegetation cover, and native forests and shrubs are found across 12% of the region, see Figure 5-4 (Manaaki Whenua Landcare Research, 2020).

The exposure and vulnerability of terrestrial ecosystems to climate change related hazards is considered at a high level below, leading to the risk ratings presented in Table 5-2.

5.2.2 Exposure

Alpine terrestrial communities in Otago are most likely to be impacted by decreased snowfall and increasing temperatures. Increases in the elevation of the permanent snowline may slightly increase the upper range limit for many species. However, rising temperatures are likely to raise the lower elevation range for many cold adapted communities, forcing alpine communities into smaller geographic areas (Halloy & Mark, 2003).

Montane and hill country dryland communities are most likely to be impacted by the increases in temperature and the increasing seasonality of rainfall. Although these communities are adapted to lack of water, increasing summer hot days and lower rainfall projections for inland Otago will stress these species (Jewell & McQueen, 2007). In addition, increased dry and hot days in summer will create greater fire risks and prolong the fire season in central/inland Otago.

The increase in severity of extreme events may lead to more intense floods and destruction of habitats in all terrestrial ecosystems across Otago (including coastal forests). Terrestrial ecosystems across Otago are more likely to experience more severe event scale disturbances which may have a greater impact on communities than gradual shifts in mean temperature and rainfall (Jentsch & Beierkuhnlein, 2008).

5.2.3 Vulnerability

The vulnerability of terrestrial ecosystems to climate change hazards, particularly to extreme events will depend (among other factors) on the degree of habitat fragmentation, the species diversity within each community, the recruitment success of juveniles, and the severity of stress from predation or invasive pest species and diseases.

Sensitivity

The Otago alpine environments include a wide range of iconic native plant and animal species. The mountain valleys support native forests up to the climactic tree limit before giving way to tussock grass and alpine shrub and herb communities at higher elevations (Mark & Bliss, 1970). These communities are characterised by adaptation to cold temperatures and high annual snowfall. They provide important refuges for alpine species including kea, rock wren, and many unique alpine plants (O'Donnell et al., 2017). The alpine species most at risk from climate hazards are those with particularly specialised niche dependencies, low reproductive rates, low juvenile recruitment success, and slow dispersal mechanisms – particularly the alpine plants.

The montane and hill country regions of Otago support a high diversity of native species including the threatened Grand and Otago skinks, Jewelled gecko, and many threatened dryland plant species (Whitaker et al., 2002). Nearly 90% of Otago's threatened species are found in the dryland habitats (Landcare Research, June 2011). These species are adapted to water-limited environments, however, they are likely to be sensitive to prolonged droughts, especially in locations where habitat fragmentation prevents the dispersal of these species to more moderate conditions.

There has been extensive loss of dryland habitats in inland/central Otago to agricultural development, hence there is a high degree of habitat fragmentation (Lloyd et al., 2017). This tends to make the remaining pockets of native communities more susceptible to event-type disturbances including fire, flood and extreme weather events.

Photographs – Grand skink (Collen, Reardon, & Tocher, 2009), Celmisia hookeri (New Zealand Plant Conservation Network).

Native low-land forests are found in more coastal areas of eastern Otago, including in the Catlins, where forests are refuges for southern rata and podocarp species. Eastern Otago also supports unique areas of inland saline habitats characterised by the accumulation of salts to the extent that the soils are moderately alkaline (Allen et al., 1997).

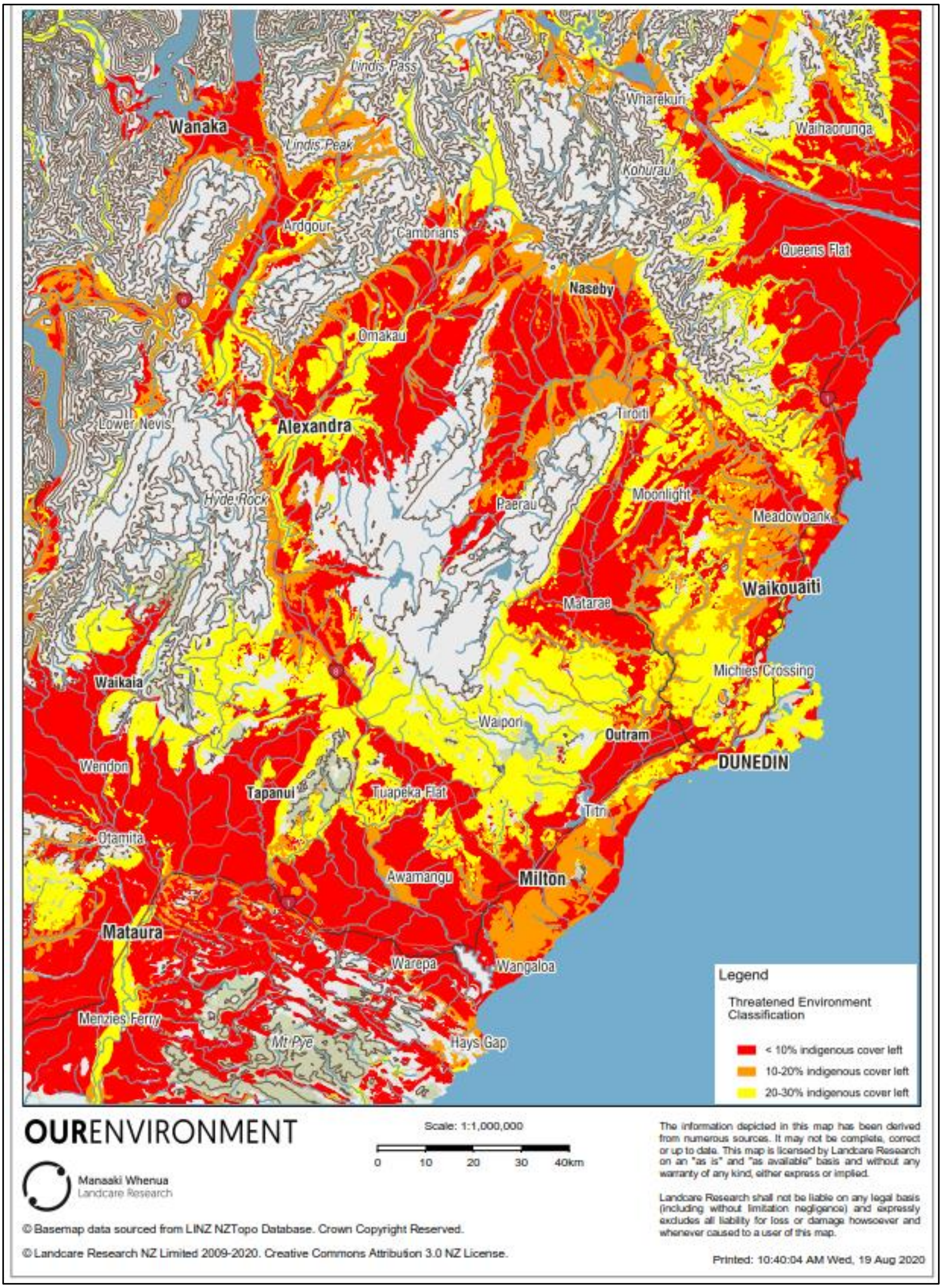

Figure 5-3: Threatened environment classification for Otago. Note: white areas indicate >30% indigenous cover remains, Source – Landcare Research.

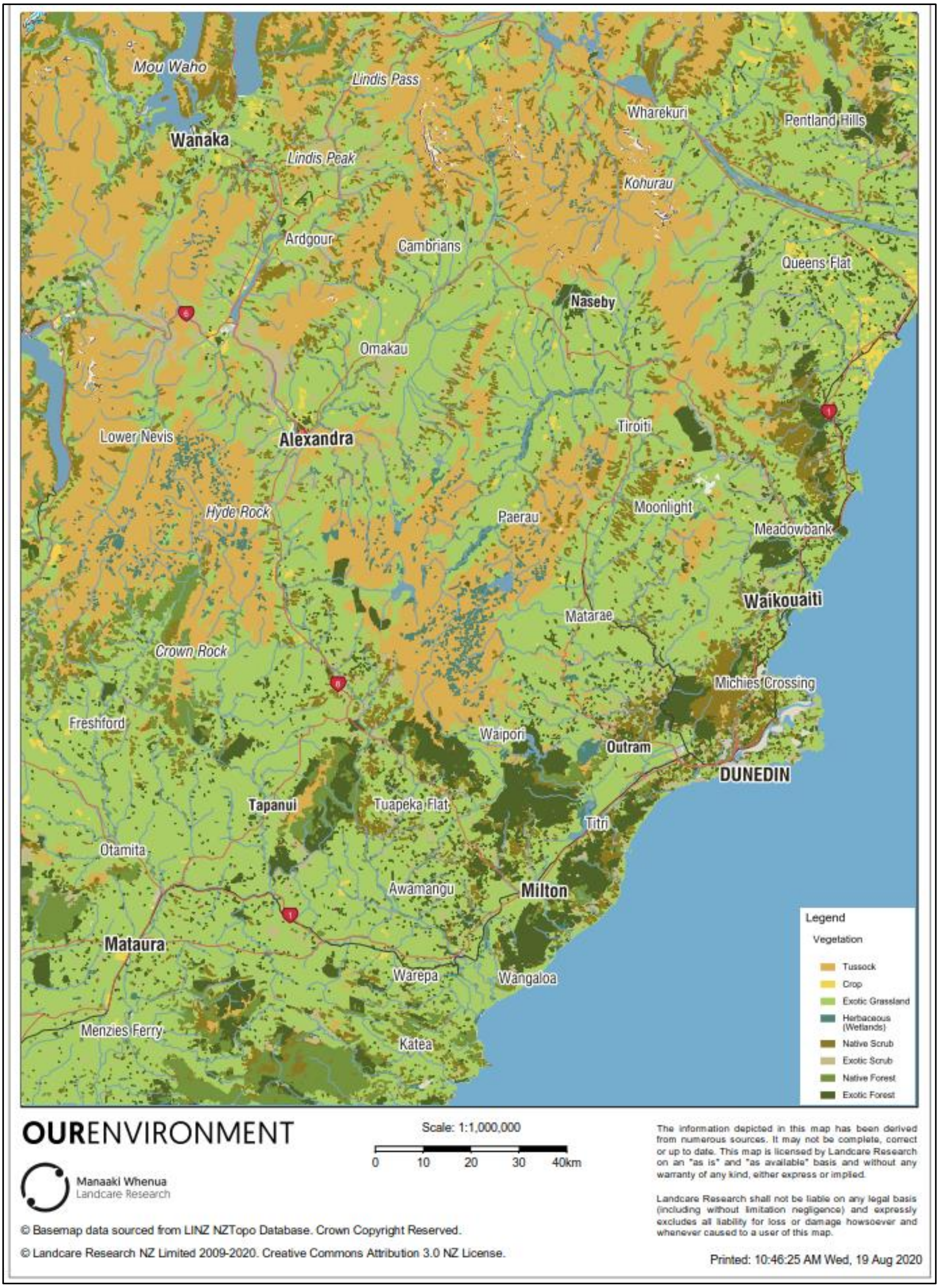

Figure 5-4: Vegetation cover for Otago, Source: Landcare Research.

Saline habitats are found particularly in the Lower Manuherekia valley, the Maniototo Plain, and in the Clutha valley (Allen & McIntosh, 1997). These habitats support a variety of specialised plants and invertebrates including saltgrass, native broom species, and Lepidoptera species (butterflies and moths) (Patrick & Dugdale, 2000).

Projected changes in climate are more moderate close to the coast, and the coastal forest systems are likely to be most sensitive to extreme weather events. Those native coastal communities (including saline habitats) found in low-lying river valleys are likely to experience greater flood events and changes in water quantity driven by changing rainfall affecting the upper catchments of rivers (Macara et al., 2019).

Adaptive capacity

The geographic spread of most types of terrestrial habitats across the Otago region provides some buffering to localised events. Montane and hill country dryland communities are estimated to have a medium level of adaptive capacity to the predicted long-term changes in temperature and rainfall, but a low capacity for tolerance of fire-weather (Rogers et al., 2005). Fire events typically cause high loss of species throughout the affected area, and New Zealand species lack adaptations to these types of events due to the infrequent occurrence of fires during pre-human history (Rogers et al., 2005). Dryland species typically can tolerate drought conditions, however, persistent drought conditions would be expected to decrease the adaptive capacity of these communities to extreme weather events and to fire weather.

Alpine communities are expected to display low adaptive capacity for all climate related hazards because of range limitations and geographic isolation. There is a geographically imposed limit on the available habitat areas for alpine species and this zone is expected to reduce over the coming century which will result in a tendency for populations to become “islanded”. The isolation of pockets of populations greatly increases the vulnerability of a species to event scale disturbances and other stressors.

Coastal native forest and inland saline ecosystems may exhibit a medium level capacity for most climate related hazards due to the more moderate effects of changes towards the coast. However, the tolerance of these communities to event-type disturbances is expected to reduce over time as the severity and frequency of extreme events increases.

5.2.4 Discussion

For all native terrestrial ecosystems the impacts of climate related hazards over the next century are likely to result in further habitat fragmentation, reduced geographic ranges, and lower recruitment of juveniles into the population (Johnstone et al., 2016). The recovery of local communities to event-type disturbances (fires/large storms/floods) are thus likely to be slowed, and in some cases may result in the loss of species locally (N1.4, N1.6, N1.9). New Zealand native terrestrial ecosystems have a low tolerance of fires as evidenced by the rapid changes in forest cover and vegetation composition following human arrival and settlement (McWethy et al., 2014) (N1.4, N1.6). In addition, terrestrial ecosystems are likely to become increasingly vulnerable to predation and niche pressures from introduced and exotic plants and animals, as well as to disease.

These types of responses are thus considered likely to lead to an overall reduction in native terrestrial biodiversity in the Otago region over the next century unless action is taken to minimise the loss of habitat and to assist recovery and species dispersal following extreme weather events (particularly targeted pest management) (Rogers et al., 2005).

Table 5-2 presents the current and future risks to terrestrial ecosystems to each of the climatic changes and hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that risks for Alpine ecosystems from nearly all climate hazards are considered to be at an extreme level by 2040 (N1.8, N1.9, N1.10, N1.11), whereas for montane/inland and other terrestrial ecosystems the risks are considered to be high by 2090 (N1.1-N1.7). Terrestrial ecosystems are expected to suffer extreme impacts from extreme weather events across Otago by 2090.

Table 5-2: Summary risk rating for the Otago terrestrial environment and ecosystems

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N1.1	Risk to native ecosystems and species due to higher temperature.	L	M	H	L	H	E	M	L	M	E
N1.2	Risk to native ecosystems and species due to change in rainfall.	L	M	H	L	H	H	M	L	M	H
N1.3	Risk to native ecosystems and species due to drought.	M	M	H	L	M	H	M	L	M	H
N1.4	Risk to native ecosystems and species due to increased fire weather.	L	M	M	L	M	H	L	L	M	H
N1.5	Risk to montane and hill country environments due to drought.	M	M	H	L	M	H	M	L	M	H
N1.6	Risk to montane and hill country environments due to increased fire weather.	L	M	H	L	M	H	M	L	M	H
N1.7	Risk to montane and hill country environments due to change in rainfall.	L	M	H	L	M	M	M	L	M	M
N1.8	Risk to alpine and high country environments due to reduced snow and ice.	M	H	E	M	H	E	L	M	E	E
N1.9	Risk to alpine and high country environments due to extreme weather events.	L	M	H	L	L	M	L	L	M	H
N1.10	Risk to alpine and high country environments due to higher temperature.	M	H	E	M	H	E	L	M	E	E
N1.11	Risk to alpine and high country environments due to change in rainfall.	M	H	E	H	E	E	L	H	E	E

5.3 N2: Risks to the freshwater (rivers and lakes) ecosystems from increasing temperatures and extreme weather events

5.3.1 Introduction

The Otago region is well known for the Clutha River and the Lakes district. The Clutha River is the second longest river in New Zealand and the largest in terms of annual water quantity. It supports two hydroelectric dams and several water treatment plants for local water supply (Otago Regional Council, 2016). The second largest catchment in the Otago region is the Taieri River located in Central Otago. It follows a winding route through the central block mountain ranges before entering the sea just south of Dunedin (Otago Regional Council, 2016). Other slightly smaller river systems in Otago include braided rivers such as the Makarora River in western Otago.

The Otago region also contains many lakes of varying size. Approximately 23% of New Zealand's lake surface area occur in Otago (Otago Regional Council, 2012). The three major inland lakes (Lakes Hawea, Wanaka and Wakatipu) were formed during glacial periods, and all three are more than 300 m deep.

Despite the generally high water volumes present across the region, some parts of Otago are characterised by water shortages, including in parts of river catchments such as the Taieri, Manuherekia, and Kakanui catchments, which experience very low flows during summer (Otago Regional Council, 2016).

The rivers and lakes of Otago host a wide range of freshwater ecosystems. The Otago region is the only known location for several species of non-migratory galaxiids, and is home to 11 out of the 23 species found in New Zealand (Department of Conservation, 2020).

The exposure of Otago's freshwater ecosystems to projected changes in temperature and rainfall over the next 100 years are considered in Section 5.3.2 below and the vulnerability of freshwater communities to these changes in Section 5.3.3 Resultant high-level impacts to freshwater ecosystems and the risk rating is discussed in Section 5.3.4.

Figure 5-5: (left) Gollum galaxias, a non-migratory native fish species, (right) the Upper Clutha River (Source – Department of Conservation, 2020).

5.3.2 Exposure

An increase in severity of extreme storm events coupled with increasing rainfall for much of Otago may lead to more frequent and intense floods through the river systems. River flow volumes for most Otago river systems are expected to increase, with the exception of Taieri/North Otago systems which are projected to show a decrease in discharge by up to 50% by 2090 (Macara et al., 2019). The decrease in summer rainfall in northern Otago is expected to contribute to the projected decrease in discharge for the rivers and lakes in this area. Increased annual dry days, temperature, and annual hot days may lead to increasing frequency and duration of drought conditions, particularly in summer in Northern Otago (Macara et al., 2019), and this is likely to lead to more lakes showing signs of thermal stratification.

The increasing rainfall is likely to contribute to a higher loading of sediment in rivers and lakes through greater erosion from surrounding landscapes (Macara et al., 2019). Higher nutrient loads in rivers may lead to increased trophic states in lakes. Higher rainfall and water volumes in rivers are likely to contribute to changes in river morphology.

Freshwater ecosystems across Otago are also likely to experience more event scale disturbances. These may have a greater individual impacts on ecosystem communities when associated with increasing stress imposed by more gradual shifts in mean temperature and rainfall (Jentsch & Beierkuhnlein, 2008).

5.3.3 Vulnerability

The vulnerability of freshwater ecosystems to climate hazards, particularly to extreme weather events will depend (among other factors) on the success of juvenile recruitment, the retention of spawning habitats, and the minimisation of erosion and sedimentation of rivers and lakes.

Sensitivity

Over the short term the general increase in temperature is likely to be buffered by the capacity of rivers and lakes to absorb heat, and the general increases in temperature are expected to be tempered by increasing annual rainfall (Hamilton et al., 2013). However, particularly in North Otago, if river flow and lake levels drop significantly during summer months this buffering capacity will be reduced exposing the freshwater communities to additional stress (Macara et al., 2019). Conversely there are also likely to be freshwater communities that are sensitive to the increased flow volumes in western Otago, especially in locations were erosion alters river morphology (Jowett & Richardson, 1996).

The highest risks to freshwater communities (both in lakes and rivers) are posed by extreme weather events. Extreme flood events result in losses in almost all ecosystem services provided by rivers (Talbot et al., 2018), and particularly cause significant loss of freshwater communities. Extreme floods can cause significant bank-side erosion as well as removing fish and invertebrates from large reaches of the river. Bank-side erosion, in particular, removes spawning habitats for native fish and invertebrates. Those taxa with short generations and those which habitually refuge deep in the river bed have quicker recovery times following extreme floods. However, the diversity of the freshwater communities is extremely reduced, and large bodied invertebrates and native fish species can take much longer to recover due to their slower reproductive rates (some galaxiids can live at least 10 years) (Rowe & Graynoth, 2002).

In contrast, the effects of small regular floods on freshwater ecosystems have several benefits. Although there is still some loss of individuals, the recovery time for local communities is generally much quicker. In addition, small scale floods (freshes) remove algae mats and accumulated fine sediment and increase the connectivity between low-land and upland reaches (Jowett & Biggs, 2006).

Lake communities will be most affected by increased sediment loads from rivers as erosion rates are predicted to generally increase, particularly where the lake catchment includes land-uses with high nutrient uses (e.g. agriculture and forestry) (Larned et al. 2020). Those lakes which are shallow and small in size will be more prone to increasing temperature, particularly in summer, and hence to developing stratified layers with higher trophic levels (Hamilton et al. 2013).

Adaptive capacity

The adaptive capacity for most freshwater communities to respond to climate change hazards is dependant on the flow of water. Fluctuations of river flows (and lake inlet/outlet flows) to levels that either cause excessive erosion (severe floods) or flows too low to maintain ecosystem services (droughts) will stress freshwater communities (Jowett & Duncan, 1990). If the frequency of extreme high and low fluctuations increases over time then the adaptive capacity of freshwater communities will reduce. It is important to note that flow fluctuations are sometimes controlled in some river reaches to provide water for abstraction – and hence the resilience of freshwater communities in these reaches may be artificially reduced (Allibone,2000, Lange et al., 2013, Sethi, 2020). Those river systems with few constraints on channel location will have a higher adaptive capacity than river reaches where the main channel is constrained by human habitation or land use.

Towards 2090, the capacity for biota in lakes and rivers to tolerate increasing temperatures will reduce (Hamilton et al., 2013). Thus, lakes in particular may exhibit a threshold response to climate change hazards – with little change over a number of decades followed by more rapid changes. The adaptive capacity for many lakes will also be dependent on the levels of nutrient discharges that result from human activities. Those lakes with little or no riparian vegetation or control of discharges from surrounding land (particularly farm land) or urban developments will have a much lower adaptive capacity compared to lakes located in areas with little or no human land use.

5.3.4 Discussion

The consequences of climate hazards and associated impacts on Otago's river and lake ecosystems are most likely to be measured by changing composition of freshwater communities and a general loss of biodiversity markers over time in conjunction with changes in physical and chemical water quality parameters (e.g. temperature, dissolved oxygen) (Allibone, 2000a). These markers will also be affected by human activities including changes in land-use, irrigation and water abstraction, and attributing the degree of changes associated with changing climate will depending on the data available regarding human activities in the river and lake catchments.

Considering the likely effects of projected climate changes alone (i.e. assuming an absence of active management of freshwater ecosystems) it is likely that by 2090 many of Otago's lakes and rivers will have suffered significant losses to freshwater communities. Losses are most likely to occur following large event-type disturbances such as severe floods, rather than in response to gradual changes, though increasing temperature and changes in rainfall are likely to add stress to the freshwater systems, decreasing the recovery capacity to extreme events (Jowett and Richardson, 1989) (N2.1, N2.2, N2.3). In addition, many of the smaller/shallower lakes may have increased trophic levels due to developing thermal stratification and increased nutrient loads (N2.1, N2.4). These changes will reduce the ecological support functions provided by many of Otago's rivers and lakes, and may result in an increased freshwater species extinction rate and loss of freshwater biodiversity (Hamilton et al., 2013). These effects may be particularly pronounced for diadromous species including many taoka and mahika kai species because they occupy different environments during different life stages and thus have multiple exposure scenarios.

As indicated in Figure 5-4, for both river and lake freshwater communities the highest risks are expected to result from increasing temperatures, with ecosystems at moderate risk from the present through to 2040, and an extreme risk of impacts by 2090. Extreme weather events are the other hazard with an extreme risk rating for freshwater ecosystems by 2090 due to the projected increases in severity of floods.

Table 5-3: Summary risk rating for the Otago freshwater environment and ecosystems

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N2.1	Risk to native ecosystems and species due to higher temperature.	M	M	H	M	H	E	M	M	M	E
N2.2	Risk to native ecosystems and species due to change in rainfall.	L	L	M	M	M	H	M	L	L	M
N2.3	Risk to native ecosystems and species due to drought.	L	L	M	M	M	M	M	L	L	M
N2.4	Risk to native ecosystems and species due to extreme weather events (floods).	M	H	H	M	H	E	M	M	H	E

5.4 N3: Risks to the coastal and marine ecosystems from climate change hazards including ocean acidification and marine heatwaves

5.4.1 Introduction

The Otago region includes more than 285 km of coastline, with a variety of environments from north to south (Lloyd et al., 2017). There are currently no marine reserves, but there are 80 coastal reserves along the Otago east coast. The lower end of the Canterbury Bight is dominated by mixed sand and gravel beaches, which transition to a rocky sedimentary coast in North Otago with shallow subtidal reefs and large kelp forests (Lloyd, et al., 2017). These kelp forests on the shallow coastal shelf support a wide range of marine life (South-East Marine Protection Forum, 2016).

The Otago Peninsula is a remnant volcanic landform with a narrow coastal shelf and deep marine canyons relatively close to the shore (Lloyd et al., 2017). These marine canyons interact with the Southland ocean current moving north up the South Island and, when conditions are favourable, creating large upwellings of nutrients from deeper waters. These upwellings create marine productivity hotspots (Wood & Probert, 2013).

South of Dunedin, the Clutha coastline is dominated by the large volume of freshwater and sediment discharged from that river. This has a strong effect on the marine ecosystem in this area (Wood & Probert, 2013). The Catlins at the southern end of the Otago region is made up of bays between old sedimentary sea cliffs. Large estuaries are found in two main locations in Otago – around and just north of the Otago Peninsula, and in the Catlins. They are important environments supporting a wide range of saltmarsh vegetation, shellfish, flatfish, galaxiids, and coastal birds such as royal spoonbills, and fernbirds (Stevens & Robertson, 2017). The Catlins, in particular, are home to a breeding colony of yellow-eyed penguins. A royal albatross breeding colony is located at Taiaroa Head on Otago Peninsula.

In the marine environment, biogenic reefs made up of bryozoan beds, shellfish beds, sponge gardens and cold water corals support hotspots of marine productivity along the Otago coast (Wood & Probert, 2013). Other marine fauna known to frequent the Otago coast and marine waters include fur seals, sealions, great white sharks, several species of whales and dolphins. Seasonal vagrants include leopard seals, elephant seals, and many species of migratory birds including godwits and arctic terns (Lloyd et al., 2017).

The exposure vulnerability of the coastal and marine ecosystems to projected climate changes is considered below, followed by a discussion of the impacts and associated risk ratings for these ecosystems.

Figure 5-6: Royal albatross at Taiaroa Head (https://albatross.org.nz/), and Tuatuku Bay (https://www.doc.govt.nz/parks-and-recreation/places-to-go/otago/places/catlins-coastal-area/things-to-do/tautuku-walks).

5.4.2 Exposure

Projected climate changes for the Otago coast are generally more moderate than those for central and western Otago. Under RCP8.5, seasonal mean warming of 2.5°C and increases in mean annual rainfall by 2090 are projected for coastal Otago, but no changes to the number of dry days or hot days (Macara et al., 2019). Coastal Otago is also likely to experience increased severity of extreme weather events, and the coastal and marine ecosystems are likely to experience increased discharge of sediment and freshwater from increased rainfall throughout the catchment of rivers across the region.

The Otago marine environment is also likely to become more exposed to increasing ocean temperature. The primary mechanism for this is through the seasonal shifting of ocean currents (Boyd & Law, 2011). During summer sub-tropical currents bring warm ocean water further south, particularly during favourable wind conditions. Conditions favouring the southerly penetration of warm sub-tropical currents are expected to increase by 2090, with these currents reaching further south than their present limits (Law et al., 2018).

Sea level rise and associated coastal hazards, such as storm surges, will expose coastal cliffs to increased rates of erosion, while bays and river mouths are likely to experience increased inundation. Changes in the salinity of coastal freshwater systems will become more likely as tidal influences reach further inland. Increased coastal flooding, which is likely to occur during large tide and storm events, may change estuary morphology.

Ocean acidification occurs as the ocean absorbs CO_2 from the atmosphere (Law et al., 2017). As it does so carbonic acid is formed which contributes to a lower pH in oceans, and decreases the availability of calcium carbonate. Calcium carbonate is the building blocks for most hard-shelled species in the marine environment. Crabs and other crustaceans, shellfish plankton and coral species rely on calcium carbonate to form their shells (Capson & Guinotte, 2014). With increasing ocean acidification the mortality rates of juveniles also increases, reducing their populations. These are foundation species in marine ecosystems and declining populations have flow on effects for the rest of the marine community (Law et al., 2017).

5.4.3 Vulnerability

The vulnerability of coastal and marine ecosystems to climate hazards, particularly to extreme weather events, will depend (among other factors) on the success of juvenile recruitment, and the retention and protection of breeding habitats.

Sensitivity

Coastal and marine ecosystems are likely to be most sensitive to event scale disturbances, marine heat waves, sea level rise and acidification of the marine environment over time (Doney et al., 2012). Destructive storm events can cause extensive erosion to large areas of the coast, and can damage the shallow marine vegetation supporting local marine communities. Likewise, storm events can change the morphology of an estuary and wash down large volumes of sediment and detritus from upriver which can choke the local ecosystem. The projected increasing volume of freshwater around river mouths (particularly around the Clutha) is expected to alter the marine communities, favouring those species more adapted to salinity changes (Macara et al., 2019). Those species that do not tolerate changes in salinity will likely become scarcer around river mouths.

The Otago coastal and marine ecosystems are currently composed of cold tolerant species (Fyfe et al., 1999). Increases in mean temperature projected for 2090 are expected to be moderate, however, the frequency of marine heatwaves is expected to increase (Macara et al., 2019). Cold tolerant species have low thresholds for heatwaves, and if the duration as well as the frequency of these heatwaves increases the immobile species of the marine environment (e.g. kelps, sponges, corals) are likely to experience increased mortality as a result (Boyd & Law, 2011).

The low lying areas of the coastal environment and estuaries are likely to be sensitive to sea level rise (Hannah & Bell, 2012). There are likely to be higher rates of erosion along the coast as sea level increases, with change occurring predominantly during storm events. These types of changes will adversely affect sea-bird breeding colonies and near-shore marine communities, with habitat being lost over time. Likewise, estuaries are likely to experience more frequent inundation events and may reduce in size until the rate of sea level rise exceeds sedimentation rates and promotes increases in estuary headspace (Rouse et al., 2017).

Ocean acidification is likely to have the most significant effect on marine ecosystems over the next century. The populations of hard-shelled species that form the foundation for many of Otago's marine communities are expected to decline as a result of decreased carbonate availability (Hepburn et al., 2011).

Adaptive capacity

The adaptive capacity for the marine and coastal environment is primarily dependent on the availability and utilisation of new habitats (Doney et al., 2012). As erosion and sea inundation occur and existing habitats are damaged or destroyed, other parts of the coast or river mouths are likely to become more favourable for occupation. South-wards range shifts of many marine species are expected to occur as a result of climate change (Lundquist et al., 2011). However, the availability of new habitat may not match the rate at which existing habitats are damaged (e.g. there is a projected decline in coastal kelp forest), which would lead to a reduction in adaptive capacity over time for many species (Lundquist et al., 2011). This reduction in adaptive capacity is likely to most strongly impact those species with long lives and slow reproductive rates (e.g. many of the most iconic native marine and coastal species).

The adaptive capacity of most hard-shelled organisms to changes in pH (and carbonate availability) is relatively low, though there are some species that can tolerate increasing ocean acidity and thus may become more common (Hepburn et al., 2011).

5.4.4 Discussion

In general, the consequences for Otago's coastal and marine ecosystems are most likely to be dependent on the rate of change and the frequency of large storm events over the coming century (N3.2, N3.7). Considering the rates of change most likely under an RCP8.5 scenario many native ecosystems are unlikely to adapt to changes at a pace that matches the changes in the physical environment. Many of Otago's most iconic species are long lived species with slow reproductive rates (and relatively low juvenile recruitment success), and without active management of these species and their habitats they are at risk of localised extinction in the region (Baker et al., 2019).

The summary risk rating for the Otago coastal and marine ecosystems to climate change hazards is presented in Table 5-4 below. High risks to marine and coastal ecosystems in Otago are expected to occur by 2040 as a result of ocean acidification and marine heatwaves, with extreme risks to these ecosystems occurring by 2090 (N3.1, N3.4, N3.11). The extreme risk rating for marine and estuarine communities will particularly be felt when ocean acidification leads to severe population decline of key food-chain hard-shelled organisms.

The risks to estuarine communities from climate change hazards are expected to be medium in the short term, with high impacts felt by 2090 (N3.6, N3.7, N3.8, N3.9). Estuaries are expected to experience pressures from both upstream changes in water quantity and quality and to ocean inundation as sea level rises.

Table 5-4: Summary risk rating for the Otago coastal and marine and ecosystems

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N3.1	Risk to native marine and coastal ecosystems and species due to ocean acidification.	L	M	H	M	H	E	L	L	H	E
N3.2	Risk to native marine and coastal ecosystems and species due to extreme weather events.	L	M	H	M	H	H	M	L	M	H
N3.3	Risk to native marine and coastal ecosystems and species due to drought.	L	L	M	L	M	H	M	L	L	M
N3.4	Risk to native marine and coastal ecosystems and species due to marine heatwaves.	L	M	H	M	H	E	L	L	H	E
N3.5	Risk to native marine and coastal ecosystems and species due to coastal flooding and ongoing sea level rise.	L	M	H	L	M	H	M	L	M	H
N3.6	Risk to estuary environments due to change in rainfall.	L	M	H	L	M	H	M	L	M	H
N3.7	Risk to estuary environments due to extreme weather events.	L	M	M	L	M	H	L	L	M	H
N3.8	Risk to estuary environments due to drought.	L	L	M	M	H	H	L	L	M	H
N3.9	Risk to estuary environments due to higher temperature.	L	M	H	M	H	H	M	L	M	H
N3.10	Risk to estuary environments due to coastal flooding and ongoing sea level rise.	M	M	H	L	M	H	M	L	M	H
N3.11	Risk to estuary environments due to ocean acidification.	L	M	H	L	M	H	L	L	M	E

5.5 N4: Risks to coastal, inland and alpine wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice

5.5.1 Introduction

Wetlands are one of New Zealand's most threatened ecosystem types due to widespread land-use changes resulting in clearance and drainage of these areas. Approximately 90% of pre-European wetlands have been removed, and the wetlands of Otago comprise just 0.8% of the total land area (Land Cover Database v5.0, Manaaki Whenua/Landcare Research, 2020). Despite these losses in habitat wetlands still support a high proportion of threatened native plants, fish, birds, and natural landforms (e.g. oxbow lakes). Wetlands may be permanent or ephemeral depending on the geography of the surrounding landscape and the levels of rainfall. In Otago, wetlands are found over a variety of landscapes from the coast, inland to the alpine mountains (Holdaway et al., 2012) (Robertson et al., 2019).

Climate change will likely affect the supply and seasonality of water, which could result in increased susceptibility to ongoing decline of wetland ecosystems. Wetlands across Otago are also at risk due to increasing pressure from intensification of human land-use and invasion by pest plants and animals.

The exposure and vulnerability of wetlands in Otago to these climatic changes is considered below, while the consequences and risk rating for these hazards are discussed in Section 5.5.4.

5.5.2 Exposure

Coastal and western wetlands in Otago may see increased moisture as a result of rainfall changes over the coming century, while inland/north Otago wetlands may experience decreased rainfall, particularly in summer (Macara et al., 2019). Climate projections for the east coast of Otago are relatively moderate, hence coastal wetlands are expected to be primarily exposed to increased salinity stress from rising sea levels, and from increased severity of flooding and extreme weather events (Macara et al., 2019).

Inland wetlands occur in the upper catchments of some of the large river valleys between the central Otago block mountain ranges. In particular, the Upper Taieri catchment supports an extensive range of unique scroll plains and wetlands. There are three wildlife/recreation reserves providing protection to a portion of these wetlands in the Upper Taieri, otherwise the remainder are found in private land used for agriculture. These wetlands support a wide range of threatened native species including lamprey, longfin eel, non-migratory galaxiids, copper tussock, native starwort, New Zealand mousetail, and water birds including marsh crake and Australasian bittern, and high value landforms including oxbow lakes, old braids and backwaters (Otago Regional Council) (Holdaway et al., 2012). These wetlands are expected to become increasingly exposed to changes in rainfall, prolonged drought periods, and increasing temperatures.

Figure 5-7: Upper Taieri catchment wetlands at Styx. Source – Otago Regional Council, 2005.

Alpine wetlands in Otago are defined as any wetland at an elevation greater than 800 m above sea level (Otago Regional Council, 2020c). Alpine wetlands tend to form in former glacial environments where remnant features such as kettle holes, tarns, roche moutonnée, and cirque basins create depressions trapping water. These wetlands typically support a range of native bog plants, and alpine herbs and shrubs. There are typically fewer species of native fish or eels in these wetlands as they may not have strong connections to downstream river systems, however, they typically support many types of alpine birds and invertebrates (McGlone, 2009). These wetlands are expected to become exposed to increased seasonality of water supply over the coming century including reduced summer supply due to reduced snow and ice, prolonged periods of drought, and increasing temperatures.

5.5.3 Vulnerability

The vulnerability of Otago's wetlands to projected climate changes depends on the speed of regional climatic changes, the frequency of extreme events, and the management of human pressures on land-use and erosion.

Sensitivity

Coastal wetlands are likely to become more frequently inundated by large flood events as the severity of extreme weather events increases over the coming decades (Macara et al., 2019). These could cause large-scale habitat destruction within coastal wetland ecosystems. Additional stresses from increased salinity related to sea inundation will also change the balance of biodiversity within coastal wetlands – favouring more salt tolerant species and disadvantaging those species that do not tolerate salinity changes (Goff & Chague-Goff, 1999). For those species with a high dispersal ability, this may just result in range changes, however, those species with limited dispersal ability will be hampered by the fragmented nature of coastal wetland habitat, and this may result in loss of these species locally (Finlayson et al., 2017).

Wetlands located in dry and seasonally dry parts of Otago are likely to display the most sensitivity to changing rainfall (Finlayson et al., 2017). Inland Otago is projected to experience decreases in rainfall and this will tend to reduce suitable wetland areas (Macara et al., 2019). This may cause existing wetlands to become more marginal, and some to become ephemeral with free water present only in winter. The pressures of reducing wetland area and increasing drought periods and higher temperatures are likely to stress many wetland species (Finlayson et al., 2017). The resulting range reduction will likely lead to decline in local populations of many species. Inland wetlands may also suffer increased habitat damage from extreme weather events, increased erosion from surrounding land, and increased pressure from exotic plant and animal pests.

Alpine wetlands are predominantly located in western Otago which is projected to receive increased levels of rainfall over the next century. However, there may be increasing seasonality in rainfall, and coupled with reduced snow and ice cover this is likely to contribute to water deficits in summer months (Macara et al., 2019). Thus alpine wetlands are at risk of area contraction and potential periods of ephemeral water due to changing water availability. Many of the plant species found in alpine wetlands are particularly specialised to cold climates, and the reduction in snow and ice along with warming temperatures is expected to have large adverse effects on these species (Talbot et al., 1992). These wetlands will also be sensitive to competition from range expansion of native (and exotic) species.

Wetland ecosystems across the range of environments typically have high sensitivities to sedimentation and increased erosion rates are expected to cause additional pressure on wetlands throughout Otago.

Adaptive capacity

Stresses imposed by adjacent human habitation and land-use is likely to reduce the capacity of coastal wetlands to recover following large flood events. Similarly, the response of individual species to these changes is dependent on dispersal ability. Mobile species of plants and animals may have higher capacity to establish different ranges, however, those species that lack significant dispersal functions (e.g. non-migratory galaxiids, many species of wetland plants) will have limited to no capacity for adaptation to projected changes (Allibone, 2000).

Wetlands exposed to damage from extreme weather events may have reduced adaptive capacity, leading to slower ecosystem recovery, and as the severity of extreme events increases the capacity to respond to these events is expected to reduce over time. Additionally, wetland ecosystems usually have a low tolerance for sedimentation, which is expected to increase in conjunction with increasing erosion rates due to rainfall changes and storm events (Thrush et al., 2004).

Otago's wetlands are likely to have a reduced capacity to adapt to climate change hazards due to pressures from human activities. Wetland areas are already very fragmented and artificially reduced in area, susceptible to local erosion and increases of sediment and nutrient loads from surrounding land (Land Cover Database v5.0, Manaaki Whenua/Landcare Research, 2020). All future loss of wetland habitat due to the increasing value of land and pressures for intensification of land-use will only compound the impacts from projected climate change and reduce the adaptive capacity of the remaining wetlands.

5.5.4 Discussion

Changes in moisture volume and availability coupled with interrelated changes in sediment loading, increasing temperature, extreme weather events, and drought conditions are expected to lead to declines in wetland diversity and geographic range across Otago (Macara et al., 2019) (N4.2, N4.3). Changes are likely to be more moderate for coastal wetlands, with the highest risk ratings associated with salinity stress and sea level rise (N4.1, N4.4). Inland wetlands are considered to be most at risk from increasing seasonality of rainfall and increasing/prolonged drought periods leading to a contraction of wetland habitat and associated stress on populations of wetland species (N4.6, N4.7).

Alpine wetlands are expected to decline more quickly than coastal and inland wetlands and to be at extreme risk by 2040 to climate hazards including reduced snow and ice, changes in volume and seasonality of rainfall, drought, and higher temperatures (N4.10, N4.11, N4.12).

The consequences for wetlands across the region are likely to include reduction in wetland habitat due to changing moisture balances, declines in populations of all wetland species, and reduced wetland biodiversity. These factors are likely to be exacerbated by continuing changes in land-use for human development/production purposes, and sedimentation due to increased erosion rates and extreme weather events.

Table 5-5 summarises the risk ratings for coastal, inland, and alpine wetlands to projected climate changes. Wetlands have some of the highest risk ratings due to the low adaptive capacity and high sensitivity of these already threatened environments. Wetlands occurring at higher elevations (montane/alpine) are likely to suffer extreme impacts from all projected climate changes in the short term (by 2040). Coastal and inland wetlands are likely to experience high impacts from changes in rainfall, salinity, flooding and sea level rise by 2040 and extreme impacts by 2090. Increasing temperature and drought are expected to lead to extreme impacts by 2090.

Table 5-5: Summary risk rating for the Otago wetland ecosystems and species

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N4.1	Risk to coastal wetlands due to salinity stress (associated with sea-level rise).	L	M	H	M	H	E	L	L	H	E
N4.2	Risk to coastal wetland due to change in rainfall.	L	M	H	M	H	E	M	L	M	E
N4.3	Risk to coastal wetland due to drought.	L	L	M	M	H	E	M	L	L	H
N4.4	Risk to coastal wetland due to coastal flooding and ongoing sea level rise.	L	M	H	M	H	E	L	L	H	E
N4.5	Risk to coastal wetland due to higher temperature.	L	M	H	L	M	H	M	L	M	H
N4.6	Risk to inland wetlands due to change in rainfall.	M	H	E	M	H	E	M	M	H	E
N4.7	Risk to inland wetlands due to drought.	M	M	H	M	H	E	M	M	M	E
N4.8	Risk to inland wetlands due to higher temperature.	L	H	E	L	M	H	M	L	M	E
N4.9	Risk to montane and alpine wetlands due to higher temperature.	M	H	E	L	M	H	L	M	H	E
N4.10	Risk to montane and alpine wetlands due to drought.	M	H	E	M	H	E	L	M	E	E
N4.11	Risk to montane and alpine wetlands due to change in rainfall.	M	H	E	M	H	E	L	M	E	E
N4.12	Risk to montane and alpine wetlands due to reduced snow and ice.	M	H	E	H	E	E	L	H	E	E

5.6 N5: Risks to Otago water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice

5.6.1 Introduction

The Otago region includes 90 major rivers and 107 major lakes (of more than 0.05 km^2). The rivers and lakes of Otago generally have relatively high water quality. Of the 117 state of the environment water monitoring sites in Otago, 39 sites reported excellent water quality (33%) and another 35 sites (30%) reported good water quality, while 25 sites reported poor water quality (21%). However, 109 of these monitoring sites are in rivers, and just 8 are in lakes (Otago Regional Council, 2019).

The New Zealand Land, Air, Water Aotearoa website summarises total rainfall in Otago as ~35 billion m^3/annum, which while considerably lower than Westland's 115 billion m^3/annum, is similar to the combined Nelson/Marlborough volume. Of the annual Otago rainfall, approximately 9.3 billion m^3/annum is discharged to the sea (Land Air Water Aotearoa, 2020).

The estimated changes to water quality and quantity throughout Otago in response to projected climate changes is considered below in Sections 5.6.2 and 5.6.3, while the risk ratings are discussed in Table 5-6 and Section 5.6.4.

It is noted that this section addresses climate risks to water quantity, specifically in relation to implications for the water body (river, lake, aquifer) itself. Water quantity implications for municipal supplies are discussed as part of risk B3 (Section 7.4).

5.6.2 Exposure

Rivers located in western and inland Otago are likely to experience substantial increases in rainfall over the next century. Conversely, it is projected that there will be increased numbers of dry days in inland and western Otago in summer (Macara et al., 2019). This increased seasonality of rainfall may lead to more extreme low-flow conditions in the upper catchments of rivers. This reduction in summer water volumes in upper catchments implies that low flow conditions will transfer to lower reaches of rivers as well.

A reduction in snowfall over the next century is expected to exacerbate the seasonal variability of river flows in western Otago. Reduced snowfall over time will lead to reduced snowpacks and higher summer snowline elevations (Willsman et al., 2015). This will mean less summer snowmelt entering alpine river catchments.

Alpine and inland lakes in Otago are projected to experience a significant shift in the seasonality of water availability. Winter rainfall is likely to increase, while summer rainfall and snowmelt contributions will decrease. Increased numbers of dry/hot days and generally warming temperatures are thus likely to lead to decreases in lake levels over the next century.

Coastal lakes in Otago tend to be shallower and generally smaller in area than the big inland lakes near the Southern Alps. The climate hazards with the largest effects on coastal lakes include drought, higher temperatures, extreme weather conditions and sea level rise.

At the Otago coast, temperatures are expected to rise approximately 2.5°C by 2090, and maximum wind speeds are expected to decrease. The number of dry days is not expected to change significantly close to the coast, however, the coastal lakes will likely also see reduced summer inflow due to changes in rainfall in inland and western Otago and reduced lake levels.

Low lying coastal lakes within 1-2 m elevation of current sea level are also likely to experience salinity stress over the next century due to rising sea levels. The intrusion of saline water to a freshwater lake has a profound impact on the water quality of the lake, changing the types of ecological communities it can support (Weeks et al., 2016).

ORC has mapped aquifers and groundwater zones around most of the major towns and communities in the Otago region (Otago Regional Council, 2020, Map C Series). Changes in rainfall are likely to affect the recharge of all aquifers across the region. However, the seasonality of rainfall recharge, or degree of increase or decrease in recharge to aquifers across the region is not well understood. Groundwater recharge is likely to be highest during winter when there is generally more precipitation, and recharge is likely to be slow (if any in inland areas of Otago) in summer. There are several major coastal aquifers in eastern Otago and the North Otago volcanics and Kakanui-Kauru aquifers are already identified as at risk of seawater intrusion (Otago Regional Council, 2020, Map C17).

5.6.3 Vulnerability

The vulnerability of water quality and quantity in Otago is related to the physical environmental changes projected to occur over the next century and will depend on the rates and scale of erosion, extreme events, and the degree of human management of effects.

Sensitivity

The increase in rainfall coupled with the increasing severity of extreme weather events is likely to lead to increased erosion contributing higher sediment loads to rivers (particularly those rivers in steep landscapes and the western mountains). For example, the Manuherekia River already has active gravel extraction at the confluence with the Clutha River, sediment build up is likely to increase as climate related flood events become more frequent over time. Furthermore, extreme weather events may lead to more frequent landslides which would alter river morphology. In extreme cases these landslides may dam a river (e.g. the north branch of the Young River) (Massey et al., 2007). These events drastically alter the downstream river flow – reducing water discharge volumes, as well as posing the threat of future floods if the dam should fail. Higher sediment loads are also expected to change the channel characteristics of many rivers. Braided rivers in particular have very mobile channels and increased winter rainfall and sediment is likely to contribute to changes in the current permanent banks.

Low flow conditions have a tendency to promote lower water quality, as conditions tend to favour algae and macrophyte growth, warmer water temperatures, and a build-up of sediment and nutrients (Jowett et al., 1990). Thus, increased seasonality coupled with increasing temperatures is expected to lead to lower summer water quality (as well as quantity) for rivers and lakes.

The rivers with the highest sensitivity to these changes are those which flow through human-modified landscapes where the river channels have been artificially altered. These rivers typically already have modified reaches either due to hydroelectric generation dams, water abstraction for irrigation or town supply, or modified banks through agricultural and urban development.

Coastal lakes are at risk of thermal stratification over summer months, with an increasing number of coastal lakes at risk of both developing and of prolonging stratification over the next century. Smaller and shallower lakes have the highest sensitivity to these processes and are likely to show signs of poor water quality earlier than larger deeper lakes (Hamilton et al., 2013).

Alpine lakes are currently dependant on summer snowmelt for maintaining summer water levels, so a reduction in snowpacks and increasing elevation of the summer snowline will severely reduce summer water inflows. Similarly, the reduced inflow and warmer temperatures of summer are likely to contribute to lower water quality developing in the summer months. Shallow inland and alpine lakes are expected to be particularly at risk of this due to thermal stratification (Hamilton et al., 2013).

The increasing seasonality of rainfall in the Otago region generally characterised by wetter winters and drier summers, as well as consequential fluctuations in river flows and lake levels may lead to increased seasonal recharge-discharge balances in groundwater aquifers resulting in higher water tables during winter months and lower water tables in summer (Unsal et al., 2014). This may be particularly apparent in inland and western aquifers where seasonal extremes are projected to become greater, and less so in coastal aquifers (Macara et al., 2019). However, the impacts of climate change on aquifers, groundwater resources and dependent ecosystems has a high degree of uncertainty due to lack of detailed studies both in New Zealand and globally (Klove et al., 2014). Depending on the age of aquifers and the groundwater residence time, there may be reductions in water quality. For aquifers with significant volumes of summer abstraction, the increased drawdown during the time of least groundwater recharge may lead to a deterioration of water quality by increasing the rate at which water moves through the aquifer sediments (Klove et al., 2014).

The degree to which groundwater aquifers in Otago are prone to salinization as sea level rises is unknown, and will likely depend on the nature of the aquifer sediments and the degree of aquifer confinement (Ingham et al., 2006). Due to the uncertain nature of this assessment no risk rating for this hazard has been provided. However, there is a possibility that additional groundwater aquifers around the coast might become prone to salinization as sea level rises. Those aquifers which are already identified as at risk are likely to become more heavily impacted by salinization by 2090. Further work to quantify this risk would be beneficial, especially for those coastal aquifers where abstraction forms a major part of potable water supply.

Figure 5-8: (left) Young River landslide, Source: (Massey et al., 2007). (right) Blue-green algae bloom in Lake Hayes in 2018. Source: (Vance, 2019).

Adaptive capacity

Constraints on the permanent riverbank morphology will limit the adaptive capacity of rivers to respond to changing flow conditions, and extreme weather events are likely to cause more damage to the river environment when the flood plain is cut off from the river. Conversely, those rivers with fewer (natural or anthropogenic) constraints may have a higher tolerance for changes with new channels forming naturally.

Deeper lakes, and lakes in locations more exposed to the wind will have a higher adaptive capacity to projected changes than shallow, sheltered lakes (Hamilton et al., 2013). The NIWA projected increases (6-12% increase by 2090) in maximum wind for inland and western Otago will likely increase lake mixing and turnover, and this will tend to slow the formation of thermal layers in lakes by mixing lake water to depth. However, once the capacity for a lake to absorb and distribute heat is approached the adaptive capacity to these changes will be reduced.

The adaptive capacity of groundwater aquifers (both coastal and inland) is linked to the size of the aquifer, the recharge rates, and the residence time of water in the aquifer system. For coastal aquifers the distance from the coast and hydrological connections will also affect the adaptive capacity.

5.6.4 Discussion

Changes in water quality are closely tied to river flow volumes, and persistent low flow or drought conditions will result in lower water quality in the river (due to less frequent flushing of sediment/nutrient and warmer water promoting algae growth) (N5.3, N5.4, N5.5, N5.6). Further, those rivers with human altered morphology (i.e. lack of riparian vegetation, increased sediment and nutrient run-off) are highly prone to developing poor water quality under low flow conditions currently – and this is projected to worsen over the next century.

Lower lake levels and less-frequent lake turnover (i.e. mixing of deep and shallow lake water) contributes to de-oxygenation of the hypolimnetic[10] water by the basal lake communities and lake stratification, although this may be buffered to some extent for larger lakes by increased wind speeds. Strong stratification also traps nutrients in the top epilimnetic layer of water, driving growth of algal blooms or macrophytes (Hamilton et al., 2013). Where conditions are favourable for algal blooms most indicators of water quality are likely to reduce below water quality standards. In addition, extreme weather events with higher severity are likely to contribute larger volumes of sediment and detritus to coastal lakes, which may lead to shallowing of some lakes – further exacerbating water quality and quantity trends (N5.8, N5.9, N5.10, N5.10, N5.11).

Flooding and/or extreme weather events are likely to lead to large injections of sediment and organic detritus to alpine and inland lakes which will increase the available nutrients for algal and macrophyte growth that may contribute to water quality deterioration (N5.12, N5.13, N5.14, N5.15, N5.16).

Surface water systems with strong links to shallow groundwater (e.g. some springs and lakes) may experience lower levels as a result of lower discharge balance from groundwater aquifers – particularly during summers when groundwater recharge is expected to be low. There may also be a risk to groundwater quality if rivers are carrying higher pollutant loads as a result of greater erosion/run-off from land – and this is transferred during groundwater recharge (N5.2).

The risk ratings to water quality and quantity from projected climate hazards are summarised in Table 5-6. River water quality and quantity throughout Otago is likely to deteriorate quickly, with high to extreme impacts projected to occur in the short term (by 2040) as a result from all climate change hazards. Small size and higher elevation inland and alpine lakes are also rated at a high and extreme risk of water quality and quantity deterioration by 2040. Water quality in coastal lakes is expected to deteriorate more slowly, with medium risks by 2040 and high to extreme risks of deterioration by 2090. We note that no risk ratings for salinity stress on groundwater in Otago have been agreed on, and this is due to the high level of uncertainty regarding the exposure of coastal aquifers in Otago to salinity intrusions.

The risk ratings for water quality and quantity tend to show relatively large step changes – with risks for many hazards jumping from low to high by 2040. This is due to the likely decrease in adaptive capacity of water systems in Otago, i.e. the deterioration of water quality may be gradual for a period, followed by a period of rapid deterioration across multiple systems throughout the region. Management of water quality given this likely response to climate hazards is not straightforward, however, it will be important to establish primary controls such as catchment nutrient limits, erosion management, and widespread riparian planting as soon as practicable. Other options include managing land-use around river margins (e.g. retiring of marginal/flood-prone land) and re-naturalisation of river margins.

[10] The hypolimnion is the dense bottom layer of water in a thermally stratified lake, it is usually low in oxygen. The epilimnion refers to the upper layer of water in a thermally stratified lake (Jolly, 1956).

Table 5-6: Summary risk rating for water quality and quantity in the Otago region

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N5.1	Risk to groundwater water quality and quantity due to salinity stress (associated with sea-level rise).	L	M	M	M	M	M	L	L	M	M
N5.2	Risk to groundwater water quality and quantity due to change in rainfall.	L	M	H	L	M	E	M	L	M	E
N5.3	Risk to river water quantity and quality due to change in rainfall.	L	M	H	M	H	E	L	L	H	E
N5.4	Risk to river water quantity and quality due to drought.	L	M	H	M	H	E	L	L	H	E
N5.5	Risk to river water quantity and quality due to higher temperature.	L	M	H	M	H	E	L	L	H	E
N5.6	Risk to river water quantity and quality due to inland flooding.	M	H	E	M	H	E	L	M	E	E
N5.7	Risk to river water quantity and quality due to reduced snow and ice.	M	H	E	M	H	E	L	M	E	E
N5.8	Risk to coastal lakes water quantity and quality due to drought.	L	L	M	M	H	E	L	L	M	H
N5.9	Risk to coastal lakes water quantity and quality due to extreme weather events.	L	L	M	L	M	H	M	L	L	M
N5.10	Risk to coastal lakes water quantity and quality due to salinity stress (associated with sea-level rise).	L	M	H	L	M	H	L	L	M	E
N5.11	Risk to coastal lakes water quantity and quality due to higher temperature.	L	M	H	M	H	E	L	L	H	E
N5.12	Risk to inland and alpine lakes water quantity and quality due to reduced snow and ice.	M	H	E	M	H	E	L	M	E	E
N5.13	Risk to inland and alpine lakes water quantity and quality due to extreme weather events.	L	M	H	L	M	H	M	L	M	H
N5.14	Risk to inland and alpine lakes water quantity and quality due to drought.	L	M	H	M	H	E	L	L	H	E
N5.15	Risk to inland and alpine lakes water quantity and quality due to inland flooding.	M	H	E	L	M	H	L	M	H	E
N5.16	Risk to inland and alpine lakes water quantity and quality due to higher temperature.	L	M	H	M	H	E	L	L	H	E

5.7 N6: Risks to native ecosystems posed by increasing threats from invasive plants, pests and disease due to climate change

5.7.1 Introduction

New Zealand has a range of exotic pest animals and invasive plants which have been introduced into the country over the last ~170 years. At a high-level across New Zealand climate change is expected to impact native ecosystems through:

- Increased range and abundance of animal pests.
- New diseases and pathogens.
- Increased range and abundance of weeds.

The Otago region is home to several thousand native species that may be impacted by increases in invasive plants, pests and disease (Department of Conservation, 2016). A number of these are already classified as threatened or at risk. For example, the Taiaroa Head on the Otago Peninsula is the only mainland breeding colony in the world for the Northern Royal Albatross (University of Otago, 2019; Whitehead et al., 2019; Department of Conservation, 2016). Many of New Zealand's indigenous ecosystems and taoka[11] species are already under pressure from exotic species such as plants, vertebrates, invertebrates and pathogens. Climate change will exacerbate these pressures by aiding the range expansion of existing invasive species (Ministry for the Environment, 2019).

New Zealand native species are unique in several ways – one of which is the specialisation of a number of invertebrate and bird species to fill the ecological niches often occupied by mammals in countries overseas. For example, kiwi fill the niche occupied by badgers in the UK and Europe, and various weta species have evolved to fill the niche often occupied by mice (Pennisi, 2017).

The introduction of animals and plants has occurred over the last ~170 years either through intentional release (e.g. trout and possums) or through accidental means (e.g. ship rats and mice). These exotic plants and animals have now developed a level of balance within native ecosystems throughout Otago. This balance is generally characterised by a decline in native species, however this decline is not due to animal and plant pests alone – but to the combination of pressures from human changes to the landscape, climatic changes, and the interaction between native species and pest plants and animals. This balance is in part being assisted by human controls on pest populations in some areas of Otago and in the areas where pest populations are being controlled a slower rate of decline of native species is being reported where monitoring is being conducted (Robertson, 2001).

5.7.2 Exposure

Increased temperatures, modified rainfall and humidity are some of the most important drivers of pest invasion, favouring the establishment of new warm-climate invasive species (Ministry for the Environment, 2019; Kean et al., 2015; Lafferty, 2009; Poulin, 2006). In addition, changes in large-scale weather patterns will influence the frequency and intensity of extreme weather events (e.g. flooding, drought, frosts) and regional winds and currents (e.g. westerly air flows across the Tasman) which in turn may affect the ability of potential invaders to be transported to New Zealand (Kean et al., 2015; England et al., 2014).

Otago native communities are also likely to come under increasing pressure from range expansion by pest species already established in the region. The projected changes in climate are likely to favour pest animals and plants more than native species as they generally have quicker reproductive cycles, and can tolerate a wider variety of habitat conditions than many native species (e.g.

[11] An object or natural resource which is highly prized.

disturbed or developed land for human purposes) (McGlone & Walker, 2011). In addition, if there is a change in food sources related to climate changes pest animals will shift feeding behaviours to include more native species in their diet.

Increasing temperatures and higher rainfall and associated humidity are likely to increase the chance of diseases spreading south to the Otago region. Currently the region is generally too cold for most diseases to take hold, but warming temperatures will favour the expansion of southern limits over time.

5.7.3 Vulnerability

The vulnerability of native ecosystems to pest plants, animals, and diseases is projected to increase due to the impacts of climate change. The key mechanisms for this are through predation and competition, as well as high pest species success rates due to lack of natural predators/environmental controls.

Sensitivity

Exotic plants and animals acting as competitors to native species are often very successful as they are usually faster growing and tend to be less environmentally specialised. Most of the invasive plants tend to act as coloniser species and as such have a vigorous growth habit in areas of disturbance (e.g. gorse/exotic broom). Once established they tend to suppress the growth of native plants until they age to the point where successional species can grow through. Generally exotic plants and animals are also more advantaged in warmer climates so are likely to outcompete the native species, thus adding another stressor to already stressed native communities (Department of Conservation, 2011).

Following the introduction of some mammals to the New Zealand environment, the native species are either out-competed or are susceptible to predation by mammals. This means that the competing exotic species are viewed as pests which threaten the survival of native New Zealand species (Royal Society of New Zealand, 2014).

The most sensitive species to growth of pest populations are those native species that are either directly in competition with pest species (for example Nassella tussock displacing native tussock species in Roxburgh, Alexandra, Cardrona, and Waitaki Valleys (Otago Pest Management Plan, 2019)), or are predated upon by pest species, such as native lizards, birds and many types of native shrubs and trees. Other species are more indirectly affected by pest species, such as native birds that rely on braided rivers for feeding and nesting grounds (e.g. Kaki/black stilt). Russel lupins spread quickly into braided river beds and once established they provide cover for mammalian predators of native birds. They also form vegetation clumps that trap sand and gravel, changing the river morphology and river bird nesting grounds and contributing to flooding and erosion. Pest species (both plant and animal) are likely to be favoured by the changing climate over the next century and populations of these species are likely to increase. Thus, pest problems for both native communities (e.g. deer, goats, possums) and agricultural/production land (e.g. rabbits, wallabies, broom, gorse) are likely to increase over time.

Many of the main identified animal pests already established in Otago (feral cats, rats, hedgehogs, stoats, weasels and ferrets) function as predators of a range of native species such as lizards, native invertebrates (like weta), native birds and eggs. Similarly, there are introduced freshwater fish species and exotic aquatic plants that are competing in New Zealand's rivers and lakes (for example Didymo).

There have been some recent cases where diseases have greatly impacted native New Zealand species such as myrtle rust which affected many native shrubs and trees of the myrtle family (Teulon et al., 2015). This fungal disease has so far been found across the North Island and the top of the

South Island, and it is likely that current climate conditions are limiting the southward spread of this fungal disease. Another fungal infection (aspergillosis) killed a number of kakapo during the 2019/2020 summer breeding season. These fungal spores are present throughout the environment, but increasing temperature and humidity may encourage further outbreaks of these types of diseases.

Adaptive capacity

Many of New Zealand's indigenous ecosystems have low adaptive capacity to human-induced pressures such as introduced exotic species, the clearance of forests, discharge of sediment and nutrients into water bodies, and over harvesting of fish. This is a common feature of island biotas, particularly those that have experienced long, genetic isolation such as in New Zealand (Frankham, 1997; O'Donnell et al., 2015). However, there are some instances where changing climate may favour indigenous species, such as higher water temperature in some areas which may reduce the abundance of introduced species, enhancing the survival of indigenous fish species (Robertson et al., 2016).

Predation is often very successful in New Zealand as native plants and animals have no natural defences or adaptive capacity to introduced predators, particularly mammals (as a function of New Zealand native ecosystems evolving in the absence of mammals (except bats) over at least 40,000 years) (O'Donnell et al., 2015). For example, most of our indigenous bird species have proven vulnerable to decline through predation by introduced mammals (Innes et al., 2010). Mammalian predators are very successful as they mostly rely on smell for hunting. New Zealand native species have evolved in an environment devoid of mammalian predators, and as such the top hunters tended to be birds hunting by sight. Hence, most native species have no natural protection against mammalian predators and their methods of hunting. The southwards range expansion of many invasive species due to climate change is expected to increase the pressures on native species, reducing their adaptive capacity for other changes (O'Donnell et al., 2017).

However, the rates of decline in many native species are not due to pest pressures alone, and the control of pest populations through programmes such as Predator-Free 2050 is not expected to reverse these declining trends in the absence of other habitat protection measures (Peltzer et al., 2019). Rather the aim is to minimise the pressures from pest populations to increase the relative adaptive capacity of native species to the range of pressures posed by human land-changes and climate changes.

5.7.4 Discussion

A changing climate is likely to alter pest and disease risk profiles, as well as present new biosecurity risks to farmers, growers and New Zealand export markets (Kean et al., 2015). Overall, the expansion of current pest species, and addition of new ones, are likely to significantly compromise the ability to maintain the integrity and functioning of our indigenous ecosystems, and will make the work of protecting our at-risk and threatened species even more challenging.

A number of taoka species that are already under threat are also particularly vulnerable to pest predation, including the previously mentioned Royal Albatross (Department of Conservation, 2020b). Without continued effective conservation management, increases in temperature may add pressure on taoka species from the further spread and establishment of invasive species.

Increased populations of plant and animal pests and spread of disease is likely to result in decreased biodiversity within native ecosystems.

Table 5-7 provides a summary of the key climate related risks that are likely to impact biodiversity through increasing plant and animal pest species and diseases across the Otago region. Currently drought is the greatest risk with this remaining medium in the mid-term and increasing to extreme in the long term (N6.1). The impacts from prolonged and more frequent droughts puts environmental stresses on native species that pre-dispose them to predation/competition from invasive pests. Higher temperatures and increased rainfall are currently low risk however increase to medium in the mid-term and then extreme in the long term (N6.2, N6.3). Increasing temperatures and changing rainfall patterns will tend to reduce the geographic distributions of native species, while favouring population growth of invasive pests.

In summary, the consequences of inadequate controls on the growing populations of invasive pest plants and animals is the loss and local extinction of native species. The combined pressures of environmental changes and predation/competition from growing pest populations will contribute to increased rates of decline in native populations as pressures from climate change exacerbate vulnerability within native ecosystems. This scenario has become apparent in parts of New Zealand where native populations of fauna and flora are aging as a result of highly reduced success rate of juvenile recruitment due to pest predation/competition (e.g. Kakapo, native podocarp/hardwood forests) (Innes et al., 2010). Pest management tools to further control and reduce pest populations, along with sanctuaries for native species with high levels of pest exclusion, are likely to be necessary to address the impacts of climate change.

Table 5-7: Summary risk rating for native ecosystems to increasing threats from invasive plants, animals and diseases due to climate change hazards

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
N6.1	Risk of plant and animal pest species and diseases affecting native biodiversity (terrestrial, freshwater, marine) due to drought.	M	M	H	L	M	H	L	M	M	E
N6.2	Risk of plant and animal pest species and diseases affecting native biodiversity (terrestrial, freshwater, marine) due to change in rainfall.	L	M	H	L	M	H	L	L	M	E
N6.3	Risk of plant and animal pest species and diseases affecting native biodiversity (terrestrial, freshwater, marine) due to higher temperature.	L	M	H	M	H	E	L	L	H	E

Economy

6 Economic Domain

The economic domain refers to key economic sectors within Otago, which support people and livelihoods. The links between the economy and other domains, particularly the human, natural environment and built environment domains, mean that impacts on Otago's economy can have a range of interacting and cascading impacts. A detailed assessment of cascading impacts is outside the scope of this study, however some examples are provided within Section 9.

The risks posed by climate change related hazards to the Otago economy are wide and varied, and will impact an extensive range of businesses and economic activities in Otago. This assessment draws on key changes to physical processes that are predicted to occur as a result of climate change in the Otago Region (Macara et al., 2019), and identifies a range of corresponding risks posed to Otago's economic sectors that are linked to the selected elements. The assessment focuses on the exposure, vulnerability and potential impacts to the economy from selected climate change hazards that have been identified as being of elevated importance. It is noted that the risk assessments provided are focused on the key risks that are predicted to occur as a result of climate change.

6.1 Summary of risks

Risks to the economic domain relate to the impacts of climate hazards on the physical environment where economic sector activity and related services are based. The sectors that generate the top 5 highest contributions to the Otago GDP are construction, primary production, rental hiring and real estate services, accommodation/food services, and health care and social assistance (Infometrics, 2019).

Through the workshop process with sector representatives, and based on the information available, those sectors considered to be most exposed to climate related hazards were primary production (including livestock farming, horticulture and viticulture, forestry and fisheries), and the tourism sector (which includes rental hiring, accommodation/food services and a wide range of other sectors) – all of which are intrinsically reliant on the Otago natural environment. Additionally, broader issues were identified around supply chain and the cost of doing business. Construction services were not included as they were thought to have capacity to adapt and move to less climate exposed areas. Risks to healthcare and social assistance are discussed in Section 4.

Specific risks to Whakatipu-rawa – Māori enterprise has not been addressed as part of this assessment. It is suggested such an assessment could be undertaken as part of a specific Te Ao Māori risk assessment.

The detailed risk assessment identified 38 individual risks to the economy, across seven sectors/areas - of which most were low to medium risk in the short to mid-term, and increase to become mostly high and extreme risks in the long term (Figure 6-1).

Table 6-1 summarises these risks within the seven sectors, and provides an overall risk rating over three time horizons[12]. As shown, each of these sectors face extreme risk from climate hazard by 2090. These are discussed within sub-sections below. While some of these sectors have significant adaptive capacity, such as fisheries, most sectors will face significant challenges with severe economic impacts unless adaptive measures can be applied.

Figure 6-2 summarises the risks posed by climate change to the economy of Otago at a district level.

[12] The risk rating for each sector corresponds to the highest risk rating from the detailed individual risk assessment within each sector.

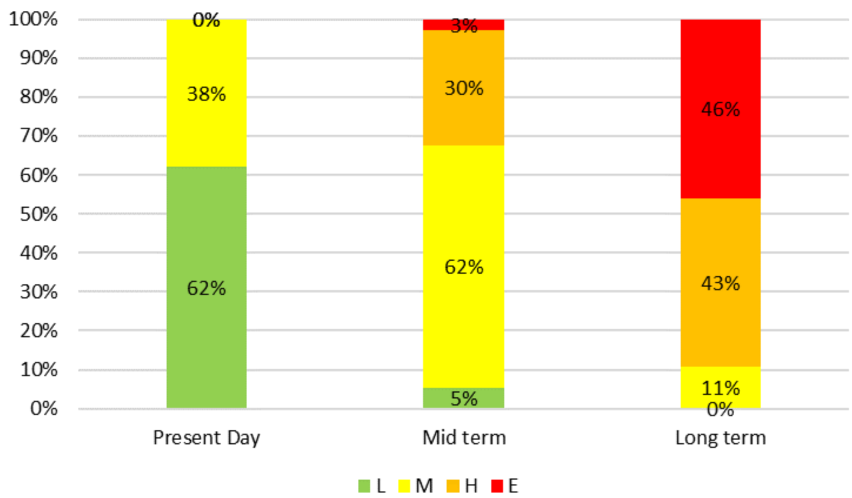

Figure 6-1: Summary of economic domain risks by risk rating.

Table 6-1: Summary of risk ratings in the economic domain

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
E1	Risks to the livestock farming sector from climate change hazards including drought, increased fire weather, inland flooding, and increased landslides	M	H	E
E2	Risks to horticulture and viticulture from climate change hazards including temperature, drought, changing rainfall patterns and extreme weather	M	H	E
E3	Risks to the forestry sector from climate change hazards including temperature, drought, fire and extreme weather	L	M	E
E4	Risks to the fisheries and aquaculture sector from climate change hazards including marine water temperature and water quality	L	M	E
E5	Risks to primary sector supply chains from climate change hazards including inland flooding, coastal flooding and increased landslides	M	H	E
E6	Risks to cost of doing business from climate change hazards including coastal and inland flooding, landslides, and extreme events	M	H	E
E7	Risks to the tourism sector from climate change hazards including higher temperatures, reduced snow and ice, inland and coastal flooding, landslides and erosion	M	H	E

*Highest risk rating per category and hazard relationship highlighted. Refer individual risk discussions for detailed ratings.

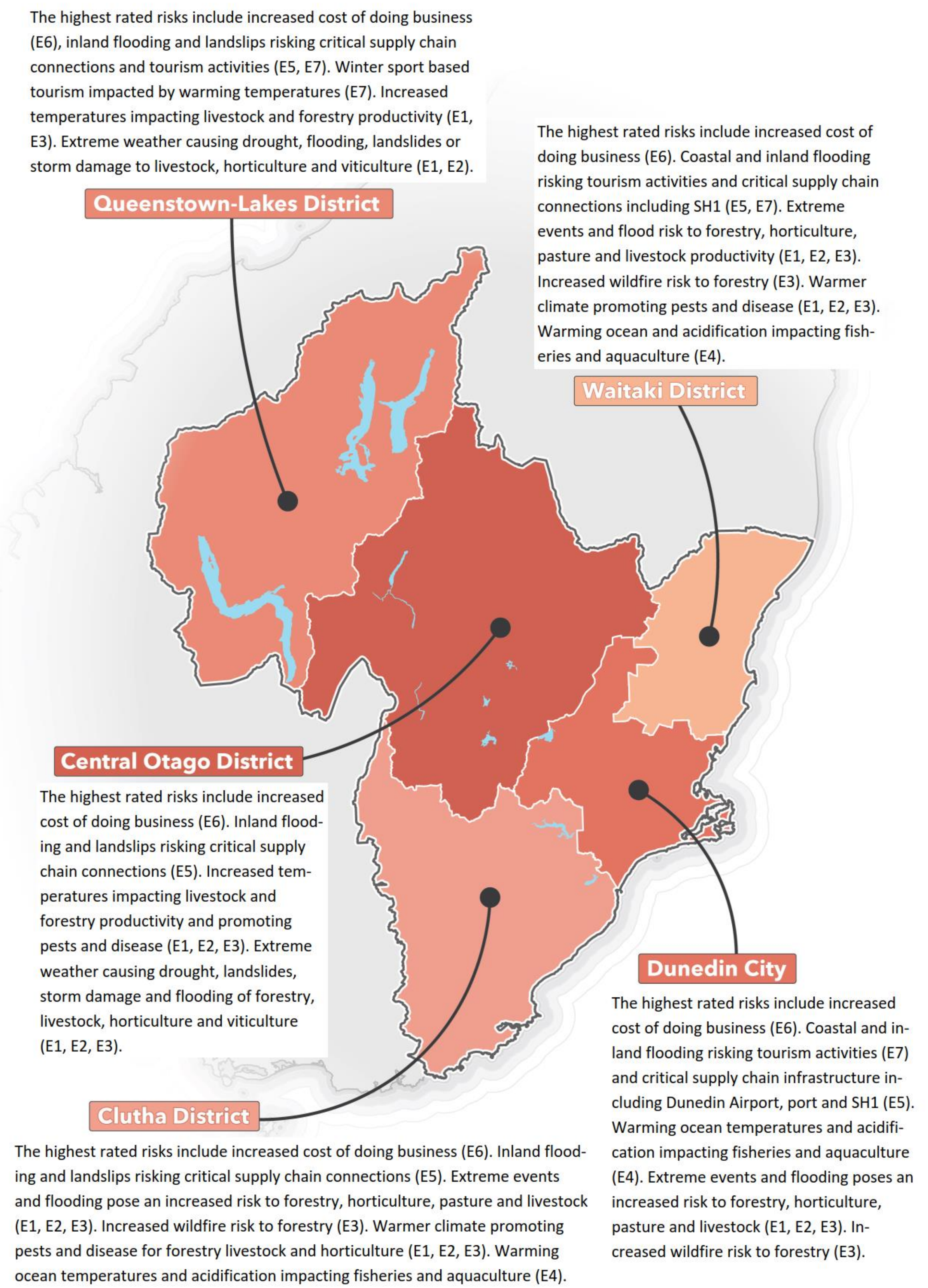

Figure 6-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the economic domain.

6.2 E1: Risks to the livestock farming sector from climate change hazards including drought, increased fire weather, inland flooding, and increased landslides

6.2.1 Introduction

Livestock farming in Otago includes dairy farming, sheep and beef farming, and deer farming as shown in Figure 6-3 and a key economic sector in the Otago Region. Livestock farming in Otago generated over $588 million in 2019, and contributed roughly 4% of the region's Gross Domestic Product (GDP), and 0.2% of the nation's GDP (Infometrics, 2019). Overall, the Otago Region is home to 13.4% of the nation's livestock (Statistics NZ, 2016b).

Livestock farming comprises around 83% of the total land area dedicated to agriculture, and forms 58% of the total region's land use (Statistics NZ, 2016a). Livestock farming is most active in the Clutha District, which generates 40% of the region's GDP from livestock, followed by Waitaki with 28%, Central Otago and Dunedin City Districts with 14% and the remaining 4% generated out of Queenstown Lakes District (Infometrics, 2019).

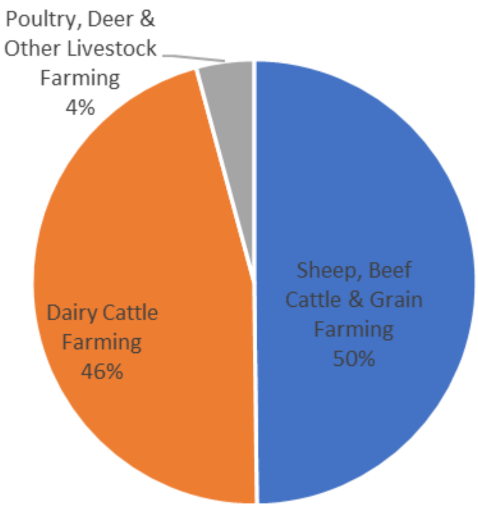

Figure 6-3: Livestock farming activity in Otago, showing % GDP (Infometrics, 2019).

6.2.2 Exposure

Otago is projected to experience a range of climate change hazards including increasing extreme rainfall events and associated flooding and landslides, wildfire, heatwaves and drought, and gradual changes such as increased temperature (Macara et al., 2019). As such, the extensive and dispersed livestock farming sector in Otago can expect to be exposed to these climate changes.

Most livestock farms throughout Otago can expect to encounter wetter winters and dryer summers (Macara et al., 2019), which may impact pasture conditions and stock water supply (Kienzle, 2008). Surface water supply reliability is expected to decrease in certain catchments, such as the Taieri headwaters of Central Otago, under higher emissions scenarios towards the late century, generating further uncertainty around water supply to stock in this region (Macara et al., 2019).

Farms may be exposed to increased flood and landslip risks with an increase in heavy rain days projected to occur in far western Otago, and extreme rare rainfall events likely to increase in intensity across the region (Carey-Smith et al., 2018). High country stations are particularly exposed to erosion and landslides, which can damage farm infrastructure and cause loss of pasture (Stakeholder Engagement, 2020).

Temperatures, including extreme hot days, are expected to increase throughout the region which will affect all livestock. The greatest temperature increases are projected for inland areas, which will affect inland districts such as Central Otago, and the high-country stations (Morris, 2013, Macara et al., 2019).

6.2.3 Vulnerability

Vulnerability of livestock farming to climate change will relate to the relevant vulnerabilities of animals, resources and inputs (land, water), and infrastructure. This is discussed below in relation to sensitivity and adaptive capacity.

Sensitivity

Livestock farming is intrinsically tied to the climate, with temperature, rainfall and sunshine hours forming critical components of soil moisture and grass growth, as well as posing a direct influence on stock health (Beef and Lamb New Zealand, 2020; Ausseil et al., 2020). Livestock wellbeing and productivity across regions of New Zealand is dependant primarily on pasture and locally grown feed crops (Morris, 2013).

Farming in Otago is a mix of highly productive lowland farming and extensive high-country farms (Morris, 2013). Recent changes in farming practices and technology mean that land-use changes are occurring, for example dairy farming which was traditionally confined to the low-lands is spreading further inland and to high country environments, usually requiring irrigation for viability (Stakeholder Engagement, 2020; Otago Daily Times, 2020). The dynamic nature of livestock farming requires precise feed availability or stock rotation to ensure successful lambing and calving, optimal feed during lactation and pasture availability to bring mature stock to optimum finishing condition (Morris, 2013). For example, deer management can be affected as the deer reproduction season is later than other livestock, falling over the summer months. As a result, deer farms require careful management to ensure high quality feed is available during these dry months, which may become more challenging during dryer summers (Stakeholder Engagement, 2020).

Lack of availability of water in Otago is an existing issue (Stakeholder Engagement, 2020; Ward & Russell, 2010), which will worsen in cases where water availability is affected by climate change. Water for irrigation and stock drinking water will be further compromised in catchments such as Taieri and Manuherekia where surface water supply reliability is projected to decrease (refer to risk B3, Section 7.4) (Macara et al., 2019). Dryer summers may also impact groundwater availability throughout the region, affecting groundwater abstraction supply. Additionally, summer soil moisture deficits are projected to increase across the region as increased dry days and higher temperatures cause increased evapo-transpiration (Macara et al., 2019). This places further stress on pasture and fodder growth, and may increase irrigation demand.

Increased winter rainfall and more extreme weather events will worsen existing flooding, such as that which occurs in the lowlands of the Taieri Plains which are vulnerable to flooding despite being protected in parts by the Taieri Flood Protection scheme (Figure 6-4) (ORC, 2014). Following a flood, pasture can take weeks or even months to dry out and recover suitably for stock to graze, pasture growth can be affected, as prolonged submergence can kill clover and rye grass which are critical pasture varieties (Beef and Lamb New Zealand, 2017). As noted, for example in the Taieri Basin, following flooding in 2014 where waterlogged soils were not suitable for grazing (Farmers Weekly, 2014).

Figure 6-4: Ponding on West Taieri Plain during June 2013 (ORC, 2014).

Farming infrastructure is sensitive to extreme hazards such as fire, flooding and landslides. Rising temperatures increases fire risk, where long dry grass, particularly in the expansive hill country stations, can become an extreme fire risk during hot dry weather (Otago Daily Times, 2019). Fire, flood and landslides all pose significant risk to buildings, access roads, assets and livestock, which would result in significant financial losses to farmers. Increased rainfall during winter may also lead to decreased pasture condition from flooding and pugging (Beef and Lamb New Zealand, 2017, Ministry for the Environment, 2001).

Increasing extreme events also pose risks to supply chain (Hughes et al., 2019) (refer to risk E5, Section 6.6). For example, extended dry weather during summer 2020 resulted in many farms not being able to de-stock quickly enough to ensure adequate feed supply, resulting in a loss of stock condition (Stakeholder Engagement, 2020). The dairy industry is particularly vulnerable to disruption in the supply chain, as dairy cows typically require regular twice daily milking, and stored milk must be transported within 1-2 days for processing (Welth & Marshall, 2017).

Livestock are highly sensitive to temperature and suffer from heat stress where a major symptom is loss of appetite. Evaluation of heat stress in livestock predicts that rising temperatures toward the end of the century will increase the risk to animal health, particularly in Otago, where stock are already at risk (Ausseil et al., 2020). New Zealand cows begin to reduce feed intake, which for the dairy industry is problematic as reduced feed intake results directly in reduced milk production (Verkerk et al., 2007; Stakeholder Engagement, 2020). Although still concerning, feed intake is less critical for sheep, beef and deer as they are not subject to the same daily production demand that dairy is, and can be managed over longer periods to accommodate seasonal dry periods (Morris, 2013).

Pasture growth is also affected by temperature and may result in reduced production and a drop in operating profit. Modelling of an Otago dairy farm has indicated reduced clover and rye pasture growth in temperatures above 20°C and 25°C respectively (Kalaugher, 2015). These varieties of pasture provide high nutritional value grazing, and are the preferred pasture composition over sub-tropical grasses such as kikuyu which are more temperature and drought resilient (Lambert, M. G.; Litherland, A. J., 2000).

Established agricultural pests, weeds, and diseases already impact heavily on NZ's economy. Through a range of factors, climate change is likely to increase the impact of current or new invasive species on-farm, to our economy, and human health (Stakeholder Engagement, 2020) (refer to risk N1, Section 5.2). Reduction in the occurrence of frosts may raise the potential for further spread of some pests (MPI, 2019). Heat increases may increase stock disease, including increased mycotoxins, flies, UV damage to udder and teats, and cancer eye (Verkerk et al., 2007). Many imported pests, weeds and diseases will likely gain an advantage under climate change scenarios that create a warmer and more disturbed environment (McGlone & Walker, 2011). For example; climate change could increase the climate suitability and geographic ranges of pests and weeds already established in NZ, as well as make the climate more suitable for incursions of organisms not currently present in NZ. Climate change may also impact upon the ecology of existing biological control agents used in NZ to supress pests and weeds and thus reduce their efficacy and contribute to loss of production (McGlone & Walker, 2011). Changing climate will also increase the risk to NZ's livestock sectors of some serious currently climate limited vector borne diseases being able to arrive and then persist in NZ. Many of these diseases are zoonotic and present a clear risk to human health in addition to livestock (Stakeholder Engagement, 2020).

Adaptive capacity

As the third highest national goods export (Statistics NZ, 2019d), livestock farming is a very high-profile sector. The agriculture industry is the focus of a nationwide effort to develop more sustainable practices and mitigate the impacts of climate change (MPI, 2019). This research and other adaptation efforts such as the *Our Land and Water National Science Challenge*, and *The Deep South Science Challenge* have the potential to introduce innovation that will safeguard the economic productivity of farms. Changing farmer understanding and opinions of climate change (MPI, 2019), combined with concerted research efforts indicate that the livestock farming sector has a "medium" degree of adaptive capacity in the face of climate change.

Some climate changes may be advantageous for livestock farming, such as a possible increase in grass growth in parts of Otago during certain times of year (Ausseil et al., 2020) and increased pasture fertilisation through higher CO^2 atmospheric concentrations (EcoClimate, 2008). Also, increased temperatures increasing the weight gain and birthing conditions of sheep, cattle and deer during times of cooler weather (Stakeholder Engagement, 2020).

Ongoing, gradual changes in the climate may occur in a way that allows farmers to adapt, for example by planting weather tolerant native species for shelter, fire resilience and waterway protection, or retiring marginal land that is vulnerable to flooding or landslides (Stakeholder Engagement, 2020; MPI, 2019).

The history of agriculture is based on adaptation, where farming practices have evolved to adapt to new territories and climates for centuries. Droughts and other climatic challenges pose a constant threat to farmers, and the knowledge gained from previous methods for adaptation may be a valuable key to future adaptation in the face of unprecedented change (AgResearch, 2008).

6.2.4 Discussion

The economic consequences of climate change on Otago's livestock farming industry may be significant, particularly towards the later century, due to the intrinsic reliance on the natural environment for stock productivity.

The combination of heavy reliance on the natural environment for stock wellbeing and precise seasonal nature of farming activities leaves livestock farming at risk of climate change.

Farms in the drier areas of Otago are currently managed to reduce feed demand over the summer months when dry weather reduces pasture production (Morris, 2013). As wetter winters and dryer summers amplify the seasonal shift (Macara et al., 2019), this will affect pasture growth further (Ausseil et al., 2020), which may impact deer management, lambing and calving, and other seasonal farming activities (Stakeholder Engagement, 2020) (E.1.1, E1.6). Increased drought risk may place further stress on surface and groundwater availability (Macara et al., 2019), which may impact pasture irrigation, and stock water availability particularly during times of increased demand. Increased temperatures (E1.5, E1.9) can affect directly impact stock health result in reduced feed intake (Ausseil et al., 2020), impact pasture growth and favour the spread of pests and diseases (McGlone & Walker, 2011). Inland flooding (E1.3, E1.7), landslides and erosion (E1.4, E1.8), and fire (E1.2) all pose a risk of direct damage to buildings, stock and pasture, and can disrupt supply chains (E5), which are of particular importance to dairy.

Although it is often easier to calculate costs of infrastructure, than it is to measure chronic or slow onset impacts such as heat stress etc (Stakeholder Engagement, 2020), both of these types of impacts will likely contribute significantly to economic losses unless adaptation measures are successful. The summary risk rating for this sector is shown in Table 6-2, focusing on the key hazards associated with climate change. As shown, drought, inland flooding as well as increased landslides and soil erosion are considered high risks at 2040, moving to extreme risks at 2090.

Table 6-2: Summary risk rating for the livestock farming sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E1.1	Risk to sheep, beef and deer farming due to drought.	M	M	H	M	H	H	L	M	H	E
E1.2	Risk to sheep, beef and deer farming due to increased fire weather.	L	M	M	M	H	E	M	L	M	H
E1.3	Risk to sheep, beef and deer farming due to inland flooding.	M	H	H	M	M	H	M	M	M	H
E1.4	Risk to sheep, beef and deer farming due to increasing landslides and soil erosion.	M	H	E	M	H	H	M	M	H	E
E1.5	Risk to sheep, beef and deer farming due to higher temperature.	L	M	H	L	L	M	M	L	L	M
E1.6	Risk to dairy farming due to drought.	L	M	H	M	M	H	L	L	M	E
E1.7	Risk to dairy farming due to inland flooding.	M	H	E	M	M	H	L	M	H	E
E1.8	Risk to dairy farming due to increasing landslides and soil erosion.	L	M	H	L	M	H	M	L	M	H
E1.9	Risk to dairy farming due to higher temperature.	L	M	H	L	L	M	M	L	L	M

6.3 E2: Risks to horticulture and viticulture from climate change hazards including temperature, drought, changing rainfall patterns and extreme weather

6.3.1 Introduction

Horticulture in Otago comprises a diverse range of crops, dominated by summerfruit (apricots, cherries, nectarine, peach and plum), wine grapes, vegetables (mainly potatoes, broccoli cabbage and cauliflower), pip fruit and tree nuts, as shown in Figure 6-5. Otago is home to 61% of the nation's summerfruit, of which cherries and apricots are the major exports (NZ Horticulture Export Authority, 2019). Otago is home to 6% of the nation's apple growing orchards, 3% of wine grape vines, and 1% of the nation's potato fields, by area (Statistics NZ, 2019). Overall, the New Zealand horticultural industry generated produce worth $9.5 billion in 2019, of which exports worth $6.2 billion accounted for 10% of total merchandise exports (Aitken & Warrington, 2019). Within Otago, the horticulture and fruit growing industry GDP contribution was $79.9 million in 2019 (Infometrics, 2019).

The largest GDP contribution in Otago is from Central Otago, where 67% of the region's horticultural GDP is generated. Queenstown lakes and Waitaki Districts contribute 12% and 10% respectively, and Dunedin City and Clutha contribute 6% and 4% respectively (Infometrics, 2019). The soils and climate of Central Otago make the district especially suited to growing summer fruit and grapes, some of which are high quality products that are a premium export such as NZ cherries and apricots (Horticulture New Zealand, 2020). A wide variety of fruit and vegetables are grown in the Waitaki District, particularly vegetables and arable crops which are typically grown on the Waitaki plains. Other significant growing areas are in the Taieri Plains and the river valleys along the coast of the region (Stakeholder Engagement, 2020).

As a primary industry, horticulture is inherently dependent on the land and climate for survival, and therefore will be affected by a changing climate, particularly temperature, drought, changing rainfall patterns and extreme weather, as discussed below (Stakeholder Engagement, 2020).

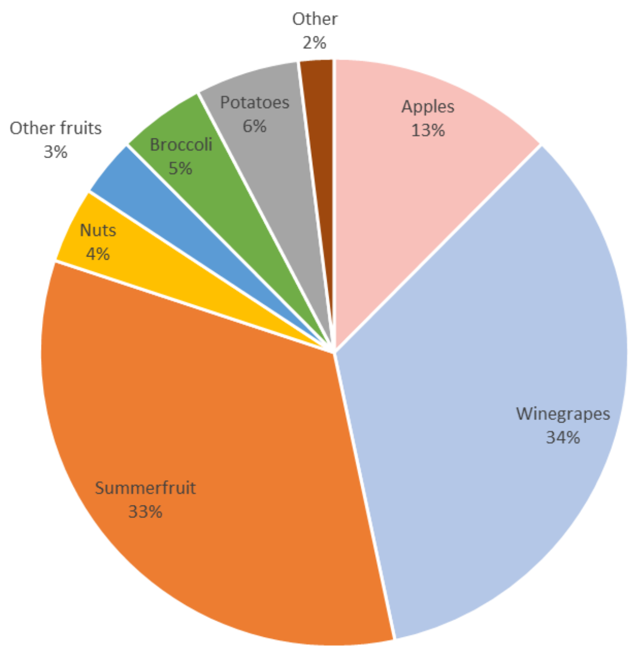

Figure 6-5: Percentage of planted area of fruit and vegetables in Otago in 2017 (Aitken & Warrington, 2019).

6.3.2 Exposure

The horticulture industry will experience increased temperatures, increased drought risk, changing rainfall patterns and more extreme weather.

Projected increases in minimum, mean and maximum temperatures will impact plant growth and irrigation demands. Crop growing in coastal and southern Otago will see less temperature increase than inland, with Central Otago crops affected by up to 5°C projected increase in maximum annual temperatures (Macara et al., 2019), and a projected increase of up to 30-40 extreme hot days per year towards the end of the century (Macara et al., 2019). Mean daily maximum temperatures are projected to increase faster than mean daily minimum temperatures, resulting in an increase in the diurnal range.

The changing temporal and spatial distribution of seasonal rainfall across the Otago Region will impact many aspects of horticulture, as wetter winters and more intense rainfall raise the risk of flooding and waterlogging. Conversely, drier summers will likely increase the pressure on irrigation supply, particularly in arid regions such as within Central Otago (refer to risk B3, Section 7.4) (Macara et al., 2019; Carey-Smith et al., 2018).

Warmer temperatures and increased summer dry days may raise the risk of drought, particularly inland where temperature increases are projected to be highest. However, increased total rainfall may mitigate this risk leaving the drought potential roughly unchanged (Macara et al., 2019). Surface water availability is projected to change throughout the region, with many areas experiencing greater water availability, but the headwaters of the Taieri and Manuherekia experiencing deficits (Macara et al., 2018). The potential evapotranspiration deficit (PED) is the gap between water demand and water availability, and is projected to increase slightly across Central Otago, where irrigation is currently in high demand (Macara et al., 2018). Other climate variables critical to horticulture are soil moisture deficit, humidity and solar radiation. These have been assessed for Central Otago, which will see some of the greatest temperature increases (Macara et al., 2018). Of these, soil moisture deficit is projected to remain relatively stable other than during the month of September, which will see a decrease. Small decreases in humidity, and small increases in summertime solar radiation are projected (Macara et al., 2018).

As extreme rainfall events are likely to increase in intensity across New Zealand, Otago growers may be exposed to increased wind and storm damage relating to extreme events (Carey-Smith et al., 2018).

6.3.3 Vulnerability

The vulnerability of horticulture to climate change hazards relates to the type of crop and is discussed below in relation to its sensitivity and adaptive capacity.

Sensitivity

Many of central Otago's main crops typically require hot dry summers, and some require winter chill (Stakeholder Engagement, 2020).

Warmer temperatures are expected to increase the number of growing days for crops (counted as temperatures above 10°C) (Macara et al., 2019). However, an extension in the duration of hot days, heatwaves, and the number of extremely hot days will increase evapotranspiration in plants, and contribute to increased soil moisture deficits (Macara et al., 2019). Therefore, warmer temperatures are likely to result in increased irrigation demand, alongside a shift fruit setting timing and issues such as fruit sunburn (Macara et al., 2019; Aitken & Warrington, 2019; EcoClimate, 2008). Most crops require irrigation for at least part of the growing season. Some, such as grapes are 'deficit' irrigated, where irrigation is withheld over summer to intensify flavours, but other main Otago crops such as vegetables, arable crops and summerfruit require summertime irrigation for optimal vegetable and fruit harvests (Stakeholder Engagement, 2020). Even under current climate conditions, continued market growth places increasing demand on irrigation supply (EcoClimate, 2008; Stakeholder Engagement, 2020), which presents a challenge to both growers and water supply regulators if additional pressure from climate causes water demand to exceed supply (Stakeholder Engagement, 2020; Ward & Russell, 2010).

The reduction in duration of frosts may mean that crops such as apricot and cherry become less viable in Central Otago, which may require increased chemical intervention to promote budbreak and flowering (Stakeholder Engagement, 2020; Lake et al., 2018). Chemical intervention has a direct economic loss as an additional cost to the farmer, and can also have a detrimental impact on the product as chemical residues detract from fruit value (Beresford & McKay, 2012).

Climate change could increase the climate suitability and geographic ranges of pests and weeds already established in NZ (McGlone & Walker, 2011; Lake et al., 2018). For example, the apple black spot and grapevine downy mildew incidence in Otago are expected to increase with increasing temperature and rainfall (Beresford & McKay, 2012). A warmer climate may also lead to the increased likelihood of new biodiversity threats as the climate in Otago becomes more favourable to overseas biodiversity threats such as the big-headed and argentine ants which currently cause widespread biodiversity loss overseas (McGlone & Walker, 2011). All horticulture industries currently suffer economic losses as a result of pests and diseases. This is can be a result of losses in yield and quality, or losses related to spoilage past the farm gate. Additionally, disease control and prevention methods typically represent 5-15% of production costs, and can present further market risks related to chemical residue on produce (Beresford & McKay, 2012).

Climate change may also impact upon the ecology of existing biological control agents used in NZ to supress pests and weeds and thus reduce their efficacy and contribute to loss of production or increase pest control costs. For example, in New Zealand, the Lucerne Weevil is currently controlled by the Moroccan parasitoid Microctonus aethiopoides. In warmer climates this technique is ineffective, as may become the case in New Zealand with warming temperatures (Lake et al., 2018). Overall, these factors are likely to contribute to increased disease and pest control costs, increased weed prevention costs, or reduced crop productivity.

As extreme weather events become more frequent, crops and related infrastructure will be exposed to related impacts such as flooding, hail and wind damage. Inland flooding may cause direct damage or contamination to crops located in the floodplain as well as damage to ancillary infrastructure and loss of arable land due to landslides (Lake et al., 2018). Although relatively infrequent, wind and hail damage causes considerable economic losses to crops when it does occur, and may become more frequent with increased severity of extreme events (Stakeholder Engagement, 2020).

Adaptive capacity

The diversity of crops grown in Otago provides an opportunity for resilience and adaptation to climate change. While some crops may be adversely affected by the changing climate, others may benefit from a warmer wetter climate with fewer frost days and lower humidity (Macara et al., 2019). Or through increased atmospheric CO^2 concentrations (EcoClimate, 2008).

The long history of selective plant breeding and genomics in horticulture means that the industry is constantly adapting, for example through modifications to meet market preferences or product durability. Therefore, this inherent aspect of horticulture provides an excellent platform for research (much of which is currently underway) into crop varieties that are well equipped to withstand a warmer climate, and may be more resistant to disease (Aitken & Warrington, 2019; Beresford & McKay, 2012). As southern temperatures warm, this may open the region to new types crops, such as kiwifruit, which currently thrive in more northern climates but are projected to become unsuitable as northern temperatures rise (Earthwise Consulting, 2008). Changes in crop type may also present an opportunity to choose crops that are less dependent on irrigation, or can use more targeted, and therefore efficient, irrigation, such as tree crops (Stakeholder Engagement, 2020).

Climate change also presents an opportunity for farmers to shift to regenerative or organic agriculture on Otago's high-class soils. This may result in shorter supply lines, increased rural job opportunities and cleaner waterways (Stakeholder Engagement, 2020).

6.3.4 Discussion

Horticulture is extremely sensitive to climatic conditions, relying on predictable water supply, sunshine, temperatures and soil conditions for crop growth and harvesting (Aitken & Warrington, 2019). Warmer temperatures, higher annual rainfall and less frosts may affect crop suitability (Macara et al., 2019) and increase crop management costs. These challenges may necessitate a shift in crops grown toward those suited to a warmer, wetter climate, and those that are less dependent on irrigation. The industry may experience significant economic losses as the climate changes unless adaptive action is taken.

Increased temperatures in Otago may benefit horticulture through increased sunlight hours (Macara et al., 2019), however warmer temperatures, changing rainfall patterns and drought (E2.1, E2.7, E2.4, E2.9, E2.2, E2.8) may increase soil moisture loss during warmer months (Macara et al., 2019), additional pressure on irrigation supply. Many imported pests, weeds and diseases will likely gain an advantage under climate change scenarios that create a warmer, wetter and more disturbed environment (Kean et al., 2015), which has the potential for severe consequences on certain crops (Beresford & McKay, 2012), and increase crop management costs. Chill dependent crops such as apricot and cherry will be affected by a projected decrease in the duration of the frost season and number of frost days experienced per month, resulting in an increase requirement for chemical intervention (E2.5) (Macara et al., 2019). Crops are also sensitive to impacts from extreme events (E2.6, E2.10) where flooding (E2.3) can cause direct damage to crops and ancillary buildings, and water-logged soil and increased incidence of pests, and wind and hail can devastate crops (Stakeholder Engagement, 2020).

A summary risk rating for the horticulture sector is shown in Table 6-3, focusing on the key hazards associated with climate change. As shown, drought, as well as changes in rainfall are considered high risks at 2040, moving to extreme risks at 2090. Economic costs are likely to increase as pest control, chemical intervention, water availability and crop productivity issues are worsened through climate change.

Table 6-3: Summary risk rating for the horticulture sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E2.1	Risk to crops and horticulture due to higher temperature.	L	M	H	L	M	H	M	L	M	H
E2.2	Risk to crops and horticulture due to drought.	M	H	E	M	H	E	M	M	H	E
E2.3	Risk to crops and horticulture due to inland flooding.	M	M	H	M	M	H	M	M	M	H
E2.4	Risk to crops and horticulture due to change in rainfall.	M	H	E	M	H	E	M	M	H	E
E2.5	Risk to crops and horticulture due to less frost.	L	M	H	M	M	H	M	L	M	H
E2.6	Risk to crops and horticulture due to extreme weather events.	L	M	H	M	M	H	M	L	M	H
E2.7	Risk to viticulture due to higher temperature.	L	M	H	L	M	M	M	L	M	M
E2.8	Risk to viticulture due to drought.	M	H	E	L	M	H	M	L	M	E
E2.9	Risk to viticulture due to change in rainfall.	M	H	E	L	M	M	M	L	M	H
E2.10	Risk to viticulture due to extreme weather events.	L	M	H	L	M	H	M	L	M	H

6.4 E3: Risks to the forestry sector from climate change hazards including temperature, drought, fire and extreme weather

6.4.1 Introduction

The forestry sector is a significant economic sector within Otago, and has potential to grow in the future, particularly in response to the Emissions Trading Scheme (Manley, 2019) and as indicated by the Climate Change Commission draft recommendations (Climate Change Commission (2021a). Forestry and logging in Otago generated around $100 million in 2019, and equates to around 0.8% of the region's GPD (Infometrics, 2019). As shown in Figure 6-6, forestry is concentrated primarily towards the east coast of Otago. The forestry and logging sector is largest in the Clutha district, which produces 50% of the regions forestry related GDP, followed by Dunedin City which produces 33%. Central Otago, Waitaki Districts and Queenstown Lakes undertake 9%, 6% and 3% of the forestry related economic activity in the region (Infometrics, 2019). Otago's forests contribute over 5% of the nation's forestry related GDP. Nationally, the forests of the Otago and Southland wood supply region cover over 200,000 ha, which is the second largest forested region area in the country (Forestry New Zealand, 2019).

As a primary industry, forestry is inherently dependent on the land and climate for performance, therefore will be affected by a changing climate, particularly temperature, drought, fire and extreme weather (Stakeholder Engagement, 2020), as discussed below.

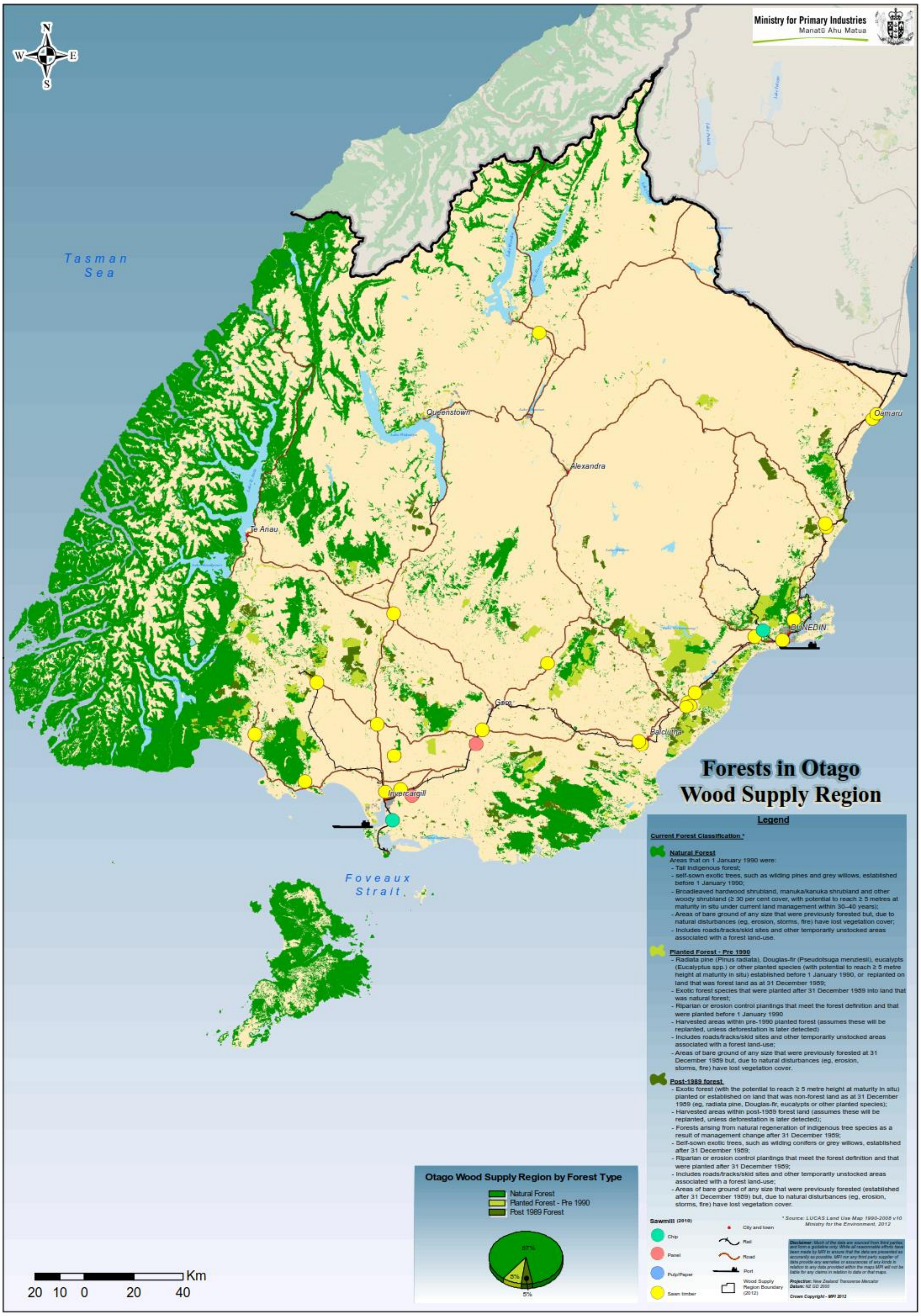

Figure 6-6: Forestry in Otago, source: MPI, 2012.

6.4.2 Exposure

The forestry sector in Otago is exposed to climate change hazards, such as extreme weather events and corresponding hazards such as high winds, floods, landslides, drought, and wildfire, and gradual changes, particularly rising temperatures (Macara et al., 2019).

Temperature increases are expected to occur across the Otago region, affecting all forest areas, which will impact forest management directly, as well as potentially raising the risk of wildfires. Currently temperatures are cooler near the eastern coast, where forestry occurs more intensively (Macara et al., 2019).

Forestry is exposed to drought, the likelihood of which is tied to temperature and rainfall and is also influenced by soil moisture and groundwater. While winter rainfall will increase across much of the region, summer rainfall is expected to decrease across the region and the number of dry days to increase (Macara et al., 2019), potentially increasing drought likelihood across the region.

Extreme wind is projected to decrease around the eastern coast of Otago, where the majority of forestry currently exists (Macara et al., 2019).

Extreme rare rainfall events are likely to increase in intensity across the region which increases the likelihood of flooding and landslides in forested areas (Carey-Smith et al., 2018).

6.4.3 Vulnerability

The vulnerability of forestry to climate change hazards is discussed below in relation to sensitivity and adaptive capacity.

Sensitivity

Warmer temperatures and other changing climate variables such as rainfall distribution are expected to eventually cause a mismatch between the climate envelope for indigenous and exotic plant species and their current distribution (McGlone & Walker, 2011; Whitehead et al., 1992). For example, the optimum average annual growth temperature for Pinus radiata has been estimated to be 12^{o}C, with an upper limit of 18^{o}C (Whitehead et al., 1992). Present day annual mean temperatures currently range between 8-12^{o}C for most coastal and inland low-lying parts of Otago and are projected to increase by 1.5-3.5^{o}C under RCP8.5 towards the end of the century. This may improve the climate for forestry in some areas, but become less optimal in other warmer areas, resulting in slower growth, changes in wood quality and therefore reduced yield (Whitehead et al., 1992).

Changing temperatures are likely to increase the prevalence of exotic weeds, most of which thrive in warmer climates (McGlone & Walker, 2011). These may cause an increased threat to seedling propagation by smothering young trees, result in increased maintenance costs due to weeding requirements, reduce productivity and increase production costs (McGlone & Walker, 2011). Of particular note, hotter, drier conditions favour the spread of wilding pines which is likely to exacerbate the existing biodiversity, water and land availability issues and related economic impacts in Otago (Wyatt, 2018). Also, New Zealand indigenous plant species commonly respond to climate conditions through the occurrence of a mast response which creates unusually large seed crops during favourable conditions. This in turn can stimulate growth in the surrounding ecological community, and spur on exotic pests, weeds and disease (McGlone & Walker, 2011). This was observed in Otago following an extended period of warm temperatures and drought which produced excessive honeydew production in mountain beech and Kamahi forest, which in turn promoted outbreaks of platypus beetle which led to die-back of mature trees (Dungan et al., 2007).

Abrupt climatic events such as drought and cold snaps can lead to forestry (and broader ecosystem) impacts. For example, example was the extreme cold snap which occurred in Otago during July 1996, which led to cold related die-off and damage among a wide range of exotic and indigenous trees (McGlone & Walker, 2011). Storm related hazards such as high winds and floods will increase windthrow and other physical damage related to wind (Figure 6-7). Increased flood risk may lead to loss of land, increased erosion, and land instability, particularly on recently harvested slopes. (Stakeholder Consultation, 2019/2020). Loss or damage to harvest due to wind, storm and flood damage can have a range of economic impacts (Moore, 2014). Snapped or damaged trunks often result in downgraded harvest value, and operations to salvage damaged logs can be dangerous, time consuming, and costly. Damage to younger crops may mean that the wood is only useable as pulp, or may not be economically viable at all and must be written off. Exposure to frequent high winds often results in sturdier trees with properties such as larger knots that make them lower grade timber (Moore, 2014).

Figure 6-7: Storm damage in a stand of trees.

The risk of wildfire is an important and serious risk to forestry (NZ Forest Owners Association, 2018), and one that will increase with projected temperature and drought frequency increases (Macara et al., 2019). Areas of high vegetation cover in locations with transmission and distribution lines will generally be of highest risk (refer also to risk B8 Section 7.9). An increase in fire-related impacts can lead to significant economic losses, insurance liability and increased fire management requirements, such as weed control, undergrowth maintenance, fire breaks, pruning and controlled off-season burning (Stakeholder Engagement, 2020; NZ Forest Owners Association, 2018). Cascading impacts from fire risk also pose a risk to the built environment and other nearby activities (refer risks B1 and B8, Section 7.2 and Section7.9) (Stakeholder Engagement, 2020).

Figure 6-8: Forest fires blaze near Dunedin in 2010 (Otago Daily Times, 2010).

Adaptive capacity

The long life span of forestry crops and intrinsic reliance on climate and soil conditions mean that there are many aspects of forestry that have limited adaptive capacity. Forestry harvest usually occurs after 25 years, which raises the potential for climate conditions to be less favourable for a certain variety over the crop lifespan (Whitehead et al., 1992). However there is some potential for adaptive farming, through the choice of climate tolerant species or change in location of new plantations to optimise growing conditions. Historically, plantation species have been selected to favour the most desirable production qualities, and it can therefore be argued that this provides continued adaptation to any changes in climate with each new generation of tree that is planted (Whitehead et al., 1992).

As a carbon sink, forestry is also a significant player in options for greenhouse gas emissions reduction, and is therefore a subject of significant interest and research (Forestry New Zealand, 2015). The emissions reduction capacity of forestry provides additional economic incentive for the sector.

Ongoing research into the physiological response of plantation species to a changing climate may improve the adaptive capacity of the sector. Additionally, the use of genetic modification may provide further adaptive capacity for issues such as biosecurity, prevention of wilding pine spread, genetic resistance to pests and pathogens, and improved yield (NZIER, 2017).

6.4.4 Discussion

The economic productivity of forestry faces risks from climate change, particularly temperature, drought, fire and extreme weather. As with all forests, plantation forestry growth is influenced by temperature, and is susceptible to drought and extreme cold (Whitehead et al., 1992). Climate change also presents opportunities for adaptation to the forestry industry through carbon sequestration, and adaptation through species selection may reduce the economic impact of climate change (Whitehead et al., 1992).

A summary risk rating for the forestry sector is shown in Table 6-4, focussing on the key hazards associated with climate change. As shown, increased fire weather and extreme events are considered high risk at 2090, and drought is considered an extreme risk. A range of economic consequences may arise from a changing climate in Otago. Warmer temperatures (E3.1) may change forest growth and yield, and lead to increased pest and weed species resulting in reduced timber value and additional pest control and maintenance costs including the occurrence of wilding pine spread (McGlone & Walker, 2011; Wyatt, 2018). Drought (E3.2) and other extreme weather (E3.4) may accelerate forest mortality or result in lower grade timber and increased management costs due to wind and storm damage (Moore, 2014). Increased risk of wildfire (E3.3) can lead to significant economic impacts from fire damage, and increase fire prevention costs such as weed control and the need for fire breaks (Stakeholder Engagement, 2020; NZ Forest Owners Association, 2018). Wildfire also poses cascading risks to other domains such as damage to the built environment (B8).

Table 6-4: Summary risk rating for the forestry sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E3.1	Risk to forestry due to higher temperature.	L	M	H	L	M	M	M	L	M	M
E3.2	Risk to forestry due to drought.	M	H	E	L	M	H	M	L	M	E
E3.3	Risk to forestry due to increased fire weather.	L	M	M	M	H	E	M	L	M	H
E3.4	Risk to forestry due to extreme weather events.	L	M	H	M	M	H	M	L	M	H

6.5 E4: Risks to the fisheries and aquaculture sector from climate change hazards including marine water temperature and water quality

6.5.1 Introduction

Fisheries and aquaculture include farmed fish such as salmon, mussels, and oysters, as well as wild fish. Otago forms part of the Southeast Fishing Region, alongside Kaikoura and Canterbury. The Southeast Region contains New Zealand's second and third largest fishing ports (Lyttleton and Timaru) which service regional inshore trawling and deep sea trawlers (Fisheries New Zealand, 2020). As a result, the economic activity associated with the majority of commercial fishing in the region does not pass through Otago directly. The remaining Otago fisheries and aquaculture sector is relatively small within the New Zealand context. Last year, Otago fisheries employed 55 people and aquaculture 9 employees, which combined is roughly 3% of the national workforce in the sector (Statistics NZ, 2019).

Fisheries and aquaculture contributes $25 million and roughly 0.2% of the Region's GDP (Infometrics, 2019). The majority of this economic activity is located in the Dunedin City (58% of GDP) with 25% based in Waitaki and 17% based in Queenstown Lakes (Infometrics, 2019). Otago's fisheries comprise mainly of smaller fishing vessels for local supply (Stakeholder Engagement, 2020). Otago's sports fishing provides considerable recreational amenity and fisheries in Otago are highly regarded internationally (Stakeholder Engagement, 2020).

The primary climate change risks facing the sector are related to marine water temperature and water quality. While these risks are significant, Otago's southern position and relatively cooler waters may present an opportunity for establishing new fisheries as the industry in more northern parts of the country that are likely to face higher marine temperatures.

6.5.2 Exposure

Fisheries and aquaculture are currently exposed to changing sea temperature, which is expected to increase with a warmer climate. Long term trends show sea surface temperatures are rising around New Zealand (Chiswell & Grant, 2018), however lower rates of warming relative to north and western New Zealand are observed off the coast of Otago, as shown in Figure 6-9 (Sutton et al., 2019). The frequency of marine heatwaves is also increasing, resulting in instances of extremely high sea surface temperatures that have lasted for days to months (Ministry for the Environment & Statistics New Zealand, 2016). Ocean acidification is occurring as oceans absorb excess CO_2 in the atmosphere, which is expected to continue until atmospheric GHG concentrations stabilize (Ministry for the Environment & Statistics New Zealand, 2016).

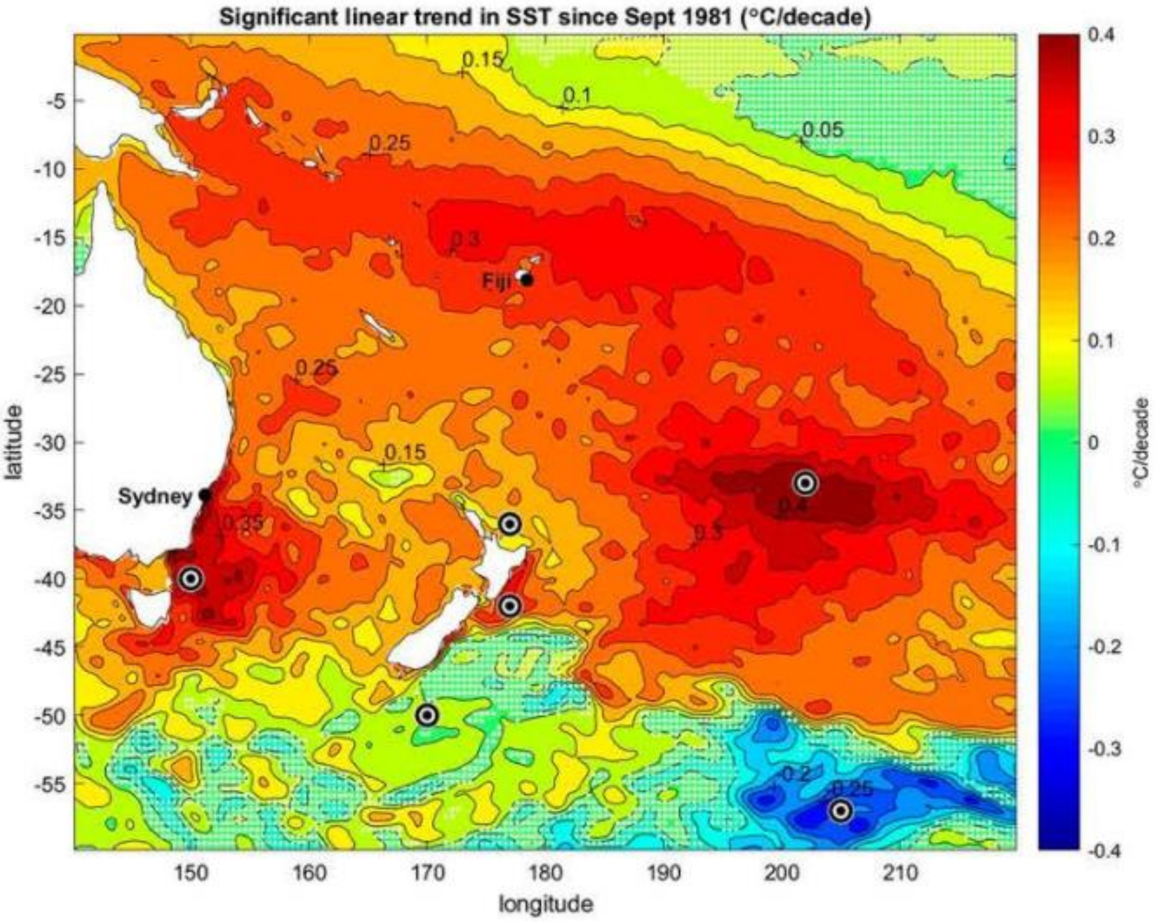

Figure 6-9: Sea surface temperature trend in °C per decade since 1981 (Sutton et al., 2019).

6.5.3 Vulnerability

The vulnerability of fisheries and aquaculture to water temperature and acidification depends on the species in question and local environmental conditions, and is discussed below in relation to sensitivity and adaptive capacity.

Sensitivity

Ocean acidification and warming cause widespread harm to aquatic ecosystems, and is expected to occur throughout New Zealand's coastal waters. The cumulative effects of ocean climate change and other anthropogenic stressors on aquatic ecosystems are likely to be high and seen in the next 20-30 years (MPI, 2017). Understanding the limits of environmental conditions that fish will tolerate depends on species and also a specific population (Dunn et al., 2009), so will therefore vary across the differing coastal environments of New Zealand. Predicting the effect of climate on fisheries and aquaculture is influenced by understanding of how large scale climate patterns affect NZ oceanography, how environmental variability affects species and how species interact with an eco system, which is a subject of ongoing research (Hurst et al., 2012).

As temperatures rise, the chemistry of oceans is changing to become more acidic. This is a significant health issue for shellfish and has been identified to be a direct cause of oyster larvae declines in the U.S. Pacific Northwest. It is considered likely that New Zealand fisheries will experience similar effects, where ecosystem impacts of ocean acidification and warming temperatures may include changing physiology and behaviour of fish and significant impacts on shellfish such as oysters that rely on carbonate chemistry for shell formation (Capson & Guinotte, 2014). While it is highly likely that New Zealand shellfish populations will be affected by ocean chemistry changes, the implications for finfish are currently unclear and the subject of ongoing research (Capson & Guinotte, 2014).

Water quality is impacted by stormwater runoff and flooding. Increased intensity of rainfall events is likely to cause increased erosion contains contaminants from urban stormwater runoff, and nutrients from agriculture runoff (Hughes et al., 2019). These contaminants contribute to reduced water quality and habitat damage, which has an adverse impact on fisheries and aquaculture.

Adaptive capacity

Some marine species are more sensitive than others to ocean acidification, and some species such as seagrasses may benefit from higher CO_2 levels which may provide some adaptive capacity to existing ecosystems (Capson & Guinotte, 2014). The changing ocean environment may also provide a more favourable habitat for species that currently reside in warmer temperatures as species migrate south to cooler climates (MfE, 2019).

Additionally, management strategies have been developed in aquafarming situations to adapt to ocean acidification through monitoring and chemical intervention during times of high acidification, as is currently occurring in the U.S. Pacific Northwest (Capson & Guinotte, 2014).

6.5.4 Discussion

Rising temperatures, ocean acidification and water quality deterioration associated with flooding and stormwater runoff is likely to have a significant impact on the health of aquatic ecosystems, which will directly impact the economic productivity of fisheries and aquaculture.

A significant opportunity in Otago is the potential for establishing new fisheries that have previously not inhabited the cooler waters off the coast of Otago. This potential is indicated through observation of marine primary productivity monitoring. Primary productivity occurs mostly in the form of phytoplankton and forms the basis of marine food webs (MfE, 2019). This index is measured in New Zealand's marine environment and provides an indicator of how ecosystems are changing. Recent data indicates that coastal productivity is increasing in southern New Zealand, including around the coast of Otago, but decreasing in Northern New Zealand as shown in Figure 6-10 (Statistics NZ, 2019). An increase in marine primary productivity may have a positive effect on the establishment of new fisheries as larger species migrate to follow this food source (MfE, 2019).

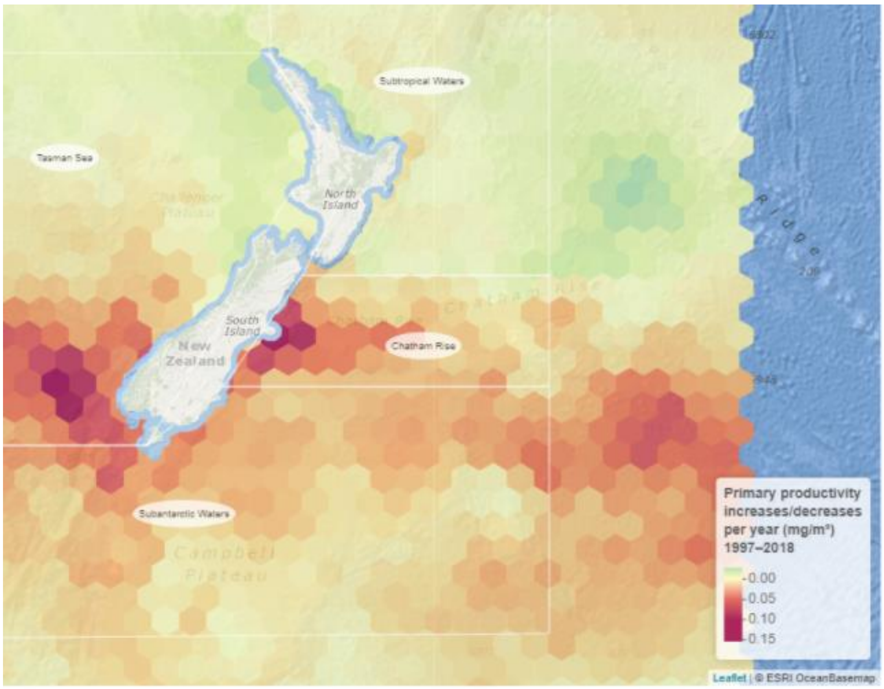

Figure 6-10: Marine primary productivity in offshore New Zealand (Statistics NZ, 2019).

A summary risk rating for the fisheries and aquaculture sector is shown in Table 6-5 focusing on the key hazards associated with climate change. As shown, marine heatwaves (E4.1) are considered a high risk at 2090, and ocean acidification (E4.2) is considered an extremely high risk at 2090. These risks may be reduced through the adaptive capacity of the Otago fisheries if species from warmer, northern waters can establish in the relatively cool Otago waters. There are still significant gaps in the understanding of how the marine environment will respond to climate change and related ecosystem and water quality deterioration (MfE, 2019). Further research is required in the area to help understand the economic impacts for Otago, as well as the wider implications for tourism and the natural environment.

Table 6-5: Summary risk rating for the fisheries and aquaculture sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E4.1	Risk to fisheries and aquaculture due to marine heatwaves.	L	M	H	L	M	H	M	L	M	H
E4.2	Risk to fisheries and aquaculture due to ocean acidification.	L	M	H	L	M	H	L	L	M	E

6.6 E5: Risks to primary sector supply chains from climate change hazards including inland flooding, coastal flooding, landslides and extreme weather

6.6.1 Introduction

Inland flooding, increasing landslides and soil erosion and coastal flooding were identified as the top climate hazards likely to impact the supply chain in the Otago Region. The supply chain relies heavily on transport infrastructure and key distribution and production facilities with disruption to these occurring more regularly due to climate impacts (Business Continuity Institute, 2019). Disruptions to the network are commonly caused by the exposure and vulnerability of key supply chain infrastructure as documented in risks B5 and B6, Section 7.6 and Section 7.7. Supply chain networks face physical, operational and reputational risks attributed to climate change, with disruption leading to losses in productivity, share price movements, damage to brand and reputation, loss of customers and increased regulatory scrutiny (Dasaklis & Pappis, 2013).

Primary industries including meat, dairy, forestry, horticulture and fast-moving consumer goods (FMCGs) are the main sectors in the Otago Region that may be affected by supply chain disruption. As outlined in several of the economy risks (E1 Section 6.2, E6 Section 6.7), these sectors are significant for the Otago economy, and disruption to the supply chains can result in a number of consequences for the regional economy.

Key land transport routes for freight movement in the Otago Region for all sectors mentioned above include SH1, SH8, SH6, SH79, SH94 and SH88 as well as KiwiRail's Main South Line (AECOM, 2011; Waka Kotahi, 2020; Otago and Southland Regional Transport Committees, 2018). Port Otago at Port Chalmers is the South Island's primary export port and is a key link in the regional, national and international supply chain (Port Otago, 2019). In 2019 Port Otago handled 1,764,000 tonnes of cargo through 458 container and bulk cargo vessels (Port Otago, 2019).

The Fonterra Distribution Centre in Mosgiel is located off SH87 with rail connection to the Main Trunk Line with one of the New Zealand's largest dairy factories at Edendale in Southland (Stuff, 2009; Enzed Transport, 2010). Fonterra also has a milk-processing plant located at Stirling in the Clutha District. Fonterra, as the world's largest dairy exporter is therefore reliant on the Otago regional supply chain infrastructure for regional, national and international trading. Flooding has previously impacted supply chains which rely on the Main South Line, such as in 2006 where a south bound train was forced to stop until flood waters receded (Figure 6-11) (Otago Regional Council, 2013).

Figure 6-11: South Island Main Trunk Line after 2006 flood on the Taieri Plains, (Otago Regional Council, 2013).

Table 6-6 summarises the main primary sectors, along with key transport routes (road and rail) and climate hazards which are relevant to these routes.

Table 6-6: Summary of key transport routes for sectors and highest ranked hazards

Sector	Key route	Hazards
Dairy	SH1, Main South Line, SH87	Flooding, Landslip, Coastal Inundation, extreme weather events
Meat	SH1, Main South Line	Flooding, Landslip, Coastal Inundation, extreme weather events
Forestry	SH1, Main South Line	Flooding, Landslip, Coastal Inundation, extreme weather events
Horticulture	SH1, Main South Line, SH87, SH83, SH82, SH8	Flooding, Landslip, Coastal Inundation, extreme weather events
FMCGs	SH1, Main South Line	Flooding, Landslip, Coastal Inundation, extreme weather events

6.6.2 Exposure

The land transport network in Otago is currently exposed to a number of climate related hazards, including inland flooding, increasing landslides and erosion, coastal flooding, and an increase in extreme weather events. In the recent National Resilience Programme Busines Case (PBC), 10 major and extreme climate related risks were identified in the Otago Region (Waka Kotahi, 2020). This included inland flooding risk for the Balclutha, Big Kuri River, Maheno, and Waikouaiti River road bridges all located along SH1. Flooding in these locations often leads to prolonged outages for the main supply chain route, which generally have limited detour availability, especially for high productivity motor vehicles (HPMVs) critical to the supply chain (Waka Kotahi, 2020). A number of these road bridges are also co-located with rail bridges which are likely to experience similar issues (Waka Kotahi, 2020). Inland flood risk is likely to increase in exposure in the mid to long-term as the frequency and duration of disruption / outage increases (Waka Kotahi, 2020).

The increasing number of landslides and erosion is also a current issue for the land transport system in the Otago region. SH6 between Cromwell, Queenstown and Frankton and between Lakes Wanaka and Hawea, SH88 between Dunedin and Port Otago and SH1 between Waikouaiti and Evansdale have been identified as having major to extreme landslip risk with this increasing in frequency and duration of outage in the mid to long term (Waka Kotahi, 2020). These locations are also located along critical supply chain routes - particularly SH6 which provides the only road access to Queenstown (Waka Kotahi, 2020).

The critical corridor between Port Otago and Dunedin city where both road (SH88) and rail are co-located has limited road detour availability for HPMVs (Waka Kotahi, 2020). As mentioned, this corridor is exposed to landslips, with this expected to increase in the mid to long term due to climate change. It is noted the corridor is also exposed to coastal erosion and coastal inundation (Waka Kotahi, 2020).

Dunedin airport is located on the Taieri Plains and is currently exposed to both fluvial and coastal flooding (Figure 6-12) (Paulik et al., 2019; Otago Regional Council, 2013; Paulik, et al., 2019a; Waka Kotahi, 2020). SH1, SH88, SH87 and the KiwiRail Main South Line provide access to and from Dunedin airport and the Mosgiel Fonterra Distribution Centre. These routes are located within the same corridor and are subject to inland flooding and coastal inundation impacting the supply chain (NZTA, National Resilience Programme Business Case, 2020c; Ministry for the Environment, National Climate Change Risk Assessment for New Zealand, 2020).

Figure 6-12: Flooding on SH1 at Mill Dam, north of Maheno, Otago in 2013 (Otago Daily Times, 2013).

6.6.3 Vulnerability

Vulnerability of the supply chain is predominantly related to the vulnerability of the physical infrastructure as discussed in risks B5 and B6, Section 7.6 and Section 7.7. Outside of the infrastructure specific vulnerabilities, there are also a number of other factors which can influence the vulnerability of the supply chain such as the geographical reach and complexity of supply chains and perishability of the goods, where dairy, meat and produce require transport from farm to consumer within a timely manner.

Organisations with localised supply chains may be unaffected by events occurring in other regions, while other organisations are exposed to disruption from international events.

When the supply chain is comprised of a large number of suppliers, the possibility to suffer negative impacts is often larger than in the case of small and local supply-production chains, as impacts to any part of the supply chain can affect the whole (Andreoni & Miola, 2014). An example of this is Fonterra's significant national and international export footprint which, as mentioned above, has a significant reliance on infrastructure and farms located within the Otago Region.

Due to 'just-in-time' production and delivery, businesses have limited back up stock and therefore even slight delays due to disruption in supply chains can have significant impacts on the delivery of products (Dillingham, 2019). This is particularly important in the supply chain of perishable items, where small delays can equate to loss of stock and have consequences for food security (Yang et al., 2017). Some parallels can be drawn from the impacts of COVID19 on supermarket supplies where increased demand meant supply chains could not keep up, resulting significant low stock across the country for certain items such as flour, pasta and rice (Oshri & Kotlarsky, 2020). Supply chain issues were identified as one of the factors which reduced household spending, impacting the broader Otago economy during COVID19 (Deloitte, 2020). Conversely, COVID19 related retail butchery shutdowns, service industry shutdowns, and reduced processing capacity resulted in reduced demand, which coupled with a dry summer, placed extra stress on value chains, and feed availability and cost (Meat Industry Association, 2020, Beef and Lamb New Zealand, 2020).

Increasing the number of different suppliers for the same commodity can increase the flexibility and resilience of a supply chain and therefore potentially reduce the vulnerability and reduce the costs and the time of recovery after an event (Andreoni & Miola, 2014).

6.6.4 Discussion

Supply chain disruptions can lead to losses in productivity, share price movements, damage to brand and reputation, loss of customers, and increased regulatory scrutiny overall resulting in a loss of revenue (Engage the Chain, 2017). Impacts of climate change on the supply chain may also result in increased variability of costs in producing goods, reduction in the quality of goods, and disruption in the time taken to deliver or transport goods (Wei & Chase, 2018).

Parts of key transport routes within Otago including SH1 and the Main South Line rail corridor are exposed to coastal flooding (E5.1), inland flooding (E5.2), landslides and soil erosion (E5.3) and extreme weather events (E5.4). Disruptions to these transport routes would impact on the primary sector, particularly dairy and meat which rely on the fast transportation of perishable items (Yang et al., 2017).

A summary risk rating for the supply chain risks is shown in Table 6-7, focusing on the key hazards associated with climate change. As shown, inland flooding and increased landslides are considered high risks at 2040, moving to extreme risks at 2090.

Table 6-7: Summary of risks to primary sector supply chains from climate change hazards

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E5.1	Risk to primary sector supply chain due to coastal flooding.	L	M	H	M	M	H	M	L	M	H
E5.2	Risk to primary sector supply chain due to inland flooding.	M	H	E	M	H	H	M	M	H	E
E5.3	Risk to primary sector supply chain due to increasing landslides and soil erosion.	M	H	E	M	H	H	M	M	H	E
E5.4	Risk to primary sector supply chain due to extreme weather events.	L	M	H	M	M	H	M	L	M	H

6.7 E6: Risks to cost of doing business from climate change hazards including coastal and inland flooding, landslides, and extreme events

6.7.1 Introduction

The cost of doing business relates to factors that influence business running costs such as insurance, asset maintenance, rent, taxes, wages and utilities (World Bank Group, 2020). The cost of doing business cuts across all sectors, but increased costs relating to climate change will be highest in locations where climate hazards have the greatest physical impact - such as coastlines and floodplains, and where significant economic activity occurs – such as towns and cities, or key transport routes.

Otago contributes 4.4% of the total domestic GDP, and is home to 4.6% of the country's population (MBIE, 2019). As the territorial authority containing the region's largest city and a major university, Dunedin City has historically produced the highest economic activity of the region, generating around 54% of the region's GDP (MBIE, 2019; MBIE, 2020). Although Dunedin City has the highest concentration of economic activity, the remainder of the region has other economic strengths, such as the more rural districts with strong primary and manufacturing industries, and Queenstown which has strong tourism and property services (MBIE, 2019).

Like the rest of New Zealand, the majority of businesses in Otago are small to medium enterprises (SMEs). Approximately 80% of Otago businesses were either self-employed or employed less than 5 staff in 2019, and only around 1% employed over 50 staff (Infometrics, 2019).

The cost of doing business is influenced by a range of factors, many of which are vulnerable to increased physical hazards related to climate change. The greatest risks are likely to arise from coastal and inland flooding, landslides, and extreme events, as discussed below. In addition to these physical risks, it is important to note that transitional risks related to changing regulation, technology and consumer and investor preferences may impose further costs and uncertainty to businesses (RBNZ, 2018), however these risks are not discussed in detail.

6.7.2 Exposure

The cost of doing business will be impacted by climate hazards in locations where business intersects with climate hazards. Economic activity is distributed across the region and will therefore be exposed to all climate hazards. Dunedin City is the district with the highest GDP in Otago, much of which is generated from university, healthcare, and property (Infometrics, 2019). As the largest economic producer in the region, Dunedin City will have the highest concentration of businesses. Dunedin City is exposed to the coast, as are parts of Waitaki District and Clutha District, and will therefore be exposed to sea level rise, which is projected to rise by up to 0.9 m by 2090 under RCP8.5 throughout New Zealand (Ministry for the Environment, 2017). This will result in increased coastal flooding particularly in low lying areas, such as South Dunedin.

Increased rainfall intensity and extreme weather events are expected to occur throughout the region (Carey-Smith, Henderson, & Singh, 2018). This is likely to expose businesses to increased flooding particularly businesses located near rivers such as the dairy farms on the Taieri Plains (Farmers Weekly, 2014). Significant rainfall events can also lead to landslides and soil erosion in steeper areas.

6.7.3 Vulnerability

The vulnerability of business in general to climate change hazards will depend on a wide range of factors. This is discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Businesses are sensitive to flooding, storm damage and landslides as these can cause significant direct damage to property and assets. Significant rainfall frequently leads to widespread flooding throughout Dunedin city, leading to evacuations, road closures, damage to infrastructure and associated power outages, such as during recent 2015 and 2018 evets (Figure 6-13) (Otago Daily Times, 2018). Following such an event, businesses or their insurers must invest in repairing, rebuilding or replacing assets. Businesses must also cope with temporary disruption such as loss of trade, loss of power and other services, business relocation, supply chain disruption, staff wellbeing, and increased insurance premiums (Hughes et al., 2019). Additionally businesses may need to invest in adaptation measures to reduce future disruption (Hughes et al., 2019).

Figure 6-13: Dunedin businesses flooded in 2015 (left) and again in 2018 (right).

Adaptive capacity

Businesses will have a limited capacity for adaptation to climate related price increases, particularly small and medium enterprises that often have smaller operating margins. Some businesses may have the opportunity to take advantage of a changing business environment due to climate change, such as adoption of activities suited to warmer climates in agriculture (Kean et al., 2015), however regardless of this, businesses are still likely to suffer from direct cost of damages from flood and landslide events, and related costs such as increased insurance premiums (RBNZ, 2018).

Businesses may decide to invest in resilience or adaptation measures to protect their business from climate hazards. For example, one Taieri dairy farmer whose farm is frequently inundated during high flows in the Taieri River has constructed a raised platform to accommodate all his stock above flood water to avoid otherwise needing to transfer his stock off site whenever there is a risk of flooding (Farmers Weekly, 2014). These types of measures can come with significant expense, and may not be economically viable for some businesses.

6.7.4 Discussions

Increased physical impacts from climate change will translate to risk of property damage, changing property values and disruption to supply chain. Property insurance is widespread within New Zealand, and therefore climate of risks are expected to be reflected in premiums. Property insurance is often negotiated annually, which allows insurers to re-evaluate climate risk, and some insurers appear to have begun adjusting their premiums to reflect emerging climate risks (RBNZ, 2018). As insurers evaluate higher risks to properties, land exposed to coastal inundation (E6.1), inland flooding (E6.2) landslides (E6.3) and more extreme events (E6.4) will see higher insurance premiums, and some properties will potentially become uninsurable (RBNZ, 2018). Increased insurance premiums or reduction in insurance availability may result in a loss of property value, which has wider economic implications (RBNZ, 2018) and ultimately may affect the viability of some businesses. These risks may impact consumers, increase the cost of living, or result in increased inequities in the economy, as discussed in H5.

Relocation or costly adaptation measures may be a necessary alternative, particularly for businesses tied to uninsurable assets (Stakeholder Engagement, 2020). Cascading effects of business closure can impact the whole community (Lawrence et al., 2018), and flood or other hazard risk can ultimately cause the closure of a community, as happened to Kelso, West Otago after repeated devastating flooding from the Pomahaka River resulted in a prohibition on any further development in the township (ODT, 2010).

Reducing impacts on business will require forward thinking adaptation and innovation across multiple levels of business and by multiple actors – including businesses themselves, related service and supply chains, sector organisations, and related public authorities. Collaborative innovation across all sectors can assist climate change adaptation. Businesses must consider and embed climate risks within decisions and incorporate agility, innovation and adaption as part of business plans and systems (RBNZ, 2018; Stakeholder Engagement, 2020).

A summary risk rating for the cost of doing business is shown in Table 6-8. This summarises the climatic changes and hazards that are expected to pose the greatest risks to the cost of doing business, determined as being of elevated importance by ORC and other stakeholders (Stakeholder Engagement, 2020). As shown, coastal and inland flooding, and increased landslides and soil erosion are considered high risks at 2040, moving to extreme risks at 2090.

Table 6-8: Summary risk rating for the cost of doing business

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E6.1	Risk to cost of doing business for all sectors due to coastal flooding.	L	M	H	M	H	E	L	L	H	E
E6.2	Risk to cost of doing business for all sectors due to inland flooding.	M	H	E	M	H	E	M	M	H	E
E6.3	Risk to cost of doing business for all sectors due to increasing landslides and soil erosion.	M	H	E	M	H	H	M	M	H	E
E6.4	Risk to cost of doing business for all sectors due to extreme weather events.	L	M	H	M	M	H	M	L	M	H

6.8 E7: Risks to the tourism sector from climate change hazards including higher temperatures, reduced snow and ice, inland and coastal flooding, landslides and erosion

6.8.1 Introduction

The tourism sector prior to Covid-19 was a key driver of economic development for the Otago region. Tourism contributed an estimated 18% to regional GDP and employed 23% of the regional workforce, and was particularly important for the Dunedin City and Queenstown-Lakes district economies (Infometrics, 2019). Prior to Covid-19, the tourism sector was a significant driver of economic development in New Zealand. In 2019, the tourism sector was the country's largest export industry, accounting for 20.4% of total export earnings, contributing 9.8% to national GDP and directly employing 8.4% of the national workforce (MBIE, 2020). In 2019, moreover, the Otago region had 15% of the tourism national market share (the second-highest of all regions) and the regional tourism spending was $4,128 million, with $1,850 million of spending from domestic tourists and $2,277 million of spending from international tourists (MBIE, 2020).

The sector itself is broad and is related to a variety of attractions and activities in both summer and winter, including alpine activities such as skiing, as well as sight-seeing, cycle-touring, wine-tours, and adventure/adrenalin tourism. These attractions and activities, in turn, support a wide range of businesses within the hospitality, retail and travel sectors.

As with the rest of New Zealand, the natural environment is a key driver for visitation in Otago. Climate change will result in gradual changes to the natural environment, including through impacts on the landscape, water quality, and a reduction in snow and ice. Climate change will also pose risks to tourism-related infrastructure, such as the region's airports and road network (refer to risks B5 and B6, Section 7.6 and 7.7). Further, increased biosecurity risks relating to climate change may also affect the tourist appeal of the natural environment (refer to risks B6, Section 5.6).

6.8.2 Exposure

The tourism sector is exposed to climate change hazards, such as extreme rainfall and associated floods and landslides, and gradual changes, particularly reductions in snow and ice, changes in seasonality and sea level rise.

Temperature increases are expected to be associated with rising snow lines and glacial retreat, more frequent hot extremes, and increasing extreme weather events. Under RCP 8.5, rainfall is projected to increase in key tourism areas of Otago, including Central Otago, with seasonal changes projected across the region. Correspondingly, mean annual floods are generally expected to become larger, with increases up to 100% in some locations in Otago by the end of the century (Macara et al., 2019).

Tourism destinations along coastal areas of Otago are exposed to sea level rise, associated coastal flooding, and coastal erosion and landslides. Coastal infrastructure (e.g. roads), buildings (e.g. accommodation and other businesses), and recreational sites and activities (e.g. tracks and beaches) will be exposed to climate change hazards (refer to risks to the Built Environment Section 7).

6.8.3 Vulnerability

Vulnerability of the tourism sector will depend on the specific nature of the business and, its sensitivity and adaptive capacity. Each of these are discussed below.

Sensitivity

The aesthetic, recreational and reputational value of Otago's tourism sector and associated infrastructure (e.g. roads, accommodation buildings, and the electricity grid) are considered sensitive to the impacts of climate change, particularly the hazards listed above. As an example, in the 2019-2020 summer season, floods resulted in significant disruption and damage to key road networks, tracks and parks, and resulted in wide-ranging business impacts in Wanaka and Queenstown (New Zealand Herald, 2020). In 2017, businesses in the Otago Peninsula, a key coastal eco-tourism destination, were cut-off and disrupted due to floods and associated landslides (Radio New Zealand, 2017).

Table 6-9 lists some key tourist attractions within the region. These all considered sensitive to climate change hazards, particularly floods and landslides, and also gradual changes to the aesthetic value of the Otago landscape due to climate change.

Table 6-9: Key tourism attractions in Otago and climate sensitivities

Attraction	Climate change sensitivities
Ski fields	Temperature rise, and reduced snow/ice
Coastal areas including Otago Peninsula	Coastal and inland flooding, and landslides
Walking tracks	Landslips, floods and changing landscapes
Alpine lakes	Temperature increases leading to increased algae, reduced inflow from snowmelt

Adaptive capacity

The majority of tourism operators in Otago are small and medium-sized enterprises (SMEs), which will likely lack the information to plan for, and resources to finance, future adaptations. There are also inherent difficulties concerning climate change adaptation in the tourism sector, as adaptations are often incremental (such as snowmaking machines to mitigate for reduced winter snowfall) and not transformational.

Given the breadth and number of tourism stakeholders, poorly planned and uncoordinated actions could result in maladaptation and future risks due to perverse incentives, misallocated investment, and insurance retreat (MfE, 2020). However, the cohesive nature of local Otago communities, and relationships between local tourism operators are likely to aid in strengthening adaptive capacity – and potentially enable diversification over time to allow services to respond to a changing climate and the changing nature of the natural environments and features they rely on.

6.8.4 Discussion

Given the significance of tourism to the regional economy, the consequences of climate change are potentially very high, and this has contributed to the risks being deemed high or extreme in 2040 and 2090.

Climate change will negatively impact tourism operations across the Otago region. Climate change impacts will result in reductions in snowfall, which will result in an increased reliance on snowmaking equipment (E7.1). This could reduce the number of days suitable for skiing, and increased temperatures will also affect the functioning of snowmaking equipment. Other recreational activities that will be affected by climate change hazards include walking and tramping, with key tracks and huts in the region at risk of inland flooding and extreme weather events, and associated erosion and landslides as shown in Figure 6-14 (E7.2, E7.3).

Figure 6-14: Routeburn track hut closures after flooding (Stuff, 2020).

The aesthetic value of the Otago's natural landscape is at risk through a reduced snowline, afforested alpine areas (changing the existing alpine grassland environments), and increased erosion of the hills (E7.1, E7.3). Another impact of climate change will be seasonal changes, which could affect the value proposition of the region's tourism market through, for instance, reducing the certainty of characteristic Central Otago summers and winters. The region's lakes are also at risk from increased algae, and stratification and declining water quality due to increased temperatures (N5), which could, in turn, affect the experience of tourists and the reputation of Otago as a sustainable tourism destination.

In coastal areas of Otago, coastal erosion and sea level rise could have impacts on recreational sites and tourism-related buildings and infrastructure, including beaches, hotels, and roads (E7.4). The disruption of roads and other transport infrastructure will also have impacts on access to the Otago region.

Key access routes (B5), including Otago's roads and airports, are at risk due to climate change, which could impact on tourist numbers. Tourists in New Zealand often visit locations as a part of a wider journey, and the disruption of key tourism routes, such as the Glenorchy-Queenstown Road and the road to Milford Sound (one of New Zealand's most visited destinations) from Queenstown, could affect the value proposition of tourism in Otago. Tourism operators are also reliant on the regions supply chains for a number of goods and services, such as food and beverages for hospitality businesses, which would also be at risk from flooding and landslides.

A summary risk rating for the tourism sector is shown in Table 6-10, focussing on the key hazards associated with climate change. As shown, the tourism sector faces extreme risk from reduced snow by 2040, and faces additional extreme risks from landslides, soil erosion and coastal flooding by 2090. The economic consequences of climate change on Otago's tourism industry are therefore likely to be significant, particularly in areas with a high reliance on tourism such as the Queenstown Lakes District. The economic impacts could include reduced employment, misallocated investment in tourism operations, and impacts on the wider economy through declining council tax revenue and reduced economic activity in associated sectors such as the retail industry and the residential property market.

Table 6-10: Summary risk rating for the tourism sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
E7.1	Risk to tourism sector due to reduced snow and ice.	M	H	E	M	H	H	L	M	E	E
E7.2	Risk to tourism sector due to inland flooding.	M	H	E	M	H	H	M	M	H	E
E7.3	Risk to tourism sector due to increasing landslides and soil erosion.	M	H	E	M	M	H	M	M	M	E
E7.4	Risk to tourism sector due to coastal flooding.	L	M	H	M	M	H	M	L	M	H

Built Environment

7 Built Environment Domain

The Built Environment Domain refers to the set and configuration of buildings, physical infrastructure, and transport. For the purpose of this assessment it consists of residential housing, commercial and public buildings, the three waters network (water supply, wastewater and stormwater), flood management schemes, as well as transport, waste, energy and telecommunications infrastructure. The links between the built environment and other domains, particularly the human, natural environment and economy, mean that impacts on Otago's built environment can have a range of interacting and cascading implications. A detailed assessment of cascading impacts is outside the scope of this study, however some examples are provided within Section 9.

The built environment within the Otago region is at risk from a range of climate change hazards including, coastal and inland flooding, extreme weather events, drought, fire weather, sea level rise and salinity stress and others. This assessment focuses on the exposure, vulnerability and potential impacts to the built environment from selected climate change hazards that have been identified as being of elevated importance. It is noted that this risk assessments provided are not exhaustive, but focus on the key risks that are predicted to occur as a result of climate change.

7.1 Summary of risks

The detailed risk assessment identified 49 individual risks to the built environment, across nine sectors/areas - of which most were low to medium risk in the short term, and increase to become mostly high and extreme risks in the medium to long term (Figure 7-1).

Table 7-1 summarises these risks within the nine sectors, and provides an overall risk rating over three time horizons[13]. The built environment sectors at highest risk are buildings and open spaces, and water supplies, from inland and coastal flooding, drought, fire weather and sea level rise and salinity stress. Both are rated as currently high risks, and extreme risks at 2040 and 2090. Additionally, risks to transport, solid waste and flood management schemes are rated as extreme at 2040 and 2090 from similar climate change hazards.

Summary sectoral risks to the built environment are presented at a sub-regional level within Figure 7-2.

[13] The risk rating for each sector corresponds to the highest risk rating from the detailed individual risk assessment within each sector.

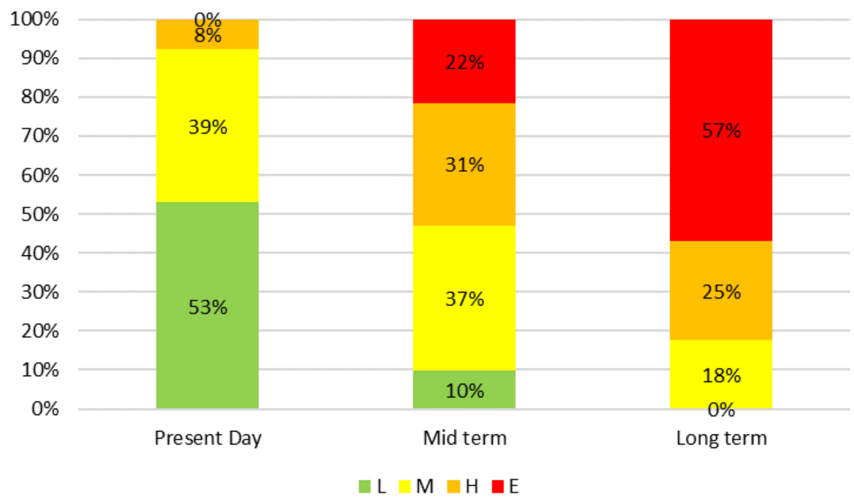

Figure 7-1. Summary of built environment risks by risk rating.

Table 7-1: Summary of risks in the built environment domain

Risks		Risk Rating* (highest per category)		
		Present	2040	2090
B1	Risk to buildings and open spaces from climate change hazards including inland and coastal flooding, coastal erosion, sea level rise and salinity stress, and wildfire.	H	E	E
B2	Risk to flood management schemes from inland and coastal flooding, and sea level rise and salinity stress.	M	E	E
B3	Risk to water supply infrastructure and irrigation systems due to drought, fire weather, flooding and sea level rise and salinity stress.	H	E	E
B4	Risk to stormwater and wastewater networks from increased temperature, sea level rise and salinity stress, extreme weather events and flooding.	H	H	E
B5	Risks to linear transport (roads and rail) from flooding, coastal erosion, extreme weather events and landslides.	M	E	E
B6	Risk to airports and ports from flooding and extreme weather events.	M	E	E
B7	Risk to solid waste (landfills and contaminated sites) to flooding and sea level rise and salinity stress.	M	E	E
B8	Risks to electricity (generation, transmission and distribution) networks from changes in rainfall, extreme weather events and flooding.	M	H	E
B9	Risks to telecommunications infrastructure due to sea level rise and salinity stress and extreme weather events.	L	M	H

* Highest risk rating per category and hazard relationship highlighted. Refer individual risk discussions for detailed ratings.

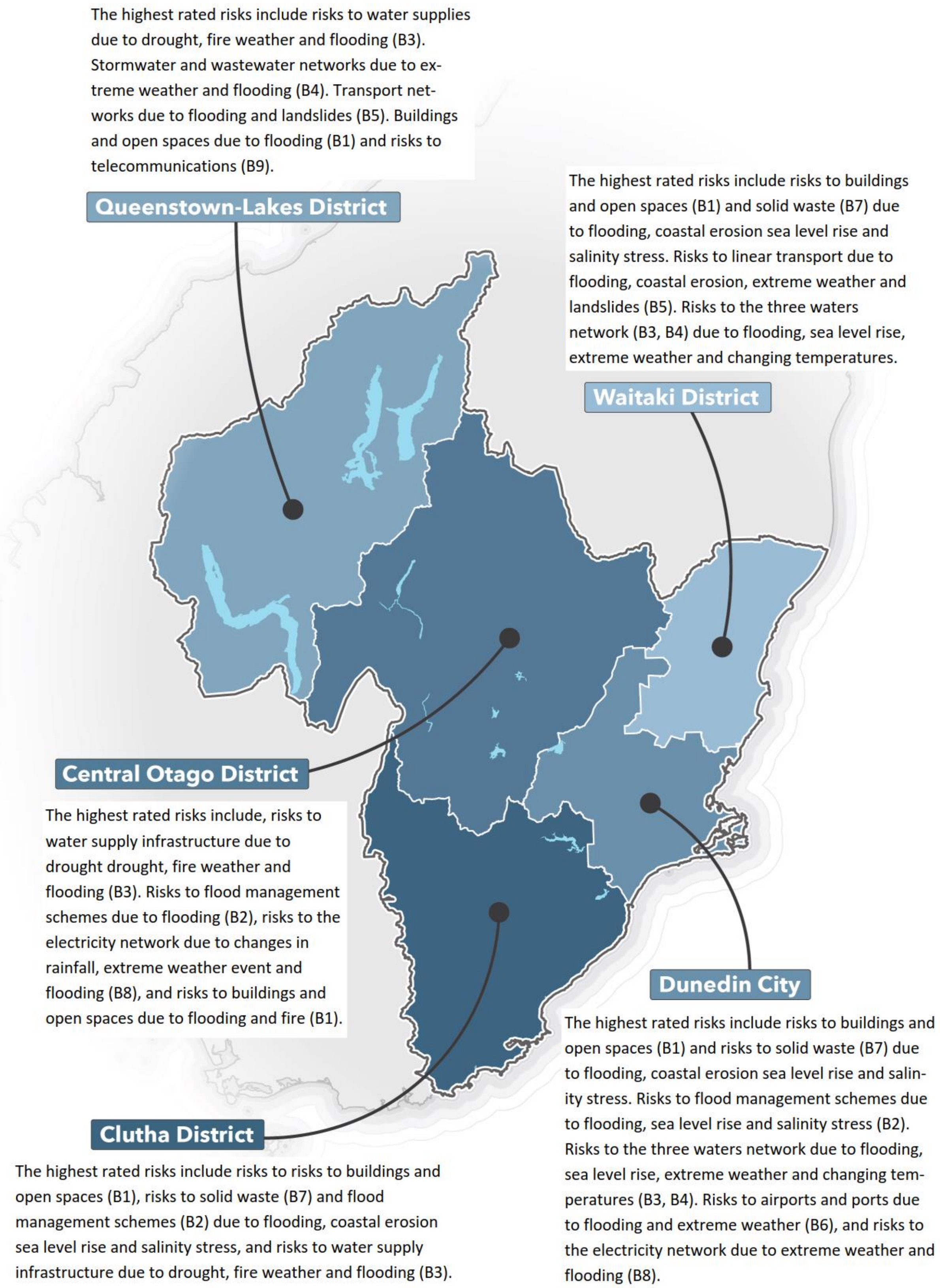

Figure 7-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the built domain.

7.2 B1: Risks to buildings and open spaces from climate change hazards including inland and coastal flooding, coastal erosion, sea level rise and salinity stress, and wildfire

7.2.1 Introduction

Buildings and open spaces are a category within the Built Environment Domain that includes urban and rural housing, commercial and public buildings, heritage buildings and public open spaces (including parks, reserves and cemeteries). Building impacts are directly linked with community impacts, and as such this risk should be read in conjunction with those identified within Section 4. Those communities with existing social and economic vulnerabilities have potential to suffer more severe consequences as a result of impacts to their immediate built environment.

There are greater than 14,000 hectares of land classified as urban within the Otago region equating to less than 1% of the total land cover in the region (Land Air Water Aotearoa, 2012). Within that urban area there are approximately 100,000 private dwellings (Statistics New Zealand, 2020).

The Otago region's housing stock is largely made up of wooden and masonry houses, and has an average age of approximately 50 years (Uma et al., 2008; Buckett et al., 2011).

There are a significant number of parks and reserves available for public use in the Otago Region. They are used for recreation, playgrounds, sports grounds and sometimes contain community facilities, all of which contribute to the community's social, environmental, and economic wellbeing. There are also approximately 80 cemeteries (excluding urupā) located within urban and rural areas in the Otago region[14].

7.2.2 Exposure

Throughout the region, buildings and open spaces are presently exposed to gradual climatic changes such as coastal erosion and sea level rise, and associated hazards such as flooding and landslides. Wildfire is also a hazard that is expected to exacerbate with climate change (MfE, 2018).

Rural and urban housing in coastal and low-lying areas such as the South Dunedin plain[15], Harbourside, Balclutha, Waitati, Aramoana, and Kakanui are exposed to sea level rise and associated coastal flooding due to their proximity to the coast and low elevations. A number of areas are exposed to inland flooding, including those communities on the Taieri Plains (including Mosgiel), Milton, South Dunedin, North Dunedin (Lindsay Creek), Karitane and communities adjacent to rivers and lakes in the Queenstown Lakes district (including Wanaka, Queenstown, Kingston and Glenorchy).

Commercial buildings exposed to either coastal or inland flooding include areas such as Queenstown Central Business District (CBD), Wanaka CBD and the Harbourside area in Dunedin (Queenstown Lakes District Council, 2020f; Dunedin City Council, 2020a).

Areas exposed to coastal erosion include St Kilda, St Clair, Clutha Delta, Moeraki, and Oamaru and Karitane. Rain induced landslides are a known issue in the region, however exposure is not well understood. Areas of known land instability exist throughout the region, with current examples in the Dunedin City and Queenstown Lakes district.

There are approximately 5,650 buildings currently exposed to coastal flooding in the Otago region (Paulik et al., 2019a). When looking at the mid-term (2040) timeframe, with 0.3 m sea level rise, the

[14] Sourced from relevant district council websites.
[15] The South Dunedin plain (referred to as South Dunedin) refers to the low-lying area between the Otago Harbour upper basin and the Pacific Ocean. This includes suburbs of Tainui and Musselburgh and parts of St Kilda and South Dunedin, Caversham, Forbury and St Clair (Goldsmith et al., 2016).

number of buildings exposed increases by 10% to approximately 6,240 buildings (Paulik et al., 2019a). Figure 7-3 presents the district breakdown of building exposure in Otago and shows that around 80% of buildings exposed are located within Dunedin City. Relative to residential buildings, commercial and public buildings represent a smaller proportion of the building stock exposed to coastal flooding and erosion in Otago, rural and urban housing represent the larger proportion of buildings exposed to coastal flooding and erosion (Stakeholder Engagement, 2020).

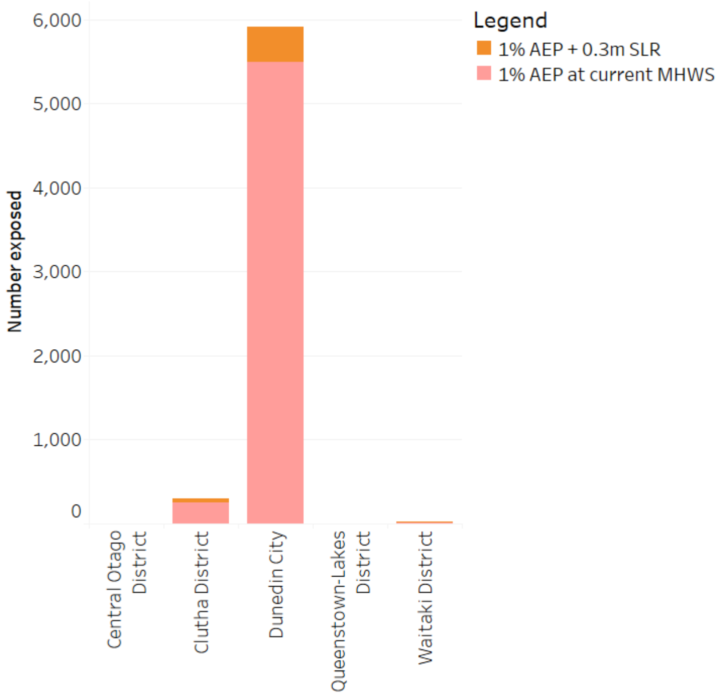

Figure 7-3: Building exposure to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

When considering exposure to inland flooding, there are over 21,500 residential and commercial buildings estimated to be exposed in the Otago region (Paulik et al., 2019). Figure 7-4 presents the district breakdown of building exposure to flooding. Similarly to coastal flooding, 75% of the buildings are located in the Dunedin City district.

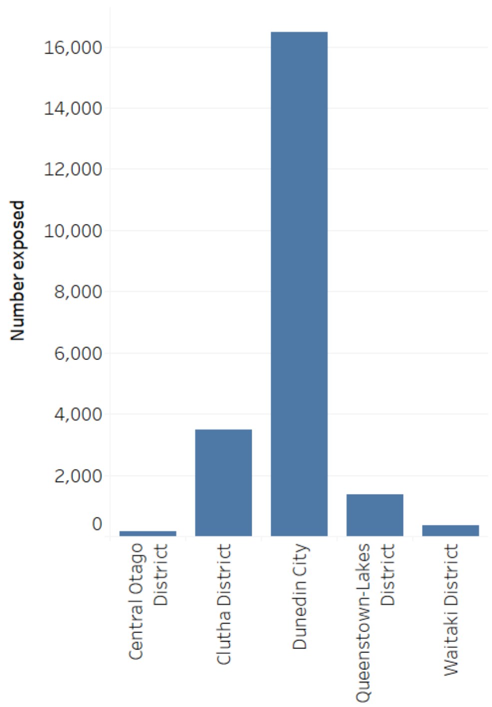

Figure 7-4: Building exposure to flooding, per district (Paulik et al., 2019).

Paulik et al, (2019a) identified approximately 50 km^2 of "natural or undeveloped land"[16] which is currently exposed to coastal flooding in the Otago region. Of this, over 75% is located in the Clutha district. When looking at the mid-term (2040) timeframe, with 0.3m sea level rise this number was shown to slightly increase to approximately 55 km^2. Figure 7-5 presents the exposure of "natural or undeveloped land" to current and future coastal flooding scenarios per district, with the highest exposure within the Clutha District.

[16] It is assumed this includes parks, reserves, cemeteries, open space etc. No further exposure information is publicly available.

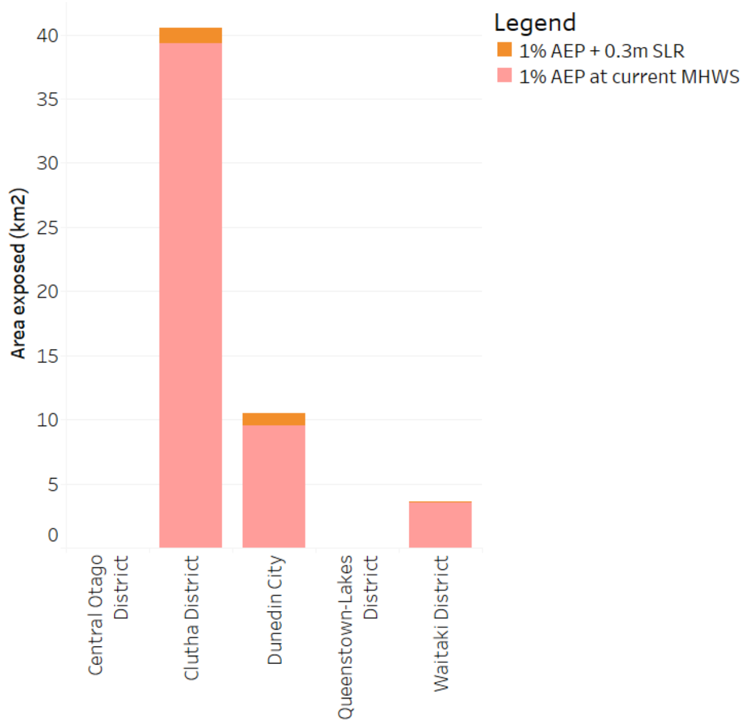

Figure 7-5: Exposure of undeveloped land to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

In regards to inland flooding Paulik et al. (2019) identified that when considering current exposure to inland flooding in the Otago region, there is approximately 20 km^2 of "natural or undeveloped land" exposed, of which approximately 70% is exposed in the Dunedin City district (Paulik et al., 2019). Figure 7-6 presents a district breakdown of the exposure of natural, undeveloped land to flooding. It shows that there is considerable flooding exposure in all districts except Central Otago.

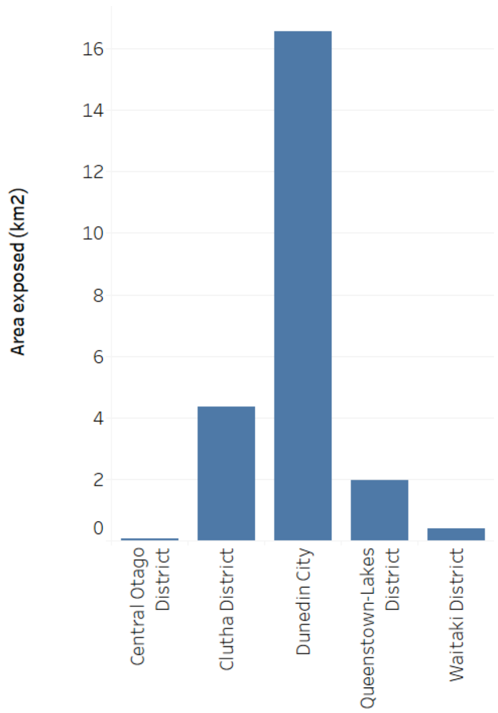

Figure 7-6: Exposure of undeveloped land to flooding, per district (Paulik et al., 2019).

Of particular relevance is the exposure of cemeteries and urupā to coastal and inland flooding, and groundwater rise. While this is currently poorly understood, low lying cemeteries / urupā exist throughout Otago, including within Dunedin City (Aramoana and Purakaunui) and Waitaki district (Moeraki).

Shallow groundwater is a significant issue in parts of Otago, particularly within South Dunedin where there are approximately 4,800 occupied dwellings (Goldsmith et al., 2016). The South Dunedin coastal aquifer is a shallow groundwater table beneath the South Dunedin plain. South Dunedin groundwater levels rise during periods of heavy rainfall (Goldsmith et al., 2016), and in locations where the groundwater table is connected to the sea, the groundwater table will rise with rea level rise (Willis, 2014). Therefore, increased rainfall and sea level rise may lead to an increase of the median annual groundwater levels. This will, in time, result in permanent / intermittent surface ponding on parts of South Dunedin. Higher groundwater levels would mean that surface ponding in response to rainfall or elevated sea levels would occur more frequently (Goldsmith et al., 2016).

A number of heritage sites, heritage buildings and New Zealand Archaeological Association sites are known to be at risk. This is discussed in Section 4.4.1.

In terms of exposure to wildfire, the 2020 fires in Lake Ohau served as a reminder of the potential exposure and impact that fire can have on the built environment. The increasing growth in population being experienced in locations such as Central Otago and Queenstown Lakes will continue to result in the expansion of the built environment interface with the natural environment. This results in an elevation in fire risk posed by this increased human activity in the natural environment that, that exacerbates the future risk resulting from climate change. Note linkages of this risk to B8 (risks to electricity transmission and distribution), E3 (risks to the forestry sector) and N1 (risks to terrestrial ecosystems).

7.2.3 Vulnerability

Vulnerability of buildings will relate to specific building characteristics, and is discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Sensitivity of buildings is influenced by design, age and condition. Building age is directly related to building condition and therefore can give an indication of sensitivity to damage (Buckett et al., 2011). Generally, older buildings have a higher sensitivity to damage due to poor maintenance and repair and the upgrade of building performance requirements (Jacques et al., 2015).

The level of damage floods cause to buildings depends on a number of factors, the most important of which are the flood characteristics (water depth, water velocity, inundation duration), building location, and the building characteristics (including type of structure, and material) (Reese and Ramsay, 2010). Sewage contamination associated with flooding contributes significantly to building damage costs and can influence habitability and future use of buildings (Stakeholder Engagement, 2020). Groundwater rise could also impact on buildings, which would lead to the risk of rising dampness and impaired stormwater drainage (Tauranga City Council, 2020).

The Otago region’s housing stock is largely made up of ageing wooden and masonry houses, and those with reinforced concrete frames, (Uma et al., 2008; Buckett et al., 2011). Heavy rainfall, coastal and inland flooding can cause damage to wood and masonry buildings due to the swelling and damage that can occur to the plasterboard wall linings, a problem which is exacerbated with older houses or those in poor condition (Reese & Ramsay, 2010; Jacques et al., 2015).

As discussed, groundwater is a significant issue in parts of the South Dunedin plain[17]. Buildings in areas of high groundwater will likely be subject to prolonged exposure to floodwaters, with resulting higher levels of damage.

Buildings in Otago irrespective of material type are highly sensitive to landslides and coastal erosion. Those buildings located in areas sensitive to landslides have the potential to be destroyed or partially damaged (Glassey et al., 2014).

Those communities with existing social and economic vulnerabilities such as poor health and a lack of social connection can suffer more severe consequences due to the reduced capacity to recover from coastal and inland flooding events (refer to Section 4.4.2) (Stephenson et al., 2018).

Open spaces generally have a lower sensitivity to periodic/ short duration inland and coastal flooding events as they can act as a flood resilience measure (Kim et al., 2016). Prolonged inundation can lead to impacts on vegetation growth as well as salinity impacts on soils.

Adaptive capacity

Existing residential and commercial buildings inherently have a low level of adaptive capacity. Buildings are built as long-standing permanent structures and are served by complex, centralised infrastructure systems that require large capital and ongoing operational expenditures. Buildings with a concrete floor slab construction are more difficult to relocate and repair, and therefore would have lower adaptive capacity than buildings with a suspended timber floor.

For new developments, property level resilience measures could increase the capacity of buildings to adapt. The local Dunedin-based “Climate Safe House” project is a community led initiative that is educating and improving the quality and design of homes to be resilient to climate change and associated hazards such as flooding. Some adaptive measures they have outlined include placing homes on recycled piles so that they are elevated above flood levels and designing the house in a way that it can be easily transported due to sea level rise (BRCT, 2020). Additionally, the Dunedin City Council 2nd Generation District Plan (2GP) requires additional resilience measures in consideration of climate hazards. The 2GP requires, for example, housing to be relocatable if built in a coastal hazard, and minimum floor levels required by Building Control based upon predicted sea level rise, freeboard and wave run-up (Dunedin City Council, 2018).

More generally, buildings that are yet to be developed have a higher likelihood of incorporating resilience measures due to better building performance requirements and current knowledge and awareness of climate-related hazards.

The majority of open spaces in Otago are permanent features where adaptive capacity is limited. Adaptation measures such as protecting areas or raising ground levels are possible, however are likely to be difficult and costly. Creation of new areas of open space will likely be possible in some instances to compensate for land lost, for example parks and reserves. Adaptation for existing cemeteries / urupā or constructing new ones will likely be complex and further investigation into this issue will be required.

7.2.4 Discussion

The risk to buildings (B1.1, B1.2, B1.3, B1.4, B1.5, B1.6, B1.7, B1.8) due to climate change can result in significant economic, social and public health consequences. Severe consequences are likely to occur to people, communities and livelihoods in areas at risk from sea level rise and associated coastal and inland flooding.

[17] The broader low-lying area of urban southern Dunedin, including St Clair, Kew, South Dunedin, St Kilda, Forbury, Kensington, Tainui, Musselburgh and Caversham.

Direct consequences to buildings from coastal and inland flooding include building damage, reduced living space, forced evacuation, and increased dampness and reduced accessibility. These can then lead to cascading implications such as financial and personal distress, social deprivation, public health concerns and a loss of community (Stephenson et al., 2018). Additionally, the devaluation of land and insurance retreat can occur due to repeat events causing personal, financial and economic stress. An example of this occurred in the 2015 South Dunedin floods which gave rise to over $28 million in insurance claims. Households were unable to return to their dwellings due to damage which caused significant financial and personal distress (refer to risk H3, Section 4.4.3) (Stephenson et al., 2018). These consequences are likely to be experienced more frequently due to climate change in areas exposed to coastal and inland flooding.

Landslides and coastal erosion can lead to significant consequences (B1.5), such as building damage/ destruction - which can in turn, lead to severe social and economic consequences (Glassey et al., 2014). Loss of property due to destruction can also cause significant personal and economic distress (Stephenson et al., 2018). Economic losses from landslide events are increasing due to more development occurring on land prone to landslides (Petley et al., 2005). Consequences as a result of landslides are likely to become more frequent with the projected increases in rainfall and rainfall induced landslides.

As with the rest of New Zealand, buildings and open spaces within the Otago region face risks from both extreme and ongoing climatic changes (B1.9, B1.10). Table 7-2 presents the current and future risks to buildings and open spaces to each of the climatic changes and hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that the higher risks are risk to urban and rural housing from inland flooding and coastal flooding (B1.1, B1.2). Both of these are rated as extreme risks at 2090. Risks to commercial and public buildings due to inland flooding (B1.6) is rated as a high risk in 2040, moving to extreme in 2090; and risk to urban and rural housing due to coastal erosion (B1.2) is extreme in 2040 and 2090.

Table 7-2: Summary risk rating for buildings and open spaces

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B1.1	Risk to urban and rural housing due to inland flooding.	M	H	E	H	H	H	L	H	E	E
B1.2	Risk to urban and rural housing due to increasing coastal erosion.	M	M	H	M	H	H	L	M	H	E
B1.3	Risk to urban and rural housing due to sea level rise and salinity stress.	L	M	H	M	H	H	M	L	M	H
B1.4	Risk to urban and rural housing due to coastal flooding.	L	H	E	H	H	H	L	M	E	E
B1.5	Risk to urban and rural housing due to increasing landslides and soil erosion.	L	M	M	L	M	M	L	L	M	M
B1.6	Risk to commercial and public buildings due to inland flooding.	M	H	E	M	M	H	L	M	H	E
B1.7	Risk to commercial and public buildings due to coastal flooding.	L	M	M	M	M	H	L	L	M	H
B1.8	Risk to commercial and public buildings due to increasing coastal erosion.	L	M	M	L	M	M	L	L	M	M
B1.9	Risk to public open spaces (parks, reserves, cemeteries) due to inland flooding.	L	M	H	L	M	M	L	L	M	H
B1.10	Risk to public open spaces (parks, reserves, cemeteries) due to increasing coastal erosion.	L	M	M	L	M	M	M	L	M	M

7.3 B2: Risks to flood management schemes from climate change hazards including inland and coastal flooding, and sea level rise and salinity stress

7.3.1 Introduction

Otago Regional Council (ORC) operates an extensive system of flood control measures throughout the lower plains of the region. These have been developed through the construction of defences against water using stopbanks, scheduled drainage channels, overland flow paths, floodways groynes and planting. The most extensive of these schemes relate to the management of water levels in the Taieri Plain and the areas surrounding the lower Clutha River. Other schemes include; the Leith flood protection scheme, the Alexandra flood protection scheme and the Tokomairiro drainage scheme[18].

The Lower Taieri Flood Protection Scheme and East and West Taieri Drainage schemes are located on the Taieri Plains southwest of Dunedin. They have a combination of stopbanks (approximately 110 km in length), flood ponding areas and flood ways and also relies on pump stations and a series of drains to remove runoff and floodwater (Tonkin & Taylor Ltd, 2018; Stakeholder Engagement, 2020, O'Sullivan, 2013). The schemes have been constructed and upgraded in various stages since the late 19th century and provide land drainage and protection from flooding of the Taieri river and other tributaries (Tonkin & Taylor Ltd, 2018).

The Lower Clutha Flood Protection and Drainage Scheme is located on the Clutha delta around and downstream of Balclutha. It is primarily a series of stopbanks that assist the passage of floodwater across the Clutha Delta to the Pacific Ocean. It is a combination of flood control and drainage schemes, and includes open drains and pump stations. It was constructed incrementally between 1957 and 1991. It comprises over 100 km of stopbanks, 200 km of contour and drainage channels, tide-gate structures, five pumping stations, river protection works and a by-pass floodway flood way (Hornblow, 2016).

The Alexandra Flood Protection Scheme is a short section of stopbank (approximately 1.5 km) that provides flood defence to the township from the Clutha River. The scheme was constructed following the 1999 flood (Tonkin & Taylor Ltd, 2018, Otago Regional Council, 2012).

The Leith Flood Protection Scheme is located along the Water of Leith in suburban and central Dunedin City. Due to the steep catchment and heavy rain that can occur in the district, the stream can quickly inundate the lower reaches, posing a flood risk to parts of the city and its inhabitants (Otago Regional Council, 2018). The scheme provides flood protection along roughly 10 km of the Water of Leith (Otago Regional Council, 2012). The Leith Flood Protection Scheme has been recently upgraded to allow for improved flood protection.

The Tokomairiro Drainage Scheme includes a network of drains and floodways that assist drainage to the Tokomairiro River as it passes through Milton and the Tokomairiro Plain (Otago Regional Council, Clutha District Council, n.d).

These flood protection and drainage schemes all have varying design standards and estimated levels of protection. The Lower Taieri Flood Protection scheme provides protection up to approximately the 1 in 100 year event (current[19]) from the Taieri River and is of critical importance due to the close proximity of the Dunedin International Airport to the river (Stakeholder Engagement, 2020).

[18] For further information on ORC flood schemes, refer https://www.orc.govt.nz/managing-our-environment/natural-hazards/flooding; https://www.orc.govt.nz/media/1722/flood-hazard-on-the-taieri-plain.pdf; https://www.orc.govt.nz/media/2202/natural-hazards-on-the-clutha-delta.pdf; https://www.orc.govt.nz/media/3796/milton-2060-strategy.pdf.

[19] Note that return periods have not been adjusted for climate change.

The design standard for the Lower Clutha flood protection and drainage scheme is not based on a particular event but rather related to flows. For the Balclutha township and the Finegand Freezing Works, the design is based off the estimated peak of the 1878 flood at around 5,600 cumecs (slightly less than the currently assessed 1 in 200 year return period flow), whilst the rural parts of the scheme have a lower standard of protection at approximately 4,000 cumecs (1 in 40 year return period flood) (Stakeholder Engagement, 2020).

The Leith flood protection scheme provides protection up to approximately the 1 in 100 year event at the time of design (2006) and has never breached or overtopped since its construction (Stakeholder Engagement, 2020).

7.3.2 Exposure

Flood protection and drainage schemes in the Otago region are currently exposed to event-based climate-related hazards such as inland and coastal flooding and gradual climatic changes such as sea level rise and salinity stress. Flood management schemes in the Clutha and Taieri areas are likely to have an increased exposure to coastal and inland flooding given their locations and proximity to coastal areas.

Spatial and temporal changes in extreme rainfall events have been analysed using rainfall records from the lower Taieri catchment. These records show that there is localised variability in extreme rainfall patterns, and that the northern end of the Taieri Plains (including the Silver Stream catchment) has experienced an increase in intensity and frequency of extreme rainfall events since the 1960s (O'Sullivan et al., 2013). This will likely place more pressure on this part of the scheme.

The Lower Clutha Scheme is currently exposed to inland and coastal flooding and is likely to have increased exposure with the projected increases in precipitation and sea levels in the area. A significant portion of the land in the Lower Clutha delta currently sits < 0.5 m above mean sea level, therefore continuous pumping could be required in order to remain dry by approximately the 2050s (Hornblow et al., 2016). Coastal stopbanks and the other flood protection and drainage schemes infrastructures are also becoming increasingly exposed to storm events and coast line retreat (Hornblow et al., 2016).

The Lower Clutha flood protection and drainage scheme has an increased exposure to coastal flooding and sea level rise at the lower end of the scheme, whilst the Taieri is tidal so has an increased exposure to sea level rise (Stakeholder Engagement, 2020). Only a smaller section of the Leith flood protection scheme is exposed to sea level rise, which is that part near the outlet (Stakeholder Engagement, 2020).

7.3.3 Vulnerability

Vulnerability of flood protection and drainage schemes will relate to specific design and capacity parameters, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Flood protection and drainage schemes are sensitive to climate change impacts due to their design and condition (Tonkin & Taylor Ltd, 2018). Those flood protection schemes that are older and are in poorer condition have a greater sensitivity to climate change and an increased likelihood of damage due to scour or breach (Environment Agency, 2006).

Flood protection schemes are sensitive to flooding events due to the excessive sediment deposition, scour and blockages that can occur, undermining the integrity of the assets (Environment Agency, 2006). Areas where there is excessive vegetation growth and stock damage can also have a greater sensitivity to flooding events due to the reduced stability and condition of the stopbank (Tonkin &

Taylor Ltd, 2018). In particular, land instability in the upstream reaches of the Taiere River are identified as a source of sediment for the downstream reaches (Goldsmith et al., 2015).

Residual risk of failure is present for all stopbanks, where the risk of failure before the design capacity is reached is present. Issues related to poor condition such as instability, scour and erosion contribute to residual risk, which is heightened by the stress that climate change applies, such as increased annual rainfall, rainfall intensity and groundwater changes (Hughes et al., 2019). The residual risk of failure is identified for the Taieri Flood Protection Scheme (Goldsmith et al., 2015) and erosion and scour are identified as a potential mechanism for failure of the Clutha Flood Protection Scheme (Hornblow et al., 2016).

Those flood protection and drainage schemes that have tidal influences such as the Lower Taieri and Clutha are likely to have a greater sensitivity to sea level rise due to the lack of drainage capacity that will occur with increases in sea levels and groundwater levels (Stakeholder Engagement, 2020). Pump stations and outfall structures in the Lower Clutha delta have an increased sensitivity to sea level rise due to the reduced efficiencies that can occur due to an imbalance of flow and head. (Hornblow et al., 2016).

The June 1980 and July 2017 floods in Otago caused significant impacts not only to the Lower Taieri flood scheme infrastructure but had cascading impacts on the community and economy as well. Figure 7-7 illustrates the flooding extent in the West Taieri area in the 1980 flood. This area relies on the Lower Taieri stopbanks to prevent inundation on a day-to-day basis due to the elevation of the area being below current high-tide levels (Goldsmith et al., 2015). During this flood, the airport was completely inundated which caused significant social and economic disruptions due to the closure of the airport for 53 days (O'Sullivan et al., 2013).

Figure 7-7: Flooding on the West Taieri, following the June 1980 flood event (Goldsmith et al., 2015).

Flooding on the Clutha delta and failure of the flood scheme can cause significant economic impacts to the main areas of industry in Balclutha which include; the Silver Ferns Meat Processing Plant, Fonterra cheese factory and the Kaitangata coal mining facilities (Hornblow et al., 2016). These facilities are all located within close proximities to the Koau and Matau branches which are known to overtop (see Figure 7-8). The November 1999 flood on the Lower Clutha delta completely inundated the Balclutha aerodrome and partially inundated the South Island Main Trunk railway, and previous flooding (in 1978) caused widespread building damages, agricultural losses and damage to bridges, roads and related infrastructure (Hornblow et al., 2016).

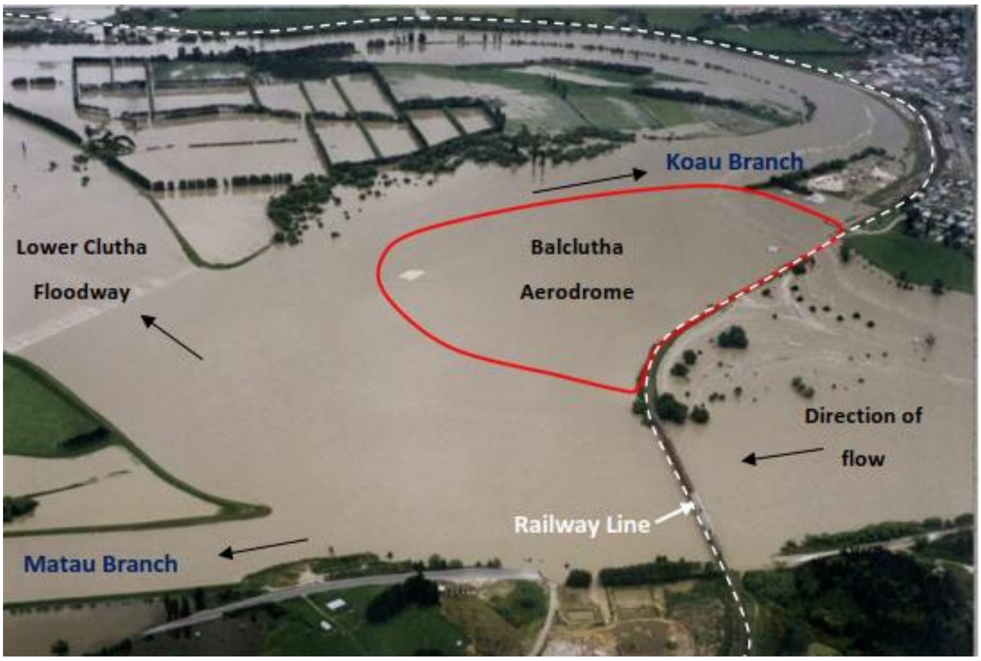

Figure 7-8: South Island Main Trunk railway (white dashed) and Balclutha Aerodrome (red) during the November 1999 flood (Hornblow et al., 2016).

Adaptive capacity

Adaptive capacity of flood management schemes in Otago is generally limited due to the affordability issues that arise with upgrading systems (Stakeholder Engagement, 2020). Moving or raising stopbanks are actions that can be considered to increase the adaptive capacity of flood management schemes in Otago, but may not be sustainable long-term solutions. These actions require significant funding and are not always feasible.

7.3.4 Discussion

Flood protection and drainage schemes in the Otago region are significant pieces of infrastructure that protect high value farmland, critical assets such as the Dunedin International Airport, State Highways and densely populated urban areas such as Balclutha, Mosgiel and Dunedin (Castalia Strategic Advisors, 2016). Significant impacts can occur if these schemes fail, which can cause severe social and economic consequences.

Sea level rise and coastal flooding can reduce drainage capacity and potentially damage stopbanks and roads (B2.3, B2.4) (O'Sullivan et al., 2013). Increases in sea levels and shoreline erosion can also cause the buffer between open ocean and stopbanks to become smaller (Hornblow et al., 2016). This can cause additional flooding and drainage impacts for the Lower Clutha flood protection and drainage scheme and can influence the performance of the stopbanks in coastal flooding events (Hornblow et al., 2016).

Increased frequency and intensity of floods can cause excessive ponding in low lying areas (B2.1) (e.g. West Taieri) which can have an impact on farms and livestock, with pastures being destroyed and left unusable and stock being forced to shift to higher ground (Stakeholder Engagement, 2020). This can cause economic and financial stress for farmers and the broader agricultural sector in the Otago region. Excessive run off from farms can also occur due to flooding which can carry contaminants into drains and pump stations impacting the water quality and efficiency of the pump stations (Stakeholder Engagement, 2020).

Damage and failure of the flood management assets can cause significant social and economic consequences such as loss of life, impaired health, loss of land or output on farms and businesses and damage to non-commercial property. Additionally, road and rail access can be reduced, disconnecting communities from critical supplies (Castalia Strategic Advisors, 2016).

Table 7-3 outlines the risks to the flood management schemes in Otago to inland and coastal flooding and sea level rise.

Table 7-3: Summary risk rating for flood management schemes

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B2.1	Risk to stopbanks and river flood management schemes due to inland flooding.	M	H	E	M	H	E	L	M	E	E
B2.2	Risk to stopbanks and river flood management schemes due to sea level rise and salinity stress.	M	H	E	L	M	H	L	M	H	E
B2.3	Risk to coastal protection structures due to coastal flooding.	M	H	E	M	H	E	L	M	E	E
B2.4	Risk to rural land drainage due to sea level rise and salinity stress.	M	H	H	L	M	M	M	M	H	E

7.4 B3: Risks to water supply infrastructure and irrigation from climate change hazards including drought, fire weather, flooding and sea level rise and salinity stress

7.4.1 Introduction

All communities and businesses within the Otago region rely on safe, secure and affordable water supply. Water supply varies throughout the region with water being sourced from both groundwater and surface water, as well as a range of urban and rural properties collecting rainwater via storage tanks.

Central Otago District Council has a total of eight municipal water supplies, serving a population of approximately 13,500. The three water supplies that serve the most people, both during normal and peak seasons, are the “Alexandra”, “Clyde” and “Cromwell, Bannockburn, Pisa, Lowburn and Ripponvale” water supplies. These water supplies are sourced mainly from shallow groundwater, which in many cases is hydraulically connected to surface water rivers – where water is drawn through river gravels. (Central Otago District Council, 2020c).

Dunedin City Council supplies water from a number of sources, including Deep Creek and Deep Stream in the Taieri River catchment, to a population of approximately 115,000 across urban Dunedin and outlying areas (Dunedin City Council, 2020d; Stakeholder Engagement, 2020).

Queenstown Lakes District Council has a total of eight water supplies, serving a population of approximately 25,000 (Queenstown Lakes District Council, 2020c). Of these water supplies, two abstract water from surface water and the remainder from groundwater (Horrell, 2019).

Waitaki District Council has a total of 15 water supplies, serving 95% of the population (Waitaki District Council, 2020), of which the majority are from surface water supplies (Tonkin & Taylor Ltd., 2005).

Clutha District Council has a total of 22 water supplies, serving a population of approximately 18,300. The majority are surface water sources, with only two being from groundwater. Approximately 30% of the water abstracted is used for domestic consumption whilst the balance is largely used for stock water (Clutha District Council, Water and Sewerage, 2020a).

Along with water supplies to communities, the supply of water for irrigation purposes in the primary sector (including pastoral farming, horticulture and viticulture) comprises a large part of the water use in the Otago region.

Irrigation in the Otago region finds it origins in the gold mining days of the 1860’s and 1870’s. During that era, many mining privileges were issued, authorising the taking of water from tributaries of the Clutha River/Mata-Au and Taieri River.

Mining privileges were licences issued under the Mining Act 1926, subsequent amendments, and previous Acts for water races, drainage races, by-washes and dams[20]. Initially, mining privileges were issued to take water for the purpose of gold mining. However, as the gold rush came to an end at the end of the 19th century the mining privileges became increasingly important for agricultural irrigation. Nowadays, mining privileges are supporting irrigation as well as a variety of other uses, including stock drinking water, domestic water supplies and hydro-electricity generation.

The taking of water under a deemed permit does not allow for effective management of the environmental impacts of that take. This is because deemed permits are not subject to the review clauses under sections 128 to 133 of the RMA and Council has no ability to restrict the ability of the

[20] Statutes include the Gold Fields Act 1862, Gold Fields Act 1866, Public Works Act 1876, Mining Act 1891, Mining Act 1926.

deemed permit holder where environmental effects are occurring as a result of that take, for example through the setting of minimum flow or residual flow conditions. This is particularly problematic in instances where deemed permits authorise the taking of more water than the quantity of water that is naturally provided by the source water body.

With the enactment of the RMA in 1991, all mining privileges were deemed, under s413 of the Act, to be a water permit (for the take or damming of water), or a discharge permit (for the discharge of water or contaminants) on the same terms and conditions as the original mining privilege. As provided by s413(3) of the RMA, deemed permits will expire on 1 October 2021, the thirtieth anniversary of the date of commencement of the RMA.

The RMA allows for deemed permit holders to apply for a resource consent that authorised the continued taking of water. ORC is currently in the process of developing an new Land and Water that will establish a freshwater management regime that ensures that the future taking of water under resource consent will look after the health and well-being of freshwater and associated freshwater ecosystems.

At the start of 2021, there were approximately 1,660 water permits, including 331 deemed permits that authorised the take of freshwater in Otago. The vast majority of these current water permits (1180) provide for the taking of water to supply Otago's irrigated land, which was estimated to be 93,080 hectares in 2018[21].

A large number of water permits are currently located within the Taieri and Manuherekia catchments, where they supply for water takes that supply irrigation schemes (Skelton, 2019). Other irrigation schemes that take water from the Waitaki Catchment, include the Waitaki Irrigators Collective (WIC) which takes water from Lake Waitaki, and the Lower Waitaki River; and the North Otago Irrigation Company (NOIC) which irrigates 20,000 hectares of productive farmland across North Otago (Waitaki Irrigators Collective, 2020).

Figure 7-9 illustrates the density of water takes throughout the region, within Freshwater Management Units (FMUs) and also *Rohe* (sub-FMU) boundaries[22]. This shows high density of takes within the Clutha / Mata-Au Freshwater Management Unit (FMU) (including Manuherekia), and also around North Otago, both of which are predicted to become dryer as a result of climate change (Macara et al, 2019).

[21] Ministry for the Environment, Our land 2018 - New Zealand's Environmental Reporting Series. p55.

[22] All regional councils are required to set Freshwater Management Units (FMUs) under the Ministry for the Environment's National Policy Statement for Freshwater Management 2020. An FMU is a water body or multiple water bodies that ORC believe is the appropriate scale for managing water, including the setting of freshwater objectives and limits. This can be a river catchment, part of a catchment, or a group of catchments. Note that the boundaries of FMUs may change through the Regional Policy Statement process (as of February, 2021).

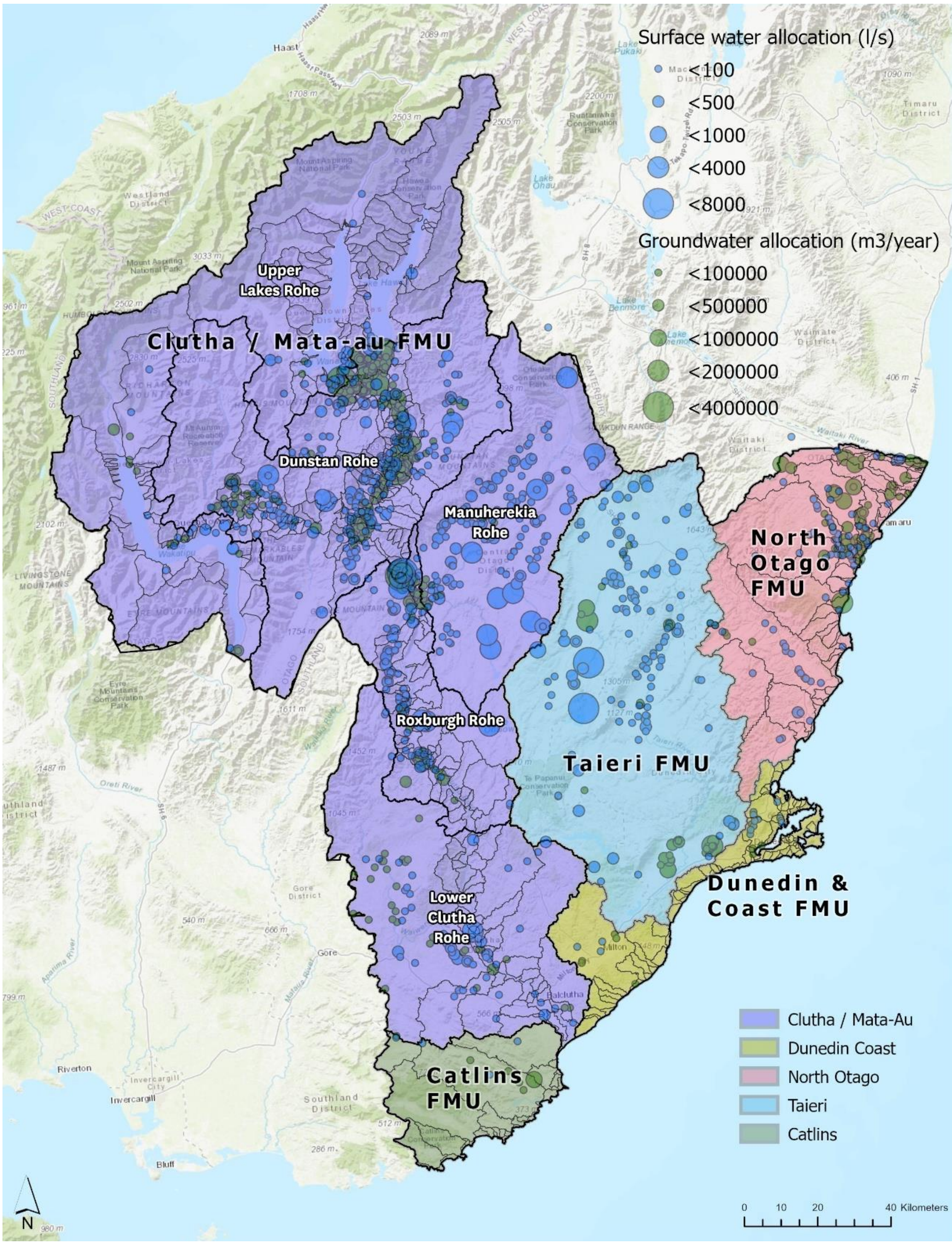

Figure 7-9: Locations of water takes within Otago (provided by ORC).

7.4.2 Exposure

Municipal and rural water supply, and irrigation systems are presently exposed to gradual climatic changes such as sea level rise and increased fire weather, and associated climate-related hazards including coastal and inland flooding and drought.

Central Otago can be one of the driest, coldest and hottest places in New Zealand and with projected increases in temperature and rainfall as a result of climate change will increase the exposure of water supplies within the region. Water supplies in areas such as the Dunstan Rohe and Taieri FMU are likely to be more exposed to increased temperatures and subsequently to drought and fire weather due to projected increases in temperature in an already semi-arid environment (Cossens, 1987; Macara et al., 2019). Exposure is projected to increase in coastal areas such as Dunedin and Lower Clutha where there is salinity stress and wider groundwater changes (Paulik et al., 2019a), increasing the pressure of water security, impacting both the availability and quality of water (Thorburn et al, 2013).

There are approximately 280 km of water supply pipes in the Otago region currently exposed to coastal flooding. Of the 280 km exposed, over 70% of them are located in the Dunedin City district (Paulik et al., 2019a). When considering the mid-term timeframe (2040), with 0.3m sea level rise, the length of pipe exposed increases to approximately 310 km exposed throughout the Otago region. Dunedin City's exposure increases by approximately 10%, associated with approximately 220 km of pipe. When considering the long-term timeframe (2090), with 0.9m sea level rise, the length of pipe exposed increases to approximately 395 km throughout the Otago region. Figure 7-10 outlines the district breakdown of water supply pipe exposure to current and future coastal flooding scenarios.

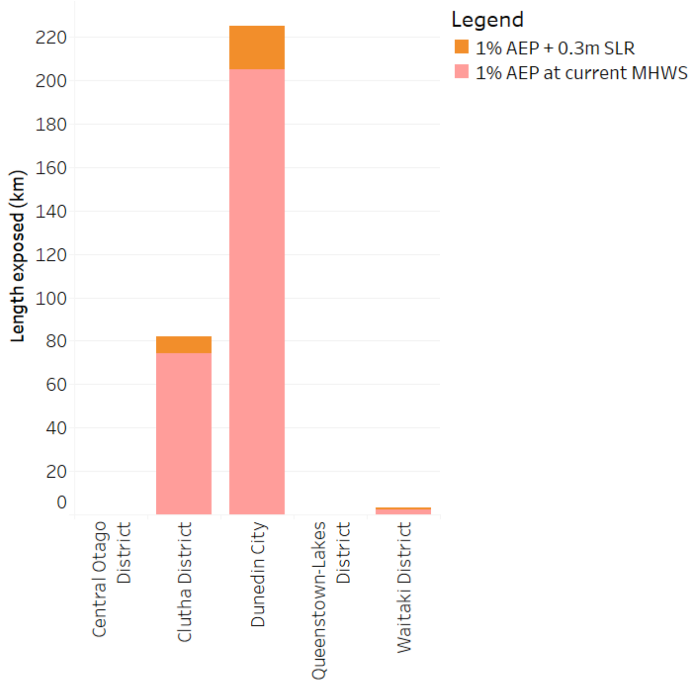

Figure 7-10: Exposure of water supply pipes to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

Currently, more than 1,000 km of water supply pipes are estimated to be potentially exposed to inland flooding in the Otago region. Of those water supply pipes exposed, approximately 65% are located within the Dunedin City district (Paulik et al., 2019). Figure 7-11 outlines the district breakdown of water supply pipes potentially exposed to flooding.

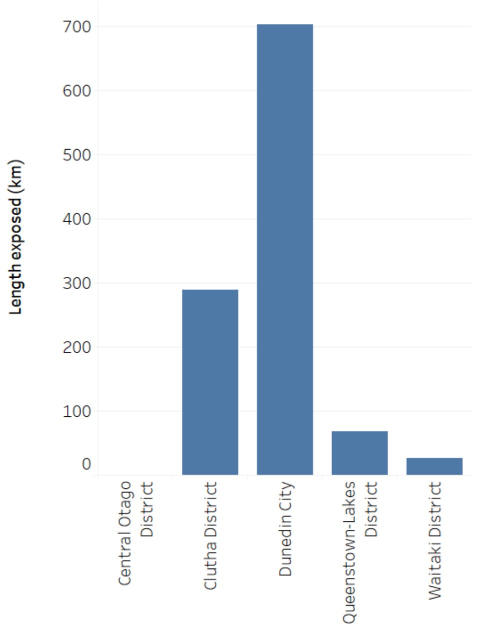

Figure 7-11: Exposure of water supply pipes to flooding, per district (Paulik et al., 2019).

When considering drought conditions across the region, and the potential implications for water supplies, this will depend on a range of factors – including projected temperature increases, rainfall changes, hydrological impacts, as well as future demand levels (and abstraction) in relation to water availability for each supply. Macara et al. (2019) present a range of findings relating to rainfall and hydrological impacts, all of which may have a bearing on drought and water availability:

- By the end of the century and with increased emissions, average annual flows are expected to increase across the region for all FMUs except in the headwaters of Taieri and North Otago. In these latter two FMUs, a large decrease in low flow is expected with time.
- Annual rainfall increases of 10-20% are projected for the majority of Otago by 2090 (under RCP8.5) with smallest increases expected near Ranfurly (0-5%). Decreases in summer rainfall of 5-10% are projected around North Otago (Ranfurly and Middlemarch) by 2090 under RCP8.5.
- Projected temperature increases are slightly higher for the inland environments than at the coast: 2.0- 3.5°C compared to 1.5-2.5°C respectively in the long-term time horizon (2100s).

It is noted that, irrigation systems have been constructed to provide water for pastures and crops in drier areas. These systems are governed by a range of regional rules that limit abstraction under drought events and it is likely that these types of events will become more frequent under climate change.

Electricity generation is driven by a combination of rainfall and snowmelt, with snowmelt providing on average 50 per cent of spring and summer inflows into New Zealand's hydro-electric storage reservoirs (McKerchar et al, 1998). Modelling has indicated little change in total yearly inflow to hydro lakes by 2050, but seasonal changes are projected for the South Island, with summer inflows reducing and winter inflows increasing (Interim Climate Change Committee, 2019). Refer also Section 7.9.

Drought and higher temperatures can lead to an increased risk of fire weather (Macara et al., 2019), which has potential to impact surface water supplies through ash and the use of fire suppressant chemicals (EPA, 2019). Areas within the region with increased exposure to fire risk include inland areas and those areas with higher degrees of vegetated catchments.

Over the past four years, water restrictions in the Otago region have been implemented at least once in the Clutha, Queenstown Lakes, and Waitaki districts (Water New Zealand, 2020). Within the Clutha district, restrictions have been implemented every year, indicating a pressure on water supplies and potentially higher sensitivity to drought and rising temperatures (refer below).

7.4.3 Vulnerability

The vulnerability of water supply infrastructure and irrigation to climate hazards will relate to specific design and capacity characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Water supply sources (availability) are influenced by both water demand and availability. These factors are exacerbated by climate change – particularly drought and temperature (Hendy et al., 2018). Water supply infrastructure (networks etc) are sensitive to climate change impacts due to their design, condition and location. For example, reinforced concrete pipes will be more sensitive to salinity effects, than pipes made from polyethylene.

Water demand generally increases during times of higher temperatures, due to increased water use for showering and for outdoor watering - which can exacerbate water shortages (Hendy et al., 2018). As seen during the 2020 drought in Auckland, water usage increased significantly, with records breaking three times in one week, with a maximum of 560 million litres used in one day (Radio New Zealand, 2020).

Climate change will increase the sensitivity of water supplies due to changes in temperature and drought and will have particular impact in parts of Central Otago and Queenstown Lakes which are predicted to experience more frequent droughts. An example is Lake Dunstan where the environment is dry, the population is increasing, and there is significant demand for abstraction. This increases the sensitivity of local water supplies to climate change impacts which may lead to future water shortages. Comparatively, in areas where there is high rainfall such as Clutha, there is reduced sensitivity due to an increased availability in supply (Stakeholder Engagement, 2020).

A significant number of towns in New Zealand do not have water meters or are only partially metered. This makes managing water demand in these towns difficult as leakage or excessive use cannot easily be detected (Water New Zealand, 2018). The water supply network in the Otago region has limited residential metering in all districts except Central Otago (Water New Zealand, 2020). As a result, managing water demand in other districts will be difficult and will potentially be exacerbated during more severe future drought conditions.

Figure 7-12 outlines the average daily residential water use from 2017-2019 (litres/person/day) for the five districts within the Otago region and the percentage of residential connections with meters. It shows that the Queenstown Lakes, Waitaki and Central Otago districts exceed the national average daily usage (approximately 280 litres/person/day), with Queenstown Lakes having double the per capita water usage than Clutha (Water New Zealand, 2020). Note, no additional breakdown was available which would provide further insight into these usage levels – for example, by season, or whether the levels included leakage or not.

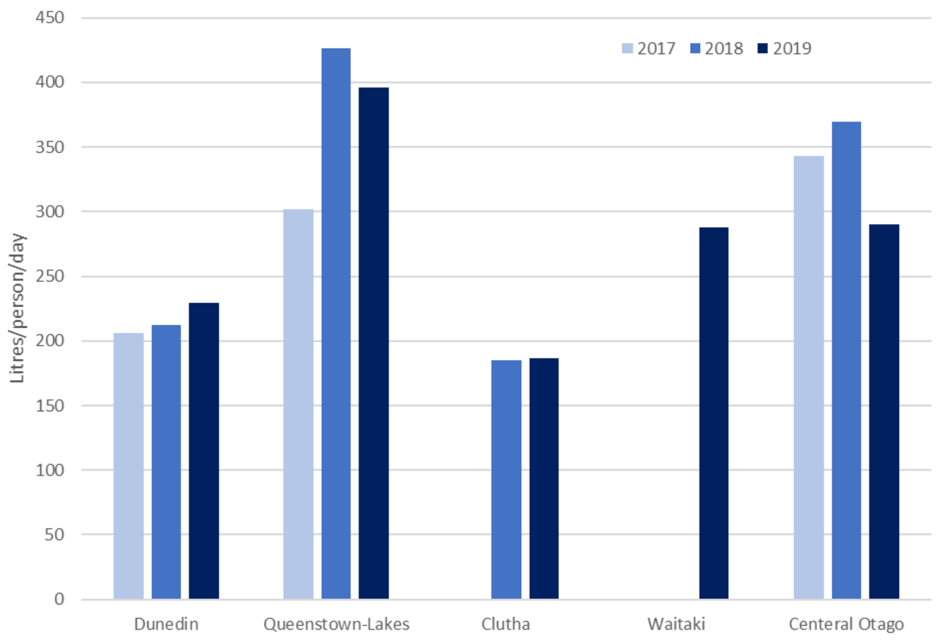

Figure 7-12: Average daily residential water usage for 2017-2019 in the five districts of the Otago region (Water New Zealand, 2020). Based on available data.

Increased precipitation and the intensity and frequency of flooding events can increase the sensitivity of water supply networks, as a result of increased contaminants (from both urban and rural sources), leading to degradation of water quality (Hughes et al, 2019).

Water supply networks are generally more sensitive where there is only a single source of water supply. Most districts within the Otago region do not rely solely on one source of water supply therefore sensitivity is reduced[23]. Rural water supplies are generally more sensitive to climate change impacts, especially where reticulated systems are absent or limited (Woodward & Hales, 2001).

Recent droughts in Otago include the 2018 drought, which resulted in a declaration of a medium-scale adverse event for Queenstown Lakes, Central Otago and Clutha Districts. This event led to significant water shortages and water restrictions being imposed in a number of communities (New Zealand Government, 2018). Extreme weather events can also lead to water supply contamination, as experienced in Oamaru in late 2018, where heavy rainfall caused an influx of contaminants and sediment into the Waitaki River - leading to severe water restrictions for a number of days.

It is noted that municipal water reductions are generally staged, with initial restrictions placed on public outdoor use (public parks, sports fields), followed by private outdoor use (gardens), and finally more restrictive measures targeted at residential and commercial use. The increasing levels of restriction will have corresponding levels of consequences for community health and wellbeing, and for business operations. For other surface and groundwater takes (for example for irrigation), restrictions need to be set to maintain the ecosystem health of the source water bodies. This will be regulated under Otago's new Land and Water Regional Plan, in line with the Te Mana O Te Wai principle that needs to be applied in freshwater management under the National Policy Statement for Freshwater Management (NPSFM).

Aquatic pests and algal blooms are a known issue within a number of lakes and rivers throughout the Otago region (ORC, 2020c). A key algae of concern which is affecting water supplies is called Lake Snow or Lindavia intermedia (Schallenberg & Novis, 2018). A projected increase in mean

[23] Sourced from relevant district councils.

temperatures and number of hot days is known to produce conditions that favour the growth of a number of pests and algal species (Robertson et al., 2016). Water supply systems located within areas where algal blooms occur are likely to be more sensitive to increased temperatures due to the potential toxicity and blockage problems caused by algal blooms within the water supply network. This is a known issue within the Queenstown Lakes District (Stakeholder engagement, 2020).

Droughts can lead to more favourable conditions for the development of algal blooms (such as lindavia) as discussed earlier (B3.1, B3.4). These events are influenced by high water temperatures, long residence times and high nutrient concentrations which can lead to a decrease in water quality, particularly in on-site systems (tanks) as well as within reticulated systems where treatment may be inadequate (van Vliet & Zwolsman, 2008). This can lead to significant health impacts (ORC, 2020e).

Fires in the Otago region have shown that water supply catchments and networks can be negatively impacted. The fire near Middlemarch in 2019 affected 75% of the Deep Stream catchment, which is the source of approximately 40% of Dunedin's metropolitan drinking water supply. Water quality was impacted due to ash and fire suppressant chemical intrusion into water sources.

In terms of irrigation demand, currently it is understood that some of Otago's catchments are, under pressure and paper allocation is significantly higher than base flows. This means the permits for water abstraction in those catchments allow more water in total to be taken than the catchment can sustain without adverse environmental effects (Skelton, 2019). Climate change and increasing demand will continue to impact the sensitivity of these catchments.

Adaptive capacity

The adaptive capacity of water supply and irrigation systems within Otago will largely depend on the ability to maintain or enhance supplies and storage, and to effectively manage water demand levels. Overseas experience has shown that demand levels can be reduced through targeted interventions, such as water efficiency, metering, pricing, and behaviour change (Tortajada & Joshi, 2013).

In Otago, water is largely supplied to cities and towns by individual local authorities (city or district councils). Given the currently fragmented nature of water supply management, improvements in adaptive capacity may largely be ad hoc across the region. It is noted however, that central government has recently established a new regulatory body (Taumata Arowai), that will administer and enforce a new drinking water regulatory system, which includes new requirements relating to management of risks to drinking water sources. Additionally, it is understood that district councils across Otago (and Southland) are working with central government to consider how water services may be delivered in the future, as part of the government's Three Waters Review (Water New Zealand, 2018). These initiatives will likely enhance the adaptive capacity of water supply within the region.

7.4.4 Discussion

Freshwater sources (rivers, lakes, aquifers) for water supplies and irrigation are under increasing pressure. The Otago population is growing and that some of the fastest growing areas are those that are dry and already have high water demand. Climate change will exacerbate these issues.

Water sources must be carefully managed to ensure they can continue to meet the needs of natural habits as well as demands for drinking water, recreation, hydroelectricity generation, and farm irrigation. They must also be managed in a manner that 'prioritises the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future' (National Policy Statement for Freshwater Management 2020). Skelton (2019) highlighted that the region requires improved mechanisms to ensure that the amount of water extracted for human use does not endanger the flow needed for ecological processes, such as providing habitat for wildlife, and for recreational use. Processes to address water source allocation are underway as part of the new Otago Land and Water Regional Plan.

Maintaining continuity of municipal water supplies is of significant importance for both communities and businesses. Severe consequences from water supply impairment (relating either to availability or water quality) can have correspondingly severe social and economic consequences on communities, public health, and businesses including the primary sector (Hendy et al., 2018). Projected increases in the frequency and intensity of drought and flooding events will exacerbate the consequences of water supply impairment (B3.1, B3.2, B3.6), and cause water quality deterioration such as algal blooms that may be of particular issue for rural, on-site water supply (B3.4) (van Vliet & Zwolsman, 2008).

The impact on water supplies from fires can have the potential for severe consequences to communities and businesses (B3.5). Fires can result in water supply restrictions (e.g. 2019 Middlemarch fire) with residents being asked to conserve water as a result of the event (Otago Daily Times, 2019f). With temperatures projected to increase with climate change, droughts and fire weather are likely to increase in frequency and intensity which will only exacerbate these events and the consequences experienced.

In summary, water supplies and irrigation schemes within the Otago region are at risk to climate change. ORC and other stakeholders have highlighted that salinity stress, sea level rise and associated coastal flooding, fire weather, drought and inland flooding are all significant hazards that present risk to water supplies. Table 7-4 summarises these current and future risks, and indicates that the highest risks are drought (B3.1, B3.4), inland flooding (B3.2) and increased fire weather (B3.5). All of these are rated as extreme risks by 2090, with municipal water supply at extreme risk from 2040 (B3.1). Rural water supply is currently at a low risk to fire weather (B3.5), however when considering the long term timeframe (2090) this risk escalates to extreme.

It is noted that these risks also relate/extend to ecosystem risks, and the requirement for ORC to protect aquatic ecosystems. This specific ecosystem risks are discussed as part of risk N5 (Risk to water quality and quantity).

Table 7-4: Summary risk rating for water supplies and irrigation systems

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B3.1	Risk to municipal water supply due to drought.	M	H	E	H	H	H	L	H	E	E
B3.2	Risk to municipal water supply due to inland flooding.	M	H	E	M	M	H	L	M	H	E
B3.3	Risk to municipal water supply due to sea level rise and salinity stress.	L	M	H	M	M	M	L	L	M	H
B3.4	Risk to rural water supply due to drought.	M	H	E	M	M	M	L	M	H	E
B3.5	Risk to rural water supply due to increased fire weather.	L	M	H	L	H	H	L	L	H	E
B3.6	Risk to irrigation systems due to drought.	M	H	H	M	M	H	M	M	M	H

7.5 B4: Risks to stormwater and wastewater networks from climate change hazards including increased temperatures, extreme weather events, flooding and sea level rise and salinity stress

7.5.1 Introduction

Stormwater and wastewater networks include the piped and natural conveyance networks, septic tanks, pump stations and treatment plants, which are critical pieces of infrastructure within all communities in the Otago region.

Stormwater systems are designed to collect, and transport rainfall from where it falls to outflows, and are typically designed to drain run-off arising from frequent, low intensity rainfall events (e.g. a 1 in 10 yr Annual Recurrence Interval (ARI) event). There are two sub-types of stormwater systems: natural and built. Natural stormwater systems consist of streams, overland flow paths and natural ponds and wetlands. Built stormwater systems include the piped network, constructed channels, stopbanks and stormwater quality improvement devices (Hughes et al., 2019).

Wastewater systems primarily consist of reticulated schemes collecting wastewater from residential or commercial properties and transporting it to treatment facilities (refer to Figure 7-13). Treated wastewater is discharged either to the ocean, rivers or via land application. Where reticulated schemes are not available (smaller communities and rural parts of Otago), decentralised systems such as septic tanks and farm effluent ponds are managed on private property (White et al., 2017; Hughes et al., 2019).

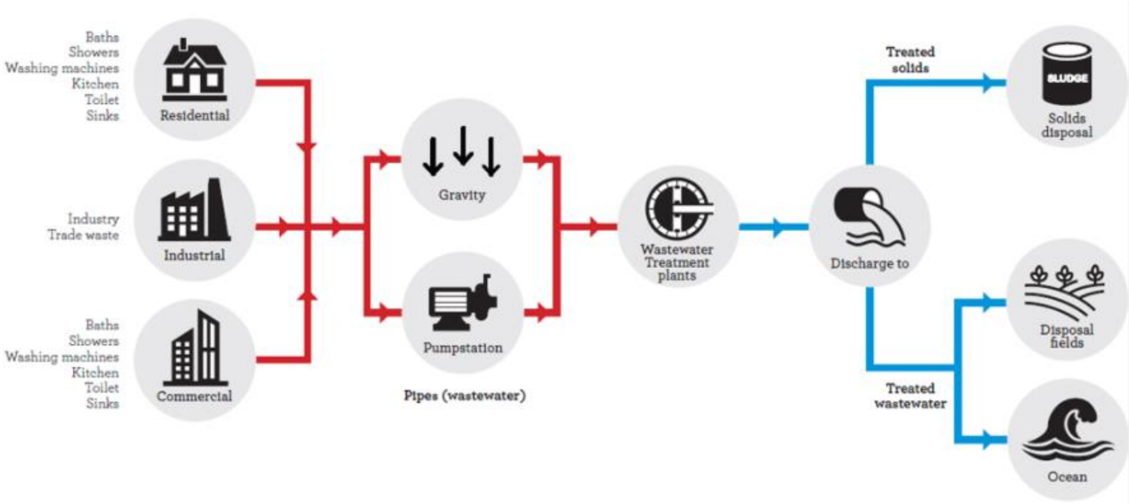

Figure 7-13: Diagram outlining how wastewater infrastructure works (Dunedin City Council, 2020a).

Stormwater and wastewater networks are critical infrastructure within communities to ensure contaminants do not get carried into public waterways. Left unchecked, they can have a negative effect on the environment and can also lead to flooding and land instability (Queenstown Lakes District Council, 2020b).

Table 7-5 below summarises the stormwater and wastewater infrastructure serving each district.

Table 7-5: Summary of stormwater and wastewater systems in Otago

District	Stormwater system	Wastewater system
Queenstown Lakes	Reticulated system for most townships, with some smaller settlements relying on soakage and discharge to watercourses.	Reticulated systems, served by wastewater treatment plants. Major plants serve Queenstown and Wanaka.
Central Otago	Generally managed via soakage.	Reticulated systems and treatment plants in townships, with smaller areas relying on septic tanks.
Clutha	Reticulated system for most townships, with some smaller settlements relying on soakage and discharge to watercourses.	Reticulated systems and treatment plants in townships, with smaller areas relying on septic tanks.
Dunedin City	Reticulated systems discharging to watercourses, coast or harbour.	Reticulated systems, served by wastewater treatment plants. Major plants are Tahuna and Green Island.
Waitaki	Reticulated system for most townships, with some smaller settlements relying on soakage and discharge to watercourses.	Reticulated systems and treatment plants in townships, with smaller areas relying on septic tanks.

Sources: Queenstown Lakes District Council (2020a); Clutha District Council (2020); Dunedin City Council (2020b); Central Otago District Council (2020b); Waitaki District Council (2018).

It is understood that there are no combined sewer systems in operation within the Region.

7.5.2 Exposure

Stormwater and wastewater infrastructure including septic tanks, treatment plants and pump stations are currently exposed to increased temperatures, sea level rise and associated coastal and inland flooding, and extreme weather events. Projected increases in the frequency and intensity of rainfall in winter and spring is likely to increase exposure of stormwater and wastewater networks to inland flooding for many western and inland parts of Otago (Macara et al., 2019).

There are approximately 135 km of stormwater and wastewater pipes currently exposed to coastal flooding in the Otago region. When considering the mid-term (2040) timeframe, with 0.3 m sea level rise, the length of stormwater and wastewater pipes exposed increases to approximately 155 km of pipes, of which over 55% are wastewater (Paulik et al., 2019a). Figure 7-14 outlines the district breakdown of stormwater and wastewater pipes exposed to current and future coastal flooding scenarios. It shows that, for both the stormwater and wastewater networks, approximately 90% of the pipes exposed are located in the Dunedin City district. There are a number of wastewater treatment plants located within close proximity to the coast with the potential to be exposed to sea level rise and salinity stress (Hughes et al., 2019) – including Tahuna and Green Island wastewater treatment plants in the Dunedin City district.

Currently there is approximately 700 km of stormwater and wastewater pipes and approximately 14,600 nodes[24] exposed collectively to inland flooding. Of the stormwater pipes currently exposed to flooding, greater than 60% are located in the Dunedin City district. Of those wastewater pipes exposed, greater than 70% are located in the Dunedin City district, with the remaining 15%, 13% and 2% located in the Clutha, Queenstown Lakes and Waitaki districts respectively. When considering the mid-term timeframe (2040) the exposure of the stormwater and wastewater networks increases

[24] Can include treatment plants and septic tanks however not specified within the report.

by approximately 60 km (Paulik et al., 2019). Figure 7-15 outlines the district breakdown of stormwater and wastewater pipes exposed to flooding currently, and under 0.3m of SLR.

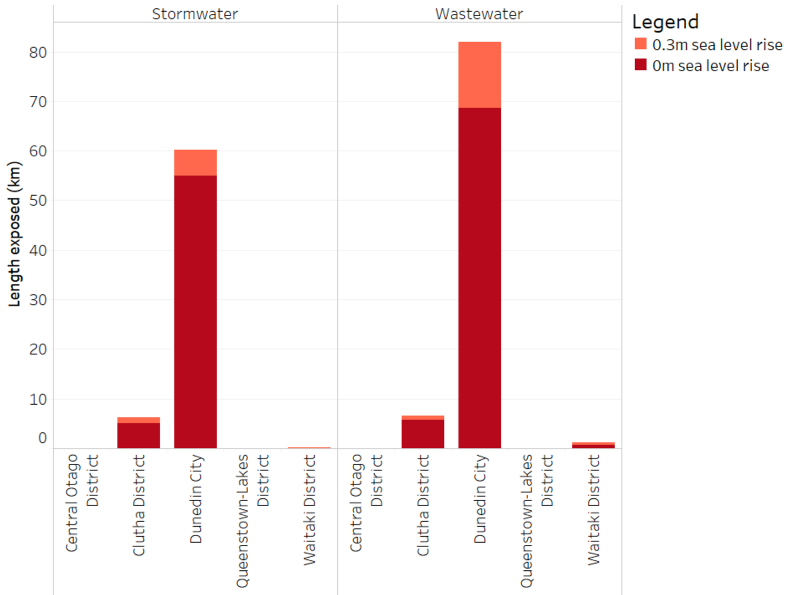

Figure 7-14: Stormwater and wastewater pipe exposure to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

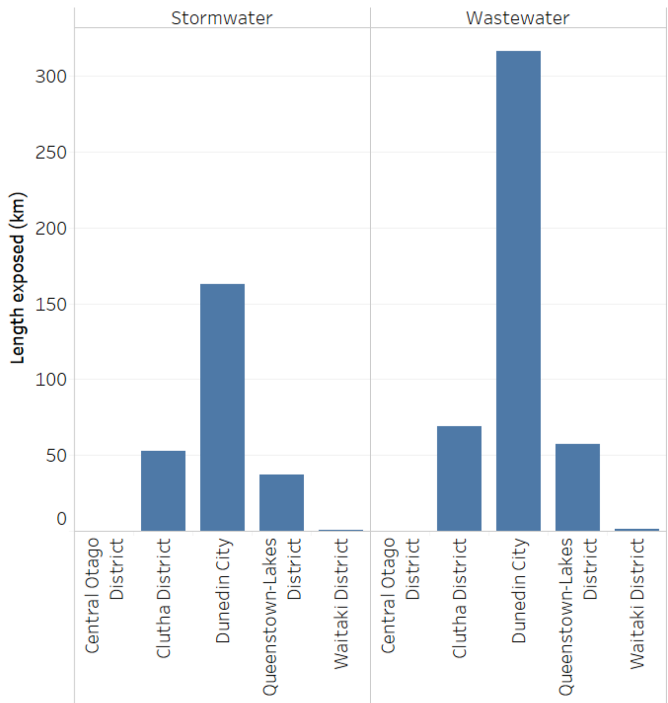

Figure 7-15: Stormwater and wastewater exposure to flooding, per district (Paulik et al., 2019).

ORC reports that there are around 14,600 properties serviced by septic tanks (which make up around 20% of the regional population). There are approximately 30 townships in Dunedin City which use septic tanks. A number of these are in low-lying coastal locations, or within floodplains (examples include Outram and Taieri Plains and Harrington Point) (Stakeholder engagement, 2020, Dunedin City Council, 2007). Further sub-regional distribution of septic systems was unavailable at the time of writing this report, and as such there are assumed to be further instances where systems are exposed to flooding (coastal and inland) and / or groundwater rise. Effluent ponds are a form of on-site wastewater treatment associated with dairy farming milking stations. Dairy farming production is strongest in Clutha, Waitaki and Dunedin City districts, with small amount of dairy activity in Central Otago and Queenstown Lakes Districts (Infometrics, 2019).

Otago Regional Council (2015) investigated hotspot areas where there were high densities of septic tanks, with potential to contaminate groundwater. These areas included Pomahaka basin, Wakatipu Basin, and the Hawea Basin. Further work would be required to check exposure to flooding or groundwater rise.

7.5.3 Vulnerability

The vulnerability of stormwater and wastewater infrastructure to climate hazards will relate to specific design and capacity characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Stormwater and wastewater networks are sensitive to climate change impacts. Sensitivity can be influenced by design, age and location, where poorly designed and older assets are more sensitive to climate change impacts both from physical and operational performance aspects. Stormwater and wastewater infrastructure are sensitive to sea level rise and associated coastal flooding as the discharge points of these systems are often at the lowest elevation of populated areas. Even small changes in rainfall extremes, including intensity and duration, can overwhelm the design capacity of these systems. In low-lying areas such as South Dunedin where groundwater is linked to the sea, sea level rise can affect the performance of stormwater and wastewater system where infiltration occurs (White et al., 2017).

Stormwater and wastewater systems that are not designed for increased flows and volumes have an increased sensitivity to sea level rise, and associated flooding and extreme weather events due to their lack of capacity (Hughes et al., 2019; White et al., 2017). With projected increases in rainfall and stormwater inflows as urbanisation increases, both stormwater and wastewater systems are likely to reach capacity and overflow even more frequently as a result of climate change (White et al., 2017).

Stormwater systems are designed to handle a given intensity and duration of rainfall. Historically across the industry, design capacity is targeted at a 10% AEP (1 in 10 yr) rainfall event, however in many areas this is currently not achieved, and stormwater systems are often beyond their originally intended capacity (McCloy, 2015; White et al., 2017). This under-capacity will exacerbate with climate change, and damaging rainfall events become more frequent. For example, parts of the South Dunedin stormwater system is understood to be designed for around a 1 in 2 year level of service (current), which will be reduced as the climate changes, resulting in more frequent overflows (White, et al., 2017).

Projected increases in the frequency and intensity of rainfall and extreme weather events can cause adverse ecological outcomes as a consequence of increased flow-related scour and modified flow patterns (Hughes et al., 2019). Additionally, flooding events can cause damage to wastewater and stormwater infrastructure and increased flows can cause infiltration into combined systems resulting in an impact to public health and receiving environments (Hughes et al., 2019). An example of this occurred in the Dunedin City district (February 2020) where due to heavy rainfall, the Tahuna wastewater treatment plant was overwhelmed by a combination of wastewater and stormwater. This caused the water around Lawyer’s Head, St Clair, St Kilda and Tomahawk beaches to be contaminated and a risk to human health (Otago Daily Times, 2020a).

Projected increases in rainfall and increases in sea level can exacerbate infiltration into wastewater pipes, reducing capacity. This can also cause the potential acceleration of corrosion and damage in wastewater pipes (Hughes et al., 2019). Saltwater intrusion can also disrupt the biological processes in wastewater treatment ponds. Sea level rise and associated coastal flooding can also cause direct physical damage to low-lying wastewater treatment plants and pump stations through wave action (White et al., 2017).

Gravity-fed wastewater systems are sensitive to increased temperatures and drought as the overall flow can be reduced allowing solids to accumulate in pipes. Increased occurrences of low flows within wastewater networks may lead to decreased contaminant dilution, resulting in higher concentrations of fats, oils, organic and soil matter entering wastewater treatment plants (Hughes et al., 2019). These increased concentrations can cause blockages, early system corrosion and/ or severe health and environmental consequences (Tolkou & Zouboulis, 2015). Increased temperatures may impact wastewater treatment performance and intensify odours (Pocock & Joubert, 2017) and may also lead to changes in the assimilation capacity of the receiving environment (Pocock & Joubert, 2017). Biological processes can occur faster in higher temperatures, potentially increasing the efficiency of some wastewater treatment processes (Tolkou & Zouboulis, 2015).

Septic tanks are sensitive to climate change, particularly in flood plains and where they are exposed to sea level rise and associated groundwater rise. An increase in the groundwater table is likely to exacerbate existing operational issues with septic tanks, cause damage to the tanks, increase the likelihood of groundwater contamination and reduce the efficiency of dispersal fields (Hughes et al., 2019).

These impacts will be exacerbated by the current operational state/condition of septic tanks. Otago Regional Council (2015) reported that of the approximately 14,600 septic tanks in the Otago region, an estimated 2200 to 7300 of these are in some stage of failure, and 2500 exceed the allowable nitrogen discharge threshold. This investigation also found that approximately 70% of the aquifers within Otago may be at medium or high risk of contamination from surface sources.

Effluent pond performance may be affected as changing temperatures affect biological treatment, and increased rainfall may cause excess stormwater to enter effluent ponds, resulting in more frequent discharges of nutrient laden wastewater to waterways (Northland Regional Council, n.d).

Adaptive capacity

Adaptive capacity is limited in stormwater and wastewater networks due their complex and permanent nature. However, due to most towns in Otago having an ageing network there is opportunity to include adaptations into upgrades that occur. These adaptations may include, improving capacity over time and when renewals are undertaken, or implementing water sensitive design at both building community and network level.

These adaptations can be applied when network upgrades occur, however can be costly (National Infrastructure Unit, 2015).

Wastewater treatment plants also have a low adaptive capacity. Their location is constrained by the networks that serve them. Both rising seas and groundwater levels place pressure on these important assets, and drive a need for strategies to defend and accommodate the hazard in the short term, allowing time for adaptive approaches to be deployed.

7.5.4 Discussion

Impacts to stormwater and wastewater networks due to climate change can result in significant social, environmental, economic and public health consequences. These consequences are likely to occur where stormwater and wastewater systems are aged and lack capacity to cope with increased flows (Hughes et al., 2019).

Extreme weather (B4.1, B4.5, B4.9), sea level rise (B4.2, B4.4, B4.6, B4.8) and flooding (B4.3, B4.7) are likely to result in in overflowing systems, damaged infrastructure or reduced level of service (Hughes et al., 2019). Consequences such as worsened water quality and increased costs for replacing and retrofitting the network can impact both communities and businesses within the Otago region (National Infrastructure Unit, 2015).

Aged stormwater and wastewater systems in coastal and low-lying areas in Otago will be at extreme risk to climatic changes such as sea level rise and associated coastal flooding at 2090 (B4.2, B4.6). Table 7-6 shows that the stormwater network is currently at a higher risk to sea level rise and associated flooding and extreme weather events than the wastewater network, however when considering the mid to long-term timeframe the risk levels align. Currently, treatment plants are at a medium risk to sea level rise, however when considering the long-term timeframe (2090) this increases to an extreme risk.

Table 7-6: Summary risk rating for stormwater and wastewater networks

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B4.1	Risk to wastewater infrastructure due to extreme weather events.	M	H	H	H	H	E	M	M	H	E
B4.2	Risk to wastewater infrastructure due to sea level rise and salinity stress.	M	H	H	L	H	E	M	L	H	E
B4.3	Risk to wastewater infrastructure due to inland flooding.	M	H	H	H	H	E	M	M	H	E
B4.4	Risk to septic tanks due to sea level rise and salinity stress.	L	M	H	L	M	M	L	L	M	H
B4.5	Risk to stormwater infrastructure due to extreme weather events.	H	H	E	H	H	E	M	H	H	E
B4.6	Risk to stormwater infrastructure due to sea level rise and salinity stress.	M	H	H	M	H	E	M	M	H	E
B4.7	Risk to stormwater infrastructure due to inland flooding.	H	H	E	H	H	E	M	H	H	E
B4.8	Risk to wastewater treatment plants and their operation due to sea level rise and salinity stress.	M	H	E	M	M	H	L	M	H	E
B4.9	Risk to wastewater treatment plants and their operation due to higher temperature.	L	L	M	L	L	H	M	L	L	M

7.6 B5: Risks to linear transport networks (road and rail) from climate change hazards including flooding, coastal erosion, extreme weather events and landslides

7.6.1 Introduction

The transport network within the Otago region plays a vital social and economic role, connecting communities, shifting freight and providing critical links for emergencies (Byett et al., 2019). Local roads (managed by Territorial Authorities) in the Otago region equate to 12% of the national total, with over 9,000 km throughout the region (Otago Regional Council, 2018). There are around 1,300 km of State Highways, managed by the Waka Kotahi New Zealand Transport Agency (NZTA), which also equate to around 12% of the national total and approximately 25% of the South Island total. There are around 1,400 km of local roads within the Otago region, of which around 95% are urban, with the remainder being split between ‘rural’ and ‘special purpose’ roads (NZTA, 2020b).

The Main South Line is the primary freight rail line which carrier freight from Southland and from Timaru to Port Otago. There is approximately 280 km of rail line within the region (Otago Regional Council, 2018).

There are over 1,000 road bridges located on local roads in the Otago region, of which approximately 620 are single-lane bridges. Of the 320 State Highway bridges in Otago, eight are single-lane bridges (Figure NZ, 2017). There are over 150 rail bridges in the Otago region, which is representative of approximately 10% of the national network.

7.6.2 Exposure

Road and rail networks are presently exposed to inland and coastal flooding, extreme weather events, coastal erosion and landslides. There are approximately 160 km of local and state highway roads exposed to current day coastal flooding (1% Annual Exceedance Probability (AEP) event), of which greater than 60% are located in the Dunedin City district. When considering the mid-term (2040) timeframe, with 0.3 m sea level rise, total road exposure increases to approximately 200 km (Paulik et al., 2019a). Figure 7-16 presents road and rail exposure to current and future coastal flooding scenarios at a district level. It indicates that approximately 90% of exposed roads are located in the Dunedin and Clutha districts, with the remainder located in the Waitaki District.

The Otago region has the highest rail exposure to present-day coastal flooding nationally, with 25 km exposed (Paulik et al., 2019a). This represents nearly 10% of the total track within the region. When considering the mid-term (2040) timeframe, with 0.3 m sea level rise, rail exposure in the Otago region increases to 30 km. Figure 7-16 indicates that over 95% of rail lines are exposed in the Dunedin and Clutha districts.

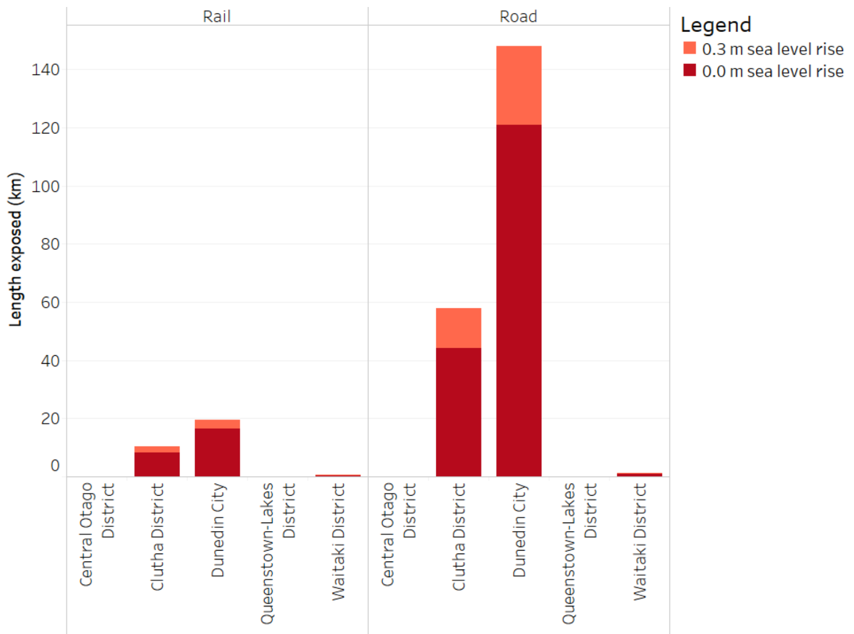

Figure 7-16: Road and rail exposure to current and future coastal flooding scenarios per district (Paulik et al., 2019a).

Currently there are approximately 1,380 km of road and 135 km of rail exposed to inland flooding in the Otago region respectively (Paulik et al., 2019). When considering the mid-term (2040) timeframe, exposure of the road network increases by 7%, with an additional 100 km. Figure 7-17 outlines road and rail exposure at a district level to flooding and indicates the majority of exposure is within the Dunedin and Clutha districts.

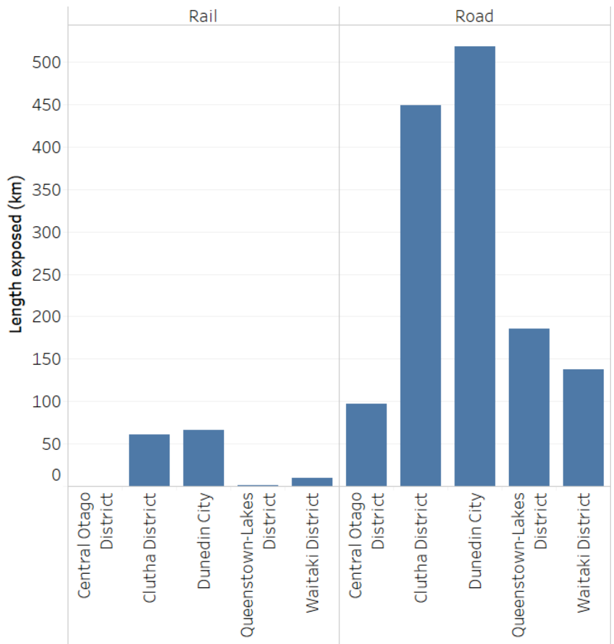

Figure 7-17: Road and rail exposure to flooding per district (Paulik et al., 2019).

There is limited information on the exposure of bridges to coastal and inland flooding in the Otago region.

Exposure of the road and rail network to extreme weather events is projected to increase in the Otago region with both an increase in the number of extreme hot days (greater than 30°C) and extreme rainfall events (Macara et al., 2019).

In the recent NZTA National Resilience Programme Business Case, exposure of State Highways to a range of hazards were identified and ranked across the Otago Region. Figure 7-18 outlines those assets that have increased exposure *and* an elevated level of criticality, due to their location and the consequences that could arise if failure occurred[25]. It is expected that the frequency of disruption and duration of outage at these locations are likely to increase in the mid to long term.

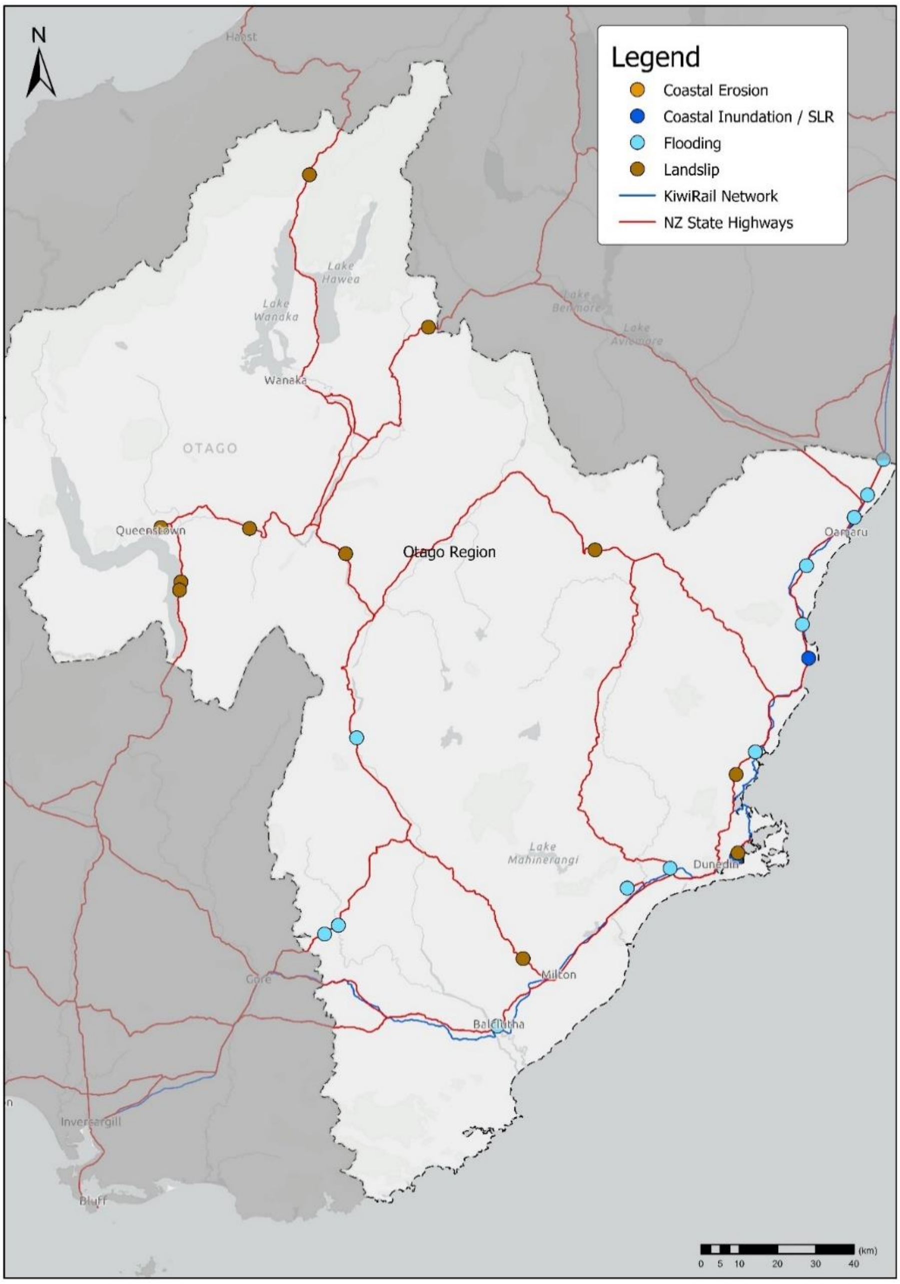

Figure 7-18: Point locations of State Highways and rail lines of elevated importance within the Otago region (NZTA, 2020c).

[25] It should be noted that although the location is denoted by a point location, they often refer to longer lengths of the road or whole corridors.

7.6.3 Vulnerability

The vulnerability of transport infrastructure (road and rail) to climate hazards will relate to specific design characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Sensitivity of road and rail networks is influenced by the design and physical condition of the asset. Age can also be used as a proxy for sensitivity, with older networks generally more sensitive, due to natural deterioration over time and differing historic design standards (Gardiner et al., 2009b). Additionally, a lack of maintenance increases the sensitivity of roads, particularly to climate-related hazards such as flooding.

Within the Otago region approximately 60% of roads are unsealed (Otago Regional Council, 2018), with the Central Otago District contributing a significant portion to this with 74% of their network unsealed (Central Otago District, Central Otago District, 2020d). Unsealed roads have an increased sensitivity to flooding due to reduced surface drainage capacity through increased likelihood of potholes and associated water stagnation. Additionally, un-sealed roads are more likely to have construction layers penetrated or submerged, which can lead to potential damage and failure of the road materials (Nordic Development Fund, 2018).

Water inundation on roads caused by flooding can cause short term disruptions where the road network is impassable, however larger events can cause substantial damage including scour, erosion and washout (New Zealand Lifelines, 2017). An example of this occurred in the 2015 Otago flood, where heavy rainfall and flooding caused road closures including State Highway 8 between Lindis Pass and Cromwell (NIWA, 2020b). Landslips and washouts occurred during this event (e.g. High Cliff Road), where a landslide undercut the roadway causing the road to collapse.

Sensitivity of the rail network to flooding is dependent on ballast material and construction. Ballast can be susceptible to wash out during flood events, causing delays from reduced speeds on the network (Network Rail, 2020). Intense rainfall and flooding can also cause damage to tracks with live conductors, as points and signalling equipment can fail due to water contact on power supplies, causing short circuits (Network Rail, 2020).

Rail lines in the Otago region have experienced severe flooding causing disruptions and delays. Figure 7-19 indicates the surface water ponding and flooding on the Taieri Gorge Railway and South Island Main trunk during the April 2006 floods. The south-bound train was forced to stop and wait (O'Sullivan et al., 2013).

Figure 7-19: Taieri Gorge Railway (left) and South Island Main Trunk (right) inundated by flood waters in the April 2006 floods (Goldsmith et al., 2015; O'Sullivan et al.,2013).

Sensitivity of the road and rail network is projected to increase with increased temperatures and the frequency of drought events, with extreme heat causing rail lines to buckle and road asphalt to melt; Gardiner et al., 2009). Rail lines are generally designed to tight tolerances, and when temperature thresholds are exceeded tracks can start to buckle causing disruptions to the network (Gardiner et al., 2009b). This has been seen in the Manawatu-Whanganui region where temperatures above 31 °C caused the buckling and derailment of a train, blocking a level crossing in the Ruapehu District. Older rail lines may have a lower tolerance to temperature rise, due to their natural deterioration (Gardiner et al., 2009b). Similarly, older roads that have deteriorated surfaces are likely to have a higher sensitivity to extreme temperatures.

Damaged road and rail networks can cause significant consequences such as the loss of access/connection to communities or a region, and the potential for injury/death of users (Gardiner et al., 2009b). This can have a significant social and economic impacts on the region such as in September 2013 on the Haast Pass where a landslip at Diana Falls closed the road, disrupting usual flows and visitors to the South Island. The recovery of both lanes took approximately 14 months (Otago Regional Council, 2018). The cost of repair for road and rail networks is also significant, as seen in the Clutha 2017 floods where the cost to clear washouts, fix culverts and remove slip material was estimated at around $1 million (Otago Daily Times, 2017a).

Degradation, damage and disruption to the road and rail network can reduce the capacity to service communities and transport services and goods (Gardiner et al., 2009b). Road and rail lines that have limited or no alternative routes have more severe consequences due to their lack of redundancy (New Zealand Lifelines, 2017).

Bridges are sensitive to sea level rise and associated coastal flooding as it can lead to saline incursion which increases the rate of material deterioration (Gardiner et al., Climate Change Effects on the Land Transport Network Volume One: Literature Review and Gap Analysis, 2009a). Additionally, flooding events can increase the instability of bridges and the likelihood of scour and washout. With projected increases in rainfall and associated flooding events, it may mean that smaller events are enough to cause damage to bridges.

Adaptive capacity

Adaptive capacity is considered limited for State Highways and main trunk rail lines due to their permanent nature, and limited alternative geographic corridors suitable for liner transport routes. Adaptive capacity is further reduced due to the range of entities that own and maintain the road and rail network in Otago, such as the NZTA, KiwiRail and local government (Byett et al., 2019). Due to the inter-dependent nature of road and rail networks, and the fact that funding is allocated from various different entities, delays in adaptation decisions and investments can occur (Byett et al., 2019).

Raising road and rail levels and increasing redundancy within the road and rail network (increased alternative route options) are options that could increase the adaptive capacity of the network (Byett et al., 2019).

Managed retreat of communities could result in exposed road/rail networks becoming redundant (Byett et al., 2019), which is also true for other infrastructure including water supply infrastructure (B3), stormwater and wastewater (B4), and electricity (B8). While not directly impacting adaptive capacity, this would result in a shift in the network location overtime toward lower exposure areas. However, the feasibility of this within the Otago region is limited to the amount of funding available and asset renewal cycles (Byett et al., 2019).

Some technical and operational solutions to increase adaptive capacity on road and rail networks have been demonstrated in New Zealand. For example, changes to design standards to ensure alignment with flood risk strategies i.e. ensuring roads and rail are built above specific design flood levels (Gardiner et al., 2009b). Additionally, transport systems are successfully operated in more extreme conditions internationally and in conditions predicted in future for New Zealand (Gardiner et al., 2009b).

It is noted by Byett et al (2019) that adaptation decisions need to be strategic and consider the network as a whole and not a subset.

7.6.4 Discussion

Road and rail assets are long-lived assets therefore become intertwined with wider economic and social systems (Byett et al., 2019). Damage and disruption to these systems not only causes consequences to the asset but has cascading consequences to society and the economy (Byett et al., 2019). Road closures due to extreme weather events, landslips and flooding can cause social disruption due to a loss of community connectedness and economic disruption due to prolonged recovery (B5.1,B5.2, B5.6) (New Zealand Lifelines, 2017).

Bridge scour and embankment collapse can occur due to the increased frequency and intensity of extreme rainfall (B5.1, B5.6) (Nemry & Demirel, 2012). Extreme winds and projected changes in temperature can cause disturbances to electronic infrastructure such as signalling and can also cause changes in construction seasons (Nemry & Demirel, 2012).

Bridges often carry critical infrastructure assets relating to other lifelines organisations. This often includes electricity distribution and telecommunications cabling, which can also fail with bridge failure, making the consequence even more severe (New Zealand Lifelines, 2017).

The road and rail networks and bridges in Otago are at risk to climate change. Table 7-7 presents the current and future risks to the road and rail network to each of the climate change hazards. It highlights that the highest risks are risk to roads and bridges from inland flooding and landslides.

Both of these are rated as extreme risks at 2040 and 2090. Risks to the rail network from coastal flooding and erosion is rated an extreme risk when considering the long-term timeframe (2090).

Table 7-7: Summary risk rating for linear transport networks

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B5.1	Risk to roads and bridges due to inland flooding.	M	H	E	M	H	H	L	M	E	E
B5.2	Risk to roads and bridges due to increasing landslides and soil erosion.	M	H	E	M	H	H	L	M	E	E
B5.3	Risk to rail due to coastal flooding.	L	M	H	M	H	H	L	L	H	E
B5.4	Risk to rail due to increasing coastal erosion.	L	M	H	M	M	H	L	L	M	E
B5.5	Risk to rail due to inland flooding.	L	M	H	M	M	H	L	L	M	E
B5.6	Risk to rail due to extreme weather events.	L	L	M	L	L	H	L	L	L	H

7.7 B6: Risks to airports and ports from climate change hazards including flooding and extreme weather events

7.7.1 Introduction

Airports and ports in the Otago region are critical economic and social infrastructure. There are two major airports located in the Otago region which receive both regional and international passengers, located in Queenstown and Dunedin (Otago Regional Council, 2018). In 2018, Queenstown International Airport experienced the fastest growth rates in New Zealand for both international and domestic passengers, with up to 45% of all visitors to Queenstown arriving by air (Otago Regional Council, 2018). There are a range of smaller airstrips / airports within the region which cater for local and scenic flights. These include: Wanaka, Oamaru, Alexandra, Glenorchy, Balclutha and Roxburgh.

Port Otago, at Port Chalmers in Dunedin, is New Zealand's third largest port (by value) with over $3.5 billion worth of exports in 2015. Port Otago is a freight port for regional and international import/export and is a key South Island gateway (Otago Regional Council, 2018). It is one of New Zealand's two deepest container ports and services the largest container ships in the New Zealand trade (Port Otago, 2020). The port also handles general cargo, Liquefied Petroleum Gas (LPG) and petroleum (Gardiner et al., 2009). It is also one of the major ports for cruise ship routes between October and April each year (Port Otago, 2020).

7.7.2 Exposure

Airports and ports are presently exposed to inland and coastal flooding and extreme weather events. Dunedin International Airport is currently the only airport exposed to inland flooding in the Otago region with no additional airports exposed when considering the mid-term timeframe (2040) (Paulik et al., 2019). Similarly, Dunedin International Airport is the only airport currently exposed to coastal flooding in the Otago region (Paulik et al., 2019a). No additional airports are exposed when considering the mid-term timeframe (2040), however when considering the long term timeframe (2090), with greater than 2 m sea level rise, the Balclutha Aerodrome is also exposed (Paulik et al., 2019a).

Given port locations are constrained to coastal/ low lying areas it is assumed that ports in the Otago region will be exposed in some manner to sea level rise and associated coastal flooding.

Airports and ports are exposed to extreme weather events which are predicted to increase in frequency and intensity with the projected increases in temperature and rainfall due to climate change. Aerodromes in Alexandra and Roxburgh that are located further inland are likely to experience greater temperature increases and number of hot days than airports in coastal regions such as Dunedin and Oamaru (Macara et al., 2019).

7.7.3 Vulnerability

The vulnerability of airport and port infrastructure to climate hazards will relate to specific design and system characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Airport and port design and condition are factors influencing the sensitivity to climate change, both for infrastructure and wider operations. Strong winds can impact runway operations due to reduced landing capacity and increase presence of foreign objects, leading to delays (The National Academies Press, 2012). Sensitivity is generally greater for runways constructed along locally prevailing wind directions. These runways may experience more crosswinds due to deviations from the prevailing wind direction (Burbidge, 2016).

Airports are also sensitive to thunderstorms, with lightning strikes having the potential to damage aircraft and escalate the potential for voltage spikes (The National Academies Press, 2012). Lightning strikes can also cause interruptions to power supply, disrupting control systems, landing lights, communications and radars (The National Academies Press, 2012). Increased temperatures can cause heat damage to asphalt/tarmac surfaces, and aprons and runways may experience damage from surface melting (Burbidge, 2016).

Extreme rainfall and flooding can result in damage to airport buildings, runways and underground infrastructure, such as electrical equipment and ground transport. Current aerodrome surface drainage capacity may also be insufficient to deal with increased intensity rainfall. Increased rainfall can require increased separation distances between aircraft during taxi, take-off and landing. Those airports with limited space to accommodate this will have a greater sensitivity (Burbidge, 2016). For example the flooding at Dunedin International Airport in June 1980 (B6.1, B6.2) (Figure 7-20) resulted in closure for 53 days, causing both social and economic impacts (O'Sullivan et al., 2013). Flooding in 2017 also caused significant impacts to the airport (Figure 7-20).

Reduced access to airports due to flooding can also cause significant impacts to airport operations (Burbidge, 2016; The National Academies Press, 2012).

Figure 7-20: Dunedin airport during the June 1980's flood and 2017 flood.

For ports, strong winds and heavy rainfall can cause localised flooding, damage to port buildings and crane infrastructure and cause disruptions to operations (Gardiner et al., 2009). Most ports are designed with 1-2 m clearance above the Mean High Water Springs (MHWS) line, however with rising sea level, this clearance will decrease, reducing the capacity of the port operations (Gardiner et al., 2009).

Adaptive capacity

Adaptive capacity of airports and ports is limited due to their permanent nature. Adaptation to airports such as relocation, redesign, and constructing flood defences is feasible but is likely to require significant capital investment and extensive planning constraints (Burbidge, 2016). Reinforcement and elevation of runways and access roads are additional ways to increase an airports adaptive capacity, however the feasibility is reliant on funding (The National Academies Press, 2012). Relocation of runways involves significant and complex requirements under the Resource Management Act 1991 with adaptations to an airport influencing not only the surrounding environment but the community as well, as experienced with noise regulations at Queenstown Airport (Queenstown Airport, 2018).

The ability of port infrastructure to adapt to climate change through relocation is dependent on the design, road and rail access, management and ultimately availability of funding for delivering adaptation actions (Ministry for the Environment, 2020). Assets that are likely to be affected by climate change include cranes and gantries which will need to be assessed for changing operational requirements (Ministry for the Environment, 2020). Modifications and enhancements to existing breakwater systems will need to be considered to cater for expected sea level rise projections and the projected increase in extreme weather events (Gardiner et al., 2009).

7.7.4 Discussion

Airports and ports are critical infrastructure in the Otago region and contribute significantly to the Otago, and national economy. Therefore, consequences as a result of climate change can have a significant economic and social impacts (Otago Regional Council, 2018).

Operational impacts for airports such as temporary reduction in capacity and runway closures increase disruption and delays at airports, lead to increased operational costs and potential for compensation (Burbidge, 2016).

Port Otago is a critical piece of infrastructure for trade to both Otago and New Zealand (Otago Regional Council, 2018). Consequences to ports as a result of flooding (B6.3) include; operational delays, overtopping and excessive ship movement at berth, and navigation difficulties. Consequences to ports as a result of high winds and extreme temperatures include; ship handling difficulties, corrosion, cargo fire risk and passage delays (Gardiner et al., 2009a). There is limited information on the impact of climate change on ports and associated infrastructure in New Zealand, however due to their critical importance and locational constraints, the risk to ports from climate change will increase over time.

Table 7-8 presents current and future risks to airports and ports to each of the climate change hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that the highest risks are those to airports from coastal and inland flooding. Both of these are rated as extreme risks at 2040 and 2090. Risks to port and wharves from extreme weather events is rated as medium in 2040, moving to high in 2090.

Table 7-8: Summary risk rating for airports and ports

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B6.1	Risk to airports due to coastal flooding.	M	H	H	M	H	H	L	M	E	E
B6.2	Risk to airports due to inland flooding.	M	H	H	M	H	H	L	M	E	E
B6.3	Risk to ports and wharf structures due to extreme weather events.	M	H	H	L	L	H	M	L	M	H

7.8 B7: Risks to solid waste (landfills and contaminated sites) from climate change hazards including erosion and flooding

7.8.1 Introduction

Solid waste for the purpose of this assessment refers to landfill and contaminated sites within the Otago region.

There are a large number of active and closed landfill sites throughout the Otago region. Victoria Flats landfill is the key active landfill that serves both the Queenstown Lakes and Central Otago districts for household, commercial, and special and hazardous waste (Queenstown Lakes District Council, 2020e). It is located on Kawarau Gorge Road on the right bank of the Kawarau River (Clifford, Cocks, & Wright, 2005). The Mt Cooee landfill serves the Clutha District for general, special and green waste, located in Balclutha and within close proximity to the Clutha River/Mata-Au (Clutha District Council, 2020c). The Green Island landfill serves the Dunedin City District for various different waste types including: general, special and hazardous, asbestos, contaminated, household batteries and prohibited waste (Dunedin City Council, 2020e). The Palmerston landfill serves the Waitaki District for general waste and green waste (Waitaki District Council, 2020d). There are also multiple different transfer and refuse stations throughout the region that are also used for the disposal of waste. The risk to the location of future or proposed sites have not been included in this assessment.

Increases in household waste is prominent in the Otago region, particularly within the Central Otago and Queenstown Lakes districts. Waste to Victoria Flats landfill steadily increased 2012 following a decrease attributed to the 2008 GFC. This increase motivated the establishment of a waste minimisation strategy (QLDC, 2018).

Known, closed landfill sites are numerous around the region, and are identified on the Hazardous Activities and Industries List for the region (ORC HAIL Register). Queenstown Lakes have identified seven key sites (Morrison Low, 2018), Clutha District 19 sites (Clutha District Council, 2018), and there are estimated to be more than 50 in Dunedin (Otago Daily Times, 2019a).

7.8.2 Exposure

Landfills and contaminated sites in the Otago region are presently exposed to increased precipitation and sea level rise, leading to the increased frequency and intensity of associated hazards such as coastal erosion as well as inland flooding and river erosion. Landfills and contaminated sites located in coastal or low-lying areas such as Dunedin, Kawarau and Balclutha will have a higher exposure to coastal or inland flooding due to their location and topography.

Coastal erosion is also a major concern, as many known historic landfills are located within the coastal margin. There will likely be a number of unknown, informal landfills.

Some initial work has been undertaken by ORC to identify exposed landfills, within parts of Otago. Figure 7-21 presents 27 historic landfills within the Otago Region that are potentially exposed to coastal erosion and an additional 63 closed landfills were identified within 20 m of a waterway (ORC HAIL Register; Otago Daily Times, 2019a).

Additionally, exposure of landfills in the Otago Region to sea level rise and associated coastal flooding was analysed in 2019. It was found that approximately 10 closed landfills were exposed in the Otago region at 1 m above the current Mean High Water Springs (MHWS) (Simonson & Hall, 2019). When looking at the long-term time frame (2090) – allowing for 1.5 m of sea level rise above MHWS, this number increases to greater than 15 closed landfills exposed (Simonson & Hall, 2019).

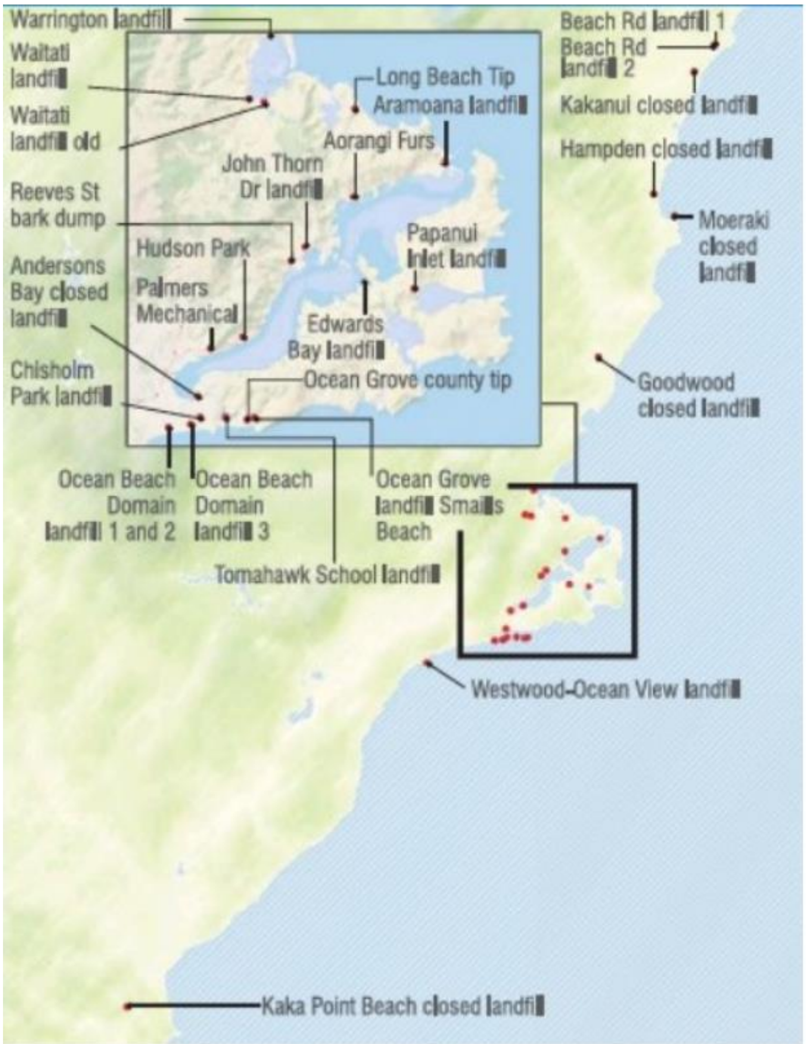

Figure 7-21: Historic landfills exposed to coastal erosion in the Otago region (ORC HAIL Register, Image source: Otago Daily Times, 2019d).

Closed landfills and contaminated sites generally will have a higher exposure to flooding and sea level rise than modern sites due to the requirements to locate recently constructed landfills in areas at lower risk to natural hazards (Ministry for the Environment, 2001).

7.8.3 Vulnerability

The vulnerability of landfills to climate hazards will relate to specific design and material characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Landfills and contaminated sites are sensitive to sea level rise and the increased frequency and intensity of flooding, with sensitivity influenced by design characteristics, maintenance and geography (United States Environmental Protection Agency, 2014). Design characteristics that can influence the sensitivity of a landfill or contaminated site may include whether the landfill has a liner, a cap; and the thickness of that cap, and whether or not there is any known issues, such as land stability or erosion. Landfills or contaminated sites with ongoing maintenance/ monitoring can gain a better understanding of sensitivity i.e. whether there are known issues with the site.

Those landfills with no liner have an increased sensitivity to sea level rise and subsequent coastal flooding, as water can cause leachate to escape and the mobilisation of contaminants (Brand et al., 2018: Beaven et al., 2020). Clay liners have a greater sensitivity to sea level rise, as salt water intrusion can increase permeability and decrease its performance (United States Environmental Protection Agency, 2014). Similarly, those landfills that do not have a cap or have a cap with a small thickness have an increased sensitivity to sea level rise, and coastal flooding due water mobilising material and contaminants.

Landfills that have already known issues such as land stability and erosion issues have an increased sensitivity to gradual climatic changes and climate-related hazards due to the decreased integrity and increased susceptibility to fail. The likelihood of landfill failure can be increased with more frequent and intense flooding events, as the infiltration of high-water volumes can adversely affect the structural integrity of the waste (Brand et al., 2018). Rising sea levels and increased storminess may also increase the likelihood of failure due to damage that can occur to the defences containing the waste (Brand et al., 2018).

Open landfills have an increased sensitivity to coastal flooding as they are likely to have less protection from extreme events and landfill material may be more easily mobilised.

No specific information was available on attributes and related sensitivities of the closed landfills throughout Otago. Based on a broad understanding of historic construction approaches the following is noted:

- Landfills constructed post 1991, after the Resource Management Act (RMA) was released, are likely to have a reduced sensitivity to natural hazards and climate change due to the rules and guidance stated within the legislation.
- There are an increasing number of informal landfills being identified (i.e. previously unknown) throughout New Zealand and it is likely that this is the case in Otago.

At a national level, further research on landfills has been identified as a priority, given the lack of understanding of landfill location, construction and fill material. This is likely further hindered by a lack of ongoing monitoring (Ministry for the Environment, 2020).

Adaptive capacity

Adaptive capacity of landfills and contaminated sites is generally low, given their permanent nature and limited ability to relocate. The potential for unknown, historical landfill locations in the Otago region further reduces the adaptive capacity of landfills, given the inability to assess and plan for future adaptations.

While adaptive capacity is generally low for landfills, there are potential options as part of wider improvement projects. One such example is the rejuvenation of the dune area adjacent to Kettle Park, which is currently under investigation as part of the DCC-led St Clair-St Kilda Coastal Plan (Tonkin & Taylor Ltd, 2020a). Option that are under consideration include dune recharge, capsulating the material, or removal of contaminated material combined with beach nourishment, reprofiling and replanting (Tonkin & Taylor Ltd., 2020a; Otago Daily Times, 2019d).

Addressing landfill-related risks can result in wider community benefits. Landfills can be managed as open space that can be naturalised to provide ecological benefits or buffers against flooding or other natural hazards. For example, remediation planning for landfills in coastal zones have the potential to reduce coastal hazard through improved dune systems and coastal retreat (Tonkin & Taylor Ltd, 2020a).

7.8.4 Discussion

Landfills failing due to natural hazards such as coastal erosion and coastal flooding occurred in the Otago region in the past (B7.1). For example, coastal erosion exposed demolition material from the Kettle Park landfill in Dunedin. As a result, hazardous material contaminated sand dunes in Middle

Beach with traces of arsenic, asbestos and other industrial chemicals. Due to the permanent nature of these sites, consequences of failure will be present long after closure and can have significant environmental, social and economic consequences (Bebb & Kersey, 2003).

It is acknowledged that there is little information on the types and quantities of waste within many of the closed landfills. For many, the existence of appropriate engineered protection (liners/caps) is unknown, and many will continue to release leachate following closure (Otago Regional Council, 1997).

Landfills and contaminated sites that contain hazardous materials and municipal solid waste (non-hazardous solid waste from household, commercial and/or industrial sources) can cause severe consequences due to the hazardous nature of the material and the significant ecological and environmental impacts that would occur if failure of the landfill was to occur and materials released into the environment (Brand et al., 2018). Additionally, those landfills that were opened after the mid 1960's are likely to have more plastics and paper, further impacting the environment if failure was to occur (Brand et al., 2018).

The failure of landfills and contaminated sites may mobilise pollutants (such as dissolved nitrogen and heavy materials) and solid waste, including glass, metal, plastics and asbestos (Brand et al., 2018). This could have negative impacts on sensitive ecosystems, groundwater and surface water contamination, reputational damage, declining health outcomes, and negative impacts on economic sectors including tourism (Brand et al., 2019).

Significant consequences of landfill failure on the receiving environment were seen in the 2019 Fox Glacier Landfill incident. Figure 7-22 displays some of the impact the Fox Glacier landfill spill caused on the receiving environment. Approximately 95% of the river length was contaminated by rubbish from the flood-torn landfill which eventually will be transported to the ocean off the West Coast. This is likely to impact ecosystems and potentially poison plants and animals or be absorbed and potentially passed up the food chain, causing further, severe public health issues.


Figure 7-22: Rubbish within river channels after the Fox Glacier landfill spill (Radio New Zealand, Radio New Zealand, 2019).

Most of Otago's closed landfills are within the Dunedin boundary whilst others are located in the Waitaki and Clutha districts. In addition to the DCC Kettle Park historic landfill, two of the sites that have the potential for severe consequences in Otago were considered to be the two Beach Road landfills, south of Oamaru, which have been exposed by coastal erosion in the past (Stakeholder Engagement, 2020)

For open landfills, inland and coastal flooding have the potential to impact waste management processes and sites in several ways (B7.1, B7.2). Direct impacts include power interruption, physical damage to buildings and the landfill site, water damage and reduced accessibility and disruption to the delivery of waste (Bebb & Kersey, 2003; United States Environmental Protection Agency, 2014).

These impacts can lead to operational disruptions which can often have significant economic consequences.

Landfills and contaminated sites in Otago are at risk to climate change. Table 7-9 presents the current and future risks to landfills and contaminated sites from the climate change hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that the risks to landfills and contaminated sites from coastal flooding and erosion are rated as extreme at 2040 and 2090.

Table 7-9: Summary risk rating for solid waste (landfills and contaminated sites)

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B7.1	Risk to landfills, contaminated sites and solid waste management due to increasing sea level rise and coastal erosion.	M	H	H	M	H	H	L	M	E	E
B7.2	Risk to landfills, contaminated sites and solid waste management due to inland flooding.	L	M	H	L	M	M	M	L	M	M
B7.3	Risk to landfills, contaminated sites and solid waste management due to river erosion.	L	M	H	M	H	H	L	L	H	E

7.9 B8: Risks to electricity (generation, transmission and distribution) networks from climate change hazards including changes in rainfall, extreme weather events and flooding

7.9.1 Introduction

Reliable electricity supply is central to modern society, and provides an essential service. Almost all other major infrastructure and services rely on it: including communication, manufacturing, finance, agriculture, healthcare, tourism, transportation and water (Burillo, 2018).

7.9.2 Generation

Hydro-electric generation in Otago region provides approximately 10% of New Zealand's electricity, associated primarily with the Clyde and Roxburgh hydro power stations on the Clutha River, some of which is currently consumed locally by Dunedin. Nationally significant sites that are located in the Otago region include, Roxburgh and Clyde switchyards, which are a critical part of the national grid.

Otago's generation sites include:

- Contact Energy's Clyde (432 MW) and Roxburgh (320 MW) Hydro Power Stations on the Clutha River, which together produce around 8% of New Zealand's electricity. The Clyde Power Station is most critical as it houses the control centre for the Roxburgh and Hawea Dams as well (Emergency Management Otago, 2018).
- Trustpower's four schemes generating around 130 MW (a combination of wind and hydro), the largest being Waipori Falls generating 72 MW.
- Pioneer Generation's 15 generation sites (a combination of hydro, gas and wind), generate a total of 43 MW, with no single site producing over 10MW.

7.9.3 Transmission and Distribution

Transpower combine the Otago and Southland regions when reporting regional overviews of their transmission assets, which are connected to the National Grid by three 220 kV circuits. Transmission capacity in the Otago region is largely driven by the local hydrology; during wet periods, significant amounts of power is exported, whilst during dry periods power can be imported (Transpower, 2019). Transmission within the region comprises of 220 kV and 110 kV transmission circuits with interconnecting transformers located at Cromwell, Dunedin (Halfway Bush) and Roxburgh (refer Figure 7-23).

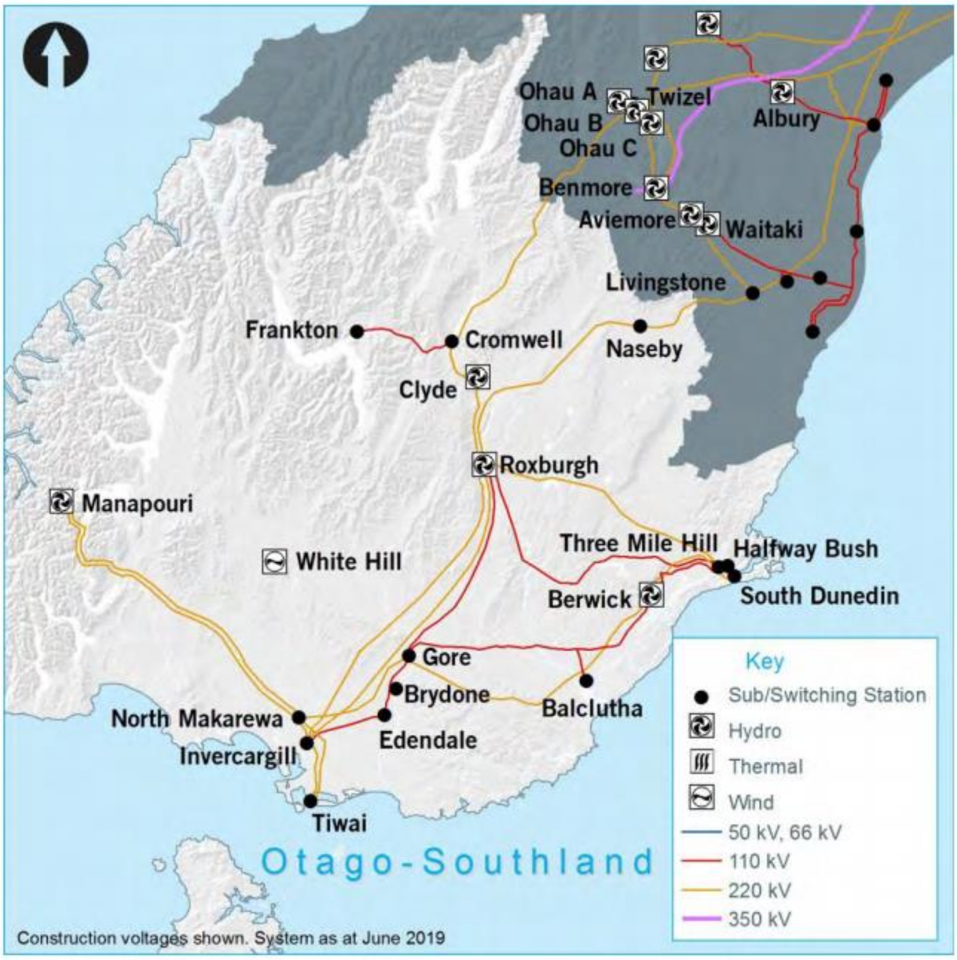

Figure 7-23: Transmission network asset locations in Otago/Southland (Transpower, Transmission Planning Report, 2019).

Transpower manage and operate the National Grid within the region, supplying electricity to three distribution companies, which are shown in Table 7-10 along with their asset distribution and supply.

Table 7-10: Distribution companies in the Otago region and their asset distribution

Distribution company	Customer supply	Delivers	Network
Aurora Energy	84,000 customers in Dunedin and Central Otago.	1400 GWh annually.	Approximately 5,500 km of lines and cables and 36 zone substations.
• PowerNet	14,800 customers in rural Dunedin, Waitaki, Clutha and Central Otago Districts.	420 GWh annually.	Largely distributed network with approximately 4,400 km of lines and cables and 32 zone substations.
Network Waitaki	12,000 consumer customers in North Otago.	230 GWh annually.	Approximately 1,800 km of lines and cables.

Sourced from (Hexamer, 2018).

7.9.4 Exposure

7.9.4.1 Generation

Generation is driven by a combination of rainfall and snowmelt, with snowmelt providing on average 50 per cent of spring and summer inflows into New Zealand's hydro-electric storage reservoirs (McKerchar et al, 1998). Modelling has indicated little change in total yearly inflow to hydro lakes by 2050, but seasonal changes are projected for the South Island, with summer inflows reducing and winter inflows increasing (Interim Climate Change Committee, 2019).

Elements of Otago's electricity generation network are presently exposed to gradual climatic changes such as reduced snow and ice, and changes in rainfall and associated extreme weather events. Water storage for hydro-electric power generation is dominated by a few key reservoirs in the South Island including the Otago region's Lake Hawea, in the Clutha River Basin. Reduced rainfall and snowmelt, as a result of climate change, can reduce inflows to the reservoirs, and in turn, reduce generating capacity (Renwick et al., 2010).

The exposure of wind and solar generation is less clear, as climate projections are more variable and less certain. New Zealand's current wind energy resource is predominantly from westerly winds. Climate change could increase these westerly wind flows, particularly during winter and spring (Electricity Authority, 2018), potentially increasing generation capacity. No information is available regarding sunshine hours.

Generation infrastructure is exposed to potential changes in electricity demand from climate change. For example, warmer winters may result in less demand for heating and warmer summers may result in increased demand for cooling (Ministry for the Environment, 2020).

7.9.4.2 Transmission and distribution

There is currently over 120 km of Transpower transmission lines located on land that is exposed to inland flooding in the Otago region (Paulik et al., 2019). Of these, the Waitaki, Dunedin and Clutha districts contribute to 95% of exposure, with exposure limited to 6 km in the Central Otago and Queenstown Lakes districts (Figure 7-24).

In low lying areas such as South Dunedin and Harbourside, transmission and distribution infrastructure is exposed to flooding. The critical South Dunedin sub-station and Grid Exit Point which services the South Dunedin area are located in these highly exposed areas (Emergency Management Otago, 2018; Stakeholder Engagement, 2020). While transmission lines are suspended above ground, the pylons may be at risk of structural damage or erosion, and lines may be rendered inaccessible during times of flood.

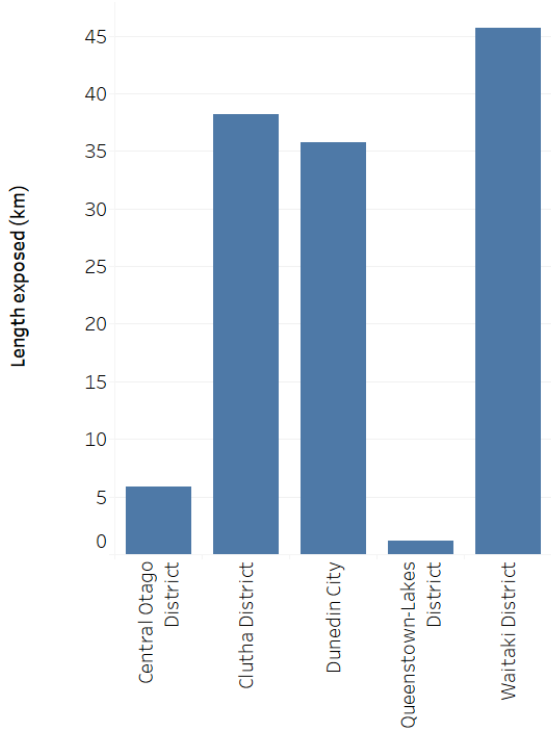

Figure 7-24: Transmission lines (National Grid) currently exposed to flooding, per district (Paulik et al., 2019).

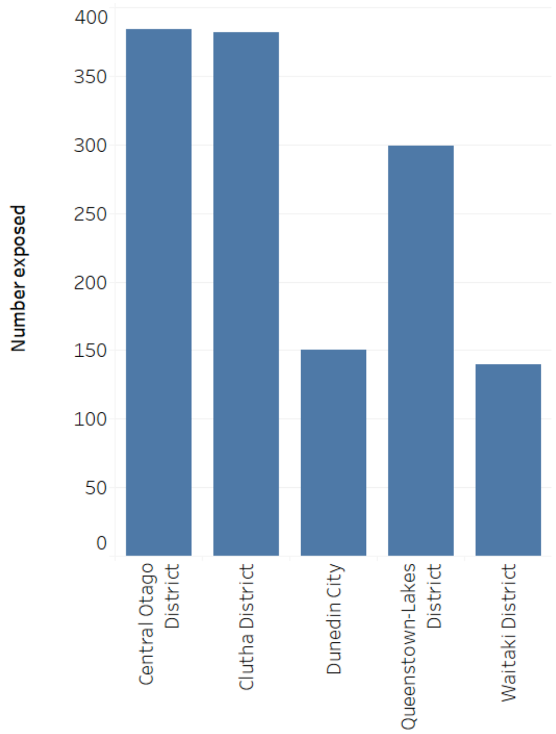

Figure 7-25: Structures currently exposed to flooding, per district (Paulik et al., 2019).

When considering the present to mid-term timeframe, there are approximately 8 km of transmission lines exposed to coastal flooding in the Otago region, with over half located in the Clutha District. When considering the long-term timeframe (2090), with 1.2 m sea level rise, exposure increases by approximately 70%. Increased exposure largely occurs in the Clutha District (Figure 7-26) (Paulik et al., 2019a).

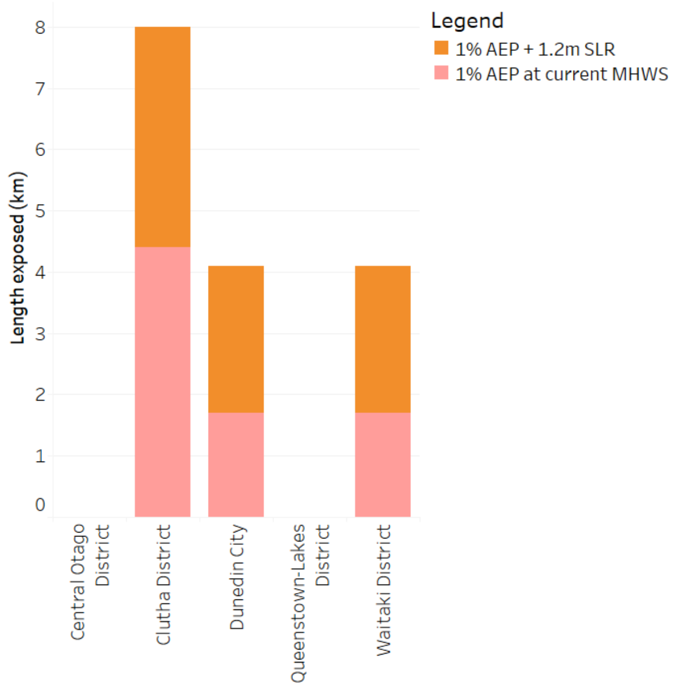

Figure 7-26: Transmission lines exposed to current and future coastal flooding scenarios (Paulik et al., 2019a).

Wildfire is an important climate hazard, and one that will increase with climate change (MfE, 2018). Transmission and distribution infrastructure can both contribute to fire risk (acting as a cause of fire) and also be affected by fires caused by other sources. NIWA provides fire weather maps for all of NZ, which draw on data such as temperature, wind, rainfall, soil moisture and vegetation type (grass, scrub, forest) to provide a fire risk index at a sub-regional scale for different scenarios: *general fire source, forestry source, powerline source and hot-work source*. Refer to Figure 7-27 for an example map. Areas of high vegetation cover (scrub and forestry), in locations with transmission and distribution lines will generally be of highest risk. An example is the forested area around Queenstown which has high vegetation cover adjacent to power lines (Stakeholder Engagement, 2020).

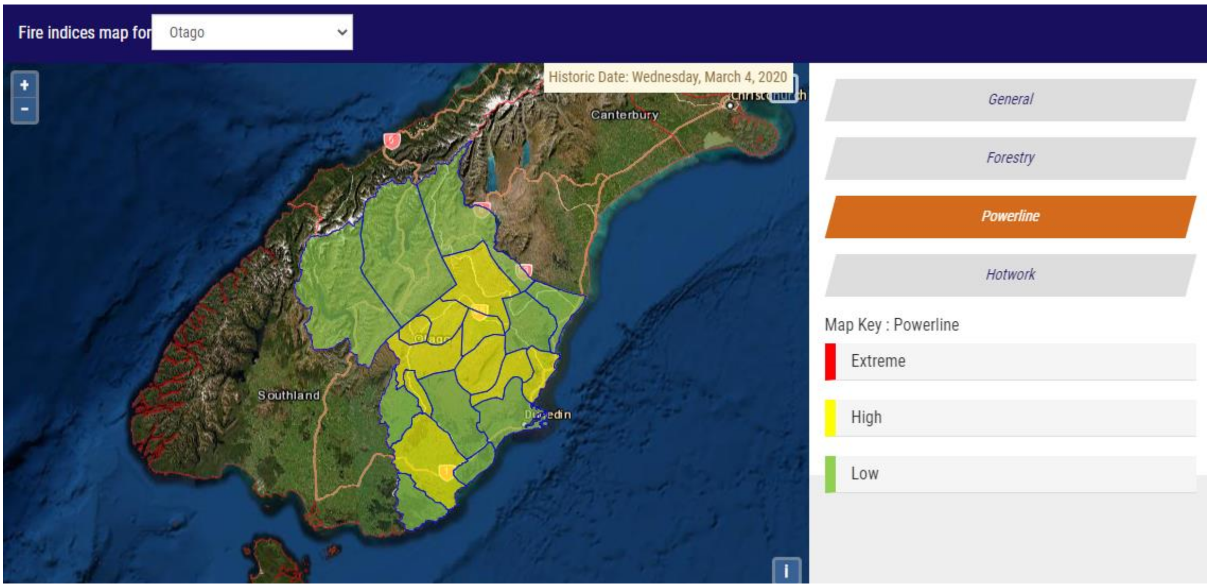

Figure 7-27: Example fire index map for Otago (https://fireweather.niwa.co.nz/region/Otago).

Transmission and distribution lines are exposed to extreme rainfall, snow and landslides throughout the Central Otago district due to the steep mountainous environment. Transmission lines located through the Lindis Pass are exposed to snow and rainfall induced landslides (Hexamer, 2018). Additionally, lines in the Cromwell/ Wanaka and Frankton/Queenstown areas have an increased exposure to extreme rainfall and landslides, and have the potential to cut supply to two main centres if damaged.

7.9.5 Vulnerability

The vulnerability of generation and distribution infrastructure to climate hazards will relate to specific design and material characteristics, and these are discussed separately below.

Sensitivity

<u>Generation</u>

Hydro-electric and wind generation is sensitive to changes in water inflows, wind patterns, and demand profiles. The key reservoirs (including Lake Hawea) are fed by precipitation falling over the Southern Alps during westerly storm events, meaning inflow variability is intimately linked to variations in the strength and direction of the predominant westerly's (Renwick et al., 2010). Generation capacity of these reservoirs generally depends on the frequency of the westerly storm events and the subsequent inflows of water.

Although hydro-electric stations are inherently sensitive to changes in rainfall and snowmelt, at present this is considered a manageable impact and does not pose a significant risk over the short term (Meridian Energy Limited, 2019).

<u>Transmission and distribution</u>

Sensitivity of transmission and distribution infrastructure is driven by age, condition and materials/design of structures. Infrastructure design typically considers historic climate conditions and extreme weather events to specify tolerances. Therefore, older transmission and distribution infrastructure have a higher sensitivity to climate change due to the potential for reduced operational capacity in future climate conditions (Burillo, 2018; Hexamer,2018).

Overhead structures, poles and lines are sensitive to extreme weather events, including strong winds and extreme rainfall as they can sag (to the point of deformation) and be damaged by falling trees causing disruptions to the network and power supply not only throughout Otago but New Zealand as well (Orion New Zealand Limited, 2019). Transpower's transmission towers, poles and lines are designed to 200 km/ hr winds and can typically withstand more, whilst local distribution networks are typically designed for around 900-1200 Pa or 160 km/hr (Hexamer, 2018). Therefore, sensitivity is greater for local distribution lines as their design is likely to be exceeded more frequently with projected increases in wind than can be exceeded at lower levels compared to transmission lines. While overhead lines may be designed to withstand increases in wind, there is likely to be increases in third party damage (e.g. uprooted trees) that lines are susceptible to. While overhead lines are unlikely to be impacted by flooding, this will reduce access for maintenance.

In terms of poles, wooden poles have a higher sensitivity to climatic changes due to the increased likelihood of degradation over time, making them more sensitive to damage from a range of hazards (e.g. extreme events, floods, fire) (Aurora, 2020; Transpower, 2018).

Ground mounted switch gear is sensitive to increased rainfall and associated coastal and inland flooding as water can cause severe damage to the asset and cause major disruptions throughout the network. Transformers have a reduced sensitivity to rainfall and flooding events as they are not as susceptible to water damage (Stakeholder Engagement, 2020).

Wildfires can damage electricity network infrastructure and render powerlines inoperable due to ionised air (Burillo, 2018; Flick Electric, 2020). As discussed above, electricity networks can potentially be the source of ignition for fires due to failure of the complex components that make up the transmission and distribution networks, as seen in the Australian bushfires in 2019.

Climate change may constrain the adequate supply of electricity in the future by reducing electricity transmission capacity and increasing electricity demand. Increases in temperature can decrease the carrying capacity of electric power cables; similarly, during summer peak period, electricity loads typically increase with hotter air temperatures due to increased air conditioning usage (Bartos et al., 2016). Additionally, higher temperatures can cause individual components to become inoperable, with protection devices cutting in if power flow is too high for the weather conditions. If too many components are offline or the capacity of the system is significantly reduced then power may not be available when it is needed causing cascading failures and black outs (Burillo, 2018).

Adaptive capacity

Electricity generation in New Zealand generally has a moderate level of adaptive capacity, due to the diverse distributed generation sources connected to the national grid.

Adaptive capacity of transmission and distribution infrastructure is considered low, given the permanent nature of some infrastructure and the location being largely controlled by population.

As distribution infrastructure is managed by numerous individual businesses that make their own investment decisions about resilience levels, and less funding is available, distribution infrastructure is likely to have lower adaptive capacity than transmission infrastructure (Climate Change Adaptation Technical Working Group, 2017).

7.9.6 Discussion

The electricity network in Otago is nationally significant infrastructure, with disruption causing the potential for significant social and economic consequences.

Damage to transmission and distribution infrastructure due to extreme events such as, sagging powerlines (to the point of deformation) and breakages due to trees falling on powerlines, can cause significant disruptions both short-term and long-term (B8.6). Short-term disruptions such as power outages can cause consequences to communities, businesses and the economy. However, outage and restoration periods are short, usually fixed within hours. For example, power was restored within 6 hours after severe weather in Dunedin, Central Otago and Queenstown Lakes caused power outages in July 2017 (Otago Daily Times, 2017b). However, extreme events can cause long-term disruptions which can have severe social and economic consequences such as disconnected communities and economic loss due to business disruption. It can also cause impacts on the power grid, such as reduction of infrastructure life-span and electric transmission capacity which can cause economic consequences (Fant et al., 2020; Bartos et al., 2016).

Public health and economic consequences also arise from power outages and failure of the transmission and distribution network. Businesses and communities that do not have back-up generators are likely to suffer significant consequences if power outages are to occur for an extended period of time, for example - due to a lack of heating in winter or reduced ability to operate. An example of this occurred in July 2020 where homes in Clyde and parts of Earnscleugh were without power for more than eight hours in temperatures that dropped to minus 10°C, presenting a risk to the community through a lack of heating. Additionally, a constant supply of electricity was needed for irrigation and frost-fighting in the affected area. If the power outage was to occur when this equipment was in peak use, then estimated costs to the local economy from lost fruit and grape production could have been catastrophic.

Both electricity generation and transmission and distribution networks are at risk to climate change. Table 7-11 presents the current and future risks to the electricity network to each of the climatic changes and hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that the highest risks are for transmission and distribution infrastructure, particularly relating to increased fire weather.

Table 7-11: Summary risk rating for electricity sector

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B8.1	Risk to generation due to change in rainfall.	L	M	H	L	L	M	L	L	M	H
B8.2	Risk to generation due to reduced snow and ice.	L	M	M	L	L	M	L	L	M	M
B8.3	Risk to distribution due to increased fire weather.	M	H	E	H	H	H	M	M	H	E
B8.4	Risk to distribution due to coastal flooding.	L	M	H	H	H	H	M	L	M	H
B8.5	Risk to distribution due to inland flooding.	L	M	H	H	H	H	M	L	M	H
B8.6	Risk to distribution due to extreme weather events.	L	M	H	H	H	H	M	L	M	H

7.10 B9: Risks to telecommunications from climate change hazards including sea level rise and coastal flooding, inland flooding, extreme weather events and increased fire weather

7.10.1 Introduction

The telecommunication sector is a critical lifeline utility, and is complex due to rapid changes in technology and the high level of inter-connectivity between various providers which share parts of the network and rely on each other. The Otago Region is served via transmission fibre cables which run along a coastal and inland route shared by a number of providers, as shown in Figure 7-28 (Hexamer, 2018).

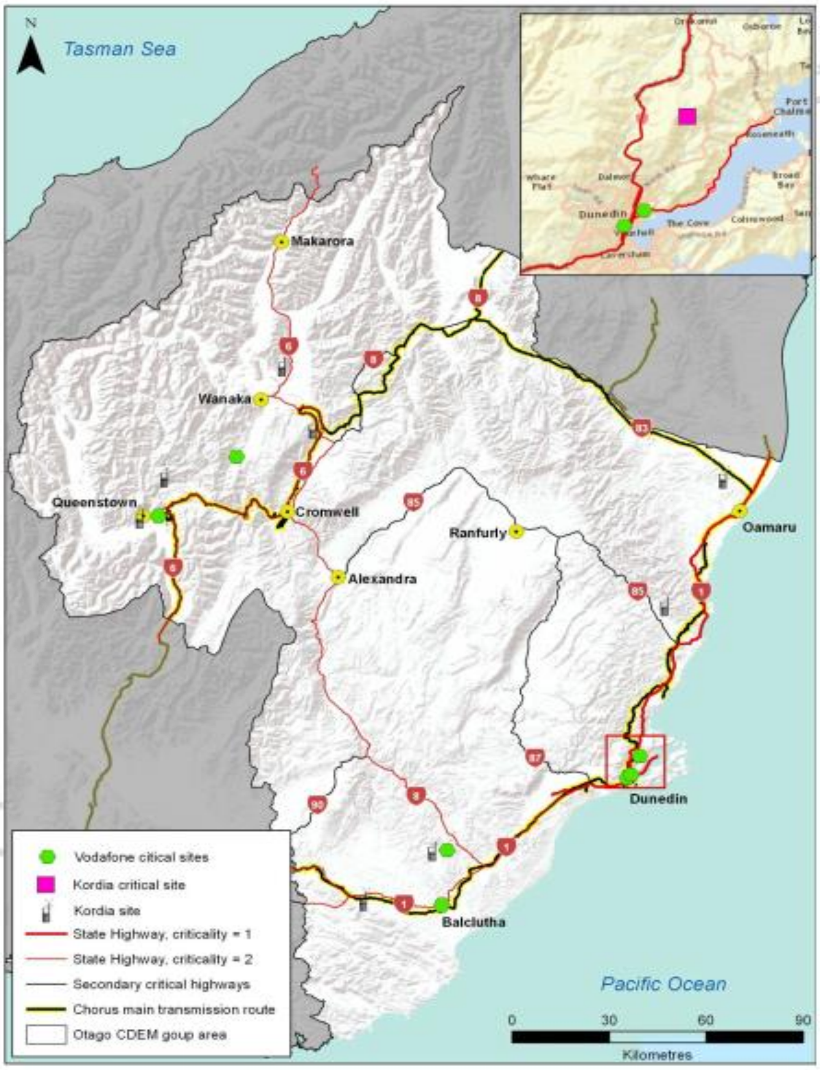

Figure 7-28: Critical communications infrastructure in the Otago region (Hexamer, 2018).

Some of the major telecommunication providers include Vodafone, Chorus, Spark and Kordia.

Vodafone operates mobiles network services in Otago, providing 2G and 3G coverage across all of the region’s major towns and highways, whilst the 4G coverage is available in Dunedin City. Vodafone has around 60 cell sites, and 200 fixed line service sites (exchanges and road side cabinets) with a high capacity fibre-optic transmission ring that passes through Dunedin in the east and loops round through to Queenstown in the west (Hexamer, 2018). Three regionally critical sites exist:

- The Dunedin Point of Presence – from where fixed line services into Dunedin are provided.
- The Balclutha Point of Interface – provides a voice interconnect between Vodafone fixed-line and the other networks in the region.
- North East Dunedin Radio Access Network transmission hub.

Chorus provides fixed line services across the region to retail service providers who in turn supply value-add services to customers. The network consists of a mixture of technologies (fibre, copper and radio) and Chorus manages the lines between consumers and roadside cabinets. Chorus also has a fibre optic trunk transmission ring that provides connectivity northwards with the rest of the country. The eastern side follows the coast through Dunedin and into Southland, the western side follows the Mackenzie Country, Lindis pass and into Central Otago before heading south along State Highway (SH) 6 to Southland. Both sides of this network have elements of shared fibres with other national network providers (Hexamer, 2018).

Other providers include:

- Spark: owns cellular and landline exchanges, and some fibre trunks and links.
- 2degrees: owns a number of cell sites in the region.
- Kordia: historically a broadcasting transmission business (TV and FM Radio), now 50% telecommunications, including wide area network (WAN).
- FX: provides a fibre optic trunk network across New Zealand.

7.10.2 Exposure

Telecommunication assets in low lying and coastal areas such as South Dunedin and Harbourside will have an increased exposure to sea level rise and associated coastal flooding in a similar manner to the electricity assets assessed by Paulik et al. (2019a). Critical telecommunication components such as the Dunedin telecommunication exchange are located in these coastal and low-lying areas, therefore are exposed to sea level rise and associated coastal flooding. Sections of the Chorus main transmission route located along the coast, will have a higher exposure to sea level rise and associated coastal flooding than the inland sections of the route. Key nodes are also exposed to flooding in areas such as Oamaru and Balclutha (Hexamer, 2018).

Telecommunication lines are exposed to extreme weather events including, extreme rainfall, snow and rainfall induced landslides throughout the Central Otago and Queenstown Lakes districts due to the steep mountainous environment. The section of the Chorus main transmission route located through the Lindis Pass is exposed to snow and rainfall induced landslides (Hexamer, 2018).

Assets are also exposed where cables cross rivers on bridge structures. Telecommunication providers are aware of the risk to the network on these river crossing structures (Stakeholder Engagement, 2020). The significant 2019 South Island flood event resulted in outages to cables near the Waitaki and Rangitata rivers. This type of exposure will likely increase with time, as extreme events become more frequent within the region.

Telecommunication assets will also be exposed to increased fire weather throughout the region, especially where these are located adjacent to vegetated areas (scrub or forestry).

7.10.3 Vulnerability

The vulnerability telecommunications infrastructrue to climate hazards will relate to specific design and material characteristics, and these are discussed below in terms of sensitivity and adaptive capacity.

Sensitivity

Sensitivity of transmission infrastructure to climatic changes is driven by age, condition and type of structure. Those telecommunication assets that are older in age and design are likely to have an increased sensitivity to climatic changes as they begin to be pushed beyond their design limits. However, with the short lived nature of telecommunication infrastructure (less than 50 years) and the increasing focus on wireless technologies, the sensitivity to climate change is arguably less (Maunsell Australia Pty Ltd, 2008).

Telecommunication cables in the Otago region contain a mixture of technologies, including fibre, copper and microwave radio. Copper and microwave radio cables are sensitive to climate change due to their older age and design and greater potential for damage. These cables are more frequently replaced with fibre cables which are considered more robust (Hexamer, 2018).

Where cables cross rivers, they are generally located on bridge structures, and therefore their level of potential damage is related to the sensitivity of the bridge itself. There are a number of bridges which cross major rivers (such as the Waitaki and Rangitata) which are prone to flooding and which serve communities within Otago.

Increased temperatures can cause stress on all telecommunication infrastructure which has the potential to reduce its life span. Higher costs can be incurred to keep equipment cool, and with increased demand for cooling, power outages may occur more frequently. Increased temperatures can also increase the chance of fire, resulting in a lack of access and/or damaged assets (Maunsell Australia Pty Ltd, 2008).

For overhead cables, extreme winds and rainfall can cause damage from third party damage (debris), localised flooding and associated reduction in ground level access to equipment, and damage to foundations (Maunsell Australia Pty Ltd, 2008; NJ Climate Adaptation Alliance, 2014). Overhead cables are often the last point of connection to properties, therefore localised impacts are likely to be increased from wind and flooding.

Adaptive capacity

Telecommunication networks have a relatively high adaptive capacity due to design life generally being less than 50 years. Fibre has a design life of approximately 20 years, with copper cabling varying within a range of approximately 10-30 years (Stakeholder Engagement, 2020). Poles, ducts and manholes have the largest range of design life, ranging from 20-50 years. The design life of network enclosures (cabinets) is between 5-20 years, with network electronics ranging from 2-25 years (Stakeholder Engagement, 2020). When considering gradual impacts of climate change, it is possible to provide staged adaptations and upgrade options that fit with individual asset design lives.

7.10.4 Discussion

Telecommunication network failure and disruptions in the ability to communicate or access information can severely impact communities, businesses and government agencies during periods of disaster or extreme events. This inability to communicate can cause severe consequences to society, wellbeing, business value and the broader economy. Overloading of the network can also occur during extreme weather events due to people trying to communicate during times of distress (B9.1) (Adams et al., 2014; EL Khaled & Mcheick, 2019).

Communities within the Otago region are familiar with the consequences that can occur when telecommunication networks fail. A "major" outage occurred in December 2019 after extreme rainfall and flooding caused slips across the South Island. Two fibre-optic cable lines were damaged due to the flooding and slips, with one of the lines having 1 km of damage. Additionally, more than 170 cell towers were affected, causing disruptions and power outages to approximately 3,600 homes and businesses across the South Island. This failure also caused disruptions to

Queenstown and Dunedin airports, where flights were cancelled or diverted due to the failure (Otago Daily Times, 2019e; Stuff, 2019).

Increased fire weather as a result of climate change has significant potential to impact on telecommunication infrastructure in the future (B9.2). Learnings can be taken from the recent 2019/2020 bushfires in Australia which caused major, widespread outages across parts of Australia, particularly in New South Wales and Victoria. These outages have led to a Royal Commission into the bushfire event, including a specific focus on telecommunications resilience. Around 1,400 facilities were impacted by the bushfires with over half experiencing outages for 4 hours or greater. It was noted that most of the outages were caused by power failure rather than direct fire damage (ACMA, 2020).

Figure 7-29 illustrates an 'impact/implication timeline' relating to climate change hazards impacting telecommunication infrastructure. This indicates that, for example, increased frequency of extreme weather can lead to asset damage and service interruptions, which can result in increased maintenance costs and higher rates of asset depreciation and need for renewals. This rise in asset renewal rates will also affect capital expenditure budgets and shorten associated asset renewal cycles (Maunsell Australia Pty Ltd, 2008).

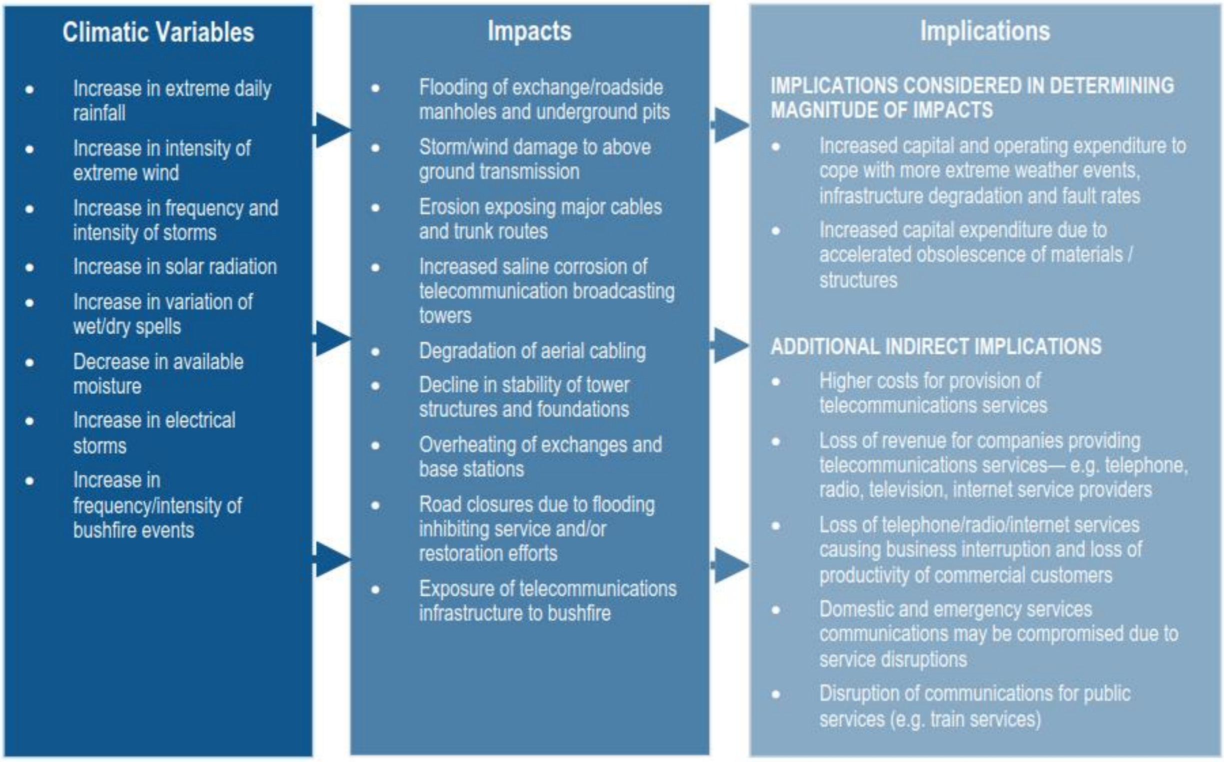

Figure 7-29: Impact timeline for telecommunication infrastructure (Maunsell Australia Pty Ltd, 2008).

Telecommunication networks are at risk due to climate change. Table 7-12 presents the current and future risks to the telecommunication network to the climatic changes and associated hazards identified as being of elevated importance by ORC and other stakeholders. It highlights that there is a low risk to sea level rise and extreme weather events at 2040, with the risk increasing to moderate at 2090.

Table 7-12: Summary risk rating for telecommunication networks

Risk No.	Risk statement	Exposure			Vulnerability				Risk		
					Sensitivity			Adaptive Capacity			
		Present	2040	2090	Present	2040	2090	Constant	Present	2040	2090
B9.1	Risk to telco assets due to extreme weather events.	L	M	H	M	M	M	H	L	L	M
B9.2	Risk to telco assets due to increased fire weather.	L	M	H	H	H	H	M	L	M	H
B9.3	Risk to telco assets due to sea level rise and salinity stress.	L	M	H	M	M	M	H	L	L	M
B9.4	Risk to telco assets due to inland flooding.	L	M	H	L	L	L	H	L	L	M

Governance

8 Governance Domain

8.1 Introduction

Governance is understood as the relationships between, coordination mechanisms for, and processes undertaken by the state, market and civil society to address collective issues (Driessen et al., 2012; Lange et al., 2013). The Governance Domain definition used in this risk assessment is: *the governing structures, frameworks and processes for decision making that exist in and between governments, economic and social institutions*. Governance sits across all aspects of New Zealand society, from the Treaty partnership between Māori and the Government (the Crown) to the relationships between local government and communities, the economy, the built environment and natural ecosystems.

The governance risks have not been specifically rated (this is discussed in Section 3.3). They have, however, been categorised in Table 8-1 in relation to whether local government or central government has primary influence in responding to the risks - or both.

Table 8-1: Summary of risk ratings in the Governance Domain

Risks		Local vs central government influence
G1	Risk that existing planning, decision making, and legislative frameworks are inadequate for responding to long-term climate change risks and result in maladaptive responses, and potential liability.	Combination of local and central influence.
G2	Risk of local authorities lacking capacity to effectively respond to climate change.	Local direct influence.
G3	Risk that the national, regional and local governance/institutional structures for managing climate change are inadequate.	Combination of local and central influence.
G4	Risk that a low level of community awareness and engagement hinders communication of climate risk and uncertainty, and leads to de-prioritisation.	Local direct influence.
G5	Risk that climate change will result in increasing damage costs, with insufficient financing for adaptation and risk reduction.	Combination of local and central influence.
G6	Risk that public services will be impacted by climate change.	Combination of local and central influence.

8.1.1 G1: Risk that existing planning, decision making, and legislative frameworks are inadequate for responding to long-term climate change risks and result in maladaptive responses and potential liability.

Overview

Adaptation poses unprecedented technical, administrative and political challenges that require proactive governance (Boston & Lawrence, 2018). At a national level, New Zealand's current policy frameworks are poorly equipped to address the nature, magnitude and duration of the problems posed by climate change. Such issues include poor alignment of policies and legislation relevant to the effects of climate change resulting in little coordination or alignment of priorities (Boston & Lawrence, 2018; Climate Change Adaptation Technical Working Group, 2017; Lawrence, 2016; Lawrence, 2015; Hana et al., 2018).

Relevant statutes include but are not limited to:

- The Resource Management Act 1991 (RMA).
- The New Zealand Coastal Policy Statement 2010 (NZCPS).
- The Climate Change Response (Zero Carbon) Amendment Act 2019.
- The National Policy Statement on Urban Development 2020 (NPS-UD).
- The Local Government Act 2002 (LGA).
- The Soil Conservation and Rivers Control Act 1941.
- The Civil Defence Emergency Management Act 2002.
- The Building Act 2004.

For example, the Building Act requires a 50 year design life with no explicit consideration of climate change effects; whereas the NZCPS uses a timeframe of at least 100 years; and the LGA requires planning for only 30 years within infrastructure plans. There is also an emphasis on short term planning over long term planning, such as the need for councils to only work under 10 year long term plans or 30 year infrastructure strategies (Climate Change Adaptation Technical Working Group, 2017; Boston & Lawrence, 2018).

There are a range of approaches for achieving informed and inclusive decision-making under uncertainty, including the dynamic adaptive pathways planning (DAPP) approach and managed retreat for highly vulnerable communities. However, there is generally little guidance and support from central government, resulting in decision makers at local government level applying legislative and regulatory requirements inconsistently (Boston & Lawrence, 2018; Stakeholder Consultation, 2019/2020).

Otago specific discussion

Inconsistencies and misalignment across legislation and policy has also created confusion in terms of what is expected of local government regarding adaptation activities and priorities. For example, the Climate Change Adaptation Technical Working Group noted that the Housing Accords and Special Housing Areas Act 2013 appeared to put priorities on housing supply ahead of natural hazard management considerations under the RMA. Similarly, councils have noted that they often feel pressure from property developers in areas vulnerable to climate change, indicating current policy frameworks and regulatory standards are not allowing councils to use their available powers effectively to safeguard future interests (Boston & Lawrence, 2018; Gibson & Mason, 2017; Climate Change Adaptation Technical Working Group, 2017). The NPS-UD (2020) requires councils to *provide at least sufficient development capacity to meet expected demand for housing and for business land over the short term, medium term, and long term.* There is also an objective that our urban environments are *resilient to the current and future effects of climate change*. However, the NPS-UD does not specify how this should be done.

Unclear roles and statutory responsibilities also result in fragmented plan-making between regional and territorial authorities and confusion on where legal liability lies for mitigating or adapting to climate change. Work done by the Deep South Science Challenge emphasised this lack of clarity, and concluded that *who is liable, and for what,* typically depends on the measure being employed and other factors particular to a given legal case.

Local government have been allocated major statutory responsibilities which relate to, or are affected by climate change, and are provided with some powers to undertake those responsibilities (Hodder, 2019). However it is widely acknowledged that these responsibilities are not clear, or given effect to. Examples of statutory responsibilities are summarised in the table below.

Table 8-2: Example statutory responsibilities for climate change

Statutory responsibility	Comment
Local Government Act	Under the Local Government Act, authorities are required to: plan and act to meet the current and future needs of local, district and regional communities.
Resource Management Act	The RMA also requires local authorities: to have particular regard to maintenance and enhancement of the quality of the environment and to the effects of climate change and local authorities' functions extend to controlling the effects of the use or development of land, including to avoid or mitigate natural hazards.
New Zealand Coastal Policy Statement (NZCPS)	Finally of note is the NCZPS which: requires local authorities to "ensure" that coastal hazard risks are managed and identified for a period of at least 100 years, taking account of climate change, and applying a precautionary approach.
National Policy Statement for Freshwater Management (NPSFM)	The NPSFM requires that: in setting limits on resource use, regional councils must have regard to the foreseeable impacts of climate change.

ORC are currently updating the Regional Policy Statement. This update is intending to provide a far more integrated approach to addressing and managing climate change impacts. In addition, more attention is being paid to embedding climate change into asset management planning and infrastructure strategies. This signals a higher degree of organisational maturity around this issue. LGNZ (2019) published a simple maturity ranking table for Councils in relation to climate risk and adaptation. 'Leading' practice included:

- **Risk assessment and adaptation:** Risks well understood, reviewed and updated regularly; adaptation actions (defend / accommodate / retreat) developed and planned; community aware and engaged in decision-making within a transparent process.
- **Leadership and governance:** Climate change is a strategic priority that influences all plans and decisions; Adaptation plans developed and monitoring and review regularly undertaken.
- **Networks and cooperation:** Regular cooperation and working groups established across disciplines and stakeholders – including civil defence, land use planning, asset planning etc; strong links to central government direction.

Climate change litigation

Globally, there are an increasing number of climate change related cases being made against public authorities. (Hodder, 2019) summarises that *'Current local government litigation risk mostly relates to decisions to limit development (short-term judicial review). In the future it seems likely to extend to the consequences of allowing development and failing to implement adaptation measures (e.g. from homeowners suffering the physical and economic consequences of climate change in the longer term)'.* If current local and global trends are any indication, there could be further litigation against central/local governments for climate inaction, relating to both mitigation and adaptation.

Kai Tahu and Treaty Implications

Inadequate policy frameworks also risk a breach of Treaty obligations by failing to engage adequately with and protect current and future generations of Māori from the impacts of climate change. This particularly concerns the principles of partnership, and participation and protection. Claims relating to climate change already sit with the Waitangi Tribunal, which has determined that climate change is a Treaty issue because of the need to prevent harm to Māori coastal property (Ministry for the Environment, 2020; Iorns, 2019). Treaty obligations may also be breached if specific consideration is not given to protecting Māori assets, meaningful engagement and involvement of Māori, and using mātauraka Māori in adaptation (Ministry for the Environment, 2020; Iorns, 2019).

At the regional level in Otago, the Treaty Partnership is overseen by the Mana-to-Mana governance body. This is made up of representatives from all seven rūnaka, and elected members of the ORC. It provides leadership for the Treaty Partnership and rightly assumes the position that Kāi Tahu Rūnaka have the authority for a full equal partnership with the ORC in the Otago Region.

The Ngāi Tahu Claims Settlement Act 1998 (Government of New Zealand, 1998) and Kāi Tahu ki Otago Natural Resource Management Plan 2005 (Ministry for the Environment, 2005) are frameworks which outline relationship obligations and responsibilities between the Crown and mana whenua in specific situations. These situations will be altered by climate change, due to its effects on Kāi Tahu economic, environmental, social and cultural values, practices and relationships. There is therefore a risk that climate change will weaken the effectiveness of these frameworks. How these frameworks operate in climate change-impacted areas should be given careful consideration at the regional level in Otago, in order to provide for good sustainable future governance and partnerships (Carter, 2020).

The National Climate Change Risk Assessment

Until the release of the National Climate Change Risk Assessment (NCCRA), central government did not have a clear set of priorities for addressing climate change risks. The NCCRA provides the first national picture of the risks New Zealand faces from climate change, and lays the foundation for a national adaptation plan. This will potentially help with some of the issues identified above by providing a nationally agreed approach to addressing climate risk and prioritise action through the National Adaptation Plan (Ministry for the Environment, 2020).

Summary

The risk that existing planning, decision making, and legislative frameworks are inadequate for climate adaptation, is considered relevant for the Otago Region, given this is also a significant risk identified at a national level (MfE, 2020). This risk has the potential to inhibit climate responses if policy and legislation remain unaligned and unclear (Climate Change Adaptation Technical Working Group, 2017). This, in turn, creates a risk that new local and central government initiatives are unable to deliver the benefits planned because they could increase the Otago Region's exposure to climate risk. This ability to influence this risk is considered to rest with both central and local government.

8.1.2 G2: Risk of local authorities lacking the capacity to effectively respond to climate change

Climate Change Adaptation Technical Working Group (2017) identified that a significant amount of technical information is available on how the climate is changing throughout New Zealand. However, the challenge lies in ensuring this information is readily available across all sectors in a format that can effectively inform decision-making. There is also a need for this information and data to be tailored to local scales, and utilised to understand the potential economic costs over the mid to long term if not action is taken. One of the biggest hinderances identified in this regard is the availability of resources (due to constrained capacity and competing priorities within Council) and funding which often results in maladaptation (Climate Change Adaptation Technical Working Group, 2017).

Along with the potential lack of some technical information and resources, lack of experience and expertise in managing climate risks may also have impact on the ability to adapt (Stakeholder Consultation, 2019/2020).

It is noted that indigenous knowledge is critical in developing culturally appropriate risk assessments and adaptation responses. The Intergovernmental Panel on Climate Change's 4th report recommends that indigenous knowledge forms the basis for adaptation strategies and practice (Carter, 2019). Local authorities currently lack capacity to make effective use of mātauraka Māori. This is largely due to limitations on funding, resources, and expertise.

Summary

A lack of capacity due to competing priorities within the Otago Region was identified as a risk, as it clearly has impact on the ability to mitigate all risks across all domains. Where local authorities do not have the capacity, expertise or experience needed, adaptation will be made more difficult. This ability to influence this risk is considered to rest primarily with local government.

8.1.3 G3: Risk that the regional and local governance/institutional structures for managing climate change are inadequate

Partly because of the general misalignment of existing planning, decision making and legislation frameworks (as outlined above), regional and local governance / institutional structures for managing climate change may also be inadequate. Current structures have poorly defined or overlapping roles and responsibilities, making it difficult for central and local government and sectors to proactively organise themselves and take action (Climate Change Adaptation Technical Working Group, 2017).

While messages and action on climate change from central government are increasing and becoming more prominent, there is still some uncertainty with regard to specific responsibilities at central and local government. Many councils realise the importance of acting on adaptation and would like to do more, however lack of support from central government can make this difficult (Climate Change Adaptation Technical Working Group, 2017).

While the NCCRA (MfE, 2020) provides a national focus on this issue, the National Adaptation Plan (NAP) will not be completed until 2022, and therefore there will remain uncertainty in this regard, as to what potential responses the government and others may take.

Summary

Without a common strategy or clearly defined roles and responsibilities, there is a risk that collaboration does not occur across national, regional and local scales. In addition, the present capacity of councils across the Otago Region is varied (Stakeholder Engagement, 2020). This may result in gaps or overlaps in adaptation activities resulting in maladaptation. This ability to influence this risk is considered to rest with both central and local government.

8.1.4 G4: Risk that a low level of community awareness and engagement hinders communication of climate risk and uncertainty, and leads to de-prioritisation.

Carefully planned and implemented community engagement is an essential component for decision making, and for implementing effective climate mitigation and adaptation strategies. Well-designed and well-implemented community engagement has been described as critical to effective, transparent and accountable governance and generally results in better policy decisions (Wiseman et al., 2010). This is due to decisions being made at the lowest, most decentralised or most local level at which effective action can be taken with trust being built between the community and decision makers (Rawsthorne & Christian, 2004; Stephenson et al., 2019; Wiseman et al., 2010; Pidgeon & Fischhoff, 2011; Rayner & Minns, 2015).

However, a major challenge facing climate scientists and decision makers is communicating technical knowledge, the risks and uncertainties surrounding potential changes over the coming years, decades and centuries to non-specialists (Pidgeon & Fischhoff, 2011). Many regional and local councils realise the importance of acting on adaptation, however limited community buy-in has been identified as a significant barrier (Climate Change Adaptation Technical Working Group, 2017).

The ability to communicate uncertainty and make decisions without a full understanding of what the future holds created a difficult situation for effectively engaging with communities. If only a small proportion of the community are pursuing adaptation, while others persist in avoiding the issue or maladaptive strategies, the former may feel isolated and disempowered. This may result in governments and other institutions being put under less pressure to undertake climate actions (effectively de-prioritising), particularly those with long lifetimes - resulting in maladaptation (Rayner & Minns, 2015; Stephenson et al., 2019).

Summary

A low level of community awareness and engagement was deemed to be a risk for Otago, as it hinders communication of climate risk, reduced buy-in, and de-prioritises action. As discussed above, well-designed and well-implemented community engagement has been described as critical to effective, transparent and accountable governance and generally results in better policy decisions. This ability to influence this risk is considered to rest primarily with local government.

8.1.5 G5: Risk that climate change will result in increasing damage costs, with insufficient financing for adaptation and risk reduction

Damage caused by climate-related natural hazards and the associated large investments required to redesign, reposition and futureproof public infrastructure (such as transport networks and water services) will significantly increase the financial burden on citizens, businesses and public authorities (Boston & Lawrence, 2018). Climate related disasters are already resulting in significant costs for the Otago Region including but not limited to the following in the past five years alone:

- 2015 South Dunedin flooding was estimated by insurer IAG to have social and economic costs of up to $138 million (Otago Regional Council, 2016a).
- 2017 Central Otago flood repairs cost nearly $1 million for central Otago District (Stuff, 2018). This event also affected most of the entire region with a state of emergency declared. The total cost of the South Island floods was estimated at $31.2 million (ICNZ, 2017a).
- 2017 Dunedin flooding cost insurers approximately $1.7 million (ICNZ, 2017b).
- 2019 December and 2020 February flood events resulted in an estimated cost for ORC of (Otago Regional Council, 2020d):
  - $0.65 million for priority 1 flood repairs.
  - $3.25 million for priority 2 flood repairs.

The expected costs of future impacts are difficult to estimate as they will depend on numerous variables, including but not limited to (Boston & Lawrence, 2018):

- The time frames under consideration.
- The path of global greenhouse gas emissions.
- The projected impact of global warming on the polar ice sheets, ocean currents and storm patterns.
- The assumptions made about the pattern and scale of future development.
- The nature and types of risks considered and their related costs (e.g. direct and indirect, market and non-market).
- How losses (e.g. of land, buildings and infrastructure) are valued.
- And the kind of adaptation measures or protection strategies adopted.

It is estimated that the annual cost of repairing land transport networks damaged by weather-related events has more than quadrupled over the past decade in New Zealand, while the economic impact of major floods and droughts is increasing (Boston & Lawrence, 2018).

Effective coastal adaptation measures are expected to reduce these losses substantially with every $1 invested in disaster risk reduction measures has the potential to save up to $15 in post-disaster recovery activities (UNDRR, 2019). However, in general, public expenditure on pre-event risk reduction is also much harder to 'sell' politically than the funding of post-disaster recovery, with voters generally rewarding governments that spend money on disaster relief, rather than investing in prevention and preparedness. This can result in significant barriers for local authorities to be able to fund and resource proactive risk reduction and mitigation activities particularly as funding for local government relies heavily on rate payers and the buy in of local communities (Reisinger et al., 2014; Hinkel et al., 2014; Boston & Lawrence, 2018).

Summary

Increasing damage costs from more extreme and frequent shock events are considered a key risk, along with the problems of financing for adaptation and risk reduction. While the costs of adapting to future climate will be significant, so will be costs of future damages. This ability to influence this risk is considered to rest with both central and local government.

8.1.6 G6: Risk that public services will be impacted by climate change

As discussed in Section 2, climate change will increase the frequency, severity and spatial extent of natural hazard events. The community impacts that result will increase demands on a range of public services including social services, agencies and emergency management services in Otago as well as across New Zealand.

Significant events will likely result in the need to draw on resources from surrounding regions not just those impacted by the event, therefore requiring clear coordination at national and regional levels for consistency in emergency response and recovery. Ensuring community participation in preparedness and response planning will be essential for the successful response and recovery from the potential increase in emergency events due to climate change (van Krieken et al., 2017; Stakeholder Engagement, 2020; Curtis et al., 2017; Ghazali et al., 2018; van Vonderen, 2018).

Otago has already experienced concurrent and cascading severe and extreme events. For example, in July 2017, heavy rain and high tides led to hundreds of homes being evacuated and a state of emergency in Waitaki, Dunedin, and eventually the entire Otago region due to significant flooding (Coomer et al., 2018). As events become increasingly complex, a multi-hazards and cross regional approach to organising the emergency management sector is likely to be needed (Lawrence & Saunders, 2017).

Other agencies' capacity and capability may also be tested and challenged as a result of climate change. Councils, government agencies and NGOs will need to respond to a range of emerging climate change impacts that may be new, or at a broader scale than previously experienced. Immigrants from different parts of New Zealand or different countries may arrive in Otago (as a result of climate risks elsewhere) and settle within communities that are new to them. This may call for new skills, or increases in resources, to deal with a range of migrant communities, and people with different or complex needs. Agencies which regularly deal with vulnerable communities may find themselves stretched as a result of new and emerging climate impacts (Stakeholder engagement, 2020).

Summary

Increasing disruption to a range of public services is considered a key risk. This will impact multiple agencies, and regions and require human and financial resources from many areas in order to respond. This ability to influence this risk is considered to rest with both central and local government.

9 Interacting risks

Climate change impacts and implications can propagate as 'cascades' across physical and human systems, compounding to form multiple impacts across various sectors. Such effects arise because of the *interdependencies* between natural and socio-economic systems as they change, and from *feedback loops* that occur between them. As such, cascading impacts have significant implications for community wellbeing, adaptive capacity, and governance (Lawrence et al, 2018). This section provides a discussion of the context of cascading risks (Section 9.1) and identifies a number of interactions between OCCRA risks (Section 9.2).

9.1 Cascading risks

Not all impacts of climate change emerge in the same way. Some have direct impacts and emerge abruptly, others emerge slowly, and there can be multiple impacts. In addition, they can occur concurrently in different combinations spatially and temporally across urban settings, infrastructure, the natural environment and the economy.

Cascading risks can therefore affect the ability of individuals, governments, and the private sector to adapt in time before damaging impacts occurs. This has implications for governance and institutions' ability to address the resulting instability within society and across economic domains.

To date, much of the initial analysis of cascading risks has focused heavily on the nature and form of triggering events such as the natural hazard or the loss of function of a physical component of critical infrastructure. In its simplest form, the chain of causality is often described as a 'toppling domino effect', where a sudden shock to the system generates uncontrolled chain losses down the line of connected systems. Another word for this is 'interdependencies'.

There are, however additional types of cascades, which can create impacts across essentially all domains, for example; into emergency management, institutions, and transboundary crises. Cascades can also result in feedback loops which can be self-reinforcing (Lawrence et al, 2018).

Understanding cascades can help identify potential downstream impacts, points of escalation of possible crises and secondary events, and the role of human-induced elements in the creation of causal pathways.

9.2 OCCRA interacting and cascading risks

The OCCRA provides a regional overview of how Otago may be affected by various hazards and threats that are caused or influenced by climate change. Most **direct** risks arise within the natural, economy, human and built environment domains, where there is direct exposure to climate hazards.

Indirect (or interacting / cascading) risks, however can result across all domains through reliance on or interaction with, elements or risks in other domains that are directly exposed to hazards. Examples include wastewater overflows (built environment) impacting on freshwater ecosystems (natural environment); or algal blooms (natural environment) interacting with public health (Human Domain) and water supplies (built environment).

As such, it is clear that the domains and elements at risk are highly interconnected and interdependent. Although the OCCRA does not consider cascading impacts in detail, a range of interactions between risks and domains have been identified in Table 9-1.

Table 9-1: Interacting risks examples

Risk No.	Risk	Interacting risks	Description
N1	Risks to the terrestrial ecosystems from increasing temperatures, changes in rainfall and reduced snow and ice.	N (General), E3, E7, H1	Terrestrial ecosystems are both affected by other natural environment risks (N2, N4, N5, N6) and these risks could exacerbate other natural environment risks (N2, N3, N5). Risks to terrestrial ecosystems also potentially have cascading impacts to cultural identity (H1), the forestry sector (E3), and the tourism sector (E7).
N2	Risks to the freshwater (rivers and lakes) ecosystems from increasing temperatures and extreme weather events.	N (General), E1, E2, E4, E7, H1, B3	The risks to freshwater (rivers and lakes) ecosystems will likely result in cascading impacts to cultural identity (H1), economic activity (E1, E2, E4, E7), and water supply (B3). This risk will also interact with the natural environment through potentially affecting terrestrial ecosystems (N1), wetlands (N3), and water quality and quantity (N5).
N3	Risks to the coastal and marine ecosystems from climate change hazards including ocean acidification and marine heatwaves.	N (General), E4, H1	The risk climate change poses to coastal and marine ecosystems will likely interact with cultural identity (H1) and the fisheries and aquaculture sector (E4). Given the complexity of ecosystems, impacts on coastal and marine ecosystems could also affect other natural environment risks, e.g. the food sources of terrestrial species (N1).
N4	Risks to coastal, inland and alpine wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice.	N (General), H1, B3	The degradation of coastal, inland and alpine wetland ecosystems could have cascading impacts on freshwater ecosystems (N2), water quality and quantity (N5) and other natural environment risks (e.g. N1). Wetlands also play a crucial role in reducing flood hazards, and this risk could therefore also have wide ranging impacts to the economy and built environment domains.
N5	Risks to Otago water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice.	N (General), E1, E2, E4, H1, B3	Risks to the water quality and quantity of Otago could have cascading impacts on other natural environment risks (N1, N2, N3, N4). This could also interact with risks in the human (H1), economy (E1, E2, E4) and the Built Environment Domain (B3).
N6	Risks to native ecosystems posed by increasing threats from invasive plants, pests and disease due to climate change.	N (General), H1, E1, E2	The risk of pest and diseases to native ecosystems could have complex cascading impacts on other natural environment risks in general, and also interact with the human (H1) and economy domains (E1, E2).
H1	Risks to Kāi Tahu sites, identity and practices, and non-Kāi Tahu cultural heritage sites, due to climate change.	N1, N3, N6, N2, N4, B1, E7, H3, H4.	Many risks in the natural environment, particularly those relating to terrestrial ecosystems (N1), coastal ecosystems (N3), native ecosystems (N6), freshwater ecosystems (N2), and wetlands (N4) are also likely to influence cultural landscapes and heritage impacting cultural identity and practices. Risks in the built environment relating to flooding of buildings (B1) are expected to affect some heritage sites. Loss of

			cultural heritage could have adverse consequences for the tourism sector (E7), and potentially mental health and connection to place (H3) and Māori wellbeing (H3, H4).
H2	Risks to community cohesion and resilience from climate change.	H1, H3, H4, H5, B3, B4, B6, B8, E1, E7	Loss of land and households will exacerbate physical and mental health issues (H3, H4), affect a sense of cultural belonging and identity (H1), and increase inequalities and cost of living (H5), adversely impacting social cohesion. Loss of or damage to cultural heritage sites and practices (H1) may also reduce social cohesion and community wellbeing. Risks to lifeline infrastructures, such as energy networks (B8), transport networks (B6) and water (B3, B4) can increase pressures on populations and communities. Climate change-related economic pressures, particularly in agricultural and tourism reliant communities (E1, E7) will also interact with displacement and community cohesion.
H3	Risk to mental wellbeing and health from climate change.	H4, H2, H5, H1, E (General)	There is a reciprocal relationship between physical (H4) and mental health, and identity and belonging support social cohesion (H2). Mental disorders may also entrench existing inequities (H5). If not seen as fair and transparent, governance processes may exacerbate this risk. Loss of cultural heritage (H1) may also impact identity and mental health. Loss of livelihoods due to climate change will also have an impact on economic wellbeing (E)
H4	Risk to physical health due to climate change.	H5, G4, H2, H3, E (General)	Health costs will increase financial burdens (E) and are likely to increase inequalities (H5), erode trust in government (G4), and lead to decreased social cohesion (H2). In addition, physical health and mental health are strongly related: poor physical health can worsen mental health and vice versa (H3).
H5	Risk to increased inequities and cost of living due to climate change.	H4, H3, H1, E (General), H2, G1, G2, G3, B1, B5, B8, B9	Increased inequity is linked to economic risks (E) and increasing costs of damages and adaptation (G6). Inequity is likely to exacerbate physical and mental health issues (H4, H3) and affect a sense of identity and belonging (H1); it may even lead to lower social cohesion (H2) as a result of inadequate adaptation and action (G1, G2, G3). Climate hazards that damage or limit access to infrastructure such as homes (B1), transport networks (B5), electricity (B8) and telecommunications (B9) have the greatest impact on marginalised people.
E1	Risks to the livestock farming sector from climate change hazards including drought, increased fire weather, inland flooding, and increased landslides.	N1, N6, N5, B1, B2, B3, B4, G1, G2, G3, G4	Risks to land based primary industries may have complex interactions with terrestrial ecosystems (N1), particularly through ecosystem balances that influence pest species populations (N6). Water quality and quantity in the natural environment (N5) as well as irrigation systems (B3) will influence water availability for irrigation, stock water and other farming purposes. Built assets within the primary industries face risks to buildings from climate change (B1), including on-site wastewater treatment (B4) and also interact with risks to flood management schemes which protect some of Otago's productive cropland and pastures (B2). Risks to linear transport (B5), and airports and ports (B6) are fundamental to supply chain operation (E5) upon which primary industries are reliant. Adaptive capacity of farmers is related to community awareness and engagement (G4), and is also influenced by decision making at the governance level (G1, G2, G3).
E2	Risks to horticulture and viticulture from climate change hazards including temperature, drought, changing rainfall patterns and extreme weather.	N1, N6, N5, B1, B2, B3, B4, G1, G2, G3, G4	

E3	Risks to the forestry sector from climate change hazards including temperature, drought, fire and extreme weather.	N1, N6, N5, B1, B2, B3, B4, B8, G1, G2, G3, G4	Risks to the forestry sector have similar interacting risks as the land based primary industries. In addition, fire risk to electricity networks is often related to fire risk from forestry (B8).
E4	Risks to the fisheries and aquaculture sector from climate change hazards including marine water temperature and water quality.	N2, N3, N5, B4, B6, B7	Risks to the fisheries and aquaculture sector interact with risks to freshwater ecosystems (N2), and coastal and marine ecosystems (N3) which influence species, availability and health of fisheries. Risks to fisheries interact with risks to water quality (N5), which may be worsened by risks to the performance of stormwater and wastewater networks (B4), and solid waste (B7). Risks to fisheries infrastructure also interact with risks to ports (B6).
E5	Risks to primary sector supply chains from climate change hazards including inland flooding, coastal flooding and increased landslides.	E, B5, B6, G6	Risks to supply chains interact with economic risks to livestock farming (E1), horticulture and viticulture (E2), forestry (E3), fisheries (E4) and have broader implications to the cost of doing business (E6) and tourism (E7). Risks to supply chains are interact with risks to linear transport (B5) and airports and ports (B6). The response and recovery of supply chains is influenced by public services (G6) through the availability of emergency management services to restore supply chain connections.
E6	Risks to cost of doing business from climate change hazards including coastal and inland flooding, landslides, and extreme events.	B1, B2, B3, B4, B5, B6, B7, B8, B9, G1, G2, G3, G5, G6	The cost of doing business is related to governance risks (G1, G2) and local governance structures for managing climate chance (G3) which may influence the resilience of New Zealand as a nation and therefore the cost of climate change to society. It is also influenced by the risk that climate change will result in increasing damages to buildings (B1), and supporting services and infrastructure (B2, B3, B4, B5, B6, B7, B8, B9), increasing damage costs (G5), and increased risk to public services (G6) which may translate to increased operational costs.
E7	Risks to the tourism sector from climate change hazards including higher temperatures, reduced snow and ice, inland and coastal flooding, landslides and erosion.	N1, N2, N3, N4, N5, N6, B1, B3, B4, B5, B6, B7, B8, B9, G6	Risk to terrestrial (N1), freshwater (N2), coastal (N3), wetland (N4), and native (N6) ecosystems as well as water quality (N5) as these influence the natural characteristics of Otago around which much tourism is based. Built assets that support tourist attractions face risks to buildings from climate change (B1), and may be subject to risks to supporting services such as stormwater, wastewater (B4), water supply (B3), transport routes (B5, B6), solid waste (B7), electricity (B8), and telecommunications (B9). Public services impacted by climate change may detract from tourist attractions (G6).
B1	Risk to buildings and open spaces from climate change hazards including inland and coastal flooding, coastal erosion, sea level rise and salinity stress, and wildfire.	B, H (general), E (general), G(general)	Risks to buildings and open spaces may interact with other risks to the built environment (B). They also have complex cascading interactions with the Human Domain as buildings are often intrinsically linked to cultural identity (H1) and community cohesion (H2), and the impacts and implications of damages to homes and community facilities include worsening mental (H3) and physical (H4) health, and increased inequality (H5). Damage to buildings and open spaces has broad economic impacts across all sectors (E, G5) and complex interactions with governance risks (G1,G2), climate management structures (G3), community awareness (G4) and public services (G6). Risks to buildings from wildfire interacts with risks to electricity infrastructure (B8), risks to the forestry sector (E3), and risks to terrestrial ecosystems (N1).

B2	Risk to flood management schemes from inland and coastal flooding, and sea level rise and salinity stress.	B, N1, N2, N4, N5, H (general), E (general), G (general)	Risks to flood management schemes may interact with other risks to the built environment (B), and increase the risk of damage to terrestrial (N1), freshwater (N2) and wetland ecosystems (N4), and impact water quality (N5). Risks to flood management schemes have cascading risks to human wellbeing (H), risks to economic sectors (E, G5) and public services (G6).
B3	Risk to water supply infrastructure and irrigation systems due to drought, fire weather, flooding and sea level rise and salinity stress.	B, N2, N5, H(general), H4, E1, E2, E7, G1, G2, G6	Risks to water supply infrastructure and irrigation systems may interact with other risks to the built environment (B). These risks are intrinsically linked to freshwater ecosystems (N2) and water quality (N5), and have cascading interactions with the Human Domain (H), particularly physical health (H4). Risks to water supply and irrigation systems have broad economic interactions (E, G5), with direct implications for livestock farming (E1) and horticulture and viticulture (E2) as some industries within these sectors are dependent on irrigation. Risks to governance decision-making (G1, G2, G3) are likely to have cascading interactions including feedback cycles across all sectors, including water supply, particularly through delivery of water as a public service (G6).
B4	Risk to stormwater and wastewater networks from increased temperature, sea level rise and salinity stress, extreme weather events and flooding.	B, N (general), N2, N5, H, E(general) E6, G1, G2, G3, G6	Risks to stormwater and wastewater systems may interact with other risks to the built environment (B). These risks may have broad cascading implications for the natural environment, and are intrinsically linked to freshwater ecosystems (N2) and water quality (N5). Risks to stormwater and wastewater have complex cascading interactions with the Human Domain (H), as well as broad economic interactions (E) particularly relating to increased cost of doing business (E6) and increasing damage and adaptation costs (G5). Risks to governance decision-making (G1, G2, G3) are likely to have cascading interactions including feedback cycles across all sectors, including stormwater and wastewater services, particularly through their delivery as a public service (G6).
B5	Risks to linear transport (roads and rail) from flooding, coastal erosion, extreme weather events and landslides.	B, H(general), E(general) E5, E7, G(general)	Risks to linear transport may interact with other risks to the built environment (B) and may have complex cascading interactions with the Human Domain (H), as well as broad economic interactions (E) particularly relating to supply chain (E5) tourism (E7) and increasing damage and adaptation costs (G5). Risks to governance decision-making (G1, G2, G3) are likely to have cascading interactions including feedback cycles across all sectors, including linear transport, particularly through the delivery of transport routes as a public service (G6).
B6	Risk to airports and ports from flooding and extreme weather events.	B, H(general), E(general) E5, E7, G(general)	Risks to ports and airports may interact with other risks to the built environment (B) and may have complex cascading interactions with the Human Domain (H), as well as broad economic interactions (E) particularly relating to supply chain (E5) tourism (E7) and increasing damage and adaptation costs (G5). Risks to governance decision-making (G1, G2, G3) are likely to have cascading interactions including feedback cycles across all sectors, including ports and airports, particularly through their delivery as a public service (G6).

B7	Risk to solid waste (landfills and contaminated sites) to flooding and sea level rise and salinity stress.	N (general), E6, G6	Risks to solid waste may have complex interactions with the natural environment (N), and have economic impacts particularly relating to the cost of doing business (E6), increasing cost of damage and adaptation (G5) and impacts on the delivery of public services (G6).
B8	Risks to electricity (generation, transmission and distribution) networks from changes in rainfall, extreme weather events and flooding.	B (general), N (general), H(General), E (general), E3, G6	Risks to electricity networks may have complex interactions with the other risks to the built environment (B) as well as interactions with the natural environment (N), particularly terrestrial (N1) and freshwater (N2) ecosystems within which much of the electricity generation infrastructure is situated. Risks to electricity networks may have complex interactions with the human (H) and economic (E) domains, in particular with the forestry sector (E3) due to shared wildfire risk. Risks to electricity networks may also have interacting risks with the governance sector (G), particularly relating to the increasing cost of damage and adaptation (G5) and impacts on the delivery of public services (G6).
B9	Risks to telecommunications infrastructure due to sea level rise and salinity stress and extreme weather events.	B (general), H (general), E (general), G (general), G9	Risks to electricity networks may have complex interactions with the other risks to the built environment (B), as well as complex cascading risks to the Human Domain (H) and have broad economic implications (E) particularly relating to the cost of doing business (E6), increasing cost of damage and adaptation (G5) and impacts on the delivery of public services (G6).
G1 - G6	All governance risks.	B (general), E (general), N (general), H (general) G (general)	Risks to governance and decision making (G1, G2, G3) are likely to have cascading interactions including feedback cycles across all sectors (N, H, E, B), that relate to the role that governance has in reducing climate related risk, responding to hazards and managing adaptation. Further, risks to governance and decision making interact with risks to community awareness and engagement (G4), damage costs and costs of adaptation and risk reduction (G5), and provision of public services (G6), which in turn have broad reaching implications for community health and wellbeing (H), the natural environment (N), the economy (E) and the built environment (B).

10 Opportunities

Climate change may result in a number of opportunities for the Otago region. The opportunities identified in this section are those where climate change has the potential to directly lead to positive or beneficial outcomes. Opportunities for adaptation and opportunities that may indirectly arise are not considered.

Opportunities are likely to arise in parallel with risks, as both are driven by the same climate variables. Opportunities may also present other risks, as new or increased activity in some areas have consequences for others, for example increased agricultural production may place further pressure on the natural environment, such as increased irrigation demand and agricultural runoff.

Opportunities that were identified for Otago include those for the primary sector, businesses, health, and heating. These opportunities were identified in the risk assessment process, but do not constitute a comprehensive list of all the potential benefits that may result from climate change. Further research in this area is required to understand the potential benefits of climate change across all elements, sectors and domains.

Table 10-1: Opportunities

Domain	Opportunity
Human	HO1: Opportunity for reduction in cold weather related mortality due to warmer temperatures. Rising temperatures may reduce winter mortality rates due to the effect on indoor temperatures, crowding and moisture levels (NCCRA, 2020).
Natural	No opportunities identified.
Economic	EO1: Opportunity for increased primary sector productivity due to warmer temperatures and increased annual rainfall, including: • Grapes: Central Otago is in the southern margin for cool-climate wine production. Wine grapes in this region may benefit from warmer temperatures and drier conditions (MPI, 2010). • Horticulture: New species may become viable, and longer growing seasons may increase productivity (Reisinger et al., 2010). • Forestry: Growth rates may increase with warmer temperatures, higher CO2 concentrations and increased annual rainfall. • Pasture: Growth rates may increase with warmer temperatures, higher CO2 concentrations and increased annual rainfall. • Fisheries: increase in marine primary productivity may have a positive effect on the establishment of new fisheries as larger species migrate to follow this food source (MfE, 2019).
	EO2: Opportunity for businesses to provide adaptation related goods and services. • As with any disruptive force, new markets and opportunities arise that businesses may embrace. Opportunities could include insurance, adaptation finance, farming technology, and consulting and engineering (NCCRA, 2020).
Built	BO1: Opportunity for reduction in winter heating demand due to warmer temperatures. Warmer winters and fewer frosts could reduce heating demand, which also may reduce fuel poverty and have positive impacts in relation to public health (see opportunity H01).

	B02: Opportunity for increased capacity from renewable energy sources: • Wind generation: Opportunities may also arise when considering wind generation in Otago, as westerly winds are projected to increase. • Hydropower generation: Projected increases in average annual rainfall may increase river hydro generation capacity during winter and spring (Ministry for the Environment, 2018).
Governance	No opportunities identified.

11 Knowledge gaps and future research

There is overwhelming agreement that changing climatic conditions will exacerbate a range of existing threats and create new risks. A wide range of research is currently ongoing across a broad range of organisations. These include ORC, Universities and Crown Researchers, as well as many of the National Science Challenges. In some cases, the Science Challenges are focused on addressing knowledge gaps that directly or indirectly relate to some of the risks discussed in this assessment, particularly the *Building Better Homes, Towns, and Cities Challenge*, *Our Land and Water Challenge*, *Resilience to Nature's Challenges*, *Sustainable Seas* and *The Deep South Challenge*.

The OCCRA has identified risks relevant to Otago, and through this process a range of knowledge and research gaps were identified. These are summarised in Table 11-1.

Table 11-1: Knowledge gaps and further research

Research area	Comment
Climate science / hazard research	
Fire hazard	There are known research gaps around wildfire, the impact of climate change on wildfire, and factors specific to Otago.
Local changes	Closer ties with Otago University research departments would provide opportunities to expand local knowledge of regional responses to climate change.
Groundwater	Improved understanding of groundwater connectivity to sea level and sensitivity to climate change in Otago throughout the region.
Water availability	Continued research on water availability, including accounting for changes in groundwater and changing demand from users during dryer summer months.
Extreme events and wind	Sub regional exposure to increased extreme events and wind is not widely available but improved understanding of this hazard may be beneficial for tree crop farmers (summer fruit and pip fruit) who are particularly vulnerable to wind and storm damage at certain times of year.
Exposure research	
Landfills	There are a significant number of informal or legacy landfills that are in undocumented locations.
Tourism	Understanding of changing exposure of remote/wilderness tourism destinations to hazards such as landslides and flooding that can be a safety risk to tourists and may result in increased rescue operations.
Built environment	Understanding of the exposure of the built environment is evolving, however substantial gaps exist throughout this domain. Examples include urupā, cemeteries, heritage sites, landfills, and lifeline infrastructure.
Vulnerability / impact science research	
Health	Impacts and implications of gradual climate hazards on mental and physical health, including research into increased prevalence of disease.
Health	Research into the health and wellbeing of vulnerable groups.
Kāi Tahu sites, identity and practices	It is currently unknown what the specific impacts on mahika kai (customary gathering of food) and taoka (treasured) species will be in Otago.
Crown and mana whenua governance frameworks	Research into understanding the impact of climate change on the effectiveness of frameworks which outline relationship obligations and responsibilities between the Crown and mana whenua (c.f. Ngāi Tahu Claims Settlement Act 1998 (Government of New Zealand, 1998) and Kāi Tahu ki Otago Natural Resource Management Plan 2005 (Ministry for the Environment, 2005)).

Terrestrial ecosystems	There are gaps in understanding and monitoring regarding the health of Otago specific terrestrial ecosystems – consider expanding long-term monitoring to include information quantifying population sizes, juvenile recruitment, breeding success, for species that are representative of different terrestrial ecosystem types.
Habitat size	It is difficult to quantify how quickly some habitats are reducing in size / the degree to which habitat fragmentation is occurring for many terrestrial habitat types in Otago.
Water quality	ORC's list of water monitoring locations appears to focus primarily on rivers and a few larger lakes, there is a gap in monitoring small lakes across the region – small lakes are considered more likely to show negative impacts related to climate change earlier than larger lakes.
Aquatic/wetland/ estuary ecosystems	It was difficult to find published examples of aquatic/wetland/estuarine ecological surveys conducted multiple times in the same locations. Therefore it is not known whether there is information that could be used to quantify changes in these systems over time.
Groundwater	It was difficult to find published information regarding groundwater quantity and quality, and also to identify coastal aquifers that may be at risk of salination due to lack of information. Risk to ground water has significant inherent uncertainties.
Threshold responses	Some types of natural environment are expected to exhibit threshold responses – particularly aquatic ecosystems where the level of adaptive capacity may buffer climate change effects. The level to which this effect may occur for different types of environments and the time periods until thresholds are reached (and rapid changes ensue) are unknown and require further research.
All primary industries	Research into sustainable farming practices, mitigation of impacts and innovation for autonomous adaptation.
All primary industries	Research into harnessing the opportunities of climate change related to changing growing conditions warmer temperatures (e.g. Our Land and Water National Science Challenge program).
All primary industries	Biosecurity/resistance to invasive pest species. Otago may benefit from further investment in understanding new biosecurity threats, and control or mitigation measures as the changing climate accommodates new pest species.
Fisheries	General research into fisheries, changing aquatic ecosystems and this relationship with commercial fishing practices.
Cost of doing business	Planning and budgeting for the growing financial burden of climate change is critical across all public and private sectors, and relies on an improved understanding of specific sectoral risks, as well wider business and governance risks. This could be in the form of research to assist businesses to consider climate risks to their businesses and incorporate agility, innovation and adaption as part of business plans and systems.
Tourism	Research into options for transformational adaptation options for tourism.
Landfills	The vulnerability of landfills to climate hazards is poorly understood.
Lifeline utilities	A range of critical infrastructure sectors would benefit on further research into specific vulnerabilities.
Business and economy	Studies of economic risks and impacts and cascading economic impacts.

12 Summary and next steps

This document provides a broad understanding of climate change risks within the Otago region, and how these risks may change over time, based on current understanding of climate science and future projections. It is informed by current climate science, and will support decision-makers across multiple sectors to develop further understanding, and work towards adaptation decisions.

This risk assessment report is a ‘first step’ and has been developed by ORC on behalf of regional stakeholders and Kāi Tahu. The partnership and collaborative approach taken in developing this assessment has been important and will be required to be maintained going forward into risk prioritisation and action planning – if the region is to respond effectively to the report findings.

Next steps

The next step is to consider the risks highlighted within this report and agree on those which are either priorities for adaptation planning or which require further research. Following this, those parties responsible for responding to identified risks (Councils, utilities, others) will need to develop appropriate plans and programmes to respond. Consideration is being given by ORC to building collaboration with stakeholders in supporting and developing these responses and a regional climate change adaptation approach.

While the risk assessment can be effective in informing planning and decision-making by individual agencies and stakeholders, a collaborative approach will ultimately be more effective for the region as a whole. Aspects of this risk assessment which would particularly benefit from collaborative regional discussions include risk prioritisation, targeting and priorities for undertaking more detailed risk assessments (e.g. governance), coordination and sharing of knowledge and communications material and messaging, undertaking studies to address gaps in knowledge and development of a positive regional approach to community resilience.

As discussed in Section 8.1.4, local councils realise the importance of acting on adaptation, however lack of community buy-in has been identified as a significant barrier. This could be a potential area for collaboration across the region (Stakeholder engagement, 2021).

Consideration of a number of specific risks is already underway is planned to be undertaken by ORC, local councils, stakeholders, organisations and individuals within the region. An example includes an ORC work programme focussing on the Clutha Delta. This involves a local investigation into coastal morphology and climate change impacts (in particular, the impact to the flood protection and drainage scheme), which has been completed, and planning is underway for targeted investigations to assist with understanding possible response options.

This OCCRA is an initial step in an ongoing process of understanding climate change risks in the Otago region and how they might change in the future. Some information gaps were identified during this process and filling these gaps will be an important step in improving subsequent assessments. Over time, further research will be undertaken by various parties and information will improve. As changes happen, the risk scape will also evolve, and as a result, the risk scorings will need to be reviewed and updated to reflect this. The risk assessment will need to be repeated at appropriate intervals in order to update the risk ratings and to reflect changes in information available. This will be done in a timeframe that aligns with updates to the NCCRA. The next NCCRA will be completed by the Climate Change Commission within the next 6 years as the Climate Change Response (Zero Carbon) Amendment Act 2019 requires a risk assessment at least every six years.

Prioritisation

Prioritisation of high risks for response / further research will need to be undertaken by ORC, Kāi Tahu and regional stakeholders following the OCCRA. Criteria for prioritisation will vary and could include: level of risk relative to time horizon (i.e. earlier risks more urgent); level of agreement on risk priority; gaps in information; potential for cascading impacts; potential for lock-in or maladaptation; potential for tipping points or thresholds to be reached; or potential for opportunistic implementation due to alignment with other investment.

Further studies and gaps

This report has highlighted information gaps and areas for further research (Section 11). Some of these will fall under the responsibility of ORC to investigate and inform while others will be more industry and sector targeted. Various bodies and organisations will help to fill these information gaps and this will likely involve partnerships between Universities, CRIs, councils, Kāi Tahu and stakeholders. Increasing our understanding in these areas will help inform decision making and improve future iterations of the risk assessment.

As discussed in Section 8.1.4, local councils realise the importance of acting on adaptation, however lack of community buy-in has been identified as a significant barrier. This could be a potential area for collaboration across the region (Stakeholder engagement, 2021).

Communications

The OCCRA report will be available for the public to utilise through the ORC website in addition to internal ORC use. ORC will develop key messaging from the findings of this report to share through communications channels and public engagement where appropriate.

In respect to the risk assessment being an ongoing and iterative process, ORC will be gathering relevant information in the period following the release of this risk assessment and prior to the next. This may involve both online and face-to-face communications and engagement. The details of OCCRA's communications and engagement plan can be found in a separate document.

Mitigation

While greenhouse gas emission mitigation was not in scope for this assessment, it needs to be noted that reduction of greenhouse gas emissions plays an important primary role in mitigating the risks from climate change. ORC is currently facilitating a complementary regional GHG inventory.

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14 Applicability

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

Tonkin & Taylor Ltd

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Appendix A: Legislative context

New Zealand participates in international climate change negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), its Kyoto Protocol, and the Paris Agreement. The Paris Agreement commits all participating countries to take action on climate change. As part of this agreement, New Zealand has committed to reducing greenhouse gas emissions by 30 per cent below 2005 levels by 2030.

Legislation has since been passed to enable New Zealand to meet its obligations under the Paris agreement. The Climate Change Response (Zero Carbon) Amendment Act 2019 provides a framework by which New Zealand can develop and implement policies to respond appropriately to climate change. The Zero Carbon Act enables government to introduce new policies that will require New Zealand to limit greenhouse gas emissions and prepare for and adapt to climate change.

In response to the Zero Carbon Act, Ministry for the Environment has undertaken the first National Climate Change Risk Assessment (MfE, 2020). Consequently, the government has released new requirements for organisations to report climate-related information under the Climate Change Response (Zero Carbon) Act (Government of New Zealand, 2019; MfE, 2020a). This reporting requirement applies to organisations that provide essential public services in New Zealand such as local authorities, and will request information on how organisations are responding to risks from climate change.

The Zero Carbon Act and related reporting requirements build on the existing responsibilities for local government to respond to climate change. Existing legislation which controls the ORC's activities and responsibilities is set out in the *Local Governance Statement* (ORC, 2017). Legislation particularly relevant to the management of climate change and natural hazards at regional government level includes the:

- Local Government Act 2002 (LGA): The LGA requires local government to develop long terms plans, with consideration of the 'future needs of communities' and 'anticipated future circumstances', and therefore must consider climate change.
- Resource Management Act 1991 (RMA): The RMA requires the management of significant risks from natural hazards, and give the status of particular regard to the effects of climate change. Among other environmental and policy requirements, the RMA allows councils to plan for climate change *adaptation* but the mandate for climate change *mitigation* has been specifically removed.
- Civil Defence Emergency Management Act 2002: The Civil Defence Emergency Management Act 2002 requires local authorities to prepare Civil Defence Emergency Management Group Plans, which must state and provide for hazards and risks to be management by the Group (Section 49(b)). This should conceivably include consideration of how those hazards and risks will change with climate change.
- Biosecurity Act 1993: The Biosecurity Act 1993, requires the regional council provides leadership in activities that prevent, reduce, or eliminate adverse effects from harmful organisms (Section 12B). While not specifically referred to, it is expected that climate change will create new biosecurity challenges (Kean et al., 2015).

The ORC Long Term Plan 2018-2028 recognises that a changing climate will present risks to the region. The Long Term Plan includes strategic priorities for building resilient communities, achieving readiness, and undertaking a risk focussed approach (ORC, 2018). ORC are proactively taking a leadership position in understanding climate risk which will allow the region to prioritise and coordinate adaptation responses. This proactiveness will position ORC well to respond to current and emerging central government requirements.

Of note, the Office of the Auditor General has recently released its draft annual plan (OAG, 2020) which signals auditors will be taking an increased focus on climate change and adaptation over the coming years, when reviewing council infrastructure strategies and long term plans.

Finally, ORC has demonstrated its commitment to addressing climate change through its Long Term Plan policy 2018-2028, and the resolution that:

"Otago must continue to prepare for the certainty that climate change will present emergency situations in many areas of our region

And will therefore continue to give high priority to adaptation to climate change, especially in our flood and drainage schemes and in South Dunedin, and to minimising our carbon emissions".

Appendix B: Climate change within Otago

Weather in the Otago region is influenced strongly by local topography. The Southern Alps form a barrier that divides the west coast from east coast and intercepts the predominant westerly winds. This results in a wet and windy climate in Western Otago, and a dry climate with hot, dry summers, and dry, cold winters in Central Otago which approximates a semi-arid continental climate with strong differences between winter and summer (Macara G. , 2015). The weather of coastal Otago is tempered by cool ocean temperatures (Macara et al., 2019).

Gradual changes are being observed within New Zealand, where atmospheric temperatures have increased, on average by 1°C per century since 1909, in addition to rising sea levels and increased frequency of severe weather extremes (Ministry for the Environment, 2018). Projected changes in atmospheric parameters under the RCP8.5 scenario for the Otago region include annual average temperature increases of up to 1.5°C by 2040 and 3.5°C by 2090, with a projected increase in summertime mean maximum temperature of 4°C to 5°C in central and western Otago (Macara et al., 2019). The frequency of extreme hot days (temperature above 30°C) is projected to increase across the region, with up to 4 more extreme hot days near the coast toward the end of the century, and up to 30-40 more extreme hot days in Central Otago (Macara et al., 2019).

Minimum temperatures are also projected to increase throughout the region by up to 2°C by the end of the century. In conjunction, the duration of the frost season and number of frost days is expected to decrease throughout the region, with most decreases occurring inland, where 10-15 fewer frost days are projected to occur by 2040 and up to 40 fewer frost days per year by 2090 (Macara et al., 2019). The number of snow days are also projected to reduce, with the greatest reductions projected to occur in the mountainous areas of western Otago.

Annual rainfall is generally expected to increase across the region, with up to 10% more annual rain by 2040 and 20% more annual rainfall by the end of the century. This is projected to vary significantly between seasons, with winter rainfall increasing by up to 40% in many parts of the region by the end of the century. However, decreases are projected for summer rainfall, particularly around Ranfurly and Middlemarch (Macara et al., 2019). A decrease in the number of annual dry days of up to 6 days is projected by 2090 for coastal and some central parts of Otago, and an increase in dry days of up to 10 days for inland Otago.

Extreme wind speed (measured as the top 1% of daily mean wind speeds) is projected to decrease in coastal Otago, and projected to increase around inland areas including Central Otago and Southern Lakes, which are projected to see an increase in extreme wind of up to 6-12% by the end of the century.

Extreme rainfall events are projected to become more severe. Short duration events are projected to have the largest relative increase in intensity, for example the 1:100 year, 1 hour duration rainfall event is projected to generate 35% more rainfall by the end of the century (Carey-Smith et al., 2018). Extreme weather events are likely to become more common with new record highs and lows (temperature and rainfall) recorded in the region every year (National Institute of Water & Atmospheric Research, 2020). Variability will occur across the districts with exposure varying between coastal and southern parts of Otago and central Otago (Macara et al., 2019).

Changes in the marine environment under the RCP8.5 scenario include increasing mean sea level and larger storm surges. Historical tide records from Dunedin Harbour show an average rise in relative mean sea level of 1.42 mm per year over the 20th century, the underlying cause of which is attributed to climate change (Ministry for the Environment, 2017). Mean sea levels are expected to continue to increase over the next century due to thermal expansion of the oceans as atmospheric temperatures rise, and increased sea volume as permanent polar ice and glaciers melt (Ministry for the Environment, 2017). Sea levels are projected to rise by up to 0.9-1.2 m by 2090 under a the RCP8.5 scenario. Storm surges, waves, wind, and the frequency and intensity of storms will also be affected by climate change. These, combined with sea level rise will generate increasing extreme high water levels along the coast of Otago. The New Zealand marine environment will also be affected by increasing ocean acidity, which occurs as the ocean absorbs CO_2 from the atmosphere (Law et al., 2017).

The projected RCP8.5 climate changes will have significant impacts on the communities, natural and built environments within Otago, and the following sections detail the high-level assessment of risk posed by climate change for Otago.

Appendix C: Glossary

Key term	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 (IPCC, 2014d).
Adaptive capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2014d).
Assets	"Things of value", which may be exposed or vulnerable to a hazard or risk. Physical, environmental, cultural or financial/economic element that has tangible, intrinsic or spiritual value (see Taonka) (Ministry for the Environment, 2019a).
Baseline	The baseline (or reference) is any datum against which change is measured.
Biodiversity	The variability among living organisms from terrestrial, marine and other ecosystems. Biodiversity includes variability at the genetic, species and ecosystem levels (IPCC, 2014d).
Cascading effects (of climate change)	Cascading effects are those that flow on from a primary hazard to compound and affect many systems in a dynamic sequence.
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 of time 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, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2014d).
Climate change	Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes or trends in the mean and/or the variability of its properties, and that persists for an extended period, typically decades to centuries. Climate change includes natural internal climate processes or external climate forcings such as variations in solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014d).
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) 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 socio-economic and technological developments that may or may not be realised (IPCC, 2014d).
Co-benefits	The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty, and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefits (Ministry for the Environment, 2019a).

Key term	Definition
Community	A community may be a geographic location (community of place), a community of similar interest (community of practice), or a community of affiliation or identity (such as industry) (Ministry for the Environment, 2019a).
Compound hazards and stressors	Combined occurrences of multiple hazards and stressors (that is, cumulative hazards) which will become more significant in the future as adaptation thresholds are reached, for example, for a low-lying coastal area, a persistent wet season (high groundwater, reduced field capacity) is followed by a coastal storm on the back of sea-level rise, coinciding with intense rainfall, leading to compound flooding impacts (Ministry for the Environment, 2019a).
Confidence	A qualitative measure of the validity of a finding, based on the type, amount, quality and consistency of evidence (for example, data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement (Ministry for the Environment, 2019a).
Consequence	The outcome of an event that may result from a hazard. It can be expressed quantitatively (for example, units of damage or loss, disruption period, monetary value of impacts or environmental effect), semi-quantitatively by category (for example, high, medium, low level of impact) or qualitatively (a description of the impacts) (adapted from Ministry of Civil Defence and Emergency Management, 2019). It is also defined as the outcome of an event affecting objectives (ISO/IEC 27000:2014 and ISO 31000: 2009) (Ministry for the Environment, 2019a).
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC, 2014d).
Driver	An aspect that changes a given system. Drivers can be short term but are mainly long term in their effects. Changes in both the climate system and socio-economic processes, including adaptation and mitigation, are drivers of hazards, exposure, and vulnerability; so drivers can be climatic or non-climatic (Ministry for the Environment, 2019a).
Emissions	The production and discharge of substances that are potentially radiatively active (that is, absorb and emit radiant energy) in the atmosphere (for example, greenhouse gases, aerosols) (Ministry for the Environment, 2019a).
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by a change in the external stresses a system is exposed to. In the context of climate change these are normally specific climate and other biophysical variables (IPCC, 2007). The number, density or value of people, property, services, or other things we value (taoka) that are present in an area subject to one or more hazards (ie, within a hazard zone), and that may experience potential loss or harm (Ministry of Civil Defence and Emergency Management, 2019).

Key term	Definition
Extreme weather event	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (for example, drought or heavy rainfall over a season) (IPCC, 2014d).
Financial risk	Financial risks are those that involve financial loss to firms. Financial risks in general relate to markets, credit, liquidity, and operations.
Frequency	The number or rate of occurrences of hazards, usually over a particular period of time (Ministry for the Environment, 2019a).
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 thermal infrared 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.
Hazard	The potential occurrence of a natural or human-induced physical event, 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 (IPCC, 2014d). In this report, the term hazard usually refers broadly not only to climate-related physical hazard events (such as floods or heatwaves) but also evolving trends or their gradual onset physical impacts (IPCC, 2014d).
Heatwave	A period of abnormally and uncomfortably hot weather (IPCC, 2014d).
Impacts (consequences, outcomes)	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 (IPCC, 2014d).
Intergovernmental Panel on Climate Change (IPCC)	Intergovernmental Panel on Climate Change – a scientific and intergovernmental body under the auspices of the United Nations.
Kaupapa Māori	Kaupapa Māori literally translates to 'a Māori way'. Smith (2005) describes kaupapa Māori as related to 'being Māori, connected to Māori philosophy and principles, taking for granted the validity and legitimacy of Māori, taking for granted the importance of Māori language and culture, and is concerned with the 'struggle for Māori autonomy over Māori cultural wellbeing'' (Cram, 2017). As an analytical approach, kaupapa Māori is about thinking critically, including developing a critique of non-Māori constructions and definitions of Māori and affirming the importance of Māori self-definitions and self-valuations.

Key term	Definition
Land use	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 (for example, grazing, timber extraction and conservation). In urban settlements it is related to land uses within cities and their hinterlands. Urban land use has implications on city management, structure and form and thus on energy demand, greenhouse gas (GHG) emissions and mobility, among other aspects (IPCC, 2014d).
Land-use change	Land-use change is 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 impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases (GHGs), or other properties of the climate system and may thus give rise to radiative forcing and/or other impacts on climate, locally or globally (IPCC, 2014d).
Likelihood	The chance of a specific outcome occurring, where this might be estimated probabilistically (IPCC, 2014d).
Lock in	The generic situation where decisions, events or outcomes at one point in time constrain adaptation, mitigation or other actions or options at a later point in time (IPCC, 2014d).
Mean Annual Flood (MAF)	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.
Māori values and principles	Māori values and principles derive from Māori views of the world. Values and principles can be defined as instruments through which Māori make sense of, experience, and interpret the world. They form the basis for Māori ethics and principles (Ministry for the Environment, 2019a).
Mātauraka Māori	Mātauraka Māori or Māori knowledge has many definitions that cover belief systems, epistemologies, values, and knowledge, both in a traditional and contemporary sense. Mātauraka Māori incorporates knowledge, comprehension and understanding of everything visible and invisible in the universe (Ministry for the Environment 2019).
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014d).
Percentiles	A percentile is a value on a scale of 100 that indicates the percentage of the data set values that is equal to, or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (or 10th) percentile may be used to refer to the threshold for the upper (or lower) extremes.
Representative concentration pathway (RCP)	A suite of representative future scenarios of additional radiative heat forcing at the Earth's surface by 2100 (in Watts per square metre), which is the net change in the balance between incoming solar radiation and outgoing energy radiated back up in the atmosphere. Each RCP can be expressed as a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014 (IPCC, 2014d).
Residual risk	The risk that remains (and may continue to rise) in unmanaged form, after risk management measures and adaptation policies have been implemented to adapt to climate change and more frequent hazards, and for which

Key term	Definition
	emergency response and additional adaptive capacities must be maintained or limits to adaptation addressed. Policy interventions and adaptation plans will need to reconcile changing residual risks with changing (evolving) societal perceptions of tolerable risk.
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event, trend or disturbance by responding or reorganising in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014d).
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends, multiplied by the impacts if these events or trends occur. The term risk is used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure. Risk results from the interaction of vulnerability, exposure and hazard. To address the evolving impacts of climate change, risk can also be defined as the interplay between hazards, exposure and vulnerability (IPCC, 2014d).
Risk assessment	The overall qualitative and/or quantitative process of risk identification, risk analysis and risk evaluation, with multiple entry points for communication and engagement and monitoring and reviews (AS/NZS ISO 31000:2009, Risk Management Standard).
Seasonality	Variability during a year based on season.
Shock	A sudden, disruptive event with an important and often negative impact.
Stress	A long-term, chronic issue with an important and often negative impact.
Stressor (climate)	Persistent climatic occurrence (for example, change in pattern of seasonal rainfall) or rate of change or trend in climate variables, such as the mean, extremes, or the range (for example, ongoing rise in mean ocean temperature or acidification), which occurs over a period of time (for example, years –decades – centuries), with important effects on the system exposed, increasing vulnerability to climate change (Ministry for the Environment, 2019a).
System	A set of things working together as parts of an interconnected network and/or a complex whole.
Taoka Māori	Taoka Māori refers to tangible and intangible items that are highly valued in Māori culture. Taoka Māori include: Natural environment (whenua/land, ngahere/forests, awa/rivers, maunga/mountains and moana/ocean). Human and non-human capital (whānau/families, hapū/sub-tribes, iwi/tribes), spiritual (mauri/the intrinsic lifeforce within living entities). Social capital (mātauraka Māori/Māori knowledge, intergenerational transfer of knowledge). Economic capital (financial value of assets including land holdings).

Key term	Definition
	Material capital (buildings including marae, commercial investments and private homes) (Ministry for the Environment, 2019).
Three waters	Three waters refers to drinking water, wastewater and stormwater.
Two waters	Two waters refers to wastewater and stormwater.
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 (IPCC, 2014d).
Value domain	The NCCRA framework outlines five 'value domains' for assessing risks and opportunities. These value domains represent groups of values, assets and systems that may be at risk from exposure to climate-related hazards, or could be beneficially affected (opportunities). These value domains are a hybrid of New Zealand Treasury's living standards framework and those used in the National Disaster Resilience Strategy (New Zealand Treasury, 2018; Ministry of Civil Defence and Emergency Management, 2019). The value domains are interconnected and apply at the individual, community and national level. They include tangible and intangible values.
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 (IPCC, 2014d).
Wellbeing	Wellbeing is achieved when people are able to lead fulfilling lives with purpose, balance and meaning to them (New Zealand Treasury, 2019). In New Zealand, the Treasury's living standards framework (LSF) notes that intergenerational wellbeing relies on growth, distribution and sustainability of four capitals: natural capital, social capital, human capital and financial/physical capital. The capitals are interdependent and work together to support wellbeing. The Crown–Māori relationship is integral to all four capitals (New Zealand Treasury, 2019). Within te ao Māori – the Māori world – wellbeing is not simply driven by stocks of capitals identified in the LSF. Instead, the drivers of wellbeing are considered against the values that imbue te ao Māori with a holistic perspective. These values are interconnected and span many aspects of wellbeing. Wellbeing results applying these values through knowledge, beliefs and practices (New Zealand Treasury, 2019).

Appendix D: Risk long list

Table D1: Long list of Human Domain risks

Sector	Risk
Human	The impact of climate change on national, regional, and local identity
	Risks to community cohesion and resilience
	Impact of climate change on mental wellbeing
	Risks to physical health due to climate change
	Climate change resulting in increased cost of living
	The impact of climate change on regional, national and international drivers of migration – including relocation of communities within Otago, NZ, and climate refugees from other countries
	The capability of agencies to adapt to climate change
	Community awareness and engagement

Table D2: Long list of Natural Environment Domain risks

Sector	Element	Climate Hazard
Biodiversity	Native terrestrial biodiversity - flora & fauna	Higher mean temperatures
		Drought
		Reduced snow & ice
		Increased fire weather
	Native freshwater biodiversity - flora & fauna	Higher mean temperatures
		Fluvial and pluvial flooding
		Change in mean annual rainfall
	Native marine and coastal biodiversity - flora & fauna	Marine heatwaves
		Sea level rise and salinity stresses
		Ocean chemistry changes
Freshwater	Water Quantity and Availability	Change in mean annual rainfall
		Drought
	Groundwater only	Sea level rise and salinity stresses
	Surface water only	Reduced snow & ice
	Water quality	Change in mean annual rainfall
		Fluvial and pluvial flooding
		Higher mean temperatures
	Water quality - lakes	Higher mean temperatures
	Water quality - rivers	Reduced snow & ice
	Water quality - coastal areas	Ocean chemistry changes
		Sea level rise and salinity stresses
Coastal, estuarine and marine ecosystems	Marine / estuary / harbour water quality	Ocean chemistry changes
	Natural coastal habitats (dunes, estuaries, rocky shores)	Sea level rise and salinity stresses
		Ocean chemistry changes
		Storms and wind
Biosecurity - safety from pests and diseases	Plant and animal pest species and diseases affecting native biodiversity (Terrestrial, Freshwater, Marine)	Higher mean temperatures
		Change in mean annual rainfall
		Reduced snow & ice
		Winds and storms
	Terrestrial pests and diseases affecting native biodiversity	Hazards not identified
	Freshwater pests and diseases	Drought, low flows
	Marine pests and diseases	Marine heatwaves
		Ocean chemistry changes
		Sea level rise and salinity stresses

Land use	**Lowland and coastal environments**	Storms and wind
		Coastal and estuarine flooding
	Lowland forests, shrublands, indigenous grasslands	Storms and wind
		Drought
		Increased fire weather
	Montane environments / hill country environments	Storms and wind
		Drought
		Increased fire weather
		Higher mean temperatures
	Alpine / high country environments	Reduced snow & ice
		Wind and storms
		Higher mean temperatures
		Change in mean annual rainfall
	Wetlands - coastal	Sea level rise and salinity stresses
		Fluvial and pluvial flooding
		Higher mean temperatures
	Wetlands - alpine	Reduced snow & ice
		Change in mean annual rainfall

Table D3: Long list of Economic Domain risks

Sector	Element	Climate Hazard
Agriculture	**Sheep-beef farming**	Drought
		Fluvial and pluvial flooding
		Increased fire weather
		Higher mean temperatures
	Dairy farming	Drought
		Fluvial and pluvial flooding
		Higher mean temperatures
	Horticulture	Higher mean temperatures
		Storms and wind
		Less frost
		Extreme weather events
Forestry	**Exotic forestry**	Increased fire weather
		Storms and wind
Seafood	**Aquaculture**	Marine heatwaves
		Ocean chemistry changes
		Increasing coastal erosion
	Fisheries	Storms and wind
		Marine heatwaves
		Ocean chemistry changes
Tourism	**Accommodation**	Sea level rise and salinity stresses
		Increasing coastal erosion
		Fluvial and pluvial flooding
	Tourism sector	Reduced snow & ice
		Fluvial and pluvial flooding
		Increasing landslides and soil erosion
		Coastal and estuarine flooding
		Sea level rise and salinity stresses
Services	**Urban services (restaurants, shops etc.)**	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
	Supply chains	Fluvial and pluvial flooding
		Heatwaves
		Increasing landslides and soil erosion
		Sea level rise and salinity stresses
Mining	**Mining and mining services**	Fluvial and pluvial flooding
		Increasing landslides and soil erosion
Manufacturing	**Factories**	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
Utilities		Drought

	Hydroelectricity generation	Reduced snow & ice
		Change in mean annual rainfall
Finance and insurance sector	**Insurance**	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Increasing coastal erosion
	Financial system	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Increasing coastal erosion
	Cost of doing business	Sea level rise and salinity stresses
		Fluvial and pluvial flooding
		Increasing landslides and soil erosion
		Extreme weather events

Table D4: Long list of Built Environment Domain risks

Sector	Element	Climate Hazard
Housing and buildings	**Urban housing**	Fluvial and pluvial flooding
		Increasing coastal erosion
		Sea level rise and salinity stresses
		Increasing landslides and soil erosion
	Rural housing, farms, and commercial buildings	Fluvial and pluvial flooding
		Increasing landslides and soil erosion
		Increased fire weather
	Commercial and public buildings	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Increasing coastal erosion
Public amenities	**Community spaces (venues, halls, libraries, leisure facilities etc.)**	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
	Parks and reserves	Increasing coastal erosion
		Fluvial and pluvial flooding
	Cemeteries	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Increasing landslides and soil erosion
		Increasing coastal erosion
Water	**Stopbanks and flood management schemes**	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Increasing landslides and soil erosion
	Municipal water supply - note different supply sources (surface - lakes/rivers) or bores. Also reservoirs and dams	Drought
		Sea level rise and salinity stresses
		Fluvial and pluvial flooding
		Extreme weather events
	Rural water supply	Drought
		Sea level rise and salinity stresses
		Fluvial and pluvial flooding
		Extreme weather events
		Increased fire weather
	Irrigation schemes	Drought
		Change in mean annual rainfall
		Reduced snow & ice
	Land Drainage for rural areas	Sea level rise and salinity stresses
		Change in mean annual rainfall
		Extreme weather events

	Stormwater infrastructure	Sea level rise and salinity stresses
		Fluvial and pluvial flooding
Wastewater	**Wastewater infrastructure**	Extreme weather events
		Sea level rise and salinity stresses
		Fluvial and pluvial flooding
	Wastewater - septic tank	Sea level rise and salinity stresses
	Wastewater treatment plants and operation	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Heatwaves
Energy	**Electricity generation infrastructure**	Fluvial and pluvial flooding
		Heatwaves
	Electricity transmission and distribution infrastructure	Extreme weather events
	Gas infrastructure	Fluvial and pluvial flooding
	Petroleum infrastructure	Fluvial and pluvial flooding
Transport infrastructure	**Roads and bridges**	Fluvial and pluvial flooding
		Increasing coastal erosion
		Sea level rise and salinity stresses
		Increasing landslides and soil erosion
		Extreme weather events
	Rail	Increasing coastal erosion
		Sea level rise and salinity stresses
		Extreme weather events
		Higher mean temperatures
	Marine facilities (including ports and marinas)	Sea level rise and salinity stresses
		Extreme weather events
		Increasing coastal erosion
	Airports	Fluvial and pluvial flooding
		Sea level rise and salinity stresses
		Storms and wind
ICT & communications	**Internet infrastructure**	Fluvial and pluvial flooding
		Extreme weather events
	Telephone lines	Fluvial and pluvial flooding
		Extreme weather events
	Mobile towers	Extreme weather events
Coastal defences	**Coastal protection structures**	Sea level rise and salinity stresses
		Increasing coastal erosion
		Extreme weather events
		Coastal and estuarine flooding

Waste management	**Landfills and solid waste management and contamination sites**	Sea level rise and salinity stresses
		Increasing coastal erosion
		Fluvial and pluvial flooding

Table D5: Long list of Governance Domain risks

Sector	Risk
Governance	Political processes could slow action at the local, regional, national and international level
	National governance structure for managing climate change may produce inconsistent and constantly changing national policy, regulatory, and planning frameworks, resulting in complexity and uncertainty for Otago councils
	Institutional arrangements of councils that are inadequate for managing climate change,
	Institutional capacity of councils that is inadequate to take required action and implement changes
	Knowledge of climate risks requires sharing of knowledge on best practices and lessons learnt between national agencies, regions and councils
	Existing land-use planning framework that are suitable for managing risks to existing and established communities, especially those highly exposed to flooding and sea level rise.
	Innovation and innovative solutions are required by Councils for achieving climate change adaptation and mitigation outcomes.
	Reluctance amongst communities and councils for undertaking managed retreat
	Financing climate action, where increasing costs puts additional pressures on council budgets, which are largely based on tax revenues from rates.
	Overlapping and inadequate legislation for managing climate change impacts on Otago
	Increased risk of litigation for public agencies that exercise inadequate duty of care for managing climate impacts
	Lack of mechanisms for undertaking a just transition to zero-carbon climate-resilient future
	Views of individuals and communities and managing community expectations, especially for financing local infrastructure, managed retreat, and residential property repairs following natural disasters
	Communication needs, including the translation of technical and scientific information into accessible knowledge for individuals and communities.

Appendix E: Stakeholder engagement list

Domain	Organisation	Engagement details
General	Otago Regional Council	Review and commentary provided by multiple teams within ORC.
	Central Otago District Council	Risk list and draft report was disseminated, and comments provided.
	Clutha District Council	Risk list and draft report was disseminated, and comments provided.
	Dunedin City Council	Risk list and draft report was disseminated, and comments provided.
	Queenstown-Lakes District Council	Risk list and draft report was disseminated, and comments provided.
	Waitaki District Council	Risk list and draft report was disseminated, and comments provided.
	Aukaha	Risk list and draft report was disseminated, and comments provided.
Economy	New Zealand Insurance Council	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Otago Chamber of Commerce	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	Queenstown Chamber of Commerce	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Ignite Wanaka	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	Otago Southland Employers Association	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Ministry for Primary Industries (MPI)	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Veterinary Association	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Dairy New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation call was held with primary sector stakeholders.
	Meat Industry Association	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Beef + Lamb NZ	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken with primary sector stakeholders.
	Federated Farmers	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken with primary sector stakeholders.
	New Zealand Winegrowers	Risk list and workshop report was disseminated, and commentary/research was provided by the stakeholder.

	New Zealand Grain and Seed Trade Association	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Deer Industry New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken with primary sector stakeholders.
	Rural Women New Zealand	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Horticulture New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	Apiculture New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Forest Owners Association	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	New Zealand Institute of Forestry	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Straterra	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Aggregates and Quarry Association	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Oceana Gold	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Fisheries Inshore New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Seafood NZ	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Aquaculture New Zealand	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Tourism Industry Aotearoa	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	Otago Regional Economic Development Group	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Agribusiness New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
Built	Ministry of Housing and Urban Development	Risk list and workshop report was disseminated, but no commentary was provided by the stakeholder.
	Civil Contractors New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Infrastructure New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Ministry of Education	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.

	Engineering New Zealand (Otago Branch)	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Water New Zealand	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Irrigation New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	BusinessNZ Energy Council	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Contact Energy	Risk list and workshop report was disseminated, , and a consultation was undertaken.
	Chorus	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Trustpower	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Pioneer Energy	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Tilt Renewables	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Network Waitaki	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Aurora Energy	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	PowerNet	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	TransPower	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Meridian Energy	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Lifelines Council	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Transport Agency	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Dunedin Airport	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Queenstown Airport Corporation	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Port Otago	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	KiwiRail	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Allied Petroleum	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Oil Services Limited	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Spark	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.

	Countrynet	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Kordia	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Otago Regional Council	Consultation was undertaken on water supply and flood management.
	Heritage New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
Human/Culture	Kaianga Ora - Homes and Communities	Risk list and workshop report was disseminated, but no commentary was provided by the stakeholder.
	Emergency Management Otago	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Fire and Emergency New Zealand	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Centre for Sustainability, University of Otago	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	New Zealand Recreation Association	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Southern District Health Board	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	Local Government New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
Governance	Otago Womens Lawyers Society	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Planning Institute	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	New Zealand Law Society - Otago Branch	Risk list and workshop report was disseminated, but no commentary was provided by the stakeholder.
	Department of Conservation	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
Natural Environment	Fish & Game	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	Ecology Team, Otago Regional Council	Consultation was undertaken on the natural environment risks identified.

Appendix F: Copy of survey questions

Survey Question asked of stakeholders were as below.

Upon review of the workshop summary report / risk table:

- Identify if there are any gaps / risks we've missed
- Do you agree or disagree with the risk scores given? Do you think any scores should be reviewed and why?
- Review the opportunities, are there any gaps or anything you can build on in this table.
- Provide any general feedback on the risk assessment you may have, this can include feedback on the other domains.

Otago climate change risk assessment forum

The Otago Regional Council (ORC) have initiated a climate change risk assessment across all of Otago to better understand the impacts of climate change and associated risks and opportunities.

Why are we doing this risk assessment

The purpose of this risk assessment is to provide an understanding of

- potential changes to some climate variables
- identify areas of risk in our region
- qualify the vulnerability of these risk areas
- consequences of the climate scenarios for these risk areas

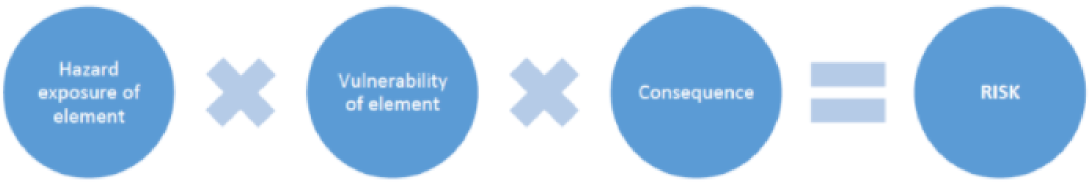
Ultimately, we aim to get a prioritisation of the region's risks for further potential information gathering and assessment and the focus of adaptation plans.

How we came up with the short list of risks and their scores

The Territorial Authorities across the region worked with us to combine our knowledge and produce an initial list assessing climate change risk across the five value domains identified (as fits with the National Climate Change Risk Assessment Framework):

1. Human
2. Natural environment
3. Built environment
4. Economy
5. Governance

A long-list of climate change risk elements were compiled based on the knowledge and expertise of participants and these were assessed for vulnerability and consequence based on the RCP 8.5 climate change projections for Otago (NIWA 2019 report).



For the built environment, natural environment, and economy domains, a full assessment was made combining vulnerability and consequence scores to generate a risk score. A short list of risks was created selecting those scores that were either major or extreme.

For the human and governance domains a simpler approach was utilised, a higher-level qualitative description of the risks was used to create the list. Climate change opportunities were also identified.

For more information on the methodology and risk assessment workshop summary, see relevant documents.

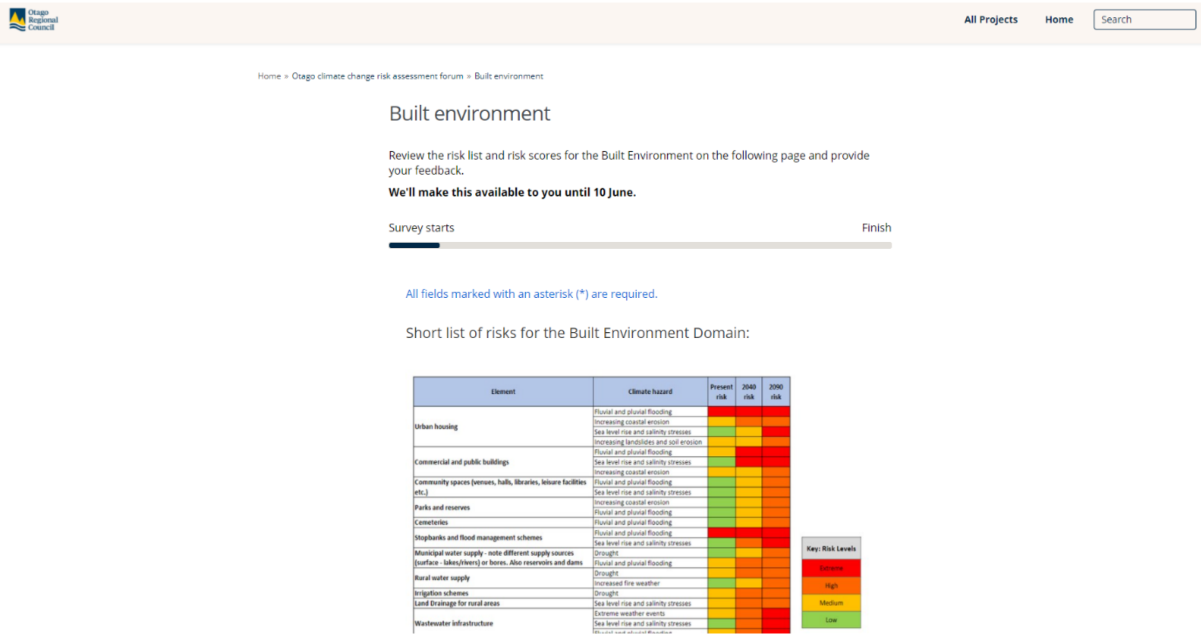
This page will be open for your feedback until 10 June.

We will then review your feedback and respond. This may involve clarifying some of your submissions or working together on reviewed scoring for some risk scores.

Thank you for taking the time to submit, we appreciate the crucial input you have provided.

YOUR FEEDBACK **FORUM**

EXAMPLE:



1. Identify if there are any gaps, are there risks we have missed?
   (Noting these may have been assigned a lower risk score so are not present in this short list, but maybe you think they should be)

   Please add your comment here...

Do you agree or disagree with the risk scores given in the short list?

Use the risk assessment table above to tell us whether you agree or disagree with our rankings.

2. Urban housing, fluvial and pluvial flooding
   Present risk: extreme
   2040 risk: extreme
   2090 risk: extreme

   ◉ Agree

   ○ Disagree

Do you agree or disagree with the risk scores given in the short list?

Use the risk assessment table above to tell us whether you agree or disagree with our rankings.

2. Urban housing, fluvial and pluvial flooding
   Present risk: extreme
   2040 risk: extreme
   2090 risk: extreme

   ◉ Agree

   ○ Disagree

3. Urban housing, increasing coastal erosion
   Present risk: medium
   2040 risk: high
   2090 risk: high

   ○ Agree

   ◉ Disagree

4. If you disagree, why?

   Please add your comment here...

Built environment

Survey starts Finish

All fields marked with an asterisk (*) are required.

Review the opportunities below:

1. Improved water sensitive design practices to mitigate flooding issues
2. Opportunities from regeneration and improved urban design – i.e. replacement of old housing stock, building innovations (new construction methods), improved energy efficiency (lower carbon footprint), improved heating system, urban intensification, and rainwater collection.
3. Increased potential for heat recovery from wastewater networks.
4. Reduced dependence on carbon-intensive transport systems.
5. Former productive land available for urban development.
6. Simplification of utility planning.

40. Are there any gaps in this list of opportunities or any you'd like to add to this list?

Please add your comment here...

41. Do you have any other feedback you'd like to provide?

Please add your comment here...

This can include feedback you may have for other domains.

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